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Astrophysics in 2005

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ABSTRACT. We bring you, as usual, the Sun and Moon and stars, plus some galaxies and a new section on astrobiology. Some highlights are short (the newly identified class of gamma-ray bursts, and the *Deep Impact* on Comet 9P/Tempel 1), some long (the age of the universe, which will be found to have the Earth at its center), and a few metonymic, for instance the term “down-sizing” to describe the evolution of star formation rates with redshift.

1. INTRODUCTION

The ApXX series celebrates its quinceañera by adding a new, astrobiology, section and co-opting an additional author to write it and to cope with many other problems.[1] Used in compiling §§ 3–6 and 8–13 were the issues that arrived as paper between 1 October 2004 and 30 September 2005 of *Nature*, *Physical Review Letters*, the *Astrophysical Journal* (plus *Letters* and *Supplement Series*), *Monthly Notices of the Royal Astronomical Society* (including *Letters* up to December 2004 only), *Astronomy and Astrophysics* (plus *Reviews*), *Astronomical Journal*, *Acta Astronomica*, *Revista Mexicana Astronomia y Astrofisica*, *Astrophysics and Space Science*, *Astronomy Reports*, *Astronomy Letters*, *Astrofizica*, *Astronomische Nachrichten*, *Publications of the Astronomical Society of Japan*, *Journal of Astrophysics and Astronomy*, *Bulletin of the Astronomical Society of India*, *Contributions of the Astronomical Observatory Skalnate Pleso*, *New Astronomy* (plus *Reviews*), *IAU Circulars*, and, of course, *Publications of the Astronomical Society of the Pacific*. Journals read less systematically and cited irregularly include *Observatory*, *Journal of the American Association of Variable Star Observers*, *ESO Messenger*, *Astronomy and Geophysics*, *Mercury*, *New Scientist*, *Science News*, *American Scientist*, *Scientometrics*, *Sky & Telescope*, *Monthly Notes of the Astronomical Society of South Africa*, and *Journal of the Royal Astronomical Society of Canada*. Additional journals provided material for §§ 2 and 7 and are mentioned there.

A few papers are mentioned as deserving of gold stars, green dots, and other colorful recognition. This is as nice as we get. Among the people who appear in the following pages are Jack Benny, the Keen Amateur Dentist, the Faustian Acquaintance, and the Medical Musician. All are pseudonyms, for Benjamin Kubelsky and three colleagues, left as an exercise for readers, not intended to include the also-pseudonymous Mr. H., who is supposed to be completing a thesis in X-ray astronomy.

1.1. Terminations

We record here a number of things that came to an end, surely or probably, in the index year. Beginnings appear in § 1.2 and more complicated relationships in 1.3. (1) The last launch of a Skylark sounding rocket happened on 30 April 2005; the first was from Woomera during International Geophysical Year 1957. (2) Both the *Letters* section of *MNRAS* and the newsletter of the European Space Agency went e-only during the year (January and July 2005, respectively) and so are no longer accessible to the least electronic author. (3) SLAC, like Brookhaven and Los Alamos before it, was shut down by an accident on 1 October (*Science* 306, 809). (4) The percentage of women in computer sciences has actually declined over the past 20 years (*Science* 306, 809), while that in physical sciences and engineering has crept slowly up. (5) NASA’s KC-135 jet, the “vomit comet,” used to produce brief experiences of weightlessness, free-fell for the last time on 29 October. (6) Kodak produced its last carousel projector in November 2004 but will support existing ones (light bulbs and things) until 2007. (7) The Yerkes Observatory (where the modern sequence of

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[1] Astrophysics in 1991 to 2004 appeared in volumes 104–117 of PASP. They are cited here as Ap91, etc.

spectral types was established by Morgan and Keenan) is to be turned into, but turned into what is not entirely clear (*Sky & Telescope* 108, No. 3, p. 19). (8) The Mohorovičić discontinuity was not reached again at 1.4 km, where the mid-Atlantic ridge was expected to be only 0.7 km thick (*Science* 307, 1707); of course every child who attempted to dig to China with a tablespoon (from California, or to California from China with chopsticks) can claim a similar result (*Scientific American* 293, 94). (9) Ball Aerospace provided (at least) its second out-of-focus telescope, this one on *Deep Impact* (*Nature* 434, 685). (10) Another try at *Cosmos-1*, a solar sail vehicle, was lost on launch 21 June, probably due to a pump failure. (11) *Gravity Probe B* gathered its last data on 1 October, with, up to mid January, no results announced and no triumphant renaming of the craft as, for instance, Lens-Thirring to indicate success.

1.2. Inceptions

Most of these beginnings are, we think, good news or at least progress toward good news. (1) *Smart-1* on its way to the Moon was probably the most fuel-efficient vehicle in history, achieving the equivalent of 2×10^6 km per liter of gasoline (*ESA Space Science News* No. 7, p. 2); the only competition would seem to be something that simply rides along with tectonic plate spreading. It arrived on 15 November after an October 2003 launch, and was so also only marginally faster than tectonic plates. (2) Some of the antennas for LOFAR are in place (10 near the beginning of the reference year; *Sky & Telescope* December 2005, p. 24). (3) The *Spitzer Space Telescope* released its first large package of papers on the cusp of the year (September 2004 issue of *Astrophysical Journal Supplement Series*). (4) *Swift* caught its first gamma ray burst on 17 December, after a 20 November launch. (5) In January 2005 the first hole was dug for Ice Cube, an advanced muon and neutrino detector in Antarctica (and a confusing notebook entry, because we generally use upward pointing arrows for good news items, while the hole probably went down). (6) The Ariane heavy lifter had its first successful launch from French Guiana on 12–13 February. It will be needed for the *James Webb Space Telescope*, unless very considerable additional descoping occurs. (7) A million dollar Kavli astrophysics prize will be given starting in 2008 (*Nature* 435, 37) along with ones in neuroscience and nano-technology. (8) The street lighting in the Canary Islands has been considerably dimmed (*Nature* 435, 41), partly in anticipation of first light at the GTC (out of period). (9) The Sloan Digital Sky Survey is being extended, primarily to examine stars for their own sake and for galactic structure (*Nature* 436, 316). (10) The *Mars Reconnaissance Orbiter* got off the ground in August, and *Mars Express* will continue to operate for another year or two (a funding extension), though one spectrometer has gone funny[2] (*Nature* 437, 465). (11) The US is once again planning to develop a major underground laboratory facility for high energy physics and other purposes, perhaps back at Homestake (Ray Davis's old site) or at Henderson, an active molybdenum mine (*Science* 309, 682). (12) France has removed an assortment of popular topical antibiotics from over-the-counter sale (*Science* 309, 872). Not astronomy perhaps, but anything that slows down the development of resistant organisms has to be good for us all! (13) SALT, the South African Large Telescope (near relative of the Hobby-Eberly Telescope) has collected some photons and a dedication (*Nature* 437, 182). (14) The Pierre Auger facility, which looks for very high energy things, released its first data on 6 July. (15) The Atacama Pathfinder Experiment, APEX, at Chajnator (a 12-meter telescope for millimeter radio astronomy and submillimeter submillimeter astronomy in the Atacama desert) carried out its first scientific observations in July 2005. (16) The Las Cumbres Observatory has acquired its first 2-meter telescopes (in Hawaii and Australia) and its first GRB afterglow (in a galaxy long ago and far away, 051111). Six telescopes and observations of many more afterglows and other transient phenomena are planned.

1.3. More Complicated Stories

Astro-E, a Japanese X-ray satellite, was successfully launched on 10 July 2005 and named *Suzaku* (red bird of the south). But its coolant was lost some time before 8 August and, although its CCD X-ray detectors will still work, the spectrometer that was one of its main goals will not. This was, sadly, the second try at *Astro-E*. The first, also unsuccessful, attempt was roughly contemporaneous with the launches of the *Chandra* and *XMM-Newton* X-ray satellites, and the projects were meant to be complementary.

Muses-C, which became *Hayabusa* after launch on 9 May 2003, was supposed to examine asteroid Itokawa, break off a bit, and bring it back in the summer of 2007. The bad news/good news items have been coming out more or less monthly on beyond the end of the reference year. It got to the asteroid. Two gyros failed. It managed to touch down, or not? It picked up some stuff, or not? And it may or may not be able to turn around and come home.

The American Physical Society, worried about folks saying, “Gee, you don't look very strong,” like a Canadian border guard many years ago, attempted to change its name to American Physics Society (*Science* 309, 378). Loud and long blew the arguments through the summer and fall, both rational and irrational. But “they fought the law, and the law won.” Changing the name would require redoing the incorporation papers, a major hassle and expense. The intention, however, is to use APS most of the time and the full name only on journals and other items for internal consumption. (Oh dear; the gastric capacity required to internally consume a year of *Physical Reviews* terrifies.)

All the other items on this list belong more or less to NASA. These consist of existing operational devices that may be turned

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[2] Expert readers may wish to translate this into some more technical term, but the published description sounded to us as if the spectrometer had gone funny.

off early, planned ones that may be greatly delayed or shrunk, items pulled out of various over-committed[3] queues and occasional/partial reversals of such decisions, recisions of the reversals, and so forth that have appeared in this context during the year. (1) *TRMM* and other sources of climate data (*Science* 307, 186 & 189). (2) *JIMO*, *Kepler*, *SIM*, *Beyond Einstein*, and even some of the projects to examine long-term effects of space on people (*Science* 307, 833). (3) *Voyager 1* and *2*, *Ulysses*, *Polar*, *Wind*, *Geotail*, *TRACE*, and *FAST* (*Nature* 434, 108). (4) The five-year career grants and archival data program (*Science* 308, 486). (5) Shuttle flights, the *International Space Station*, and *Hubble Space Telescope* in multiple stories (*Science* 309, 540; *Nature* 436, 603 & 163), and, in even more multiple stories, not all on paper, *JWST* (*Science* 309, 1472; 308, 935).

2. SOLAR PHYSICS

2.1. The Solar Interior

2.1.1. Neutrino Modulations

After we got the solar neutrino flux right in first order, which was heralded as a major breakthrough a few years ago, we can now concentrate on second-order terms, such as variations due to the Earth's orbit, solar rotation, and the solar cycle. The sinusoidal annual periodic variations in the ^{8}B solar neutrino flux have been verified by data from the Sudbury Neutrino Observatory over a 4-year time interval, displaying a 7% modulation due to the Earth's orbital eccentricity (Aharmim et al. 2005), also consistent with results from Super-Kamiokande (Sturrock et al. 2005). The neutrino modulations due to magnetic field variations caused by solar rotation and the solar cycle are harder to establish (Caldwell & Sturrock 2005), and also require new physics in terms of a large neutrino transition magnetic moment, as well as sterile neutrinos (Caldwell 2005; Caldwell & Sturrock 2005). The intrinsic neutrino magnetic moment is now constrained to less than a few times 10^{-12} of the Bohr magneton (Miranda et al. 2004). Earlier interpretations in terms of the spin-flavor precession scenario are now pretty much ruled out (Balantekin & Volpe 2005; Caldwell & Sturrock 2005).

2.1.2. Solar Abundance Discrepancies

The *p-p*, *pep*, ^{8}B, ^{13}N, ^{15}O, and ^{17}F solar neutrino flux measurements even start to constrain the heavy-element abundances in the solar interior (Bahcall et al. 2005b; Bahcall & Serenelli 2005). Standard solar models are in good agreement with the helioseismologically determined sound speed and density in the solar interior, the depth of the convection zone, and the abundance of helium at the surface, as long as heavy-element abundances are not involved (Bahcall et al. 2005a, 2005b). Downward revisions of the photospheric abundances of oxygen and other heavy elements do not help, but upward revisions of the photospheric neon abundance could possibly help (Antia & Basu 2005; Drake & Testa 2005), or not (Schmelz et al. 2005). Dips in the inverted equation of state at 0.975 and 0.988 $R_\odot$, however, could not be corrected by tuning the helium abundance, but were rather attributed to inappropriate approximations in the used equation of state (Lin & Däppen 2005). Other authors conclude that a combination of opacity increases, diffusion enhancements, and abundance increases remain the most physically plausible means to restore agreement with helioseismology (Guzik et al. 2005). Absolute helium abundances (of 12.2 ± 2.4%) were also determined during flares (Feldman et al. 2005).

2.1.3. Tweaking the Helioseismic p-Mode Oscillations

Helioseismic measurements determine the depth of the solar convection zone with an impressive accuracy to $R_{\rm CZ} = 0.713 \pm 0.001\ R_\odot$ (Bahcall et al. 2004). With similar accuracy, the solar rotation axis is determined to an angle of $i = 7\overset{\circ}{.}155 \pm 0\overset{\circ}{.}002$ (Beck & Giles 2005). Attempts were even made to determine Newton's gravitational constant G with helioseismic methods, but the achieved accuracy could not beat previous experimental methods (Christensen-Dalsgaard et al. 2005). Another unsuccessful attempt was a trial to detect deviations from the constant rotation rate in the solar core (Chaplin et al. 2004), where thermal metastabilities are also expected (Grandpierre & Agoston 2005). A number of effects have been studied that could explain tiny deviations of the standard *p*-mode oscillation frequencies and line widths, such as: the magnetic field in the second helium ionization zone at 0.98 $R_\odot$ (Basu & Mandel 2004), at 0.99 $R_\odot$ (Dziembowski & Goode 2005), or even in the photospheric magnetic carpet (Erdélyi et al. 2005), solar-cycle variations of MHD turbulence in the convection zone (Bi & Yan 2005; Chou & Serebryanskiy 2005; Toutain & Kosovichev 2005) and tachocline (Foullon & Roberts 2005), the Reynolds stress on the *p*-mode damping rates (Chaplin et al. 2005), mode conversion and damping by Alfvén waves in vertical fields (Crouch & Cally 2005), and the effect of inhomogeneous subsurface flows (Shergelashvili & Poedts 2005).

2.1.4. Local Helioseismology through a Showerglass

The epicenter of an earthquake is determined by correlating local seismic detectors. In analogy, *local helioseismology* probes the physical properties of sunspots and active regions by localized variations of the subsurface sound speed, mostly concentrated in shallow subsurface layers at $r \approx 0.98$–$1.00\ R_\odot$. One method is time-distance helioseismology, which can study mass flows, active regions, and sunspots. This method measures travel times with the ray or the Born approximation, but it turned out that the first-order approximations fail to capture scattering effects (Birch & Felder 2004). Improvements concentrate on the inversion of noisy correlated data with the time-distance method (Couvidat et al. 2005; Gizon & Birch 2004), comparison of subsurface flows between the time-

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[3] In first draft, this item said "over-committeed," which may also be true.

distance and ring analysis (Hindman et al. 2004), ring analysis of two-dimensional (2D) shearing flows (Hindman et al. 2005), or comparison of time-distance or ring analysis with GONG and MDI data (Hughes et al. 2005; Komm et al. 2005). A problem of local helioseismology is the *acoustic showerglass* effect: magnetic fields under sunspots or active regions suppress the photospheric signatures of acoustic waves impinging onto them from the underlying solar interior and shift their phases, impairing the coherence of seismic waves this way, smearing the holographic signatures of possible sub-photospheric anomalies (Lindsey & Braun 2004, 2005a, 2005b; Schunker et al. 2005). Put in simple words, the investigators try to get a sharp image through a showerglass!

2.1.5. More Puzzles about the Solar Dynamo

Continuing the hotly debated question from previous years, authors entertain us further whether the dynamo is located in shallow sub-photospheric layers (Brandenburg 2005) or deep down in the tachocline (Gilman & Rempel 2005; Dikpati et al. 2005b; Ulrich & Boyden 2005). In support of the latter, the first self-consistent MHD simulations of the tachocline and meridional circulation (Chou & Ladenkov 2005) were conducted by Sule et al. (2005), but realistic MHD models that simulate the entire convection zone down to the tachocline are still not yet computationally feasible (Brun et al. 2004). This year, the controversy also digressed into a number of side issues. Chatterjee et al. (2004) explore a 2D kinematic solar dynamo model based on the Babcock-Leighton idea with a full-sphere numerical simulation and find that the dynamo is circulation-dominated, but Dikpati et al. (2005a) repeat the exercise and find that the dynamo is rather diffusion-dominated, while the discrepancy is then explained by a different treatment of the magnetic buoyancy (Choudhuri et al. 2005). One study extends the dynamo equations to include the competing role of buoyancy and downflows and was able to reproduce the 22 yr cycle (Li et al. 2005e). However, a cycle is not simple in nonlinear dynamics; fluctuations in the Babcock-Leighton dynamo were actually shown to lead to period doubling and to transition to chaos (Charbonneau et al. 2005b), possibly explaining the anomaly of the Maunder minimum (Charbonneau 2004, 2005; Charbonneau et al. 2004). Spherical harmonic decomposition of magnetic field data revealed also intermittent oscillations with periods of 2.1–2.5 yr, 1.5–1.8 yr, and 1.2–1.4 yr (Knaack & Stenflo 2005; Knaack et al. 2005; Kane 2005b), as similarly found in cosmic-ray modulations (Starodubtsev et al. 2004). While we believed that the magnetic cycle of 22 years (Hale cycle) clocks everything on the Sun, correlations with the equatorial rotation rate actually reveal that the phase of the beginning of a 22 yr cycle in the latitudinal gradients is out of phase by 180° (Javaraiah et al. 2005). A new technique based on dynamo spectroscopy and bi-orthogonal decomposition of data was presented to actually compare theoretical dynamo models with observations (Mininni & Gómez 2004). Did you know that the northern hemisphere rotates faster during the even cycles, while the southern hemisphere wins the race in the odd ones (Gigolashvili et al. 2005; Ballester et al. 2005), which was even expected theoretically (Itoh et al. 2005)? Other issues of dynamo models touch on the requirement of supercritical helicity fluxes (Brandenburg & Subramanian 2005; Choudhuri et al. 2004), or the radiative background flux in magneto-convection (Brandenburg et al. 2005). The life histories of over 3000 supergranules have been simulated and tracked and revealed lifetimes of 16–23 hours (DeRosa & Toomre 2004). The rumblings of the internal dynamo seem also to be detectable in the quiet Sun by frequent shocks that bump up into the photosphere (Socas-Navarro & Manso 2005).

2.2. Photosphere

2.2.1. The Tiniest Solar Magnetic Features

Imaging of the photosphere at 0.″1 resolution, an unprecedented capability at the Swedish 1-meter Solar Telescope on La Palma that became available only recently, allows us to resolve magnetic features in the solar photosphere down to the diffraction limit of ≈70 km, which is about the size of the city Los Angeles. While we are familiar with the photospheric granulation pattern, which forms a grid of convection cells with typical spatial scales of 1000–2000 km, the tiniest magnetic features at 0.″1 scale are mostly found in the intergranular lanes, described as novel configurations of magnetic flux that are not directly resolvable into conglomerations of flux tubes or uniform flux sheets (Berger et al. 2004). The novel structures are also described as *elongated ribbons*, *circular flowers*, and *micropores*, which are thought to be crafted by the dynamics of weak upflows in the flux sheets and downflows in the immediate surroundings, becoming unstable to a fluting instability so that the edges buckle and the sheets break up into strings of bright points (Rouppe van der Voort et al. 2005). The tiny magnetic flux tubes are subject to a swaying motion, but with an amplitude smaller than 0.″3 (Stangl & Hirzberger 2005). There is no comparison of such a surface swaying motion on Earth; the biggest earthquake known in California moved the coast of the Tomales Bay only by 20 feet.

2.2.2. The Fractal Complexity of the Magnetic Field

The spatial distribution of the photospheric magnetic field is as fractal as the Atlantic coast of Norway. Threshold-based sampling in two active regions revealed that the cumulative distribution functions of the magnetic flux are only consistent with a lognormal function, but not with an exponential or power-law function, suggesting that the process of fragmentation dominates over the process of concentration in the formation of the magnetic structure in an active region (Abramenko & Longcope 2005). The fractal complexity is thought to result from the continuous emergence of a multitude of mixed-polarity magnetic concentrations, which are subsequently tangled up into intricate regions of interconnecting flux (Close et al. 2004b), a dynamic process that is captured in the recent *flux-tube tectonics model* of Priest et al. (2002). Talking about mixed-polarity concentrations, network magnetic patches were found to harbor a mixture of strong (≈1700 G) and weak (≲500 G) fields (Socas-Navarro & Lites 2004), exhibiting a dynamics that is not consistent with the predictions from helioseismology (Meunier 2005). The topological complexity is also illustrated by numerical simulations, which reveal about 10 magnetic separators for each magnetic null point (Close et al. 2004a). Beveridge & Longcope (2005) found a simple relation between the numbers of separators (X), coronal null points (N_c), flux domains (D), and flux sources (S): $D = X + S - N_c - 1$, which can be used to characterize the magnetic topology and bifurcation processes.

2.2.3. Modeling of the Magnetic Field

The Lorentz force and a corresponding lower limit of the cross-field electric current density was measured in the photosphere, amounting to ≈1%–10% of the gravitational force in active regions (Georgoulis & LaBonte 2004). The photospheric magnetic field is therefore obviously not force-free, contrary to other recent studies with force-free extrapolations (Marsch et al. 2004; Wiegelmann et al. 2005a). Force-free extrapolations, however, fit the coronal field lines observed in EUV significantly better than potential fields (Wiegelmann et al. 2005a). The nonpotentiality in active regions was found to occur (1) when new magnetic flux emerged within the last 30 hours, and (2) when rapidly evolving, opposite-polarity concentrations appear (detected with 4″ resolution; Schrijver et al. 2005).

2.2.4. Automated Pattern Recognition

Finally we get the computers to do our work. Tired of manual and visual inspections of countless features in solar images, tools come finally online that perform *automated pattern recognition*, which allow us to analyze orders of magnitude more data, while nobody becomes unemployed, since the maintenance of these new tools requires additional skilled manpower. In a Special Topical Issue of *Solar Physics* (vol. 228), a total of 24 papers were presented that describe these new tools, such as: fractal and multi-fractal analysis (Georgoulis 2005; Abramenko 2005a; Revathy et al. 2005); automated boundary-extraction and region-growing techniques (McAteer et al. 2005c); multi-scale Laplacian-of-Gaussian operator and interactive *medial-axis-transform* segmentation techniques (Berrilli et al. 2005), enhancing, thresholding, and morphological filtering (Bernasconi et al. 2005; Qu et al. 2005), Euclidean distance transform (Ipson et al. 2005), and artificial (Zharkova & Schetinin 2005) and auto-associative neural network techniques (Socas-Navarro 2005a, 2005b).

These tools have been applied to a number of photospheric features, such as granulation (Del Moro 2004), Hα dark features (Liu et al. 2005b), the chirality of filaments (Bernasconi et al. 2005), the inversion lines of filament skeletons (Ipson et al. 2005), or going from *tactical to practical*, i.e., to predict space weather and geoeffective events (Georgoulis 2005; Qu et al. 2005).

The sharpest high-resolution images have been supersharpened with high-order adaptive optics and speckle-masking reconstruction (Denker et al. 2005), with phase-diversity speckle technique (Criscuoli et al. 2005; Bonet et al. 2005), with multi-channel blind deconvolution (Simberova & Flusser 2005), multiple spectral order stereoscopy (DeForest et al. 2004), or with a combination of these methods (Van Noort et al. 2005).

2.2.5. Sunspots Dynamics

Inversion of Stokes line profiles cannot distinguish whether the thermal structure under a sunspot is monolithic or “spaghetti-like” (Socas-Navarro et al. 2004). In the plumes above the umbra, however, things become very dynamic, since both upflows and downflows with velocities of 25 km s^{-1} have been measured at different days (Brosius 2005), as well as intermittent wavepackets of 5 minute oscillations (Lin et al. 2005a). Some penumbral segments were even observed to rapidly disappear after a flare, probably as a result of magnetic reconnection (Deng et al. 2005).

Polarimetry of sunspot penumbrae with high spatial resolution (0.″5) confirm the picture that low-lying flow channels coincide with the horizontal magnetic field, or possibly emerge and dive down into sub-photospheric layers like a “sea serpent” (Bello Gonzalez et al. 2005). Bellot Rubio et al. (2004) find a perfect alignment between the magnetic field vector and flow velocity vector in the penumbral flux tubes, which is also confirmed by Sánchez-Almeida (2005) from fitting of 10,000 Fe I spectra. The flows in the penumbral flux tubes become supersonic and form shocks at larger radial distances, suggesting that the Evershed flows are driven by the siphon flow mechanism (Borrero et al. 2005). Observations with 0.″2 resolution give support to fluted and uncombed models of the penumbra (Langhans et al. 2005).

2.3. Chromosphere and Transition Region

2.3.1. DOT Tomography

While the chromosphere has been generally perceived as a thin layer above the solar surface, three-dimensional (wavelength-) tomography of its vertical structure is now performed with the newly installed Dutch Open Telescope (DOT) on La Palma, Canary Islands. Its revolutionary design features a wind-swept open telescope on a non-blocking open pedestal to minimize atmospheric seeing, documented in DOT Paper I (Rutten et al. 2004a). DOT Paper II shows simultaneous high-resolution (0.″2) image sequences in the G band and Ca II H line, which show the anticorrelation and temporal delay of reversed granulation features in different heights, believed to be produced by a mixture of convection reversal and gravity waves (Rutten et al. 2004b). DOT Paper III backs up with 3D radiation-hydrodynamics simulations of the granulation to simulate the observations and concludes that magnetic fields play no major role in the formation of reversed granulation (Leenaarts & Wedemeyer-Böhm 2005). DOT Paper IV investigates bright points (with a lifetime of about 9 hours) within longer-lived magnetic patches that outline cell patterns on mesogranular scales, and concludes that the magnetic elements constituting strong internetwork fields are not generated by a local turbulent dynamo (De Wijn et al. 2005b). DOT Paper V observes a surge above the solar limb (2 hours before the largest X-class flare ever recorded) and finds evidence for upward motion of material with velocities of >50 km s^{-1}, brightness variations with periods of ≈6 minutes in the surge, and an inverted Y-shape configuration that suggests magnetic reconnection at the bottom of the surge as its driving mechanism (Tziotziou et al. 2005).

2.3.2. Acoustic Waves in the Chromosphere

"Is there a chromospheric footprint of the solar wind?" ask McIntosh & Leamon (2005) and find a positive answer in the strong correlation between solar wind velocity and composition measured at 1 AU and chromospheric diagnostics of O^{+7}/O^{+6} oxygen density ratios. A search for high-frequency modulations in the chromosphere with *TRACE* UV images finds evidence for acoustic modulations with periods down to 50 s in internetwork areas, a possible signal for acoustic heating of the corona (De Wijn et al. 2005a). Correlated analysis of photospheric magnetograms with MDI and chromospheric UV continuum images with *TRACE* showed that the oscillatory high-frequency power is enhanced in the photosphere but reduced in the chromosphere, which may be explained by the interaction of acoustic waves with the magnetic canopy (Muglach et al. 2005). Non-LTE radiation hydrodynamic simulations revealed that the *TRACE* UV continuum bands (1600, 1700 Å) are sensitive for the detection of high-frequency acoustic waves in a chromospheric height range of 360–430 km (Fossum & Carlsson 2005a). The same authors, however, come to the conclusions that high-frequency acoustic waves are not sufficient to heat the chromosphere (Fossum & Carlsson 2005b). The 3D topography of magnetic canopies in and around active regions was also mapped helioseismically from the propagation behavior of high-frequency acoustic waves in the chromosphere (Finsterle et al. 2004). Helioseismic global modes cause 5 minute oscillations that can be traced even above the chromosphere in coronal network bright points (Ugarte-Urra et al. 2004). The occurrence of acoustic waves also complicates the definition of an average temperature in time-dependent chromospheric models, yielding ionization temperatures up to a factor of 150 higher than the mean or median temperature (Rammacher & Cuntz 2005).

2.3.3. Spicular Flows Revealed

More accurate physical properties of chromospheric spicules have been derived from Stokes polarimetry in Ca II and He I lines, yielding mostly nonthermal broadening ($\gtrsim$16 km s^{-1}) and upper temperature limits of $T \leq 13{,}000$ K (Socas-Navarro & Elmore 2005), as expected for upwardly propelled cool chromospheric material. Line broadening of EUV lines across the solar limb is mostly associated with unresolved flows in spicules and macrospicules (Doyle et al. 2005a). Both initial rise and subsequent fall motion has been observed as a sudden change of the Doppler velocity sign (Xia et al. 2005). Using the Hanle and Zeeman effects in spicules, magnetic fields of ≈10 G and inclination angles of ≈35° to the vertical have been inferred (Trujillo Bueno et al. 2005).

2.3.4. Small-Scale Variability

Have you ever analyzed 130,000,000 objects of an astronomical database? McIntosh & Gurman (2005) analyzed that many EUV bright points observed with the EIT telescope on *SOHO*. The statistics of the lifetime of these events was so overwhelming that deviations from straight power-law distributions could be determined, varying with temperature filters and time during the observed 9 years of the present solar cycle. Numerical MHD simulations of such elementary heating events envision separator and separatrix reconnection as drivers of these small-scale phenomena (Parnell & Galsgaard 2004).

While nanoflares and EUV bright points seem to originate in the corona, the so-called "EUV explosive events" seem to be formed deeper down in the transition region and chromosphere, according to some multi-wavelength studies that cover the entire chromospheric temperature range (Doyle et al. 2005b; Mendoza-Torres et al. 2005). Their average size is estimated to 1800 km and their occurrence rate to 2500 s^{-1} over the entire Sun, but they are insufficient to contribute significantly to coronal heating (Teriaca et al. 2004). Another type of small-scale phenomena, so-called "blinkers," seems not to be connected with the phenomenon of "EUV explosive events" (Bewsher et al. 2005).

2.4. Corona

2.4.1. Footpoint-driven Hydrodynamics of Coronal Loops

The solar corona is believed to have a low plasma-β parameter almost everywhere, so the magnetic pressure dominates over the thermal pressure, and thus is responsible for the appearance of myriads of loops. These bright loops are denser than the ambient corona, and thus have to be filled by chromospheric material, since there is no way to constrict coronal plasma to the observed densities (beyond twist angles $\gtrsim 1.5\pi$; Chae & Moon 2005). So, we have the picture that coronal loops are like heat pipes, which are constantly flushed by heated plasma that is ablated from the chromosphere. Therefore, it seems straightforward to measure the electron density $n_e(s)$, the electron temperature $T_e(s)$, and the flow speed $v(s)$ along these coronal heat pipes to model and understand the hydrodynamics of the solar corona. The reality, however, seems to be more complicated, because it is very tricky to properly isolate a single loop from the thousands of other foreground and background loops along the same line of sight. Nevertheless, new loop modeling attempts have been performed, using constraints from multi-wavelength observations with CDS, EIT, *TRACE*, *Yohkoh*, or optical instruments, and find evidence for energy input (heating) at the loop footpoints (Ugarte-Urra et al. 2005), upflows driven by chromospheric evaporation (Singh et al. 2005), unidirectional flows along a loop (Gontikakis et al. 2005), plasma cooling from soft X-ray to EUV temperatures (Winebarger & Warren 2005), downflows of plasma on both loop sides (Borgazzi & Costa 2005), and "high-speed coronal rain" (Müller et al. 2005). Statistical approaches focus on the tomographic reconstruction of the coronal differential emission measure (DEM) distribution (Frazin et al. 2005; Frazin & Kamalabadi 2005a), or measuring plasma downflows that imply departures from the ionization equilibrium and thus violate basic assumptions of the DEM method (Lanzafame et al. 2005). Modeling approaches include realistic spatial heating functions (Mok et al. 2005; Landi & Landini 2005), and find that only pulsed footpoint heating can reproduce the strongly peaked DEM with the slope of $\propto T^5$ observed in stars (Testa et al. 2005), and that coronal condensation and catastrophic cooling around the loop apex is also a consequence of footpoint heating (Müller et al. 2005; Mendoza-Briceno et al. 2005).

2.4.2. The Conundrum of Coronal Heating

After the coronal heating problem has been with us for over six decades, a *par force* strategy using high-performance computers and all available MHD physics we know of seems to be in place. Such an ab initio approach has been carried out by Gudiksen & Nordlund (2005a, 2005b), who simulated in a computational box using a 3D MHD code that handles the photospheric boundary condition with granular velocity fields (constrained by observed *SOHO* MDI high-resolution magnetograms), mimics the resulting tanglings and braidings of magnetic field lines in the transition region and corona, and finally simulates the dissipation of braiding-driven currents in coronal loops, which match the characteristics of loops observed in EUV with *TRACE*. The full-MHD simulations by Gudiksen & Nordlund (2005a, 2005b) also reproduce the footpoint heating (mentioned above), i.e., the heating is largest at low heights ($\lesssim$5 Mm) because of the stronger stressing of the high plasma-β environment in the transition region. Actually, 90% of the total dissipated energy is dissipated below the transition region in these simulations. This result is geometrically different from Parker's original scenario, where braiding and related current dissipation is almost uniformly distributed throughout the corona, although the basic physics (of dissipation of DC currents) is essentially the same. Footpoint braiding seems be more efficient for hot loops than for cool loops as a consequence of a lower filling factor and higher horizontal velocity (Katsukawa & Tsuneta 2005). Further support for the preferential current dissipation in the transition region was also furnished by detailed MHD forward-modeling of the DEM distribution, flow speeds, and emissivity of EUV lines in the temperature range of the transition region (Peter et al. 2004). Alternative scenarios with nanoflares distributed in the coronal part à la Parker were not able to diagnose the spatial heating distribution from loop hydrodynamic simulations (Patsourakos & Klimchuk 2005).

Other studies on the coronal heating problem focused on the dependence of the heating rate on the driving velocity and emerging flux (Galsgaard & Parnell 2005; Galsgaard et al. 2005), the "tectonic" build-up of current sheets along quasi-separatrix layers (Mellor et al. 2005; Priest et al. 2005), the switch-on mechanism as a function of Parker's magnetic field misalignment angle (Dahlburg et al. 2005), the Rayleigh-Taylor instability that organizes coronal heating in a spatially intermittent way (Isobe et al. 2005), global scaling laws of the heating flux density ($F_H \propto B/L$, with B the magnetic field and L the loop length) from full-Sun (Schrijver et al. 2004) and full-star simulations (Schrijver & Title 2005). Sub-photospheric flux tubes that emerge and drive reconnection in the transition region have been found to behave quite differently depending on their twist: low-twist tubes slingshot while high-twist tubes tunnel (Linton & Antiochos 2005). In one case, the type of magnetic reconnection was identified as *separator reconnection* during the emergence of an active region (Longcope et al. 2005).

While coronal heating in closed magnetic fields (e.g., in active region loops) seems to be controlled by DC currents, the coronal heating in open field lines (mostly in coronal holes and in the solar wind) seems to be accomplished by dissipation of AC currents, most likely conveyed by high-frequency Alfvénic waves. Related studies concentrated on wave energy dissipation by viscous and resistive damping (Craig & Fruit 2005), two-fluid simulations of turbulence-driven Alfvénic heating (O'Neill & Li 2005), and the nonthermal line broadening of minor ions caused by high-frequency Alfvén waves (Ofman et al. 2005).

2.4.3. Coronal MHD Oscillations and Waves

The relatively new discipline of *coronal seismology* continues to prosper, as the over 40 refereed publications during this year indicate. New studies on MHD oscillations of coronal loops, mostly conducted with the aid of MHD simulations, explore second-order effects now, such as the influence of density stratification on resonant damping (Andries et al. 2005a; Del Zanna et al. 2005), the damping of vertical oscillations by wave tunneling (Brady & Arber 2005), diagnostics of density stratification from harmonic overtones (Andries et al. 2005b), oscillations in loops with a hot core and cool shell (Mikhalyaev & Solovev 2005), and the influence of loop curvature and asymmetric excitation (Murawski et al. 2005a; Selwa et al. 2005a, 2005b; Selwa & Murawski 2004; Taroyan et al. 2005). A statistical study of coronal loop oscillations with radio type II bursts established that the excitation of oscillations is triggered by the passage of a flare shock wave (Hudson & Warmuth 2004). A spectral study with SUMER (Solar Ultraviolet Measurement of Emitted Radiation, on *SOHO*) concluded that the initiation of longitudinal loop oscillations is not caused by (symmetric) chromospheric evaporation, but rather by a one-sided (asymmetric) pulse of injected hot plasma (Wang et al. 2005c). Fast MHD oscillations (with a period of 10 s) have even be detected on the star EV Lac (Stepanov et al. 2005).

While MHD oscillations require a settling into an eigenmode, we also observed a variety of phenomena associated with propagating waves, particularly in open field regions, long loops, and strongly asymmetric loops. New theoretical/numerical studies on propagating waves include wave damping by phase mixing, which could not explain the observed strong damping (DeMoortel et al. 2004), siphon flows and oscillations in long coronal loops due to Alfvén waves (Grappin et al. 2005), the effects of magnetic shear on MHD normal modes (Arregui et al. 2004), the impulsive excitation of MHD waves in a loop arcade (Murawski et al. 2005b), and MHD wave propagation near magnetic null points (McLaughlin & Hood 2005).

New observational studies deal with the discovery of high-frequency (≈10 s period) waves in far-UV 1600 Å (DeForest 2004) and in radio (Ramesh et al. 2005), the first detection of global waves in soft X-rays with *GOES* SXI (Warmuth et al. 2005), high-cadence radio observations of an EIT wave during the first 4 minutes (White & Thompson 2005), and the origin of global (EIT) waves (Cliver et al. 2005).

2.4.4. Twisted, Stressed, and Kinked Magnetic Fields

It is still difficult to measure the coronal magnetic field, but new full-Stokes spectropolarimeteric measurements with the coronal Fe XIII 1075 nm line are pioneered, yielding fields of 4 G at heights of 70 Mm above the limb (Lin et al. 2004a). Other coronal magnetography techniques employ the circular polarization of radio emission, finding fields of 20–85 G in heights of 23–62 Mm (Ryabov et al. 2005). Another fingerprinting technique employs 3D magnetic field modeling to match up 2D EUV images (Wiegelmann et al. 2005a, 2005c), which can also be used the other way around for automated loop detection (Lee et al. 2005).

Although most of the coronal field lines are dipolar to first order, and thus close to a current-free potential field, there is far more interesting physics hidden in the second-order deviations, such as nonpotential fields and the associated currents. It is therefore no surprise that most of the 40 papers published about the solar coronal magnetic field deal with twisted, stressed, kinked, and nonpotential fields. Dynamic modeling of the magnetic field braiding reveals that the quiet-Sun corona is often neither quasi-steady nor force-free (Schrijver & Ballegooijen 2005). Non-current-free coronal field lines can already be diagnosed from sub-photospheric MHD models (Amari et al. 2005; Gibson et al. 2004), which recycle the coronal magnetic flux on timescales as short as 3 or 1.4 hr (Close et al. 2005b), constantly injecting magnetic helicity into the corona (Amari et al. 2004), contributing to the coronal heating of soft X-ray emitting loops (Maeshiro et al. 2005; Yamamoto et al. 2005), which may stay in equilibrium even as sigmoids (Aulanier et al. 2005; Regnier & Amari 2004), or lead to plasmoid eruptions (Kusano 2005). The height where a twisted flux rope loses its equilibrium is lower than 25% of the active region separation (Lin & van Ballegooijen 2005). Some active region loops may have more than 2π twist and are thus prone to the kink instability (Leka et al. 2005; Tian et al. 2005b), or have one leg rotated by 40°–200° by a nearby sunspot (Gibson et al. 2004). One active region was estimated to contain an unusually large amount of free magnetic energy (6×10^{33} ergs) before an X10 flare (Metcalf et al. 2005). Magnetic loops with the same handedness of the writhe and the twist may rotate in the corona for a long time (Tian et al. 2005c).

2.4.5. Coronal EUV Emission

Disentangling the inhomogeneous and fractal landscape (McAteer et al. 2005a) of coronal EUV emission was always challenging. New methods explore rotational tomography for 3D reconstruction of the white-light and EUV corona (Frazin & Kamalabadi 2005b). Coronal EUV emission is highly anisotropic. An 8-year long study of *SOHO* EIT data demonstrated that the He II 30.4 nm flux displays polar/equatorial anisotropy of 90% at solar minimum to 60% at solar maximum, as well as a difference of 20% between the north and south polar fluxes (Auchere et al. 2005). Historically, coronal EUV emission varied much more; X-ray and EUV emission was 100–1000 times stronger at the time of the formation of planetary atmospheres than at present (Ribas et al. 2005).

2.4.6. Coronal Holes

The elusive tracers of coronal heating were also sought in void regions like coronal holes, where source confusion and crowded structures are minimized. Links between plasma upflows (detected from Ne VIII Doppler shifts) and isolated closed-field regions in coronal holes have been found (Wiegelmann et al. 2005b). Correlations between the EUV intensities in coronal holes and quiet-Sun regions were taken as evidence for continuous reconnection between open and closed field regions (Raju et al. 2005). Macrospicules were found to have either a spiked jet or an erupting loop, suggesting reconnection between the network bipole and open magnetic fields (Yamauchi et al. 2005). Other indirect tracers of coronal heating were extracted from Mg x line width decreases, probably caused by damping of upwardly propagating Alfvén waves (O'Shea et al. 2005b).

2.4.7. Quiescent Filaments and Prominences

We counted 29 papers on investigations of quiescent filaments or prominences, which include their automated detection (Bernasconi et al. 2005; Fuller et al. 2005; Qu et al. 2005; Zharkova & Schetinin 2005), their production mechanism (Liu et al. 2005e; Spadaro et al. 2004; Litvinenko & Wheatland 2005), a new mass determination method (Gilbert et al. 2005), their thermodynamic stability (Costa et al. 2004; Low & Petrie 2005; Petrie & Low 2005; Petrie et al. 2005), their oscillations (Diaz et al. 2005; Dymova & Ruderman 2005; Foullon et al. 2004), with ultralong periods up to 8–27 hours (Foullon et al. 2004), their wave damping (Terradas et al. 2005), their absorption and volume blocking (Anzer & Heinzel 2005; Stellmacher & Wiehr 2005), their NLTE radiative transfer (Gouttebroze 2005), their magnetic topology (Lites 2005), their chirality (Mackay & van Ballegooijen 2005), their possible electric field (Lopez Ariste et al. 2005), and their fine structure in form of threads (Lin et al. 2005c) and barbs (Chae et al. 2005; Lin et al. 2005d; Su et al. 2005a). Did we miss anything?

2.5. Flares

2.5.1. Direct Observations of Magnetic Reconnection Sites

Some kind of magnetic reconnection is thought to be the driver of flares/CMEs in every flare model. Thus, a direct observation of a magnetic reconnection site would be the "holy grail." Such a discovery was indeed announced in the observation of the 18 November 2003 flare, where the formation of a current sheet was observed behind an erupting CME, with flare loops forming in the wake beneath (Lin et al. 2005b). The CME sped off with a velocity of 1500–2000 km s^{-1}, and lateral reconnection inflow speeds of 10–100 km s^{-1} and outflow speeds of 500–1000 km s^{-1} were measured, leading to a reconnection rate with Mach numbers of $M = 0.01$–0.23 (Lin et al. 2005b). In the early stages of 13 well-observed two-ribbon flares, a strong correlation was found between the magnetic reconnection rate and the acceleration of the associated erupting filaments, yielding support for the flare model developed by Forbes and Lin, which is driven by the converging footpoints (Jing et al. 2005; Sakajiri et al. 2004). An indirect calculation of the reconnection rate (of ≈ 0.001–0.03) was determined from the footpoint motion seen in the EUV (Noglik et al. 2005) and UV (Fletcher et al. 2004). Further tail-lights of the reconnection process have been sighted in radio type II bursts observed at 40–80 MHz and 300 MHz, believed to be the signatures of the upper and lower reconnection outflow termination shock (Aurass & Mann 2004). While the newly-reconnected magnetic field line arcade is rooted in a two-ribbon structure in most flare models, observations also reveal the occasional involvement of a remote third ribbon, moving away from the flare site with a speed of 30–100 km s^{-1} (Wang 2005).

Forced magnetic reconnection was simulated in more detail, showing the current sheet thinning and onset and progress of fast magnetic reconnection, and leading to similar final states with Hall-MHD fluid or particle kinetic codes (Birn et al. 2005). Other theoretical studies emphasize the importance of viscous heating in magnetic X-points (Craig et al. 2005a), the kinetic effects of the Hall current in the reconnection process (Morales et al. 2005), multiple fast shocks created by the secondary tearing instability (Tanuma & Shibata 2005), and the structure of the reconnection outflow jets (Vrsnak & Skender 2005).

2.5.2. Magnetic Field Changes During Flares

While a magnetic reconnection process changes only the local connectivity, the changes induced on larger scales or even in the photospheric boundary are less obvious. Nevertheless, major flares, such as white-light flares with energies of 10^{33} ergs (Li et al. 2005b), can lead to large irreversible magnetic flux increases of up to $\lesssim 10^{21}$ Mx (Zharkova et al. 2005), which are able to heat sunspots (Li et al. 2005c), disintegrate δ-configurations (Liu et al. 2005c; Wang et al. 2005a), weaken the penumbral structure, and slow down its Evershed flow (Wang et al. 2005a).

Of course, you want to know if the preflare magnetic configuration allows us to predict the flare magnitude. Power spectra of magnetograms revealed a steeper spectrum for X-class flare-producing active regions, so some active regions are "born bad" and become predictably more violent later on (Abramenko 2005b). Then flares occur preferentially in regions with a high gradient in twist and close to chirality inversion lines (Hahn et al. 2005), and in regions with strong shear flows, counter-streaming, and complex flow patterns (Yang et al. 2004).

The coronal magnetic field changes during a flare should lead us to the relevant flare model. Observational studies find loop-loop interactions with coalescence instability (Wu et al. 2005b) or quadrupolar double arcades with undetected far-end ribbons (Wang et al. 2005a).

2.5.3. Particle Acceleration During Flares

The more we can nail down the magnetic topology of reconnection regions from direct observations, the better we can hand over the likely parameters of accelerating fields to the theoreticians. There is no shortage of theoretical models and simulations of any imaginable particle acceleration scenario, such as Fermi and betatron acceleration in collapsing magnetic traps (Bogachev & Somov 2005), particle acceleration in turbulent current sheets (Dmitruk et al. 2004; Wu et al. 2005c), in reconnecting current sheets (Wood & Neukirch 2005), in 2D X-points (Hamilton et al. 2005), in 3D reconnecting current sheets with chaotic orbits (Efthymiopoulos et al. 2005; Dalla & Browning 2005), proton acceleration in coalescing loops (Sakai & Shimada 2004, 2005) and between two colliding moving solitary magnetic kinks (Sakai & Kakimoto 2004), and acceleration in field line advection models (Sokolov et al. 2004), and in phase-mixing regions of shear Alfvén waves (Tsiklauri et al. 2005a, 2005b). Unfortunately, the observers cannot catch up with sufficiently discriminative diagnostics. Two innovative studies attempted to measure the level of microturbulence, which controls stochastic acceleration, from so-called (hitherto undetected) "resonant transition radiation" in radio data (Nita et al. 2005; Fleishman et al. 2005).

2.5.4. RHESSI Observations

RHESSI (the *Reuven Ramaty High−Energy Solar Spectroscopic Imager*) has completed four years (2002–2006) of its mission and certainly continues to stimulate solar flare research, producing over 80 papers during the last year. Since the strength of *RHESSI* lies in (1) the first imaging at high energies, (2) the high spectral resolution that allows one to resolve most of the gamma-ray lines, and (3) the high-resolution spectroscopy also at lower hard X-ray energies, we summarize some new *RHESSI* results in the same order: (1) imaging with *RHESSI* revealed the evolution of progressing reconnection along a flare loop arcade (Grigis & Benz 2005a; Li et al. 2005a), the so far unexplained loop-top altitude decrease in the initial phase of flares (Veronig et al. 2005a), and the obscured view of a giant flare with an energy of $\approx 10^{34}$ ergs (Kane et al. 2005); (2) gamma-ray line modeling with *RHESSI* showed us a 511 keV e^+/e^- annihilation line that is so broad that the ambient ionized medium needs a temperature of 10^5 K, instead of the expected much lower chromospheric value (Share et al. 2004); and (3) high-resolution spectroscopy with *RHESSI* gave us new insights into the energy partition of thermal, nonthermal, CME-mechanical, and nonpotential magnetic energies (Emslie et al. 2004, 2005; Saint-Hilaire & Benz 2005), the soft-hard-soft evolution of hard X-ray spectra compared with acceleration models (Grigis & Benz 2004, 2005b), the low-energy cutoff of the electron spectrum (Sui et al. 2005), the physics of the Neupert effect, i.e., the correlation between the thermal soft X-ray and the integral of the hard X-ray time profiles (Veronig et al. 2005b), and the size dependence of solar flare spectral properties (Battaglia et al. 2005). Other exciting *RHESSI* discoveries are the quasi-periodic hard X-ray pulsations that could be explained in terms of the MHD kink mode, which supposedly modulates the electron injection in a multiple flare-loop system (Foullon et al. 2005). Another surprising result was that no coherent radio emission was detected in 17% of hard X-ray flares (Benz et al. 2005), since both emissions are produced by electrons of similar energy and occasionally coincide with subsecond accuracy (Arzner & Benz 2005). A puzzle is also the absence of linear polarization in Hα emission, which limits the anisotropy of energetic protons and refutes earlier positive reports (Bianda et al. 2005).

Theoretical modeling of *RHESSI* data included fast electron slowing-down and diffusion in high-temperature coronal sources (Galloway et al. 2005b), inversion of hard X-ray spectra with generalized regularization techniques (Kontar et al. 2004, 2005; Kontar & MacKinnon 2005; Massone et al. 2004), Fokker-Planck modeling of electron beam precipitation (Zharkova & Gordovskyy 2005) producing asymmetric footpoint hard X-ray sources (McClements & Alexander 2005), and the viewing angle of Hα impact polarization (Zharkova & Kashapova 2005).

2.5.5. Flare Oscillations and Waves

The discovery of a harmonic oscillation in a solar flare feels like the beginning of a symphony concert, after the cacophonic tuning of orchestral instruments that inevitably precedes every concert performance comes to a halt. It is really not much different in the performance of a solar flare, except that harmonic oscillations of the flare plasma are conducted and triggered by a magnetic instability. The first high-fidelity record (with high spatial resolution) of a long-period ($P \approx 9$–12 and 9–23 minutes) quasi-periodic oscillation of (3–25 keV) hard X-ray radiation during solar flares was imaged in a trans-equatorial flare loop with *RHESSI*, interpreted in terms of MHD kink-mode modulated injection of X-ray-emitting electrons (Foullon et al. 2005).

A similarly exciting discovery was made in form of downward-propagating quasi-periodic transverse waves with periods of $P = 90$–220 s in post-flare supra-arcade structures, interpreted in terms of propagating MHD kink-mode waves (Verwichte et al. 2005), in contrast to the standing mode mentioned above (Foullon et al. 2005). After the longitudinal MHD slow-mode oscillations were discovered in soft X-rays with *SOHO* SUMER a few years ago, they could also be rediscovered in *Yohkoh* data (Mariska 2005, 2006), and were also claimed to be discovered on the M-type dwarf AT Mic with the *XMM-Newton* telescope (Mitra-Kraev et al. 2005).

One of the first imaging observations of the MHD fast sausage mode has been accomplished in radio wavelengths with the Nobeyama interferometer, where periods of $P = 14$–17 s (global sausage mode) and $P = 8$–11 s (possible higher harmonics) have been measured (Melnikov et al. 2005). Additional flare-triggered oscillations have also been detected in Hα with periods of $P = 40$–80 s (McAteer et al. 2005b), and in seismic (photospheric) magnetogram data, probably triggered by precipitating high-energy protons (Donea & Lindsey 2005).

2.5.6. Flare Simulations

Hydrodynamic flare simulations of the chromospheric heating in response to precipitating high-energy particles have become more refined and multi-wavelength comprehensive, predicting that moderate flares have a long gentle phase with a near balance between flare heating and radiative cooling (Allred et al. 2005; Berlicki et al. 2005), while the gentle phase is much shorter or even absent in strong flares (Allred et al. 2005), possibly the case in dME flare stars or even in Barnard's star

(Paulson et al. 2006). The occurrence of chromospheric evaporation *before* the impulsive flare phase was interpreted in favor of the magnetic break-out model (Harra et al. 2005). The interpretation of data is complicated because upflows of heated plasma and downflows of catastrophically cooled flare plasma can be simultaneous and almost cospatial (Kamio et al. 2005), masking the blueshifted upflows (Warren & Doschek 2005; Doschek & Warren 2005). Simulations also show that localized heating events far away from the loop apex can produce bright EUV knots near the loop top during the cooling phase (Patsourakos et al. 2004). Further complications could arise from the consequences of non-equilibrium ionization balance, which can make standard temperature diagnostic unreliable (Bradshaw et al. 2004).

2.5.7. Flare Radio Observations

Some unusual radio observations during flares included the first "zebra pattern" observations at frequencies of 5.6 GHz, believed to be produced by coupling Bernstein waves in magnetic fields of 60–80 G (Altyntsev et al. 2005), fiber burst observations in postflare loops used to infer the 3D magnetic field (Aurass et al. 2005), and simultaneous remote radio and in situ particle detections of solar energetic electron events (Klein et al. 2005).

2.5.8. The Largest Solar Flare

To classify the magnitude of a flare, the soft X-ray flux registered by the *GOES* spacecraft is generally used. For the 4 November 2003 flare, however, the detectors on the *GOES-12* satellite saturated. Brodrick et al. (2005) managed to quantify the magnitude of this largest solar X-ray flare on record by using the recordings of a pair of 20.1 MHz riometers, which register the ionospheric attenuation of the galactic radio background, yielding a magnitude of 3.4–4.8 mW m^{-2}, corresponding to *GOES* class X34–X48.

During the same month, on 20 November 2003, the largest geomagnetic storm of solar cycle 23 was registered, triggered by a CME that left the Sun with a projected speed of $\approx$1660 km s^{-1} and with a very strong southward pointing axial field of the magnetic cloud (Gopalswamy et al. 2005a). The "Halloween" period of October/November 2003 was extremely active, resulting in 80 CMEs, many ultrafast (>2000 km s^{-1}), with a record of 2700 km s^{-1} on 4 November 2003, and many of these were highly geoeffective (Gopalswamy et al. 2005b).

2.6. CMEs

2.6.1. Erupting Filaments and Prominences

Statistical studies reveal that filament eruptions have a very high association rate with flares and CMEs in active regions (Jing et al. 2004). Therefore, the most interesting questions about filaments are concerned with the instability that causes them to erupt, especially since the consequences are the launches of CMEs and their possible geoeffective impacts. Observational evidence for the MHD helical kink instability has been established (Rust & LaBonte 2005; Williams et al. 2005), and a confined (failed) eruption has also been observed and consistently simulated (Török & Kliem 2005; Fan 2005). However, the observational determination of sufficient magnetic twist can be underestimated according to force-free field simulations (Leka et al. 2005). Romano et al. (2005) find that the transport of magnetic helicity exceeding the kink instability criterion is primarily due to photospheric motion, rather than emerging flux. In addition, reconnection in overlying fields, such as envisioned in the magnetic breakout model or tether-cutting model, are also a controlling factor for the eruption of a filament (Sterling & Moore 2004, 2005).

2.6.2. Magnetic Field Configuration of CMEs

The magnetic breakout model, in which magnetic reconnection above a filament channel is responsible for disrupting the coronal magnetic field, seems to be the favorite workhorse of current CME modeling. The first MHD simulation of the complete breakout process including the initiation, the plasmoid formation and ejection, and the eventual relaxation of the coronal field to a more potential state was presented by MacNeice et al. (2004). The magnetic helicity is found to be well conserved during the breakout; about 90% is carried by the escaping plasmoid, while about 10% remains in the corona (MacNeice et al. 2004). However, the amount of helicity seems not to be critical (Phillips et al. 2005). Also, there seems to be no lower limit, since even a mini-sigmoid with 2 orders of magnitude smaller magnetic flux than average was found to erupt and to produce a mini-magnetic cloud (Mandrini et al. 2005). The free magnetic energy available to drive a CME (which entails the coronal null region in the magnetic breakout model) was found to be concentrated at 1.25–1.75 solar radii (DeVore & Antiochos 2005), containing two catastrophic points (Zhang et al. 2005c). The eruption speed becomes Alfvénic at 2.5 solar radii, and the magnetic fields in the erupting flux rope can be well approximated by the Lundquist solution when the ejecta are at 15 solar radii and beyond (Lynch et al. 2004).

While the magnetic breakout model is found to be consistent with most observations, alternative models with emerging flux and small-scale reconnection in the chromosphere were found to explain some surge-CME events (Liu et al. 2005d). The newly emerging flux that triggers a CME often emerges with an opposite sign in the helicity than that of the pre-existing active region (Wang et al. 2004b).

2.6.3. CME Global Waves

The launch of a CME often causes a detectable concentric wave that propagates spherically over the solar globe, also called *Moreton wave*, *EIT wave*, or *radio type II burst*, depending on the wavelength and height at which it is detected. The phenomenon of EIT waves and EUV dimming is now shown to be clearly a coronal phenomenon, detected even at coronal temperatures of 2 MK in the Fe XV 284 Å line (Zhukov & Auchere 2004; Chertok & Grechnev 2005), and even up to 6 MK (Poletto et al. 2004). Dimming is also seen in the chromosphere (detected in the He I 1083 Å line) in the form of a transient coronal hole (DeToma et al. 2005). A reconciling picture was put forward by Chen et al. (2005d), who simulated how the typical features of EIT waves can be reproduced by successive stretching or opening of closed field lines in the wake of an erupting flux rope, causing the wave speed to stop near separatrices and to accelerate between active regions and quiet Sun regions. EIT waves can be best detected with automated algorithms from the dimming they leave behind the wave front in the form of a temporary density rarefaction (Podladchikova & Berghmans 2005; Robbrecht & Berghmans 2005). The Hα/EIT wave is thought to show up in the corona and interplanetary space as a shock wave (radio type II burst; Cliver et al. 2004; Knock & Cairns 2005) or as modulation of the optically thin gyrosynchrotron emission (radio type IV burst) excited by the passage of the shock (Vrsnak et al. 2005a; Pick et al. 2005; Pohjolainen et al. 2005).

2.6.4. The CME-Flare Connection

The flare phenomenon is now clearly established as a byproduct of the same magnetic instability that drives a CME. There is statistically really no significant difference in the kinematic properties of flare-associated CMEs and non-flare CMEs (Vrsnak et al. 2005b). Also, the correlation between flare-associated X-ray plasma ejections and CMEs was found to be strong (Kim et al. 2005a). The intimate relation between CMEs and flares becomes even clearer when we look at the cusped postflare loops that rise in altitude in the wake of erupting flux ropes (Goff et al. 2005). The very onset of a flare-associated CME was for the first time observed in the optical green line (Fe XIV 5303 Å) at a temperature of 2 MK (Hori et al. 2005).

2.6.5. 3D Vision of CMEs

Even we do not have the 3D capabilities of the soon to-be-launched *STEREO* (*Solar Terrestrial Relations Observatory*) mission at hand; yet some novel 3D visualizations of CMEs have been accomplished by using the white-light polarization of LASCO images (Dere et al. 2005), as recently pioneered by Moran & Davila (2004). A triangulation method to reconstruct basic 3D geometric parameters of CMEs with the *STEREO* spacecraft has also been already developed (Pizzo & Biesecker 2004).

2.6.6. CME Kinematics

The trajectories of CMEs are difficult to reconstruct from one vantage point alone, because they follow a curved path along the Parker-Archimedean spiral, but in combination with the all-sky monitor SMIE on the *Coriolis* spacecraft, more accurate trajectories and 3D velocities could be determined, which could enhance the accuracy of space weather predictions (Reiner et al. 2005). The CME direction seems to be the most important parameter that controls the geoeffectiveness of very fast halo CMEs (Moon et al. 2005).

The speed distributions of accelerating and decelerating CME events were found to be nearly identical lognormal distributions (Yurchyshyn et al. 2005). The acceleration of CMEs tends to be higher for flare-associated CMEs than for filament-associated CMEs, but counter-examples were found that suggest that flare-associated CMEs with large acceleration are additionally boosted by helmet streamer disruptions or subsequent CMEs/flares (Moon et al. 2004).

The rate of mass injection at the onset of a “halo” CME could be determined to $\approx 10^{16}$ g hr^{-1} from metric radio data (Kathiravan & Ramesh 2005).

2.6.7. Difficulties with Predicting the Arrival of CMEs at Earth

3D MHD simulations of propagating CMEs reveal that the arrival time of CME shocks at Earth strongly depends on the ambient background solar wind, the standoff distance between the shock and the driving ejection, and the inclination angle of the shock with respect to the Sun-Earth line (Odstrcil et al. 2005; Jacobs et al. 2005; Lee 2005; Wu et al. 2005a). Heliospheric in situ magnetic field measurements allow quantification of the correlation length of magnetic field parameters for passing interplanetary CMEs and ambient solar wind, which yields better predictions for CME arrival times at Earth (Farrugia et al. 2005). A large statistical study showed that just over a quarter of the 938 HCMEs observed by LASCO were associated with a forward shock near L1, suggesting that about half of the earthbound HCMEs are either deflected away from the Sun-Earth line or do not form a shock (Howard & Tappin 2005). Although “halo-CMEs” are considered as Earth-directed, a fraction of 15% miss the Earth (Kane 2005c). Given the maximum observed CME speeds of ≈ 3000 km s^{-1}, the shortest travel times of CME-driven shocks are expected to be no less than ≈ 0.5 days (Gopalswamy et al. 2005b).

2.6.8. Particles Accelerated in CMEs

There is a long-standing dichotomy between flare-accelerated and CME-accelerated particles, which differ in timing, spectra, and composition (Lin 2005; Tylka et al. 2005). While solar energetic particles (SEPs) are believed to be accelerated in CME shocks, to our surprise, no obvious correlation of SEP onset and rise times of 20 MeV protons with any CME parameter was found (Kahler 2005). Full 3D MHD and kinetic hybrid simulations of particle acceleration in a propagating and evolving CME shock and sheath structure reveal that the acceleration efficiency of GeV particles strongly depends on the fast-mode shock evolution, controlled by the increased magnetic field strength in the plasma compression behind the shock

(Manchester et al. 2005b). Also, the fact that the kinetic energy in accelerated particles represents a significant fraction of the CME kinetic energy implies that shock acceleration must be relatively efficient (Mewaldt et al. 2005).

On the other hand, some SEPs might also originate in flare sites. Klein & Posner (2005) found that <54 MeV protons are accelerated simultaneously with dm–km type III emitting electrons, supposedly in altitudes of 1.1–1.5 solar radii, in one-third of the analyzed events. In one large (*GOES* class X17) flare, three phases of particle injections were determined: an impulsive injection of radio type III–producing electrons first, than a second impulsive injection 11 minutes later (lasting 18 minutes), and a third gradual one 25 minutes later (lasting 1 hour), where the latter two delayed acceleration phases could not be localized (Klassen et al. 2005).

2.7. Heliosphere

2.7.1. Acceleration of Solar Wind

Where is the solar wind accelerated? Analysis of *SOHO* UVCS data suggests that the slow solar wind is accelerated in the legs or in the stagnation flow (Nerney & Suess 2005) near the cusp of streamers, or above the streamer core beyond 2.7 solar radii, right where the heliospheric current sheet starts (Antonnucci et al. 2005). LASCO observations suggest that open and closed field lines reconnect near the streamer cusp and form blobs of higher plasma density that are ejected into the slow solar wind (Lapenta & Knoll 2005). If there is no streamer around, an active region can also substitute (Woo & Habbal 2005). In addition, the effects of differential rotation of the solar surface forces continuous disconnection and reconnection at the more or less rigidly rotating coronal hole boundaries, which modulate the formation of the slow solar wind (Lionello et al. 2005).

The fast solar wind is believed to originate from small coronal funnels in the transition region in coronal hole regions, where hydrogen is far from ionization equilibrium and Lyα emission comes from temperatures of $\approx 5 \times 10^4$ K (Esser et al. 2005). The physical process responsible for accelerating the fast solar wind is the interaction of open magnetic field lines with smaller coronal loops through magnetic reconnection (Fisk 2005), driven by magnetic footpoint diffusion (Giacalone & Jokipii 2004). Another piece of evidence for the chromospheric origin of the fast solar wind comes from the correlation between solar wind velocities and the ratio of ionic oxygen (O^{+7}/O^{+6}) densities (McIntosh & Leamon 2005). Magnetic field extrapolations of coronal funnels place Ne^{7+} and C^{3+} ions into altitudes of 5–20 Mm, where the flow speed increases from zero to 10 km s^{-1}, as the birthplace of the fast solar wind (Tu et al. 2005).

The interface between fast and slow solar wind in interplanetary space was found to have two distinct parts: a smoothly varying boundary layer flow that flanks the fast wind from coronal holes, and a sharper plasma discontinuity between intermediate and slow solar wind, explaining the correlations between wind speed variabilities, charge state composition, and magnetic field orientation in the heliosphere (Schwadron et al. 2005).

2.7.2. Turbulence in Solar Wind

The solar wind is a "turbulence laboratory" (Bruno & Carbone 2005). One source of turbulence is (hypothetical) high-frequency Alfvén waves, produced by successive merging and braiding of flux tubes on granular and supergranular scales in the chromosphere and transition region (Cranmer & van Ballegooijen 2005). The source of long-period Alfvén waves observed in the solar wind can also be associated with leakage from helioseismic modes (Zaqarashvili & Belvedere 2005). The dominant-turbulence model of Isenberg (2005) describes the turbulent heating of the distant solar wind by the dissipation of wave energy generated by the isotropization of interstellar pickup protons, through cyclotron resonance and particle pitch-angle scattering.

2.8. Solar Cycle and Space Weather

2.8.1. Sunspot Predictions

The statistics of sunspot numbers have now been consolidated back to Galileo's observations in 1610, which tell us not only the average cycle period (10.9 ± 1.2 years), but also about the cycle asymmetry (with a fast rise and slow decay), that the rise time decreases with cycle amplitude, that large-amplitude cycles are preceded by short-period cycles, that the secular amplitudes increase since the Maunder minimum, and about hemispheric symmetries (Hathaway & Wilson 2004). Subcycles with periods of 152–158 days were also noted from flare rates (Ballester et al. 2004) or other solar indices (Kane 2005c). Such subcyles are also called *Rieger periodicities* and were even discovered on stars, e.g., with a 294-day cycle on UX Arietis, believed to be caused by equatorially trapped Rossby-type waves modulating the emergence of magnetic flux at the surface (Massi et al. 2005). The centennial increase in global geomagnetic activity was, however, considerably smaller than the secular increase in solar activity (Mursula et al. 2004). Predictions include a strong next cycle (XXIV) with a sunspot number of 145 ± 30 in 2010, and a weak following cycle (XXV) with 70 ± 30 spots and a long cycle peaking in 2023 (Hathaway & Wilson 2004).

The prediction methods of solar activity becomes increasingly more sophisticated, resembling the flow charts of electronic circuits. In one study we read that fuzzy logic, neural networks, and genetic algorithms are the most popular artificial intelligence techniques (Attia et al. 2005). The authors describe LAGA-POP (linear adapted genetic algorithm with controlling population size) and FLNN (fuzzy logic neural network), which they explain in the following way: "This is a particular implementation of a fuzzy system equipped with fuzzification and defuzzification interfaces" (Attia et al. 2005). Another algorithm, MRD-GA (multi-resolution dynamic genetic algorithm), is described as a "linguistic fuzzy system with a general rule-based structure" (Attia et al. 2005).

2.8.2. Sunspot Postdictions

Long-term solar activity reconstruction on centennial to multi-millennia timescales is accomplished by cosmogenic isotope records, such as ^{10}Be and ^{14}C (Miletsky et al. 2004; Mordvinov et al. 2004; Lee et al. 2004; Volobuev 2004), which are produced mostly in the upper atmosphere, and thus are anticorrelated with the sunspot number (Scherer et al. 2004), but this *archeo-magnetic* reconstruction method is not really a measurement but rather a "postdiction," and thus is not considered reliable for future predictions (Usoskin & Kovaltsov 2004). Some authors defined a new parameter to characterize the long-term solar cycle variability, the *sunspot unit area*, which is the size of a sunspot averaged over a cycle, but then lost the *Waldmeier effect* and the *Gnevyshew-Ohl rule* (Li et al. 2005d).

And regarding the present cycle, Reimer (2004) finds that "an ingeniously constructed record of sunspot activity shows that the current episode is the most intense for several thousand years. But that does not let us off the anthropogenic hook of global warming." There is no systematic trend in the level of solar activity that can explain the most recent global warming (Benestad 2005), although it has been reported that the total solar irradiance increased by 0.15 W m^{-2} between the solar minima in 1987 and 1995 (Dewitte et al. 2004).

In addition to the solar cycle variation, other quasi-periodic patterns have come to our attention, such as the "*flip-flop*" phenomenon, where the most dominant active regions flip spontaneously to the opposite side of the star (Berdyugina 2004; Fluri & Berdyugina 2004).

2.8.3. Space Weather

The concept of *space weather* was launched some 10 years ago to describe the short-term variations of solar activity and their effects on the near-Earth environment and technoculture. More recently, the term *space climate* was introduced to include the longer-term variations of solar activity and their implications for the heliosphere and near-Earth space. The beginnings of this new industry, however, go 150 years back. The September 1859 solar terrestrial disturbance is considered as the first recognized space weather event (Cliver & Svalgaard 2004). But only in 2004, a *First International Symposium on Space Climate* was organized, documented in some 50 articles in the Topical Issue of *Solar Physics* volume 224.

It is always entertaining to hear how the solar cycle directly affects our life. Apparently, the space weather even affects the wheat market prices on Earth, as a study from medieval England up to modern-day USA by Pustilnik & Yom-Dim (2004) demonstrates, via a chain reaction of sunspot activity→solar wind modulation→variation of cosmic rays→cloudiness and weather changes→drop of agriculture production→wheat price bursts.

Another very practical application of space weather is the study of the impacts of geoeffective events. Solar energetic particles (SEPs) can reach the Earth when the magnetic connectivity of the flaring active region is matching, with a tolerance of 25°–30° in heliographic longitude (Ippolito et al. 2005), although sometimes apparently not-connected events rooted in the eastern solar disk happen (Miroshnichenko et al. 2005b). During a 7-year period of the current solar cycle, 64 geoeffective CMEs were found to produce major geomagnetic storms at Earth (Srivastava & Venkatakrishnan 2004). The SEP event of 14 July 2000 (the "Bastille-day flare") was investigated by using simultaneous ground-based and satellite measurements of the particle flux, together with a tissue equivalent proportional counter on board a Virgin Atlantic Airways flight from London Heathrow to Hong Kong, but fortunately no increased radiation levels were detected (Iles et al. 2004).

2.9. Decadal Anniversary of SOHO

The happy 10th launch anniversary of the *Solar and Heliospheric Observatory* (*SOHO*) spacecraft was jubilated on 2 December 2005, from which we quote a succinct "numerical" summary by Bernhard Fleck:

"Ten years of operation without a single service or tune-up is no piece of cake for a spacecraft. As anyone who has operated scientific instruments in a lab will know, it's amazing how many things can go wrong, requiring some form of intervention or repair. But that has not been an option for *SOHO* and its instruments—if it breaks, it's broken, and all you can do is adjust to a new reality. But miraculously, we're doing very well even after all these years."

Some amazing facts about *SOHO*'s first decade:

- 140 Ph.D. theses have been written on or about *SOHO* data.
- 289 scientific meetings on subjects related to *SOHO* appear on our meetings pages.
- 944 news stories appear on our newsroom pages (only recorded between 1997 and 2005!).
- 1000 comets have been found. *SOHO* is the most prolific comet-finder observatory of all times, and has identified almost half of all comets for which an orbit determination has been made.
- 2300 reviewed papers using *SOHO* data have been published.
- 2300 scientists (approximately) appear in the author lists of those papers (we like to say that every current solar scientist has had the chance to work with *SOHO* data).
- 3230 science planning meetings have been held.
- 2,000,000 command blocks have been sent to the spacecraft by the ground system.
- 5,000,000 distinct files have been served by the web server.
- 10,000,000 exposures (almost!) have been made by the CDS instrument.
- 16,000,000 distinct hosts have been served by the web server.

- 50,000,000 exposures have been taken by MDI. They're probably quite high on the list of "the world's most durable camera shutters." Don't try to beat it with your favorite SLR camera!
- 266,000,000 web page requests have been served.
- 16,000,000,000,000 bytes (16 Terabytes) of data are contained in the *SOHO* archive.
- 85,000,000,000,000 bytes (85 Terabytes) of web pages/data have been served.

3. SHORT, SWEET, AND SURMISED

Here are two highlights from near the end of the reference year. The "short" refers to the duration of the events—the second main class of gamma-ray bursters (§ 3.1.1) and the encounter of the *Deep Impact* mission with comet 9P/Tempel 1 (§ 3.2.4). "Sweet" means reasonably well defined results in the two cases; and "surmised" suggests that the results confirm at least some previous predictions. Each highlight is accompanied by related topics in gamma-ray and solar-system astronomy.

3.1. Gamma Rays and Cosmic Rays

These live together because both are very high energy astrophysics in the modern sense of "high energy per particle or photon," rather than the 1960's sense of "high energy per event."

Two sorts of gamma ray bursts were predicted, and two sorts were observed. Unfortunately, they were not the same sorts. The predicted ones came from shock breakout in core collapse supernovae (Colgate 1968) and from the last gasp of Hawking radiation during the evaporation of mini-black-holes (Hawking 1974). The first time one of us attempted to describe the two observed sorts, they were the classic ones discovered by Klebesadel et al. (1973), and the soft gamma repeaters, of which the 5 March 1979 event was first. But with the association between SGRs and nearby supernova remnants, neutron stars, etc. (Ap94, § 5.3), they ceased to count. Then the two sorts were those of long and of short duration (means near 20 and 0.3 seconds; Kouveliotou et al. 1993), also characterized as having relatively softer and harder spectra.

3.1.1. The Short Lady Bursts

The fat lady burst in 1997 (Ap97, § 11), when *BeppoSAX* caught X-ray tails which, in turn, permitted the identification of optical and radio counterparts with measured redshifts. A ha! GRBs were not wimpish, repeating surface events on old, nearby neutron stars, the dominant model through the 1980s (Ho et al. 1992), but one-shot stellar demises, happening perhaps once in a million years per galaxy, but so powerful that the BATSE catalog surveyed most of the observable universe (Ap98, § 6.3).

Only gradually as the inventory of counterparts accumulated did it become clear that (1) they were all wedded to long duration events, (2) association with star formation regions and other considerations strongly suggested a best-buy model of core collapse in rapidly rotating massive stars with rapidly rotating black holes as the product, and (3) some, at least, had simultaneous Type Ic supernovae, which peeked out as soon as the GRB faded (Ap03, § 4). Notice that there is at least some connection with the first (Colgate) predicted sort.

But what, then, was responsible for the short duration bursts, whose statistics suggested smaller distances and so smaller total power and whose X-ray tails were so faint they had to be piled up to show (Montanari et al. 2005)? Luckily, there was a spare, underused old model hanging at the back of the closet[4]—the merger of a binary neutron star pair or neutron star plus black hole, brought together by loss of angular momentum in gravitational radiation (Guetta & Piran 2005; Aloy et al. 2005; Miller 2005, the most recent appearances of the model, not the first). A definite prediction was that the short duration bursts should, or anyhow could, occur far from any recent star formation, since gravitational radiation is a very slow way to do anything (including establish a reputation in observational astronomy).

As we closed our eyes to the ongoing stream of literature, the first short one, GRB 050509b, had just turned up in a cluster of galaxies at $z = 0.225$, where the stars are about 360 Myr old, and any associated supernova must have been much fainter than those associated with long-duration bursts (Castro-Tirado et al. 2005). And we slip surreptitiously out of period to record that GRB 050709 happened at the outskirts of a $z = 0.160$ star-forming galaxy, far from any young stars, that it was considerably fainter than most long GRBs, and that again no supernova was spotted (Fox et al. 2005; Gehrels et al. 2005; Villasenor 2005; Hjorth 2005; Piro 2005).

These are, in other words, pretty much what you would have expected from the NSX2 models, though curiously one of the pioneers of those has since disowned the idea (B. Paczynski 2005, private communication). Some people just can't stand to be right (though we have the opposite problem). Istomin (2005) suggests that the double pulsar J0737−3039AB will eventually give rise to a short duration GRB. You will surely join the editor of *PASP* in hoping that the ApXX series is not still around to report the event!

3.1.2. Other Sorts of GRBs

It is time, clearly, for some additional classes. A short-short type, apparently new this year (Rau et al. 2005), might possibly be the long-promised Hawking radiation chirps (Halzen et al. 1991). They last less than 0.25 s and have $V/V_m = 0.48$ according to the *INTEGRAL* catalog and 0.52 in BATSE (that is, an essentially homogeneous distribution in space).

If you are feeling less adventurous, there are still the optically dark and gamma-poor (or X-ray-rich) GRBs. The first are defined by a small ratio of optical to X-ray luminosity (Castro

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[4] At least one of your authors can confirm that old models find employment in anything more remunerative than hanging at the back of the closet remarkably difficult to locate.

Ceron et al. 2004), perhaps because the visible light fades very fast, say Filliatre et al. (2005) and Jakobsson et al. (2005), each of whom managed to catch one in the infrared by hurrying to the error box. If the cause is severe Compton losses, then a large GeV luminosity is a prediction (Beloborodov 2005, who was thinking of GRB 941017).

The X-ray enthusiastic sort are not, say the pundits (this year at least) a separate class, but merely an extreme of a continuum with the classic events (Amati et al. 2004 on X-ray afterglows; Mirabal et al. 2005; Rees & Meszaros 2005; Sakamoto et al. 2005). Lamb et al. (2005) deduce that these gamma-poor events are so narrowly beamed that the total rate must approach that of Type Ic supernovae. Are there indeed SNe Ic to be seen with them? Occasionally (Tominaga et al. 2004), but not often (Levan et al. 2005; Soderberg et al. 2005).

The record redshift for a gamma ray burst is held by the (long duration) event 050904 at $z = 6.29$ (measured with the Japanese Subaru telescope). Its spectrum resembled that of QSOs at similar redshift in showing Gunn-Peterson troughs at both Lyα and Lyβ, with a bit of flux in between, meaning that the diffuse baryons in those days were not yet quite completely ionized. The GRBs differ from the AGNs in the absence of strong Lyα emission and absence of proximity effect (ionization of nearby intergalactic gas clouds). These characteristics mean that GRBs, if you catch them quickly enough, will be at least as useful as QSOs for tracing out structure and evolution in the $z = 6$–10 universe.

Two more GRB thoughts hang precariously off the end of the index year or the topic. First is the existence of X-ray flares, occurring minutes after the main event and containing just about as much energy (Burrows et al. 2005). Second is the possibility that there is a completely different sort of short duration GRB in the form of extragalactic (but nearby) analogs of the giant flare of the soft gamma repeater $1806-20$. The event itself dates all the way back to 27 December 2004 (Mereghetti et al. 2005; Schwartz et al. 2005; Rea et al. 2005; Yamazaki et al. 2005; Hurley et al. 2005; Gaensler et al. 2005b; Palmer et al. 2005; Lazzati 2005) and belongs somewhere in the neutron star section. But if you had been 10 Mpc instead of 10 kpc from it, you would have seen only the tip of the iceberg, sorry, light curve, and thought it a GRB. Historically, the absence of host galaxies for short duration events seemed an obstacle to using soft gamma repeaters for part of the population, and you will have to sneak into the preprint e-files to read about the one that happened within striking distance of M81 and M82.

And the rest is sound bites.

- Significant gamma ray polarization has been announced again, not for the same event as last year's (Willis et al. 2005).
- X-ray spectral features remain marginal (Butler et al. 2005).
- There is dust around the long-duration events (Savaglio & Fall 2004), but not usually enough to result in a SCUBA source (Smith et al. 2005c, 2005d)
- The environment set up by the progenitor is what you would expect from a Wolf-Rayet star ejecting its envelope at a few thousand km s^{-1}, even in cases where, embarrassingly, we don't see a host galaxy for the WR to have lived in (Fiore et al. 2005; Klose et al. 2004).
- The X-rays can flare back up very late (Burrows et al. 2005).
- Theory papers no longer outnumber observational papers, and none this year was sufficiently deviant to cite for that reason alone, though we found Fryer & Heger (2005) on the problem of getting enough angular momentum distressing.
- The rate is at least 1/Gpc^3–yr (Guetta et al. 2005), from which you can figure out how long you have to wait for a GRB to kill the present authors and estimate whether the editor of *PASP* is likely to do it first.

3.1.3. Steadier Gamma Rays

There are, of course, also non-bursting gamma ray sources. The largest category is, and has been for many years, the unidentified (Cheng & Romero 2004), which is not at all the same as saying there are no candidates (Borsch-Ramon et al. 2005 on microquasars, which they also advocate for cosmic ray sources; Foschini et al. 2005 on FRI radio sources; Ng et al. 2005 on pulsar wind nebulae). Fegan et al. (2005) conclude that most of the GeV sources are not TeV sources, of which there is also an unidentified component (Aharonian et al. 2005f; Mukherjee & Halpern 2005), some in the direction of the galactic plane and some not (Walker et al. 2004).

As for identified TeV sources, some are pulsars (Aharonian et al. 2005c), some are pulsar false alarms or exceedingly variable (Aharonian et al. 2005b on B1706–44), one is a microquasar (Aharonian et al. 2005h; Cui 2005), one is the young shell supernova remnant (SNR) along the sight line to the Vela SNR (Aharonian et al. 2005d, who, however, do not confirm SNR 1006 down to 10% of the previously reported Cangaroo flux), and others are assorted flavors of active galactic nuclei (Aharonian et al. 2005a, on a $z = 0.117$ BL Lac object).

The best loved of these TeV sources remain the first two found, Mrk 421 (Piner & Edwards 2005) and Mrk 501 (Xue & Cui 2005); and the most debated question remains whether seeing these through the expected intergalactic sea of optical and infrared photons is or is not puzzling. The last word on this gets said so many times each year that we have forgotten whether it is Yes or No (Minowa et al. 2005; Schroedter 2005; Matsumoto et al. 2005; Mii & Totani 2005).

Within the last year, Sgr A*, our very own black hole, seems to have become well established as a TeV gamma source (Atoyan & Dermer 2004; Aharonian et al. 2005g). That the photon production mechanism is the annihilation of Kaluza-Klein dark matter particles (Bergström et al. 2005) is perhaps less well established, though a 1–10 TeV K-K particle yields both the right gamma ray spectrum and the right amount of dark matter in the universe.

3.1.4. Godzilla Particles

What else has lots of energy each? The cosmic rays. We start with the ultrahigh energy ones ($\geq 10^{20}$ eV per primary), which are not very well understood, and work down to the lower energy population, which has not been very well understood for longer. UHECRs have to get to us through the photon sea of the cosmic microwave background, a bit like the problem of UHE gamma rays traversing the infrared sea, but with the difference that we don't really know where the UHECRs started out. There is, in addition, a data discrepancy, with the newest detector finding fewer of the highest energy particles (Cronin 2005, on Fly's Eye) than were reported earlier (Teshima 2005).

There is no basic physics problem if the lower flux is correct or if the primary particles are not protons reaching us from well outside the Local Supercluster. The alternatives are (1) decay/annihilation products from dark matter particles in our own halo or (2) nearby unrecognized sources. Seckel & Stanev (2005) provide a good precis of the problem and note that distant sources would also produce very high energy neutrinos when the primaries collide with intergalactic photons. Items that puzzle us include:

- Is the distance primary protons can travel against pair production on the CMB actually well known? Aloisio & Berezinsky (2005) suggest a sort of anti-GZK effect.
- Are the arrival directions random or clustered (Abbasi et al. 2005; Amenomori et al. 2005, a result from an air shower array in Tibet, suggesting the heliosphere as a source)? There is also an extensive air shower array in Tehran (Khakian Ghomi et al. 2005), for which we think we are interested only in the departure directions.
- What are the highest energies that can be reached with conventional processes (Serpico & Kachelriess 2005 within the Milky Way; Honda & Honda 2004 in 3C 273)?
- What about somewhat unconventional but physically possible processes (Vlahos et al. 2005, anomalous resistance during galaxy formation; Ouyed et al. 2005 on neutron stars turning to quark stars; Crocker et al. 2005, very high energy neutrons from Sgr A*)?
- And, not exactly a question (except for "why didn't I think of that?"), but an expression of admiration for the prediction (Huege & Falcke 2005) that there should be radio flashes when UHECRs hit the upper atmosphere, followed closely by the detection of such flashes (Falcke et al. 2005). The flashes are due to synchrotron in the Earth's magnetic field and were seen at 43–73 MHz by LOPES, the prototype of the LOFAR detector now operating in Karlsruhe. The events last tens of nanoseconds. Hm. We begin to see why we didn't do this.

"Galactic" cosmic rays range downward from 10^{17} eV (where the Larmor radius is the size of the Milky Way) or 10^{15} eV (the "knee" in the spectrum, attributed by Ptuskin & Zirakashvili 2005 to processes in supernova remnants) on down to the only marginally relativistic, which don't get inside the heliosphere and so are not well studied. They too have been attributed to a range of sources (Westphal & Bradley 2004 on interplanetary dust; Bosch-Ramon et al. 2005 on microquasars; Fender et al. 2005 on X-ray binaries). Volk et al. (2005) "tentatively conclude that galactic supernova remnants are the source population of GCRs" endorsing the 70+ year old thoughts of Baade & Zwicky (1934).

"Galactic" is, in this context, a somewhat flexible term. Combet et al. (2005) conclude that the cosmic ray actinides were accelerated within 150 pc of us, vs. 1.25 kpc for Li, Be, and B. Higdon & Lingenfelter (2005) put most of the acceleration of the heavier nuclei in superbubbles, also close to us; and Derbina et al. (2005) draw attention to the rapid change in composition, from a mean mass of five amu[5] at 10^{12}–10^{15} eV to 30 amu at 10^{17} eV. This ought also to reflect differences in location of the acceleration process, but in the opposite sense, if 10^{17} eV is already "extragalactic."

And now that you know all about the astrophysics of cosmic rays, what are they good for? Ionizing interstellar clouds that are opaque to UV radiation (Padoan & Scalo 2005; Giammanco & Beckman 2005), and probing the insides of pyramids, though Maglich (2004) points out that chambers can be imitated or concealed by stone that is not of constant density.

3.2. Ozymandias, Chimney Sweepers, and Other Sinks and Sources of Dust

ApXX tradition requires "gee whiz" items to come first or last in sections. Given that at least one comet (9P/Tempel l), one planet (Pluto), and one moon (Titan) earned green dots this year, there appears to be no logical ordering, large to small or small to large, of solar system topics that will work. Thus we reserve the right to say "gee whiz!", "green dot," or "wow" at random points in the text.

3.2.1. Planets

Mercury has a magnetic field, which used to be a fossil, but is this year attributed to a dynamo in a residual molten core (Margot et al. 2005). We have no advice on how to see the field, but if you will settle for some photons, it is useful to pick a time when Mercury is very close to Venus, as in February 2005, and to employ binoculars (ours are 7 × 50 US Navy World War II issue).

Venus somehow got herself resurfaced half an eon (5×10^{8} yr for the Graiko-challenged) ago without any residual evidence for plate tectonics (Ap91, § 2). The volcanic features include ones called coronae and novae, which somewhat resemble nasturtiums (Kostama & Aittola 2004). Transits of Ve-

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[5] We are not unaware that this unit ought now, according to the International Union of Pure and Applied Chemistry, to be called the Dalton. Indeed it was the only thing we learned at a meeting of another organization, which is unique in our experience as being one where not even the Electoral College is actually allowed to vote.

nus across the Sun (next opportunity 2012) can be thought of as chances not to see reflected photons, as coming in singles and triples as well as the current pairs (McCurdy 2004), or as one of many things predicted but not seen by Kepler (Posch & Kerschbaum 2004).

Earth has taken refuge with Ptolemy at the center of the universe (§ 5) but was probably assembled in much the same way as Venus, out of pieces that already had atmospheres and oceans (a good deal of which were lost; Genda & Abe 2005; Zahnle 2004).

All of the ancient and modern planets (except Earth) were strung out across the sky in order MVMJSUNP on 10–13 December 2004 (Sinnott 2004). The last time this happened was in February–March 1801, and the next will be in April 2333.

Aspects of Mars relevant to habitability appear in § 7. We note here that (1) The two best oppositions for a long time have now passed. In case you missed them, along with the alignment of the previous paragraph, Nakakushi et al. (2004) report on some of the 2003 discoveries. (2) A molten iron core has, after all, survived from early times (Fei & Bertka 2005), but there is no Earth-like solid core. Lillis et al. (2005) discuss the dynamo further, and all agree that Martian seismic data are really needed to make further progress. And (3) if you were living on the Martian surface, you would see airglow (Bertaux et al. 2005) as part of the night sky brightness (but mercury lines from high pressure lamps must surely be rare), not to mention an occasional meteor, as photographed by the Mars Rover (Selsis et al. 2005). You might also see, if unlucky, the sort of impact that has put meteorites on the Martian surface, to be found by Opportunity (Anonymous 2005a). These cannot be called Martian meteorites, since the name is already taken for bits of Mars found on Earth. The impacts responsible for those would have been even less lucky to experience.

Jupiter did not have a particularly good year and has to share the effects of the (solar) coronal mass ejection of 1–20 November 2000, which swept past Earth on 11–12 November, Jupiter on 18–20 November, and Saturn on 7–8 December, producing aurorae on the last two (Prange et al. 2004). The Jovian aurorae were seen by *Galileo* and the passing shock by *Cassini*, which was nearer Jupiter's orbit than Saturn's at that time.

Saturn on the other hand was playing catch-up, by displaying some of the phenomena earlier shown by Jupiter, including disk X-rays (Bhardwaj et al. 2005a and 2005b), due largely to solar fluorescence and scattering, bursts of dust emission (Kempf et al. 2005),[6] and zonal atmospheric temperature bands, seen in mid IR, that are not the same as the bands in reflection from the visible clouds (Orton & Yanamadra-Fisher 2005). The *Cassini* package of Saturnian data appears in Porco et al. (2005a) and the three following papers. On 13 January 2005, Saturnians had an opportunity to see the Earth transit the Sun. No reports so far on whether they attempted to use this event to measure the length of the SU (Sastronomical Unit). Is this easier or harder than measuring the AU by timing Cytherean transits from Earth? Another of those exercises left for students who are not already behind on their theses.

Uranus flaunted its brightest-ever NIR cloud feature (IAU Circ. 8586). The spot briefly reflected 17% of all the *K*-band light from Uranus seen by the Keck II telescope. At adaptive optics resolution ($0\farcs05$), the surface brightness contrast ratio was about 50.

The upper atmosphere of Neptune contains some CO, which surprised us much less than the source, which is said to be partly a comet impact less than 200 years ago (Lellouch et al. 2005). No, we didn't see it.

Should UB313 (at 97 AU and with radius of 2400 to 3200 km) be counted as the 10th planet (Brown 2005)? No strong feelings, except that it would spoil the pattern of moving straight from Pluto to the moons of Pluto. And if you don't think Pluto is a planet, feel free to go sit in the asteroid section (§ 3.2.3) with the Medical Musician, who always insists on buying tickets at discount.

3.2.2. Moons

Charon (otherwise known as Pluto I) occulted a star (IAU Circ. 8570), thereby setting a firm lower limit of 1179 km to its diameter. Charon was, apparently, available for this task because of a major impact long ago which broke it off from the then unnamed Pluto, imitating in this respect our own Luna (Canup 2005; Melosh 2005). Most other moons are said to have formed in disks around their parent planets or to have been captured from supplies called asteroids. The captured sort are also called irregular, meaning that their orbits can have large eccentricities and inclinations (including retrograde) and, as a rule, large semimajor axes, while the satellites themselves tend to be small. The gee-whiz item here is the probable recognition of two more Plutonic moons (IAU Circ. 8625). Other, out of period, reports suggest they are smaller scraps from the same impact event.

Neptune's S/2002 N1 immediately falsifies the previous paragraph on how moons form by probably being a fragment broken off Nereid, whose color and retrograde orbit it shares (Grav et al. 2004).

Two new moons of Uranus are of the irregular sort (Sheppard et al. 2005b), bringing his total to eight irregular and one regular. Jupiter shares this dominance of irregulars, while Saturn and Neptune were more or less half and half until the 2004–2005 proliferation of Saturnian moons (or anyhow their discoveries; most are probably older than 2 years but younger than 4.56 Gyr).

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[6] The 100 Å grains come largely from ring material, vs. Io in the case of Jupiter, and are accelerated by $\boldsymbol{E} = \boldsymbol{v} \times \boldsymbol{B}$ in the corotating planetary magnetic field. And in case you are wondering why this is a footnote, it is because the number of nearly unrelated ideas that can be crammed into a single sentence is about the same as the number of tasks the most forgetful author can keep track of without having to make a list.

How many moons does Saturn have? Well, many. Twelve more (11 retrograde) announced in IAU Circ. 8523, with periods of 820–1154 days, a new one in the Keeler gap with a period of only 0.594 day (IAU Circ. 8535), and so forth. The names reach up to XXXI, Polydeuces (IAU Circ. 8432), but our greatest sympathy is reserved for XXX Thrymr, with hardly a vowel to his name (IAU Circ. 8471). Many of the newish ones are in Kozai resonances (Carruba et al. 2004), and some chaos, in the orbits, never mind the names, is expected. At some point, we suspect there may need to be some sort of definition of "moon" or "satellite" that sets a lower limit to their sizes, to prevent the cataloguing of chips off the old Hasselblad camera that still orbits Earth. Oh, that is called "space debris," you say?

Some moons of Saturn are more equal than others. The winners in 2005 included Iapetus (which has a ridge around its center, looking remarkably like the two hemispheres of a cheap toy ball glued together; Anonymous 2005b). Phoebe, the outermost large moon, has diverse surface materials, including ices, organics, iron compounds, and olivines and other silicates (Clark et al. 2005c; Dalton 2005; Johnson & Lunine 2005). Enceladus must be warm inside and probably has a rocky core (Johnson 2005).

First prize, however, to Titan, mapped to within an inch (well, perhaps a meter) of its life by *Cassini* for more than a year and smashed in the face by the *Huygens* probe on 14 January 2005. Interesting results include (1) very rapid atmospheric rotation compared to the surface (shared, so far as we know, only by Venus; Porco et al. 2005b), (2) absence or at least rarity of much-anticipated hydrocarbon seas (West et al. 2005; Sotin et al. 2005; Prockter 2005, with possible volcanic release of methane), and (3) mesospheric temperature structure in the atmosphere (Griffith et al. 2005), sparsity of craters, absence of magnetic fields, and much else (Mahaffy 2005 and next seven papers).

The gee whiz item (otherwise known as WHEW) was still trapped in press releases and other non-citable sources as a reference year closed. This was the role of the Robert A. Byrd Greenbank radio telescope[7] and the VLBA in monitoring the descent of *Huygens* and thus mapping the hurricane-speed winds. *Cassini* was supposed to have captured these Doppler data, but was somehow tuned to the wrong frequency. The ground based telescopes saved the day, or anyhow the data.

Jupiter's best known moons were discovered by Galileo (meaning the Florentine, not the satellite, and you can tell because he doesn't walk around wearing italics) and probably formed in a disk like planets around stars (Woolfson 2004), although Amalthea must have migrated inward since (Takato et al. 2004). What surprised us most, however, is how often Galilean moons occult and eclipse each other as seen from Earth, during the few months every 6 years when Sun and Earth are respectively in the moons' orbit plane. Many of these mutual events were observed in 1997 and 2003 (Pauwels et al. 2005; Dourneau et al. 2005), something like 21 in 1997 and 15 in 2003.

You already knew that stuff coming out of volcanoes can be pretty noxious, but Io's volcanic gases are noxiouser than Earth's (Schaefer & Fegley 2005).

Mars has two moons, and no more need apply, at least none larger than 0.1 km (Sheppard et al. 2005c).

While moon more or less rhymes with June, spoon, tune, and so forth, Luna would seem to rhyme only with tuna. She (in most mythologies) was formed when some large, late impacting object hit Earth. Isotopic data have further restricted this to impact after the Earth completed core-mantle differentiation (Boyet & Carlson 2005) and the impactor to something that also formed quite close to 1 AU from the Sun (Belbruno & Gott 2005). The present lunar surface is mostly basalt (Christensen et al. 2005), as is true for Earth, though we keep most of ours under water; but the Moon has been considerably polluted by solar wind particles (Hashizume & Chaussidon 2005). Unlike most of us, the youngest lunar crescent ever seen gets a bit younger every year. Odeh (2005) reports the new Moon of 2004 March 20 seen at age 17 hr 18 minutes and with only 35 minutes between sunset and moonset. If you want to do a decent job of assembling a tag along the lines of "we were having tea and missed it," you need to check where Odeh was that day relative to your longitude.

All children are told that stars twinkle and planets don't (a truism already conditional on location and seeing). In fact, even the Moon twinkles, and lunar scintillation can be used to monitor atmospheric turbulence (Hickson & Lanzetta 2004). Does the Sun twinkle? Of course it does (Seykora 1993). It's a star, isn't it?

For the moons of Venus and Mercury, see § 14 on hens' teeth, flying pigs, and horse feathers.[8]

3.2.3. Asteroids

As usual the little things appeared in more papers than the big things of the Solar System (well there are more of them). We green-dotted for exclamation (Gee whiz!) the suggestion that the Trojan asteroids of Neptune might have formed in situ and be the youngest accreted objects in the solar system (Chiang & Lithwick 2005). But you are also going to be told that (87) Silvia has two moons (Marchis et al. 2005), for which the IAU has already OK'd the names Romulus and Remus

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[7] The most unprofessional and disrespectful author—so said the referee of a completely different paper—takes full responsibility for wanting to call this The Byrd in the Hand. It was not precisely what most of the radio community said they wanted, but was surely very much better than anything obtainable from two Bushes.

[8] And at least one of the authors would be interested in feedback from anyone who has recently watched the Marx Brothers film for either the first or some subsequent time.

(IAU Circ. 8582). They are probably bits knocked off in some past collision.

It is, however, future collisions, and with Earth, that one worries most about. Galad (2005) concludes that 100 years of orbit data are not enough to assess the probabilities very well, but 99942 Apophis will miss Earth in 2029 by rather more than previously advertised (IAU Circ. 8593). Lyden (2005) suggests what to do if you see one coming—pull it out to a near Earth orbit or L5 and use the metals.

Binary asteroids, a gee whiz subject a few years ago, are now in the dime a dozen class, or anyhow at most an IAU Circular each (8483 on 2005AB with a period of 17.9 hours, and 8526 on a pair 2″.67 apart, whose period must be considerably longer). This has not prevented a certain amount of unpleasantness about the discovery of 2003 EL_{61}, whose total mass is probably not all that much smaller than Pluto plus Charon. We sidestep this by citing only IAU Circ. 8577 and by noting that the perusing and purloining of other folks' coordinates can be traced back to the early quasar era and probably to Galileo, whose solution was the common one of his time, announcing discoveries in more or less meaningless sentences, whose letters could be rearranged to say things like "Venus imitates the phases of the Moon." Aw, go on, try it with "we have seen a really massive binary asteroid."

Quite a number of asteroids were mentioned by name as well as number. Here are introductions to only two: Eros for its complicated cratering history (Thomas & Robinson 2005), and 832 Karin, which is perhaps the parent body of the chondritic meteorites (Sasaki et al. 2004).

Also once whiz-worthy (Ap00, § 3.4) are asteroids that used to be comets (but whose activity has died away) and the converse (because a coma or tail turned up after discovery). The Damocloids (with orbits like 5335 Damocles) are, says Jewitt (2005), inactive Halley-family comets, three with comet names and 17 with asteroid names, all recent discoveries, and not (yet) hanging over anybody's head. Albedos suggest that nearly half of near-Earth asteroids are old comets (Fernandez et al. 2005) and the class with asteroid names assigned and gas features caught later reached the point where we gave up recording anything except IAU Circular numbers (from 8421 to 8622 and a dozen or more in between). The green dot item here, discussed in IAU Circ. 8582, is an issue of nomenclature, and may not strike you as Earth- or even asteroid-shaking. If you are an asteroid, you can have a permanent number (meaning a well-established orbit) after being seen at four oppositions, one recent. But a comet needs two perihelion passages (a much longer time interval for any period longer than 2 years). This seems somehow unfair to the objects concerned, and possibly to their discoverers and observers. All are Centaurs, and the decision has been made to let them keep their comet names but also declare them to be periodic, with numbers 165P, 166P, and 167P, from which you may get the idea that there are not really so very many well-established periodic comets.

3.2.4. Comets

Tempel 1 = 9P (well, we told you there weren't very many of them) became comet of the year when the *Deep Impact* mission impacted it deeply on 4 July 2005. Its speed changed a bit (giving hope to all who aspire to knock assorted NEOs into O's less N to E; Kuehrtt et al. 2005). The actual scientific results appeared slightly out of period (A'Hearn et al. 2005, and the next five papers). Some of the things to be said are that Tempel 1 came from the Kuiper (Edgeworth) Belt; the material was very loosely consolidated (more like ashes rising from a fire than even house dust); that the density was only that of porous ice; the surface was cratered; the dust to water ratio in the object was larger than expected; and the volatiles included organic stuff. We suppose this would have gladdened the heart of Prof. Raymond Arthur Lyttleton (of Cambridge and of the sand bank model) if it were still beating. Curiously, the comet spat out a couple of jets shortly before impact (Anonymous 2005c) on 14 and 21 June. If the *Deep Impact* mission was the cause, this demonstrates the existence of advanced potentials with two polarizations and some birefringence.

What else might one say about comets? Well, first you have to discover them. Messier found a mere 20, a yield of only one for every five of his catalogued non-comets.[9] But if the King of Denmark were still giving comet medals, Caroline Shoemaker would have set him back 32 so far, and images recorded by *SOHO* 1000, and counting. Actually there is once again a Comet Medal, named for Edgar Wilson and intended to recognize non-professional (and human) discoverers. It was shared this year by R. A. Tucker (C/2004 Ql) and D. E. Machholz (C/2004 Q2; IAU Circ. 8554), and Machholz's comet, at least, was briefly a naked eye object, in January and February 2005 (IAU Circ. 8484).

Next best to discovering comets is keeping track of them (compare human relationships). P/1819 W1 (Blanpied) was recovered in 2003 (IAU Circ. 8485). And Hale-Bopp has, so far (IAU Circ. 9490) been followed out to 21 AU, where it still had an 8″.5 tail. It has a way to go to beat the Halley record detection distance. When you do follow them to large heliocentric distances, comets occasionally show unexpected bursts of activity, which have been attributed to collisions with otherwise invisible material (Gronkowski 2004a) and to the solar wind charging up the dark side, leading to electrostatic ejection (Gronkowski 2004b).

At the opposite extreme are the Sun-grazing comets (well reviewed by Marsden 2005). Nearly all the *SOHO* discoveries are of this sort, and have short life expectancies. They arise from the break-up of larger bodies and so come in several kinematic groups, of which we remember only the Marsden group (because we like him) and the Kreuzer (because we like

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[9] You are assumed to know that Ml is the Crab Nebula and M3l the Andromeda Galaxy. But, quick, without looking them up, what are M2 and M30?

his sonata).[10] No comet (even Halley, concerning which we caught only one index-year paper, Saxena 2004) is worth a lot more than a small coin, because, say Neslusan & Jakubik (2005), there are at least 10^{11} more waiting patiently out in the Oort Cloud. Any one that experiences a single passage through the inner solar system (as a result of encounters with giant molecular clouds, other stars, or whatever) has a 25%–50% chance of capture or complete removal (Dybczynski 2004). Such numbers, plus the inventory of Halley-like comets, lead Napier et al. (2004) to conclude that the dark Halley-type comets currently outnumber the luminous ones and constitute a dangerous reservoir of potential and nearly invisible Earth-impactors. The very small albedo comes from a coating of loose, fluffy organic materials. 3200 Pantheon is well on the way (Hsieh & Jewitt 2005), with a surface less than 7×10^{-6} of which is covered by freely sublimating water ice. It is the parent body of the Geminids.

Just how organic is that organic stuff? Keheyan et al. (2004) would like to attribute prebiotic petroleum in the Earth's crust to early comet arrivals and the petroleum itself to cosmic-ray effects on hydrocarbons. The idea of pre- (or non-) biological petroleum has, in western countries, been most closely associated with the name of Thomas Gold (1987), but even if we were sure he had been right, we would not be sure whether to buy or sell ChevronTexaco stock. The Medical Musician says "sell," on the grounds that the company no longer sponsors the Metropolitan Opera radio broadcasts.

Other comets bearing gifts were those of 44 BCE and, conceivably, 4 BCE (McIvor 2005). The least un-Roman author is inclined to feel that Rome might have been better off if Julius had not been assassinated that day, but this may be because the Caesar she knows best is that of Shaw, not Shakespeare.

3.2.5. The M's

Still smaller things are called meteoroids, meteors, and meteorites, depending on when and where you encounter them, and, we promise, which is whichly won't be on the exam. Shower meteors appear to be the most thoroughly studied, perhaps because it is easier to plan observing runs in advance for them than it is for sporadic ones. They display structure on at least three timescales. First a given meteor trail can flicker as rapidly as 100 Hz (Babadzhanov & Konovalova 2004, reporting data on the Geminids from Dushanbe), due, it seems, to being made of small grains glued together by stuff of lower boiling point (Koten et al. 2004). That the trails are sometimes helical must mean that the grains are irregular enough for rotation or precession to show, and we mention it primarily for the sake of noting that the discovery was made on 1 January 1986 (photoelectrically by J. Westlake) with a pre-discovery by visual methods by W. H. Steavenson on 26 July 1916, conceivably a record for time interval between prediscovery and recognition (*Sky & Telescope*, 110, No. 3)

Second, there is structure within individual showers (Pecina & Pecinova 2004 on the Leonids as seen from Ondrejov in 2000–02; Porubčan & Kornoš 2005 on the Quadrantids). The latter consists of five streams, only two of which appear to share the orbit of comet 2003 EH1, which struck us as a tad odd until Jenniskens & Lyytinen (2005) pointed out that the comet was also C/1490Y_1, so that there had been lots of time for both it and its debris to shift orbits. The same paper notes that the Phoenicids are to be associated with a comet that is both 2003 WH_{23} and D/1819 W_1 (Blanpain), a set of phenomena ripe with opportunities for mispronunciation.

Third comes temporal structure on scales longer than the annual recurrence time implied by names like Quadrantids, Geminids, and Lacertids. The Leonids won't really be back until 2034 (Vaubaillon et al. 2005), and still less should you plan your career around the Tau Herculids, seen in 1930, but not expected back until 2022 and 2049 (Wiegert et al. 2005). The parent comet, 73P/Schwassmann-Wachmann, split in 1995, leaving, we suppose, Schwassmann and Wachmann.

Even sporadic meteors show an annual frequency cycle (Ahn 2005, reporting that the amplitude and peak time were the same in the years 960–1179 CE as now). This must be some product of the direction of Earth's orbital motion, rotation, and day length (or, rather, night length, day-time meteors being rare). Explanation of why the Leonids have slipped back about 1.5 days per century is left as an exercise for the student. (No, not you Mr. H.; your thesis is supposed to be about X-ray astronomy).

Shower particles would not be useful sources of terrestrial petroleum or other volatiles, even if the particles were big enough to survive passage through the air. Spectra of Leonids (Kasuga et al. 2005) show evidence of Mg, Fe, Ca, and Na, but no atoms or obvious molecules of C, H, O, or N.

The chunks that do reach Earth are promoted to meteorites (compare the queening of pawns in chess). Individual grains within some of these meteorites preserve records of the formation of the solar system and the events immediately preceding and following. Decoding is more or less at the stage of completion where Thomas Young left Egyptian hieroglyphs to take up light as waves.

So-called presolar grains are recognized by isotopic ratios different from those of general solar system material, especially for isotopes with progenitors of short half life (extinct radioactivities), though it may not be possible to exclude inhomogeneities in the presolar nebula of ^{26}Al and other parents as an alternative (Boss 2004).

The grains of the year in 2004 (Ap04, § 3.1.6) were the first nine presolar silicate grains. Messenger et al. (2005) conclude that they probably came from supernovae, but picked up their

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[10] We attempted to normalize our judgment in consultation. The Faustian Acquaintance assures that the sonata is at least worth more than the small Austrian coin of the same name, and the Medical Musician, whose instruments are piano and organ, said "Find me a violinist and I'll show you." Jack Benny was rejected without audition.

organic mantles in the general interstellar medium. Other grains have been remelted within the early solar system. They are called chondrules (from the Greek word for cartilage, and we are grateful not to have studied anatomy with whoever chose the name). We caught during the year four very localized heat sources that might have done the melting. McBreen et al. (2005) suggest lightning due to a nearby gamma ray burst; Boss & Durisen (2005) favor shocks when planets are formed by the gravitational instability mechanism; Krot et al. (2005) make their planets by the accretion mechanism and melt chondrules when planetesimals collide; and Aleon et al. (2005) use high energy particles from the young Sun. It is not obvious that they cannot all be right (unlike multiple hypotheses for, say, the formation of the Moon).

3.2.6. Zodiacal Dust

At some point we have crossed over into the regime of grains so small that they scatter sunlight into the plane of the zodiac. This is, after the Sun and Moon, the largest *natural* contribution to the background light of the night sky (Flanders 2005). The largest non-natural contributions[11] hardly bear thinking about, but see Cinzano & Elvidge (2004) for an update on where the damage has been worst. There is a 2175 Å absorption feature to be found in interplanetary dust (Bradley et al. 2005). And if you really want to see how the dust moves around, then look at the Doppler shift of the Mg I 5184 Å line in scattered sunlight. Reynolds et al. (2004) report mostly upper limits and are gracious enough to credit the idea to Ingham (1963), one of our favorite infrared spectroscopists and bicycle repair persons.

3.2.7. Where Did It All Come From?

Perhaps there have always been two models of how the solar system formed. Long ago, an encounter of the Sun with another star competed with processes occurring around the Sun as it formed (and lost). Distant encounters are not so rare as close ones and are now blamed for some of the more distant solar system features, for instance the outer edge of the Kuiper Belt (Kenyon & Bromley 2004), with Sedna as a possible captured member of the other system.

But the "processes around" story has now split into two subscenarios: a rapidly-occurring gravitational instability in the protoplanetary disk, giving rise to large planets in one gulp (Boss & Durisen 2005) vs. gradual growth from grains to planetesimals to embryos to planets. Significant numerical progress seems to have been made on the latter idea during the year (Goldreich et al. 2004, who note that the late phases have a good chance of including impacts like the one responsible for our Moon, but that Charon is more difficult; Leinhardt & Richardson 2005, also on the "oligarchic" phase when the biggest planetesimals win out over the others). We think it is within this gradual accumulation model that Matsumura & Pudritz (2005) explain why only terrestrial planets are to be found close to the Sun. Their model is a sort of 3/16″ socket wrench, since, unlike a variable or monkey spanner, it cannot apply to the large number of other systems with close-in Jovian planets.

After formation comes migration, and we caught precisely a handful of papers associating migration of the major planets with the phase of late bombardment on Earth, Moon, Mercury, and Mars, and with the establishment of the Kuiper Belt (and see § 7.3).

1. Morbidelli (2004) says that the outward migration of Neptune and formation of the KBO must have happened after late bombardment or the bombardiers would not still have been available.
2. Murray-Clay & Chiang (2005) conclude from the asymmetric distribution of KBO orbits that Neptune took at least 10^6 years to reach its present position.
3. Gomes et al. (2004b) attribute late bombardment to migration of Jupiter and Saturn.
4. Strom et al. (2005a) similarly ascribe late bombardment to asteroids ejected from the main belt by migrating big planets.
5. Tsiganis et al. (2005) and the two following papers provide a four-way association, in which Jupiter and Saturn moving in chased Neptune out, caught the Jovian Trojan asteroids, and sent other stuff inwards about 700 Myr after solar system formation.

Some of these considerations are clearly of the variable wrench category and applicable also in § 6. Others are not.

4. DOWNSIZING AND OTHER ISSUES IN GALAXY FORMATION, EVOLUTION, AND CONVOLUTION

Downsizing is not a good thing to have happen to your employer or your space mission, but it may just be a good minimalist description of the history of star formation, that is rate vs. time (or redshift), metallicity, and site. We have expended a good many words in previous editions trying to describe the results of ever-larger surveys of moderate to high redshift galaxies and ever-larger numerical simulations intended to hindcast the observations, being sometimes forced to say that the data on stellar populations, colors, metallicities, ages, redshifts, locations, and environments just couldn't be collapsed into anything much shorter than the original paper (Ap01 §§ 11.3 & 11.4; Ap02 § 10.4; Ap03 § 9; Ap04 § 10.6).

It helps to start with the ancient idea of "primordial galaxies," meaning hypothetical glaring sources of Lyα emission resulting from the first major burst of star formation in elliptical galaxies and other spheroids. There simply weren't any, until the concept was recast as "star-forming galaxies at high redshift" (Ap96 § 12).

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[11] The terminology is perhaps not quite right. To quote one of our favorite defectives on the police farce, what is more natural than to die when a bullet goes through your heart?

4.1. A Current Picture

Under the rubric "first lights" the 21st century version of that search is now a driver for a wide range of upcoming large telescope projects. Meanwhile, Drory et al. (2005) provide a succinct description of current knowledge: at every redshift, the most massive galaxies have the oldest stars. Here are a baker's dozen papers expressing aspects of the same sentiment. (1) Kajisawa & Yamada (2005), (2) Jimenez et al. (2005), (3) Bauer et al. (2005), who note that the specific star formation rate, $(dM/dt)/M$, declines toward higher masses at all redshifts, (4) Labbe et al. (2005) noting that the largest M's have the largest M/L ratios at $z = 2$–3 the same as they do now, (5) Smith et al. (2005e), pointing out that fainter galaxies become quiescent at smaller z, (6) Yee et al. (2005), phrasing the process as most of the star formation in a given epoch declines with time, (7) Tanaka et al. (2005), with things happening first in both large masses and dense regions, (8) Perez-Gonzalez et al. (2005), saying that the luminosity of the galaxies with most of the star formation in their epoch declines with time, (9) McCarthy et al. (2004b) concluding that massive galaxies formed early and fast, (10) Ferrari et al. (2005), (11) Coia et al. (2005), the largest masses at large redshift are in clusters with mergers, (12) Hammer et al. (2005), ellipticals make their stars earlier than spirals, and (13) Holden et al. (2005b).

There were undoubtedly some equally informative papers that got indexed under some topic other than downsizing and so are missed out here. Virtually all the cited papers give numbers for quantities like the fraction of stars formed after $z = 1$, before $z = 5$, or at some intermediate range, in galaxies of particular (stellar) masses or luminosities. None of these much changes the picture from that of Ap04 § 10.6. The current star formation rate is about 0.02 $M_\odot$ Mpc^{-3} yr^{-1}. It was a good deal larger at intermediate redshifts of 1–4 (e.g., Le Fevre et al. 2005a), and smaller again in the more distant past (5.7×10^{-4} in the same units, say Taniguchi et al. 2005). Or to say it all again differently, ellipticals were half through by $z = 2.3$ (Holden et al. 2005a), while spirals like the Milky Way dawdled in comparison (Ortolani et al. 2005), and nearly everybody was about through by $z = 0.35$ (Panter et al. 2005).

Inevitably, discordances remain. Some of these arise if, as Caputi et al. (2005) say, massive galaxies were assembled and stars formed in a two stage process, at $z \geq 4$ and $z < 1.5$, with different fractions of the two components in different galaxies, and, therefore, in different samples and surveys. The two stages can be described as the formation of "galaxy parts" and final mergers.

Qualitatively, at least, the items in the preceding three paragraphs are consistent with a standard bottom-up, hierarchical picture of galaxy formation. Less obviously consistent are (1) the conclusion of Lin et al. (2004b) that galaxies now brighter than L^* experienced a merger after $z = 1.2$ and (2) the more qualitative remark of Silva et al. (2005) that the continuity between SCUBA (ultraluminous, far infrared) galaxies at large redshift and giant ellipticals now implies that large spheroidal galaxies formed most of their stars when they were already single objects. Perhaps this means that at least some SCUBA galaxies conform to the early definition of "primordial" and that their modern counterparts can be recognized.

Well, it may remain true that the details cannot be summarized in any format shorter than the original papers. But we still like "downsizing" as a first step.

4.2. Environmental Issues

Does the amount or rate of downsizing depend on anything except the mass of the entity you are looking at? Because the biggest, most evolved galaxies tend to live in the most massive, evolved clusters in the deepest potential wells at any given time, intrinsic and environmental effects are not easily separable. It is, therefore, perhaps not surprising that one can find support for, at least, the statements that (1) environment is unimportant (Treu et al. 2005), (2) environment matters and, for fixed morphology, mass in stars, and ages of those stars, SFR is smaller in dense regions (Christlein & Zabludoff 2005), (3) environment matters and there is more star formation in clusters (Moss & Whittle 2005), and (4) environment matters now but did not at $z \approx 3$ (Bouche & Lowenthal 2005). In contrast, we would not expect to find any contradiction of the conclusion that dynamical evolution proceeds faster in dense regions (Einasto et al. 2005). It is not all that difficult to find hands to wave at each of the contradictory items (2), well, there is less gas (Koopmann & Kenney 2004) and (3), well, there are more mergers (Conselice et al. 2005).

4.3. Digressions

Absolute numbers for star formation rates obviously depend on there being reliable measurement techniques. Blue light (hot stars), emission lines (H ɪɪ regions), X-rays (high mass X-ray binaries and supernova remnants), radio (electrons and field from SNRs), UV (hot stars), and mid to far IR (blue light absorbed and reradiated by dust) have all been used. And no they don't always all agree, but, in optimistic mood, we highlight Dopita et al. (2005), who report that absolute calibration of UV, Hα emission, near IR, and mid IR are all in good shape, relegating to a dependent (nay, even dangling) clause the conclusion that even infrared bands are a less than gold standard (Conti & Crowther 2004; Boselli et al. 2004). The difficulties are dust heated other ways and new star light escaping unmodified, and one paper focuses on each.

Long ago, the least teachable author was taught to worry about the "last gasp" issue, that is, the current gas supply and current star formation rates in nearly all galaxies cannot last more than a small fraction of the Hubble time. The factual statement remains true, for example 10^7–$10^{8.3}$ yr for luminous compact blue galaxies (Garland et al. 2005), at most 10^9 yr for blue compact dwarfs (Kong 2004), right on out to a lensed $z = 2.5$ galaxy (Sheth et al. 2004). Gas exhaustion has been ubiquitous since about $z = 0.7$ (Bell et al. 2005). But she is no longer much worried. Starburst galaxies (meaning by definition that they don't do it for very long) are naturally overrepresented in any magnitude-limited sample. And, as the very word "downsizing" implies, star formation really is dying away, due, say Bell et al., primarily to gas exhaustion and not to a decline in the merger rate. We live in an evolving universe in which no extended epoch can reasonably be regarded as typical or untypical.

4.4. Galaxy Types: L, S, and D

L is for lenticular, otherwise known as S0. Since the time that Hubble's early/late classification scheme ceased to be thought of as an evolutionary sequence, astrofolk have been asking what process(es) can be responsible for these disk galaxies with little or no remaining gas or star formation, found commonly in intermediate zones of rich clusters. Phrased that way, the question almost answers itself (though perhaps with a wrong answer). Ram pressure stripping is responsible for one well-known transformation in progress in Virgo (Crowl et al. 2005). Burkert et al. (2005) note penetration by smaller galaxies and Vollmer et al. (2005) other processes in clusters that remove gas. Burstein et al. (2005), however, say that gas stripping is not the answer, and Owen et al. (2005) blame bursts of star formation (probably however also connected with entry into clusters). Another case, we think, where two or more can be correct.

S is for spiral, and they get only sound bites this year, while the Milky Way has been dispersed among several sections.

- M82, the quintessential messy galaxy (well, Irregular is the polite term) has underlying spiral structure (Mayya et al. 2005b), and you will be happy to hear that the arms trail, at a pitch angle near 14°.
- Thick H I layers, whose rotation lags that of the thin disk, are fairly common (Barbieri et al. 2005 with a map of NGC 4559).
- Low surface brightness (LSB if we should need them again sometime) galaxies have thin disks (Bizyaev & Kajsin 2004).
- Thick disks, once nearly the exclusive property of the Milky Way, are actually common once you know how to look for them (Tikhonov et al. 2005; Mould 2005). That they don't all share the rotation speed of their thin disks (Yoachim & Dalcanton 2005) would seem to rule out puffing up of a thin disk by gravitational encounters as a universal formation mechanism (not to mention top-down type processes), but don't worry. There are lots of other possibilities (Brook 2004 on accretion processes).
- Barred spirals (SBs) form a continuum with the unbarred (we're saving the disbarred remark for next year), and the strongest bars have the strongest spiral arms and shortest lifetimes (Buta et al. 2005). Since significant numbers of bars exist by $z = 1$, again, once you know how to look for them (Jogee et al. 2004), we think this must mean that they come and go. Gadotti & de Souza (2005) appear to agree, but their picture of thick bars with large stellar velocity dispersions disappearing quickly into thick disks won't fit with everything else published this year.
- Cores decoupled from their surrounding galaxies in kinematics (Shalyapina et al. 2004) or composition (Sil'chenko 2005) or both were a discovery within living memory, but are now "a well known class of astrophysical object."
- Some spirals have the most massive ("maximal") disks that their inner rotation curves permit, and therefore very little central dark matter (Fuchs et al. 2004). Others do not (Dutton et al. 2005; Kregel & van der Kruit 2005).
- With equal confidence we can say that some spiral disks appear to have sharp outer edges (truncations, Trujillo & Pohlen 2005), and others do not (Bland-Hawthorn et al. 2005 on NGC 300; Tanvir 2005).
- And how well you can see through the disk of a spiral depends mostly on just where you look (Holwerda et al. 2005a, 2005b).

D is for dwarf. Well, usually d is for dwarf, as in dIrr, dE, dSph (irregular, elliptical, spheroidal) etc., but we are saving what little clout we have with the editor and University of Chicago Press for more important battles than being allowed to start a sentence with a lower case letter! Whichever case, they are the commonest sorts of galaxies, making up 85% of a nearly complete catalog of 362 (Karachentsev et al. 2005), reason enough perhaps for them to appear in more indexed 2005 papers than any other class. But, in addition, one hopes that they may preserve (or re-enact) the processes by which larger, more famous galaxies have formed.

Let's start with a nice contradictory pair of results. According to Mathews et al. (2004a) there are no dwarf galaxies in groups at redshifts $z \gtrsim 2.5$ (based on a dynamical analysis of the nearby NGC 5044 group). This implies that they all arrived recently, and indeed, the star ages are close to 5 Gyr, so they didn't exist at large redshifts. That is, there are no old dwarfs. On the other hand, according to Momany et al. (2005) there are no young dwarfs. All have stars at least 10 Gyr old, including Sag DIG which they present in detail. Can these be reconciled? Of course! What do you think theorists are for? If, as Corbin et al. (2005, writing about HS 0872+3542) indicate, dwarfs are assembled from star clumps whose sizes come between those of globular clusters and those of small galaxies, the stars can be much older than the dynamical entities. We picked out a dozen or so other dwarf highlights and present them without specifying which are truly new, lest the ghost of Fritz Zwicky haunt our proofs.

There are relatively more dwarfs in clusters than in the field (dEs and dSphs, not surprisingly; Trentham et al. 2005). Conversely, they are not overrepresented in voids (Hoyle et al. 2005).

The first truly isolated dwarf (a dSph) appears in Pasquali et al. (2005) and, say the authors, "Following IAU rules…is named APPLES1." A search for ORANGES1 with which to compare it is under way.

Some of the Local Group dwarfs began life before reionization (Ricotti & Gnedin 2005), meaning, we think, their oldest stars, not necessarily the dynamical entities.

Some live in real halos with their own dark matter (Piatek et al. 2005 on the Ursae Minoris dwarf; Wang et al. 2005d on Fornax). Fornax is likely to have experienced a recent merger (Colemanet al. 2005). Well, we said….

A couple of dEs in the NGC 5044 and 3258 groups have kinematically decoupled cores (De Rijcke et al. 2004), as does our own Sextans dSph (Kleyna et al. 2005).

Dwarf S0's coexist in the Coma cluster with dEs (Aguerri et al. 2005b). The dE's they say, are descended from dIrr's (this has been disputed in earlier years), and the dwarf S0's are harassed former bright, late spirals.

Dwarf galaxies can form from tidal tails, but the conditions are more restrictive than we used to think (Duc et al. 2004; and there indeed is Zwicky's ghost; forming galaxies this way was originally his idea, he said). Duc et al. say that the torn-out protogalaxies remain bound only when they are still inside the main dark matter halo.

dIrr's have star formation concentrated toward their centers with older stars farther out, more or less the opposite of spirals (Tikhonov 2005; Hunter & Elmegreen 2004).

Two categories that are more or less always dwarfs are the LSB galaxies (Sabatini et al. 2005) and the BCDs (Gil de Paz & Madore 2005).

And in case you have been entertaining doubts, there was reaffirmation of the article of faith that dwarf galaxies occupy different regimes of the correlations of size, dynamical, and chemical properties from those belonging to globular clusters and to big ellipticals (De Rijcke et al. 2005). Indeed they derive their blue light from different sources, residual star formation rather than extended horizontal branch stars (Boselli et al. 2005).

4.5. E is for Elliptical

We indexed only about 30 papers of this shape in 2005 (a bad year for the featureless, perhaps, as political events have shown) and starred for special attention an "it's all OK" paper. Dekel et al. (2005) reassure that the outer parts of giant ellipticals really are dominated by dark matter. The appearance of a small velocity dispersion is the result of highly eccentric star orbits, representing the first stars torn loose during the last major merger. An analysis of gravitational lensing (Ferreras et al. 2005) concurs, with DM dominating outside 20 kpc and rather little inside 4 kpc. The smaller the galaxy, the further out luminous matter remains dominant. Padmanabhan et al. (2005), after looking at 29,469 SDSS ellipticals with spectra, report details of the correlations of M/L, dark matter fraction, etc., as a function of galaxy luminosity, surface brightness, size, and so forth. In quick summary, more dark matter means more everything except starlight.

As your authors age, we become ever fonder of the oldest stars in the oldest systems, perhaps the globular cluster populations of ellipticals. The Readers Digest Condensed version mentions only the total number of clusters relative to galaxy brightness, S. Davidge & van den Bergh (2005) have managed to measure S for the heavily obscured Maffei 1, the nearest (field-ish) elliptical, and find $S = 1.2 \pm 0.6$, not particularly anomalous for field Es they say (it is bigger in clusters). What are the units? Um, er. Something like number of clusters per $10^8\ L_\odot$ in the B band. And, lest we forget to mention it elsewhere, another "it's all OK" item. If ellipticals are made from spirals (which have smaller S), can you get the right number in the product without having to wait several Hubble times for all the young, bright stars to evolve to death? Yes, say Goudfrooij et al. (2004) and Li et al. (2004). You also automatically account for two populations, old clusters from the parts assembled and the younger, more metal rich clusters from the assembly process.

A proper characterization of cluster properties is not, of course, limited to the S value but includes ages, metallicities, and deviations from the solar pattern of heavy element abundances. Kaviraj et al. (2005) and Puzia et al. (2005) contributed to that topic during the index year, and yes, multiple populations exist.

Where are the SCUBA galaxies of yester-z (1–3 or thereabouts)? Gone to ellipticals every one, say Takagi et al. (2004) and Swinbank et al. (2004). No information was provided on when will they ever learn.

Why do some ellipticals continue to form stars longer than others (Cotter et al. 2005)? Surely almost as many reasons as there are ellipticals, but we rather like the suggestion of Springel et al. (2005) that, when a merger product includes two black holes, their orbiting quickly quenches core star formation, turning accretion of gas into an outgoing wind. And if not, not, and the core remains blue, with low level on-going star formation for as long as 7 Gyr after the merger. Does this contradict the statement a few paragraphs above that the blue light in Es comes from extended horizontal branch stars?

4.6. X is for XBONG and Many Other Types

At least a dozen appeared during the reference year, some perhaps more interesting than others. X, say Hornschemeier et al. (2005) stands for X-ray Bright, Optically Normal Galaxies, and there aren't any, the phenomenon being an artifact of poor wavelength resolution at large redshifts. In fact, they report, in suitable spectra, [O III] looks as strong as it is in Seyfert galaxies for their X-ray bright sample. Some other portions of the optical/X-ray/radio ratio space are empty because of other selection effects (Anton & Browne 2005), so don't sell all your

XBONG stock (and don't go looking for it in the back pages of the *Wall Street Journal* either; 5 letters is too many for a stock ticker symbol; see § 11 at 702)

A category that may or may not be empty is that of H I-filled but starless halos. Doyle et al. (2005c) find that none of 3692 H I sources are invisible in regions where the Milky Way imposes less than $A_B = 1$ mag. But there were some fiscal 2005 H I clouds that rated press releases. The key issue is whether these clouds really live in their own dark matter halos or are merely gas pulled out of some more normal galaxy in a group or cluster (Minchin et al. 2005; Osterloo & van Gorkum 2005, Virgo clouds; Walter et al. 2005 a stray H I cloud in the M81 group).

Existence continued throughout the year for—

- Markarian galaxies (Stepanian 2005),
- clump cluster galaxies (Elmegreen & Elmegreen 2005), another sort of pre-elliptical,
- UV excess galaxies, which are rather like Markarian ones, but found by Kazarian & Martirosian (2003),
- void galaxies, which are unbiased (Goldberg et al. 2005), apparently the nicest thing anybody said about them during the year,
- assorted blue compact galaxies (Lin & Mohr 2005, who note that mergers are commoner in clusters).
- Extremely Red Objects, which are, variously, obscured AGNs (Brusa et al. 2005); another sort of pre-elliptical (Brown et al. 2005b); a mix of pure bulge, disk, and interacting galaxies (Sawicki et al. 2005); distant, old clustered objects with intermediate star formation rates, including about one-third E+A galaxies (Doherty et al. 2005). We shouldn't dream of saying these chaps don't read each others' papers, but we hope they don't try to believe all of them at once.
- E+A galaxies (meaning ellipticals but with spectra displaying the absorption lines of A stars), which are not the same as IRAS galaxies, another sort of poststarburst (Goto 2005); not all the same sort of beasts (Pracy et al. 2005); not another sort of proto-elliptical, but arguably a form of proto-S0 (Bekki et al. 2005); not inhabitants of rich clusters, being found mostly in small groups and the field now (Blake et al. 2004); not to be confused with e(a) galaxies, which display nebular emission lines (Balogh et al. 2005, who prefer to call E+A's k+a, meaning a mix of stellar K and A spectral types, which, if you were a star might get you declared symbiotic.[12] It probably is easier not to be a number of different things simultaneously than to be a number of different things simultaneously.
- Lyman break galaxies which also show broad absorption lines, like some QSOs (Ivison et al. 2005),
- Damped Lyα galaxies, which could be either the edges of big things or the whole of smaller things (Hopkins et al. 2005a, the latter view, and Chen et al. 2005b, the former view; Weatherley et al. 2005 favoring protogalactic fragments for those at $z > 1.75$; Okoshi & Nagashima 2005 favoring LSB galaxies for $z = 0$–1, again not a contradiction),
- Lyα emission blobs (Mori et al. 2004), which are currently petitioning to be renamed primordial galaxies with lots of supernovae.
- SCUBA galaxies are named for a bolometer (operable under water we suppose) rather than any specific physical characteristic, and so are allowed to have a range of underlying energy sources, all of which lead to their being big and bright and dusty (Greve et al. 2005; Chapman et al. 2005; Pope et al. 2005; Houck et al. 2005; all with an assortment of details, and the last reporting redshifts from the *Spitzer Space Telescope* for some objects with no optical counterpart).
- Satellites of spirals, with a color luminosity correlation extending over a range of 12.5 mag (Gutierrez & Azzaro 2004),
- low surface brightness galaxies, with a new catalog of 81 of them, vs. 18 known before (O'Neill et al. 2004). Malin 1 remains unique, say Minchin et al. (2004), but a little Irvine bird has whispered in our ears that even Malin 1 isn't exactly like Malin 1.
- And the favorite of the year, the ultracompact dwarfs, which are neither dE's (Mieske et al. 2005a on a couple of M32 clones in Abell 1689, plus fainter galaxies bridging the luminosity gap to the UCDs in Fornax) nor overblown globular clusters (Huxor et al. 2005, on objects in the halo of M31 with colors like globular clusters but half-light radii of 30 pc like small galaxies). As for what they are, well, you know the choices. They started out to be that way (Bastian et al. 2005); something bad happened to them on the way to the cluster (Hasegan et al. 2005);[13] or, naturally, more complex scenarios (Fellhauer & Kroupa 2005; Clark et al. 2005b).

4.7. Galaxies as Families

The traditional collective noun is the wastebasket, but galaxies as a collectivity, are, we learned this year, a one-parameter family (Coenda et al. 2005), a two-parameter family (Lauger et al. 2005), whose parameters are central concentration of light and degree of symmetry under 180° rotation in the UV to I bands, at least for $z = 0$ to 1, or bimodal in distribution over one or more parameters. For instance, Wiegert et al. (2004) report that several properties are bimodal on either side of $B - V = 0.29$ out to $z = 3$, but that there are fewer red galaxies at $z > 1.4$. Nuijten et al. (2005) find a bimodal number vs. color relation, with the red/blue ratio dropping from $z = 0$ to $z = 1$, and also a division by whether bulge or disk dominates. And Gallazzi et al. (2005) focus on the bimodal distributions of mass, star age, and metallicity on either side of a stellar mass of $\log M = 10 \pm 0.3$.

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[12] Symbiotic stars are a class of cataclysmic variable with one hot and one cool star and, as a rule, less exchange of bodily fluids than in the novae, dwarf novae, and so forth.

[13] The author who has just acquired her first-ever device for playing old movies opines that of the ones that seemed hysterically funny 40 years ago, *A Funny Thing Happened on the Way to the Forum* stands up best. Going back another two decades, it is Jack Benny's *To Be or Not to Be*.

Looking back to $z = 2.5$ or more, as you surely do not need to be told, the commonest class is "peculiar" or "irregular" (Cassata et al. 2005), though still with 20% normal E and S0 galaxies and 27% normal spirals. One begins to feel the need of another classification scheme to record changes of type, luminosity, mass, etc., at moderate to large redshift. Conselice et al. (2005) have suggested one.

Collective clustering properties and their changes with redshift are presented by Ilbert et al. (2005) and Le Fevre et al. (2005b, 2005c). A two-word summary is "bias evolves." That is, the brightest galaxies were more concentrated in the most dense regions at $z = 1$ than they are now. This sounds like a large scale manifestation of "downsizing," which is where this section began, and it is, therefore, almost time to move on to the universe as a whole.

4.8. Anthropogenic Downsizing

"Anthropogenic" these days is normally associated with "climate change" or "extinctions," and you will find it hidden there. But the Milky Way has experienced a sort of anthropogenic downsizing from the time of Harlow Shapley (1919) to the present. We remarked upon this some years ago (Trimble 1993), but Vallee (2005) has followed the trend down to the present. Shapley's galactocentric distance for the solar system of 18.5 kpc has shrunk to a mere 7.9 kpc. The interarm spacing has also shrunk a bit (3.5 to 3 kpc over about 20 years) while the pitch angle since 1980 has remained steady at 12°. Most curious of all, the number of arms reported over the years has shifted gradually from two to four, without passing through three. We think this may have been organized by the same group that markets end-of-the-season peaches that go from green to rotten without passing through ripe.

5. TAKE MY UNIVERSE, PLEASE

No, you are too young to remember the stand-up, borscht-belt comedian from whom this line is borrowed (though two of your three authors and the Faustian Acquaintance of earlier ApXX's are not). It means that, although patient readers will eventually encounter updated values of the standard cosmological parameters and other conventional progress, the more unusual ideas come first. Oh, and Earth is in the middle, as per Ptolemy, Brahe, and many other distinguished predecessors in summarizing the cosmos.

5.1. Old Kosmoi Never Die

Well, no, we didn't encounter any Earth-centered models this year, but Grujic (2005) advocates a Newtonian model, with vacuum energy outweighing the matter and with fractal structure. The universe of Skalsky (2005) is also Newtonian, but with $\Lambda = 0$. Other old friends whose age begins to approach ours include—

- Hoyle-Narlikar conformal cosmology, discussed by Papoyan et al. (2003), in which the CMB is due to the decay of a primordial vector boson.
- Quantized non-cosmological redshifts, supported by Bell (2004) from structure in $N(z)$ for sources in the Sloan Digital Sky Survey, and opposed by Basu (2005), who concludes that apparent redshift periodicities in the distribution of gamma ray bursts arise from selection effects. If so, then we won't need the mechanism, involving stimulated Raman scattering, suggested by Holmlid (2004).
- Quantized orbits, on the Keplerian scale (vs. Bohrian) would seem to be even more problematic, but that appears to be what is intended by Chatterjee & Magalinsky (2004).
- Modified Newtonian Dynamics explains (well, they say predicts) the observed relationships of scale lengths and accelerations in disks and halos of spiral galaxies (Milgrom & Sanders 2005). It could be tested by the behavior of star streams in the halo of the Milky Way, say Read & Moore (2005).
- G varying with separation fails as a model for local peculiar velocity fields (Whiting 2005).
- The Dynamics of Dinculescu (2004) seems to be even more Modified, so as to bring the temperature of the CMB into galactic structure.
- Tired light cannot explain the time dilation seen in the light curve of SN 1997ex at $z = 0.361$, say Foley et al. (2005). Our only objection is that they credit tired light to a 1986 paper rather than to Zwicky (1929). Variable particle masses don't fit either, according to the same paper, with credit this time to Narlikar & Arp (1997), not quite the first team in that race, but at least coming out of the right stable.
- An Einstein–de Sitter model (held down flat by matter alone) can fit supernova data if there is intergalactic metallic dust, says Vishwakarma (2005). He says it also explains "all other existing observations."
- Gravity might be Lyra (Rahaman et al. 2005), Saez-Ballester (Mohanty & Sahu 2004) or repulsive (Rahaman et al. 2004), though we cannot claim to be much attracted by any of them.
- The spin (vector) driven inflation of Garcia de Andrade (2004b) probably belongs here, too, although, given that ordinary inflation is described as driven by a scalar field, it is primarily the venue and the September 2001 submission data that suggest the conclusion. The related model of a torsional, Einstein-Cartan universe (Garcia de Andrade 2004a) may or may not deserve a separate bullet.

5.2. Newer Universes Hang in There Too

Coles (2005) gave the "State of the universe" address for the year, with a solid review of the current conventional wisdom. It has, of course, both dark matter and dark energy (next section). Here are some variants that would seem to be acceptable within a broad conventional cosmo-church.

Non-zero rotation and shear (Jaffe et al. 2005) provide a possible fit to the weak quadrupole and octopole asymmetries and the strong north-south one in the *WMAP* first-year measurements of CMB fluctuations. Will you have heard about the next two years' data by the time this appears? We hope so! The Jaffe et al. model is of Bianchi type VII, with $\omega/H = 4.3 \times 10^{-10}$ and $\sigma H = 2.4 \times 10^{-10}$ toward $(l, b) = (220°, 60°)$. Oh, and this universe is open, with $\Omega = 0.5$.

Branes remain popular and will undoubtedly do so right up to the end of (our) universe, which will occur in the collision and mutual annihilation of positive and negative tension 3-branes (Gibbons et al. 2005).

Loop quantum gravity allows you (well, some of you anyhow) to avoid an initial singularity in the universe (Mulryne et al. 2005; Boyarsky et al. 2005; Bojowald et al. 2005), but the middle one of these also has a big black hole. Such a universe can bounce, and its volume at the bounce (in Isotropic Loop Quantum Gravity) reveals the minimum length scale on which one cuts off modes when calculating things to prevent getting infinite answers. But if Date & Hossain (2005) gave a number, we missed it.

Non-trivial topology, like rotation and shear, continues to hover at the edges of the *WMAP* data. Aurich et al. (2005) propose Picard space, which is hyperbolic in the form of an infinitely long horn of finite volume. The space (Picard 1884) is older than relativity, and we are not sure whether the author was one of the ballooning Picards or if he thought of his hyperbolic space while hanging from a (we hope) positively curved balloon.

There exist, says Lake (2005), positive Λ, $\Omega \approx 1$ non-flat universes, and, what is more, we live in one (*WMAP* again). The models are not, according to the author, finely tuned to get Λ right.

The Euclidean form of log N– log S for normal galaxies over a very wide range in apparent brightnesses (Tajer et al. 2005) means, we trust, only that the galaxies are quite close to us by cosmic standards.

And, say Alam et al. (2004), the best fit to supernova data remains a changing w in the equation of state $P = -w\rho$ from $w = 0$ at $z = 1$ to $w = 1$ now. This is more or less a Chaplygin gas, whose death (by liquefaction?) we announced a year or two ago. Alcaniz & Lima (2005) more or less concur, on the basis of angular diameters of radio sources (a very old and frequently misleading cosmological test). Biesiada et al. (2005) agree with Alam et al. that supernovae are the right test, but conclude that the answer is not yet in. Incidentally, Alam et al. provide a very nice brief introduction to eight possible alternatives to conventional constant Λ, some of which we have probably missed in earlier years.

5.3. Degrees of Darkness

As in the previous 10 or more years, there were conventional and unconventional candidates for dark matter. Traditions upheld include that it is not mostly in galactic disks (Ciardullo et al. 2004 on M33), not mostly halo white dwarfs (Creze et al. 2004), not mostly cosmic string (Jeong & Smoot 2005), though maybe a bit (Sazhin & Khovanskaya 2005), and not a major constituent of the Sun (Kardashev et al. 2005)

Approaching this time from the conventional side, we greenstarred the thought by Boehm & Schaeffer (2005) that candidates might best be classified not into three discrete groups of cold, warm, and hot, but rather into a continuum based on their damping lengths in the early universe and the requirement that they not wipe out structure on the scale of galaxies. This permits consideration of candidates with some coupling to neutrinos (superweak, presumably) and photons (weak electromagnetism?), as well as those that do only gravitation.

WIMPs and axions (reviewed by Zioutas et al. 2004) are the candidates of longest standing, and there could be, they say, some of each, though neither has yet interacted detectably with laboratory apparatus (Akerib et al. 2004).

Kaluza-Klain particles (meaning the lowest mass ones that conserve KK parity) get to be number two this year (Bergström et al. 2005), and it would be lovely to be able to say with enthusiasm that the TeV gamma rays coming from the direction of the center of the Milky Way are their annihilation products. There were, however, at least three other "DM annihilation has been seen" papers during the year. Zhao & Silk (2005, neutralinos clustered around 10^2–10^3 $M_\odot$ black holes), Beacom et al. (2005, the 511 keV line from the direction of the galactic center), and Elsässer & Mannheim (2005, the extragalactic EGRET background) unfortunately require three different mass ranges for the mutually self-assured destructive particles, and Ando (2005) says that none of them works wildly well anyhow.

Unified DM-dark energy scenarios entered their fourth year (Zloshchastiev 2005) and are perhaps ready for preschool.[14] The tensor graviton of Dubovsky et al. (2005) also gives the Friedmann equations an extra acceleration-inducing term, and so probably belongs in this paragraph.

Supermassive black holes (meaning $\sim 10^5$ $M_\odot$) have been in and out of the inventory a number of times. This year, Jin et al. (2005) favor them for dwarf spheroidal galaxies because they promote shallow (core vs. cusp) central density profiles. If, however, they contribute a typical density of only 1.5×10^5 $M_\odot$ Mpc^{-3} (Mahmood et al. 2005, on evolutionary scenarios vs. data), then they are not even a 1% solution, however respectable they may be.

And we proceed onward to Fermi balls (Munyaneza & Biermann 2005); baryon clumps (Froggatt & Nielson 2005); neutralino clumps of about one Earth mass and one AU in size (Diemand et al. 2005), one of which should pass through the solar system every 3000 yr.[15] Annihilation in galactic ones could be the unidentified gamma ray sources. Since the clumps are made of a traditional DM candidate, perhaps they should appear higher on this list.

Here are some more. Droplets of non-hadronic color super-

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[14] We have already discovered that a Ph.D. is not quite enough to understand some of these papers.

[15] The most recent having undoubtedly been responsible for the 10 plagues.

conducting phase of very dense strangelets of quarks and antiquarks (Oaknin & Zhitnitsky 2005). These produce positrons in the decay process and so account for the 511 keV line from the galactic center. The charged monopoles of Dubrovich & Susko (2004) have masses of 10^{16} GeV like all other undetected magnetic monopoles, but they carry a charge of 68.5 *e*, rather than 1/3 or 1 or zero.

Lest you conclude that (at most) one of these can be right, take comfort from Karachentsev (2005) whose analysis of motions in the Local Group and four other nearby small groups of galaxies implies the existence of two sorts of dark matter, one more dissipative (but apparently too abundant to be all baryons) than the other.

Concerning the nature of the dark energy, Ap04 § 8.6 noted the remarkable absence of seriously non-standard DE candidates. With the papers of Arbab (2004) and Garcia de Andrade (2004a, 2004b), this class would seem no longer to be empty.

Mainstream on the basis of its source, but seriously inflammatory was the thought (Kolb 2005) that there might be no dark energy, with the appearance of accelerated expansion due to very large scale structure. Mainstream, but apparently wrong. Large scale inhomogeneities, at least up to the size of the horizon, just don't have the desired effect (Siegel & Fry 2005). Other dark energy alternatives include:

1. Extra-dimension gravity on large scales, which modifies the Friedmann equations (Elgarøy & Multamaki 2005).
2. A new $M \approx 10^{-5}$ eV particle (Dvali 2004), where some of the DE resides in the masses of the particles and some in the scalar field potential. It should be detectable through its interactions with neutrinos, slowly changing their masses with time.
3. "A scalar field self-interacting through Ratra-Peebles or supergravity potential" (Maccio 2005). It predicts more lensed arcs at the epoch of cluster formation ($z = 0.2$–0.3) than does a pure cosmological constant.
4. A candidate for phantom energy (Amendola 2004), that is $|w| > 1$ in the equation of state. The field could cluster on astrophysical scales and so contribute to structure formation, acting like a long-range repulsive part to gravity (and so, we suppose, making voids rather than clusters if it clumps).
5. A fit with $w = -2.85$ to supernova and other data (Bassett et al. 2004).
6. Another highly-flavored (or anyhow non-vanilla) equation of state that accounts for the very small quadrupole and octopole moments of the cosmic microwave background (Enqvist & Sloth 2004).

Perhaps in some ways more useful than a list of candidates is the suggestion that they should be classified in terms of what they "predict" for $H(z)$, d^2H/dz^2, etc. (Evans et al. 2005a), in the same way that Boehm & Schaeffer (2005) suggested classifying DM candidates by their damping lengths during structure formation. We confess, however, to having indexed Evans et al. as "Back to McVittie," who was a great fan of q_0 and higher-order perturbative terms for the equations of cosmology.

Are you expecting a big rip? Or have you ever worried that some of your own expansion over the years might be cosmological? Then you will forgive our violating the ApXX rules and referring you to a paper not yet published (Price 2005). He has shown that the Earth (etc.) are not expanding and why, and described what will happen if acceleration gradually overcomes, first, gravitational binding, then electromagnetism, and eventually the color force.

5.4. Is the Universe Full of Stuff?[16]

Oh yes, no fewer than 40 kinds, tabulated by Fukugita & Peebles (2004), including negative binding energies, the dark sector, thermal relics, baryons in many forms, stellar radiation and neutrinos, cosmic rays, magnetic fields, and kinetic energy of the intergalactic medium, all reported as fractions of the closure density (Ω's) for $H = 70$ km s^{-1} Mpc^{-1}. In particular, neutrinos contribute 1.1% of the total and the CMB only 0.1%. Other compilations of the numbers of standard, hot big bang, ΛCDM cosmology are to be found in Abazajian et al. (2005a, using halo occupation data from SDSS) and in Rebolo et al. (2004), also with no surprises, though mild evidence for deviation from the $n = 1$ Harrison-Zeldovich spectrum of perturbation amplitudes, in the direction of less power on smaller scales.

The conventional numbers, you will recall unless you have spent the last three years in a witness protection program, hiding from press releases, the standard astrophysical literature, and even these reviews, are a Hubble constant of 65–70 km s^{-1} Mpc^{-1}, a little less than 30% of the closure density in all forms of matter (about 4% baryons), and a little more than 70% in cosmological constant, dark energy, or whatever, plus the Harrison-Zeldovich spectrum (equal amplitude on each scale as it enters the horizon), a normalization of the matter fluctuations now, called σ_8, near unity, and consistent numbers for the age of the universe, q_0 (the second derivative of cosmic length scale), and bias (the degree to which luminous matter is more [or less] clustered than dark matter).

Nothing happened in index year 2005 to disturb this consensus. Perhaps one should not be surprised. In January 2002 an official distance modulus for the Large Magellanic Cloud was announced ($m - M = 18.50$). And the 21 papers published since then all agree within 0.5 σ with this HST Key Project value, yielding a χ^2 of only 0.189 (K. Krisciunas 2005, private communication).

H_0 is once again attracting more independent researchers. We caught only eight values published during the fiscal year, but they ranged from 86.4 km s^{-1} Mpc^{-1} (Bonamente et al. 2004, from the Sunyaev-Zeldovich effect in Abell 64) to 50 as a lower limit (Stritzinger & Leibundgut 2005, from the

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[16] Frivolous readers may remember this as the title of a paper parodying the style of the Keen Amateur Dentist of earlier ApXX's. The answer was, of course, considerably more complex than yes, no, both of the above, or none of the above.

requirement that Type Ia supernovae make less than 1 $M_\odot$ of ^{56}Ni). The median is 66 (Jones et al. 2005c) from an S-Z measurement in a different cluster.

The sole q_0 for the year is a concordant -0.7 to -1.0 (John 2004) from a five-term fit to SNe Ia data. His third derivative, called r_0, is between 0 and $+6$, while the 4th derivative is close to $+10$. Oh, and $H = 60$–70, with which few would quarrel.

The baryon contribution needed to form structure on the 0.054 Mpc^{-1} scale (Tocchini-Valentini et al. 2005) falls close to the $\Omega_b h^2 = 0.22 \pm 0.002$ level needed to agree with big bang nucleosynthesis. It is, however, arguably too early to declare these numbers off bounds for revision. The observed deuterium abundance remains a smidge less than the theorists would like (Crighton et al. 2004), and the predicted ^{7}Li in old stars is more like two smidges too much (Fields et al. 2005 on the theory; Melendez & Ramirez 2004 on data). Fields et al. put forward a way to lower the theoretical prediction to match the raw data. Richard et al. (2005) suggest, contrapuntally, that the theorists are right and the oldest stars have hidden about half their lithium via gravitational settling.

The usual number near 0.24 for total matter density can be extracted from data on gamma ray bursters (Ghirlanda et al. 2004), the 2dF survey of galaxy redshifts (Eke et al. 2004), and the Sloan Digital Sky Survey (Cole et al. 2005, actually a full, standard set of parameters).

The universe truly needs something like a cosmological constant, even if flatness ($k = 0$) is not a prior (Mitchell et al. 2005, on lensed QSOs and radio sources). And all current data are perfectly happy with $w = 1$ in the pressure-density relation, $P = -w\rho$ (Rapetti et al. 2005) despite all the imaginative variants in the previous section.

The age of a consensus universe is close to 13.7 Gyr, and the oldest galaxies and stars ought to be at least a bit younger, since a source with age equal the total should have $z = \infty$. We caught no disagreements on the actual number, but only on whether numbers arising from particular methods are meaningful. Dauphas (2005) says "yes" for the $14.5^{+2.8}_{-2.2}$ Gyr for the Milky Way from U/Th in meteorites and old stars. The age comes from counting backward til you reach the U/Th production ratio, and we wonder whether the conclusion remains true if the production ratio, said to be 0.571, varies with place or time because of different neutron exposures in the *r*-process. In this context, Christlieb et al. (2004) note a subclass of *r*-process that can make a range of Th abundances.

On the other hand, Yushchenko et al. (2005a) focus on the range of barium to mercury abundances coming out of *r*-process sites and conclude that the ratio of Pb peak to actinides will vary, so you can't do it that way. Within the thin disk, there do not seem to be these large variations in Ba-Hg abundances, and so the 8.3 ± 1.3 Gyr value found by del Peloso et al. (2005a, 2005b) applies at least to the stars in which Th/Eu was measured. They are about as old as the oldest disk white dwarfs.

5.5. More Diffuse Stuff

The two numbers for which we found the largest variances were the bias parameter b (the extent to which luminous matter is more, or less, clustered than the DM) and the mass normalization σ_8. It has become clear in recent years that bias simply does depend on galaxy type (Wild et al. 2005; Conway et al. 2005, larger for early types), galaxy mass (Seljak & Warren 2004, big for big galaxies and clusters), length scale (Myers et al. 2005), redshift (Croom et al. 2005; Le Fevre et al. 2005c, larger at large z), and galaxy luminosity (Zehavi et al. 2005). Worse, Eisenstein et al. (2005a) and Ouchi et al. (2005) conclude that the variables are not separable, luminosity and length scale getting mixed up in the first analysis and topology and density in the second.

The sad implication is that serious models of large scale structure and streaming will be expected to match all these trends as well as the average value of 1.3 or whatever you would like it to be.

We wish we could say something equally rational about σ_8, although it is supposed to be the rms value of the excess of total matter over the cosmic average on a comoving length scale 8 h^{-1} Mpc. Thus it could reasonably be an (increasing) function of time, but should not depend on the types of objects used as tracers or the volumes occupied by those objects, as long as they are large compared to 8 Mpc^3. But, in fact, the values reported during the year did not by any means all fall within each others' error bars, ranging from 0.6 (Blanchard & Douspis 2005, using X-ray clusters) and other small values (Weinberg 2005, otherwise a standard parameter set) up to 1.11 (Percival et al. 2004, from consideration of the 2dF redshift survey). Blanchard & Douspis suggest that baryons may be greatly depleted in the cores of rich clusters, which are then more than half dark matter. The median value is not terribly helpful. It is 0.85, but the published numbers cluster in two clumps, one at 0.6–0.7 and one at 0.9–1.1, and a number that nobody found from any data sample is a funny choice for the "right" answer. It may, however, be a reasonable choice if you merely need to calculate something. Well perhaps we will have an answer for you, or at least a better posed question in Ap06.

The "I wish I had thought of that" green with jealousy star goes this year to Menzies & Mathews (2005) for cosmological aberration. Our Earth-based velocity relative to the microwave background is about 370 km s^{-1}, more than 10 times the speed around the Sun that James Bradley (looking for heliocentric parallax) found in 1729 (We remember it well), and the shift in apparent position is therefore $0\overset{\circ}{.}07$ or 254″. This will not, for the most part, shift back and forth every six months (only the Bradley part, as it were), but it can matter in some studies of very large scale structure from surveys, weak lensing, non-Gaussianity of the CMB, and so forth, and perhaps the Sunyaev-Zeldovich effect (Chluba et al. 2005). The authors provide a correction formula and a table of corrected positions for the 50 most aberrated objects at $z > 1$. Neither Zwicky nor an earlier ApXX candidate for the second most aberrated astronomer appears in the table.

WE INTERRUPT THIS UNIVERSE TO BRING YOU THE EARTH

5.6. Ptolemaic Cosmology

Here, right in the middle of the universe, is the Earth. Why? Well, we don't want adherents of older models[17] to feel that we don't give their ideas a fair hearing. Discussion of the Earth obviously ought to focus on it as a prototype for planets in general, so the core and mantle come first. The rest of the Solar System lives in § 3 and exoplanets in § 6.

5.6.1. Inside Out

The inner (solid) core rotates a smidge faster than the mantle and crust, by $0\overset{\circ}{.}3$–$0\overset{\circ}{.}5\ \mathrm{yr}^{-1}$, report Zhang et al. (2005b), following analysis of the speeds of earthquake waves vs. the direction they are going. That the rotation is slowing was known to Darwin (George) and comes, among other sources, from reports of ancient eclipses. The data (Tanikawa & Soma 2004) are not precise enough to distinguish central from surface rotation. The dynamo that makes us so magnetic is reputed to live in the core, so this must be the proper place to record (a) that the late Triassic field was a geocentral axial dipole (Kent & Tauxe 2005, an analysis of paleolatitudes), (b) that the last major pole flip occupied the time from 795 to 776 kyr ago (rather slower than sometimes stated; Singer et al. 2005a), and (c) that the flips have been modeled (again) by Takahashi et al. (2005a) with a 5200 yr transition period, over which there can be briefly two N or two S poles. They note that we are, given the average time between pole reversals, badly overdue for the next one, and that the average surface field strength has declined about 10% in the last 170 years. The world, or at least the current polarity episode, is perhaps coming to an end.

Radiogenic terrestrial neutrinos come from inner and outer cores and the mantle. In a most impressive analysis of antineutrinos ($\bar{\nu}_e$) captured by protons in the KamLAND detector, somewhere between 4.5 and 54.2 of them have been recorded, where 19 were expected (Araki et al. 2005).

At the core-mantle boundary, you will find a great deal of "geography," though we think they mean topography—high and low points, rather than features with names (Rost et al. 2005). There is, for instance, a dense, partially molten blob under Australia.[18] Differentiation of the mantle from the core occurred about 4.53 Gyr ago, only 30 Myr after formation (Boyet & Carlson 2005).

Every year, somebody tells us whether the convection in the Earth's mantle occurs in one zone or two, and so we pass on the information that indeed it occurs in one zone or two, though not with confidence which. A vote this year for one from Class & Goldstein (2005) and White (2005). The issue they address is whether there is a need for an un-degassed primordial reservoir of ^{3}He. They say not.

Crust formation began 4.35 Gyr ago (Watson & Harrison 2005) and it must be an ongoing process, because every other solid Earth paper indexed this year dealt with cratering and other processes that destroy crust. Some of them addressed—

- Possible periodicities, yes according to Yabushita (2004), though with a 10% probability of being a chance result, for cratering episodes.
- Possible periodicities in the behavior of the fault that will eventually dump two of your three authors into the Pacific Ocean (Weldon et al. 2005), though not, you will be sorry to hear, soon enough to stop the publication of this paper. The next epoch of major stuff is due in 2051, or perhaps 2000 if the period is getting shorter. Oops. That's now.
- Erosion at 24 meters Myr^{-1} for the past 500 Myr, some sort of average over the land surface (Wilkinson 2005). If the Earth's surface is 30% land, this actually comes quite close to the 3 $\mathrm{km}^3\ \mathrm{yr}^{-1}$ of fresh crust material produced at divergent boundaries that the rockiest author learned about the years she taught geophysics.

5.6.2. Air

The atmosphere appeared in 56 fiscal year papers, roughly half pertaining one way or another to climate and climate change. Some of the following paragraphs are more astronomical than others, so feel free to read them in random order.

Gamma-ray flashes from the upper atmosphere were a 1994 discovery (Fishman et al. 2004) and were predicted by C. T. R. Wilson (1925) of the cloud chamber. *RHESSI* has been seeing them all along, in numbers that imply rates of something like 50 per day (Smith et al. 2005b). But the global lightning flash rate is, they say, 44 ± 5 per second, so 50 per day (or even 5000 if the beaming correction is like that for GRBs) isn't all that many. The total power is about 40 MW/flash (of typical 0.5 ms duration). Photons extend up to 20 MeV, corresponding to the potential drop from cloud tops to ionosphere.

The Van Allen belts have been putting themselves back together after a nasty encounter with a giant solar flare on 1 November 2004 (Horne et al. 2005). For details of the damage see Surridge (2004, ionosphere) and. Baker et al. (2004, Van Allen belts). Similar processes must be important for the radiation belts of Jupiter and Saturn. A nearby GRB would also be hard on our atmosphere (Thomas et al. 2005).

Co-listed under "oops" is a second observation of the wavelength dependence of the Earth's albedo as measured from earthshine. It does not show the red chlorophyll edge at 7000–7400 Å that was a highlight of Ap04 (Montanes-Rodriguez et

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[17] The most adherent author drives a 1980 Toyota and has a deep understanding of what it means to be an older model.

[18] In principle, this must have contributed to attracting the 2003 General Assembly of the International Astronomical Union to Sydney, though probably less so than the quality of the wine and the charm of the wombats.

al. 2005). Both could, however, be right, since this year's data were recorded when the center of the sunlit hemisphere was in mid-Atlantic, a seriously deforested area.

Not everything that happens on Earth is our fault ("anthropogenic" is the polite term). There are solar cycles, with which some aspects of the Indian monsoons show correlations (Hiremath & Mandi 2004; Wang et al. 2005f). The major, long icy episodes on Gyr scales may be causally correlated with epochs of nearby star formation (de la Fuente Marcos & de la Fuente Marcos 2005). Something happening in the interstellar medium was also blamed for ice ages by Yeghikyan & Fahr (2004), in particular spiral arm passages (Gies & Helsel 2005) for a 100 Myr timescale. Coming down to timescales of 10^4–10^6 yr, there have been seven glacial cycles during the late Pleistocene (last 700,000 yr), for which there are more than 30 models (Huybers & Wunsch 2005). One of them (Haug et al. 2005) was indexed under "Milankovich lives," meaning primacy of changes in Earth's orbital parameters. In addition, cycles, or anyhow variability, in the solar flux that reaches the surface, is probably responding to anthropogenic aerosols (Pinker et al. 2005; Wild 2005). The current broadband albedo, in case you should need it, is 0.29 (Wielicki et al. 2005).

There was a very early H_2-rich atmosphere according to Tian et al. (2005a), whose eventual replacement by an oxygen-rich one might be described as floragenic, but was not by Falkowski et al. (2005). They provide numbers for the Jurassic and Tertiary (thereby falsifying a claim we saw somewhere else that no one uses "Tertiary" any more). There was also the Permian catastrophe, one of the 30+ hypotheses for which was the flora not doing their duty, so that atmospheric O_2 dropped (Huey & Ward 2005). One of the implications is that organisms of similar sensitivity can live only below an altitude of 500 m. As many of the Permianently extinguished were ocean dwellers, we are not quite sure how to interpret this, except by noting that at least one of the authors can do integrals only below about 6500 feet.[19]

And, in as due solemnity as is possible to the author who generates the most CO_2, nearly all the rest is global warming, changes it is likely to wreck, and human responsibility therefor (Means & Wentz 2005, correcting an earlier error in calibration of satellite microwave data for the troposphere). Interesting tracers include dates of the French grape harvest (Chuine et al. 2004, reporting earlier warm periods but 2003 unprecedented); sediments and tree rings (Moberg 2005, with 1000–1100 CE like the 20th century before 1990, but "now" out of statistics); glacier lengths (Oerlemans 2005, with coherent warming over the globe since 1850, probed from more than a dozen sites, one of which we had to look up; Jay Mayen is an island off Greenland). See also Schaer & Jendritzky (2004) and Stott et al. (2004), with considerations of how much is anthropogenic.

Another aspect of the atmosphere obviously relevant to astronomy is the quality of various observing sites. A grim thought from a UCLA colleague is that, now more than ever, you are likely to choose a site that is better during your test years than it will ever be again, because of climate change. A dozen papers mentioned a comparable number of sites. The firmest statement came from Sage (2004), saying that Dome C (Antarctica) is the best spot on Earth for a new telescope. It is also praised by Walden et al. (2005) and Aristidis et al. (2005), and is compared with others in a variety of ways by Racine (2005). He makes the point that surface turbulence is responsible for much of seeing and can be corrected by adaptive optics over a larger field of view than higher turbulence. Indeed an out-of-period paper indicated that a very large fraction of Dome C seeing happens below 35 m, and you could build your dome on a platform thicker than that.[20]

The importance of high altitude winds is stressed by Carrasco et al. (2005) and by Garcia-Lorenzo et al. (2005), who are enthusiastic about La Palma, where the wine is much better than at Come D, sorry Dome C. American Antarctica is dry not just in the precipitational sense.

5.6.3. Air Breathers

The non-human biosphere appeared in 33 indexed papers. As long as we are busy blaming ourselves, recall that earlier generations of humans did the continents they entered (or anyhow the resident megafauna) no good (Miller et al. 2005a on Australia). The current situation is that more species become extinct while waiting to be listed as "endangered" than do afterward (Fish and Wildlife Service 2005). The most artificially augmented author is reminded of a recent series of events at her home institution, but dare not be more specific or organized.

The evolution of the horse has been declared to be considerably more complex than the Eohippus-Mesohippus-Equus sequence many of us learned as children. But the most obvious change (MacFadden 2005) is that Eohippus is now (or rather once again) Hyracothere.

Your turtle paper for the year concerns the death of Aeschylus (Nisbet 2004). Funk et al. (2005) deny that clipping off their toes is terribly bad for frogs, though if strict grammatical rules were enforced, so that "their" referred back to Funk et al., we bet they would change their minds. Bradshaw et al. (2005) have confirmed that elephants don't forget (and we wonder how frogs feel about people who clip their toes).

Platypi have 10 distinct sex chromosomes (Gruetzner et al.

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[19] And, in response to the two most obvious queries, yes, she can do integrals at sea level, and no, it is not likely that this particular skill was an essential one for brachiopods. (The junior, but oldest, author lives at the ragged integral edge of 6400 feet.)

[20] Presumably in consultation with the folks who designed Mickey Rooney's shoes.

2004). We understand, we think, that only two sexes are involved but have not essayed the experiment.[21] A dead whale can support an exceedingly complex ecology of truly revolting creatures for about a century (Smith 2005a), equivalent, we estimate, to supporting 100 humans for 10 years, if only calories count. But somebody has to be willing to eat the bones as well as the wings. Whales don't have wings, you say? Well, neither do pigs, though they were domesticated many more times and places (Larson et al. 2005) than chickens.

Some early mammals ate some of the late dinosaurs, report Hu et al. (2005) on the basis of a fossil of the former with a fossil of the latter inside. Long ago, mammals eating dinosaur eggs was one of the 30+ hypotheses for the extinction of the latter. But they didn't eat them all, because Sato et al. (2005) report finding some fossil dinosaur eggs in pairs, implying that the oviducts existed in pairs, as they do in modern birds.

A few survival issues appeared during the year. "Reagan lives," meaning that trees really do produce some atmospheric pollutants (Purves et al. 2004; their arboreal methane production is out of period). The flora and fauna of Mount St. Helens are gradually recovering (Dale et al. 2005). Leeches can live 20 years according to Dobos (2004), who describes them as "hardworking animals" deserving of eventual retirement. Armadillos didn't used to get leprosy, until people started spreading it all over the place (Monot et al. 2005).

The gerenuk (see photo in *Science* 308, 1040) is the living original of a widely reproduced gold Ur-statue of a ram, goat, or deer standing on hind legs, with front feet and horns entangled in some sort of thorn bush. The best known of these is said to have been among the irreplaceable archeological artifacts lost this most recent time war came to Ur.

The no-man's…no-hominim's…no-hominid's…land between human and non-human is occupied by the longstanding and definitely unresolved questions of how many species and subspecies of Homo co-existed at various times and places and how much, if any, interbreeding there was. The green wow-dot of the year was, obviously, the meter-high (knee-high to a giraffe?) Homo floriensis (Brown et al. 2004; Morwood et al. 2004; Mirazon-Lahr & Foley 2004), and no, we are not voting on the possibility of dwarfism or something else other than separate descent from Homo erectus under island pressure for small stature.

The 10 Homo species that appeared within a million years are briefly presented by Carroll (2005), as part of a piece on adaptive radiation of lobe-finned fishes. There were 11 of those, one of which eventually gave rise to land animals (including us). Only one Homo has survived as well, and we shudder to think what it is likely to give rise to. We caught no opinions this year on the amount of genetic mixing with Homo sapiens neanderthalis, but, with a typical male BMI of 28.7, and a diet with about 30% more calories than the Inuit, he would have fit right into modern America (Churchill 2005).

5.6.4. Hot Air Breathers

We recorded 73 papers about humans collectively or individually, while noting on the fringes that the wizard gene is recessive to Muggle, though arguably with incomplete penetrance (Craig et al. 2005b). Young Mr. Potter and Cinderella both appeared in the index year literature as examples of "reduced parental investment when parent-child relatedness is low" (Raymond 2005). We green-dotted the unpleasant fact that foreign-born postdocs are typically paid rather less for more work than ones whose relatedness to the PI is likely to be higher (Davis 2005). As for the saga of Larry Summers (see Singer 2005b), in response to his remarks about Jewish farmers and white basketball players, the white female Jewish author, who once grew enough wheat to make one loaf of bread and was the free-throw champion of her junior high school,[22] gives him fair warning, based on the recent history of women being called to the Torah in reform synagogues, that, if you once let us in on equal terms, we will quite probably take over!

More computing power is already needed for climate modeling, says Palmer (2005). This will become even more true if Benford (2005) is correct that the perfect mate for most women will eventually be a very intelligent robot. We have not asked him about the state of his own relationships, though his office is only a few doors down the hall. A few of you may even remember when computers were human, and very typically female (Agar 2005).

Science has nothing on the real world in some of these respects. An advertisement in *Time Magazine* (21 March 2005, pp. 44–45) shows 26 outstanding Ford dealers. These include two women, one black, one Asian-American, and 22 white males. Oh well, and while we are at it, Shapiro (2005a), reviewing the *Oxford Dictionary of Science Quotations*, asks why Simone de Beauvoir's remark, "to be a woman, if not a defect, is at least a peculiarity," is relevant to science. Where has he been? In case you had any doubts, gender and social class both matter for (or anyhow are statistically correlated with) Ph.D. receipt and subsequent careers (Bornmann & Enders 2004). The X and Y chromosomes arose from autosomes, and the X has more than its fair share of "disease genes," meaning that common mutations of them are bad for you (Ross et al. 2005).

Want to get your papers published? Well, really, why else would you write them? So, when you are submitting, it pays to make both positive ("X, Y, and Z would be suitable reviewers") and negative ("P, Q, and R might not be entirely fair to

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[21] Chickens??? is the punchline of an old Army joke that the editors would prefer not to print, but which the authors will be happy to share with anyone who provides a plain brown, self-addressed, stamped envelope.

[22] Lest you doubt these matters, let it be confessed that everybody in Mrs. Miller's B3 class was required to grow wheat; VT was the tallest female in her 7th grade class; and something like 1/3 of both groups were Jewish.

this paper") recommendations (Haynes et al. 2005). But even very high skills at this are unlikely to enable you to beat the record held by Ernst Mayr (Diamond 2005, an obituary), for the largest number of books published past age 90. Mayr himself also credited sitzfleisch. But it is worth noting that the astronomical pattern of publication (a flood from thesis and postdoc years; another as tenure decision approaches) is not universal (Upadhye et al. 2004). Indeed middle-aged persons also do neat science (Wray 2004).

Making significant money from popular science writing is harder than it used to be, says Barker (2005). The obvious individual to mention in this context is Carl Sagan, whose nonelection to the US National Academy of Sciences is still being discussed. The new president says (Cicerone 2005) that "there were good people on both sides of the debate." Some of them apparently did nothing, this being the requirement for the bad people to win, and if you remember the quote as "for good men to do nothing," you may well have put your finger on part of the problem.

The only higher honors in science than various Academy memberships are postage stamps (Feynman of the diagrams, Gibbs of the free energy, von Neumann of multiple theorems, and McClintock of jumping genes this year) and Nobel Prizes. Karazija & Momkauskaite (2004) provide some statistics on the physics winners. It pays to be a theorist and also to live a long time. The average age of the laureates and the interval between the critical work and the prize have both increased with time. Given that retirement often means no more research grants, this may not be as dreadful as it sounds. In any case, the records are held by Ernest Ruska (1986, for work done 53 years earlier) and S. Chandrasekhar (1983, for work done 49–53 years earlier). And in case you might have forgotten, TNT was invented by Bernard J. Fluorscheim not Alfred Nobel (*Nature* 436, 477, reproducing an item from the 30 July 1955 issue).

An earlier ApXX noted with envy that armadillos sleep about 19 hours a day, much of it spent dreaming. This year, Roenneberg et al. (2004) have investigated the mid-point of normal sleep cycles as a function of age, casting, it is widely supposed, some dawn's early-light on why high school students find it difficult to get going in time for 8:00 AM classes. The sleepiest author extrapolated the graphs and concluded that her 1:30 AM mid-point is appropriate for age near 102. Given that the constellation called by Hooke "the English rose" consists of stars from $m = 6.3$ to 7.8 (Beech 2004), he must have managed to stay awake through some very dark hours. Twitchiness will help you stay slim (Ravussin 2005), but we recommend that this be confined to daylight hours if you share sleeping accommodations.

Levels of literacy: Farmer & Meadow (2004) opine that the Harrappan script was not a real written language, but only a record of tribal names and such. H. G. Wells was about as literate as folks get, and his version of the future became less dystopian as he aged (*Nature* 436, 785, reprinting an item from the 10 April 1905 issue), quite the opposite of most of our friends and relations. And if you need to fold a newspaper for delivery, Petroski (2005, surely the most literate engineer whom we have never had the pleasure of meeting) is not only an expert but remembers before rubber bands and plastic bags that tell you not to put them over your children's heads.[23] There were many styles, appropriate to different thicknesses of paper. It cannot be quite true that every kid of that generation had a paper route, but these days the normal adult American doesn't even read a paper, let alone have a kid who delivers them.

The World Year of Physics (2005, calendar, not fiscal) will have come to an end by the time you read this. For some of the highlights, see Stachel (2005, and eight following papers) and Bennett (2005 and several surrounding papers). But according to a spring 2005 appeal for donations from AAAS, Einstein doesn't rank at all, and the donor levels are Da Vinci (low) through Copernicus, Galileo, Franklin, Edison, and Director (high). And Director hasn't even appeared on a postage stamp.

The reference to the Hirsch number (for Jorge at UC San Diego) seems to have disappeared. It is a way of ranking one's colleagues and such, a tad difficult to explain, but here goes. Suppose you have written umpteen papers, some very frequently cited, some only rarely. Your Hirsch number is then the largest N for which it can be said that N of your papers have been cited at least N times. Twelve at tenure decision was said to be adequate for some disciplines. Impossible not to be reminded of an Eddingtonian number N', the largest number of days, N', on which you have cycled at least N' miles. We suspect that 120 might be a pretty high number for someone at tenure decision (and unlikely to get much larger in later years). Next to Cambridge, Eddington's home base, is Oxford, whose student-faculty ratio has deteriorated in recent years from $9:5$ to $12:2$ (Collier 2005). This ratio hovers around $20:1$ for most University of California campuses, except UC Merced in spring 2005, where there were already some faculty but no students and, therefore, that most desirable ratio, zero.

This last could count as either a UC item or as "yes, but are they on postage stamps?" item. "The new (2004) Laureates' names will rank right up there with Newton and Coulomb," said UC Santa Barbara Chancellor Henry T. Young (2004). Well, Newton and Coulomb never won Nobel Prizes either, and we think we would probably have picked Maxwell rather than Coulomb to represent electromagnetism.

5.6.5. Friends in the News

Ene Ergma is described as "an astrophysicist who is now the leading politician in the Estonian parliament" (Villems et al. 2004). Not only that; she still comes to astronomical conferences. Angela Merkel, new leading politician in Germany,

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[23] No, the rubber bands do not usually carry text advising you not to put them over your children's heads, but only because there isn't space, and we suspect that the designer of the California raisin label will soon find a solution to that.

holds a Ph.D. in quantum chemistry (*Science* 309, 1471). We don't claim friendship with her, but only with the quantum, upon long ago advice ("just be happy with the quantum," meant ironically) from Richard Feynman, on whose diagrams see the book review by Kane (2005a).

Wayne Rosing, director of Las Cumbres Observatory, has joined the LSST group at UC Davis (Tyson 2005). Michel Mayor and Geoffrey Marcy have shared the million dollar Shaw Prize (*Science* 308, 1739). And Vitaly L. Ginzburg (2004) has invited us all to become familiar with 30 problems that every physicist should know something about, (not, typically, including the solution, since controlled fusion and string theory are among them). He adds that "posthumous recognition is not all that important to me, because I am an atheist." Carlo Rubbia has been removed as head of the Italian agency ENEA (*Science* 309, 542) for reasons other than purely scientific. That same page and the next one record something comparably unfortunate happening to the former chair of the Committee on Science and Technology in the British Parliament and the possibility that another Brit, whose inaccurate testimony put a mother who had lost two babies to SIDS in jail for 3 years, might himself be slightly punished (at the year in jail level, not at the slaughter of the firstborn level, though if we had been on the jury…). Other arguably disproportionate punishment attended the case of gene therapist J. Wilson (Anonymous 2005f), compared to that, say, typically imposed on a driver whose vehicle kills someone while he is supposedly in control of it. Probably the less said about J. Robert Schrieffer (who, unlike a couple of those intermediate people, really is an acquaintance for many of us) the better.

A method due to Sherlock Holmes (who is not cited) is noted by Muscarello & Dak (2004) as valuable. "Many more crimes might be solved if detectives were able to compare the records for cases with all the files on past crimes," they say. And a result claimed long ago by Thomas Gold (also not cited) that "all positive quantities are correlated" has been confirmed for IQ and health, even after correction for socioeconomic status (Deary et al. 2005). Padmanabhan (2005) quotes Raman[24] as having declared that there would be no astrophysics within miles of Bangalore. No, we didn't actually meet Raman, but we do know his son, the astrophysicist of Bangalore.

Money. Now that we have your attention, the states that get the most federal science dollars per capita are Massachusetts and Maryland, with the least going to South Dakota and West Virginia (Anonymous 2005g). Federal dollars per scientist in the various states might be more revealing, but the numbers were not provided. Zebrowitz & Montepare (2005) have found a signature for hard times: the popular actresses have more mature faces than those belonging to more prosperous decades. That more prosperous countries do more science and more science per capita remains a fact of life (e.g., *Nature* 436, 495). But if you look for actresses with more mature faces in poorer countries, we think you will be disappointed. Our own personal sample is limited to Hollywood/Broadway actresses who were fellow graduates of Hollywood High School (Swoosie Kurtz, Linda Evans, Stephanie Powers), all of whom now have mature faces, owing to membership in the class of 1960.

There is already a whole generation of astronomers who were not there when SN 1987A went off (Gaensler 2005), let alone, we suppose, able to remember Jack Benny in *The Horn Blows at Midnight*, the Kennedy assassination, or Pearl Harbor. Remembering the Maine, Plymouth Rock, and the Golden Rule is now reserved for cast members of *The Music Man*.

Astronomers are a bit better than other species of physical scientists about participating in outreach activities (Jensen 2005). There is even an lAU Working Group on the topic. And some other things being accomplished with a little help from our friends: The US now leases icebreakers as well as rocket launches from Russia (Erb 2005). Nepalese (Sherpa) porters really can carry heavier loads than the rest of us, more efficiently (Bastien et al. 2005a). It seems sadly probable that humans are included in the statement "Many animals may spend most of their time at or above the carrying capacity of their ecosystems" (*Science* 309, 609). Are the depressed more likely to walk into door frames, have their computers both fail and fall on their toes, and so forth, or is it that, as Smiley (2005) says, "…proneness to report minor injury can be added to the list of other known signs of emotional distress." We are currently seeking a suitable pseudonym for someone who appears to demonstrate this syndrome in spades. No one was ever tangled in so many traffic jams, airport delays, sexual harassment cases, and assorted violence and mayhem. He appears here as the Medical Musician on a pro tem basis.

Progress comes from dissatisfaction (Nettle 2005, a book review, and G. B. Shaw said from irrational people) but the scales of stellar magnitude used by Ptolemy, Al Sufi, Ulugh Beg, Tycho, and some early telescope builders (Beyer, Flamsteed) were actually quite close to the official semimodern Pogson scale (Fujiwara & Yamaoka 2005). And we rather like the units of time in which the day was divided into 100 ke (Soma et al. 2004). You will have had an extra 0.001 ke for your activities on 31 December 2005, owing to the leap second. We hope you made good use of it.

And a comparable number of items have fallen off the edge of the typewriter, some deserving cheers (to ICTP Trieste for its hospitality to East African Ph.D.'s and to ArXiv for holding the line on who can post[25]), some wows (for neat new information on tracing history of languages and on primates as sprinters and endurance runners), and other expressions of earthly engagement.

WE RETURN YOU TO OUR STUDIOS WHERE THE UNIVERSE IS IN PROGRESS

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[24] Who received his Physics Nobel Prize the same year, 1930, that his nephew began the work on degenerate stars that would result in his 1983 Prize.

[25] Your least posted author hastens to report that she is not in the privileged group.

5.7. The Backgrounds

The 18 CMB papers recorded in academic year 2005 failed to outnumber the 23 pertaining to all the other backgrounds, but have nevertheless been forced into a separate section while we start with the shortest wavelengths.

The gamma ray background can nicely be accounted for as the sum of blazars, once the Milky Way contribution has been removed (Strong et al. 2004). The Milky Way part itself can be modeled with proton and electron spectra much like the local ones, and the γ's derived from π^0 decay, inverse Compton scattering, and bremsstrahlung. Dark matter decay or annihilation also raised its candidential head (Elsässer & Mannheim 2005), requiring the DM particle mass to fall near 515 GeV, not otherwise a popular choice.

The X-ray background is either slightly older than the CMB, if you think of its discovery in 1962, or slightly younger, if you think of it as the sum of emission by active galaxies at moderate redshift. A double handful of papers considered the situation, and we cite only one that expresses content with that model (Civano et al. 2005, because they have finally found a sample of sources harder than the background at 2–8 keV) and one that expresses discontent (Mainieri et al. 2005, though with abiding faith that the missing sources will eventually be resolved, if not in the *Chandra* era, then by some later, greater collecting area).

At 90–265 Å there are only limits to be had, and less than you would expect just from our local bubble of ionized interstellar gas (Hurwitz et al. 2005). Your choice whether these photons should be called soft X-rays or hard UV.

Most of the far UV we see comes from the Milky Way and is quite patchy (Murthy & Sahnow 2004), though obviously there must be an extragalactic sea as well, unless all galaxies are perfectly opaque shortward of, say, 912 Å. No, say Shimasaku et al. (2005) who find that lots of photons get out of galaxies, with the UV background brightest near $z = 3$ and declining on either side.

The less harsh UV is typically called ionizing radiation, and the main disagreement over the past decade or so has been the relative contributions from QSOs and from star-forming galaxies, and how the ratio varies with redshift. Some of each at $z = 2$–4 said Bolton et al. (2005), not quite the conventional answer.

The optical background has been close to $10^8\ L_\odot\ \mathrm{Mpc}^{-3}$ since Oort estimated it *many* years ago. There are two ways to attempt the measurement: add up all the galaxies you can see and divide by the volume they occupy; or get above the atmosphere and attempt to look between the galaxies. Some folks did each during the past year. Driver et al. (2005) added up galaxies and hit very close to the Oort value, at $1.99 \pm 0.17 \times 10^8 h\ L_\odot\ \mathrm{Mpc}^{-3}$ in a band they call b. So did Baldry et al. (2005) using a different galaxy survey and the AB band, but reporting in different units, so that ρ_L is 10^{19} W Hz^{-1} Mpc^{-3}. Minowa et al. (2005) compare the results of the two methods, and conclude that the sum of Subaru galaxies (that is, a third survey) is, at 9.43 nW m^{-2} sr^{-1}, only about half of what they see peeking between galaxies. It is left as an exercise for the student (Not you, Mr. H: back to that thesis) to show that the numbers reported in these three different ways are at least approximately consistent. We gave up somewhere around the time we realized that you can see only the steradians above the horizon. That Oort came reasonably close says, among other things, that, while little galaxies greatly outnumber big ones (§ 4.4), most of the light comes from the big ones.

The 1–20 μm background has a QSO component, though a modest one, say Silva et al. (2004) and Franceschini et al. (2005). Galaxies dominate and include a new class much brighter in the 15 μm *ISO* band than at 2.2 μm (Johansson et al. 2004). The confirmation from looking between the galaxies has proven over the years quite difficult, but Matsumoto et al. (2005) say that they and the *IRTS* (*Infrared Telescope in Space*) have done it, see more IR than they expected from the redshifted UV of Population III stars, and conclude that Pop III star formation ended at $z = 9$ (which acquired a green dot in the process of being redshifted from UV to IR).

5.8. The Microwave Isotropic Relict Thermal Blackbody Cosmic Background

Now about the CMB, or 3 K or relict radiation, depending on our mood. You have the choice of an "all is well" school, e.g., Eisenstein et al. (2005b) on detection of correlation between large scale structure in the 2dF and SDSS galaxy surveys and in the CMB, Barkats et al. (2005) on the $\theta = 4'$ polarization structure seen from Crawford Hill, and Readhead et al. (2004), somewhat similar results from the Cosmic Background Imager, or, if you prefer, a "problems remain" school. Items on that slate include (a) failure to detect gravitational lensing of the radiation by groups and clusters of galaxies (Lieu & Mittaz 2005), though the effect, called magnification dispersion, is seen for distant QSOs, (b) evidence for non-trivial topology from Aurich et al. (2005), and (c) evidence for non-Gaussian distribution of amplitudes (Land & Magueijo 2005b; McEwen et al. 2005).

Here are three items that are meant mostly for fun. First, Amendola & Finelli (2005) note that the spectrum of primordial fluctuations must have included decaying modes as well as growing ones. While these won't have contributed to present large scale structure (§ 5.10), they might still be detectable at less than 10% of their strength when recombination occurred. Second, Perjes et al. (2005) opine that the CMB fluctuations on the sky "underwent reversals approximately 2 Gyr ago," so that we now see a negative image of the last scattering surface. We suspect that, given the very extensive analyses of *COBE* and *WMAP* data and everything in between, that this must be (a) well known to everybody except us, (b) trivial, or (c) not true. And third, yet another source of spectral distortion of the blackbody radiation, is the "gradient-temperature Sunyaev-

Zeldovich," which would measure the electron conductivity of the gas in X-ray clusters (Hattori & Okabe 2005). Incidentally, most of the S-Z distortions that are seen can be tied to clusters already known or, in the case of the zone of avoidance, suspected (Hernandez-Monteagudo et al. 2004).

And, finally, the aspects of the observed 3 K radiation that most of us find at least a little worrisome. First is the north-south symmetry, which has been more fully described, but not understood (Hansen et al. 2004b). This is a fluctuation larger than expected. Second are the fluctuations smaller than expected, the quadrupole and next couple of umppoles. We caught four viewpoints.

- A mere statistical fluctuation say O'Dwyer et al. (2004, arising from our choice of vantage point, well, not a whole lot of choice perhaps available).
- The small $\ell = 2$ and 3 amplitudes are OK, but the correlation of azimuthal planes of $\ell = 2$, 3, and 4 is "uncannny" (Land & Magueijo 2005a).
- Meaningful and a potential source of information about the dark energy equation of state according to Enqvist & Sloth (2004).
- More complicated than you thought say Schwarz et al. (2004), because the quadrupole plane and two of the three octopole planes are perpendicular to the ecliptic and normally aligned with the dipole and with the equinoxes, while the third octopole plane is perpendicular to the supergalactic plane (all at more than 99% confidence). This is all odder than it sounds, for if the solar system is a source or sink of some of the radiation, there should be an annual term in the data beyond the ± 30 km s^{-1} Doppler swing due to our orbit around the Sun, and there is not.

5.9. Large Scale Magnetic Fields

Is the intergalactic magnetic field a background? Well, sort of, we suppose. It is, anyhow, going to get no more attention that it does here, because there doesn't seem to have been much 2005 progress over the previous few years. The situation remains that you can start with fields made in small things (pulsars, quasars, gamma ray bursts, or whatever), push them out, and stir them around. Or you can start with very week seed fields (10^{-19} G is perhaps enough; Takahashi et al. 2005b) on longer length scales and amplify them with spiral galaxy rotation (Schekochihin et al. 2005a), with Balbus-Hawley instabilities (Kitchatinov & Rüdiger 2004, building on an idea from Velikhov 1959, where 10^{-25} G might be enough to start with), or with turbulence from supernovae (Balsarsa et al. 2004). And a mechanism we truly do not understand, even by the standards of the previous ones, by which Siemieniec-Ozieblo (2005) gets primordial field emerging on all length scales simultaneously.

Dynamos have been operating in laboratories for more than a century (starting at Siemens in the 1880s). Schekochihin et al. (2005b) compare more recent ones to the dynamos of planets, galaxies, and clusters in a space defined by magnetic and ordinary Reynolds and Prandtl numbers.

Did you know how far back the observations can be pushed? Yamazaki et al. (2005) report that the mean field on 1 Mpc scales must have been less than 3.9 nG at $z = 1000$, or we would know about it from, yes, the faithful old CMB. At redshifts less than that but larger than zero, the fields are less ordered than they are here and now (Goodlet & Kaiser 2005, a Faraday rotation result). For a review of observations since $z = 1000$ and on many length scales, see Vallee (2004).

5.10. Very (and Not So Very) Large Scale Structure and Streaming

A potentially very stringent test of the consensus ΛCDM cosmology is its ability to match observations of structure on scales from the largest superclusters of galaxies down to the cores of individual galaxies and the satellites around them, when theorists start with the initial conditions of a ΛCDM universe and evolve them forward in time to $z = 0$. Our magenta star paper (the green pen was hiding under the newspaper that day) from the theory side is Springel et al. (2005), reporting the largest ever calculation of this sort. They begin at $z = 127$ with $(2160)^3$ particles in a box that is today 684 Mpc on a side (Gnedin 2005). There is postprocessing to pick up baryon-induced features, and they do, for instance, get enough halos of $10^{13}\ M_\odot$ by $t = 850$ Myr to host the high redshift QSOs being found by SDSS and other surveys, and in place by $z = 5.7$ (Ouchi et al. 2005). An envelope back (well, we used a form letter from the NSF) will show you that the mass per particle must be $1.3 \times 10^9\ M_\odot$, so that the calculation cannot be expected to resolve objects smaller than that. The largest things are sheets, filaments, and cores where the sheets and filaments cross.

The starred observational paper is Miller et al. (2004b) reporting that the biggest structures in the distribution of 2dF QSOs are some 200 h^{-1} comoving Mpc between $z = 0$ and 2.5. Jones et al. (2005a) concur that, while it may get better than this, it doesn't get any bigger. It would be improper to proceed without allowing Ribeiro (2005) his word. His word is "you guys are all wrong," and you are failing to find fractal structure on still larger scales because you have chosen to use the wrong definition of distance in analyzing the observations. Only the luminosity or redshift distance is appropriate, he says, not the comoving distance and not another sort whose source he does not cite. Angular diameter and parallax-type distances are different yet again, and also inappropriate in models more complex than Einstein–de Sitter, where several are degenerate (Mattig 1958). Well, it may be so. A good friend once remarked that the fact you can't get bread to rise doesn't mean there is no yeast effect.

Balancing back the other way, a few more "all is well" papers pertaining to big things, before we start with small ones and come back up. (1) Jena et al. (2005) report that they get a good match to the statistical properties of the Lyα forest (of QSO absorption lines) with the usual universe and plausible values of ionization and heating (e.g., Madau et al. 1999). (2) Weinberg (2005) concludes that all is well with galaxy surveys, the red galaxies being in the cores and the blue ones in filaments. (3) The north/south asymmetry in galaxy distribution is merely a local hole, underdense by about 25% and at the upper end of the normal range of big things (Busswell et al. 2004). Frith et al. (2005) find that we are within that hole and that it could be as large as 430 Mpc ($z = 0.1$), not easy to get out of ΛCDM; and then they partially back off again because the samples don't extend far enough beyond this distance to be sure of the normalization. (4) It is definitely good news that various codes for evolving the early universe down to $z = 0$ more or less agree (O'Shea et al. 2005a; Heitmann et al. 2005).

5.10.1. The Smallest of the Large

The general idea is that standard models predict more small scale structure than is seen. Two manifestations of the problem are called core/cusp (meaning predicted central density profiles of galaxies and clusters are steeper than the observed luminosity distributions) and missing satellites (meaning less substructure in large halos is seen than predicted). The pendulum has swung between "problem" and "OK" several times in previous ApXX's.

This year we will merely report, first, that the data may not be so unambiguous as generally advertised (Metcalf 2005 on substructure from gravitational lensing; Mashchenko et al. 2005 on satellites of the Milky Way as massive and largely dark, our couple of dozen being seriously outnumbered by the 160 belonging to NGC 5044, Faltenbacher & Mathews 2005), and, second, that the models may not be so unambiguous as generally advertised, (1) because of insufficient mass resolution (remember those $1.4 \times 10^9\ M_\odot$ particles in even the most extensive simulation), including an explicit statement from Xiao et al. (2004) about the importance of being resolved for cusps, and (2) because of the enormous complexity in tying the mass patterns calculated to the light patterns observed (Gao et al. 2004).

You will have to decide on your own emotional reaction to the following. For decades there has been a deficiency of satellite galaxies in the planes of disk primaries (Ap00, § 7.2), and it was called the Holmberg effect. Early this year, that distribution was confirmed for the Milky Way's tribe (Kroupa et al. 2005), and there was an explanation in terms of satellites falling in along filaments (Benson 2005). But, about the time Christmas ornaments began appearing in the stores (August), the Holmberg effect was replaced by an anti-Holmberg effect in the data (Brainerd 2005), and there were also, as it were, anti-predictional calculations (Knebe et al. 2004; Zentner 2005) saying that satellites should be found preferentially in the disk plane.

5.10.2. Medium

Are the shapes or angular momenta of individual galaxies typically aligned parallel or perpendicular to the enveloping large scale structure? Yes, say the data (Aryal & Saurer 2005, and a handful of additional index-year papers). And, curiously, both are predicted, or, anyhow, calculated (Bailin & Steinmetz 2005).

The Local Group is our own particular medium sized structure. It should be regarded as consisting of subgroups belonging to the large members (us, Andromeda, and perhaps M33) says Karachentsev (2005). This reflects the way it probably formed, from an off-center collision between proto-M31 and a similar galaxy (Sawa & Fujimoto 2005). Both subgroups continue to grow, not so much in cosmic time as in observing time. The addition of AND VIII and AND IX began § 10.9 of Ap04. And this year we welcome a Milky Way satellite in the direction of Ursa Major, at $M_v = -6.75$ the faintest yet (Willman et al. 2005b). Hardly more than a faint overdensity of stars in SDSS, it probably also has the lowest surface brightness seen to date. A characteristic radius near 250 pc makes this a real, if feeble, galaxy. The same group (Willman et al. 2005a) report also a 23 pc sized, $M_v = -3$ entity about 45 kpc from us that could be described as a very faint dSph galaxy, a diffuse globular cluster, or an intermediate sort of object.

We indexed 40 some other papers about individual members of the Local Group, roughly half concerning M31, which, you must certainly be tired of being told, is rather less like the Milky Way than it was when it (or at least we) were younger (Hurley-Keller et al. 2004 on the planetary nebulae; Fusi Pecci et al. 2005 on globular clusters; Mould et al. 2004 on the history of star formation; Williams & Shafter 2004 on which is larger). This is not what is generally meant by galactic evolution.

The SMC, LMC, NGC 6822, And IX, Sculptor, Fornax, NGC 185, and NGC 147 are all to be left hanging alone around the church door, except the last two which are bound to each other (McConnachie et al. 2005) at least since 1998 (van den Berg 1998), while we elope with M33. Quite remarkably, both its overall proper motion and its rotation have been seen, using VLBA positions of water masers (Brunthaler et al. 2005). Its galactocentric transverse velocity is 190 ± 59 km s^{-1}, and the authors have derived a distance near 730 kpc and a mass for M31 of at least $1.2 \times 10^{12}\ M_\odot$ if M33 is bound to it. We indexed this under "van Maanen revisited," because his (incorrect) reports of spiral rotation in the plane of the sky before 1920 retarded the recognition of the existence of external galaxies for decades. His spirals had leading arms (like leading questions always suspect). M33 today has trailing ones.

If you care to go looking for other tribes like ours, Karachentsev & Kasparova (2005) provide advice that only galaxies bigger than $10^9\ M_\odot$ can have two or more companions and only those more massive than $10^{10}\ M_\odot$ can have more than three. And, being kinder than we, you will not entirely direct your hunt toward trying to disprove this.

Shakhbazian compact groups (Tovmassian et al. 2005) have the same mass to light ratio (37 on average), sparsity of radio sources, and occasional discordant redshifts as Hickson compact groups. The latter consist largely of old galaxies and so must either last a long time or have just formed out of previously existing units (Mendes de Oliveira et al. 2005). The two classes appear to differ primarily in discoverer name. Comparable compact groups exist at slightly larger redshift according to de Carvalho et al. (2005) who, by not citing Shakhbazian, perhaps hope to have the class named for themselves.

5.10.3. A Little Bigger

As a special treat, we shall refrain from telling you the ghastly joke of which the punch line is “The baby is a little Bigger” and confess immediately that this subsection deals cursorily with clusters of galaxies, apart from a topic or two (like cooling flows) which live in § 10.

The least-bound author cherishes a long-standing affection for what are variously called intergalactic or intracluster stars and starlight. Such must actually exist since 10 indexed papers reported properties, and no one claimed not to be able to find the stuff (see “yeast effect” above). It begins to seem probable that there are at least two types. One of these is traced by planetary nebulae, whose distribution in the Virgo cluster is clumpy and associated with large galaxies in both position and velocity space (Arnaboldi et al. 2004; Feldmeier et al. 2004; Aguerri et al. 2005a). The other is bluer, somewhat more diffuse, and associated with infalling galaxies (Willman et al. 2004), disrupted spirals (Adami et al. 2005), and even on-going, in situ star formation in gas filaments in the clusters (Crawford et al. 2005). Clusters as far back in time as $z = 0.25$ already have some intracluster light, find Zibetti et al. (2005) by stacking SDSS images.

A calculation designed to put 20%–40% of light between galaxies also says that those liberated stars should have velocity dispersion about half that of the galaxies in the same location. The calculators (Sommer-Larsen et al. 2005) were not surprised, so probably we shouldn’t be either. Data for stray planetary nebulae in the Coma cluster concur (Gerhard et al. 2005).

5.10.4. That Last S

VLSSS is Very Large Scale Structure and Streaming, and indeed deviations from homogeneous mass distribution are necessarily accompanied by deviations from uniform Hubble expansion, as long as Newton, Einstein, Galileo, or somebody like that was roughly right. Whether the structure or the streaming is dynamically and logically prior, we will let you know as soon as we find out why the egg crossed the road. Meanwhile, the closest thing to a paradox lying around is that the local velocity field is quite cold (small deviations), while the larger scale includes items like the 600 km s^{-1} dipole (Karachentsev et al. 2003) and the Great Attractor (Mieske et al. 2005b).

By analogy with ordinary bias (that is, luminous stuff is more clustered than dark stuff) there is also velocity bias. That is, objects made of baryons can have different velocity distributions from the dark matter particles in the galaxies (etc.) that they share. Which way does this go? Well, we think that Faltenbacher et al. (2005) conclude that galaxies in clusters move faster than the dark matter and Kim et al. (2005) conclude that gas moves slower. Both of these are necessarily calculations, as there are no direct measurements of DM particle velocities. Not only do those two theoretical conclusions sound contradictory, Whiting (2005) reports that, while there are indeed local deviations from Hubble flow, the peculiar velocities don’t actually point toward the light concentrations. That is, either the peculiar velocities are not a response to gravitational tugs of massive lumps, or light doesn’t trace mass, or both.

But at least we have good measures of the sizes of the peculiar velocities, n’est pas? Well, not entirely. Errors in distance determinations can amplify them (Gibbons 2005, on use of the fundamental plane, but the phenomenon would seem to be general). As always, we collected a couple of dozen papers addressing various standard distance indicators, most of them expressing reservations.[26]

5.11. Formation of Galaxies and Clusters

There used to be two models—top down (or monolithic) and bottom up (hierarchical, with mergers). The closest to antimerger statements we found this year were (1) well, all right, but it has been a *long* time since some big, early-type galaxies experienced a major merger and had significant star formation (Fritz et al. 2005), and (2) well, all right, but sometimes the process gets a little out of hand and leaves you with a single overluminous elliptical (Sun et al. 2004, who provide the name “fossil group” for these).

The pro-merger ideas and data are sufficiently numerous that we provide only capsule summaries of three favorite subtopics.

- The host cluster of Cygnus A, with 118 members, 77 new, is really two clusters of Abell richness = 1 in the process of making an Abell 2 (Ledlow et al. 2005).
- The product depends on the mass ratio of the input disk galaxies—up to 3 : 1 you get an elliptical; 4 : 1 to 10 : 1 yields an S0 or something similar; while greater than 10 : 1 merely disturbs the larger disk (Bournaud et al. 2005). Apart from the precise numbers this seems obvious enough not to mention, except that there is a counterclaim that disks can survive even 1 : 1 mergers (Springel & Hernquist 2005), provided that a good deal of gas was there to begin with and can settle back down into a flat layer.

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[26] Expressing reservations should not be confused with making reservations. The two verbs are essentially synonymous only for very special cases like olive oil. In any case, the author who belonged for $28\frac{1}{2}$ years to the ethnic group maligned in the joke for which “reservations” is the punch line wishes to record a strong preference for underrecognized restaurants where they are not necessary.

- All the processes at once can be seen in the gradual change of populations in the calculations of Martin et al. (2005a) and the observations of Conselice et al. (2005).

6. EXOPLANETS: PLEASE, SIR, MAY I HAVE SOME LESS?[27]

Yes, more, more, more remains a major theme (McCarthy et al. 2004a with two doubles; Moutou et al. 2005 with a set providing modest support for the idea that the smallest orbits go with the most metal rich hosts, and many others uncited). But also more discovery and detection methods are beginning to prove themselves. Udalski et al. (2005) reported the second clear microlens case from OGLE. Alonso et al. (2004) found the first non-OGLE transit planet. And there are another 40 OGLE transit candidates (Udalski et al. 2004) to be followed. They only had to look at 230,000 stars to find them, and much of the hard work remains to be done to get confirming (or falsifying) radial velocity data for them all. Pont et al. (2004) say yes for OGLE Tr-111, with $P = 4$ days. This is the first transit planet with a period in the standard "hot Jupiter" range, rather than near 1.5 days. The systems don't actually pile up at $P \approx 1.5$ days but are just passing through, say Pätzold et al. (2004). The transit method is not, incidentally, a good way to find brown dwarfs (Bouchy et al. 2005).

6.1. More Observations

Shkolniket al. (2005) say they have seen the Io effect (activity enhancement) in the form of Ca II H and K emission synchronized to the orbits of two hot Jupiters orbiting υ And and HD 179949. The Rossiter-McLaughlin effect (distortion of line profiles of rotating host stars as planets transit across) has not been seen by Ohta et al. (2005). We mention it partly for the pleasure of being able to cite Rossiter (1924) and McLaughlin (1924) who first thought of it.

Now about "direct detections." Jura (2005) notes that the tail of a Hale-Bopp-ish comet will reflect as much light as an Earth, and Griessmeier et al. (2005) conclude that LOFAR might be able to separate the radio emission due to a Jupiter from that of the parent star (this is already well done within the solar system).

There was, we were told during the year, an honest to gosh image of a planetary companion (Chauvin et al. 2005b). It is called 2M1207b and orbits the brown dwarf 2MASS J1207334−393254 (never mind; it won't come when you call it anyway) in TW Hya. The pressier releases, however, attended the announcements of TrES-l (Charbonneau et al. 2005a) and HD 209458 (Deming et al. 2005). In each case, the authors started with a known transit system, measured its brightness when the planet was off to one side somewhere, measured it again when the planet was in back, and then subtracted the smaller number from the larger one. The difference is then very approximate photometry of the planet in 1–2 colors (so far). In principle this could presumably be pushed to spectroscopy, though variability of the Earth's atmosphere will be a problem. HD 209458b observed this way is larger than you would expect for its mass and equilibrium temperature, as is TrES-l. The problem may be a generic one (Laughlin et al. 2005a) for reasons that are not entirely understood (Laughlin et al. 2005b).

What is "more" buying us? A second M dwarf host (Butler et al. 2004); additional "hot Neptunes" (Marcy et al. 2005), which conceivably descend from hot Jupiters via evaporation (Baraffe et al. 2005); and the first triple star host (Konacki 2005). The system is currently stable, but forming it must have been a bit tricky (Hatzes & Wuchterl 2005). The close stellar pair has had an orbit since Griffin (1977) published it in a series of papers still in progress.

The class "not many more" appeared in a search of (1) the open cluster NGC 7789 (Bramich et al. 2005) and (2) of the globular cluster 47 Tuc (Weldrake et al. 2005), each of which yielded fewer transits than expected if the incidence of planets is like that in the solar neighborhood. On the positive side, each team now has a nice new set of variable stars to study.

The preference of planets for metal-rich stars is familiar enough to rate only one mention this year (Fischer & Valenti 2005). That the hosts have a fairly uniform distribution of ages across 3–12 Gyr is less familiar, but still gets only one citation (Karatas et al. 2005), because that is all we found. As the stars age to red giants, their habitable zones move out and, for solar type stars, the Gyr duration may be long enough for life to evolve (Lopez et al. 2005).[28]

The possibility of living with a red giant was number one on our SETI list. It also includes (1) the search for transits by non-spheroidal objects (Arnold 2005) and (2) a search for at most 1 ns optical laser pulses from 13,000 solar type stars (Howard et al. 2004). The one possible candidate was HIP 107395, and the authors note that we could outshine our Sun by a factor of 10^4 in a sufficiently narrow cone and narrow wavelength band.

Remember ϵ Eridani and τ Ceti? These were the first stars ever asked to produce SETI-type radio signals, almost 50 years ago. They failed, but remain the only G to early K single dwarfs within 5 pc. Both have debris disks, say Greaves et al. (2004). Lynden-Bell & Debenedetti (2005) ask whether there might be life without water. That depends, we feel, on the quality of the

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[27] The alternative title for this section was "Waiting for a phone call from Stockholm," because it is the opinion of the only one of your authors to have danced with a Nobel Prize winner that the discovery of this whole new set of astronomical objects is the single most exciting event of the last 15 years or so and fully prize worthy. The actual phrase comes from the late Howard Laster, whose daughter, living in Sweden, was expecting her first child during that critical October week many years ago. Oh. It was Eugene Wigner, who used to cut a mean Viennese waltz.

[28] Although not of the index year, we do like Stern (2003) with his "Delayed Gratification Habitable Zones" to describe this situation.

wine available. The observation, however, comes from editor Ball (2005) who notes that physicists and astronomers are more likely than biologists and chemists to ask these “what if” questions. We think the genre was probably invented by historians, but note that author Lynden-Bell has lived for many years with a mathematical physicist who often appears in these pages. It’s all right. They are married (and serve very good wine).

“More” also means you are allowed to do statistics. The minimum required is $N = 3$ to define the direction of a linear correlation and the dispersion around it. Working with a somewhat larger sample, Mazeh et al. (2005) deduce that, within the hot Jupiter class, there is an inverse correlation of planet mass with period, and Halbwachs et al. (2005) find that planets and binary companions occupy different zones in a period-eccentricity diagram, even after allowance for migration, circularization, and so forth. They believe this implies different formation mechanisms.

6.2. More Theory

Clever planning has brought us to the end of the observations with a paper that just cries out to proceed from page 16 of the index (exopl date/search/SETI) to p. 17 (exopl calc/dyn). Here live a couple of dozen papers about formation, migration, and orbit stability. The six topics following were chosen for micro-highlighting more or less for their discouraging words.

Beer (2004) says that none of the exosystems formed the same way our endosystem did and none will have Earth mass planets. They use a Box-Cox transformation without citing Gilbert or Sullivan.

There is an ongoing worry about whether protostellar disks last long enough for any planets to form. This is obviously silly; they must, or it wasn’t done that way. Hernandez et al. (2005), Briceño et al. (2005), Calvet et al. (2005), and Carpenter et al. (2005) explore some of each of those possibilities. So you are not allowed to let worry about this problem keep you awake until after you have read all these papers. Afterward you will be too tired to stay awake.

Agnor & Asphaug (2004) report that more than half of planetesimal collisions during a supposed planetary growth process actually break things up rather than accumulating larger masses. This does not, of course, matter in the gravitational instability and hybrid formation scenarios (Boss 2005b; Currie 2005).

As for migration, note, say Cody & Sasselov (2005), that it cannot lead to much planetophagia, because the resulting changes in stellar mass, composition, convection zone depth, temperature, and age do not lead to the patterns seen in real hosts. They trace the idea of accreting stars just a little further back than the paper that often results in the name Bondi accretion to Lyttleton (1936) and Hoyle (1939).

It is comforting to know that, where we see two or three planets around the same star, the orbits are stable for reasonable lengths of time, but less so to realize that this has been achieved by theorists revising the observational data to produce resonances (Gozdziewski et al. 2005 for μ Arae and Ferraz-Mello et al. 2005 for HD 82943b and c). The original data for the latter system appear in Mayor et al. (2004).

Poor lone, lorn planets and brown dwarfs can be left behind when a core that aspired to stardom is photo-eroded by a nearby OB star (Whitworth & Zinnecker 2004). The Hollywood equivalent is not having your option picked up.

6.3. More Disks

In an ideal world, there are two sorts—protoplanetary, before the planets have formed, and debris or exozodi, some combination of leftovers and broken up comets, asteroids, etc., after planets form. In practice, the two phases are likely to overlap, and the words do too. Smith & Bally (2005) attribute a debris disk to IRC 9 in Orion, which will someday be an A V star and which they describe as a young analog to Vega, likely still to have protoplanetary stuff. On the other hand, they provide an ideal introduction to the green dot on this topic, the conclusion (Su et al. 2005b) that the Vega debris disk must itself be transient. Observations with *Spitzer* led Su et al. to a calculation that a production rate of 10^{15} g s^{-1} is needed to maintain the supply of small grains. The alternative to a sporadic event is a truly enormous reservoir of asteroid material, much larger than 3×10^{30} g.

A not quite random selection of other debris disk and exozodi items during the year includes (1) first examples of stars with both planets and 70 μm excess disks (6 of 26 stars examined by Beichman et al. 2005 with *Spitzer*), (1) the pre- to post-transition around the Be star 51 Oph which has a warm inner dust disk and gas (Thi et al. 2005), the only Be star that can make this claim, (3) partial clearing and asymmetry of the β Pic disk, the very first discovered (Telesco 2005; Weinberger 2005), and (4) the relative rarity of collisionally-produced grain disks around main sequence stars (Song et al. 2005 on BD 20°307 which has amorphous and crystalline silicates around it but no PAH). Rieke et al. (2005) conclude that the transition from the lost protoplanetary disk to secondary stuff is largely complete for stars 150 Myr old, and that there is thereafter considerable variety in disk sizes, central holes, and so forth.

7. ASTROBIOLOGY[29]

It has taken us 15 editions of ApXX to recognize that a comparatively new discipline has joined our traditional two of astronomy and astrophysics, and it is one deserving its own section. You may perhaps excuse our tardiness by noting that

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[29] The Gold Star for this section is awarded to United States District Judge John E. Jones III for his decision in favor of the plaintiffs in the Dover, Pennsylvania, case concerning the teaching of “intelligent design” vs. Real Science. Every budding scientist (and lawyer) should consult Jones for his opinion (http://www.pamd.uscourts.gov/opinions/jones/04v2688d.pdf).

astrobiology draws on such seemingly disparate fields as chemistry (organic and inorganic), geology (terrestrial and other solar system bodies, if we play fast and loose with meaning of "geo"), biology (molecular, traditional, evolutionary, etc.), or what about *Organic Geochemistry* (as a subject and the name of a journal), biogeochemistry, and just about any subdiscipline in astronomy and astrophysics you care to name. One section in Ap05 is barely an introduction to the subject and we shall concentrate on but two related topics that were chosen by the junior, but oldest, author (who was on his way to becoming a dipterologist in his youth but found he couldn't remember or pronounce the Latinate names). Even these two, however, call on a number of journals (and books) not often referenced in, for example, *PASP*, *AJ*, *ApJ*, or *MNRAS*. One of these is *Astrobiology*, the namesake journal for the field, which is a mere child whose first issue appeared in March 2001. (Compare this to *AJ* "Founded in 1849 by B. A. Gould.") Going through one issue of *Astrobiology* we counted references to 39 different journals, not all of which did we peruse for relevant papers. Perhaps this is why we waited so long for a try at the subject. In any case, since this is our first shot for a full section in this field, we shall often call upon papers from outside the index year.

For a recent review in the usual astrophysical literature, see Chyba & Hand (2005). Another useful resource is the 2005 National Research Council study *The Astrophysical Context of Life*, which may be downloaded (free!) from http://www.nap.edu/catalog/11316.html. It is a critical study, with recommendations, of the status of the field. Also check out NASA's Astrobiology Institute website (http://nai.arc.nasa.gov).

And now, first things first.

7.1. Life Is Where You Find It, Or Not

What is life? Sure we know the answer: "I can't define it but I know it when I see it."—quoting a Supreme Court Judge's opinion on an entirely different subject. But, sorry, Your Honor, life is not that simple, so to speak. How can we define it so that we can recognize it when we do see it, or think we detect it—and not just on Earth? Conrad & Nealson (2001), who happen to be the authors of the first research paper published in *Astrobiology*, put it this way: "Elimination of Earthcentric biases from life detection strategies thus increases the probability that we will not only know life when we see it, but have the statistical acumen to prove that we have seen it, as well."

Schulze-Makuch & Irwin (2004) list three "fundamental characteristics" that they deem necessary to distinguish life from non-life (and see Irwin & Schulze-Makuch 2001). Whether these make up a "definition" rather than a "checkout" list is a matter we shall not go into. You might wish, however, to read the long discussion by Ruiz-Mirazo et al. (2004) on how a proper definition should be posed and what issues it should address. Cleland & Chyba (2002) go further and argue that we must understand life at a deeper level before we make up definitions; e.g., in defining "water" without knowing what H_2O is on the molecular level we may be spinning our water wheels. Worse yet, we may even miss recognizing strange microbial life on Earth that doesn't fit our preconceived notions—as discussed by Cleland & Copley (2005) and Davies & Lineweaver (2005).

The first characteristic for life from Schulze-Makuch & Irwin is that it be "composed of bounded microenvironments in thermodynamic disequilibrium with their external environment." Since, it is supposed, the external environment consists, at least partially, of a solvent that can contain accessible nutrients, the "bounded" makes sense. Otherwise, the organism soon becomes indistinguishable from its external environment because of diffusion driven by gradients. "Disequilibrium" is better than "in thermodynamic equilibrium" because the latter is a fancy way of saying that you and your environs are one; i.e., you're dead.

The second characteristic is that life is "capable of transforming energy and the environment to maintain a low entropy state." This defines the interaction of what is in, or on the surface of, the bounded microenvironment with its surroundings. With no interaction the parcel of life would, by the second law of thermodynamics, "move spontaneously toward a state of maximum entropy," thus leading to an adverse result as in the above.

Finally, life is "capable of information coding and transmission." Were this not so then the "organism"—and we might just as well use that term—would be incapable of passing on information that could be used to create a duplicate or near-duplicate of itself.[30] Non-duplication seems like a dead end, although this may be overly picky. Note that lateral gene transmission may (and does) occur between different organisms without replication or reproduction.

How does what we find on Earth conform to the above conditions? Leaving aside viruses, which appear to be a special (and probably degenerate) case, Earth teems with microorganisms. The simplest organisms are the prokaryotes. Each consists of a membrane—with often an outer protective cell wall—that surrounds the cellular cytoplasm and its contents. Inside resides a (usually circular) free floating chromosome containing the cells genetic DNA. (Extrachromosomal DNA may be present in plasmids, which have various functions.) Ribosomal inclusions in the cytoplasm are involved in protein synthesis. The prokaryotes are subdivided into the Bacteria and the Archaea based on distinct differences in DNA and cell wall composition and structure. (See the pioneering efforts of Woese 1987.) All the rest of terrestrial life are eukaryotes, which have a distinct nucleus containing most of the genetic material, energy mod-

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[30] "Organism" need not imply "organic" in the chemical sense. Some argue that silicon could form the basis for life instead, although not as efficiently. See, for example, § 5.3 of Schulze-Makuch & Irwin (2004).

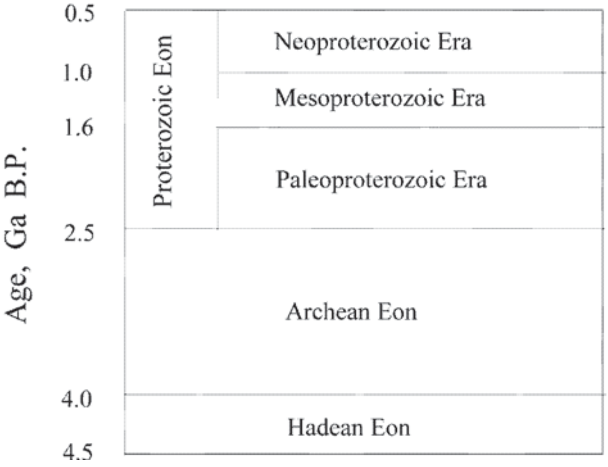

FIG. 1.—The eons and eras of Earth's distant past from 0.5 to 4.5 Ga as measured before the present (B.P.). Adapted from Knoll (2003).

ules (mitochondria and, in plants, chloroplasts), and other material.[31] Since eukaryotes are most likely chimera composed of prokaryotes who decided to combine forces in the distant past, this year's review will let them be. (See, e.g., Margulis 1992, 1999; and for a discussion of many of the topics gone into here we recommend the splendid book by Knoll 2003.) In any case, terrestrial life fits the above definition of life—which is no surprise.

Modern prokaryotes are doing very nicely. D'Hondt et al. (2004) estimate that the Earth contains 4–6 × 10^{30} cells (finally an astronomical number!), mostly in open ocean, soil, and in deeper oceanic and terrestrial subsurfaces. (See also the oft-cited paper by Whitman et al. 1998.) They used samples from the Oceanic Drilling Program retrieved from depths down to 420 m from Pacific Ocean sites. Typical cell concentrations were 10^6 cells cm^{-3}. Schippers et al. (2005) and Teske (2005) have verified that such samples contain live bacteria and archaea (rather than just inactive or dormant cells), with the latter perhaps being more abundant. In any case, prokaryotes seem able to survive trying conditions, to say nothing of hyperthermophiles who enjoy basking in the hot springs of Yellowstone or around midocean ridge vents.

How small are the smallest terrestrial prokaryotes? Prompted in part by possible organic remains in Martian meteorites, but also for identification of terrestrial life dating back perhaps nearly four billion years, the National Academy of Sciences organized a workshop to address this very question (National Academy of Science 1999). The consensus of the participants was that modern—give or take a billion years or so—terrestrial cells have a lower size limit of 250 ± 50 nm. There are exceptions, and possible exceptions, to this limit. Huber et al. (2002) report a novel (perhaps representing a new phylum) member of the Archaea plying its trade in a hot submarine vent off Iceland. It tops out at 150 nm. It appears to be, however, a symbiont that attaches itself to an archaean host. Further down the scale, Kajander et al. (on page 50 of the NAS report) find organisms ("nanobacteria") of size between typical viruses and bacteria in animal serum that can be cultured in suitable media. Whether these organisms are really self-sufficient was a matter of contention. For now we shall stick with the consensus view. This is not to say, however, that life operating under a different set of molecular rules could not be smaller and still function. Note that there are also some Sumo wrestler sized bacteria. *Thiomargarita namibiensis*, a colorless sulfur bacterium, has a diameter of 750,000 nm. As Schulz & Jørgensen (2001) point out, this means that the range of prokaryote volumes exceed 10^6 (about ten times more than the span between mouse and elephant).

7.2. Life in the Old Country

If we are to detect and identify life on Mars, for example, we should ask how it is done for the very early Earth when life was in its infancy. The earliest identifiable microfossils of good pedigree appear to be those in cherts from the Transvaal Supergroup (South Africa) and date from about 2.6 Ga B.P. (See, e.g., Altermann & Schopf 1995. We use Ga, Gyr, and Gya interchangeably, as all appear in the literature.) They are in the form of rods, spheroids, and filaments that bear close resemblance in shape and size to well-attested prokaryotic microfossils found in later geological formations—although, to our untutored eyes, they could be anything. They were part of an assemblage that formed components of a community that formed stromatolitic reefs in an ancient sea. (Stromatolites are domed, candelabra, and wavy-laminated shapes that are common in some fossil beds, although they may be distorted by later geological processes. You can still find them in select places, such as coastal Bermuda and Western Australia. See Knoll 2003 for a good selection of photographs.) This gets us back to the very early Proterozoic or late Archean eons. (For a snapshot of where we are in Earth's history, see Fig. 1.) How much further back can we go? And here is where things get murky—and controversial.

On an optimistic note Chyba & Hand (2005) opine "It is broadly agreed that robust and abundant fossil evidence is present in ≈3 Gya rocks, and that substantially controversial isotopic evidence exists in 3.8 Gya rocks." This puts us smack dab in the Archean.

One promising example (not mentioned by Chyba & Hand) is Rasmussen (2000) who reports on the "probable fossil remains of thread-like organisms" in 3.235 Ga Australian rocks of deep sea origin formed in a hydrothermal setting. The threads

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[31] There are some exceptions to this statement. *Giardia lamblia*, an intestinal parasite that can infect campers drinking water from pristine looking streams, has neither chloroplasts nor mitochondria. Its, and its cousins', place in evolutionary biology is problematic.

are 550 to 2000 nm in diameter and up to 300 μm long, and are of uniform thickness. If they are the remains of living organisms, then thermophilic prokaryotes are the likely suspects. (Fossil remains from deep-sea hydrothermal systems formed prior to the Cambrian [i.e., prior to ~600 Ma B.P.] are more then rare. Rasmussen claims his are the first found.) It seems that no further work has been done on these deposits, but Brasier et al. (2005, and see below) suggest they are "promising and worthy of re-examination."

Schopf, et al. (2002, and see the many earlier references therein) discuss putative microfossils from the Apex chert, Chinaman Creek, of the Warrawoona Group in Western Australia.[32] They are 3.5 Ga old and resemble modern (and ancient) cyanobacteria (also known as "blue-green algae," but are not always of that color and they are prokaryotes, not eukaryotes). Most modern cyanobacteria make their living through photosynthesis and, in the past, must have played a crucial role in the oxygenation of Earth's atmosphere (see Knoll 2003, Chap. 6, and his color Plate 2; and the review of Canfield 2005). The possible microfossils look, to our eyes, so very much like later accepted cyanobacteria fossils that we smile in appreciation. However—

The most complete discussion we found of the c. 3.5 Ga Apex cherts is Brasier et al. (2005). They combine a detailed study of the geology of the Warrawoona Group with a suite of microscopic studies of the chert (including optical and electron microscopy, digital image analysis, etc., and they include many informative figures).[33] Their conclusion is that the Apex microfossils are "pseudofossils" that resulted from the incorporation of carbon-rich material into recrystallizing silica. The debate continues.

What other kinds of evidence point to biological activity in ancient rocks? Terrestrial organic organisms must deal with carbon as a vital part of being "organic." Isotope-wise, however, they seem to show a preference. Samples of biotic material show an underabundance of ^{13}C compared to the more common isotope ^{12}C (more common terrestrially by about 100 to 1). It's not that our life "likes" the lighter isotopes better but rather the slightly lighter, and thus faster atoms (or carbon containing molecules) collide more frequently with their targets. Hence the small statistical preference for the lighter atoms in the reaction product is the result of reaction kinetics. The process is referred to as "fractionation." (See, e.g., Hayes 2004 for a complete, though difficult for us, discussion.) The underabundance of the heavier isotope compared to the lighter (and this is not restricted to carbon) is expressed as the difference of the ratio ^{13}C/^{12}C in a biological sample compared to that in an accepted laboratory standard. The difference is denoted by δ^{13}C in parts per thousand (‰); that is

$$\delta^{13}\mathrm{C} = 1000\left[\frac{(^{13}\mathrm{C}/^{12}\mathrm{C})_{\mathrm{sample}}}{(^{13}\mathrm{C}/^{12}\mathrm{C})_{\mathrm{standard}}} - 1\right].$$

Typical values for biotic remains are –20‰ to –30‰.

Brasier et al. (2002) report fractionations in the Apex cherts of –30‰ to –26‰, entirely consistent with a biological origin. But they then point out that such fractionations may be produced abiotically by Fisher-Tropsch synthesis and have nothing to do with biology.[34] To test whether abiotic fractionation can take place in hydrothermal geological environments, McCollom & Seewald (2006) performed some neat laboratory experiments and found, alas, that fractionations typical (or exceeding) those associated with biology can indeed be produced. A general review is due to Holm & Andersson (2005).

This leaves us in a quandary. As amateurs, the evidence, for or against, the presence of life in the deep Archean seems to be up for grabs. Sniffing between the statements in many papers, however, we get the distinct impression that most investigators in the business do believe that life started well before rock solid (so to speak) positive evidence makes its appearance in the geological record. How else then to explain the presence of prokaryotes in the very early proterozoic or late archean? Those little bugs were, and are, complicated creatures.

It is now a little over 50 years since Miller (1953) demonstrated that organic compounds, including amino acids, can be made by zapping, spark-wise, a glass container filled with methane, ammonia, hydrogen, and water vapor. (See Lazcano & Bada 2003, for a brief history of the experiment.) A true it-can-be-done experiment, and there have been more done like it since. As usual, however, questions remain about the state of the Earth's ancient atmosphere, and other sites may have been where life originated, such as hydrothermal vents, as just one example.

One, among many, fundamental question yet to be answered is why certain biological molecules are essentially either all left(L-)-handed (amino acids in proteins) or right(R-)-handed (sugars in RNA and DNA). This is the "homochirality problem." To force homochirality requires either a left- or right-hand bias in radiation influencing the chemistry, for example, or an initial bias in handedness as life chemistry starts its thing. Jorissen & Cerf (2002) review several mechanisms by which this might be accomplished. Examples are circularly polarized solar UV, or unpolarized UV acting in concert with a magnetic field (e.g., the Earth's) that is not perpendicular to the light beam. Both seem marginal, but possible. That Earth in its early history could have acquired homochiralic material from outside

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[32] Compared to this, astronomers sorely lack romantic names for their objects. Consider a new IAU Commission XXX, *Astronomical Nomenclature, With Panache*.

[33] Their description of the geology of this ancient land, while not poetry, almost lets you hear and smell that part of Australia as it was assembled. For more information on the geology of the region see the website for the Geological Survey of Western Australia (http://www.doir.wa.gov.au/GSWA).

[34] The Fisher-Tropsch process(es) was designed to produce liquid hydrocarbons and was used extensively by coal-rich, but oil-poor, Germany in WWII for synthetic oil production.

remains a possibility. Among suggestions of how such material could have acquired a L- or R-hand bias in space we have, for example, Lucas et al. (2005b) who invoke circularly polarized UV in star formation regions.

7.3. Life in the Really Old Country

We have had little to say about the origin of terrestrial life but if we think it was around in the middle-aged Archean, then might it have started in the earliest Archean or in the Hadean (from "Hades" itself)?[35] The Hadean eon is well-named because early on the evidence is for intense meteoritic bombardment. When, how intense, and of what duration is a matter of controversy. Looking at exposed terrestrial rocks is tricky because we lack a continuous record prior to some 3.7 Ga B.P., which is just a little after the Hadean (see Fig. 1). Our nearby Moon may serve as a surrogate as its geology settled down long before Earth's. Hartmann (2003) argues that the rate of lunar impacts has decreased exponentially and rather smoothly with time from 4.0 Ga (and perhaps back to 4.2 Ga). As an example (using his eq. [1]) we find that for each km^2 of lunar surface there was roughly a one in ten chance that a crater of diameter greater than 1 km would have been formed by an impact in the interval 4.0–4.2 Ga. Not a healthy environment.

Another model for lunar bombardment is the "Late Lunar Cataclysm" or "Late Heavy Bombardment" (LHB), which may have taken place around 3.9 ± 0.1 Ga B.P. The evidence for this, as an event involving a goodly part of the solar system, include: dating of the Martian meteorite ALH84001 (of which more later; see Turner et al. 1997); dating of lunar melt samples showing a lack of ages older than 3.9 Ga, although earlier lunar impacts may have been covered (Cohen et al. 2000); and some evidence preserved in Hadean zircons (which will appear again later; see Trail et al. 2006). This model turns the exponential drop-off of the above on its head with relatively few impact events prior to ∼3.9 Ga (excluding the early assimilation of solar system bodies) and then all Hell breaks loose in the late Hadean or early Archean. One suggested cause of the LHB is a major reshuffling of the positions of the gas planets after the dissipation of the solar nebula. Gomes et al. (2005a, and see the related papers Tsiganis et al. 2005 and Brunini 2006) performed numerical simulations of planetary and planetesimal disk interactions (and orbits) starting from what they consider to be a reasonable initial configuration. They find that after some 0.7 Ga the orbital periods of Jupiter and Saturn came into a 1 : 2 resonance ($P_S/P_J = 2$) and their orbits became eccentric. The result was a dance involving Saturn, Uranus, and Neptune that destabilized the planetesimal disk (and the asteroid belt) thus delivering a flood of material into the inner solar system. Hence the LHB at about the right time.

And now the possible good news. Zircons are remarkably tough crystals and can survive even after their parent rocks have been eroded or broken up. Wilde et al. (2001), and its companion paper Mojzsis et al. (2001), report examination of zircons from Western Australia that have ages ranging back to 4.4 Ga B.P. (from U-Pb-Th dating). An updated examination with more detail is discussed in Cavosie et al. (2005, and see the popular version in Valley 2005). Harrison et al. (2005) trace the crust to perhaps 4.5 Ga, or a little before, as in Watson & Harrison (2005) (from Hf isotopic ratios) although most, or all, of it was rapidly recycled back into the mantle. The better news from them is that the evidence suggests that supracrustal rocks were around as long ago as 4.2 Ga and liquid water oceans lapped (if that's the appropriate word) their shores. ("Cool" water is implied by the ratios of ^{18}O to ^{16}O in the zircons.)

Considering all the above, a mental picture of the ancient Earth still escapes us, as does the beginning of life. Perhaps we should go along with Knoll (2003) who concludes that "Origin-of-life research resembles a maze with many entries, and we simply haven't traveled far enough down most routes to know which ones end in blind alleys."

7.4. An Extraterrestrial Visitor to Antarctica[36]

Observational astronomers don't necessarily have it easy in Antarctica but they don't have to rise out of sleeping bags to begin their daily trek across rock, snow, and ice looking for meteorites during the two months or so when the climate is bearable. A prime location are the Allan Hills off the Ross Sea about 150 miles from McMurdo Station (a convenient distance for a helicopter). The hills are mostly free of ice but there are several fields where meteorites stand out. A description of one of the fields and its finds may be found at the website for the *Antarctic Meteorite Location and Mapping Project*.[37]

On 27 December 1984 a 4.2 kg, 15 × 10 × 8 cm, meteorite was found at Allan Hills and now has the designation ALH84001 (ALH for the hills). It is of a class called "shergottites" named after a similar one found at Shergotty, India, in 1865.[38] Of the some 30,000 known meteorites that have been found on the Earth, ALH84001 and Shergotty are only among 16 that are known to have arrived from Mars. (That number seems to fluctuate over the years in the literature.) How do we know their origin? The most convincing evidence we have seen is summarized in Figure 5 of McSween (1994, and see Bogard & Johnson 1983) adapted from the review article by Pepin (1991). It shows the correlation between ground level concentrations of gases (CO_2, N_2, ^{40}Ar, ^{36}Ar, ^{20}Ne, ^{84}Kr, and ^{132}Xe) in the Martian atmosphere sampled from *Viking* landers and gases trapped in glass inclusions in the shergottite EET79001. Would

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[35] Earth may have been seeded with life from the outside, as in "panspermia," but we won't touch that one.

[36] We recommend the long review chapter by Jakosky et al. (2006) for much more information about Mars than we go into.

[37] See http://geology.geol.cwru.edu/∼amlamp/ALH-DAV (J. Schutt 2006).

[38] This class is often referred to as the SNC class from the names of the type specimens Shergotty, Nakhla, and Chassigny.

that every scientist be blessed at some time with such a straight line with small error bars.

There are several classes of shergottites, and ALH84001 is an orthopyroxenite—and now you know. Bridges & Warren (2006), in reviewing the properties of the shergottites, report that ALH84001 is 97% orthopyroxene, which is the commonest silicate in meteorites and is the major constituent of most chondrites. ALH84001 was not recognized as a shergottite until nearly 10 years after its discovery when Mittlefehldt (1994) took a good look at it. He found that in amongst the dominant orthopyroxene were carbonate inclusions (as interstitial grains) of about 100–300 μm size. He suggests that these inclusions were formed by "multiple infusions of fluid." The material was then subject to shock, after which much smaller ($\sim$10 μm) carbonates were deposited in fractures. Borg et al. (1999), using Rb-Sr and Pb-Pb dating, conclude that the carbonate inclusions (or "globules" or "flattened pancakes") were formed at 3.9–4.0 Ga B.P., an age when Mars was subject to heavy bombardment (Neukum & Wise 1976, and shades of LHB). It may be, however, that water did infiltrate ALH84001 at a time near enough to confuse the issue (of which, more later). The initial crystallization age of ALH84001, from Sm-Nd and Rb-Sr analysis, is given by Nyquist et al. (1995) as 4.5 ± 0.13 Ga, which makes it the oldest of the known shergottites.[39] Measurements of the radiometric exposure age indicate that it was ejected from the Martian surface by an impact a mere 15 ± 0.8 Ma ago according to Nyquist et al. (2001).[40]

Inside the carbonate globules, and especially concentrated around their rims, are small magnetite crystals (McKay et al. 1996) some 5–100 nm in size. A subgroup of these are identical (or nearly so) to those made by a terrestrial magnetotactic bacterium called MV-1 (Thomas-Keptra et al. 2001). The crystals are not terrestrial contaminants picked up by ALH84001 while it sat in Antarctica for 13,000 years before being picked up.

Also present are traces of organic compounds such as polycyclic aromatic hydrocarbons (PAHs).[41] Some of these appear to have been produced by terrestrial bacteria, but not all—especially in the carbonate globules.

7.5. The Leap to Life

McKay et al. (1996), in a paper that has generated a great deal of healthy controversy and study, proposed that ALH84001 contains the remains of Martian life forms, albeit on the nanometer scale. As a result, no Earth-born rock has received as much attention as has ALH84001. McKay et al. took the above (of § 7.4) into account but also pointed to ovoid particles of size 10–100 nm in the carbonate globules plus rod-like structures a mere 100 nm long. If they are biotic, then they qualify as some sort of nanofossils by the standards of § 7.1.

Herein lies the first difficulty. The argument that independent terrestrial life has a lower size limit of 250 ± 50 nm means that if the Martian nanofossils are biotic, then they must have functioned in a mode different from what we are accustomed to.[42] There is nothing intrinsically wrong with this idea but, at present, it isn't testable. Of course the ALH84001 ovoids and rods may be the desiccated shrunken remains of what were originally more robust organisms. But we don't know.

The magnetite crystals as biomarkers fair no better. Golden et al. (2004) conclude that—(1) the ALH84001 crystals do not have the same structure as those made by the bacterium MV-1 and, (2) the crystals could just as well have been produced abiotically by hydrothermal processes early on in the life of the meteorite.

The presence of organic molecules such as PAHs has somewhat the same problem. Zolotov & Shock (2000) calculate (but no with experiments) that these could have been synthesized by a combination of the cooling of magmatic and impact generated gases. And, talking of impacts, Treiman (1998) says there were four to five impact events in the life of ALH84001 spanning roughly 3 Ga (his Table 1) with question marks as to the timing of some of them. So when were the nanofossils formed? We don't know.

Direct evidence for biotic markers in ALH84001 seem ambiguous at present. However, the good news is that early Mars was both wetter and warmer than it is now (or in the comparatively recent past). Opportunity, in its travels, has come up with evidence for deposits that seem to demand water at some time, to say nothing of the channels seen from orbiters. The story is too long to tell here—and there are some detractors—and we thus suggest Bullock (2005) and Christensen (2005) for more popular reviews, Jakosky & Mellon (2004), Jakosky et al. (2005), and Bibring et al. (2006) for more of the hard science.

But hope springs eternal, as it should. For example, Gibson et al. (2001) discuss the much younger shergottites Nakhla and Shergotty and conclude they have the same (perhaps) biotic virtues at ALH84001. Stay tuned, as they say.

8. BETWEEN AND BEFORE THE STARS

It is always a little difficult to decide the precise particle density at which interstellar material becomes star formation,

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[39] Our eyebrows lifted when we read this. We are back to the earliest solar system days!

[40] This long review paper is a great resource with many clear figures. On reading it, you will find out that some shergottites crystallized only $\sim$180 Ma ago (during our Jurassic period) implying that magmatic activity on Mars is probably an ongoing affair. EET79001, discussed earlier, was ejected about 0.7 Ma ago—nearly yesterday. For a neat website giving updated geological period designations, with colorful charts, go to http://www.stratigraphy.org, maintained by the International Commission on Stratigraphy.

[41] PAHs are molecules of linked benzene rings. They are nothing new under the stars as Yan et al. (2005) have detected them in dusty ultraluminous IR galaxies at $z \sim 2$ using *Spitzer*.

[42] We leave the serum nanobacteria out of this because they are probably not independent.

and so, not wanting to have to say that § 8 differs from § 9 only in Section Number, we have run them together here.

8.1. Interstellar Gas Compositions

Just which molecules occur diffusely in space? Glycine, no (Snyder et al. 2005, and the main problem remains uncertainty as to which wavelengths to look for, though earlier ApXX's have trumpeted its discovery more than once). The first ketone, yes (Widicus Weaver & Blake 2005). It is $CO(CH_2OH)_2$ the simplest ketose monosaccharide. They believe it is part of a pattern of formation of "prebiotic" compounds in hot prestellar cores. And yes for CH_3CCD in the Taurus Molecular Cloud (Markwick et al. 2005). The least musical author had green-starred this in hopes of being able to report it as MethylMusic,[43] but suspects it must somehow belong to the propyl family.

Molecular oxygen remains elusive, according to Wilson et al. (2005a), who examined the Small Magellanic Cloud with the Swedish satellite *Odin*. And all is not PAH that smells, though it is likely to have multiple carbon bonds (Ruiterkamp et al. 2005 on the diffuse interstellar bands).

Only senior molecules will remember when HCO^+ was called X-ogen, but it remains true that negative molecular ions are much less common than positive ones (Morisawa et al. 2005). Well, it is generally said to be more blessed to give than to receive (Take my Chancellor, Please!). Indeed all of H_3^+, H_2D^+, and HD_2^+ are wandering around out there (Flower et al. 2004). No news yet of D_3^+, but the authors report predictions for ortha/para/meta state ratios just in case. Also calculated and expected to exist are HeH^+ and $^3He^2H^+$ (Engel et al. 2005), the latter of which at least must be rather rare.

Deuterium is, obviously, much overrepresented in ISM molecules compared to atomic abundance, which sloshes around $1\text{–}2.5 \times 10^{-5} = D/H$, reduced from the big bang production number of 2.5 by both astration (nuclear processing in stars) and depletion onto molecules and grains (Williger et al. 2005). The umpteenth first detection of the 92 cm spin-flip transition of neutral deuterium came from Rogers et al. (2005), looking toward the galactic anticenter with a purpose-built array at Haystack and finding emission at the 6 σ confidence level. They plan to look for absorption toward the galactic center soon.

Additional new molecules of the year include HC_4N in IRC +10 216 (Cernicharo et al. 2004). This is only the second such molecule with an even number of carbons in the middle (the first was HC_2N, not surprisingly), while odd ones, up to and beyond 7 Cs in the middle are known, the H and N representing the continents.

The familiar formic and acetic acids, methyl formate, methyl and ethyl cyanide, and methanol were traced out in a high mass star formation region by Remijan et al. (2004). Might one possibly ever find purines and pyramidines? Peeters et al. (2005) say they would last only hours in a solar nebula at 1 AU, 10–100 years in the diffuse ISM, but the cloud lifetimes in dense clouds. This is, you may notice, a good, firm, positive maybe.

Comito et al. (2005) report so many molecules in a single paper (929 transitions of 26 identified species plus some unclaimed features) that one would almost suppose the authors had to pay their own page charges personally, like the least grant-worthy of your ApXX authors.

8.2. Interstellar Dust

The oldest and most stable fact about galactic dust is that it absorbs about one magnitude per kiloparsec in the plane (Trumpler 1930; Amores & Lepine 2005). Establishing chemical and structural properties and how these vary within and among galaxies has taken a little longer. Here are a few one-word descriptions—

- Alphatic, meaning carbon chains as well as the rings of PAHs (Mason et al. 2004), and rather similar in the Milky Way, ultraluminous infrared galaxies, and Seyferts.
- Fluffy (Cambresy et al. 2005), meaning that it emits better than it absorbs, they say, leaving us in hopes that this doesn't violate one of Kirchhoff's laws or even one of the laws of thermodynamics.
- Hollow (Min et al. 2005), an idealized calculation.
- Frozen, a new component of hydrocarbons, reported by Simonia (2004) and seen via photoluminescence.
- Grayer, around ultracompact H II regions (Moore 2005) with implications for grain sizes more complex than we expected.
- Heated, in mergers, with details requiring the power of ALMA and the *Spitzer Space Telescope* (Xilouris et al. 2004).
- Grayer also around active galaxies and QSOs (Gaskell et al. 2004), but denied by Willott (2005).
- Deficient in metal-poor galaxies (Galliano et al. 2005) and in damped Lyα clouds (Junkkarinen et al. 2004).
- Chemisorbed to account for the 2175 Å feature (Fraser et al. 2005a).
- Multi-componented in both the Milky Way (Rawlings et al. 2005) and other spirals (Stevens et al. 2005).
- Dangerous, in supernova remnants, owing to the presence of iron needles (Gomez et al. 2005, concerning the Kepler remnant). Well, haven't you been warned not to stick your hand casually into public wastebaskets, lest you encounter unshielded, unclean needles?

8.3. Gas Phases and Their Motions

Would you like it hot or cold first? Well, some like it hot, which means the coronal phase now probed with Ne IX, O VII, O VIII, and such (Yao & Wang 2005). The idea that there should be such a phase, made up of partially overlapping supernova remnants, belongs to Spitzer (1956, the person not the space mission, though we would be the last to deny him the right to

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[43] The Medical Musician declined to be drawn on this one. Even our friends have some taste!

appear in italics). Other galaxies also have some (Doane et al. 2004). The filling factor is more than 10%, but how much more remains unclear.

Our very own local superbubble consists largely of this hot, ionized, tenuous stuff, though with neutral clouds embedded (Welsh & Lallement 2005; Oegerle et al. 2005; Witte 2004; Vallerga et al. 2004). Welsh & Lallemant add that they have seen, for the first time, the 10^5 K interfaces between the clouds and the 10^6 K bubble medium and at the bubble surface. Redfield & Linsky (2004) reported that the local ISM is subsonically turbulent with mean velocity 2.24 km s^{-1}.

Voyager 1 may actually reach this medium in another 10–20 years. Meanwhile, 95 AU out in December 2004, it crossed The Terminator (shock) where supersonic solar wind gives way to subsonic solar wind (Stone et al. 2005 and the next three papers). You will live to see the final crossing; we will live to see it; Ed Stone et al. will live to see it; *Voyager 1* we are not so sure about.

Less hot ionized gas is called H II (except by a few territorial members of the Division of Plasma Physics who think it should all be called plasma, along with stellar interiors, QSO emission line gas, and so forth). The ionized phases were responsible for most of the very fine scale structure recognized in the ISM (Lehner & Howk 2004 on O VI), because the recognition normally comes from variations in electron density along the line of sight to pulsars (Hill et al. 2005; Zhou et al. 2005, for instance). But it now seems fair to say that the neutral hydrogen is at least as particulated (Brogan et al. 2005 on 10 AU scales).

H I was obviously the phase of the year. It came (1) warped (Revaz & Pfenniger 2004), (2) cold (Gibson et al. 2005), (3) en route to molecules and with cosmic rays (Giammanco & Beckman 2005), and, perhaps most important for the future, (4) increasingly well surveyed (McClure-Griffiths et al. 2005, writing, or anyhow observing from the Dominion Radio Astrophysical Observatory) and characterized (Heiles & Troland 2005), though this last paper scored 2.5 on our "um" scale for the remark that "observed quantities are only indirectly related to the intrinsic astronomical ones," especially, they say, magnetic field strength, for which they report 6 μG.

Then H_2 forms (more easily on rough grain surfaces; Cuppen & Herbst 2005), and where there is enough of it, you get giant molecular clouds (Stark & Lee 2005), dark clouds (catalogued by Dobashi et al. 2005), and Bok globules, which rotate, say Gyulbudaghian & May (2004) with periods near 10^7 years. This seems long, given that characteristic timescales for formation, destruction, and conversion to stars of GMCs are also a few times 10^6 to 1–2 $\times$ 10^7 years (Bergin et al. 2004; Monaco 2004; Tassis & Mouschovias 2004; Goldsmith & Li 2005).

Most authors during the academic year described the cloud motions and internal structure as turbulent (Löhmer et al. 2004a, one of many), though Tarakanov (2004) held out for generalized Brownian motion, and he blamed the fractal structure (with $n = 2.35$) on clouds bouncing around off each other after ejection by stars.

The most puzzling velocity structure remains the high velocity clouds, and not everything that was written about them during the year can be simultaneously true of all of them. If we are allowed two votes, one will go to the general idea that some are left-overs from galaxy formation, analogous to the clouds responsible for certain QSO absorption lines (Maller & Bullock 2004; Hoffman 2004; Weidinger et al. 2005). A second, even more diffuse, vote goes to the conclusion that the HVCs associated with M31 and M33 are not all the same sort of beast (Westmeier et al. 2005). The principle alternative to left-overs falling in is gas expelled from galactic disks in fountains falling back down.

8.4. Star Formation

Subtopics one might reasonably worry about include timescales, efficiencies, turn-off, triggering, the special problems of making massive stars (which probably exceed their Eddington luminosities en route), effects of turbulence and magnetic fields, and accounting for the distribution of masses of single and binary stars (aka IMF) that must result. Notice that some of these could be answers to some of the others.

The most attractive idea of the year is called "collect and collapse," for which only the name is new, the idea going back to Elmegreen & Lada (1977). It is that a massive star and its H II region can sweep up a great deal of gas, which will then fragment. Examples are given by Deharveng et al. (2005), Hosokawa & Inutsuka (2005), and Oey et al. (2005 on the W3/W4 region). Of course that first massive star had to come from somewhere, and disagreement persists on whether the normal mechanism is accretion onto a single core from its surrounding disk and envelope or merger of several smaller protostars. In lieu of voting this year, we green-dotted two papers that indicate observational signatures of the two processes (Lintott et al. 2005; Bally & Zinnecker 2005).

Pushing the problem back in time to "cores in molecular clouds" brings us to the SCUBA map by Kirk et al. (2005), revealing cores with flat centers, sharp edges, and molecular masses about the same as their virial masses of 0.4–4.8 $M_\odot$. Some cores fall apart without ever making stars (Vazquez-Semadeni et al. 2005a); others are just about to make stars (Crapsi et al. 2005, some portions of whose argument are not totally obvious); and in between comes the Balbus-Hawley instability (Padoan et al. 2005), which deposits stuff onto both the incipient star and its disk. All stages from starless cores to young clusters can co-exist in a given star formation region (Teixeira 2005).

The bigger questions received no global answers this year. We think these are a few incremental steps. Local fields in star formation regions are in the mG range (Fish et al. 2005), and the efficiency with which gas is turned into stars declines as the field strength goes up, down to 5% when the magnetic pressure exceeds the thermal pressure (Vazquez-Semadeni et al. 2005b, a calculation), presumably because the field has to leak out by ambipolar diffusion (Boss 2005a). This also renders the process somewhat spasmodic (Tassis & Mouschovias 2005), a choice of words endearingly reminiscent of some of the people working in the field.

The main trigger for assembling large molecular clouds remains, we think, passage of gas through a spiral arm, though if anybody said so this year, we missed it. On the next scale down, molecular gas is set into contraction, and there were votes for passage of a globular cluster through the galactic molecular gas layer (Kobulnicky et al. 2005) and an intergalactic cloud hitting a galactic one (Wang et al. 2004c), at which point the former ceases to be a high velocity cloud. Within clouds, important phenomena include collisions of subclumps (Koda et al. 2005), plane parallel shocks (Urquhart et al. 2004), and Type II supernovae (Salvaterra et al. 2004), whose behavior takes us more or less back to collect and collapse.

Binary star formation is, perhaps, half as well understood as the single sort, but the most divided author has private reasons for liking the tendency of Ochi et al. (2005) or at least their model to produce binaries with mass ratios near 1. It should be noted in this context that turbulent star formation (Krumholz & McKee 2005) tends fairly naturally to establish the range of clump masses seen in NGC 7538 (Reid & Wilson 2005) and to produce multiple fragments close enough together to be relevant both to binary formation (Machida et al. 2005; Clark & Bonnell 2005) and to ejection of occasional stars from clusters, perhaps explaining why these runaways tend to have smaller masses than the stars left behind in the clusters (van den Bergh 2004).

How did most of the globular clusters form? Um, er has been a traditional answer, since they aren't making them any more, at least in our galaxy. But the answer closest to home is that of Kravtsov & Gnedin (2005), who say that the immediate parents were giant molecular clouds in the gas disks of disk galaxies, with baryon mass equal to $10^9\ M_\odot$, which later merged to make the bigger galaxies we see now. The peak formation epoch via this mechanism was $z = 3$–5. Big, young non-globular clusters were typically put together from a bunch of smaller clusters (Homeier & Alves 2005; Chen et al. 2005a).

9. STARS OF STAGE, SCREEN, RADIO, AND Ap05[44]

As recently as 2001, "optical observations of stars" was still the largest single class of astronomical paper published world wide. The rule that our own papers are not highlights of the year precludes citation, but a reprint-preprint package will be sent in plane brown wrapper to anyone who requests it. Stars also made up 15 of the preliminary topic classes (from YSO to aging neutron stars) for Ap05, plus four more for binaries and two for star clusters (out of 76 total). The ordering of topics is the least imaginative possible, from young stellar objects onward.

9.1. Young Stellar Objects

Three classes, 0, 1, and 2 (or 0, I, and II, well we didn't say our lack of imagination was unusual in the field) are distinguished. The class zero objects are supposed still to derive most of their energy from accretion (Groppi et al. 2004), and the envelope in waiting remains more massive than the core (Froebrich 2005). Class I (the traditional YSOs) and Class II (the T Tauri stars) are already dominated by nuclear energy, and only those with the larger outflows can power Herbig-Haro objects (White & Hillenbrand 2004). Vorobyov & Basu (2005) say that the transition from Class 0 to Class 1 represents the exhaustion of the reservoir of material available for accretion. Doppmann et al. (2005) disagree, saying that accretion and outflow can coexist in Class I.

Models of these phases have improved to the point where it is sometimes possible to get the same age for a cluster from lithium depletion and from pre-MS isochrones (Jeffries & Oliveira 2005 on NGC 7547). Many YSOs are X-ray sources, and it can be a good way to pick them out. Ozawa et al. (2005) report Types I, II, and III, post T-Tauri's, as X-ray sources in the ρ Ophiuchi region. If you care to ask whether the X-rays are produced primarily by magnetic processes or by accretion shocks, the answer is yes (Preibisch 2004 on magnetic processes; Swartz et al. 2005 on shocks). YSO X-ray sources do not show conspicuous activity cycles (Pillitteri et al. 2005).

A slightly modified classification scheme says that $0 =$ all accretion energy; $1 =$ accretion $+$ nuclear; $2 =$ all nuclear $+$ outflow; and $3 =$ junk cleared out of the way, starting at the inside of the disk (Barsony et al. 2005). Notice that the energy sources are not directly observable, so that YSOs are generally studied and classified using somewhat different criteria, for instance growth and then dissipation of disks over millions of years (Rodriguez et al. 2005a), with faster dissipation at larger masses, dust evolving chemically and settling to the plane of the gas disk, and small grains disappearing first. Schütz et al. (2005), Hernandez et al. (2005), Briceño et al. (2005), Calvet et al. (2005), and Carpenter et al. (2005) are by no means the only papers on these processes, but their clustered publication makes them easy to consult.

Conservation of angular momentum from an interstellar blob will inevitably yield a protostar rotating faster than break-up. Indeed young stars tend to be fast rotators, but the YSO rotation papers indexed this year all focused on spin-down and took three points of view (a) magnetic coupling to the disk is not how it happens (Matt & Pudritz 2005, who suggest wind on open field lines as an alternative), (b) the disk is not the whole story (Littlefair et al. 2005, comparing NGC 2264 and IC 348), and (c) extraction of angular momentum by magnetic coupling to a disk is quite a likely mechanism (Covey et al. 2005).

Which are our favorite YSOs? T Tauri itself, of course, a

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[44] The absence of television and blogs from the list of things to be stars of dates the section heading to, roughly, pre-1952 and originally described Jack Benny, whom we still join a few times a year in traveling to Washington to visit our money.

bound triple star (Skinner et al. 2004), whose variability on timescales from 2.68 days to 40 years is explored by Mel'nikov & Granking (2005). Both the naked and the dead, sorry, the naked and the classical T Tauri stars, have magnetic fields in the few kG range, with the sample not, we think, large enough to tell if there is a systematic difference (Johns-Krull et al. 2004; O'Sullivan et al. 2005; Symington et al. 2005).

FU Ori and its ilk, for which the conspicuous flaring is attributed to accretion disks, but for which the evidence for companions (planetary or stellar) is piling up (Malbet et al. 2005; Clarke et al. 2005; Grinin et al. 2004).

And anything named for George Herbig, whether Ae, Be, or Ze. None of the last class turned up during the year, but there did appear (1) the second Herbig Ae star with a magnetic field near half a kG (Hubrig et al. 2004), and no decision on whether this is smaller than the T Tauri fields, (2) the second Herbig Be with an $m = 2$ spiral in its disk (Quillen et al. 2005),[45] (3) 10 Ae and Be stars with X-ray luminosities either about the same as the less massive T Tauri YSOs (Skinner et al. 2004), or, on the other hand, brighter (Hamaguchi et al. 2005), and (4 Ae/Be's with disks either centrally puffed up (Eisner et al. 2004, reporting resolution with the Palomar Test Bed Interferometer) or flaring outwards (Acke et al. 2005). The former are dust disks, the latter gas, so both could be correct.

9.2. Brown Dwarfs

"Brown dwarf" is widely held to be a good name because (a) brown is not an (additive) color, (b) the spectra are conspicuously non-thermal, so that cooler = bluer in some infrared colors, and (c) they are not stars. Not surprisingly, they are very like stars in some ways, different in others. Let's start with the idea that BDs can do just about everything that stars can do.

- Live alone (Luhman et al. 2005a)
- Have BD companions (Zapaterio Osorio et al. 2004; Burgasser et al. 2005, the latter on brown dwarf pairs orbiting M dwarfs)
- Be companions (Forveille et al. 2004; Pravdo et al. 2005), with smaller separations for smaller masses
- Have planets (Chauvin et al. 2004)
- Be subdwarfs (Burgasser et al. 2004, the second case)
- Exhibit resolvable outflows (Whelan et al. 2005), with the method, called "spectroastrometry" (line centroid offsets vs. velocity), explained in detail and fine print
- Pulsate (Palla & Baraffe 2005) but with deuterium fusion as the driver rather than hydrogen ionization and, admittedly, a calculation rather than an observation
- Gravitationally lens stars behind them (Jaroszynski et al. 2005, observations)
- Emit X-rays (Stelzer 2004, the second example)
- Form the same way as low mass main sequence stars (Muzerolle et al. 2005; Mohanty et al. 2005; Luhman et al. 2005b), which is to say that the young ones have accretion disks
- Be triples (Bouy et al. 2005)
- Sustain magnetic fields despite being fully convective. Berger et al. (2005) report radio emission from a 2MASS source, arguably gyrosynchrotron despite the absence of Hα and X-ray emission. There is a 3 hour period, which could be rotation or orbit, and the L3.5 object is J00361317+1821104
- Have both magnetic fields and accretion when young (Scholz et al. 2005b on a couple with variable emission lines)
- Rotate with more or less the same range of periods when young (Caballero et al. 2004).

And now some differences, with the most notorious last.

More weather (Maiti et al. 2005), in the form of variability due to dust clouds moving around in the atmosphere.

More complex atmospheric structures that need a fifth fitting parameter (Tsuji et al. 2005), the usual temperature, log g, chemical composition, and microturbulence, plus the thickness of the cloud deck.

Absence of binary X-ray sources. We don't mean that there are not some neutron star XRBs and "black widow pulsars" with M_2 in the brown dwarf mass range, but that close double BDs are not *Chandra* X-ray (or ATCA radio) sources, where similar M dwarfs would be (Audard et al. 2005).

Additional formation mechanisms that involve ejection from triples and clusters before they have had a chance to grow to proper stardom. Compare Deanna Durbin with Shirley Temple and see Lucas et al. (2005a), Umbreit et al. (2005), and Luhman et al. (2005c), who all also address the issue of—

The Brown Dwarf Desert. You must not imagine either a water-based organism crawling desperately across the surface of a brown dwarf or the BD itself calling plaintively for ammonia in the midst of a terrestrial desert, but, rather, a distressed observer in an otherwise perfectly nice desert that just happens to have very few brown dwarfs in it.

This doesn't even mean few, total, compared to low mass stars and orphan planets in regions where you expect all three (Lucas et al. 2005a). Instead, if you plot numbers of spectroscopic and visual binaries in which M_2 = low mass star, brown dwarf, or (hot) Jupiter, there is a deep dip in the BD mass range (Kouwenhoven et al. 2005; Chauvin et al. 2005a; Bouchy et al. 2005; Umbreit et al. 2005; Luhman et al. 2005c). Part of the reason, say Matzner & Levin (2005), is that their formation by fragmentation in disks is inhibited by radiation. According to Padoan & Nordlund (2004), very large density fluctuations due to supersonic turbulence are needed to overcome this inhibition

9.3. A Few Favorite Stars (Besides Jack Benny and Carole Lombard)

Some of these are binaries and probably belong in another section, but we suffer from the delusion that you can deny the consequent by denying the major premise, so that the absence

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[45] Is there also a Hirsch or Eddington number for the maximum number N'' of astronomical disks with at least $M = N''$ arms? If so, it must be close to $N'' = 4$.

of foolish consistency is a hobgoblin of large minds. Indeed we begin with some newly declared or affirmed binaries.

Arcturus (Verhoelst et al. 2005)

FK Comae (Kjurkchieva & Marchev 2005)

AB Doradus. Well, it has been a triple for a long time, but the newly measured mass and luminosity of component C (SM Close et al. 2005a; Reid 2005) provide a revised calibration of the bottom end of the luminosity-mass relation. It is fainter and cooler than had been expected for its mass of 0.09 $M_\odot$ and age of 50 million years. This then casts some doubt upon the identification of brown dwarfs from luminosity and temperature alone in open clusters of known age.

α Cen A has also been accompanied for many years, but it has a new Zeeman magnetic field of 247 G (Kordi & Amin 2004). Well, newly measured anyhow.

Fomalhaut, resolved with the VLT interferometer in what was mostly a stability test (Davis et al. 2005b). Is it inappropriate to claim as a favorite telescope something that shares our initials?

Altair, which is not only α Aql but also the brightest δ Scuti star, displaying seven modes at amplitudes less than a millimagnitude (Buzasi et al. 2005). Well, at least most people can pronounce that one.[46]

The most massive stars (who have our Atkinsonian sympathy) galumph in between 120 and 200 $M_\odot$, and this is not just a matter of running out of statistics in a Salpeter (power-law) initial mass function but a real cutoff (Oey & Clarke 2005; Figer et al. 2005; Kroupa 2005).

The most dense stars, on the other hand, are those of smallest mass, with as ponderous an average density as 75 g/cm^3 for a 0.092 $M_\odot$ star (Pont et al. 2005). Surprise at its being this large means it is time we taught stellar structure again, preferably using the text book that differs only in middle author from the present paper.

The nearest stars. Remarkably, these continue to proliferate. This year, the solar system was nearly and newly assaulted by the 16th nearest star (Deacon et al. 2005, SCR 1845−6357), a white dwarf, at 4 pc probably closer even than van Maanen 2 (Scholz et al. 2004—and we are a little vague on the nature of van Maanen 1), and at least a gaggle of others less than 10 pc away according to Golimowski et al. (2004), Costa et al. (2005 whose Figure 3 [Fe/H] $= +0.5$ isochrone should, we think, be –0.5) and Scholz et al. (2005c).

A bunch of peculiar chemical compositions for CP stars, of which we record only the very high abundance of tantalum in χ Lupi (Ivarsson et al. 2004), to express sympathy with the original Tantalus crawling over the desert looking for a brown dwarf. Or something like that. Oh all right. The metal cannot absorb water, and who knows how it does with fruit trees.

Additional items that surprised us:

- The discovery of a number of faint DY Per stars in the LMC led us to wonder a few years ago whether DY Per was a DY Per star. (Alcock et al. 2001). It is (Zacs et al. 2005).
- More than half of all known yellow hypergiants live in the young open cluster Westerlund 1 (Clark et al. 2005a).
- Oe stars exist, but are rather rare compared to Be stars (Negueruela et al. 2004).
- The 65 stars originally classified as B[e] are actually a mixed bag (Miroshnichenko et al. 2005a). Mixed heritage is also characteristic of the sdB and EHB stars (Maxted et al. 2004, the proceedings of a conference), and of the blue stragglers (Clark et al. 2004), though it sounds as if Porter & Townsend (2005) and Sills et al. (2005) may be advocating their respective mechanisms (rapid rotation and main sequence binary collisions and mergers) for all blue stragglers.
- Am stars are considerably more common than plain old A's, especially in binaries (Yushchenko et al. 2004).
- Pre- and post-main-sequence stars cross the same stretches of the HR diagram above the zero age main sequence, and it is not always that easy to tell them apart. Miroshnichenko et al. (2004) have reclassified HD 35929 from a Herbig Ae, pre-MS star to post-MS.
- Spectral types by integer steps, for instance from A0 to A9, were enough for Morgan, Keenan, and Kellman (indeed some of the steps are almost never used), but Luhman (2004) has found some stars that require further subdivision at the level of M2.25, for instance.

9.4. The Sun

The Sun?!?! Out, out. Down Bowser. Back to § 2 where you belong. But perhaps two small items can creep through the pet door here.

First, the Sun has been losing metals, not primarily to the solar wind but to theorists. With the new, lower Z, it comes exceedingly close to the average of nearby disk stars, both early (Lyubimkov et al. 2005) and late (Luck & Heiter 2005; Taylor & Croxall 2005). In light of the well known correlation between high metallicity and hosting planets, you might wonder whether the Sun has also been losing planets. Not unless you count Pluto. The (other) disadvantage of reduced metallicity is a poorer fit to the spectrum of solar oscillations, via effects on the depth of the convection zone and such (Bahcall et al. 2005b).

Second there is the activity cycle. The Sun has been, of late, very spotty, and, if you can trust tree ring data as a proxy, has not been this active since about 8000 BP (before 1950, you may recall from Ap04). There has been a corresponding increase in solar luminance at Earth of about 1 W m^{-2} since the Maunder minimum (Wang et al. 2005g, who are not completely clear about what data go into their record of solar luminosity and magnetic field since 1713). And, predict two of the papers

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[46] Improbable as it may seem, the most acquisitive author this year actually turned down money to make a recording of acceptable pronunciations of the names of a number of stars and constellations on the grounds that (1) there are real differences between the amateur and professional communities even within the USA and (2) she could think of no honorable purpose (for either community) for which some of these would be needed. The potential employer declined to explain what the purpose was. But if you should be offered such a recording for a price, stand assured that none of us will profit from it.

that call attention to the present vigorous activity, the future will be less so, perhaps by 2010 (Ogurtsov 2005), perhaps not until more like 2100 (Solanki et al. 2004; Reimer 2004).

Carrington's numbers for his elements (of the solar rotation and spot poles) were very nearly right (Beck & Giles 2005), a confirmation which would have excited the fastest rotating author more if she had known they were in doubt. Carrington, you may recall, was the first to see a white light solar flare and not blame it on the beer produced by the family firm.

9.5. Pulsating Stars

Twenty-some classes of pulsating variables appeared in the 2005 literature. Should keeping track of them be aspersed as botany? No! It's stamp collecting, and we're proud of it. In addition, detailed matching of pulsation properties is often the best handle on equations of state, opacities, and convective energy transport. The Cepheids are perhaps the most important, since they anchor the extragalactic distance scale. In this context it would be more comforting if—

1. There were general agreement about just how the period-luminosity-color relation depended on composition (Persson et al. 2004 vs. Gieren et al. 2005). Age comes in there somewhere too (Bono et al. 2005). The good news on this front is confirmation of the number near 1.3 used to convert observed radial velocities to photospheric motion in the Baade-Wesselink method of measuring Cepheid luminosities provided by Merand et al. (2005), who used CHARA to measure $R(t)$.

2. The relationship between masses from evolutionary tracks and from pulsation analyses were more like an identity than it is. The pulsation masses always come out smaller, which, since we all believe that massive stars shed at various times, should be fine (Brocato et al. 2004), apart from the tiresome detail that the required mass loss is smallest for the biggest stars (Caputo et al. 2005, and noted in our summary as "odd").

3. More of them showed increases in period as expected for a first crossing of the Hertzsprung gap, instead of the negative dP/dt's found by Moskalik & Dziembowski (2005). Polaris and a few others do have large positive period derivatives, and Polaris itself, as has been much advertised, also has a smaller pulsation amplitude than in the good old days. Turner et al. (2005) conclude that it is at the red edge of the fundamental instability strip for first crossers, where convection is winning over pulsation. For more of the effects of convection-pulsation coupling see Grigahcene et al. (2005) and Dupret et al. (2005), both focused on γ Dor and δ Scuti stars, and Munteanu et al. (2005) on LPVs.

If you aren't massive enough to be a Cepheid, you can be a Pop II Cepheid, an anomalous Cepheid, a Type II Cepheid, or a short period Cepheid (Caputo et al. 2004). Pritzl et al. (2005) are clear that at least three of these are physically distinct classes (with Type II Cepheids approximately equal to the old class of W Virginis stars), but less clear on how you know what to call one when you meet it. Adopting the technique that has, over the years, led to friendly relations with a number of outstanding senior graduate students, we will stick with Dr. Cephei.

If you are even more mass challenged,[47] you can be an RR Lyrae star, about whose masses (Cacciari et al. 2005) and period changes (Derekas et al. 2004) much can be said, as in the case of the Cepheids. The OGLE samples of RR Lyrae stars in the Large Magellanic Clouds and in the Milky Way are now large enough that the manifestations of the Blazhko effect can be correlated with other properties (Smolec 2005). The differences are not primarily a metallicity effect, though the metal-poorest stars are brightest. The shortest known Blazhko period, 7.23 days, belongs to RR Gem (Jurcsik et al. 2005).

Each year a few stars get promoted from mere low-amplitude pulsation to asteroseismology. This year we caught θ Oph (which is also a β Cephei star) observed by Handler et al. (2005) and Briquet et al. (2005), who are polite enough to cite each other. And Procyon has been restored to the pantheon, by Claudi et al. (2005, radial velocity data, not to mention a whole conference on the subject, Kurtz et al. 2005b and 21 following papers, some of which report data from places where even Jay Pasachoff has never been).[48]

Every other pulsation class is rudely confined to one paper each. LSIV -14 116 is the first pulsating, helium-rich sdB (Ahmad & Jeffery 2005). The non-He-rich sort are now called V361 Hya stars if they have periods of minutes and PG 1716+427 stars if they have periods of hours (Ramachandran et al. 2004). GW Vir stars are the same as pulsating PG 1159 stars, from which you can deduce that there are at least two of them; in fact about 10 say Nagel & Werner (2004), with the blue edge of the instability strip at 160,000 K. Of the 10, four are type DOV white dwarfs ($\log g \geq 7$) and six are nuclei of planetary nebulae ($\log g = 1$–6).

Pulsation of Be stars is responsible for some of the periodic optical variability of Be X-ray binaries (Fabrycky 2005). Like the wheels on the stuff that is tall and skinny and green and grows around houses, this was just added to make it more difficult, though not by us.[49]

δ Scuti stars and γ Doradus stars live in the same part of the HR diagram (near the A main sequence). Does any star do both? Candidates come and go (Chapellier et al. 2004; Henry et al. 2005), and HD 8801 (Henry & Fekel 2005) is this year's

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[47] Don't you wish.

[48] We held a small, informal competition for this naming opportunity, and the eclipse chasing and other activities of Jay Pasachoff were deemed to have taken him to more, and more difficult, places than even the outreaching of Edward Sion, the site testing of Jan Erik Solheim, and the crescent Moon viewing of Brad Schaefer.

[49] As in the riddle:
Q: What's tall and skinny and green, has wheels, and grows around houses?
A: I don't know.
Q: Grass.
A: Grass doesn't have wheels!
Q: I know. I just put that in to make it more difficult.

candidate. It is an Am star without known binary companion (relatively rare). In fact, many chemically peculiar stars pulsate, or, if you prefer, many δ Scuti stars are spectral types Am-Fm (Yushchenko et al. 2005b). RV Tauri stars are known primarily for their minima of alternating depth. Their chemical peculiarities are best described as dust/gas separation. (Giridhar et al. 2005).

The semi-regular (asymptotic giant branch) variables occupy multiple ridge lines in HR diagrams, period-luminosity, period-temperature, and other diagrams. Papers on the subject this year (Schultheis et al. 2004 and several others) left us no wiser than Ap04 § 4.12, but of the opinion that "chaos" would be a good description, except that it has to be saved for a handful of large-amplitude stars whose behavior is chaotic (not stochastic and not the sum of a bunch of constant-amplitude modes) in the technical sense (Buchler et al. 2004).

A star approaching the main sequence is quite likely to pass through one or more instability strips, and indeed a few of them show periodic, low-amplitude variability (Zwintz et al. 2005), though they seem to avoid the center of the instability strip in NGC 6383.

Whether the radii of Miras vary through their light cycles depends on whether you use infrared interferometry (yes, Boboltz & Wittkowski 2005) or the SiO maser emission (no, same paper), though both sets of photons come from $8''$–$11''$ from the centers of the stars.

Some of the elliptically modulated variables in the LMC also show a "long secondary period." Soszynski et al. (2004) do not claim this as a pulsation phenomenon, but it's new this year and so has to go somewhere!

Despite the conciseness of the paper, Kopacki (2005) managed to mention SX Phe stars, Pop II Cepheids, BL Her stars, red giant tip stars, and RR Lyraes, all in M13, all variable, and all apparently pulsating.

Like each other class, the β Cephei stars get only one paper (Davis et al. 2005a) of a handful recorded, but you get two stars, because it is a $P = 557$ day binary (with both interferometric and radial velocity data) consisting of two 9 $M_\odot$, $M_V = -3.8$-ish stars, both of which are β Ceph variables and Bl giants. Several earlier papers have reported β Ceph masses, and they always seem to be very close to 9 $M_\odot$. The variability of β Cephei itself was discovered by Frost (1902), who selected the name β Canis Majoris stars for the class, a confusion which has persisted down to the present time. The paper by Daszyńska-Daszkiewicz & Niemczura (2005) on them is cited for the shear challenge of spelling the names correctly.

9.6. Some Other Favorite Stars

Many of these are variable. Some probably pulsate. But they appeared in the index year papers for some other reason.

Pugach (2005) points to some variable stars whose correlation of $B-V$ color vs. V magnitude has the opposite sign to what you would expect from temperature variations.

Vogt et al. (2004) have discovered that if you wait long enough (34 years in their case) you find variability on timescales up to 8000 days or more. It will presumably take another 34 years or so to determine periodicity if any.

R CrB stars, though known firstly for fading and secondly for pulsating, also have mass outflow from both disk and bipolar structure, like other AGB stars (Rao et al. 2004).

η Carinae, the prototypical luminous blue variable, gets two papers because it is generally advertised as a binary. In one, it displays a new sort of pumped Fe II emission (Johansson & Letokhov 2004), and in the other, the Homonculus Nebula around it is reflecting X-rays for the first time (Corcoran et al. 2004). Some other LBVs are also pulsators at periods longer than the expected fundamental (Dziembowski & Slawinska 2005). The implication is that we are seeing strange modes driven by an iron opacity bump. The stars must be in the helium core burning phase and have lost a good deal of mass.

Though we have cast nasturtiums at the multiple ridge lines of semiregular variables (for more, see Fraser et al. 2005b), some day they are all going to have individual names, though the largest class may remain "other" as it currently is for 6616 of the 10,311 stars catalogued by Pojmanski & Maciejewski (2005).

Asymptotic giant branch stars lose mass. That's what they are best at, and the details depend on metallicity (Marshall et al. 2004), or only on luminosity and temperature, not on composition (van Loon et al. 2005), or on luminosity, radius, mass, temperature, and surface gravity (Schroeder & Cuntz 2005), which is probably enough parameters to take care of what might really be extra radiation pressure on grains when there are more metals to condense.[50] Garcia-Segura et al. (2005) believe that magnetic fields are also important in driving the higher-speed collimated winds, though we and Schoenberner et al. (2005) endorse a prolonged, low velocity superwind as the main mass stealer. In any case, stripping goes so deep that the layer seen can briefly be as hot as 200,000 K (Werner & Drake 2005 for H1504+65 and a number of new candidates).

And pretty soon, if they are very good, they get to be planetary nebulae. Actually the key parameter is probably not goodness but some combination of mass and mass loss (because, as remarked in earlier years, some stars go from extended horizontal branch to white dwarfs without ever being nuclei of PNe). Definitive distance scales for galactic planetaries have been established every couple of years. Phillips (2005) has done it again. His is on the short end of the existing range. We are long folks ourselves, but as Phillips' references extend back only to 1992, it is inevitable that our own great works on the subject, as well as those of Josef Shklovsky and Michael Feast, go uncited. The observations also say that his set of PN nuclei have no main sequence companions earlier than K0. The various observed PN shapes are not primarily an evolutionary

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[50] Yes, there are five, and you were expecting Gamow's elephant, weren't you?

sequence but reflect the initial stellar mass, hence, presumably, the amount of stuff available (many papers, of which Phillips [2004] can be the representative). The bipolars come from the biggest stars.

What you see is not always what you get. The systematic difference between element abundances found from collisionally excited and recombination lines (recombination is bigger) implies large quantities of cold, hydrogen-poor, gas hiding somewhere (Wesson et al. 2005, the last of a number of papers on this during the year). Liu et al. (2004) suggest that vaporized planets might be responsible, making this the 29th way of detecting exoplanets.

Given the wide range of PN progenitors (all stars up to $8 \pm 2\ M_\odot$ and some merged binaries, Ciardullo et al. 2005), lifetimes must vary a good deal, but a thousand years will do as an average. Sabbadin et al. (2005) report on NGC 6741, which, at age 1400 yr has already been recombining since year 12 of the revolution. And then they get to be—

9.7. White Dwarfs

Fifty-one papers on WDs were indexed (plus some on possible Type Ia progenitors and cataclysmic variables exiled to other pages). A very old issue is the DA/DB (H vs. He atmosphere) dichotomy and how individual stars decide which to be when. No, the answer didn't come in this year, but if you have only one green dot to give out, it should probably go to Kalirai et al. (2005a) for the remarkable discovery that there are no DBs in young open clusters. An out of period result extends unexpected WD populations to older open clusters and a globular or two. That WDs with M-dwarf companions, with 5% DBs, fall half way in between single field WDs (10% DBs) and cluster stars (0% He) must be trying to tell us something about this phenomenon (van den Besselaar et al. 2005). The paper reports numbers 3–15 of DB + MV binaries and numbers 2 and 3 of DC + MV. A good many of their DBs live in the temperature gap at $T = 30{,}000$–$45{,}000$ K where there are few or no single white dwarfs with helium atmospheres.

The correlation between main sequence mass and white dwarf mass matters for figuring out how much stuff they give back to the interstellar medium, for deciding how many core collapse supernovae you should get from a given initial mass function, and other issues in stellar populations. A critical part of the calibration is study of white dwarfs in young open clusters. This year, Williams et al. (2004b) and M35 told us that stars up to at least $5.8\ M_\odot$ make WDs. The biggest main sequence stars make the biggest white dwarfs. Low metallicity yields more massive WDs from a given MS mass (Kalirai et al. 2005b). And the magnetic WDs are on average a good deal more massive (0.93 vs. $0.66\ M_\odot$) than the others Wickramasinghe & Ferrario (2005).

As long as the magnetic fields have crept in, this is probably the place to note that one implication of the Wickramasinghe & Ferrario results is that WD fields are fossils left over from their main sequence lives rather than the products of ongoing dynamos. Tout et al. (2004) concur, and Jordan et al. (2005) report that 4 of 4 nuclei of planetary nebulae have field strengths intermediate between those of Ap/Bp stars and WDs, though their statistical conclusions about flux loss should perhaps await a slightly larger sample.

White dwarfs in cataclysmic binaries more often than singles have strong fields. Townsley & Bildsten (2005) say you can make sense out of the pattern if the birthrate of strong fields is 8% for both, but the ones in CVs last longer. If so, then the total absence of detectable fields in WDs paired with M dwarfs that are not CVs is remarkable (Liebert et al. 2005c). The authors suggest it is a selection effect against high mass, small radius (faint WDs) in their sample, which comes from SDSS. The strongest white dwarf field reported to date is a GG (GigaGauss; Vanlandingham et al. 2005) and intrudes on the neutron star range.

Some of the DB fields are strong enough to prevent hydrogen accretion via a propeller mechanism, while allowing interstellar metals to get in as grains (Friedrich et al. 2004). Does this at last solve the problem of how there can be helium-atmosphere WDs with significant metal abundances? No, because other DB fields are weaker. But having landed in the heavy element swamp, let's look around a bit.

It is possible to find (holding our ear trumpets up to try to catch your question) astrofolk who remember when white dwarfs came with H or He surfaces plus van Maanen 2 with some iron. Then arrived the PG 1159 stars, with mostly C+O, which they retain, until gravitational settling changes them to DOs and DAs (Gautschy et al. 2005, a pulsation calculation). They are also allowed a bit of H or He if they want (Vauclair et al. 2005, also on pulsations). But the advent of high resolution UV spectroscopy made clear that heavy elements are actually quite common and that, for hydrogen-dominated atmospheres, accretion of interstellar material provides a reasonable explanation (Koester et al. 2005a, 2005b; Gianninas et al. 2004 on L157, a $1.24\ M_\odot$ star). The heaviest, rarest element seen so far is germanium (Vennes et al. 2005), in three DAs, and the Ge abundance is nearly solar.

The chiefest puzzle is presented by helium + metals. Petitclerc et al. (2005) reviewed four possible mechanisms: radiative levitation, mixing or dredge up from the CO (etc.) interior, ISM accretion with the hydrogen batted away, or leftovers from the PG 1159 phase. They vote for this fourth for the stars they studied with *FUSE*. Where hydrogen and helium coexist, the surface ratio can be inhomogeneous (Pereira et al. 2005), and HeH^+ can be a significant opacity source (Harris et al. 2004).

White dwarfs are, in general, slow rotators (Karl et al. 2005 and other papers stretching back 40 or more years). So are at least some of the sdB progenitors (Charpinet et al. 2005). Ferrario & Wickramasinghe (2005) suggest that WDs are not really any slower than neutron stars in relation to what is possible, and that the magnetic fields are also analogous, but their fast rotator has a period of 700 s. They propose that it is a merger product (one of three possible initial conditions for white dwarfs), and the faithful envelop back says this is "fast" in the same way that a 0.7 s pulsar is "fast," given the respective break-up periods near 1 s and 1 ms. Their "slow" is 50–100 years, corresponding to weeks or months for a neutron star (not in the observed, or observable, range).

White dwarfs can pulsate. You have already met the GW Vir (pulsating PG 1159) stars. The ZZ Cetis are the ones with hydrogen atmospheres, and, in contrast to Ap04 (§ 4.10), which declared the instability strip to be free of non-variables, this year it is impure (Mukadam et al. 2004; Mullally et al. 2005).

White dwarfs necessarily cool and fade as they age, and, if we fully understood the underlying physics, the process could be used quite independent of main sequence turn-offs to measure the ages of stellar populations. Alternatively, one can try to decide whether one understands the processes by seeing whether the ages come out the same. A major glitch occurs when the interior nuclei settle into a crystal and lock up in zero point fluctuations much of the energy that could otherwise be radiated (Mestel & Ruderman 1967). For only one star is the crystallization expected within the ZZ Ceti strip, and its period spacing suggests that half or thereabouts of the interior has indeed crystallized (Kanaan et al. 2005; Brassard & Fontaine 2005).

Beyond this point, the white dwarf sequence in globular cluster M4 yields a perfectly reasonable 12.1 Gyr (Hansen et al. 2004a). Less satisfactory is the case of the old open cluster NGC 6791, with a main sequence turnoff age of 9 Gyr and a white dwarf age (from the shape of the luminosity distribution) of 2.4 Gyr (Bedin et al. 2005). It is also somehow difficult to assign reliable effective temperatures to the cooler WDs (Farihi 2005) and so to decide which cooling curve they should be compared to (Jao et al. 2005).

Given the local density of 0.01 pc^{-3} (Pirzkal et al. 2005), there should anyhow be an adequate number to study, and the range in masses in the least biased samples available is wider than some thinkle peep (Liebert et al. 2005b; Ferrario et al. 2005).

9.8. Active Stars

Well, they all are, at some level, but the section addresses manifestations, correlations, cycles, causes and such. First, the broadest sort of definition: stellar activity is taken to mean chromospheres and coronae, star spots, flares at whatever wavelength you happen to be looking at, and other evidence for strong magnetic fields and winds. Solar activity so defined results in the Sun controlling space out to the edge of the heliosphere. We caught for the first time this year "astrospheres" used to mean the same thing for other stars, plus evidence for their existence (Wood et al. 2005a, 2005b). Detection requires there to be some neutral gas around the star for the wind to interact with. Wood et al. picked out 10 of 17 stars within 10 pc and only 3 of 31 further away via Lyα absorption at the interface. And since they absolutely had to look through our heliosphere to see the other stars, that registers in many absorption features as well. Some of the systematics arise because very active stars have mostly polar spots leading to bipolar winds, while for the Sun (Tu et al. 2005) the wind starts out from coronal holes at a range of latitudes.

9.8.1. Magnetic Fields

Now it is a truth universally acknowledged that a single star in possession of a good field must be in want of a dynamo. Many are to be found in Peter & Stix (2005, the proceedings of an October 2004 conference). And this is in truth relevant because it is also generally acknowledged that stellar activity is largely driven by magnetic processes. Stellar dynamos in turn require both rotation and convection, the former being as a rule the easier to measure independently and so the topic of more papers.

Dynamos, it seems, can exist in stars ranging all the way from brown dwarf masses (§ 9.2) up to O stars, though θ^1 Ori C is the only O with a measured field (Gagne et al. 2005), and the change from a shell dynamo (in stars with radiative core and convective atmosphere) to a distributed one (in fully convective stars) changes spot numbers or distributions (Scholz et al. 2005a). At the other, high mass, end Mullan & MacDonald (2005) say they can get up to 100–200 G, approaching the observed range for OB stars. The dynamo fields are not always nice, tidy dipoles. The example that jumped out this year (Petit et al. 2005) is the binary component σ Boo A, a G8 V star with both poloidal and toroidal field and rotation period of 6.4 days. The orbit period is much longer, and you would not expect synchronization unless the system was a few Tyr old (see Abt & Boonyarak 2004 on the range of periods for which synchronization does occur).

The dynamo process must also in some sense be self-defeating. A strong dynamo and field will drive out more wind (at least up to some limit) and keep it co-rotating further out, thus slowing the rotation, as is generally said to have happened to the Sun. The two papers noted on this general topic, however, said that magnetic braking is not the reason that many chemically peculiar stars are slow rotators (Glagolevskij 2003) and that the expected faster rotation at a given mass for LMC and SMC stars compared to the Milky Way (fewer heavy elements = less radiative pressure wind driving = less slowing) is not actually seen (Penny et al. 2004).

9.8.2. Rotation

Rotation does, however, in general slow with age (after the initial spin-up during accretion mentioned above, and see Strom et al. 2005b on h and χ Persei spin-up compared to field stars). The slowing can be both calculated and measured and the expected die-off of activity observed (Telleschi et al. 2005; Ribas et al. 2005). Both papers compare solar mass stars over a range of ages, and part of the purpose is to "predict" what the Sun must have been like in the past and plausible effects on the solar system as a habitable environment.

Just how slow can rotation get? The 521 days for HD 2453 discussed by Glagolevskij (2004, including a Mercator projection of the surface) is a more direct measurement than the lower limit of 37 years deduced for one roAp star by Ryabchikova et al. (2005).

Differential rotation is a topic likely to appeal to track runners, especially if phrased as the number of rotations required for the equator to lap the poles by one. This happens in just 3 or 4 periods for some A stars with shallow convection zones (Reiners et al. 2005), and also in a few periods for the Sun (but this is 120 days rather than the 40 hours for the A stars), and takes more than 400 of the 0.424 day rotation periods of LO Per (Barnes et al. 2005). Yes, of course there are models that redistribute internal angular momentum to produce the differential rotation seen (Charbonnel & Talon 2005). We worried a bit that the dynamos might suffer, but the effect seems to go the other way—the dynamos disturb the differential rotation (Covas et al. 2005; Itoh et al. 2005).

To summarize again, yes, activity does die away (Gondoin 2005 on NGC 188 vs. younger clusters), but you will not be any more surprised than we were to be told that both the early spin up/down processes (Lamm et al. 2005) and the later evolution of activity are more complicated than generally supposed. Indeed Pace & Pasquini (2004) despair and say that at least the Ca II K flux cannot be used as an age indicator at all. Silvestri et al. (2005), however, rode, well, published to the rescue with a calibration that extends beyond 4 Gyr (based on old open clusters and MV+WD pairs dated with WD cooling ages) on out to 10 Gyr. The Vaughan-Preston (1980) gap, meaning the absence of nearby stars with activity levels between those of the Sun and Hyades, is just more of that tall, skinny, green stuff with wheels put in to make it more difficult, growing around observatories.

9.8.3. Cycles and Other Periodic Behavior

What about stellar activity cycles? Well, they are bound to appeal to those who have always resented Paris being a movable feast.[51] That AB Dor (single young star near 1 $M_\odot$) has two cycle periods of 20 and 5.5 yr (Järvinen et al. 2005) goes some way to make up for the stars found by Hall & Lockwood (2004) which have none. For some of their 10 not-even-unicycles, the H and K emission is larger than the flux at solar minimum. To decide whether the stars are experiencing the equivalent of a Maunder minimum, one really needs to wait patiently and see the transition back to cyclic activity in a few to a few hundred years. In and out of Maunder (etc.) minimum is a long sort of aperiodic cycle, we suppose. There are also short ones. UX Ari (a sort of RS CVn binary) for instance joins the Sun in having a Rieger cycle (294 days) which Massi et al. (2005) attribute to trapped Rossby waves.

"Active longitudes" is the idea that spots, excess magnetic flux, and chromospheric emission may tend to pop out at the same place repeatedly over very long periods of time (e.g., Alekseev & Kozhevnikova 2005 on LQ Hya, a single dMe star). The behavior of K^1 Ceti (Rucinski et al. 2004) may mean that both an active longitude and the pattern of differential rotation have been stable for 30 years. It is, however, one of the five dwarf novae (of which WZ Sge is the best known) whose orbit period has bounced back from the minimum possible and is now increasing and so should probably not be taken as a model for anything else. Should one actually believe in active longitudes? The evidence in the case of the Sun is an artefact (Pelt et al. 2005). This does not mean that the phenomenon isn't there, only that the current data don't demonstrate it (compare, again, the yeast effect). The authors do not address whether other stars might also be misleading us.

A few details of how the magnetic, rotational, and convective energies are fed to chromospheres and coronae so that we can see them remain to be worked out. This surely has a better chance of happening for the Sun than for stars where observations have little or no angular resolution, though sometimes stellar astronomers rush in where solar ones fear to tread: (1) a review of coronal X-rays (Guedel 2004), (2) the first extrasolar flare X-ray oscillations, on AT Mic (M Ve, Mitra-Kraev et al. 2005), and (3) an assortment of possible correlations with magnetic field, mass, age, and metallicity (Lyra et al. 2005), not, we suspect, separable correlations.

Some observations whose authors surely meant to be helpful: (1) EV Lac, a dMe, flares at radio, optical, and X-ray wavelengths, but not all at the same time (Osten et al. 2005), (2) normal single stars behave as if they have acoustic flux plus a uniform distribution of magnetic flux tubes (Cardini 2005); RS CVn, BY Dor, and similar classes do not.

And one of our favorite paper pairings from the year. The ergodic theorem applies to single AB Dor and binary V471 Tau (that is, only rotation and T_e matter, not how the stars got that way; Garcia-Alvarez et al. 2005); and the ergodic theorem does not apply to HD 283572 (a weak lined T Tauri), 31 Comae (in the Hertzsprung gap), and EK Dra (ZAMS), all in the same region of the HR diagram, but their coronae know the difference (Scelsi et al. 2005).

9.9. Stellar Physics and Evolution

The physics contemplated here is largely that which goes into the three auxiliary relationships of the four equations of stellar structure (radiative opacities, equation of state, nuclear reaction rates) and the convective version of the equation for temperature equilibrium and energy transport.

9.9.1. Opacities

The standard remark about opacities is that real stars always seem to need more than the theorists can find. This year, not

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[51] No, the least cosmopolitan author does not understand what this means, unless that different people will most appreciate Paris at different times in their lives. If so, she hasn't reached hers yet. Traditional movable feasts drift around the calendar (like Easter, and unlike Christmas).

true for A stars in the UV (Garcia-Gil et al. 2005) but otherwise fairly pervasive (Ramirez & Melendez 2005). Depending on the context, water (Jones et al. 2005b), other molecules and dust (Ferguson et al. 2005), and magnetic line broadening (Kochukhov et al. 2005) are likely to be contributors.

Most disquieting, the problem of insufficient opacity has spread to the Sun, now that its CNO abundance has dropped to the local stellar average (Bahcall et al. 2005a, 2005b; Turck-Chieze et al. 2004). Two recent major compilations of calculated opacities (OPAL, Opacity Project) do not differ enough for it to matter which one you use (Badnell et al. 2005). One can just about restore equilibrium by assuming a neon abundance also equal to the average of nearby stars and gas (Drake & Testa 2005) and by pushing your choices of initial heavy element abundances, opacities for them, and diffusion effects all in the same direction (Guzik et al. 2005). The required equilibrium is being able to calculate observed helioseismological frequencies from the same model that reproduces the observed solar neutrino flux.

9.9.2. Equation of State

We caught only one positive statement, that the standard model for the Sun is good enough (Young & Arnett 2005), and no negative ones.

9.9.3. Nuclear Reaction Rates and Cross Sections

Nuclear astrophysics has advanced to the stage where uncertainties in the major energy-producing reactions do not dominate our (mis)understanding of anything, with the exception, it seems of triple alpha building of ^{12}C. Fynbo et al. (2005) and El Eid (2005) report a change in laboratory data for a strong resonance at 11 MeV above the ground state of the product nucleus, whose effect is to increase the triple alpha rate at AGB temperatures and decrease it in supernovae. Because of the competition between $3\alpha \rightarrow {}^{12}\mathrm{C}$ and ${}^{12}\mathrm{C}(\alpha, \gamma){}^{16}\mathrm{O}$, one effect should be a somewhat larger C/O ratio both for massive stars heading into later nuclear reaction phases and for the white dwarfs that are Type Ia supernova progenitors. The final C/O ratio in the universe at present is somewhat less sensitive to the triple alpha reaction rate than has been suggested in the past (Schlattl et al. 2004), a result of potential importance in anthropic considerations (§ 7, above).

Among other reactions, the NeNa and MgAl cycles, high temperature analogies of the CN cycle, must occur because the right mix of products is seen in assorted red giants (Antipova et al. 2005). Authorities disagree about whether (Werner et al. 2005) or not (Lugaro et al. 2004) expected reactions can produce as much fluorine as some RGs have. This is, however, primarily a matter of getting sufficient mixing between the H and He burning shells rather than of reaction rates. The dominant process is

$$^{14}\mathrm{N}(\alpha, \gamma)^{18}\mathrm{F}(\beta^{+})^{18}\mathrm{O}(p, \alpha)^{15}\mathrm{N}(\alpha, \gamma)^{19}\mathrm{F}.$$

Other nucleosynthetic issues nearly neglected here include the existence and source of primary nitrogen and which sorts of stars make most of the neon, carbon, and various isotopes of oxygen. This leaves us with lithium, as frequently seems to be the case. It is required that some stars produce it (the Li-rich red giants) and, arguably, that others destroy it (those on the lithium plateau in globular clusters). In both cases, rotationally induced mixing is helpful (Steinhauer & Deliyannis 2004 for main sequence stars; Denissenkov & Herwig 2004 for red giants), and recall Cameron & Fowler (1971) concerning transport of ^{7}Be, the form in which the ^{7}Li must be made in stars, which leads us to—

9.9.4. Extra Mixing

Rotationally induced mixing and, perhaps, other sorts in excess of that expected from the simplest mixing length theory (which carries energy and stuff just to the point where the radiative temperature gradient drops to the adiabatic value and then stops) have been declared necessary in a number of contexts. Pasquini et al. (2004) discuss lithium yet again and Origlia et al. (2005) the ratio ^{12}C/^{13}C in a couple of open clusters. As for how it happens, Mathis et al. (2004) address shear-induced turbulence from differential rotation and Young & Arnett (2005) convection-induced mixing into radiative regions in close binaries. A test of the extent of overshoot, via its effect on the C/O ratio in white dwarfs, should be possible from changes in ZZ Ceti pulsation frequencies when their cores crystallize (Corsico 2005), provided of course that one has understood all the other physics that enters into determining C/O.

Within mixing length theory, mild surprise was occasioned by (a) values of the mixing length to pressure scale height ratio less than 1 for a couple of exoplanet hosts (Fernandes & Santos 2004) because it is 1.63 for the Sun and (b) the existence of no fewer than four sorts of scale length in three-dimensional stars (Käplylä et al. 2005). If your reaction is that three-dimensional stars are the only sort you have seen, then probably we should back off and say three-dimensional models of stars.

Although the Sun is the only star on which we can resolve small convective elements as a test of theory, rising and falling gas distorts the line profiles of other stars in ways that are now more or less understood (Gray 2005).

9.9.5. p, s, r, and ν Processes

Well, these have to go somewhere, and, since they happen in stars, here they are in with the Marx Brothers (about whose amusingness your authors disagree) and all. The *p*-process makes proton-rich isotopes of heavy elements and, say Hayakawa et al. (2004), what really happens is knocking loose of neutrons by energetic photons. The *s*-process happens in stars less metal poor than $[\mathrm{Fe/H}] = -2.6$ (Simmerer et al. 2004), and its products have now been seen in a globular cluster and the nearly-merged galaxy IGI (Caffeu et al. 2005, firsts for both, say the authors).

The *r*-process makes the isotopes with more neutrons than the most tightly bound ones at the bottom of the valley of beta stability. Where does it happen? We caught one vote for NS+BH mergers (de Donder & Vanbeveren 2004) and two votes for proto–neutron star winds in core collapse supernovae (Suzuki & Nagataki 2005; Kohri et al. 2005).

A few rare isotopes, e.g., ^{45}Sc and ^{49}Ti, can be made only by neutrino interactions. Pruet et al. (2005) recommend hot bubbles with p/n ratio >1 in supernovae. As long as this is not a travel recommendation, we are perfectly happy to take it.

9.9.6. Real Time Stellar Evolution

We take this to mean significant changes in a time less than, say, the sum of the ages of the authors, with a courtesy extension to events rather longer ago than that, which, however, happened at a sharply enough defined times that they could have been observed as RTSE events if astronomers had been looking with suitable tools. Examples of this extension include the Becklin-Neugebauer object, which must have started its escape from the θ^1 Ori region about 500 years ago (Rodriguez et al. 2005b) and HD 56126, which stopped being an AGB star 1240 years ago and is now a proto–planetary nebula (Meixner et al. 2004).

The 2005 examples of evolutionary changes in our combined lifetimes have nearly all appeared in previous editions of ApXX and so get only one paper each this time around. FG Sge was first, and it would seem that the fun is now over, since it has looked like a typical AGB star for the past decade, with constant luminosity, appropriate mass loss rate, and so forth (Gehrz et al. 2005). Two other (probable) examples of very late helium flashes and associated major changes in surface temperature, composition, and luminosity are V605 Aql (Lechner & Kimeswenger 2004) and V4334 Sgr (Sakurai's object) which should loop back to the red again in about 2250 (Hajduk et al. 2005), with special recognition for the commentary by Asplund (2005), who mentioned Our Book.

The status of McNeil's nebula is less certain. Ojha et al. (2005) this year claim it as an EXOr or FUOr (young, variable accretion disk) and three papers uncited concur (two) or at least don't discur (one).

V838 Mon appeared in the most notebooked papers (six) and with the least certain status. Several make firm statements, though none so firm as the colleague who told us insufficiently privately at a conference that Ap04 was full of banana chips for doubting the planetary companion hypothesis, so the pale green star goes this year to Banerjee et al. (2005) for their firm "cause and energy source still unknown."

Groenewegen (2004), however, received the coveted pink blot for having noticed that 3 of 2277 known S/M/C stars have switched from O rich to C rich in the last 20 years (a comparison of OGLE, 2MASS, and DENIS data sets). If you will get out your abacus[52] you can verify that this means one such switch per star in 15,000 years. The author posits last thermal pulses of helium burning that just happen not to have been seen as FG Sge-type events. The sample stars are in the Magellanic Clouds, where producing C stars is relatively easy because of the smaller initial amount of O to be overcome.

9.9.7. Slower Evolution

This is the sort calculated from the standard four coupled non-linear differential equations or deduced from the appearance of Hertzsprung-Russell diagrams and their ilk. Important public service in this context consists of calculating and publishing large numbers of evolutionary tracks like those of Claret (2004) for 0.8–125 $M_\odot$ solar composition stars, using the best available opacities, nuclear reaction networks, and equations of state, and reasonable amounts of mass loss and convective overshoot. The larger masses are followed up to the end of carbon burning. Nearly everything turns out well.

Now comes the less happy part. There are discrepancies between the masses of stars estimated from spectroscopic criteria and from evolutionary tracks. The spectroscopic masses are larger for FGK dwarfs (Valenti & Fischer 2005a) and smaller for early O stars (Massey et al. 2005). And there are stars like ν Eri, with a number of β Ceph type modes, whose full range of properties cannot be fit with the same model from any one set (Ausseloos et al. 2004).

If you want to attempt stellar population synthesis to compare with the integrated spectra of a bunch of stars, you need to connect the L, T_e, and composition of your models with the observed quantities color, magnitude, and line intensities using a reference set of individual stellar spectra, observed or calculated (Martins et al. 2005). Detailed questions someone might want to ask or answer include:

1. Do evolved stars sometimes loop back blueward of the red giant region? Yes, sometimes, say the calculations of Ventura & Castellani (2005) and the observation by Southworth et al. (2004) of V621 Per.

2. Do stellar collisions and mergers ever really matter? Yes, say Laycock & Sills (2005) in a paper that got a multi-colored dot,[53] because, by including pre–main-sequence stars in their repertoire (for instance pre-MS+WD merger) they were able to produce high mass horizontal branch stars and other curiosities.

3. What is the minimum mass a star must start with to survive the superwind phase and carbon ignition and evolve on to core collapse? Well, it is different for single stars and primaries of close binaries which are likely to lose lots of mass to their companions. So the mass cut is larger in close binaries, right? Wrong, say Podsiadlowski et al. (2004). Typical numbers are

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[52] The darkest-haired author owns at least four of these and remains ashamed to admit to her Uncle Hugo and Aunt Hepzibah, a.k.a. Mitsunori and Nobuko Kawagoye, that she has still not learned to use any of them.

[53] Remember we also own a collection of raisin labels.

10–12 $M_\odot$ for single stars and 6–8 $M_\odot$ for close binaries. The cut also comes at smaller masses for small metallicity and larger overshoot, again backward from what at least one of us would have guessed. And to top it off, the neutron stars they liberate from close binaries go off with smaller kick velocities than do the singletons, as a result of differences in the supernova onset process.

At this point, nothing could surprise us, and so we end the subsection with a few thoughts on the initial mass function, which may remind you of the few words said by Prof. Dumbledore before the opening-of-term dinner in Harry Potter I.[54]

What is the IMF? The distribution of stellar masses, $N(M)$, on the ZAMS at some formation event. Are binaries as a rule included properly? No. What does it look like? A power law or right hand side of a Gaussian at large mass, a flattening or turn over somewhere below 1 $M_\odot$, and a real turn down into the brown dwarf desert. Is it everywhere the same? The traditional answer, pertaining largely to the upper mass end, is yes, and this persists at least approximately for big young clusters that will eventually be globular clusters in two dIrr galaxies (Larsen et al. 2004). But there were also some no's, with starburst clusters having a larger maximum star mass than the field in the same galaxies (Chander et al. 2005), though this could mean simply that the biggest stars don't live long enough to be liberated.

Variations on the low-mass end of the IMF are better established. The peak is near 0.8 $M_\odot$ in the Taurus star formation region vs. 0.1–0.2 $M_\odot$ in Orion (Luhman et al. 2004). The Cha I region also has fewer 0.1–0.3 $M_\odot$ stars than Orion (Feigelson & Lawson 2004). And three young clusters studied by Barrado y Navascues et al. (2004) all have some brown dwarfs but a gap in $N(M)$ near 0.05 $M_\odot$.

Is the IMF understood? Yes, by several groups, though it is not quite certain that they all have the same understanding. Bate & Bonnell (2005) emphasize your old friend the Jeans mass (for the peak) and stochastic processes (for the slope of the high mass end), while Larson (2005) and Jappsen et al. (2005) emphasize other properties of the gas: cooling processes and turbulence, respectively.

9.10. Binary Stars

To say that binary stars don't get no respect would be an exaggeration as well as a double negative. But they don't get as much respect as they deserve, making up more than half of all stars, at least outside the M dwarf range, but only 4 of 19 pages in our index. Neglect of binaries in a stellar population will make you think it is younger than it really is (Zhang et al. 2005a; Xin & Deng 2005) and will lead you astray in matters of chemical evolution as well (de Donder & Vanbeveren 2005). Many interesting astronomical entities are found only in binaries, including cataclysmic variables, X-ray sources, and recycled pulsars. Nelson et al. (2004) have provided a very extensive set of evolutionary models that include white dwarf cooling, shell flashes, and much else and lead to no disastrous contradictions with observed populations.

Evolution of individual systems was historically done by assuming conservation of both mass and angular momentum. This is no longer the norm. Petrovic et al. (2005) is a fairly random sample relevant to Wolf-Rayet binaries. And, in a nod to another very old problem, Williamon et al. (2005) have found that the dumpee during the first phase of Roche lobe overflow mass transfer settles down to become a normal star again fairly soon. According to folklore, the first person to try to follow the mass recipient was a Berkeley graduate student named Benson who, in despair, abandoned the problem and astronomy.

On the observational side, a whole handful of green dots, reproduced here in black and white (because we pay our own page charges)—

- Really good numbers (measured and derived) for mass, luminosity, temperature, and age of the Sirius AB system (Liebert et al. 2005a). Given a system age of 225–250 Myr and a white dwarf cooling time of 124 ± 10 Myr, the initial primary must have had a pre-WD lifetime of 91–136 Myr and so an initial mass of 5.056 ± 0.3 $M_\odot$. And theory with calibration says that a 5 $M_\odot$ star should leave a 1 $M_\odot$ WD, which is just what you find there. That Sirius may not be a member of the Sirius supercluster (King et al. 2003) is just one of those things that are sent to try us.
- The largest dynamical masses we've seen in a long time, 80 + 80 $M_\odot$ for a pair of Wolf-Rayet stars (Rauw et al. 2005).
- In another echo of the distant past, the revived suggestion that Population II stars have a smaller fraction of initial binaries than do Population I stars. Carney (2005) says 10% for halo stars on retrograde orbits vs. 28% for Pop I stars in the same range of binary periods, etc., though to end up with the 10% binaries now seen in the core of 47 Tuc, Ivanova et al. (2005a) say the initial incidence must have been very close to 100%.
- Binary Cepheids, of which there were zero when we were children, now add up to at least 18, of which 8 or 9 are actually triples (Evans et al. 2005c).
- On the subject of triples and quads in general, about 1/3 of the weak hierarchical systems examined by Orlov & Zhuchkov (2005) will not last more than a million years, suggestive of recent capture, perturbation, or exile from their parent clusters. Apparently lots of now single and double stars have come up (or down?) through this route. Data for a range of young star samples imply that a typical formation event yields 2–3 stars per core (Duchene et al. 2004; Ratzka et al. 2005), while calculations yield 5–10 (Goodwin & Kroupa 2005), a configuration not often observed.

And now the green dot you faithful readers have both been waiting for, another study of the distribution of binary system

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[54] These were "nitwit, blubber, oddment, tweak" and it has only recently occurred to us that the purpose may have been to elude a magic spam filter, confirming evidence being the absence of Spam™ from the extensive menu listed for the dinner. The next notebook line is a description of the first camel race run with robotic jockeys.

mass ratios with a second peak at $M_2/M_1 \approx 1$ as well as the peak at small values (Fisher et al. 2005). We find ourselves cited but not credited with the once anathematic idea that the distribution is bimodal. If you would like to look for yourself, the largest sample available is the 9th (mostly online) catalog of the orbits of spectroscopic binaries (Pourbaix et al. 2004). The previous, 8th, catalog appeared on paper in 1989.

Because stars are not actually point masses or rigid spheres, members of a pair drag on each other, gradually rotate the line of apsides (Wolf & Zejda 2005), and, in due course, circularize the orbits (Meibom & Mathieu 2005, who find that older populations are circularized out to longer orbit periods), synchronize rotation and orbit periods (Abt & Boonyarak 2004), and bring together into close orbits star pairs that must have been wider when they formed (Guenther et al. 2005 on BS Indi, at about 0.435 day and 30 Myr the shortest period young binary). Ivanov & Papaloizou (2004) give an improved model for tidal circularization and synchronization for the case of low mass stars, which are fully convective, with turbulence providing the viscosity.

Ah, but wipe that smile off your face (or wherever you customarily carry your smile). Many of the calculations and often the interpretation of data assume that stellar rotation and orbit axes are parallel. This is wrong for about half the systems examined, with apsidal motion data, by Petrova & Orlov (2003).

And please wave goodbye to the following sorts of binary system, since we will not mention them again, at least until Ap06—

Cool Algols (Mader 2005 on AV Del, the 7th with an orbit, the first having come from Popper 1976). Also Algols with superhumps, which, like CV superhumps, are caused by a beat frequency between the orbit and disk precession frequencies (Retter et al. 2005).

RS CVn systems with apparent abundance anomalies, for which Morel et al. (2004) say that non-LTE effects are a better bet.

A β Lyrae system with material still flowing from M_1 to M_2 (Djurasevic et al. 2004).

A W UMa star on the way to becoming an FK Comae (rapidly rotating giant) or blue straggler (Qian et al. 2005).

V471 Tau, the prototype of the V471 Tau stars, now fading and perhaps perturbed by a 3rd star (Ibanoğlu et al. 2005). And, since V471 Tau stars these days are more often called pre-CVs,

° The cataclysmic variables. What? A whole notebook page with 30 highlighted papers gets one lousy hollow bullet? Yup, and 4 papers.

One for the single nova in a local dwarf galaxy (Neill & Shara 2005), which is a lot for that observation, we promise.

Two for GK Per (nova 1901), which now looks a good bit like Cas A and might be called a CNR (no, not a French sponsoring agency, but a classical nova remnant by analogy with SNR; Anupama & Kantharia 2005, Balman 2005).

Three for a fixed amount of accreted hydrogen as the trigger for nova explosions (Schaefer 2005) from a very clever examination of the three recurrent novae that have exploded at least three times in recorded history (another version, we suppose, of the Hirsch citation or Eddington bicycle number).

Four for R Aqr, which these days is a mere symbiotic star, but which experienced two outbursts in 1073 and 1074 CE (recorded as guest stars in Korean history) plus two more in 1350 and 1814 that launched expanding shells (Yang et al. 2005).

9.11. Population III, First Lights, and Reionization

These topics were belabored in Ap04 (§ 7) and Ap03 (§ 3.8) and not another word do you get until another year, two years, three years…of *WMAP* data have been released and interpreted (or, perhaps, interpreted and released). But perhaps just a few numbers. Most of the early metals came from Pop III stars of 10–50 $M_\odot$, while most of the reionizing UV and black holes came from 50–140 $M_\odot$ stars (Tumlinson et al. 2004; Daigne et al. 2004). But the metals turn off Pop III star formation when only 1/3 of the necessary photons have been generated (Matteucci & Calura 2005).

Less than half the early UV comes from QSOs, say Dijkstra et al. (2004). Or is it more complicated, with up to $z = 15$ dominated by soft X-rays from accretion on black holes, then stars taking over to wipe out remaining high density gas at $z = 6$–7 (Ricotti et al. 2005)? And we all know that the current intergalactic ionization is largely maintained by AGNs. 0% QSO light at the beginning would suit Malhotra et al. (2005).

And there we will leave the issue until someone wins the Vera & Robert Rubin Prize for spectroscopic confirmation of a $z > 7$ source, *WMAP* speaks again, or the Messiah comes (on whichever number visit you are anticipating).

9.12. Stars in Clusters—Open

The smallest cluster contains one star and is reached via “the cluster richness distribution [which is] continuous down to the smallest cluster, consisting of one” (de Wit et al. 2005). This way of looking at things accounts for the distribution of O stars amongst clusters, runaways (at least half), and 4% non-runaway field stars. Clusters with mass less than 25 $M_\odot$ exist and cannot contain any early O stars. Their demise is also not the main source of field stars (Soares et al. 2005). Mechanisms for producing runaway stars were first put forward by Poveda et al. (1967), which is relatively easy to find, and Ambartsumyan (1938, which we put forward as a challenge to search engines). If, as above, a single star can count as a cluster, then each of the following topics is described in a cluster of papers.

- The closest moving group, centered literarily if not physically on AB Dor (Zuckerman 2004), contains about 30 other stars.
- The TW Hya moving group really consists of two associations of different ages (Lawson & Crause 2005).
- There are moving groups that are not remnants but the

products of transient spiral waves sweeping existing stars into dynamical groups (Famaey et al. 2005).

- The Pleiades is part of one of these sweep-up operations (Quillen & Minchev 2005).
- In h and χ Persei, only the former shows mass segregation (Bragg & Kenyon 2005), another dynamical process unless it is primordial, and watch out for the use in this paper of "Hubble law" to mean the density distribution in the cluster.
- Other moving groups have escaped from larger clusters (Chumak et al. 2005).
- Open groups do fall apart, concerning which we highlighted 8 papers. You get only the one that points out the cluster can still be identified for a long time after it ceases to be bound (Fellhauer & Heggie 2005).
- Gould's Belt seems to be an example of this process, currently expanding but still identifiable (Bobylev 2004a).
- The star formation efficiency determines whether a cluster is ever really bound, if you start with a virialized cloud. Hardly ever, say Tilley & Pudritz (2004).

If you would like to initiate a project on open clusters yourself, Kharchenko et al. (2005) provide a handy catalog of new ones, typically richer than the 520 previously known. All clusters contain some binaries, and we think the range found (15%–54%; Bica & Bonatto 2005) is too large to be just statistical fluctuations and selection effects. There must be real differences, and if you ask whether these are primordial or the result of dynamical evolution in the cluster, the answer will surely be "yes." Some real differences among clusters in their initial mass functions include substructure and breaks (Pollard et al. 2005 on M10 and Balaguer-Nuñez et al. 2005 on the sum of 5 clusters).

Stars tend to huddle (cluster may be too technical a term) around the centers of galaxies. There are clearly two or more types of such huddles. Sarzi et al. (2005) report stars mostly $\geq$1 Gyr old at centers of 23 spirals. Walcher et al. (2005) discuss younger ones with 5×10^5–$6 \times 10^7\ M_{\odot}$ within 5 pc of the centers of late spirals which, if stripped, would then look like ultracompact dwarfs or big globular clusters. Some ellipticals also have central clusters of 10^6–$10^8\ M_{\odot}$, 10^7–2×10^8 yr, blue stars (Elmegreen et al. 2005). A mechanism for forming the young stars very near the center of the Milky Way was proposed by Christopher et al. (2005) and one for forming young star clusters from galactic accretion disks by Nayakshin (2005b). And you will surely agree that the subject of nuclear star clusters deserves more serious reviewing than it gets here (*ARA&A* new CEO, are you listening?).

9.13. Stars in Clusters—Globular

Perhaps one ought to start by distinguishing globular clusters from other sorts of astronomical objects. This was easy as long as only Milky Way populations were under consideration, but is no longer entirely possible. For instance, M31 has some collections of stars that are intermediate between dSph galaxies and globular clusters (Huxor et al. 2005). And a question almost as old as the most pack-rattish author's Toyota[55] is whether the clusters with very large numbers of massive stars forming today are "really" young globulars. This obviously asks for a prediction of what will still be there in 10 Gyr or so. The answer, according to our predictors of the year, is "yes" for some (de Grijs et al. 2005), but by no means all (Eggers et al. 2005). Less extrapolation is needed as the clusters age, and the case is firm for intermediate age globular clusters (1–5 Gyr) in early type galaxies (Hempel & Kissler-Patig 2004). A confirmed hierarchist would say that they are the product of the last major merger during assemblage of the galaxies. Don't wait too long to go back and check, though; even globular clusters can die (Koch et al. 2004).

If you've seen one globular cluster, you've seen them all? This was once nearly true (and probably still is through Messier's 4-inch refractor). But if you also measure luminosity, characteristic radius, location and velocity in the host galaxy, age, metallicity, and [α/Fe] or some other deviation from solar heavy element mix (or even a sort of product of age and composition called color), the clusters of nearly every galaxy separate into two or more populations. These can be studied either for their own sakes or as guides to the galaxy formation process. The Milky Way now has three populations (Mackey & Gilmore 2004) representing about 7 merger events and a major initial collapse. A similar monolith + sacrifice of dwarf spheroidals scenario is discussed by van den Bergh & Mackey (2004) and by de Angeli et al. (2005).

Great big elliptical galaxies have great big cluster systems, with metallicity extending up to solar and a wide range of all properties (Woodley et al. 2005 on Cen A; Forbes et al. 2004 on M60; and Brodie et al. 2005 on NGC 4365, with probably three populations of different composition).

The galactic globular cluster of the year was, once again, ω Cen, with papers referring to its unsavory past as a dwarf elliptical galaxy, to the remarkably large value of helium abundance in some of its stars, and its unfittable white dwarf population (Ideta & Makino 2004; Piotto et al. 2005; Monelli et al. 2005). And the maximum complexity star goes to Sollima et al. (2005) for identifying five separate populations of red giants in ω Cen with different ages, metallicities, and kinematics.

The multiplicity of pulsars in 47 Tuc (Ransom et al. 2005, one with a mass as large as 1.68 $M_{\odot}$) and in Terzan 5 (Ransom 2005, the current record-holder) pail by comparison (you need a bucket to carry all the preprints), and fade into the general,

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[55] We are indebted to the Faustian Acquaintance for the information that the Maxwell, Jack Benny's transport of choice, was manufactured until the year of FA's birth (though not in the same country), so that Saxon, the 1980 Toyota, may well be about the same age as the Maxwell, which vanished when Benny made the transition from radio to television, for the excellent reason that it was played by Mel Blanc, who did not look much like J. C. or any other Maxwell.

long-standing problem of whether there are enough X-ray binaries in the clusters to give rise to all the recycled and binary pulsars seen (Ivanova et al. 2005b). In case you aspire to settle this observationally, the field of 47 Tuc actually contains about 300 X-ray sources (Heinke et al. 2005), but 70 are background sources, about 25 the millisecond pulsars themselves, and most of the rest are cataclysmic variables and chromospherically active binaries.

The better you get to know globular clusters, the more types you find, and we allude cheerfully to the multiplication of entities beyond the two original Osterhof types, called I and II curiously (Contreras 2005 on M62 with its 200+ RR Lyraes; Castellani et al. 2005 on M3) without aspiring to tell you the cause.

The second parameter problem means an attempt to assign cause(s) to the range of horizontal branch morphologies among clusters with the same overall metallicity. This year, the discussions should probably be described as "presented" rather than "voted for": Caloi & D'Antona (2005) on helium abundance, which requires a population of stars that produce $\Delta Y/\Delta Z = \infty$; Cho et al. (2005) on CNO/Fe variations; Zhao & Bailyn (2005) on fraction of close binaries; and Smith (2005b) on deep mixing.

10. BETTER MOUSETRAPS, SQUARE WHEELS, AND DOGS' DINNERS

The first of these are generally regarded as good (assuming you want mice to beat a path to your door), the second as bad (unless you have misinterpreted the consequences of the kinetic coefficient of friction being smaller than the static), and the third as rather a mix (at least in cultures where dogs were fed table scraps[56]). This section contains some of each, and your authors feel that, by § 10, they are already in enough trouble without stating which is which.

10.1. Widgets

One ought to be able to distinguish widgets that actually exist from plans (and we will try to do so), but there are borderline cases. A contract has been signed and casting begun for the first of the 8.4 m mirrors needed for the Giant Magellan (he was only 5'4" you say?) Telescope, but you should not try to apply for observing time just yet (Schechter 2005; Anonymous 2005e). OWL, the OverWhelmingly Large telescope, received another official blessing (Gilmozzi 2005), but no mirror segments have been cast yet.

Among existing devices, and starting with the longest wavelengths, we welcome the increasing productivity of the Giant Meter Radio Telescope (*Bull. Astron. Soc. India* 32, 191, and following papers, the proceedings of a conference honoring Govind Swarup's 75th birthday). In the submillimeter regime, first results came from a new array (Ho et al. 2004 and the next 17 papers) and from a portable submillimeter telescope (Oka et al. 2005), meaning the wavelength, not the size, which is 18 cm. It has been used at the Atacama site at 4840 m (15,880 ft, at which height your most oxygen-challenged author can't even do derivatives). MINT has been observing the cosmic microwave background at 2.1 mm from Cerro Toco (Fowler et al. 2005). And Motohara et al. (2005) have carried out a submillimeter study of a $z = 2.565$ dwarf galaxy that will end up with less than $10^{10}\ M_\odot$ of stars when all the gas is gone. They used a Zwicky telescope (gravitational lensing). A submillimeter telescope made with four parabolic cylinder reflectors is in the planning stages (Balasubramanyam 2004).

Also in the transition from planning to construction is the lower-frequency LOFAR which will, it seems, go ahead on more than one site (Kassim 2005), including The Netherlands plus Germany, Western China, and NW Australia. The plural, we think, is LOFARIM. The Square Kilometer Array isn't that big yet, but has already defined a number of key projects (Carilli & Rawlings 2004, proceedings of a conference).

Optical astronomy remains more than half of the observational total, and mirror coatings last longer if purged with very dry air (Roberts et al. 2005a). We experienced an out-of-period, back to the future moment in reading that the Gemini north mirror will be coated with silver rather than aluminum next time around.

Partial adaptive optics (unlike half an eye, according to the intelligent design folks) is actually useful (Tokovinin 2004). New methods of wave-front sensing were proposed by Bharmal et al. (2005) and by Oti et al. (2005). A laser guide star is now in use at Keck (Melbourne et al. 2005). The superconducting tunnel junction detector (whose advent we hailed a few years ago) is approaching routine use at the William Herschel Telescope (Reynolds et al. 2005a, with the AM Her nature of V2301 Oph among its discoveries). CHARA is now using all six telescopes (McAlister et al. 2005) to measure shapes of rotating stars, gravity darkening, and such, while the VLT tries to fool mother nature with a new sort of coronagraph, a four-quadrant phase mask (Boccaletti 2004).

If robotic telescopes are still not quite routine, conferences on them have become so (Strassmeier & Hessman 2005, and the following papers). A sort of giant speckle interferometer with a balloon-borne focal camera called Carlina has seen fringes on Venus (Le Coroller et al. 2004). A 1500 m effective aperture with adaptive coronagraph could image planets like Jupiter out to a few parsecs. Carlina lives with the robotic telescopes because live volunteers for ascending to the focal plane are likely to be scarce.

GALEX, an ultraviolet survey instrument, launched in April 2003, reported back in a set of 31 papers (Martin et al. 2005b and the next 30).

At the highest gamma ray energies (where photons reveal themselves by doing horrible things in the upper atmosphere), H.E.S.S. in Namibia yielded so many papers this year that it

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[56] The Faustian Acquaintance has recently acquired a dog, who, being named Pele, eats, we presume, Brazil nuts.

hardly feels new. All can be recognized in our reference list and elsewhere as Aharonian et al. (200ℵ).

VERITAS was the subject of a conference (Swordy & Fortson 2004), but with the site somehow permanently under attack, perhaps it is time to fill it with wine and declare “in veritas vino.”[57] (Northcutt 2005 on the difficulties of using an O’odham site.)

The search for gravitational radiation soldiers on. Frosatti (2005) has designed a spherical detector to operate at 0.068 K, at Leiden, and at a cost of 3 milliLIGO. The one that cost 1 LIGO reported an upper limit on flux from pulsars (Abbott et al. 2005), while the AURIGA bar set a limit on emission from the giant flare of SGR 1806−20 of $10^{-5}\ M_{\odot}c^2$ (Baggio et al. 2005). And an award for subtle courage goes to *Physics Today* and *Nature* this year. The volume by Collins (2004) devotes much of the 2nd half of its 864 pages to how LIGO won out over all other technologies, to the sorrow, distress, and sometimes damage to careers of their proponents. The greatest loser was arguably Ronald Drever of Caltech. *Physics Today* invited him to review the book. The first half consists largely of unkind (and sometimes untrue) remarks about Joseph Weber and the searches he carried out (for astrophysical neutrinos as well as gravitational radiation). And *Nature* invited his widow to review the book.[58] Both reviews are a good deal more restrained than you might have expected.

Time standards get ever better (Diddams et al. 2004 and several following papers). They start somewhere around the klepsydra era, as do Davis (2004) on photographic emulsions and Taylor & Joner (2005) on photometry of the Hyades.

Widgets designed for use in the laboratory have made or imitated (a) aurorae (Pedersen & Gerken 2005), (b) Herbig-Haro objects (Lebedev et al. 2004) and other sorts of magnetic jets (Lebedev et al. 2005), and (c) grain alignments analogous to the Davis-Greenstein alignment of interstellar grains. Abbas et al. (2004) used micron-sized non-spherical grains illuminated by lasers and rotating at 1–22 kHz. But they need to use much stronger ambient magnetic fields than are present in the ISM for the grains to align this year or decade. The purpose of the laser illumination is to permit measurement of the rotation rate. And foots are aplan (should this be feet?) to produce “Hawking radiation in an electromagnetic waveguide” (Schützhold & Unruh 2005).

10.2. Forces Majeures

Each year there are, of course, people who want to improve human understanding of the universe by abolishing relativity in favor of Newton or even Galileo, quantum mechanics in favor of diceless play, and thermodynamics in favor of free lunches. But most of them do not publish in the journals we read. Thus the time machines of 2005 (or 1905 or 2105? Ori 2005), as well as the violations of Lorenz invariance (Alfaro 2005), and the entities that might challenge the laws of thermodynamics (Barnich & Compere 2005) and improvements of the Michelson-Morley experiment (Antonini et al. 2005) in our notebooks were relatively innocuous.

The four forces were all alive and well during the year, at least at low energy and redshift. Gravity always wins, both in numbers of papers and in dominating the structure of large things made spherical (authors and readers excluded) and so comes at the end. The nuclear shell model is still useful (Caurier et al. 2005), though the magic numbers are different for nuclides whose neutron numbers are either much larger or much smaller than that of the most stable nuclide of the same atomic weight (Fridmann et al. 2005; Janssens 2005). And we had never noticed that no stable nucleus has exactly 19 neutrons (plus vice neutrons etc.).

The weak interaction remains sufficiently weak that one is always glad to hear that anything has been detected. Believe it or not, $\mathrm{GdCl_3}$ dissolved in water makes a good Cerenkov detector for antineutrinos (Beacom & Vagins 2004, with a special thanks to the second author for the vial of this very sour salt that lives on our bookcase; it is not noticeably poisonous). The neutrino flavor switching seen by the MINOS experiment between Fermi Lab (source) and the Soudan mine in Minnesota (detector, Anonymous 2005k) does not seem to have sour as any of the available flavors, which have been coupled by a new, best-ever value of $\sin^2\theta_w = 0.2397 \pm 0.0017$ (Czarnecki & Marciano 2005). This is said to be the last experiment that will be performed at SLAC. A second nuclide has exhibited double beta decay, ^{54}Zn (Blank et al. 2005). The first was ^{45}Fe, ending up as Cr. This is not the magical sort of double beta decay that would imply some neutrinos are their own antiparticles (majorons) but the plain old difficult sort, in which two neutrinos must be emitted.

On the electromagnetic front, the unanswered (or multiply answered) question of the decade or thereabouts is whether $\alpha = e^2/\hbar c$ was different in the part of the past explored by QSOs at large redshift. Six papers voted during the year, of which we cite only Levshakov et al. (2005) riding both horses in midstream to report that their VLT sample of spectra between $z = 1.88$ and now shows no evidence for change, but the earlier Keck sample does. Other things that didn’t change much during the year were the proton-electron mass ratio (Ivanchik et al.

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[57] This thought somehow involved us in an extended discussion with our advisory committee on the identity of the best vintage ever. The Faustian Acquaintance voted for Haut Brion 1964. A name-tagless bearded AAS participant advocated the 1961. The Keen Amateur Dentist doesn’t drink, making him a marvelous person to sit next to at conference dinners where the glasses are filled automatically. And the Medical Musician responded with an incomprehensible anecdote concerning a very elaborate meal served in a Paris penthouse by an Enron executive. Mr. H. had been consuming some less prestigious vintage, making him unavailable for comment.

[58] By analogy with Winnie the Pooh, who lived under the name of Sanders, she has always lived under the name of Trimble, and yes, like *The Horn Blows at Midnight* and SN 1987A as current events, there must be a whole new generation who will never know.

2005), the charge on the photon, less than 3×10^{-33} of that on the electron (Kobychev & Popov 2005), and the sizes of the electron orbits herded by Maeda et al. (2005). Their whip is applied radiation at the 13–19 GHz that would be the orbital frequency if lithium electrons were classical horses.

Gravity being the weakest force required the largest number of indexed papers (24) to keep it together. If you are having only one thought on the subject this year, it should probably be that general relativity continues to triumph over its enemies (Williams et al. 2004a on lunar laser ranging; Stairs et al. 2004 on PSR 131534+12). Some GR effects that appear as expected include Lens-Thirring precession (Miller & Homan 2005, from a BHXRB, not *Gravity Probe B*), gravitational radiation (Espaillat 2005, from the CV ES Ceti, not LIGO), ergospheres in Seyfert galaxies (Niedzwiecki 2005, from spectrum fitting, not visits), and black holes in higher-dimension supergravity (Eluang et al. 2005, Gibbons et al. 2004, from calculations, not measurements).

Nemiroff (2005) suggests that one might be able to see the gravitational lensing of the gravitational force itself (if you should happen to find yourself 24 AU from a transparent Sun). Various limits were set to secular changes in G, the gravitational coupling constant (Pitjeva 2005). We suspect that the number, $\dot{G}/G \le -2 \pm 5 \times 10^{-12}$ yr^{-1} probably applies to GM of the Sun, rather than G alone. Thus it might suffer a glitch when the kilogram is redefined in terms of the Planck constant or Avogadro's number (Mills et al. 2005), instead of in terms of a chunk of metal in Paris (which has always been at risk of small additions or subtractions during those movable feasts). At least five non-GR descriptions of gravity also appeared, of which loop quantum gravity (Mulryne et al. 2005) appears to be the most conventional, and inhomogeneous gravity (Clifton et al. 2005) the least.

10.3. Physics of the Early Universe

There must once have been a quark-gluon plasma. Whether this has been recreated in accelerator experiments remains to be determined (Wilczek 2005b; Aronson 2005). Baryogenesis obviously also happened and has definitely not been duplicated in the laboratory, so that we are all made of 13.7 Gyr year old baryons. Four possible mechanisms appeared in the reference journals of which the most mysterious is that of Davoudiasl et al. (2004), in which there is a gravitational interaction between the derivative of the Ricci curvature scalar and the baryon number current in the expanding universe. This breaks CPT (charge-parity-time-reversal) invariance and, with baryon number violation, can make the observed baryon to photon ratio of 6×10^{-10}.

An expert has assured us all that "…the world is a multi-colored, multi-layered" superconductor of Higgs condensate (Wilczek 2005a). Whether this contradicts the earlier conclusion that all the world's a stage remains to be determined. And, as for what you have to look forward to, another expert opines that "…a physical theory of everything should at least contain the seeds of an explanation of consciousness" (Penrose 2005).

10.4. The Forces at Work

Gravity comes first in this round, since it always wins one way or another. One way it has won in galaxies over the years is called violent relaxation (Lynden-Bell 1967) and green stars and stripes for the recognition that a new dynamical theory is needed, because the existing one is not, as it were, transitive, for successive processes, $A + B \neq B + A$ (Arad & Lynden-Bell 2005). Readers will perhaps have noticed that dots, stripes, and other graffiti are often awarded to authors who change their minds or correct their own mistakes. This is probably not an adequate motivation for deliberately publishing a wrong paper.

Where gravity meets electromagnetism, you find some of the traditional instabilities and also the extraction of energy from black holes. The two-stream or Kelvin-Helmholtz instability may happen for the two interpenetrating superfluids in neutron stars if the relative velocity of the two fluids is large enough (Andersson et al. 2004). Numerical simulations of ordinary Bondi-Hoyle-Lyttleton accretion show instabilities whose underlying physics is unclear (Foglizzo et al. 2005). Such accretion is reviewed (stably we hope) by Edgar (2004). Accretion disks for galaxies, young stellar objects, black holes, and all are the topic of Greaves et al. (2005 and five surrounding papers). A new mechanism for producing quasi-periodic oscillations in neutron star–X-ray binaries (Rezania & Samson 2005) probably also belongs here. It can also, they say, make drifting subpulses in pulsar radio emission.

Energy extraction from black holes via the Penrose process, the Blandford-Znajek process, and perhaps others (Wang et al. 2004a) has had its good years and bad years. Komissarov (2005) seems to be saying that 2005 will not be remembered with the Mosel wines of 1972, let alone the haut brion of 1961 (or 1964). Production of astrophysical jets through the Balbus-Hawley instability giving rise to hoop stresses was new this year (Williams 2005) apart from conference proceedings (Massaglia et al. 2004).

Does MHD require gravitation to work, or is it purely electromagnetic? In either case, Blackman & Field (2005) conclude that the Zeldovich relations are not applicable to real cases with large magnetic Reynolds number. If this is true, we are sure that Zeldovich would have been first[59] to sign on the paper, apart from the very small difficulty associated with being dead. We count it only a small difficulty because Krisciunas et al. (2004) provides an example of a paper with two deceased authors, and one who has disappeared. RC, please, phone home (or Kevin).

Electromagnetism left to its own devices tends to radiate. Nineteen radiation processes went into the notebook this year,

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[59] Well, second. In Russian, Z comes between B and F, and he was a great believer in alphabetical order.

many of which appear elsewhere in company with the sources that use them. You will surely be thinking of electrons, so we begin with a TeV flare mechanism in which relativistic protons excite Δ resonances (Boettcher 2005, interpreting data in Daniel et al. 2005). The charmingly named "striped wind" process is a possible source for optical radiation from the Crab pulsar (Petri & Kirk 2005, properly crediting the idea to Pacini & Rees 1970 and to Shklovsky 1970). The name was even more charming in the first draft, when temporarily displaced fingers dubbed it dytiprf einf yo rmiy bidinlr lihy grom the Crab pulsar. The "Carousel of sparks" for drifting subpulses in pulsars has a certain charm too (Janssen & van Leeuwen 2004).

Quantum electrodynamics matters for the magnetar radiation process proposed by Heyl & Hernquist (2005), in which MHD waves are modified by polarization of the vacuum (not the one in the closet, the one in the equations).

Gyrosynchrotron radiation has been around for a long time (well, probably very close to 13.7 Gyr) but Burgasser & Putman (2005) may well be the first to inflict it upon M and L dwarfs (for their radio emission). The coherent cyclotron maser process (Begelman et al. 2005) is one way to produce radio temperatures in excess of 10^{12} K (an inverse Compton limit that applies to incoherent, single electron radiation; Kellermann & Pauliny-Toth 1969, Readhead 1994). A simpler trick is beaming (Horiuchi et al. 2004).

And two more putatively new processes this year challenge Ehrenfest's theorem. First is optical Cerenkov line radiation (Chen et al. 2005c), which happens when thermal relativistic electrons hit gas and drive its refractive index above $n = 1$ close to the frequency of a resonance line. And there is the inverse Faraday effect, in which a circularly polarized laser pulse changes spin states in a magnet in 200 fs (Kimel et al. 2005). Ehrenfest's theorem? Ah, we mean the one that says it is difficult to explain something even when you understand it, and almost impossible when you don't.

A few others of the processes of 2005 defy assignment to a specific force except perhaps the force and road of casualty,[60] including anthropic reasoning (Livio & Rees 2005); the rediscovery process for $P(D)$, this time for the CMB (Herranz et al. 2004); and Fourier transforms in which you either throw away the phase information and keep only the amplitudes, or conversely (Singal 2005). The intention was to improve analysis of radio interferometric images, but the test photos shown are pictures of people at an India-New Zealand test match. You still see faces if you keep only the phase information, but not if you keep only the amplitudes. Many folk at test matches (we think it is a form of spectator sport) see faces best before the third beer.

10.5. Cooling Flows

The phrase is shorthand for X-ray-emitting clusters of galaxies whose central gas temperatures and densities imply the gas should radiate away most of its energy in much less than a Hubble time. They are common enough that the "last gasp" picture won't do. What has been done over a number of years (with 22 papers this time around) is to reheat them somehow or otherwise evade the problem. Among the more or less discrete (meaning separate, not modest, like many of our colleagues) ideas were—

- Try looking at it as gas flows going both ways, with central heat input from Type Ia supernovae etc., and the problem disappears (Mathews et al. 2004b), plus a bunch of specific heating mechanisms.
- Turbulent scattering plus thermal conduction (Chandran 2004)
- Core oscillations (Tittley & Henriksen 2005)
- Radio lobes (Reynolds et al. 2005b with viscosity as an important transport mechanism, comparable with conduction; Nulsen et al. 2005 with a link to energy deposition far from the "cooling core" otherwise known as preheating)
- Gas flow through or near an accretion disk (Soker & Pizzolato 2005)
- Dynamic friction (El-Zant et al. 2004)
- Intergalactic supernovae (Domainko et al. 2004)
- Active galaxies plus conduction (Fujita & Suzuki 2005).

And the green sources of the year were (a) bubbles driven by jets from AGNs (McNamara et al. 2005, the first of many papers on the general idea) and (b) the Tsunami model (Fujita et al. 2005, with the publication schedule of *ApJ* such that they must have called it that before 2004 December 26). Despite all this energy input, classic cooling flow clusters continued to exist in the index year (Morris & Fabian 2005) and hadn't changed much since $z = 0.4$ (Bauer et al. 2005a).

10.6. The Milky Way Swollaws[61] and Other Unsettling Issues

The star most anxious to leave the Milky Way was clocked at 853 km s^{-1} (heliocentric) and 709 km s^{-1} relative to the Galactic rest frame (Brown et al. 2005c). It must have read some of the same papers we did, including the one on the Parenago (1959) effect, (Drobitko & Vityazev 2004, the general idea being that the disk kinematics are different for O-F stars and F-M stars), and the ones about crystal-like structure in the nearby interstellar medium (Shatsova & Anisimova 2003), the co-existence of leading and trailing density waves (Mel'nik 2005), and the presence of two pattern speeds for SiO masers (Deguchi et al. 2004). Either the Milky Way has been swallowing another satellite to make the Monocerus Ring, or its

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[60] This is an FSQ (Famous Shakespearean Quotation), making no sense out of context and not much more in [*The Merchant of Venice*, Act II, Scene 9, Line 30].

[61] Occasionally a word spelled backward remains marginally pronounceable and so can be used to indicate the inverse operation.

disk is warped. Conn et al. (2005) conclude that we cannot currently tell the difference.

The Cartwheel galaxy shows non-thermal radio spokes as well as optical ones, but they are not the same spokes (Mayya et al. 2005a).

Is the universe a WHIM? For all that operators of a submillimeter telescope opine that the bulk of the visible universe is at about 10 K (Ho et al. 2004), the majority view is that the single largest pool of $z = 0$ baryons resides in a Warm/Hot Intergalactic Medium at about 10^6 K (Nicastro et al. 2005b). Shull (2005) said it first during the index year and McKernan et al. (2005) were the last to say that some issues still need to be resolved, in their case whether the hot gas emitting O VII and O VIII lines near the Milky Way is real WHIM vs. the North Polar Spur, SN outflows, or something else. And there were about 10 related papers that appeared in between. We will invoke the principle of the excluded middle by saying some of our best friends are made of baryons; some of our best friends are slightly missing (or a few pickles short of a sandwich as Ann Landers would have put it); and, therefore, at least a few baryons are still missing (Sembach et al. 2004 on observations; Kang et al. 2005 on theory of the various phases).

10.7. Unusual and Alternative Histories

Most of these pertain one way or another to the history of astronomy (etc.), but a couple belong to a history of the universe in which young galaxies have significant intrinsic metallicity which decreases as they age (Harutyunian 2004). In close association, of course, the abundance of hydrogen increases with time (Harutyunian 2003). The Milky Way, whose oldest stars are the least metal rich, whether you examine the field or globular clusters (Cohen & Melendez 2005), either missed the boat or caught one going the wrong direction. And a datum you could attach to either point of view is that QSO absorption gas has an Fe/H ratio which grows from $z \approx 3$ to $z \approx 0.3$ (Prochaska et al. 2004). If large redshift means long ago and far away, then heavy elements have been created over the years. If large redshifts belong to sources recently expelled from nearby galaxies, then heavy elements have been destroyed in the expulsion process.

The chief historical green dot is not, perhaps, science, but the statement (*Time Magazine*, 1 August 2005, p. 39), “there have been some 525 nuclear explosions above ground since Hiroshima; not one of them has been an act of war.” Try telling that to the people who were at Nagasaki in August 1945. A more useful factoid is that 45% of the Hiroshima and Nagasaki initial survivors are still alive (Land 2005), as were precisely 25% (114 of 456) of the 1940 graduating class of the US Naval Academy, as of 2005 September 30. A sizeable fraction of that class did not survive 1941 December 7. And, if you can bear to look a gift tooth in the mouth, dates of birth of corpses that began life from about 1943 to nearly the present can be determined from $^{14}C/^{13}C/^{12}C$ ratios in teeth (Spalding et al. 2005) because of the range of ages at which various teeth sprout[62] and the radioactive input from those not-in-anger above ground bomb explosions.

In more traditional scientific oopsery, Stevenson (2005) told us that WKB stands for Eugene Wigner, Hendrik Kramers, and Leon Brillouin. The ghost of Gregor Wentzel would rise to protest, but he is busy dancing one of those Viennese waltzes with Graffin Maritza. Sir Harold Jeffreys was apparently unknown to the author but would surely have volunteered the information that tsunami is its own plural, like zori and sheep. We are always very careful to say WKB-J method. And some others:

“Scientists have known since the 1950s that they were seeing too few solar neutrinos” (*Science* 306, 1458), but Ray Davis didn’t start looking until the 1960s.

“He [Fred Whipple] was the Leonard Medalist (1970) and the Bruce Medalist (1986) of the Meteoritical Society.” (Hughes 2004.) But the Bruce is given by the Astronomical Society of the Pacific, whose advisory committee one of us and a Las Cumbres colleague have joined so recently that we do not yet know whether our advice will be taken.

“…which enabled Joseph [Barclay] to announce in 1856 the discovery of a companion star to Procyon” (Barclay 2004). This would have surprised both Alvan G. Clark, who did not discover the companion to Sirius until 1862 (and is generally credited as the first to see photons from any white dwarf) and even more Schaeberle who thought, and said, in 1895 that he was the discoverer of Procyon B.

“…firm evidence that the universe is expanding” credited to V. M. Slipher in 1917 (Heavens 2005). Not quite. It was the redshift-distance relation, and, while Slipher measured the first set of redshifts (and Milton Humason the second) the distances and the publication of the correlation came of course from Hubble. Granted that Slipher and Humason sometimes get too little credit and Hubble too much, this is, nevertheless the sort of overcorrection of steering that sometimes afflicts cyclists with small Eddington numbers.

“Fermi won a Nobel Prize in 1938 for his discovery of the properties of slow neutrons” (Maltese 2005, in a book review). Well, the citation, which mentions new elements first, was of course wrong, and we fly swiftly back in memory to the moment when, perusing the aging pages of *Comptes Rondue*, we discovered that the French Academy has hastily revised the citation of the LeConte Prize to award it to Blondlot “pour le corps de ses ouvres” rather than for the discovery of N-rays. It was a talk by Philip Morrison called “The N-ray dosage and protection problem” that sent us to the library to see what had been done about the citation. About half the talk, like the Collins (2004) book, consisted of unkind remarks about Joseph Weber.

“1955…there was almost no television” (*Nature* 433, 785).

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[62] Presumably in the absence of attention from the Keen Amateur Dentist.

We cannot speak from personal experience about the situation in London, but in Los Angeles there were 7 channels (3 network, CBS = 2, NBC = 4, and ABC = 7, and 4 local, 5, 9, 11, and 13, other even numbers belonging to surrounding communities like San Diego and Santa Barbara) and the first live remote coverage of an on-going news event (the search for Kathy Fiscus, a little girl who fell down a disused well shaft) was already more than five years in the past.

"Happy hundredth birthday to…Dippy, the giant Diplococus…that took up residence on 12 May 2005…" (*Nature* 435, vii). Either they mean 1905, or postal copies of *Nature* have been coming even later than they used to.

"Eddy dubbed this the Maunder minimum, after E. Walter Maunder (1851–1928) who had called attention to this aberration in the 11-yr sunspot cycle" (Robinson 2005a). William Herschel and Gustav Spörer had actually noticed the prolong minimum earlier. The name clearly obeys Stigler's law (things get named for the last person to notice them and not credit his predecessors), but Spörer gets his minimum for the one around 1450, and Herschel almost got a planet (as well as a recording of his symphonies in the "contemporaries of Mozart" series along with Salieri, Václav Pichl, François-Joseph Gossec, and nine others of mostly comparable musical obscurity).

Radick (2005) addresses alternative histories, wondering what would have happened if Darwin had stayed home. Far more credit to Wallace, he concludes. And if Einstein had given up on math, then, said Einstein himself, Langevin, though we are inclined to favor Lorentz and Fitzgerald for special relativity and suspect that general relativity would have had a long wait.

10.8. Oops, Being a Compendium of Undiscoveries and Other Unfortunate Events

Supernova SN 2002kg was a brightening of luminous blue variable V37 in NGC 2403 (Weis & Bomans 2005). SN 1954J in the same galaxy can make the same claim (Van Dyk et al. 2005). And 2003qw has been promoted to an AM CVn star (Nogami et al. 2004).

Poor PN H2-1 (where H stands for Haro) has been recognized so often as a bright knot in the Kepler SNR, forgotten, and rediscovered (Riesgo & Lopez 2005) that the poor thing is almost raw from being dragged in and out of catalogs.

Since all stars vary at some level, some day we will cease to sympathize with photometrists whose standard stars vary (Viehmann et al. 2005, IRS 7 in the core of the Milky Way in this case). Very similar bad luck afflicted the search for planet transits in NGC 6940 by Hood et al. (2005), nearly all of whose observed stars were non-members. And they didn't have any transits either.

DO Dra and YY Dra are both variable, and are in fact the same star (Hoard et al. 2005), which may be useful to it if it wants to be observed from two countries who don't honor each other's passports.

FH Leo is a common proper motion pair (late F plus late GV), not a cataclysmic variable (Dall et al. 2005). The cause of its outburst, caught by *Hipparcos*, remains unclear, though the authors suggest engulfment of a planet or scattered light from Jupiter.

Hipparcos itself is still digging out of the difficulties with its non-uniform sky coverage, coordinate system, and so forth. The coordinate system rotates (Bobylev 2004b). The Pleiades will never quite forgive it for pulling them into 119 pc vs. the correct 132–138 pc (Soderblom et al. 2005). And while there will some day be a new catalog (van Leeuwen 2005), don't sit up all night waiting for it, unless you are the sort of astronomer who normally sits up all night anyhow. In the day time, of course, one sits down (or so said Victor Borge).

The Palomar-Green catalog of QSOs is only about 50% right near its magnitude limit because the color cut fell near the peak of $N(U-B)$ and the 2 σ error bars on colors were about equal to the FWHM of the real distribution (Jester et al. 2005). Thus, about half the real QSOs are missing, half of those included don't belong, and the colors are perilously close to random. It is, however, doing very well compared to the USNO-B1 catalog, in which 99.9% of the listed objects are not real, and only 47% of those that belong are present (Levine 2005). It is a catalog of objects with proper motions of $1''$–$5''\ \mathrm{yr}^{-1}$, and the comparison sample is the Luyten half-second, LHS, catalog.

"Saturn is in the southwest after sunset, south in midevening" *Planetary Report* 25, No. 2, p. 1. Well, Velikowski said the direction of the Earth's rotation had reversed at some time. As *Huygens* descended upon Titan, only one-half of the intended 700 pictures were sent back, because a controller forgot to send the command to switch on the right side of the hardware (Anonymous 2005d).

At least two periodicities were so odd that apparently they aren't true, 246 days for CH_3OH in a star formation region (Goedhart et al. 2005); and mid-infrared counts of galaxies from *ISO* have spectral features passing through the wave bands, not quantized redshifts (Pearson 2005).

"Einstein, who had no formal scientific training beyond a qualification to teach high school physics" (*New Scientist*, 20 April 2005, p. 46).

"If a star is greater than about 3 solar masses, it ultimately evolves into a black hole" (*Sky & Telescope* 110, No. 3, p. 103–104).

"Young stars are made mostly of hydrogen…. The tremendous heat inside them turns some of the hydrogen into other gases. Older stars also have helium and even carbon. Even the Sun has some helium" (Levy 2005).

11. FIRST, LAST, ALWAYS, AND OTHER ORDINAL NUMBERS

Here reside assorted astronomical extrema, things of which there are many, things of which there is at most one, and candidates for the Lincoln's doctor's dog prize.

11.1. Countdown

Numbers in the index year literature ranged from 1–2 × 10^{11} (not, as you might have supposed, the number of stars in the Milky Way but the number of objects in the Oort Cloud required to keep up the supply reaching us; Neslusan & Jakubik 2005) down to $10^{-25.7}$, the cooling of the interstellar medium provided by excited C II, in ergs s^{-1} per H atom (Lehner et al. 2004).

Green stars went to 44,000 and 702, each of which requires a bit of explanation. The NSF plans to improve the success rate in its proposal application process by making its RFPs (requests for proposals) more narrowly targeted, so as to receive fewer proposals per year. The current number is 44,000 (Bement 2005). And 702 is the number of chemical elements that could receive symbols under the current system of one or two letters each. Only 111 are in use so far (Hayes 2005), including a few of which the news hasn't come to Harvard. Of various other such systems, airport codes are the fullest, at 10,678 out of $17{,}576 = 26^3$. Chemical elements are the least heavily utilized, while radio stations beginning with K (west of the Mississippi) and W, internet country codes (242/676, with a small prize for the correct identification of "to" and "tv" which puzzled us in reviewing a paper a couple of days ago), and stock ticker designations (3928/10,278 probably the most rapidly variable of these numbers) come in between. And an assortment of other numbers, only about half of which can truly be described as odd.

141 × 10^6 sources in the third SDSS data release (Abazajian et al. 2005b, and the last author is Zucker, close to a record in itself).

11 × 10^6 observations of variable stars logged into the AAVSO system (Waagen 2004).

693,319 galaxies, QSOs, and stars in the NYU Value-Added Galaxy Catalogue (Blanton et al. 2005, and if the value added is more than about 2 cents apiece, we can't afford it).

473,207 graduate students in technical fields in the US last year, an NSF report quoted in *Science* 309, 1169.

365.xxx days in each of the past two and upcoming millenia. Yes, no two are the same because of the changing rules for leap years, and we are irresistibly reminded of G. B. Shaw's attempted calculation (*In Good King Charles' Golden Days*) of the number of mistresses per day needed to achieve a particular lifetime total. He got it wrong, and the first 10 readers to send in the correct version will receive an item from our celebrated collection of envelope backs.

193,123 QUEST1 objects in a variability survey from QSOs, using a 1-meter telescope in Venezuela (Rengstorf et al. 2004).

110,563 UV-excess candidates for QSOs from SDSS (Richards et al. 2004). About 95% of them really are.

61,977 stars with proper motions exceeding $0''.15$ yr^{-1} from the POSS digitized catalog (Lepine & Shara 2005). They recover all the LHS and NLTT stars from surveys originally carried out by Luyten.

20,000, the approximate number of astronomy papers published per year, according to Colless (2005), including meeting abstracts, conference proceedings, and all. The number read for this review is smaller by a factor of about 2.6.

11,788 sources in the DIRBE point source catalog (Smith 2004).

10,862 light curves of eclipsing binaries in a fully automated analysis from OGLE II (Devor 2005).

3000 nuclei with known spin, parity, and half lives (NuDat at BNL 2005).[63]

2980 isolated galaxies (Allam et al. 2005), where the definition involves both separation and relative size of nearest neighbor.

2204 gamma ray bursts in a BATSE catalog that includes 589 non-trigger events (Schmidt 2004).

2200 white dwarfs in the globular cluster ω Cen (Monelli et al. 2005).

1509 pulsars, including AXPs and SGRs, but not accretion-powered (Manchester et al. 2005a).

1319 EGRET photons remaining as the background when 187 of 1506 belonging to sources have been accounted for (Thompson et al. 2005). This is a considerable improvement over the first report of the gamma ray background, "and the remaining 22 events…" (Kraushaar & Clark 1962).

1095 the largest number of ADS papers attributed to a single author at the moment when A. V. Filippenko surpassed the 1094 of Ernst Opik (whose oevre is unlikely to increase further). On the other hand, Opik also has 16 musical compositions to his credit.

899 groups of galaxies near $z = 1$ (Gerke et al. 2005), but the authors say that both type 1 and type 2 errors are close to 50%, meaning that something like 450 of the supposed groups aren't, and a comparable number are missing.

871 Herbig-Haro objects up to the time of Phelps & Ybarra (2005). Their new one is on the edge of the Rosette Nebula and has outflow on 1–3 pc scale.

827 point X-ray sources in *Chandra* images of 11 spiral galaxies (Kilgard et al. 2005).

NOTE: we are leaving out another six items in the 700–800 range to keep you from noting that this year's numbers truly do not favor initial digits of 1 and 2.

748 days in orbit reached by Sergei Krikalev in *ISS* on 16 August (distributed among 6 flights).

555 emission lines in a single VLT spectrum of Orion (said to be the maximum number anywhere in that wavelength range; Esteban et al. 2004).

520 open clusters cataloged by Kharchenko (2005).

388 GRBs seen by *INTEGRAL* up to the submission time of Rau et al. (2005), an average rate of 0.3 per day, very close to what was forecast from BATSE data. *INTEGRAL* is sensitive

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[63] See http://www.nndc.bnl.gov/nudat2/.

to smaller fluxes but does not see as much of the sky for as much of the time.

231 radio supernova remnants in the Milky Way (Green 2005a).

225 the number of papers written by *Observatory*'s most prolific author in the 1971–2000 period. He is D. J. Strickland (also one of the current editors). Second place would seem to be held by The Most Underappreciated Astronomer (see § 11.3) with 220. VT scores a mere 5.

213 items in a table in *Science* 308, 943, for which the text says "nearly 200." Well we suppose 200 is near to 213, or conversely, but the word surely carries an implication of fewer.

115 protons in the nucleus of the most recently confirmed element (Dmitriev et al. 2005). The story is second hand from *Nature*, who appear to have simplified somewhat. They say ^{243}Am zapped by ^{48}Ca makes element 115 which decays to 5 alpha particles plus ^{268}Db. Now 5 α's is 20 particles; $268 + 20 = 288$; but $243 + 48 = 291$, so we suppose three somethings (probably neutrons) must spray off at the first step.

104 lensed arcs (plus 12 more radio ones) in 128 *HST* clusters (Sand et al. 2005). Notice that the average is close to one per cluster, though we don't suppose that is how they are really distributed.

79 pulsation frequencies in FG Vir (Breger et al. 2005).

MYSTERY NUMBERS: Table 4 of *A&A* 435, 1173 lists observatories in a system where Greenwich = 0, Heidelberg = 24, Hamberg = 29, Helwan = 87. Not by longitude, since Palomar = 261 and 675, while Mauna Kea = 568. And not by foundation date, since Mt. Wilson and Yerkes come after Palomar. Our Editor informs us that these are multipoint constraint (MPC) numbers. The paper (Emelyanov 2005) is really about emphemerides of 54 outer satellites of Jupiter.

63 total moons of Jupiter to spring 2005 (Sheppard et al. 2005a), and 50 for Saturn.

48 high mass X-ray binaries in the Small Magellanic Cloud (Coe et al. 2005). Most are BeXRBs with the X-ray variability partly tied to the Be star variability.

40 new DQ type white dwarfs (Dufour et al. 2005).

32 leap seconds added since 1972 (Anonymous 2005h). You will have had another one by the time this appears, and we hope you used it well.

31 short period RS CVn stars (Dryomova et al. 2005), which they say are the same as pre-contact W UMa stars.

22 lensed quasars (the radio sort) in the CLASS survey (York et al. 2005).

14 micromagnitudes, the precision of the photometry reported by Kurtz et al. (2005a).

13 AM CVn stars (Nogami et al. 2004).

11 magnetars, McGarry et al. (2005 reporting the seventh anomalous X-ray pulsar, which is also the first magnetar in the SMC).

10 eigenvectors to fit 95% of the variance of 16,707 QSO spectra (Yip et al. 2004).

10 planets (Brown et al. 2005a) counting 2003 UB 313, whose radius is probably rather larger than that of Pluto (and a brief nod to the Abraham Lincoln story about the number of legs on a horse).

9 catalogs of spectroscopic binaries (Pourbaix et al. 2004).

8th supernova in NGC 6946 (Li et al. 2005f).

7th cool Algol with an orbit (Mader 2005). Definition of the class and the first orbit came from Daniel M. Popper (IAU Symposium 151) in 1992. There are times when he would seem to be a candidate for second most underappreciated astronomer.

6 accretion-powered millisecond pulsars (Galloway et al. 2005a).

6d search under way (Jones et al. 2004). No, they are not covering two 3d universes, but only most of the southern sky to $z = 0.15$. It means 6 degree field.

5 periods in a CV (Araujo-Betancor et al. 2005). They are orbit, superhump, rotation, nonradial pulsation, and a 3.5 hr period of unknown cause.

5 often the maximum number of authors given credit for a paper on ADS. One wonders whether Thoralf J. Aaboen (the first real name in the Orange County phone directory) might be prepared to offer adoption, in much the same way that a mathematician with an Erdos number of five offered to sell "six" a year or two ago.

5, not, the pentaquark has fragmented (Close 2005).

4 different mixing lengths in a 3D calculation of convection (Käpylä et al. 2005).

4, the number of terrestrial hemispheres in which *Sky & Telescope* is published (Fienberg 2004). There must be some analog of the Hirsch citation number and the Eddington cycling numbers to be found here, N''' for a publisher, equal to the maximum number of hemispheres, N''', in which he publishes N''' magazines.

3 white dwarfs in CVs with fields in excess of 100 MG (Gänsicke et al. 2004). They are not, say the authors, particularly rare, just very faint and so difficult to find.

3 asteroid orbits that fall entirely within that of the Earth (Meeus 2005). The third is 2002 JY$_8$. It actually has a semimajor axis a smidge larger than 1 AU but with its orbit somehow oriented to stay inside ours.

3 Virginias in astronomy, the largest annual percentage increase among any of our small numbers, with Virginia McSwain whose thesis abstract appears in *PASP* 117, 309 and Virginia Kilborn of Swinburn University, who co-authored a paper on dark H I galaxies in *ApJ Letters* during the year. Both were (also) named for much older relatives.

3 intermediate polars with periods below the gap (de Martino et al. 2005), number 3 being HT Com.

3 black South African co-authors on Jerzykiewicz et al. (2005), a paper we also indexed under "bad luck" because it reports that their first comparison star proved to be a slowly pulsating B variable and their second a δ Scuti star.

2 subdwarf L stars (Burgasser et al. 2004, adding 2MASS 1626+3926).

2 the number of arms you would think you were seeing in

the inner 150 pc of the X-ray gas of cluster Abell 2029 (Clarke et al. 2004).

2 (through 5) the QSOs in which the big blue bump has been confirmed as an accretion disk by seeing the Balmer edge only in polarized light (Kishimoto et al. 2004).

2 EGRET sources which are not Blazars (Sguera et al. 2005 adding 3C 111 to Cen A).

2 DA + LV binaries, GD 140 added to GD 165 (Farihi & Christopher 2004).

2 hybrid PG 1159 stars, meaning there is some hydrogen in the atmosphere as well as C, O, and He, affecting their pulsation periods (Vauclair et al. 2005).

2 pre-main-sequence stars in which X-rays come entirely from accretion, not magnetic activity (Swartz et al. 2005).

Zero used to be the number of Cepheid variables in star clusters. It is now 20, with the most recent in the LMC cluster NGC 1866 (Brocato et al. 2004).

Non-integer, the cosmic abundance of holmium is twice that of hafnium (G. Wallerstein 2005, private communication).

11.2. Firsts

Dozens of these were recorded, a good many of which have crept into the object-oriented earlier sections. Of those that did not, we cannot resist (say “the first” in front of each, or somewhere in the middle).

- Natural source of transition radiation (Nita et al. 2005). What is transition radiation? Oh dear, we were afraid you would ask that and have a copy of the new *Oxford Dictionary of Physics* on order, but it was predicted by Ginzburg & Frank (1946) and found in cosmic ray detectors by Yodh et al. (1973).[64]
- Detection of the hyperfine splitting of H I radiation (aka 21 cm) is one of our favorite stories of predict, discover, and confirm, and everybody behaving like a community of scholars and publishing the three detection papers together. This time around, hyperfine splitting of deuterium, in the form of the DCO^+ molecule in the ISM (Caselli & Dore 2005).
- Astrophysical masers remain the best-buy explanation of strong, variable emission of OH and a number of other molecules, especially with anomalous line ratios. But Weisberg et al. (2005) have seen the driving directly as pulsed OH maser emission on source vs. off, when looking at the pulsar B1641−45 ($P = 0.455$ s). The on-off subtraction is necessary because there is a good deal of diffuse OH emission in the region.
- The Lyα forest in spectra of distant QSOs (indeed some nearby ones if you have a UV spectrograph above the atmosphere) has been around for 30 years, but Nicastro et al. (2005a, 2005b) have reported the first X-ray forest. It consists of two lines and is, therefore, unlikely to be a forest that you are unable to see because of the trees.
- All-sky survey at short radio wavelength (1.6 cm) underway at ATCA (Ricci et al. 2004). They found 221 sources in the first 1216 square degrees, about half each galactic and extragalactic. And we refrain from saying that, if this is to be truly all-sky, they will need either an additional, northern site, or more penetrating radiation.
- Gustave Arrhenius estimated greenhouse warming at the end of the 19th century (and came very close to modern numbers). But the idea can be traced back to Fourier in 1827 (Pierrehumbert 2004), and concocting the best remark about decomposition as a solution is left as an exercise for the student (No, Mr. H. X-ray clusters).
- Five dimensional space. No, not an observation, but as a way of tackling unified theories. The first was Nordstrom (1914) rather than Kaluza (1921). Nordstrom also owned half a solution to the Einstein equations (with non-zero electric charge; the other half belonging to Reissner) and a whole bunch of department stores.
- Successful use of long baseline optical interferometry to measure polarization (Ireland et al. 2005).
- X-rays from an AGB star, a flare in Mira (Karovska et al. 2005).
- And our candidate for the 2005 Lincoln’s Doctor’s Dog’s Favorite Jewish Recipes award is the first 3D spectroscopic study of Hα emission in a $z \approx 1$ field galaxy with an integral field spectrograph (Smith et al. 2004). Indeed it is very probably the first galaxy to have such an instrument, qualifying it also for inclusion in § 13.

11.3. Extrema

Some of these are human (indeed occasionally all too human) and some astronomical. They are mixed this year as they were in the literature.

The longest time interval between Parts I and II of a series is 26 years (Ahmed et al. 2005). This is, however, dwarfed by the 40+ years “in press” for a paper cited by Chumak et al. (2005). The paper, by Olin J. Eggen, was intended for volume IV, on clusters and binaries, of the *Stars and Stellar Systems* compendium. This has not (so far) been published, though Chumak assigned a 1965 date to it.

The shortest half-life of an element possibly present in stars? Well, you know about Tc and perhaps even Pm, but Bidelman (2005), examining a high-resolution spectrogram of HD 101065 = V 816 Cen, has found lines possibly due to tran-

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[64] And why, you will ask, didn’t we just tunnel through the 20 yards to Prof. Yodh’s office and ask? Well, only if all else fails does your least penetrating author try following directions. But here is what he said: transition radiation is the electromagnetic radiation that is emitted when a charged particle traverses the boundary between two media of different dielectric or magnetic properties. Like Cerenkov radiation, this process depends on the velocity of the particle and is a collective response of the matter surrounding the trajectory. Like bremsstrahlung, it is sharply peaked in the forward direction if the particle is ultrarelativistic, in which case most of the energy is in X-rays. TR from particles traversing successive boundaries exhibits interference and diffraction patterns. We suspect that stage, screen, and radio are indeed media of different dielectric properties.

sitions of Po, Ac, Pa, and the transuranics Np through Es. Of the 11 known isotopes of Einsteinium, ^{254}Es has the longest half life, 276 days, comparable perhaps with the interval between the writing of this (Christmas 2005) and your first chance to read it.

Largest redshifts are easy to tabulate because somehow authors always mention the point in some conspicuous place in their papers. The 2005 ones were: (a) supernova, $z = 1.55$ (Strolger et al. 2004), (b) radio galaxy $z = 5.2$ (Klamer et al. 2005), (c) "overdensity" meaning something that might evolve into a cluster or supercluster, $z = 5.77$ (Wang et al. 2005b), consisting of 17 Lyα emitters stretched across 70 Mpc (comoving we assume), (d) X-ray selected clusters, $z = 1.39$ (Mullis et al. 2005 who say that others should be easy to find), (e) giant radio galaxy, $z = 3.22$ (Mack et al. 2005). It is B3 1231+397B and is a compact, steep spectrum (young, recurrent) core source, (f) PAHs, $z \approx 2$ (Yan et al. 2005), (g) H_2O maser, $z = 0.66$ (Barvainis & Antonucci 2005), (h) cluster detected with weak lensing, $z = 0.9$ (Margoniner et al. 2005). This is the lens redshift not the lensee. The lowest z galaxy functioning as a lens is ESO 325–G004 at $z = 0.0341$ (Smith et al. 2005f).

Largest error this year may be the 2×10^{45} cm^2 cross section for neutrino capture mentioned in *AJP* 73, 495. It is also described as belonging to "carbon tetrachloride (C_2Cl_4)." Well no. Carbon tet is CCl_4. That other cleaning fluid is perchloroethylene. What's the use of having had a chemist father if you can't tell these apart by sniffing them (cautiously, of course). The most chlorinated author spent measurable parts of her childhood joyfully sniffing CCl_4, and we know at least one referee who will not be at all surprised to hear this.[65]

Some stellar extrema. The hottest main sequence star has $T = 48{,}000$ K say Massey et al. (2005). The largest radius is 1500 $R_\odot$ for KW Sgr, V354 Cep, and KY Cyg (Levesque et al. 2005). All are about 25 $M_\odot$ and $3 \times 10^5\ L_\odot$ and probably in the double shell burning phase. The shortest M dwarf binary period is 0.1984 day for BW3 V38 (Maceroni & Montalban 2004). Candidates for the most massive star, the shortest Blazhko period RR Lyrae, the hottest post-AGB star, etc., hide in other sections.

The smallest space telescope at present is the 15 cm, 60 kg *MOST* (Matthews 2005). It is used primarily (you thought we were going to say MOSTly, didn't you) for astEroseismology (we lost that one several years ago).

Among neutron stars, the slowest rotation period is 9600 s (Bonning & Falanga 2005) for LS I +65010. The period has been shrinking at -8.9×10^{-7} s s^{-1}, so it will someday cease to be the slowest. The fastest moving pulsar has $V = 1083$ km s^{-1} in the plane of the sky (Chatterjee et al. 2005, reporting a VLBA proper motion). The fastest rotation hovered near 1.55 ms for so long that we were beginning to think the limit was trying to tell us something (except that there is now an out-of-period counterexample). And the youngest neutron star seen as a source of thermal X-rays (Gonzalez et al. 2005) has $P/2\dot{P} = 1700$ yr.

The fastest obituary into print was probably that for John Noriss Bahcall, who died on 17 August and was remembered in the 1 September issue of *Nature* (Ostriker 2005). The piece describes Bahcall as a hedgehog (not, given his expertise in galactic structure, nuclear physics and astrophysics, and science politics, perhaps entirely fair) and the author as a fox.

The largest cities (*Nature* 437, 302) are currently Tokyo, Mexico City, New York, Saõ Paulo, Mumbai, Delhi, Calcutta, Buenos Aires, Shanghai, and Jakarta. Interesting perhaps to compare with the list from 1950 that the most populous author memorized in Miss Munro's 7th grade social studies class, when she wasn't busy growing wheat or shooting free throws. New York, Shanghai, Tokyo (so far so good), Moscow (oops), Chicago, London, Berlin, Leningrad, Buenos Aires, Paris. The lists of longest rivers and largest islands seem to have held up better and are occasionally still useful. The countries around the Mediterranean and their capitals fall somewhere in between (but quiet rejoicing that the bit of the list that says "Israel, Palestine" is going to be true again, something she had not hoped to see in her lifetime, along with one Germany). Oh, and would someone please clarify just how many pieces of the former Yugoslavia actually touch the sea?

Some cosmic biggies. The largest structure is still the SDSS Great Wall, about 80% larger than the Harvard Great Wall (Gott et al. 2005). The brightest X-ray cluster (Bradač et al. 2005). The widest (radio) gravitational lens sprawls over 41″ behind Abell 2218 (Garrett et al. 2005). Mind you, 41″ is the apparent height of a middle-sized author seen from a distance of 5.5 miles. Too close, we can hear you exclaiming.

The brightest radio BAL quasar (Benn et al. 2005) probably isn't very bright, but in the good old days, broad absorption line sources were all radio quiet. This one has $z = 3.37$ and a broad line region velocity width to –29,000 km s^{-1}. The most extended H I disk reaches to 8.3 × the Holmberg diameter for NGC 3741. The galaxy has $M/L = 107$ in solar units, mostly because of small luminosity. The dynamical mass is in fact only about eight times the baryon mass (Begum et al. 2005). And what is the Holmberg diameter? In previous years we would have told you that is twice the Holmberg radius. But this year it is twice the Hafberg diameter.

On scales between the cosmic and the comic we find (1) the most distant star stream of the Milky Way (Clewley et al. 2005) out at 70 kpc in the halo and consisting so far of six horizontal branch stars and three carbon stars sharing an orbit, (2) the largest supernova remnant in the SMC (Williams et al. 2004c), 98 × 70 pc in extent, 45,000 years old, and perhaps a Type Ia since there is no pulsar and no OB association nearby, (3) the darkest GRB, 001109, meaning the one with the smallest ratio $L_{\rm opt}/L_{\rm X}$ in the early afterglow (Castro Ceron et al. 2004).

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[65] The junior, but oldest, author recalls the glorious days of yester-year when such sniffing was part of the pleasure of revealing watermarks in stamps. And we know the "most chlorinated" author will not be surprised to hear this.

The last photographic survey, UKST Hα+[N II], ended in late 2003 (Parker et al. 2005). They used Kodak Tech-Pan film. A publication called *Kodak Plates and Films for Scientific Photography* still sits on our bookshelf. It is a souvenir of the 1975 AAS meeting in Bloomington (which also featured a concert of Scott Joplin music) and cost $2.50. And (from another AAS/Kodak publication of the same vintage) we note that 2006 marks the 35th anniversary of the retirement of William F. Swann whose 30 years of working with the astronomical community included the production of the 14 × 14 inch plates for the Palomar Observatory Sky Survey. The article about him was written by William C. Miller, then the photo-maven at what were then the Hale Observatories. But Kodak even then measured wavelength in nanometers.

The most under-recognized astronomer? Contemplate Robinson (2005b) in the usual 50 and 25 years ago column, and notice that, amongst all the credit, the chap who developed the radial velocity spectrometer (a descendent of which caught the first exoplanet) is not named. The pickiest reader of course wrote and complained, and a correction appears in *Sky & Telescope* (109, No. 5, p. 13). It may or may not be significant that shortly thereafter (1) Robinson stopped writing that column and (2) your present author's subscription vanished. Who was he? You think Ap05 should be more meticulous than *S&T*? So do we. It was Roger Griffin of Cambridge, whose orbits of spectroscopic binaries are rapidly soldiering on toward 200 papers, leaving him feeling rather smug at having adopted Arabic rather than Roman numerals from the beginning.

12. BIG BLACK BLANGS

Sorry, no. Make that Blig Back Blangs. No. Blig Black Bangs. Never mind. Horizontal bars.[66] Well, we told you last year that the one twist tonguer we've never been able to manage is the big black bug bled bad blood (yeah, it's even hard to type). Anyhow, this section deals with supernovae and their remnants (compact and diffuse), active galaxies and other manifestations of black holes in galaxies, and a few other incendiary strays.

12.1. Supernovae

There used to be two sorts of supernovae, Type II (with hydrogen lines in their spectra) and Type I (without). There are once again two types, core collapse (Type II plus Types Ib and Ic) and nuclear detonation/deflagration (Type Ia). The former happen to stars initially heftier than about 8 $M_\odot$ (dependent on composition, presence of a companion, rotation, and probably other things). The latter happen to degenerate, white-dwarf-ish, stars or cores driven by accretion or merger above the Chandrasekhar limiting mass.

Some galaxies have lots: 2004et was the 8th in NGC 6946 and was perhaps imaged as a yellow supergiant beforehand (Li et al. 2005f). And some people discover a lot—39 up to the end of 2003 for the Rev. Robert Evans in Australia, and 100+ by amateur groups coordinated by Guy Hurst in the UK (Evans 2004). How many total? Well, index year 2004 ended with 2004es, and 2005 began with 2004et (IAU Circ. 8413), continuing on up to 2005eo (IAU Circ. 8605), making, we think, 223 events in the fiscal year (minus the invariable few that turn out to be well-known variable stars and such). The system whereby faint SNe get preliminary designations and move into the mainstream only when/if properly confirmed (CBET) has now been made permanent (IAU Circ 8476).

What about typical numbers per galaxy per year? The unit is the SNU (SuperNova Unit) of one per century per $10^{10}\ L_\odot$, and, like all good units, it leads to typical values near 1. Three groups keep catalogs (CfA, Asiago, and Sternberg) and Tsvetkov et al. (2004) provide web addresses so you can run the numbers for yourself. Typical results (Petrosian et al. 2005; Mannucci et al. 2005) say that (a) only S and Irr galaxies have core collapse events, while Ia's can happen anywhere, (b) even the nuclear events are much commoner in late type galaxies, with rates of all types varying by factors of 20–30 from earliest to latest galaxies; Scannapieco & Bildsten (2005) attribute the Ia statistics to there being both prompt (0.7 Gyr after star formation and including the brightest ones) and delayed (up to 10 Gyr and including the faintest ones) events, (c) star forming and starburst galaxies have more than their fair share, (d) the nuclear explosions are less common by factors of 2–3 in magnitude-limited samples than the core collapse events and by larger factors in volume-limited samples, and (e) you find larger rates (again in SNU) looking back in redshift to 0.25–0.7, by factors of 3–7 (Dahlen et al. 2004; Cappellaro et al. 2005). And we don't know quite what to make of the discovery that SNe Ia are commoner by a factor of about four (0.43 h_{75}^2 vs. 0.10 SNU) in radio loud than in radio quiet galaxies (Della Valle et al. 2005).

But the green supernova of the year is 2003gd (Hendry et al. 2005), for which pre-need images establish the progenitor as a red supergiant, the first thus directly confirmed, though we all firmly believe that RSGs should be commoner than the BSGs seen for SN 1987A and 1998A (a somewhat indirect argument for the latter; Pastorello et al. 2005). Several other papers recorded limits on SN II progenitors from images taken fortuitously in advance, of which the most interesting is probably 2004dj in NGC 2403k discussed by Maiz-Apellaniz et al. (2004) and Wang et al. (2005e). It appeared in a young star cluster previously examined by Sandage (1984). Which star is missing is not yet certain and, therefore, also whether it was a red or a blue SG whose core collapsed.

And now a set of standard answers to three remaining standard questions about progenitors and mechanisms of nuclear explosions and mechanisms of ejection from core collapses.

In the search for SN Ia progenitors, there were votes for all the traditional ways of forcing a white dwarf up in mass:

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[66] With apologies to Spike Jones, Doodles Weaver, and the Man on the Treezing Tri-flap.

(1) supersoft X-ray binaries (Lanz et al. 2005 on the Cal 83 system of white dwarf plus normal star), (2) novae (Kato & Hachisu 2004, though they note that even helium accretion and explosion on a WD will remove material, (3) WD+AGB (Kotak et al. 2004), and (4) most obvious of all, merger of two white dwarfs (Tovmassian et al. 2004), apart from the detail that they have failed the existence test for decades. Morales-Ruenda et al. (2005) present yet another sample that has no WD binaries of sufficiently small orbit and sufficiently large total mass to work.

As for the explosive mechanism, detailed calculations of subsonic deflagration converting to supersonic detonation, typically with off-center ignition, continue to improve (Gamez et al. 2005; Wunsch & Woosley 2004), even though the first ignition point may fizzle (Garcia-Senz & Bravo 2005). We've built some campfires like that and, so, worrisomely, have the controlled burn folks at the forest service. A green star to Spyromilio et al. (2004) for an examination of infrared lines in the first year of light decline of a Type Ia that revealed the gradual conversion of cobalt to iron (a total of about 0.4 $M_{\odot}$). This confirms that the production of lots of ^{56}Ni and its subsequent decay energy really does power these events.

As for the mechanism by which the gravitational potential energy released in core collapse ejects SN II (etc.) outer layers and makes them shine, we caught 8 papers saying that, whatever you might have thought before, rapid rotation and strong magnetic fields in the parent star, the collapsing core, winds from the core, and disk of continuing accretion material are a Good Thing, and at least 3 expressing doubts about whether the problem has yet been solved. Let Wilson et al. (2005b) stand for the "it's all going to be all right, guys" camp (since he has been working on the problem longer than just about anybody) and Ardeljan et al. (2005) stand for the "hold your horses, because you are going to need more" camp, because they get an explosion (after including the Balbus-Hawley instability, a compression wave, and a shock) but it is a puny one that ejects only 0.14 $M_{\odot}$. Ought everybody to get the same answer? Apparently not. Branch et al. (2004) point out that different explosion patterns work for different events.

12.2. Supernova Remnants

Most of the obvious ones got at least a nod. Let's start with SN 1987A and work backward. It now consists largely of stuff previously ejected and now illuminated by the light flash and collisions with SN ejecta. There are, so far, no contradictions, say Sugerman et al. (2005), but we were frankly unable to identify the features called the hourglass and Napoleon's Hat (North and South) in their figures. The limit on optical emission from a central compact remnant has been pushed down to 4 $L_{\odot}$ (with allowance for 35% absorption, Graves et al. 2005), and it will not be easy to do better.

Cas A has less than 1.5 $M_{\odot}$ of dust (Wilson & Batria 2005). That sounds large for a limit, but the supernova of 1685± something did eject lots of new heavy elements now in gaseous form (Hwang et al. 2004). The much smaller amount of dust present in the Crab Nebula (Green et al. 2004) is equally unsurprising, given that it is also not a habitat of new gaseous metals.

Kepler (V 843 Oph = SN 1572 = 3C 358) and Tycho (= B Cas = SN 1604 = 3C 10) each received a paper focussed on using the full range of original observations to confirm that all those = signs are true (Green 2004, 2005b).

The Crab Nebula has become slowly more massive over the years, this year reaching at least 6.4 $M_{\odot}$ for the visible nebula plus pulsar, according to Negi (2005), almost enough to account for the entire progenitor star. That less than 20% of the pulsar spin-down energy goes into relativistic protons (0% would fit the data, Aharonian et al. 2004a) confirms a deduction many years ago by the crabbiest author. She was also much pleased to see an explanation of radial fingers of gas as twisted magnetic filaments (Carlqvist 2004) because she was, long ago, required to deny their existence and entitle her thesis "Motions and Structure of the Filamentary Envelope of the Crab Nebula." A fading green star for the gradual fading of the Crab radio flux, by 9% since 1948 (Stankevich & Ivanov 2005), interrupted by two centimeter/millimeter outbursts following the pulsar glitches of 1975 and 1989. The poor thing used to be a standard source, and we wonder whether one would now have to say that Cas A faded faster than reported in the past, when it was compared to 3C 144. Meanwhile, such radio emission as there still is at the latter location shows ripples and wisps, much like the optical ones reported long ago by Walter Baade (Bietenholz et al. 2004). The relative phasing is complicated and implies two in situ acceleration mechanisms.

The remnant of SN 1006, supposedly a Type Ia and the brightest of modern times, was treated rather badly this year. Not only could Winkler et al. (2005) find no more than 0.06 $M_{\odot}$ of iron hanging around (vs. 0.5 $M_{\odot}$ or so required to power a bright SN Ia), but also H.E.S.S. saw less than 10% of the TeV flux previously reported from the HEGRA and CANGAROO facilities (Aharonian et al. 2005e).

The Vela supernova remnant(s) received a whole week's worth of papers, largely considering whether the bright bit in the corner is a separate younger SNR. We will weasel by saying just that the radio structure of the whole region is very complicated (Hales et al. 2004) and that the corner bit is a gamma ray source (Katagiri et al. 2005).

SNR RX J1713.7–3946 = G347.3–0.5 was reported as the first TeV source among the shell-type remnants (Aharonian et al. 2004b), but we find difficulty in imagining it famous under either of those names, which pertain to the X-ray and radio emission.

12.3. Single Neutron Stars and Black Holes

These include the pulsars, isolated (cooling) neutron star X-ray sources, almost certainly the anomalous X-ray pulsars

(AXPs) and soft gamma repeaters (SGRs), and isolated stellar mass black holes (except there weren't any this year). The classic questions about neutron stars include the initial values of temperature, magnetic field, rotation rate, and space velocity; how these change with aging; and the use of the observed or deduced properties to decide about birthrates, equation of state, and whatever else you might like to know.

The index holds 63 relevant papers from fiscal 2005, and the colored dot is attached to the giant flare of SGR 1806–20 on 27 December 2004. It saturated *INTEGRAL* with about 100 times the flux of any previous flare (Mereghetti et al. 2005) and had various precursors (within 100 s), tails to 3000 s, a 7.56 s pulsation period as it faded (presumably the stellar rotation period), and 60 ms QPOs (Hurley et al. 2005; Gaensler et al. 2005b; Terasawa et al. 2005; Lazzati 2005; Palmer et al. 2005; Cameron et al. 2005). A mechanism associated with crust instability appears likely, and considerable importance may attach to the fact that it would have looked like a short-duration GRB if we had been observing from a not-too-distant external galaxy. The burst was powerful enough to affect ionization of the upper atmosphere, and it was seen as a Sudden Ionospheric Disturbance by radio amateurs; probably also by various defense installations, but they don't report in *Sky & Telescope* (109, No. 5, p. 32).

On the subject of pulsars, we refer you to a review of observations (Seiradakis & Wielebinski 2004) and as many of the following as you can fit on your buffet plate without spilling.

Timing noise nearly always dominates the second derivative of pulsar periods (Hobbs et al. 2004, 2005), but one whose fax number we neglected to record is so quiet that even its third derivative is meaningful $(-1.28 \pm 0.28) \times 10^{-31}\ \mathrm{s}^{-4}$ (Livingstone et al. 2005) from 21 years of glitchless data. It implies $n = 2.839 \pm 0.003$ for the parameter whose value is 3 for pure magnetic dipole radiation (and different from 3 for the few other pulsars with measured n).

Geminga seems to have fled from an OB association (Pellizza et al. 2005). The details are a bit model dependent, but the general idea is that it came from a moderately massive star, and, since the association is still there, cannot be very old.

The velocity required by the previous point is nothing like a record for pulsar proper motion (1083 km s^{-1} for B1508+55, Chatterjee et al. 2005). Mdzinarishvili & Melikidze (2004) conclude that pulsars found from Australia reflect two separate populations with initial velocity and initial field positively correlated. Hobbs et al. (2005), on the other hand, conclude that the young pulsars have a single $N(v)$ distribution and so are a single population.

In general, there seems to be reasonable accord between observations and "predictions" for both initial field, centered somewhere around 2.5×10^{12} G, and initial rotation period, near 15 ms, (Vranesevic et al. 2004; Walder et al. 2005; Loehmer et al. 2004b). Lovelace (2005) concludes that magnetic field is reduced by accretion and recovers slowly. Normal processes can slow the rotation period to at least 8.39 s before death intervenes (Kaplan & van Kerkwijk 2005).

Giant radio pulses have become common enough that Kuzmin & Ershov (2004) advocate two classes (with emission arising from outer gaps and from poles). The Crab pulsar does it, but, for once, does not hold the record. $T_b \geq 5 \times 10^{39}$ K belongs to the millisecond pulsar B1937+21 (Soglasnov et al. 2004), and the temperature reduction mechanism proposed by Gil & Melikidze (2005) for 0532 (beaming and other relativistic effects) probably also applies to B1937. You can reduce the implied T_b by a factor of 10^8, which still leaves it hotter than hell (or heaven, using a traditional description of the illumination there).

Temperature evolution is generally probed with the isolated neutron star X-ray sources. To quark (so as to accelerate cooling) or not to quark is the question. On the conservative ("our") side, Page et al. (2004) look at the various possible enhanced cooling processes (quark stars, direct URCA, pion or hyperon condensate), and conclude that the minimal extension to Cooper pairs and modified URCA is sufficient for all cases where thermal X-rays are actually seen, while two upper limits appear to need enhanced cooling. Additional "other physics" appears in Gusakov et al. (2004, strong proton superfluidity) and Khodel et al. (2004, multi-sheeted neutron Fermi surfaces to activate direct URCA cooling).

"Magnetar" is shorthand for the class of neutron stars with very strong magnetic fields, including the soft gamma repeaters, the anomalous X-ray pulsars, and perhaps some others. Does everyone agree with this definition? No. At least three papers during the year held out for fields near 10^{12} G, like ordinary pulsars, rather than 10^{14}–10^{15} G, and other effects contributing to the AXP/SGR phenomena. Malov & Machabeli (2005) favor an electric cycle, Istomin et al. (2005) a field strongly concentrated toward the poles so that rotation periods can slow to about 10 s (with magnetic dipole radiation continuing), and Mosquera Cuesta & Salim (2004) propose significant effects of strong gravitational fields. We don't entirely understand these, but it is impossible to dislike a paper that begins by citing Born & Infeld (1934).

The now-conventional strong field view is upheld by Halpern & Gotthelf (2005) and Gaensler et al. (2005a). Figer (2005) concludes that the progenitors were at the upper limit of the mass range of stars that can make neutron stars rather than black holes (30–50 $M_\odot$), and readers with long memories may remember from § 9.5 the probable correlation of large white dwarf masses (hence hefty progenitors) with strong fields for them. Kaspi & McLaughlin (2005) may have seen some faint thermal X-ray emission from neutron stars that correspond to AXPs in quiescence; and Woods et al. (2005) record what they indicate is the third example of a new class of burst peculiar to AXPs. Sedrakian et al. (2003) would like all pulsars eventually to evolve to AXPs or SGRs, but how the fields strengthened as the rotation slows was not obvious.

12.4. Binary Neutron Stars and Black Holes

Are they really black holes? Well, they are astrophysicists' black holes anyhow, that is, entities with (1) masses too large for neutron or quark stars (10.65 $M_\odot$ for V404 Cyg, Cherepashchuk 2004; 13–14 $M_\odot$ for GRS 1915+105, Fujimoto et al. 2004; and a distribution through the mass range 4–15 $M_\odot$, more or less what the theorists expect, Bogornazov et al. 2005), (2) discernible general relativistic effects of spin close to the maximum allowed (Aschenbach 2004), and (3) evidence for a horizon, when the luminosities and spectra of the BHXRBs are compared with NSXRBs in quiescence (McClintock et al. 2004). Indeed allowing for the smaller scales of everything, they are a good deal like the centers of active galaxies, including our own feeble Sgr A* (Jester 2005) in several respects including, probably, 3 : 2 resonances in QPO frequencies (Török 2005; Homan et al. 2005). Among other analogies, a good deal more than half of the available energy should and does come out in jet kinetic energy (Jester 2005; Gallo et al. 2005). The QPOs for standard AGNs are going to be a tad difficult to observe, unless the TAC gives you really long observing runs (Vaughan & Uttley 2005).

Can you always tell an NSXRB from a BHXRB? As in many previous years, the accreting, compact member of SS 433 was firmly established as a probable neutron star of 2.9 $M_\odot$ (Hillwig et al. 2004) and as a definite black hole of 30 $M_\odot$ (Cherepashchuk et al. 2005). The donor, whose spectrum we see, is in either case an A supergiant of 9–10 $M_\odot$.

Binary neutron star can mean NS + something else or NS + NS, and binary pulsar can mean pulsar + something else or pulsar + pulsar. All exist. The first pulsar + pulsar was a highlight last year, and theorists have since been beavering away to interpret all that has been seen. We note, arbitrarily, two papers from the "all is well" camp, on the X-ray light curve (Campana et al. 2004, with the stars illuminating each other) and on the radio eclipse as synchrotron absorption (Lyutikov 2004), plus one, we think, rather odd evolutionary scenario (Piran & Shaviv 2005) in which the initial masses of the stars were each only about 1.45 $M_\odot$. Oh, if you need to phone, the number is J0737–3039. The galactic center transient radio source, GCRT J1808.4–3658 could, say Turolla et al. (2005), be another pulsar pair. The discoverers, Hyman et al. (2005), suggest several other possibilities.

Faulkner et al. (2005) have caught the fifth binary, meaning pulsar + another NS, that will merge in less than the Hubble time, thereby increasing the predicted rate of short-duration galactic GRBs by 25%, we estimate.

In the neutron star plus something else category, Galloway et al. (2005a) report the 6th accretion-powered millisecond pulsar (with the shortest rotation period yet of 1.67 ms) and they draw attention to the puzzle of why one sees the rotation in these six and not in the other 750 LMXRBs, although sometimes the accretion turns off, and you can then see the rotation period that is otherwise powering the source (Campana 2004 on SAX J1808.4–3658 in quiescence). Also in the NS + other bin lives the first millisecond pulsar to experience a glitch (while anyone was watching; Cognard & Backer 2004); the first HMXRB with a neutron star whose rotation period does not show in its light curve (Blay et al. 2005); more of those super-outbursts that are flashes of carbon burning on the NS surface (in't Zand et al. 2004); the first Type I X-ray burst outside the Milky Way, naturally in M31 in a globular cluster (Pietsch & Haberl 2005); and Rossby waves on the surfaces of neutron stars as an explanation for the decrease in QPO frequencies when X-ray bursts fade (as an alternative to the radius of the photosphere shrinking back). Of many papers, we cite only Heyl (2005), because it seems to have been his idea last year, and we were having tea and missed it.

The opposite case, of something else not plus a neutron star, is exhibited by a bunch of OB runaway stars, none of which is a *ROSAT* source, implying that none has held onto a close NS or BH companion (Meurs et al. 2005), though others have recorded runaway XBRs on other occasions (Sepinsky et al. 2005).

12.5. Ultraluminous X-Ray Sources (ULXRS) and Intermediate Mass Black Holes (IMBHs)

Do they or don't they color their no hair?[67] They are X-ray sources, mostly in other galaxies, bright enough to exceed the Eddington luminosity for the sort of 5–15 $M_\odot$ black holes found in the previous section, extending up to about 10^{41} ergs s^{-1}, assuming isotropic emission. This is the Eddington limit for a 10^3 $M_\odot$ accretor. Most definitions just say brighter than 10^{39} ergs s^{-1}, and the faint end of the distribution is commoner than the bright end. The choices then are (a) sources other than accreting compact objects, (b) beaming, (c) intermediate mass black holes of 100 to perhaps as much as 10^4 $M_\odot$, and (d) accidental projections of very bright, much more distant sources. The alternative to (d) is ULXRSs with non-cosmological redshifts (Galianni et al. 2005). We and Gutierrez & Lopez-Corredoira (2005) are voting for the conventional wisdom here, they because the areal density of the ones with large redshifts is that of random sources, that is indeed accidental projections.

As for the rest, there is no general agreement on whether the ULXRSs constitute a class separate from the general run of high-mass X-ray binaries. Yes, say Miller et al. (2004a) on the basis of X-ray temperatures less than 0.25 keV for the brightest (vs. 0.3–2 keV for galactic BHXRBs) and also the absence of optical identifications; and no, say Swartz et al. (2004) from the absence of discontinuities in spatial, spectral, color, or variability distributions with luminosity.

And here are the cases for some combination of (a), (b), and (c). Liu & Bregman (2005) have provided a catalog of the 109

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[67] Black holes have no hair and it must, therefore, be wigs rather than Clairol hair coloring, about which only their hairdresser knows for sure.

brightest *ROSAT* sources in about 65 galaxies. These preferentially inhabit late type galaxies and star formation regions. Some are supernova remnants, H II regions, and compact groups of young massive stars. A few coincide with old globular clusters (and could be IMBHs in those). Liu & Bregman have deferred dividing the rest between BHXRBs and IMBHs until Paper II. And galaxy mergers can make shock features potentially confusable with our target class (Smith et al. 2005a). A popular view is mostly BHXRBs with a few IMBHs (Fabbiano 2005; Liu & Mirabel 2005, whose catalog of 229 in 85 galaxies has some background AGNs and SNRs mixed in).

The best cases during the index year for ordinary though massive BHXRBs seem to be (a) M101 in which Kuntz et al. (2005) have shown that one has a mid-B supergiant as its optical counterpart, (b) M74 where Krauss et al. (2005) have recorded spectrum and variability like those of an end-on microquasar jet, (c) N4559 with a similar source (Soria et al. 2005), and (d) the Milky Way some of whose sources reach 10 times the Eddington luminosities in cases where the black hole mass has been established (Okuda 2005).

And the best cases for accretors in the 10^3–10^4 $M_\odot$ range include (a) M82, assuming its 55 mHz oscillation frequency is a low-frequency QPO like those of BHXRBs of smaller masses and higher frequencies (Fiorito & Titarchuk 2004), (b) NGC 628 with a 2-hour quasi-period, scaled in the same way (Liu et al. 2005a), (c) NGC 5204 because of its very cool (0.2 keV) inner disk (Roberts et al. 2005b), and (d) Holmberg II because the optical and radio emission from the surrounding nebula argue against significant beaming (Lehmann et al. 2005; Miller et al. 2005b).

We now hand over even further to the theorists and ask "Can you account for these things and put them someplace where they will have material to accrete at a rate at least large enough to support the Eddington luminosity?"

Pas de probleme (we think this sounds less rude than "no problem" as a substitute for "you're welcome") says one school of thought. Intermediate mass black holes should be left from the collapse of Population III star cores and other events in the early universe. Indeed the Milky Way might well have a supply of them, contributing a bit to its dark matter (Tutukov 2005; Islam et al. 2004; Zhao & Silk 2005).

Feeding may be more difficult. Baumgardt et al. (2004a, 2004b) consider the case of a 10^3 $M_\odot$ black hole grown from a 100 $M_\odot$ seed in a globular cluster, and point out that all that will be left nearby will be small black holes, whose accretion will emit very few X-rays and butter no parsnips. Two papers indicate that, to be an ULXRS, an IMBH must have a biggish star in orbit close enough for Roche lobe overflow (Portegies Zwart et al. [2004] on M82 X-1 and Tutukov & Fedorova 2005). Volonteri & Perna (2005) say point blank that IMBHs can be left wandering in galactic halos from hierarchical galaxy formation, but they simply must carry their own baryons around with them to reach even 10^{39} ergs s^{-1}.

A green star, therefore, for the idea that at least a few ULXRSs in M82 and elsewhere may well be the nuclei of captured satellite galaxies, for whom 10^3 is the "right" mass (§ 12.7, though none has been seen), and who indeed will be toting baryons (King & Dehnen 2005).

12.6. Sgr A* and Its Environment

Sgr A*, at the center of the Milky Way, is not even an MLXRS (moderately luminous X-ray source) at a bit less than 10^{34} ergs s^{-1} in X-rays and less at other wavelengths, though the radio emission, its spectrum, variability, and so forth have been very extensively studied ever since its prediction by Lynden-Bell & Rees (1971) and discovery by Balick & Brown (1974). The proper motion of Sgr A* (after removal of the amount due to galactic rotation) is less than 1.5 milliarcsec yr^{-1}, and uncertainty in its three-dimensional location is the largest source of error in measuring its mass from the velocities of the stars around it (Ghez et al. 2005).

The current mass accretion rate is very small, less than a few $\times 10^{-7}$ $M_\odot$ yr^{-1}, recognized because no gas was lit up when star S2 passed close in 2002 (Nayakshin 2005a), and the amount that actually fuels radiation is still smaller, more like 10^{-11} $M_\odot$ yr^{-1}. Most of the rest that gets as far as the Bondi radius is lost in a wind, at least this year (Bower et al. 2005). The source doesn't just sit there, however. A near infrared flare was caught for the first time this year (Eckart et al. 2004, who have fit a synchrotron self-Compton spectrum). We think Clenet et al. (2005) have detected a quiescent counterpart, for which two green ears and a tail should probably be awarded. The X-rays display quasi-periodic oscillations, with frequencies in 3 : 2 : 1 resonance (Abramowicz et al. 2004, Aschenbach 2004). The periods are 692, 1130, and 2178 s, which require the Sgr A* black hole to have a spin parameter $a = 0.996$, shared with three microquasars. This is very close to the maximum permitted by general relativity, and Aschenbach (2004) suggests this may be the true maximum, with the estimate by Thorne (1974) a smidge too large. The millimeter emission varies on similar timescales, but not with any obvious P or QP (Mauerhan et al. 2005). The flux harder than 165 GeV either varies within a year or is very poorly determined (Aharonian et al. 2004c). Our galactic feeble center is by no means unique. Totani et al. (2005) have found at least one, and maybe six other very faint AGNs, of which, they say, the Milky Way is typical.

A faded green star (because the idea was already out there last year) goes to the thought that one can account for conditions in the gas surrounding Sgr A* (mapped by *INTEGRAL*) if the central X-ray source was brighter by a factor near 10^5 a few hundred years ago (Revnivtsev et al. 2004). This is still only a small fraction of $L_{\rm edd}$, which is nearly 10^{11} $L_\odot$ for a 3×10^6 $M_\odot$ black hole. Is there a theorist in the house to explain it all? Of course. But the most relevant related point may come from observers. Stark et al. (2004) present CO maps of the galactic center region implying, they say, that gas piles up around 150 pc and, every 2×10^7 yr, collapses inward, making a bunch of giant molecular clouds, followed by massive stars and the dumping of $4 \times 10^7\ M_\odot$ of gas into the central region. The present moment would then be the end of such an event, and we are perhaps lucky to have caught the instant when the gas disk has nearly all been turned into stars, leaving very little central gas fuel for the black hole (Nayakshin & Cuadra 2005).

What is around Sgr A*? Well, that gas disk for starters, whose 119 km s^{-1} H I rotation speed (Dwarakanath et al. 2004) must mean that it is about a parsec in radius, for the density and temperature that radiates 21 cm, plus much denser molecular gas that could continue to form stars (Christopher et al. 2005). Lots of stars, which are generally held to be young and massive and to constitute an example of a nuclear star cluster, or a bunch of NSCs (Stolte et al. 2005). Still, there are people who would doubt existence of the tooth ferry even if they had ridden on it themselves, and Davies & King (2005) counter-propose tidally stripped low and intermediate mass (hence older) stars, formed much further from the galactic center and recognized as interesting only for the subset whose orbits bring them in close.

In the X-ray regime, there are diffuse sources (Muno 2004), the 511 keV line (Parizot et al. 2005), and Sgr A East, which is a supernova remnant, indeed just possibly the only known remnant of a Type Ia event arising in a white dwarf of less than Chandrasekhar mass, compressed to ignition temperature and density as a result of passing close to a black hole (Dearborn et al. 2005). A bunch of faint, mostly hard compact X-ray sources (Belczynski & Taam 2004; Muno et al. 2004) include a number of intermediate polars (moderately magnetized cataclysmic variables), Wolf-Rayet stars, OB stars, RS CVn binaries, young pulsars, BH and NSXRBs, and millisecond pulsars with accretion from winds in some cases and RLOF in others, Most of the common zoo and domestic species in other words.

A new sort of radio beast is GCRT J1745–3009 (of unknown distance), which in 2002 exhibited a string of 10 minute bursts, 1.27 hours apart, captured in 330 Hz data by Hyman et al. (2005) and Kulkarni & Phinney (2005). Observations of the region in earlier and later years show nothing down to 15 mJy (vs. 1 Jy bursts). What is it? A nearby brown dwarf; a nulling pulsar, magnetar, or coherent microquasar; example of kinds of beaming and beacons predicted long ago? Or something that hasn't been though of yet.

12.7. The Black Hole Bulge Connection

If every galaxy has one, why do people talk about them so much? Well, the same could probably be said about human private parts, which also have in common with black holes a central location and, as a rule, concealing material around. And here we had better let the analogy go, and proceed to outstanding questions. Every biggish galaxy (with a spheroidal component) has a black hole whose mass is somewhere around 10^{-3} of the spheroidal stellar mass, and the correlation is somewhat tighter if you choose spheroidal velocity dispersion rather than mass for your abscissa. Data revealing this count as one of the triumphs of extended programs with the *Hubble Space Telescope*, whose angular resolution was required to separate the dynamical effect of the central black hole from that of other stuff you find growing around galaxy centers. Questions not yet fully answered (or at least not everybody offers the same answer) include, (1) how far down in mass does the correlation extend? (2) which came first, the black hole or the stars, or (3), if (2) is the wrong question, how did they co-form to end with the ratio they now have (notice that this accepts that bulge star formation is way past its prime and so are QSOs and all)? (4) what was the situation like at moderate to large redshift, and do the standard ΛCDM scenarios of structure formation deal with it well? and (5) what still needs to be asked before it can be answered?

The small mass end remains mysterious. Modelers (e.g., Kawakatu et al. 2005) predict that there should still be black holes (though perhaps with smaller ratios to the total) down at least to $10^4\ M_\odot$, outside the range currently accessible to observations (e.g., Valluri et al. 2005 on NGC 205; Barth et al. 2005 on dwarf Seyferts).[68]

As for which crossed the road first, the possible answers are stars first, black holes first, and co-formation (with two sub-answers, constant ratio and BH/bulge ratio dropping with time). All four appeared during the year. Begelman & Nath (2005) predict (if that is the right word) that feedback from BH accretion into the protogalaxy should keep the BH/σ_v ratio the same for all redshifts and all halo masses, even small ones. Cai & Shu (2005) make the same prediction, from a magnetic feedback mechanism, provided that all sources begin with 46 mG. One observed sample concurs, Adelberger & Steidel (2005a) finding that the BH/bulge ratio at $z = 2$–3 is the same as now over the black hole mass range 10^6–$10^{10.5}\ M_\odot$. They are, however, outvoted by samples with BH/bulge larger at moderate to large z (Akiyama 2005, $z = 2$–4 data; Merloni et al. 2004b, synthesis of many kinds of data; Bonning et al. 2005 pointing out that both accretion and star formation are small now, but the stars have been gaining on the black holes for some time; Treu et al. 2004 on Seyferts). And there are probably also more theorists on the side of BH/bulge larger in the past, including Wyithe & Loeb (2005) and Koushiappas et al. (2004), who say that black holes can grow only a factor of 2 in mass

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[68] Whether it is OK to compare Seyferts with normal galaxies requires a small digression. AGNs in general are clearly not normal in that they are making better use of their black holes than average, but what about the BH to bulge mass ratios? Silge et al. (2005) say that Cen A hosts a black hole 5–10 times more massive than average; Wilman et al. (2005) and Capetti et al. (2005) say normal for Perseus A and the Seyfert NGC 5252 respectively. And Mathur & Grupe (2005) and Collin & Kawaguchi (2004) find a number of Seyferts with inferior black holes and predict that, when these reach the average mass for the hosts' velocity dispersion, accretion will drop to well below the Eddington rate and the central sources turn off.

since $z = 15$ when seeds stopped forming because of reionization. They also conclude that the smallest seeds will have the Jeans mass during the dark ages, $10^5\ M_\odot$, so that galaxies with bulge star masses less than $10^8\ M_\odot$ cannot have BHs in the proper proportion. Treu et al. (2005) report Seyferts with large BH/bulge ratios at $z = 0.37$, which counts as BH first.

Alexander et al. (2005) belong to the stars first camp, although their main point is that quite a lot of the black hole mass growth occurs behind obscuration. Martinez-Sansigre et al. (2005) concur, saying that a complete sample would have obscured QSOs (type 2) outnumbering the unobscured (type 1) by a factor of 3. They present a correctable sample of *Spitzer* sources with $z = 1.4$–4.2. The opposite conclusion, that most black hole growth by accretion is by unclothed accretion, is reached by Barger et al. (2005) using statistical arguments.

Is accretion the only way black holes can grow? Obviously not. When protogalaxies merge, their central black holes must also merge or go whirling around each other forever (such binaries exist but are not terribly common). Ap04 reported a majority view against mergers as an important process in BH mass growth. This is probably still more or less true, firmly so according to Shankar et al. (2004), but a significant role for mergers is advocated by Saitoh & Wada (2004), Yoo & Miralda-Escude (2004), Di Matteo et al. (2005, making the point that outflow from the BH eventually stops both accretion and star formation), and Hao et al. (2005, discussing violent mergers which preserve a standard ratio because the star formation rate is a few hundred times the accretion rate).

Semi-finally, three groups have worried about the most distant QSO in current catalogs. It has $z = 6.42$ and a black hole of at least $10^9\ M_\odot$. Walter (2004), Yoo & Miralda-Escude (2004), and Shapiro (2005b) all make the point that nature and theorists have to work so hard to make that big a black hole so quickly that they just don't have a chance to make all the stars as well. Walter also notes that the expected $10^{12}\ M_\odot$ of stars isn't actually seen either.

And the concept of "downsizing" seems to apply to black holes as well as to their host galaxies (§ 4). Heckman et al. (2004) report that most accretion is now occurring on black holes of less than $10^8\ M_\odot$ (just as most star formation is now occurring in galaxies of 10^{10}–$10^{11}\ M_\odot$), and that this is smaller than the average accreting black hole of the past.

12.8. Active Galaxies and Their Nuclei

Of the 139 papers, read (R), precised (P), and indexed (I) on this topic (where $R > P > I$), only one ended up with a star, Nipoti et al. (2005) on the ancient question of why some are radio loud and some more radio quiet. Their answer is that true, radio loud, quasars and the quiet QSOs are merely two modes of the same population. A number of other very old questions received at least one answer during the year, and for those questions that seem to invite yes or no, typically both appeared.

Confinement summarizes the puzzle that the extended clouds of relativistic particles and magnetic field required to emit synchrotron radio don't just expand freely at the speed of light. X-ray gas confines radio jets on 130 kpc scales, say Evans et al. (2005b). This is one of the classic candidates, though at one time the pressure was thought to come from a hot intergalactic medium with density close to the critical cosmological density.

Equipartition between magnetic field and relativistic electrons seems to apply in the contexts where it was first supposed to, the lobes and hot spots of Fanaroff-Riley II radio sources (the sort with two large lobes and hot spots on either side of a galaxy with jets feeding them). So say Hardcastle et al. (2004) and Croston et al. (2004, 2005). The latter also note that it would be odd to find field and electrons in equilibrium if the energy in protons were larger, so it probably isn't. Beck & Krause (2005) re-discuss energetics in the case where the protons are winning (by 40 : 1 or so), as they expect from certain kinds of shock acceleration.

The microquasar GRS 1758–250 further justifies its name by also having equipartition in its radio-emitting lobes (Hardcastle 2005). The jets themselves (FR II, microquasar, or what have you) will generally not be in equipartition (Tyul'bashev & Chernikov 2004), but it is the wrong issue to investigate anyhow, because nearly all the energy is in bulk, mildly relativistic flow (Nagar et al. 2005; Jorstad & Marscher 2004; semi-randomly out of half a dozen papers that made the point during the year). The case of the Milky Way core is slightly puzzling. We think LaRosa et al. (2005) are saying that the field wins, although the equipartition particle density, at 2 eV cm^{-3}, is like cosmic rays here. A ha! In this context the protons probably have 100 or so times the electron energy density (as in cosmic rays), and so they are perhaps in equipartition with the observed mG field. Abacus time, guys.

Binary black holes in orbit would seem to be an inevitable result of mergers of galaxies each of whom had one. Quasar 0957 with a period near 12 years is the longest-discussed and probably best-established example. Cases were made this year for 3C 345 with a period of 480 yr (no, Lobanov & Roland 2005 haven't seen more than one), 3C 273 (Zhou et al. 2004 using a model for jet acceleration), NGC 4716 (two variable nuclei, 60 pc apart; Maoz et al. 2005), PKS 1510–089 ($P =$ 336 days and the 4th minimum arrived on schedule; Wu et al. 2005d). You might draw two different statistical conclusions from these examples. If some of the best and brightest AGNs have binary BHs, they must be common (or that is why the sources are bright, not we think claimed by anyone this year); or, conversely, since the literature isn't totally overflowing with examples, they must be rather rare. Theorists can, of course, explain both. On the one hand, once a binary BH clears out the loss cone (stars available for disruption and accretion), a Hubble time is needed to repopulate (= rare among observed sources; Merritt & Wang 2005). And, on the other hand, if there are any stars available at all, the binary will be much better at the tearing apart than a mere single monster (Ivanov et al. 2005). The process is a tad complicated, but our old friend Kozai (1962) of the resonances comes in somewhere. And here we had thought it was just for asteroids. Binary black holes even in a vacuum will lose angular momentum and energy to gravitational radiation and merge after

$$t_0 = \frac{5}{512} \frac{c^5}{G^3} \frac{a^4}{M^3},$$

where a is the current semimajor axis and M is the mass of each of two equal black holes, perhaps $10^8\ M_\odot$ each. Enjoy the calculation says your server.

"Alignments" means various optical phenomena, including star light and emission lines, with radio jets, and we can all think of several possible causes. At one time the phenomenon was thought to be limited to $z \gtrsim 1$, and it remains true that more alignment is seen at large redshift and high luminosity (Inskip et al. 2005 on 6C galaxies). But NGC 1068 and Cen A show, respectively, aligned line emission and star light (Gratadour et al. 2005, Oosterloo & Morganti 2005). We found support for at least two of the standard mechanisms: photoionization of gas near the jets (Whittle et al. 2005) and jet triggering of star formation (Klamer et al. 2004, reporting that the first stars and first metals in a $z = 4.7$ galaxy formed along the radio jet).

Super-Eddington luminosities are apparently rare, say Paltani & Türler (2005), though they discuss in detail only 3C 273, for which they find a real black hole mass of 6–8 × $10^9\ M_\odot$ from reverberation mapping, 10 times the number from emission line velocity widths, implying a more or less face-on disk.

Type II AGNs have as their prototype the Type II Seyfert galaxies, whose broad line regions are obscured by their accretion tori and so visible only in scattered (thus polarized) light. You might suppose that the brighter sorts of AGN would be harder to hide. Indeed Type II QSOs were announced as a highlight a few years ago. They have become common (Zakamska et al. 2005, a bunch more from SDSS samples). Grindlay et al. (2005) announced the first Type II blazar, GRS 1227+035, recognized in balloon X-ray data.

Unification is the classic yes and no issue, where the angle from which we view a system is proposed as a major discriminant among AGN types and subtypes. It is part of the story, say Varano et al. (2004), who have compared FR II radio sources with quasars and find that the opening angle of the torus gets larger as the luminosity of the accretion disk gets larger. But not the whole story. There are also strong correlations of properties whose observed values will depend on orientation with properties whose observed values should be orientation-independent, for instance Marchã et al. (2005) on optical emission lines (independent) vs. core/jet radio ratio (dependent) and Shi et al. (2005) on radio flux (beamed) vs. 70 μm emission (isotropic). And we think that Imanishi & Wada (2004) are proposing strength of nuclear starburst proportional to AGN luminosity as the cause of some of these correlations.

Both please. Are the best and brightest AGNs also vigorous star formers? Yes for samples reported in at least seven reference-year papers, of which only Storchi-Bergmann et al. (2005) on NGC 1097 get cited. But not always. 3C 31 has $10^9\ M_\odot$ of molecular gas within 1 kpc of its center but is not forming stars (Okuda et al. 2005). How are we supposed to know it is an AGN? Well, it carries its 3C around with it. In contrast, the Wolf-Rayet galaxies like NGC 6794 do it all with stars (O'Halloran et al. 2005). And every year someone points out that there is or ought to be an evolutionary sequence, with mergers yielding a star burst and jets forming later. This year it was Tadhunter et al. (2005).

ADAF, ADIOS, and all. Very many accreting black holes are not luminous in proportion to the amount of available gas. The two major competitors for the answer to "what becomes of it?" are down the tubes, taking energy along (known as ADAF or advection dominated accretion flow) and blowback (of which ADIOS is one sort). Two not quite random papers of many, (1) blowback of various sorts as the explanation for poor correlations of black hole masses, Bondi accretion rate, and X-ray luminosities (Pellegrini 2005), and (2) ADAF as a picture of broad line emission regions in AGNs (Czerny et al. 2004, with a special color-changing star for their having voted this way over their own previous hypothesis).

Radio loud/quiet. The basic dichotomy was not challenged this year (though the exciting class of radio intermediate galaxies exists). One must begin by distinguishing correlations from causes. That the radio-louds have more supernovae (Della Valle et al. 2005) and more microvariability (Jang 2005) are presumably side effects of mergers and jets, correlated but not causal. That radio-quiets have relatively feeble jets that can neither escape the host galaxy (Barvainis et al. 2005) nor provide powerful X-ray emission (Ulvestad et al. 2005) comes closer to sounding like a cause, but why the weak jets? The largest sample examined during the year (6000 SDSS QSOs and quasars; McLure & Jarvis 2004) reveals that the black hole masses and host properties overlap far too much between the loud and quiet groups to be the dominant cause (and three papers that declare big black bludges, sorry, holes, to be the determining factor remain trapped on pp. 49 and 67 of the notebook). McLure & Jarvis suggest an evolutionary sequence (cf. Nipoti et al. 2005) or black hole spin, an idea hallowed by multiple presentations over the years. Bachev et al. (2004) voted for spin this year, while Ye & Wang (2005) said that there must be a second parameter, which they describe as "power law index of variations of magnetic field on the disk." Depending on the extent to which the disk is magnetically coupled to a (spinning or not spinning) black hole, this could be an indirect causal connection.

And an observation that is new this year, at least to us: all radio loud hosts have central optical profiles that are cores rather than cusps (Capetti & Balmaverde 2005; de Ruiter et al. 2005). The authors propose that galaxies with cuspy centers will be forever silent, while currently quiet cored galaxies are the radio sources of the past and future.

Lifetimes of AGNs are another of the truly old questions. Do a few galaxies do it all their lives, or most for 1% of the age of the universe each? The recognition that central black holes are nearly ubiquitous would seem almost to have settled the issue, and all the votes we caught this year were for 10^7 yr of being really bright and 10^8 yr of significant accretion on to the BH, much of it in hiding (Hopkins et al. 2005b; Bonning et al. 2005; Adelberger & Steidel 2005b; Croom et al. 2005). The turn-off comes for lack of gas, and Hawkins (2004) calls attention to a class of Seyferts and QSOs (face on and with no broad absorption line features) where we can see it happening. An occasional unwary star venturing too close can allow a brief resurgence (Tremain 2005; Gomboc & Cadez 2005), and a black hole that gets too massive turns itself off (Ann & Thakur 2005).

The hosts? Well, they are big (meaning massive) and fat (meaning spheroidal) and old (meaning that star formation at least started a long time ago). A baker's dozen or more papers provided parts of that description, which could equally well apply to a good many of our friends and relations, so the coveted green dots go to two other related ideas. First, there is a strong positive correlation between accretion rate and metallicity (Shemmer et al. 2004). And, second, downsizing (§ 4) applies even to nuclear activity, in the sense that, at $z = 1$, a source about as bright as a modern Seyfert lived in a much more massive galaxy as a rule (Gilli et al. 2005).

Evolution? There were more in the past, as you have known since Sciama & Rees (1966) used the redshift distribution to refute steady state cosmology. Soon after, observations were being urged to reveal whether the fraction of galaxies with nuclear activity had declined (density evolution), or was it the luminosity per source (luminosity evolution), or both? A moment's thought, or a decade of the literature, should persuade you that there is no way to tell the difference if $N(L)$ is a pure power law. Thus it is structure in the luminosity function that now enables Barger et al. (2005) to say luminosity evolution scaling as $(1+z)^3$ out to $z = 1.2$ for optical evolution and Wall et al. (2005) to say density evolution for Parkes radio sources since $z = 1$. Wall et al. also note that the number density (in comoving coordinates) turns down again at $z \geq 3$. Silverman et al. (2005) report the first X-ray selected sample that also shows this turnover (or anti-evolution if you must). Their second point, that most of the X-ray luminosity today and back to $z \approx 1$ comes from relatively low L_X sources, is echoed by Merloni et al. (2004a). This is presumably yet another aspect of downsizing (§ 4), though it also presumes that the evil selection effects of magnitude limited samples are not overwhelming.

Non-cosmological redshifts? Among many other challenges nearby large-redshift QSOs would have is that of passing their light through many (sometimes very many) absorbing clouds of smaller redshift between them and us. Ejected gas is one way to do this. Most of the astronomical community agrees that there is such a class of "associated" lines, distinguished by line width, gas density, temperature, and composition from intergalactic gas clouds; that they extend only to about -1000 km s^{-1} shift relative to the QSO rest frame; and that the velocities are even that large only from the brightest (assuming cosmological distances) QSOs (Aoki et al. 2005; Gallagher et al. 2005; Benn et al. 2005). Probably no set of observations can move members of one camp into the other, but Zackrisson (2005) has an idea. If QSOs are ejected from the nuclei of nearby galaxies carrying large intrinsic redshifts (which decrease with time) in their pockets, then the recently-ejected should consist only of ionized gas and/or young stars with no proper host. Unfortunately, this comes perilously close to what you expect for the largest redshifts in the standard picture.

13. TO RER IS HUMAN

Hubristically emulating the High Priest on Yom Kippur,[69] we begin by confessing our own sins in (mostly) Ap04, ordered by section number. These are of two sorts, class A (rigid) where there is no doubt that we were wrong and class B (limp, or blimp, a folk etymology), where a correspondent appears to be disagreeing with a paper cited as a highlight as well as with our taste in choosing it, rather than one of theirs. Many of the items made us say, "urr," and occasionally "um" or "duh."

13.1. Our Urrs, Class A

Sections 2 and 7: 100 $M_\odot$ planets should have been 10–100 $M_\oplus$ planets even in these days of growing BMIs.

Section 4.8: Should V_r in the formula $V_r = 4.74\mu d$ have been V_t (for transverse, rather than radial)? Actually not in context. You cannot measure V_t separately from μ and the expression applies only to spherical expansion.

Section 4.12: Mira variables with confirmed period changes include R Hya and R Aql.

Section 4.13: The star with the changing Blazhko period is XZ Cyg, not XZ Cam, which our correspondent describes as "a perfectly lovely star in its own right, but I believe it is an eclipsing variable rather than an RR Lyrae."

Section 10.4: The galactic ring [of stars] is not called Canis Majoris chides a Reliable Correspondent. Indeed surely not by its mother, though we and the authors being cited meant it in the non-rigorous sense of "the constellation you look through to see something." It is called Canis Major.

Section 11.4: The telescope with the shortest interval as largest, at least in modern times, was the Dominion Astrophysical Observatory's 1.8-meter, completed 2 years ahead of the Mount Wilson 100-inch, because of wartime delays in the US.

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[69] In barest outline, he confessed first his own sins, then those of his family, and finally those of the whole nation. A slightly expanded version appears in Leviticus 16.6, 16.11, and 16.21, but for the full version you must go to the commentary Mishnah Yoma, Ch. 3. Mishnah 8; 4 : 2; and 6 : 2. The customary tune is said to be the only one in current use that can be traced back to the time of the Second Temple. Thus this last section begins with our own errors of earlier ApXX, goes on to some family failings, and ends by drawing on the entire nation of astronomers.

Section 13.1: The second brightest supernova? How about 1972 event in NGC 5253 says George (and you must guess which one since at least four have contributed comments on ApXX reviews over the years).

Section 13.1: The correct central wavelength of the 4430 Å diffuse interstellar band was first pointed out even earlier, in *Zeitschrift für Astrophysik* 64, 512 (1964) also by George.

13.2. Our Urrs, Class B

Ap03, § 6.4: A Correspondent casts doubts on the reported detection of a magnetic field in β Lyrae.

Ap04, § 4.14: B Correspondent suggests that any attempt to identify the Egyptian lion constellation with Leo is likely to cause heart attacks among (other) experts. Before making up our minds, we want to know who they are. (Compare the issue of whether blowing up the houses of parliament is a good or bad thing to do.)[70]

Section 8: One of the non-standard cosmological models yields a concordance age of 14.1 Gyr, if $H = 48$ km s^{-1} Mpc^{-1}.

Section 9: The (proof?) reader who objected to our consideration of "who to cite in Ap05" in favor of "whoM to cite" says that he is "just being objective, not accusative, and, since he is married, not dative and certainly not genitive."

Section 9.10: Falsification of the Chamberlin-Moulton hypothesis and when it occurred. The first strong theoretical line of argument came from Lyman Spitzer in 1937. He concluded that gas pulled from the Sun would dissipate not condense. If you think falsification requires an observation or experiment, then it is probably the presence of deuterium in the planets and its absence in the solar atmosphere.

Section 11.5: Concerning spectral types of stars in the SMC. We had said "4161 spectral types…well, spectral types for 4161 stars, but apparently only about 10 types." The authors respond, "there are 4161 spectral types, not 10, but a lot of them are the same. On the other hand, they're in *Monthly Notices*, not the SMC."

Consciences cleansed, we proceed to the usual assortment of um-provokers. No names are mentioned, but the references are real.

13.3. Numerical Urrs

"Corresponding to a uniform enrichment to a few hundred thousand solar" (*ApJ* 629, 615, abstract). Hey, can I have the gold?

"…model uncertainties make the accuracies of these values at least twice the magnitude of the precision" (*AJ* 128, 2826, abstract).

"…an estimate of the star formation rate at redshift 3.1 × 10^{-2} h^3 $M_\odot$ yr^{-1} Mpc^{-3}" (*A&A* 430, 83, abstract).

"Finally, in § 5, we draw our conclusions" (*MNRAS* 357, 156; but look on p. 157). But there are only four sections, and we honestly did not understand whether the 2.2–2.4 cm height was the thickness of the C ring or amplitude of its warp.

"…a fading of the characteristic luminosity by a factor 1.35 because $z = 0.2$" (*MNRAS* 355, 767, conclusions). Apparent brightness drops as $(l + z)$ to various powers, x, for various cosmological models, but $x = 1.65$ isn't any of them.

"several" is anyhow larger than seven (*MNRAS* 354, L7, abstract).

"nascent Trapezium" with five stars (*ApJ* 622, L141, abstract). Oh, all right, there is also θ^1 Ori E.

"…due to an error in the conversion to SI units, …the densities…are all too small by a factor of 10^6" (*A&A* 435, 339, erratum).

$H = 71$, $q = 0.5$ still in use (*A&A* 435, 863) to analyze a radio galaxy at large redshift.

"January temperatures were in the range –25° to 35° C" (*Science* 308, 397) in an article on the possibility of recreating Pleistocene ecosystems in Siberia which would seem to require organisms tolerant of a very wide temperature range.

16% of US youth in 1999–2000 were above the 95th percentile for 2000 in CDC sex-specific BMI growth charts. (MMWR 54, 203, and no it won't help a bit to know that CDC = Centers for Disease Control and MMWR = Mortality and Morbidity Weekly Report, one of our more cheerful bits of regular reading). They do better in Lake Wobegon.

909 women report how they spent their day in *Science* 306, 1776. The sum of the mean hours per day devoted to all activities was 27.2 hours, of which 6.9 were spent working and none sleeping. Perhaps medians would have been better.

"…[scientists] descended on San Diego. Even many of those based in the US flew in" (*Nature* 432, 257). A UK author can perhaps be forgiven for not knowing quite how long it takes to get from Bethesda MD or Cambridge MA to San Diego CA by bus, train, or car. The article was about reducing carbon dioxide production.

Eros as described in *A&A* 433, 356 (but look on p. 371) has a mass given in kg and volume in km^3, but density g cm^{-3}.

"…0.2 mas, plus or minus a factor of 2" (*ApJ* 627, 674, abstract). Like the adders deprived of their slide rule, we find it difficult to go forth and multiply under these conditions.

"$L_X = 28$ ergs s^{-1}" for class 0 protostars in ρ Oph (*ApJ* 613, 393, summary on p. 410).

A graph in *ApJ* 613, 517 (Fig. 5) has axes labeled 1, 5, 10, 15, 20 and 0, 1, 2, 3 but no units or names of the quantities.

"The speed of light, or c, is a really big number, 186,282 miles per second. Multiply it by itself, and the result is, well, a really big number, 37,700,983,524." (*Smithsonian*, June 2005, p. 11). Now, in what set of units is this useful? Yes, your least metric author did the same thing at age 8, but she rounded off to 186,000, much shortening the computation and then asked her father what to do with it. Publish immediately was not the answer.

Contrary to Morrison's dictum, it is possible to waste $\$10^8$ (*Nature* 436, 14) on a conservation project for Steller's sea

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[70] Especially since the Keen Amateur Dentist sometimes now sits there.

lions (named for their discoverer, not their sparkling appearance) which requires the grantees to avoid making the most informative measurement.

"…the leading experiments are still sensitive enough to set limits 1–2 orders of magnitude less stringent than those traditionally presented" (*Phys. Rev. Lett.* 95, 101301, abstract). Not, we were going to say, the best argument for funding, but in light of the previous item…

13.4. Ur-People

From the APS/CSWP Gazette, Issue 24, No. 1, p. 9. A very nice picture of Yuri Suzuki, winner of the 2005 Maria Goeppert-Mayer Award. But the caption on the picture says Agnes Pockels. And somewhere it has to be recorded that Goeppert-Mayer's daughter (wife of astronomer Donat Wentzel) died this past year after a long, painful course of scleroderma.

"The dynamical problem of Henon-Heiles hardly needs any introduction" (*Ap&SS* 295, 375) so they don't give it one. Another paper read later the same day described it as a "well known potential," which doesn't help as much as they probably meant it to.

"…members of the Review Committee from universities, schools, the oil industry, the shallow geophysics communities…" (*A&G* 46, 3.7). Gee, we don't say things like that about astronomers.

"Lunar Hill's limiting case" (*Ap&SS* 293, 271). No, no citation, but we are reasonably sure that Lunar is not a first name.

"Paloma-Green quasars" (*Ap&SS* 295, 397, abstract). Paloma is the Spanish for dove, and you can make your own gentle comment.

"I don't have any particular reason to think he is not up to it, but…" (*Nature* 437, 610) is one astronomer describing another, newly chosen for High Position. With friends like these…

"India's Atomic Energy Commission says…that his country, on considering…" (*Science* 309, 365). The temptation is to say something about limited democracies, but we found ourselves this year participating in an organization where not even the Electoral College is allowed to vote.

A plea for contributions to keep the papers of R. Franklin, M. Perutz, etc., together (*Science* 307, 519) gives absolutely no indication where to send a check, who to contact, or, for that matter, whether it would be deductible.

"P.P.J. thanks [two names] for fruitful discussions" (*A&A* 430, 47, acknowledgments on p. 56). But the authors are HC, PP, RS, and BA.

"Vandervoort 1983, 1984, 2004, hereafter OS^3, LM, and M^2, respectively" (*MNRAS* 354, 601, introduction).

"…known as the Lari method…" (*MNRAS* 358, 397). Lari is one of the authors, and if you wonder about self-bestowed eponyms, contemplate what Feynman called the diagrams ("the diagrams" of course; we asked him).

"Holmberg relation" (*A&A* 434, 887, look on p. 893). This one is absorption in a galactic disk, A_v vs. blue magnitude. No citation, of course.

Figure 10 of *A&A* 434, 167 would seem to represent science fiction creatures, chess persons, or a pudgy pinhead presenting a pear to a princess.

"Stuff works when the repairman is available" (*New Scientist* 11 December, p. 64) is so obviously true that it must be Enoemos's Law.

13.5. Where-ur and When?

"…the Indian Ocean tsunami event of Sunday 2005 December 26" (*Observatory* 125, 202). Well, December 26, 2005 was a Monday, but you had to be reading this with us in October 2005 to wonder whether it might be a ghastly prediction.

"…mutual phenomena of the Galilean satellites in Romania." (*A&A* 439, 785, title). The most we can say is that, Romania, currently holding the record for most times in and out of the IAU, has a better chance for mutual phenomena than most.

"…quasar host galaxies with adaptive optics" (*A&A* 439, 497, title) and if that's where you want to keep your AO system, you have a perfect right, if you can get it there.

"…assembly of stars and dark matter from the SDSS" (*MNRAS* 356, 495, title). Well it was a very massive survey.

"…in the Sun and in silico" (*A&A* 429, 1093, title). Like Spike Jones's phone call, they don't say who it is, but, we suspect, not the same as "in vitrio" though many glasses have significant silicon content.

"The Needles in the Haystack Survey" (*MNRAS* 354, 123) would have been a great name if it had been done from Haystack Observatory. But it wasn't.

13.6. Nonce Words

These are new ones[71] made up for a single occasion and, one might hope, never to be heard from again. Some of these are words, some authentic (pronounceable) acronyms, some not even that.

Gasoline is a parallel *N*-body gas dynamics code (*NewA* 9, 137, title).

Decretion disks are the outer parts where angular momentum is transported outward (*Astron. Rep*. 48, 800, title). In earlier years, excretion disks have been mentioned, and we can understand a non-English speaking author recoiling from the first dictionary definition.

"Quaternary is a hangover from a previous naming system, the rest of which has been discarded" (*Nature* 435, 865). Yeah, like the Cretaceous-Tertiary boundary.

A caterpillar that eats snails in Hawaii (*Science* 309, 575) is a phytophagous species. If you have eaten snails only in France, you don't know what you are missing.

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[71] The etymology is Middle English "for then ones" misunderstood as "for the nones," and go ahead, admit it, you were expecting Ur-words.

The quipu we grew up with are now khipu (*Science* 309, 1065), but they arguably carry more information than they used to, justifying a change.

COSMIC = COntinuous Single-dish Monitoring of Intraday variability at Ceduna (*AJ* 129, 2034). CHIPS = Cosmic Hot Interstellar Plasma Spectrometer (*ApJ* 623, 911). BEAST = Background Energy Anisotropy Scanning Telescope (*ApJS* 158, 93), described as a cosmic microwave background "experiment" (well, wouldn't you like to make some changes?). IMF = interplanetary magnetic field (*ApJ* 625, 525). CHORIZOS (*PASP* 116, 859) is a χ^2 code. ALIVARS = Algol-Like Irregular VARiable Stars (formerly antiflare stars, *Ap&SS* 291, 123). HINSA = H I Narrow Self Absorption (*ApJ* 622, 938), and practitioners of ahinsa will have to decide whether it is the absorption or the neutral hydrogen that is being denied. Or, perhaps, the narrow self. RASSCALS (*ApJ* 622, 187) is a category of groups of galaxies. The GOY model (*A&A* 432, 1049) need not have been, since the earlier papers are Gledzer and Yamada & Ohkitani. Reflections on Reflexions (*MNRAS* 357, 1161) means there will always be an England, or anyhow an English different from American.

The "maser mechanism of optical pulsations" (*MNRAS* 354, 1201) is suffering from wavelength disorder. "The optical and electronic regions of the electromagnetic spectrum" (*Science* 308, 630) have the related Lambda's disease. "Losanges" (*A&A* 424, L31, look on p. L32) might be flat and sweet or might come from Los Ange(le)s. If the latter, they might well have been found in the "Sedentary Survey" (*A&A* 434, 385).

"…despite fulsome opposition…" (*Nature* 433, 688) may not be precisely what the authors were thinking, and ditto for "the polemic and long-sought correlation" (*ApJ* 629, 797). In contrast, "photon tiring" (*ApJ* 616, 525) was intended, but it is not the same as tired light and is not likely to be found from Sedentary Surveys.

"Standard Sirens" (*ApJ* 629, 15) come from the inspiral of black hole binaries. And now that you know what song the Sirens sang, have you any thoughts on what name Achilles adopted when he hid among the women? And how did he ever find shoes to fit?

"The nearest clusters with large $\sigma_{\rm los}$ are the idoneous ones to discriminate models" (*A&A* 424, 415), but we hate to think what they must be models for. If we had to guess, it would be a toss-up between "ideal" and "obvious."

"ugwz-type subclass of ugsu dwarf novae" (*PASP* 116, 1117, though we hate to bite the journal that accepts us).

Concerning Auger and the need for enhanced computing power, "all agree that as it gobbles up data…" (*Science* 309, 687). Selbbog is marginally pronounceable if you wish to convey the opposite idea by going backward. "Spews out" is also available in the realm of graphic metaphor, indeed perhaps excessively graphic.

The green dot for names of the year had to be divided. Candidate one is Edasich for ι Draconis (*Sky & Telescope* 109, No. 6, p. 74), reducing us from two pieces of information (where/when you can see it and an approximate brightness) to zero. And candidate two (*ApJ* 620, 948) is the recommendation to distinguish things that will produce planetary nebulae from things that will produce planets by calling them "preplanetary nebulae" and "protoplanetary nebulae." And we managed to remember which was supposed to be which almost long enough to tell our class about it.

13.7. Ur-Symbols

Z is used to mean metallicity relative to the Sun (*A&A* 430, 1133) and so takes on values 0.1 to 2.5 or 3.0 (and we still want the gold).

"…ρ_Q and P_Q being respectively the pressure and energy density" (*A&A* 436, 27) providing the possible definition of "respectively" as "bass ackward." M_v does double duty (*ApJ* 622, 938) for virial mass as well as absolute visual magnitude.

13.8. Ur-Duh

The most surprising trait here is that anyone was surprised by them. For instance "complex models are more frequently required for sources with…higher signal-to-noise ratio" (*A&A* 433, 1163). "Faculty members are assessed not only on the quality of their teaching or even their research, but on how fundable their research is" (*Nature* 434, 1059). "A cooling flow does exist in the moderate cooling flow model…" (*ApJ* 622, 847, abstract). "Students believe that batteries get light as they run down" (*Science* 308, 191). Well indeed they must, though we would not want to be in charge of measuring the ΔM that goes with this $\Delta E/c^2$.

"Should large organic molecules be found in extraterrestrial samples, it would be interesting to check the handedness of their optical activity" (*Nature* 435, 437). Amino acids were promoted from racemic to a slight excess of the terrestrial rotatoriness a few years back. And yes it made ApXX at the time. "Textbooks still parrot the conventional thinking that no fossil sharks are found before the Devonian" (*American Scientist* 93, 248) provides another example of the difficulty of keeping on top of things

13.9. Ur-No

This comes as close as we can get to the words uttered by S.W. Hawking at a conference many years ago when Dennis Sciama asked him, "Is that right, Steve?" We hope they would both vote with us on most of the following.

"Planets have their elegant circular orbits yanked into ugly distended ovals" (*Sky & Telescope* 109, No. 1, p. 45), presumably by that notorious Yank Johannes Kepler. The primary meaning of "oval" is not elliptical but egg-shaped (have some pity for the poor hen) and you might also want to rethink resonances in general before adopting the advice in that article on how to push children in swings.

"…the two disks are chemically well separated [and] they overlap greatly in metallicity" (*A&A* 438, 139, abstract).

"The deuterium enrichment (in molecules like N_2H^+/N_2D^+) is presently ascribed to the depletion of CO in high density cores" (*ApJ* 619, 379). It may well be so, but no explanation of the mechanism was provided.

"With topspin, the velocity of air relative to the surface at the top of the ball is higher…if the ball has topspin, the thin layer of air in contact…is traveling faster at the bottom than at the top" (*New Scientist* 11 December, p. 65). Could this be why we have never been able to pitch decently?

"Ecologists have established that nitrogen and carbon isotopes are heavier in marine organisms" (*Science* 306, 1466). Not the same author, but kin to "…increasing atomic weight (or the positive charge of the nucleus)" (*Nature* 433, 461). Well, Mendeleev had trouble with that one among the heavier elements.

"All our helium is left over from when the planet first formed [and] leaks out of the middle of the Earth" (*Nature* 433, 906). Well, arguably, but a good deal of it was initially left over in the form of Uranium and Thorium.

13.10. Ur-Phrases

It is possible that some of these would have done better in a primordial language. But not probable.

From a large envelop mailed by Duke University, "Contents inside." Like the closed box model of cosmic chemical evolution last year, consider the alternatives. Or have you received a shipment in a Klein bottle from them lately?

From a student essay, "A week ago, Hans Bethe died and contributed to the field of science." Of all the people who might be suspected of continued, significant, posthumous scientific contributions, Hans would surprise us least.

From a mailing by an organization we really like, "If you move, be sure and let us know your new address, and the post office won't always forward your (Publication Name) to you."

"You show me your O VI and I'll show you mine" (*Ap&SS* 289, 469, title, selected undoubtedly by authors who also have a large central black hole, cf. § 12.7).

"High Energy Density Laboratory Astrophysics" (*Ap&SS* 298, No. 1, title of conference proceedings). The energy density in our lab depends a lot on whether the postdocs are there (the sign is up to you).

"The International Chicken Genome Sequencing Consortium" (*Nature* 432, 695), and "Opportunities in researching disaster" (*Science* 309, 983, teaser caption; to show that we are equal opportunity journal disparagers).

A few cases where the authors seem to have done it deliberately, but you would have had second thoughts; "In spite of the wealth of data, or perhaps because of it" (*A&A* 433, 305, abstract). "…assuming spherical symmetry [for the baryons]….we find that the halo mass is rounder than the baryonic distribution" (*ApJ* 623, 31, abstract). "Fresher than fresh" was a frozen foods slogan; "rounder than round" belongs perhaps to genetically engineered apples. "The introduction of a new physically meaningless parameter" (*A&A* 428, 545), "assuming that all the detected X-ray radiation is either nonthermal or thermal" (*ApJ* 616, 452, footnote to table 3). Yet again, consider the alternative.

"The shower was not bright meteor and lower activity in comparison with other meteor showers" (*A&A* 424, L35, introduction).

"Uncertainties in the nebular geometry and the degree of dust clumping are most likely responsible for the blue rise" (*ApJ* 616, 257, abstract). A confused source in all senses.

And some cases where even we would have had second thoughts. "…two bodies getting entangled in thin layers of dynamical chaos" (*MNRAS* 360, 401). "…despite some philosophical differences with us about the passbands…" (*PASP* 117, 485, acknowledgments). "…send (expendable photocopies of) papers to one of the following…referees…, and then inquire of him by phone in 40 days" (*Dio* 13.1, p. 19) and presumably 40 nights.

"Quod erat demonstrandum; Latin for: which was to be proved," a footnote to QED (*A&A* 436, 549, but look on p. 554). Aw gee. We thought they meant quantum electrodynamics.

"Local universe" has begun to appear all over the place, though we started cringing only at, arbitrarily, *ApJ* 624, 155. Do they mean the Virgo supercluster? Redshift less than 0.01, 0.1, or what? Or perhaps just a region within which one can find "a large dwarf galaxy sample" (*AJ* 129, 2119).

"Animals like autists concentrate on details" (*Nature* 435, 147), from a review of T. Grandin & C. Johnson, *Animals in Translation*. If you have never before read anything by or about Temple Grandin, now is the time to start. If you don't occasionally have a "hey I was like that" experience, how did you get to be a scientist?

The same colleague has supplied our closing quote for many years, and you will hear from him in just a moment, but first a word from a colleague who was actually pleased at something in Ap04: "We are encountering difficulties in having our [topic mentioned in Ap04] proposals allocated in larger than 2-meter telescopes. I will use your reference in the next proposal…and see if I am allocated."

And, finally, with only the ethnicity pseudochauved, "Uzbanian people says: wishes to live before next bearthday in order to all would assemble around the celebral table newly and say wishes one more!" Your authors are not sure what will happen in the next year, but hope indeed to say wishes one more to you all.

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[72] What VT has yet to realize are the tremendous advantages of being an Emeritus Professor. —CJH.

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