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Invited Review

Astrophysics in 2003

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ABSTRACT. Five coherent sections appear this year, addressing solar physics, cosmology (with *WMAP* highlights), gamma-ray bursters (and their association with Type Ia supernovae), extra-solar-system planets, and the formation and evolution of galaxies (from reionization to assemblage of Local Group galaxies). There are also eight incoherent sections that deal with other topics in stellar, galactic, and planetary astronomy and the people who study them.

1. INTRODUCTIONS

Triskaidekaphobics may prefer not to read this installment of ApXX, and their numbers may well be augmented even before the introduction is over. This is, in fact, the 13th overview of 365.24 days of the astronomy and astrophysics literature. The earlier ones are cited here as Ap91, Ap92, …, Ap02 and appear in volumes 104–115 of *PASP*. The authors have tried to read systematically the contents of about 30 journals and other periodicals. Only about 10% of what has been read gets cited, and being cited is not always an unqualified compliment.

Section 2 was assembled using papers found on the Astrophysics Data Service, maintained with support from NASA and including *Solar Physics*, *Geophysics Research Letters*, *Astroparticle Physics*, *Acta Astronomica Sinica*, *Chinese Journal of Astronomy and Astrophysics*, *Journal of Geophysical Research*, as well as the journals scanned for the other sections.

Used in compiling sections 3–13 were the issues that reached library shelves between 1 October 2002 and 30 September 2003 of *Nature*, *Physical Review Letters*, *Science*, the *Astrophysical Journal* (plus *Letters* and *Supplement Series*), *Monthly Notices of the Royal Astronomical Society*, *Astronomy and Astrophysics* (plus *Reviews*), *Astronomical Journal*, *Acta Astronomica*, *Revista Mexicana Astronomía y Astrofísica*, *Astrophysics and Space Science*, *Astronomy Reports*, *Astronomy Letters*, *Astrofizica*, *Astronomische Nachrichten*, *New Astronomy*, *Journal of Astrophysics and Astronomy*, *Publications of the Astronomical Society of Japan*, *Bulletin of the Astronomical Society of India*, *Contributions of the Astronomical Observatory Skalnate Pleso*, *IAU Circulars*, and, of course, *Publications of the Astronomical Society of the Pacific*. Some of the journals read for fun, without compulsive note-taking, were *Observatory*, *Journal of the American Association of Variable Star Observers*, *Astronomy and Geophysics*, *Mercury*, *New Scientist*, *Sky and Telescope*, *Monthly Notes of the Astronomical Society of South Africa*, and *Journal of the Royal Astronomical Society of Canada*.

Do we ever cite ourselves? Well, now and then, but you are supposed to be polite enough not to notice, and we promise to do the same if you should ever indulge in self-citation.

1.1. Lots of Launches

Up went: (1) *Integral*, a gamma-ray satellite on 17 October 2002; (2) *GALEX*, the galaxy evolution explorer satellite, the first designed to image most of the sky in ultraviolet and take spectra of much, on 28 April, with first images on 21 and 22 May; (3) *Muses-C*, which is supposed to hit asteroid 1998 SF36 with a projectile and catch the dust, during the week of 8 May; (4) *MOST* (microvariability and oscillations of stars, the first Canadian astronomical satellite), which reached orbit on 30 June; (5) a coven of Mars missions, *Mars Express*, *Beagle-2*, *Sprit*, and *Opportunity*, in June and July; (6) *SIRTF*, the space infrared telescope facility, on 25 August, with first images on 1 September, and whether this was 2 days or 15 years late depends on the point of view; (7) *SMART-1*, the first ESA mission to the Moon on 27 September; (8) *SORCE* on 25 January (a solar mission); and (9) the first Korean science satellite, carrying an ultraviolet astronomy instrument constructed at the University of California, Berkeley, near the end of September.

On the ground, LIGO (the laser interferometric gravity observatory) began a first science run; VIRGO (the European equivalent) expects first twitches in spring 2004. And the Polar Cap Observatory, which had been intended for a site near the north magnetic pole (unfortunately not located with the USA), is to be replaced by several portable antennas that will operate first in Alaska and then in Canada.

1.2. Holding Their Own

Cassini returned its first Image of Saturn to the Jet Propulsion Laboratory about 1 November. *Nozumi* is still en route to Mars, but after a succession of problems may not be able to maneuver effectively or return data. *Rosetta*, the comet mission whose delayed launch made its original destination impossible, is now expected to head for Churymov-Gerasimanko in 2004. *Stardust*, a comet sample return mission, set out in February 1999 and should encounter its target, 81P/WILD2, in January 2004. The comet has begun to display a dust tail, which is probably a good thing.

SOHO, at age eight, has survived another glitch by using its backup antenna to return data. *Gravity Probe B* (once called the Stanford gyroscope experiment) is currently scheduled for a 2004 launch on a Delta rocket (which is either about a year or about 20 years late).

1.3. Lots of Losses

Down came, most notoriously, the *Columbia* shuttle on 1 February 2002. *BeppoSAX* was returned deliberately to Earth (lest it return on its own someplace where it didn't have an invitation) about 1 April, and *Galileo* immolated itself somewhere deep in the Jovian atmosphere on 21 September. *Pioneer 10* is still headed outward, but its last word, from 83 AU on 22 January, included no news of having reached the heliopause.

Ground-based entities in various states of temporary or permanent suspension include (1) VERITAS (an ultra-high-energy cosmic-ray detector), whose intended site is of importance to Native Americans; (2) closures of groups by the Max Planck Society, including the radio astronomy program at Bonn; (3) the Gran Sasso underground laboratory, most of whose experiments were closed at the end of May (only temporarily, we trust), including the construction of the solar neutrino facility, Borexino, because of a possible fluid leak into the local water supply; (4) Mount Stromlo Observatory, which lost much of its library, shop facilities, and archives, and some of its telescopes (including the Great Melbourne, which had recently completed the MACHO project) to wildfires on 18 January; and (5) all of humanity, though not perhaps for a century or so (Rees 2003).

2. THE SUN

2.1. The Solar Interior

2.1.1. Solar Fundamentals

Although no graviton has ever been detected, it has been calculated from the geodesic equation of general relativity that the solar gravitational deflection angle of a graviton is equal to the light deflection angle (Ragusa & Céleri 2003). What about the gravitational constant? Wait for next year; the latest seismic solar model is sensitive to Newton's constant (Lopes & Silk 2003), as well as to supersymmetric dark matter (Lopes et al. 2002b, 2002a). Does the Sun shine by *pp* or CNO nuclear fusion? New neutrino experiments set upper limits of 7.3% to the fraction of energy that the Sun produces via the competing CNO cycle, which is an order-of-magnitude improvement over previous limits (Bahcall et al. 2003). Is the solar diameter constant? According to the analysis in the variation of *f*-mode global oscillations, there is no evidence that the Sun shrinks (Antia 2003), while apparent variations are in phase or antiphase with the solar cycle (Delmas & Laclare 2002; Noël 2002) or have a period of 515 days (Reis-Neto et al. 2003). Is the solar rotation constant? The equatorial rotation rate with a mean of $P = 26.929 \pm 0.015$ has been found not to vary over the last 34 years (Haneychuk et al. 2003), but studies over longer times find variations with an approximate 179 year cycle (Javaraiah 2003). The rotation rate of individual spot groups is found to increase with their age (Sivaraman et al. 2003) and there is a solar-cycle-related variation (Altrock 2003). Also, the mean photospheric magnetic field did not vary over the last 30 years (Kotov et al. 2002), although the high-frequency mean noise spectral density varies significantly (Chaplin et al. 2003). Answers to these fundamental questions became possible only because the solar interior quantities have been measured with unprecedented accuracy: the adiabatic sound speed can be inferred to better than a few parts in 10^4, which becomes a serious challenge to theoretical solar standard models (Boothroyd & Sackmann 2003). The largest uncertainties reside in the abundance of heavy elements, because the inversion from helioseismic data is ill-conditioned (Antia & Chitre 2002), but the new CNO reaction rates (Bahcall et al. 2003) might provide better abundance limits using the constraints of the total solar luminosity.

2.1.2. Neutrino Mixing Holds Up

After the long-sought solution of the solar neutrino problem reported last year (see Ap02), we are particularly eager to see a corroboration of the "noble-breaking" results. The theoretical interpretation of the neutrino phenomenology is currently being investigated in the context of two-, three-, and four-neutrino mixing, from atmospheric ν_μ oscillations, with the Kamioka Liquid Scintillator Antineutrino Detector (KamLAND), the KEK-to-Kamioka (K2K), and the Sudbury Neutrino Observatory (SNO) experiments; but the three-neutrino mixing scenario (ν_e, ν_μ, ν_τ) seems to hold up for all data sets, solar, atmospheric, and reactor (Fogli et al. 2003a, 2003b). Time-series analysis of the Super-Kamiokande neutrino flux exhibits a prominent oscillation with a period of 13.75 days, which is half a solar rotation, pointing to a modulation of the neutrino source near the tachocline by the dipole ($m = 2$) structure of the internal magnetic field (Sturrock 2003). Production rates based on resonant interactions of the neutrino magnetic moment with the solar magnetic field in the tachocline (Pulido 2002) and spin-flavor flips in the convective and radiative zones (Friedland & Gruzinov 2003) have now been computed, while forthcoming experiments with KamLAND and Borexino are planned.

2.1.3. The Sun's Heartbeat

You can easily increase your heart rate and blood pressure with strenuous activities. Similarly, helioseismologists measure deviations from the almost-constant frequency of global *p*-mode oscillations (i.e., the solar heartbeat) in solar active regions (Howe et al. 2002) and in rotating sunspots (Zhao & Kosovichev 2003), and as a function of the solar Hale cycle (Jain & Bhatnagar 2003; Jimenez et al. 2002; Jimenez-Reyes et al. 2003; Eff-Darwich et al. 2002), large scale surface flows (Roth et al. 2002), or turbulent background flows (Skartlien 2002). Helioseimic frequency measurements have been found to agree between different instruments (*SOHO*/MDI and GONG) to better than 10^{-5}, where the discrepancies were actually blamed on the data pipeline software rather than on instrumental effects (Basu et al. 2003)!

2.1.4. The Workings of the Solar Dynamo

A solar dynamo mechanism needs to explain the evolution of the poloidal magnetic field into a toroidal field (ω-effect), as well as the subsequent regeneration of the poloidal field (α-effect), to close the cycle. Since the differential rotation on the solar surface was found to be anchored all the way down through the convection zone, while the radiative core is believed to rotate as a solid body, the interface between the convective and radiative zone (called *tachocline*) is the obvious place for the ω-effect, while the engine for the α-effect is still unknown. In Babcock-Leighton models, the poloidal field is regenerated by the decay of active regions and by their subsequent poleward migration due to interactions with meridional flows. Recent work invokes either surface-bound shallow convection (DeRosa et al. 2002; Robinson et al. 2003; Nishikawa & Kusano 2002; Rüdiger et al. 2003) or rotationally-influenced magneto-shear instabilities and turbulence in the tachocline (Miesch 2003; Petrovay 2003; Cally 2003; Kim & MacGregor 2003; Choudhuri 2003; Cline et al. 2003; Marik & Petrovay 2002; Zhang & Liao 2003; Hathaway et al. 2003) as drivers of the α-effect, so there is competition between surface-driven and deep-seated α-engines (Mason et al. 2002). Of course, the communication between the tachocline and surface field requires buoyantly-rising flux tubes that have a sufficiently long memory to remember their magnetic helicity at emergence, which has been scrutinized in a number of studies and MHD simulations (Choudhuri 2003; Cline et al. 2003; Fan & Gibson 2003; Fan et al. 2003b; Linton & Antiochos 2002; Abbett & Fisher 2003; Rempel 2003; Rempel & Dikpati 2003; Sánchez Almeida et al. 2003; Kuzanyan et al. 2003). On the solar surface, manifestations of the solar dynamo have been tracked from polar field reversals (Durrant & Wilson 2003; Bilenko 2002), polar (filament) ring currents (Makarov & Filippov 2003), bipole emergences at high latitudes (Durrant et al. 2002), "switchbacks" of filament channels (Gaizauskas 2002), torsional oscillations of the butterfly diagram (Spruit 2003; Vrsnak et al. 2003a), cycle-related variations in helicity injection (Welsch & Longcope 2003; Moon et al. 2003), UV irradiance (Pauluhn & Solanki 2003), or facular areas (Walton et al. 2003; Woodard & Libbrecht 2003). Occasional "hiccups" of the dynamo can suppress the polar reversal, such as during the Maunder minimum (Mackay 2003).

The dynamo action on the interplanetary field has been simulated with full-Sun magnetic field extrapolations over an impressive time span of (the last) 340 years, finding a decay time of 5–10 years for the high latitude component (Schrijver et al. 2002). Other modeling attempts back to the Maunder minimum yielded a interplanetary magnetic field 7 times lower at Earth's distance than today (Wang & Sheeley 2003b), as well as quasi-periodic fluctuations of the interplanetary magnetic field in the range of 1–3 years (Wang & Sheeley 2003a).

2.2. The Photosphere

2.2.1. Bits and Pieces of Magnetic Fields

The photospheric network (N) is known to contain small pores with strong kilogauss magnetic fields, probably a result of the convective flow pattern that accumulates magnetic flux in the network sinks. What is new is that the internetwork (IN) also contains tiny strong-field "bits," which are hard to detect, because unresolved mixed polarities (even at 1″ angular resolution) reduce the observed polarization, leading to discrepant field strength measurements in visible and infrared wavelengths (Socas-Navarro & Sanchez-Almeida 2003; Bellot-Rubio & Collados 2003; Steiner 2003; Uitenbroek 2003). Thus, most of the internetwork magnetic flux goes undetected. Patches of magnetic field above the noise level cover about 45% of the observed area and yield a mean unsigned flux of 20 G, while strong-field "bits" seem to occupy only 2% of the surface (Dominguez-Cerdena et al. 2003a, 2003b). The replacement time of the quiet-Sun magnetic flux has been clocked to 8–19 hours (Hagenaar et al. 2003; Krijger & Roudier 2003).

2.2.2. Texture of the Magnetic Carpet

Quiet-Sun photospheric regions are made up of an interwoven array of small magnetic fragments, termed the "magnetic carpet" (Schrijver et al. 1997). The texture of the photospheric magnetic carpet is examined by extrapolating photospheric magnetograms and plotting the connectivities to conjugate bipoles, which exhibit intricate ornamental patterns, depending on whether they connect to the nearest neighbors or bridge to remote neighbors. It is found that 60%–70% of magnetic flux fragments connect to nearest neighbors within

10 Mm, while only 50% extend higher than the chromosphere (2.5 Mm), and only 5%–10% actually connect up to coronal altitudes of >25 Mm (Close et al. 2003). Solar carpet producers now reveal their secret manufacturing techniques. When two magnetic bipoles interact, there are four distinct, topologically stable states possible, produced by either a global separator bifurcation, a local double-separator bifurcation, a new, global sepatratrix quasi bifurcation, or a new, global spine quasi bifurcation (Beveridge et al. 2002). The solar carpet never stays the same: its hairs constantly change connections and reconnect into other patterns, marking changes with soft X-ray bright points (McDonald et al. 2002) and flux tube oscillations (Muglach 2003; Cadavid et al. 2003; Ryutova et al. 2003; Hasan et al. 2003; Luo et al. 2002).

On the other hand, one should not believe that active regions contain only closed magnetic field lines. It was actually found that up to 30%–50% of the interplanetary magnetic field (IMF) connects to plages of active regions (Schrijver & DeRosa 2003). The IMF seems to accomplish what Baron von Münchhausen was unable to do, to pull himself out of the swamp by his own hair.

2.2.3. Sunspot Dynamics

Evershed flows are found to be aligned with the near horizontal magnetic fields to within $\pm 2°$ all the way from the inner to the outer penumbra, so the magnetic field is indeed frozen in, as confirmed observationally for the first time (Bellot-Rubio et al. 2003). The velocity profile of Evershed flows indicates a critical transition from subsonic to supersonic, and a final relaxation to subsonic speed through a tube shock (Georgakilas et al. 2003a, 2003b).

Who combs the sunspots so that they always show a nice, radial-filamentary penumbra? The penumbral magnetic field has an intricate and unexpected interlocking comb structure, which is now explained by means of the downward pumping of magnetic flux by turbulent, compressible convection (Thomas et al. 2002). The submerged field lines might be expected to float quickly back to the surface because of magnetic buoyancy, but numerical MHD simulations of vigorously-sinking plumes show sufficient enstrophy (i.e., squared vorticity) to keep them down, to drag them beneath the unstable convection cells into a stably-stratified region, where the magnetic flux can be amplified and stored (Thomas et al. 2002). Other numerical MHD simulations of magnetoconvection show formation of magnetic pores (Hurlburt et al. 2002) and rotating sunspots with inflow of pores that can trigger flares (Gerrard et al. 2003). Helioseismic observations beneath a rotating sunspot revealed subsurface vortical flows down to 5 Mm and evidence for opposite vortical flows down to 9 Mm, which might be powerful helicity generators (Zhao & Kosovichev 2003).

Oscillations in sunspots are another dynamic phenomenon that enjoys much attention. The oscillation periods are always around 3 minutes and are known to be driven by upwardly-propagating acoustic waves. Running penumbral waves have also been found to be closely related to the same oscillatory phenomena (Rouppe van der Voort 2003). The observations, however, are always tricky. Blueshifts are easier to detect than redshifts (Brynildsen et al. 2003). Wavelet analysis shows three modes (5.5, 6.3, and 7.5 mHz) in umbral oscillations with different stability, frequency drifts, frequency splitting, or intermittency (Christopoulou et al. 2003). Umbral magnetic field variations show intrinsic and "false" oscillations due to time-dependent opacity effects (Khomenko et al. 2003). Magnetographs saturate in strong sunspots, and thus we have to resort to Stokes polarimetry (Parfinenko 2003). Discrepancies of sunspot temperature and magnetic field measurements between different lines result from different heights of line formation (Penn et al. 2003). Not to mention real high resolution instruments, such as the Swedish 1 m Solar Telescope in La Palma, which can resolve details down to 100 km ($0\farcs15$) on the solar surface, via adaptive-optics–corrected images (Berger & Berdyugina 2003).

2.3. Chromosphere and Transition Region

2.3.1. Short-Period Waves

Biermann and Schwarzschild already suggested in 1948 that the energy to heat the chromosphere and to supply its radiative loss comes from acoustic waves generated by turbulent convection at and beneath the photosphere (for recent theoretical studies on their excitation and propagation, see Musielak & Ulmschneider 2003a, 2003b; Rammacher & Ulmschneider 2003). For decades, however, it was established that the acoustic power of the observed long period waves (mainly in the domain of 3–5 minutes, as amply provided by global oscillations) is insufficient to do the job. Now, using the "Göttingen" Fabry-Perot spectrometer in the Vacuum Tower Telescope at the observatory on Tenerife and applying speckle reconstruction and wavelet analysis, researchers have discovered short periods in the range of $50\ \mathrm{s} < P < 100\ \mathrm{s}$ that carry sufficient acoustic flux ($\approx 3 \times 10^6$ ergs cm^{-2} s^{-1}) to match the chromospheric radiative losses (Wunnenberg et al. 2002).

For the longer periods, a distinct correlation between phase differences and local suppression of oscillations in different chromospheric heights has been found (McIntosh et al. 2003), as well as spatiotemporal correlations between chromospheric and transition region emission on arcsecond scales for oscillation periods of $P = 3$–10 minutes (DePontieu et al. 2003a, 2003b; Muglach 2003), which track the vertical trajectories of upward-propagating acoustic waves. Upward-traveling kink-mode waves with periods of $P = 8$–12 minutes were found to couple with sausage-mode waves of periods $P = 4$–6 minutes (McAteer et al. 2003). Besides the acoustic waves, gravity waves have also been detected in the chromosphere (Rutten & Krijger 2003).

2.3.2. Revamping Atmospheric Models

The era of hydrostatic atmospheric models for the chromosphere is gone. Spatial inhomogeneities (moss, spicules, *K*-line and *G*-band bright points, jets visible in EUV, Hα, C IV, Lyα), MHD shocks (Ryutova & Tarbell 2003), obliquely-propagating shear Alfvén waves excited by newborn ions (Chen & Zhou 2003), spicular dynamics (James & Erdélyi 2002; James et al. 2003; Whitelam et al. 2002), temporal variations of up to 40% in the continuum radiance (Wilhelm & Kalkofen 2003), correlated variabilities in EUV intensity and Doppler shifts (Brkovic et al. 2003), super-hydrostatic density scale heights that entail an extended chromosphere up to heights of $\approx$5000 km (probed now with *RHESSI*, Brown et al. 2002a; Aschwanden et al. 2002), intermittent heating from chromospheric reconnection processes (Chae et al. 2003; Lee et al. 2003c), the non-forcefreeness and funnel structure of the chromospheric magnetic field (Leka & Metcalf 2003; Martinez-Galarce et al. 2003), the nonequilibrium CO chemistry (Asensio-Ramos et al. 2003), non-Maxwellian electron distributions that cause helium enhancements (Smith 2003a), and many more other “unorthodox” observations constantly cry out for revisions of chromospheric models. So we live in an era of permanent revamping of atmospheric models, which probably will last as long as new data pour in.

2.4. The (Not So) Quiet Corona

2.4.1. Heating of Coronal Loops

The elusive *coronal heating problem* has been pondered again with a number of old and new data analysis strategies: by inferring the run of energy balance along loops (Winebarger et al. 2003a, 2003b), by temperature diagnostics from multiwavelength data (Del Zanna 2003; Del Zanna & Mason 2003; DiGiorgio et al. 2003; Landi & Chiuderi-Drago 2003; Nagata et al. 2003), by correlating the heating rate of coronal loops (constrained by scaling laws or observables) with the magnetic flux density at the footpoints (Démoulin et al. 2003; VanDriel-Gesztelyi et al. 2003; Falconer et al. 2003; Fludra & Ireland 2003), or by studying the variability of the 1 MK interface (moss) in the transition region (Antiochos et al. 2003). Multiwavelength data, of course, have the virtue of more comprehensive temperature coverage and thus are believed to lead to a more credible “true” temperature diagnostic. However, since coronal loops turned out to have a multithreaded structure down to $\gtrsim 1''$, multiwavelength images with insufficient spatial resolution, such as the EUV Imaging Telescope (EIT) and the Coronal Diagnostics Spectrometer (CDS), invariably show broad temperature distributions (Martens et al. 2002; Schmelz 2002) that characterize entire multi thread bundles rather than individual threads. Lesson number 1: broad temperature coverage is useless without high spatial resolution. Moreover, if the cool background plasma cannot be separated from a hot loop along a line of sight with broadband temperature filters (e.g., *Yohkoh*/SXT), the determination of the heating function is highly ambiguous (Reale 2002). Lesson number 2: broadband temperature filters have no temperature discrimination along the line of sight. Also, the use of a single pair of narrowband temperature filters (e.g., *TRACE*) yields ambiguous (filter ratio) temperatures (Testa et al. 2002; Del Zanna et al. 2003). Lesson number 3: two narrowband filters are not enough. We bet that NASA will outfit the next generation of solar (EUV and soft X-ray) imagers with both a tremendously high spatial resolution and a humongous number of narrowband temperature filters.

Since the interpretation of the observations is quite ambiguous, we have to resort to modeling to obtain a yes/no answer for a specific coronal heating model. Modeling of heating and cooling of coronal loops has indeed been undertaken with increased sophistication, by fitting the observed nonthermal (presumed turbulent) line broadening to the heating function of coronal loops (Chae et al. 2002); by modeling acoustic waves generated in the corona (Suzuki 2002); by performing hydrodynamic simulations of coronal loops using siphon flow models (Spadaro et al. 2003), nonequilibrium ionization and radiation (Bradshaw & Mason 2003a, 2003b), or intermittent heating (Warren et al. 2002, 2003); by comparing hydrostatic loop solutions with observables (Winebarger et al. 2003a, 2003b); or by simulating statistical nanoflaring and cellular automata models in unresolved coronal loops (Browning & Van der Linden 2003; Buchlin et al. 2003; Mendoza-Briceno et al. 2002; Sigalotti & Mendoza-Briceno 2003; Jain & Yashiro 2002). The most striking results are that most of the loops observed with *TRACE* cannot be modeled with hydrostatic solutions (Winebarger et al. 2003a, 2003b) and require spatially and temporally intermittent heating functions (Warren et al. 2002, 2003).

2.4.2. MHD Oscillations of Coronal Loops

After the discovery of fast kink mode MHD oscillations in coronal loops observed with *TRACE* 3 years ago, we are reading now about slow mode (acoustic) MHD oscillations that were discovered with SUMER a year ago (Wang et al. 2003e, 2003f). There are a number of differences: (1) Fast kink mode oscillations represent transverse displacements (like violin strings), while slow mode (acoustic) oscillations display longitudinal bounces (like the air mass in Scottish bagpipes). (2) Kink mode oscillations have been observed in EUV loops with temperatures of $T \approx 1$–2 MK, while acoustic oscillations have been detected in soft X-ray loops with temperatures of $T \approx 6$–7 MK. (3) Kink mode oscillations have shorter periods ($P \approx 3$–6 minutes) than acoustic oscillations ($\approx$10–30 minutes). (4) Transverse kink mode oscillations seem to be triggered by an external shock wave emanating from a flare epicenter, while longitudinal oscillations seem to be triggered by a pressure disturbance from a small flare at one footpoint of the oscillating loop. All oscillations suffer strong damping, where kink modes could be damped by either phase mixing (Ofman & Aschwanden 2002) or resonant absorption (Goossens et al. 2002), while the slow mode oscillations seem to be damped by thermal conduction (Ofman & Wang 2002; DeMoortel & Hood 2003). Recent theoretical studies deal with the observability of the (noncompressive) kink mode by line-of-sight variations (Cooper et al. 2003), the sound speed compatibility of acoustic waves in two different temperature filters (King et al. 2003b), resonant damping for loops with elliptical cross sections (Ruderman 2003), and phase-mixing of three-dimensional MHD pulses (Tsiklauri et al. 2002, 2003).

Besides MHD oscillations with standing nodes (eigenmodes), propagating MHD waves have also been observed recently in EUV. They are generated at one footpoint of large diverging EUV loops and have been caught only during upward propagation. The wave propagation speed corresponds to the acoustic speed, so they have been identified as sound waves. In addition, the temperature along the propagating wave does not vary, which confirms their nature as compressive waves (DeMoortel et al. 2003; Marsh et al. 2003a). Periodic wave packets with periods of $P \approx 50–100$ s were also detected in coronal holes (Marsh et al. 2003b). Most spectacularly, the predicted fast mode (impulsively-generated) propagating waves with periods of $P \approx 6$ s have also been discovered in white light during a recent solar eclipse (Williams et al. 2002b; Katsiyannis et al. 2003). Quasi-periodic 5 minute oscillations (Minarovjech et al. 2003) and Doppler-detected sound waves (Sakurai et al. 2002) have also been reported in green line observations.

On even grander scales, global waves have been observed to propagate concentrically over the solar surface whenever a strong flare or coronal mass ejection (CME) is launched (Harra & Sterling 2003; Hudson et al. 2003). Of course, these global waves have already been known as Moreton waves (in Hα) and EIT waves (in EUV), but now they are detectable even in He I (Vrsnak et al. 2003b) and in soft X-rays (Hudson et al. 2003). All in all, we now seem to have pretty complete observational detection of all predicted MHD oscillation modes in the solar corona, all of which have been discovered over the last 5 years.

2.4.3. Coronal Magnetic Field

We will probably never understand the coronal magnetic field without understanding the solar dynamo first. Then we will be able to predict the twist of coronal structures based on the law of magnetic helicity conservation and the hemispheric rule, even if we do not exactly understand the interfering effects of the Coriolis force and differential rotation. Thus, a number of studies investigated the emergence of buoyant rising flux tubes and their magnetic twist, writhe, and helicity (Abbett & Fisher 2003; López-Fuentes et al. 2003), the injection of helicity into the corona (Magara & Longcope 2003), the evolution of helicity in active regions and individual loops (Pevtsov et al. 2003a; Sakurai & Hagino 2003; Tian & Liu 2003; Zhang & Low 2003; Ma 2002; McAllister et al. 2002), which might become kink-unstable (Gerrard & Hood 2003; Török & Kliem 2003), the relaxation of bihelical fields (Yousef & Brandenburg 2003), and the decrease of helicity after eruptions (Bleybel et al. 2002). The observed and theoretically predicted helicity were found to disagree sometimes (Sakurai & Hagino 2003; Tian & Liu 2003). Other faithful approaches to modeling the tricky coronal magnetic field include the marriage of magnetohydrostatic solutions (MHSs) with stereoscopic observations (Wiegelmann & Inhester 2003), classifications of magnetic topological building blocks (Pontin et al. 2003; Beveridge et al. 2002; Petrie & Lothian 2003; Longcope & Klapper 2002; Longcope & van Ballegooijen 2002), and characterizations of the large scale magnetic field evolution through the solar cycle (Mordvinov & Willson 2003; Meunier 2003; Mackay et al. 2002; Sykora et al. 2003).

2.4.4. Quiescent Filaments and Prominences

Quiescent filaments in the solar corona are like "dormant snakes": their identity is recognizable from their (curled, rolled-up, twisted) geometry, but their real danger and true nature is underestimated in the dormant stage. Higher cadence observations revealed a number of dynamic processes in the not-so "quiescent" filaments: fast kink mode MHD oscillations (Diaz et al. 2002, 2003; Terradas et al. 2002), periodic motions along a filament initiated by a subflare (Jing et al. 2003), flare-triggered heating of a filament (Ji et al. 2002), and horizontal motions with swift speeds of $v = 5–70$ km s^{-1} in a wide range of temperatures (Kucera et al. 2003). The magnetic field of quiescent filaments has been pondered with MHS models (Aulanier & Démoulin 2003), MHD models (Lionello et al. 2002), non-LTE radiative transfer diagnostics (Schmieder et al. 2003), and three-dimensional velocity fields (Morimoto & Hiroki 2003), using resonance polarization in hydrogen and helium lines (Wiehr & Bianda 2003), the Zeeman effect of the hyperfine structure (López-Artiste et al. 2002), and pattern recognition techniques (López-Artiste & Casini 2003). The chirality was found to follow the hemispheric helicity rule for both quiescent filaments (80% are dextral in the northern hemisphere) and active region filaments (74%; Pevtsov et al. 2003b). It was claimed that the two competing scenarios of the flux rope and sheared arcade model can be discriminated by the hydrodynamic behavior of cool condensations (Karpen et al. 2003).

2.4.5. Unification of Small Scale Phenomena

Just slightly after this review period, a paper came out that promised the unification of small scale quiet Sun transient phenomena (Harrison et al. 2003), which carry a bewildering variety of labels, such as blinkers, explosive events, EUV network brightenings, EUV cell brightenings, active region transient brightenings, soft X-ray bright points, network flares, heating events, nanoflares, microflares, EUV brightenings, etc. In the hope that it makes our job easier, we include this out-of-period study. The authors attempt a more physical classification and distinguish between "density/filling factor events" that are very unlikely to be a direct result of reconnection, while "temperature events and high velocity events" should be directly related to magnetic reconnection processes, which are expected to produce plasma outflows and plasma heating. The christening of the first type of events, in good old English tradition, was proposed to be chosen from the authors' heritage. It will probably take a couple more unification papers to come up with a more conventional nomenclature based on physical terms. How about (1) *chromospheric reconnection events* (which produce only compressional waves, but no plasma heating or nonthermal particles, because of the high radiative losses and short collision times) and (2) *coronal reconnection events* (which produce plasma heating in addition to nonthermal particles). The second class is essentially a synonym of *flare events*, which can be further subdivided according to their magnitude into *milliflares, microflares, nanoflares,* and *picoflares*, in compliance with ISO 9000.

Let us not forget the real physics that has been addressed by nanoflare researchers: "What is the real nature of blinkers?" ponder Marik & Erdélyi (2002); they simulate a magnetic reconnection process in the transition region with a fully nonlinear, time-dependent, dissipative, radiative two-dimensional MHD code and reproduce the observational details seen by CDS eyes (e.g., Bewsher et al. 2003; Brkovic & Peter 2003; Peter & Brkovic 2003). Madjarska & Doyle (2003) also wonder whether " blinkers, explosive events, and spicules are the same phenomena." Since redshifts of 2–20 km s^{-1} have been observed in (C III, O VI, and Ne VIII) transition region lines, it was concluded that bright network regions are dominated by spicular downflows, in response to microscale energy depositions higher up (Doyle et al. 2002). Support for magnetic reconnection processes was drawn from the observed magnetic flux cancellation seen in chromospheric Hα events (Lee et al. 2003c) as well as in coronal EUV bright points (Madjarska et al. 2003). The best evidence that microflares share the same physical process as larger flares now comes from *RHESSI* observations, which effortlessly resolve the thermal ($T \approx 6$–14 MK) and nonthermal components in the 3–15 keV energy range and corroborate the correct timing (Neupert effect) as well (Krucker et al. 2002a; Benz & Grigis 2002).

2.5. Flares and CMEs

2.5.1. Magnetic Reconnection

It is no secret that magnetic reconnection processes are the omnipotent engines of solar flare events. Quite different magnetic configurations, however, are still considered as drivers: Petschek-type or Sweet-Parker geometries with current-driven anomalous resistivity (Uzdensky 2003; Nitta et al. 2002; Litvinenko 2003; Karlicky et al. 2002a; Craig & Watson 2003), quadrupolar double arcades with an intervening current sheet (Uchida et al. 2003), three-dimensional reconnection in separatrices of sheared arcades (Somov et al. 2002; Titov et al. 2003), or secondary current microsheets generated by exhaust jets from primary large scale current layers (Watson & Craig 2003). The spatiotemporal evolution of a magnetic reconnection process can be traced from conjugate footpoints (Asai et al. 2003a; Fletcher & Hudson 2002; Lee et al. 2003d), from footpoint ribbon separations (Wang et al. 2003a), from the altitude increase of reconnection-associated coronal hard X-ray and radio emission (Gallagher et al. 2002; Vilmer et al. 2002), from reconnection outflows seen in EUV (Gallagher et al. 2002), or from white light flare kernels that move along magnetic separators (Metcalf et al. 2003). Puzzles that remain are, e.g., the dissimilarity of the double ribbon footpoint geometry between Hα and hard X-rays (Asai et al. 2003b), and the nonsimultaneity of hard X-ray emission in apparent conjugate footpoints (Krucker et al. 2002b; Sui et al. 2002).

2.5.2. First Harvest from RHESSI

The *Reuven Ramaty High Energy Solar Spectroscopic Imager* (*RHESSI*) observed over 7000 solar flares during the first year of its mission. Thanks to the germanium-cooled detectors, *RHESSI* has a superb spectral resolution that allows researchers to separate the thermal flare plasma from the nonthermal electron spectra and to spectrally resolve the line profiles of gamma-ray lines. No wonder that the first harvest from *RHESSI* deals mostly with spectral modeling: tackling the energy distributions of trapped electrons (Alexander & Metcalf 2002), the steep microflare spectra in the 3–10 keV range (Krucker et al. 2002a), spectral energy budgets (Saint-Hilaire & Benz 2002), nonuniform thick target ionization (Kontar et al. 2002), the photospheric backscattering albedo (Alexander et al. 2002), hard X-ray polarization by coronal scattering (Hudson et al. 2003), and spectral inversion techniques (Conway et al. 2003; Massone et al. 2003). On a related note, the first detection of chromospheric return currents in response to electron precipitation in flares has been claimed, inferred from linear polarization in Hα and Hβ lines (Hénoux & Karlicky 2003).

The *RHESSI* measurement of extended hard X-ray halos around compact flare sources is likely to be the first detection of photospheric albedos (Schmahl & Hurford 2002), although a spectral detection has also been claimed from *Yohkoh* data (Zhang & Huang 2003). The nuclear de-excitation lines from ^{14}N and ^{12}C in gamma-rays were for the first time resolved during the 21 April 2002 flare (Share et al. 2002). The first gamma-ray images of a solar flare were just published in the month after this review period and revealed the rather disturbing puzzle that the centroid of the 2.223 MeV source (believed to be produced by thermalization and capture of neutrons in the chromosphere) was significantly displaced (by $20'' \pm 6''$) from the centroid of the 0.3–0.5 MeV hard X-ray sources (produced by electron bremsstrahlung), which raised the heretical question of whether electrons and ions are accelerated in different coronal sites, or bifurcated to different chromospheric precipitation sites (Hurford et al. 2003)! For *RHESSI* observations of GRBs, see § 4.

2.5.3. Radio Diagnostics

High energy (nonthermal) particles accelerated in flares can be diagnosed in hard X-rays only in sufficiently dense plasmas but can readily be traced from radio waves in both low and high density regions. Here is a selection of such radio diagnostics: detection of ultrashort pulses with full width at half-maximum (FWHM) durations of 40 ms (Altyntsev et al. 2003) and 8 ms (Chernov et al. 2003) in microwaves, and $\lesssim$100 ms in submillimeter wavelengths (Raulin et al. 2003); diagnostics on MHD fast mode waves and oscillations from radio quasi-periodic time structures with periods down to 0.5 s (Grechnev et al. 2003); double plasma resonances (electron Bernstein mode and second harmonic cyclotron mode) from decimetric "dotlike" emission (Krishan et al. 2003); mode conversion from cyclotron maser emission into upper hybrid Z-mode waves from "zebra structured" Type IV emission (LaBelle et al. 2003); interactions of electrons with whistler waves (Stepanov & Tsap 2002); group velocity delays in upper hybrid waves measured in microwave millisecond oscillations (Yasnov & Karlicky 2003); small scale inhomogeneities and turbulence probed from decimetric millisecond spike bursts (Kuznetsov & Vlasov 2003; Fleishman et al. 2003; Meszarosova et al. 2003); anisotropic electron distributions probed from gyrosynchrotron spectra (Fleishman & Melnikov 2003a, 2003b; Fleishman et al. 2003; Lee et al. 2003e); velocities of electron beams (Melnik 2003); radio emission associated with a filament disappearance in the preflare phase (Fárnik et al. 2003; Tokhchukova & Bogod 2003); injection of accelerated electrons into secondary extended flare loops (Melnikov et al. 2002); slow drifting radio emissions that are associated with plasmoid ejections from reconnection sites (Karlicky et al. 2002b); the spatial fragmentation of collisionless shocks based on Type II burst characteristics (Thejappa et al. 2003); or loop-loop interactions that lead to repeated flaring (Pohjolainen 2003). Most of the radio diagnostics on energetic particles and their wave-particle interactions are done with nonimaging spectrographs or are not resolved with current radio interferometers, but plans are under way to build a solar-dedicated Frequency Agile Solar Radiotelescope (FASR) imaging array (Gary 2003).

2.5.4. Flare Timing

A number of flare studies deal with the relative timing of emissions in different wavelengths, time series analysis, strange attractor dimension, periodicity tests, solar cycle statistics, or self-organized criticality, to extract some information on the well hidden nonlinear dynamics that controls flares.

If the timing of soft X-rays corresponds to the integral of the hard X-ray time profile (Neupert effect), it confirms the model of chromospheric evaporation dynamics, which was found to be true for most of over 1000 analyzed flares (Veronig et al. 2002; Veronig 2003). The subsequent downflows of the cooling plasma are now called "warm rain" (Brosius 2003). Another timing test is the coincidence of soft X-ray dimming and Hα brightening during the cooling phase from $T = 10^7$ to 10^4 K, which was found to be consistent for the X9.2 flare on 1992 November 2 (Kamio et al. 2003). The cooling time, however, can only be understood in hydrodynamic simulations by adopting a multithermal, multiloop model (Reeves & Warren 2002). The oppositely-directed upflows of heated plasma and downflows of cooling plasma have been measured for the first time cospatially in the same flare ribbons (Teriaca et al. 2003a). An interesting timing is also the sudden disappearance of a small sunspot during a flare (Wang et al. 2002a).

A periodicity of 160.01 minutes was found in the occurrence of flares (Bai 2003a), but nobody has a clue what physical mechanism could be responsible for that. Other periodicities were found at 51, 84, 129, and 153 days (Bai 2003b; Özgüc et al. 2003), which are easier to understand because they mostly correspond to integral multiples of the solar rotation period of 25.5 days. Many flare-producing regions prefer to emerge at the same solar longitude, at so-called hot spots (Bai 2003c; Berdyugina & Usoskin 2003), which explains the rotation-synchronized periodicity. However, a wavelength-dependent bias to detect fewer flares near the limb has also been noticed (Conway & Matthews 2003). Moreover, the waiting-time distribution (of intervals between subsequent flares) has been found to vary during the solar cycle (Wheatland & Litvinenko 2002); this can be modeled in terms of magnetic separator lengths (Craig & Wheatland 2002; Wheatland 2002; Wheatland & Craig 2003). On the other hand, the flare rate is not exactly proportional to the sunspot number: it seems to lag it (Temmer et al. 2003).

2.5.5. Erupting Filaments and Prominences

A recent review of the theory of solar eruptions (Lin et al. 2003) says clearly what the key aspects or eruption physics are: (1) the cause or eruption, and (2) the evolution of the morphological features, such as the rapid ejection of large scale magnetic flux, ribbon separation in Hα, rising soft X-ray and Hα arcades, flare loops with hard X-ray footpoints and looptops, etc. The observational papers, however, spell nothing but trouble for simple theoretical models; e.g., a failed eruption of a filament, because it accelerated first but then decelerated, and the filament threads drained back to the Sun (Ji et al. 2003), not unlike the *Challenger* disaster in 1986; a dual filament initiation of a CME that is launched by three different driving factors (Uralov et al. 2002); a helically-twisted prominence that got destabilized by the kink mode instablility after five turns but did not succeed in finding a new equilibrium and erupted (Romano et al. 2003); the formation of a prominence requires magnetic reconnection in the chromosphere, rather than in the corona (Chae et al. 2003); another prominence was found to erupt because of magnetic reconnection between two tearing legs with parallel electric fields but antiparallel axial magnetic fields (Karlicky et al. 2002c).

While the "loss-of-equilibrium model" (Forbes & Priest 1995; for recent three-dimensional versions, see Roussev et al. 2003) and the "magnetic breakout model" (Antiochos et al. 1999; for recent applications, see Maia et al. 2003; Manoharan & Kundu 2003) have been considered as the leading models in recent years to drive filament eruptions with subsequent flares and CMEs, the pendulum now swings back, and a string of studies and numerical MHD simulations emphasized that it is rather the kink instability of the twisted filament or helical flux rope that provides the ultimate push before eruption (Rust & Kumar 1996; Titov & Démoulin 1999; Fan & Gibson 2003; Leamon et al. 2003; Török & Kliem 2003; Török et al. 2003; Kliem et al. 2003, with the last two papers appearing sligthly after this review period, because of a slow referee, of course). A tricky detail that has been discovered in MHD simulations is that the twist and writhing of an emerging flux tube that has opposite handedness to the observed soft X-ray sigmoid still produces intense current layers with the right handedness (Fan & Gibson 2003; Leamon et al. 2003; Kliem et al. 2003). This reminds us a bit of M. C. Escher's famous lithographs with labyrinths of staircases and other geometric patterns in which you cannot tell what is top or bottom, concave or convex, left-handed or right-handed.

2.5.6. CMEs

What is the geometric shape of a CME? Perhaps the *STEREO* mission will clear up this mystery. Meanwhile, there are still widely-diverging geometric models and concepts in use, ranging from helically-twisted flux ropes (Amari et al. 2003; Birn et al. 2003; Foley et al. 2003; Liu et al. 2003; Low & Berger 2003; Riley et al. 2002), narrow conelike jets (Dobrzycka et al. 2003), and transequatorial loops (Glover et al. 2003), to multiple magnetic cloud encounters (Wang et al. 2002c). However, the new Solar Mass Ejection Imager (SMEI) now provides tomographic three-dimensional reconstructions (CAT scans) that render the complex CME shapes quite realistically (Jackson & Hick 2002); we have just not yet built up the vocabulary to put it into words.

Another unsolved controversy is whether helicity is conserved (Amari et al. 2003; Blackman & Brandenburg 2003) or not (Song et al. 2002), and whether the magnetic polarity related to CMEs is balanced or not (Green et al. 2003b, 2003c; Nindos et al. 2003). Part of the unbalanced flux connects via open field lines directly into interplanetary space (Luhmann et al. 2003).

Further attention is given to the velocity and acceleration profiles, possibly revealing the height ranges of the mysteriously-hidden forces. A rapidly-accelerated CME was found to be accelerated with an *e*-folding time of 138 s up to a peak velocity of 1500 m s^{-2} at a distance of 1.7 solar radii, with subsequent falloff up to 3.4 solar radii, where the velocity (2500 km s^{-1}) became constant (Gallagher et al. 2003). Similar values were also measured by Ko et al. (2003), Ramesh et al. (2003), Shanmugaraju et al. (2003), and likewise for radio Type II burst data (Mann et al. 2003; Vrsnak et al. 2002). CMEs associated with flares have been found to be faster than those associated with eruptive filaments (Moon et al. 2002). A total of 88% of Earth-directed CMEs are associated with flares, and 94% with eruptive filaments (Zhou et al. 2003). There is a close association between microwave prominence events (82%) and white light CMEs (Gopalswamy et al. 2003). Flares and CMEs are also found to follow the same waiting-time distribution (Wheatland 2003).

2.6. Space Weather

2.6.1. Solar Energetic Particles

Solar energetic particles accelerated in the shock front of a CME have been directly detected by *Ulysses* (when a CME crossed the *Ulysses* trajectory near the ecliptic in 2001), while the *ACE* spacecraft in the off-site was spared (Simnett 2003). The *ISEE-3* spacecraft was also run over by a magnetic cloud and reported that the cloud expanded by a factor 1.5 in radius since its launch 59 hr earlier (Rodriguez-Pacheco et al. 2003).

There were 58 extremely high solar energetic particle (SEP) events (with fluxes of $\geq$10 protons cm^{-2} s^{-1} sr^{-1} with energies of $\geq$60 MeV) during 1973–2001, each one capable of producing peturbations in the geophysical environment (El-Borie 2003).

Elemental fractionation was found to produce a first ionization potential (FIP) effect with heavy element enhancements of $\approx$2–7 in small SEP events (Slocum et al. 2003). In particular, He^3/He^4 enhancements were found to be quite common in SEP events, by factors of 0.003–2 (Torsti et al. 2003a, 2003b). The peak at $He^3/He^4 = 0.015$ led the authors to propose a renormalization of the standard SEP abundance, overriding the traditional value of 5×10^{-4} (Torsti et al. 2003a).

Milagrito, designed as a very high energy (few hundred GeV threshold) water-Cerenkov gamma-ray observatory, detected up to 22 times the enhancement of the background rms fluctuations during the 1997 November 6 solar flare (GOES X9-class), indicating solar energetic particles with energies $\gtrsim$100 GeV (Falcone et al. 2003). Solar neutrons have been detected for the first time by a neutron monitor during solar cycle 23 for the flare of 2000 November 24 in Bolivia (Watanabe et al. 2003b).

2.6.2. Geoeffective Events

The average transit time of a CME from the Sun to Earth is found to be 64 hr, or 78 hr to reach the peak of the geomagnetic storm (Zhang et al. 2003). Fast CMEs might produce stronger shocks in a slow solar wind region (Kahler & Reames 2003). On the other hand, nearly all fast halo CMEs are found to be associated with SEP events, but the solar wind speed in the SEP production region does not seem to be decisive (Kahler & Reames 2003).

Near relativistic electrons (40–300 keV) seen by *ACE* are accelerated by CME-driven shocks but are released only at a distance of 2–3 solar radii (Simnett et al. 2002; Haggerty & Roelof 2002). In addition, prompt protons in gradual events were found to originate in CME-driven shock waves close to the Sun, although not directly in the flare region (Ohki 2003).

2.6.3. Solar Wind

Recent *SOHO* UVCS observations clearly show that preferential heating and acceleration of positive ions occurs within the first few solar radii of the high speed solar wind (Teriaca et al. 2003b). The theoretical model of dissipation by ion-cyclotron waves seems plausible to do the job too, but the required high frequency fluctuations (in the millisecond range) are of course not observable with current instruments. Nevertheless, modeling and testing of the resulting anisotropic particle distributions along this avenue became a busy industry (Cranmer & Van Ballegooijen 2003; Li 2003b; Patsourakos et al. 2002; Tam & Chang 2002; Tu et al. 2002; Vocks & Mann 2003).

2.7. Solar Cycle

Sometime in the future, everything that is mentioned in this section about solar cycle observations will find a physical explanation in terms of solar dynamo theory and go in § 2.1.4. For now, however, we are still left with a number of phenomenological results that we cannot model properly. This year we counted some 50 solar cycle studies. According to them, the solar dynamo manifests itself in the low degree acoustic mode global oscillations (Jimenez et al. 2002), the low order spherical harmonic of sunspot group patterns (Juckett 2003), the total length of (magnetically) neutral lines (Mordvinov et al. 2002), the "group" sunspot number (Hathaway et al. 2002), the tilt angle of sunspot groups (Muneer & Singh 2002), the coronal hole area (Harvey & Recely 2002), the Sun's "open" magnetic flux (Mackay et al. 2002), the white light eclipse corona and magnetic field (Sykora et al. 2003), soft X-ray bright points in the solar corona (but less than a factor of 2; Hara & Nakakubo-Morimoto 2003), the latitude of prominences (Li et al. 2002a) and sunspot groups (Li et al. 2003b), the clustering of active regions (Pojoga & Cudnik 2002) and their violence (Tian et al. 2002); the solar flare index (Özgüc et al. 2003); solar total irradiance (Jones et al. 2003a; Krivova et al. 2003); UV irradiance (Foukal 2002; Pauluhn & Solanki 2003); the Earth's global temperatures (Foukal 2002); wintertime (Earth) northern hemisphere temperatures (Gimeno et al. 2003); climate changes (Solanki 2002) caused by solar-cycle modulation of the Earth's reflectance or albedo (Goode & Dziembowski 2003; Goode et al. 2003); the Earth's polar ring currents (Makarov & Filippov 2003); cosmic-ray modulation at 1 AU (Cliver et al. 2003); or the Jovian and galactic (7 MeV) electron transport (Ferreira et al. 2003). Comparison of the traditional sunspot number with the "group" sunspot number (Hathaway et al. 2002) confirms both the *Waldmeier effect* (anticorrelation between cycle amplitude and elapsed time between minimum and maximum of cycle), the *amplitude-minimum effect*, the *even-odd effect*, and *secular trends*, like the 80 year Gleissberg cycle. A relationship between solar cycle amplitude and length has been suggested (Solanki et al. 2002). Mathematical models of the sunspot cycle are now exercised with a Hurst exponent and a Van der Pol oscillator superposed on a fractional Brownian motion (Pontieri et al. 2003) and wavelet entropy (Sello 2003).

Other cyclic variations were also noted: seasonal variations in the geomagnetic AU, AL, and DST indices, which were explained by electric fields that modulate the semi-annual magnetic variation and even affect universal time (UT) variations (Ahn & Moon 2003); 1.2–1.7 year periodicities in heliospheric parameters (Mursula et al. 2003); or 250–285 day periods in cosmic-ray intensity (El-Borie & Al-Thoyaib 2002).

3. *WMAP*-PING THE COSMOS

Here lives the universe of 2003. The data—images and power spectra—are spectacular, though most of the basic numbers haven't changed much since a vote was taken on popular values of H, Λ, and all at the 1997 General Assembly of the International Astronomical Union. Bowing to peer pressure, we now nearly always abbreviate 3 K microwave cosmic background relict radiation as CMB, but will occasionally slip and use actual words.

The most spectacular press release about the universe (we almost said "in the universe") reported the first year of data and interpretation from the *Wilkinson Microwave Anisotropy Probe* (*WMAP*)satellite. The data are normally presented as a spectrum of amplitudes of temperature (or brightness) fluctuations expanded in multipole moments. The whole sky gives you only one dipole and one or two quadrupoles, but a hundred values of $l = 100$, which are averaged to get that data point. Error bars are set by cosmic variance (not enough values for that l) for all l less than 340. The most conspicuous features are peaks in the amplitude, called acoustic because they arise approximately from pressure or acoustic waves at the speed of sound in the almost homogeneous gas near $z = 1089$, when matter and radiation decoupled. At least three of these, near $l = 220$, 540, and 800, show up. Their central l values, heights, and widths are collectively sensitive to the full set of cosmological parameters (but see the original papers for which parameter dominates which peak and why), which are determined by collective Bayesian fits. Polarization also counts, though at the moment the data say only that it is associated with the amplitude fluctuations in the way we expect from an epoch of inflation long ago.

The interpretation of the *WMAP* data includes numerical values for many of the things you always wanted to know about the universe but were afraid to ask (lest our answer should run to 14 pages, single spaced). Two considerations make the numbers persuasive. First, the error bars are tighter than those

Table 1
COSMOLOGICAL PARAMETERS

Parameter	Value
Hubble's constant	$H_0 = 71 \pm 4$ km s^{-1} Mpc^{-1}
Total density	$\Omega = 1.02 \pm 0.02$ (in units of critical density)
Age of the universe	$t = 13.7 \pm 0.2$ Gyr
Baryon density	$\Omega_b = 0.044 \pm 0.004$
Matter in all forms	$\Omega_m = 0.27 \pm 0.04$ (of which dark matter $\approx$0.23)
Dark energy	$\Omega_\Lambda = 0.73 \pm 0.04$ (with the equation-of-state parameter w less than -0.78)
Initial fluctuations	$n = 0.833 \pm 0.086$ at 0.05 Mpc^{-1}, steepening to 1.03 ± 0.04 at 0.002 Mpc^{-1}
Redshift of decoupling	$z = 1089 \pm 1$ (but thickness $\Delta z \approx 200$)
Age at decoupling	$t = 380$ kyr, with thickness of 120 kyr
Redshift of matter-radiation equality	$z = 3200 \pm 200$
Normalization of power spectrum	$\sigma_8 = 0.84 \pm 0.04$ (0.9 ± 0.1 in a later paper)
Baryon optical depth	$\tau = 0.17 \pm 0.04$ (that is, a photon has a 17% chance of having been scattered since decoupling)

from earlier data sets, and second, the best values are not outside the error bars associated with those earlier data. The game plan for this section is to start with *WMAP* and its findings and then go on to other sets of cosmic numbers, followed by consideration of some of them individually, ending with variants around the standard ΛCDM (meaning cold dark matter with a cosmological constant) model.

By way of reminder, that standard model will have values for (1) the Hubble constant, from which a critical, or closure, density can be derived; (2) the fraction of that critical density in each of several components: baryons, cold dark matter, hot dark matter, cosmological constant or equivalent, and possible minor constituents, including photons, black holes, and gravitational radiation; (3) a spatial curvature ($k = 0$ is flat); (4) an age; (5) a spectrum of primordial fluctuations (not to be confused with the spectrum of power in the CMB), where $n = 1$ means equal power on each length scale as it comes within the horizon; (6) normalization of that spectrum on some large length scale that has not yet had time to go nonlinear; and (7) information on the epoch at which photons began to reionize the baryons from the optical depth to electron scattering. This last was the number that surprised the largest number of readers.

The second *WMAP* year will have been released before you read this and will surely add information, though some critical items, including polarization details, await the next generation satellite, *Planck*. Planck was Max; Wilkinson was David and skippered the program until his death in 2002.

3.1. Wilkinson Speaks

The press release made the Valentine's Day issue of *Science* (Bennett 2003), and was being applied soon after (Bridle et al. 2003a). The official package (Bennett et al. 2003a, and the following 12 papers) said rather little about the hardware (described in Bennett et al. 2003b) but provided lots of details of how the data were analyzed and what they mean. Bennett et al.'s (2003a) Table 3 lists 33 "best" cosmological parameters (their quotation marks). Here are a subset, reordered in accordance with how long reviewers have regarded them as important (Table 1). All are dominated by *WMAP* data, but the authors explain that some ground-based CMB observations, *COBE* data, and results on Type Ia supernovae and large scale structure (from the Two Degree Field, 2dF) have been folded in.

More qualitatively, there is no evidence for any non-Gaussianity (that is, the angular power spectrum fully specifies the statistical properties of the CMB). Tensor modes are less powerful than scalar modes (ratio limits 0.5–1.0 for various types of tensor modes). The radiation is polarized with the amount of polarization anticorrelated with the temperature fluctuations on scales of 1°–2°. The quadrupole and octopole moments are smaller than expected from a continuation of an $n = 1$ spectrum from larger values of l (smaller angular scales) by 2–3 σ.

3.2. Implications for Inflation and Other Theories

The *WMAP* universe has been described as "vanilla" (probably by someone who never bit into a vanilla bean), meaning no major surprises. The vanilla universe had an epoch of exponential expansion (inflation) back around $t = 10^{-32}$ s, which generated both isotropy and fluctuations and a variety of other good things. Inflation is actually a class of models (a few of which can now be ruled out) rather than a single, unique one, and other scenarios for what happened during or before the big bang make sufficiently similar predictions that they are equally viable at the moment; for instance, the brane cosmologies described in the conference proceedings edited by Martis (2003).

Items that are specifically consistent with inflationary scenarios and are parts of tests that could have been flunked are: (1) density very close to the critical one (though not long ago it was all supposed to be in some sort of positive pressure matter), (2) purely Gaussian and purely adiabatic fluctuations, (3) a tensor component less than the scalar one (but it should turn up somewhere down at 42% or thereabouts), (4) the anticorrelation of temperature and polarization, and (5) an initial power spectrum with slope n nearly unity. Bridle et al. (2003b) and Seljak et al. (2003) have added structures in the 2dF survey and in the Lyα forest to the *WMAP* ones to conclude that $n = 1$ is a reasonable fit for all $k = 0.005$–0.15 Mpc^{-1}. The early beginning of reionization means that there is no significant warm dark matter component to slow down structure formation.

Most important for further confirmation (or falsification) of inflation are tighter limits on n and its possible variation with length scale; tests of whether the small quadrupole moment might be due to complex topology; and detection of the tensor component due to gravitational radiation in the early universe, which should show up in polarized as well as total flux (Dubrovich 2003).

3.3. Concordant Data Sets

The pre-*WMAP* sets of CMB data from BOOMERANG, MAXIMA, and DASI contributed to the numbers presented by Durrer et al. (2003). The error bars are somewhat larger than the ones in § 3.1 here, in light of which there are no significant disagreements with either earlier or later data. Some single mission results included ARCHEOPS, the balloon-borne precursor of *Planck* (Benoit et al. 2003), DASI detection of polarization (Leitch et al. 2002; Kovac et al. 2002), results on smaller angular scales from the Very Small Array at Tenerife (Grainge et al. 2002; Slosar et al. 2002; Rubiño-Martin et al. 2003), and the Cosmic Background Imager (Myers et al. 2003; Sievers et al. 2003). All report some set of Ω's, n's, and such that are consistent with the customary and *WMAP* numbers.

Type Ia supernovae get a separate paragraph, because their apparent brightnesses versus redshift are sensitive to luminosity distance rather than to angular diameter distance (probed by CMB fluctuations). Additional events near $z = 1$ strengthen the conclusion that the universe did slow down its expansion in a matter dominated phase for a while and has taken off again since $z = 1$ (Tonry et al. 2003). The combinations of parameters that come out of the analysis are $Ht = 0.96$ (1 to within the uncertainty) and $\Omega_M = 0.28 \pm 0.05$ for flat space. The rate of SNe Ia near $z = 0.5$ is $1.5 \times 10^{-5}\ h^3$ Mpc^{-3} yr^{-1}. Dust along the line of sight is not distorting the results, according to Sullivan et al. (2003), though even they are happier with early type hosts.

3.4. Distance Indicators

We caught only one new one on sale this year, the flux-weighted surface gravities of early (A, B) supergiants in spiral galaxies (Kudritzki et al. 2003), and will mention only one paper (often of many during the year) on each of a number of old friends.

- Surface brightness fluctuations yield distances that are 7% too large (Mieske et al. 2003).
- The Tully-Fisher relation needs separate calibration for cluster and field galaxies and also for large redshift (Milvang-Jensen et al. 2003), with the former more of a surprise than the latter (cluster = brighter; and more distant = brighter for a given circular velocity).
- A Type II supernova distance for NGC 1637 is one-third smaller than its Cepheid distance (Leonard et al. 2003).
- Carbon stars, of the third dredge-up sort, have bolometric magnitudes of −4.7 independent of initial metallicity (Mouhcine & Lancon 2003).
- Stars in the red giant clump have absolute K magnitudes nearly independent of age and initial metallicity (Pietrzynski et al. 2003).
- RR Lyrae stars yield distances in agreement with those from red giant tip, red clump, and short period Cepheid stars (Dolphin et al. 2003).
- Eclipsing, double-lined spectroscopic binaries in the Pleiades might resolve the discrepancy between the *Hipparcos* distance and that found by fitting the main sequence to the Hyades (Paczynski 2003).
- Type Ia supernovae have an extra 0.1 mag dispersion in peak brightness because the explosions are not perfectly symmetrical (Wang et al. 2003c,) as well as a 0.2 mag dispersion from the range in Ni^{56} production that is associated with initial metallicity (large [Fe/H] makes less Ni^{56}; Timmes et al. 2003). Oh dear. That was two papers, wasn't it?
- Cepheid variables imply a distance modulus to NGC 4258 that is a whole magnitude bigger than the dynamical one from the motion of its H_2O masers (Ngeow et al. 2003). How much is that in megaparsecs? Get out your slide rule (it's 58%).
- The Large Magellanic Cloud is a tram stop on nearly all distance expeditions. Respectable indicators like Cepheids and RR Lyrae stars (analyzed with the same Baade-Wesselink algorithm; Kovacs 2003) put it about 51 kpc away, but we also caught a 44.2 (Fitzpatrick et al. 2003) and a 53.2 (Clausen et al. 2003), both, as it happens, from observations of spectroscopic, eclipsing binaries, one each.

3.5. Hubble's Variable Parameter and Others

If you actually need to calculate (or teach) something that requires a numerical value of the age of the universe, the baryon density, and so forth, then use the ones from § 3.1. Here is an examination of the ranges around the official numbers that were reported by other astronomers using other methods. Why bother if they are wrong? At least two reasons. First, it is just barely possible that they are not wrong (consensi have drifted before), and second, when the universe has been completely understood, then all methods of measuring a given quantity will yield the same numerical value, and, until they do, we still have something to learn from the divergence.

Values of H_0 during the year reached from 85 km s^{-1} Mpc^{-1} (Saunders et al. 2003) from an observation of the Sunyaev-Zeldovich effect in cluster Abell 173 to 48 ± 6 (Kochanek 2003) from time delays in several gravitationally-lensed QSOs. The median of the 25 numbers we recorded was 65, reported by Kochanek (2003; same data, different assumptions), by Jerjen (2003; surface brightness fluctuations in the dwarf elliptical galaxies in Fornax, which turns out to be 20.3 ± 0.7 Mpc away), and by Vinko et al. (2003; a Type Ia supernova in NGC 3987 at 74.5 ± 5.0 Mpc).

The age of the universe is expected to exceed the ages of any individual objects in it. This is (we say only very cautiously among friends like you) still a bit marginal. Numbers from the year were 14.1 ± 2.5 Gyr (Wanajo et al. 2002) and 15.5 ± 3.2 Gyr (Schatz et al. 2002) for metal-poor halo stars. The error bars take in the official value, but that stars always look just a smidge too old for the Hubble constant hasn't changed for 60 years. If you want to know how long we will have to work on the problem, consult Cirkovic (2003) on physical eschatology. Experts on mental eschatology suspect that the more nearly-terminal author may already have run off the end of her tether.

The temperature of the universe is currently 2.725 ± 0.001 K, according to an analysis of *COBE* data by Fixen & Mather (2002). The uncertainty could be reduced to 10^{-5} K with a suitably-targeted new mission. At a redshift of 0.2, the temperature was 3.377 ± 0.102 K, which really is larger, just as it should be (Battistelli et al. 2002 on the Sunyaev-Zeldovich effect in cluster Abell 2163).

The primordial helium abundance measures the baryon density independent of the value found from CMB fluctuations. It is not possible for a theoretical calculation of the expected Y_p for any particular value of baryon density to agree with all the observational determinations this year, since these are marginally disjoint. That is, Holovatyy & Melekh (2002) report $Y_p = 0.220$–0.244 from H II regions in compact blue dwarf galaxies (allowing a range of $\Delta Y/\Delta Z$ that takes in negative values!), while Chiappini et al. (2002) set a lower limit of 0.244 by extrapolating the D/H gradient in the Milky Way back to what it must have been before any stars had formed. Some modeling has also gone into $Y_p = 0.237$–0.250 (Cassisi et al. 2003b) from an analysis of the horizontal branch in globular clusters and the ratio of HB to RG numbers. The smallest error bars belong to Luridiana et al. (2003), who have corrected line strengths in H II regions for collisional effects to find $Y_p = 0.239 \pm 0.002$.

None of these is really inconsistent with what you expect from big bang nucleosynthesis (BBN) in a universe that is about 4% baryons. Population III stars could have contributed a bit of helium that we would incorrectly attribute to the early universe (Salvaterra & Ferrara 2003). This is, at most, $\Delta Y = 0.003$, but in principle it separates the best observed Y_p just a bit more from the best BBN prediction, though honest error bars continue to overlap.

The abundance of deuterium in places where stars have not messed things up by burning it is even more sensitive to baryon density, but we did not catch any new determinations this year and so no new potentials for conflicts.

The integrated Sachs-Wolfe effect is the expected correlation between relatively small angular scale fluctuations in the CMB and the distribution of gas in protoclusters that are still expanding, so that photons passing through come out blueshifted. Rather tight limits on the actual correlation relative to what would be expected if $\Lambda = 0.65$–0.70 were flagged as worrisome last year and remained so at the beginning of fiscal 2003 (Boughn et al. 2002). All is now apparently well, with the effect seen when *WMAP* data and the large scale structure in the Sloan Digital Sky Survey (SDSS) of galaxies and clusters are compared (Michal et al. 2003).

Because Λ also sets the volume of space at various redshifts, the frequency of gravitational lensing (both multiple images and distorted shapes, strong and weak lensing, respectively) is "predicted" by a given values of Λ and a model for the evolution of the source and lens populations, which are at least partly observed. There are both more lensed arcs (Zaritsky & Gonzalez 2003, Las Campanas Survey; Gladders et al. 2003) and more strongly-lensed QSOs (Pindor et al. 2003, an SDSS sample) than one expects, by a factor 10, or thereabouts. If we had to bet, it would be in favor of Λ plus more work needed on the astrophysics of the populations of sources and lenses. But the discrepancy is of very long standing.

The total energy of the universe can be zero even with a cosmological constant, provided that you live in a critically open, $k = 0$, Friedmann-Robertson-Walker model (Faraoni & Cooperstock 2003).

The parameter called σ_8 remains a topic of real disagreement. It is the rms density fluctuation on a length scale of 8 h^{-1} Mpc (comoving), and the "8" was originally chosen in the expectation that the observed value would be very close to one. If σ_8 is big at present, then there should be lots of rich clusters and strong gravitational lenses; if small, then fewer of each (Oguri 2003, QSO lensing in 2dF; Bahcall & Bode 2003, evolution of the number of rich clusters). Now, the origin of the difficulty is that if you measure the masses of a bunch of clusters or lenses, you are really measuring a product $\sigma_8\Omega_m^x$, where x can be anything from 0.14 (Bahcall & Bode) up to at least 0.68 (Bacon et al. 2003), and *WMAP* and other data sets have left a very strong impression that Ω_m is not only known but known to be very close to 0.27. Putting this back into the various products yields σ_8's ranging from less than 0.7 (Allen et al. 2003) to 1.0 (Chen 2003). The *WMAP* σ_8 itself is rather poorly constrained at 0.84 ± 0.1 and so overlaps everything else at the 95% confidence level. Where then lies the problem? Of the 17 σ_8's found other ways this year, only five were in the range 0.9–1.0 needed to account for the numbers of rich clusters and strong lenses, while 12 fell below 0.8 if Ω_m is 0.27. On the whole, the larger values came from cosmic shear (weak lensing, Bacon et al. 2003; Hoekstra et al. 2002) and the smaller values from individual clusters of galaxies (Schuecker et al. 2003a; Diego et al. 2003). But it isn't even that simple, for Brown et al. (2003a) report 0.73 ± 0.09 from a cosmic shear survey, and Szalay et al. (2003) conclude that 0.915 ± 0.06 is the best fit (for $\Omega_m = 0.3$) to two-dimensional clustering in the SDSS. We have left at least a dozen papers uncited and the problem unsolved, much the same as last year.

Minor constituents that, in principle, contribute to the total density include (1) gravitational radiation with $\Omega_g h^2$ less than 8.5×10^{-4} in the frequency range 10^{-11} to 10^{-8} Hz (Potapov et al. 2003 from timing of millisecond pulsars) and (2) black holes at galactic centers, whose share is only 10^{-5} of the closure density (to within a factor of about 2, Aller & Richstone 2002; Yu & Tremaine 2002). This latter is equivalent to the statement that black holes are 0.1% of the stellar mass and stars make up only about 1% of the cosmos (Bell et al. 2003b).

3.6. Dark and Stormy Nights

The two most venerable candidates for dark matter still in the inventory are very low mass axions, whose properties laboratory experiments could intrude upon in the next few years (Bradley et al. 2003), and the much heftier WIMPs. These have not collided detectably with laboratory materials in the index year either (or you would have heard about it from others), but some limits on their masses and cross sections for interactions with baryons can be set from their lack of effect on (1) megaparsec scale structure (Miller et al. 2002) and (2) internal structure of the Sun (Lopes et al. 2002a, who conclude that the mass must exceed 60 GeV and the cross section fall below 10^{-40} cm^2). What actually surprised us most is that the formulas one uses to calculate the particle velocity and number distributions for a given density (Vergados & Owen 2003) go back to Eddington (1916), whose particles were stars.

A couple of equally venerable candidates got fairly bad publicity this year.[1] There are, first, cold, compact clouds of molecular hydrogen (Walker et al. 2003; Drake & Cool 2003), and second, white dwarfs or other MAssive Compact Halo Objects (Pauli et al. 2003; Afonso et al. 2003). Strange quark nuggets of about 0.5 $M_\odot$ are intended to function as MACHOs and so should probably be eliminated with them (Banerjee et al. 2003).

Another class includes somewhat newer suggestions that remain within the realm of possibility, as far as we can tell. In order from small masses to large these are (1) branons (massive brane fluctuations, which could be cold, warm, or hot; Cembranos et al. 2003) with masses of 10^2–10^4 GeV and cross sections of less than 10^{-43} cm^2 at the low mass end, (2) the lightest state of Kaluza-Klein (KK) gauge bosons, rendered stable if KK parity is conserved in extra dimensions (Cheng et al. 2002); the decay products might be observable, (3) superWIMPs, whose only interaction is via a super weak force, with cross sections below the limit of foreseeable detectability (Feng et al. 2003), of which the KK particles are one possible type, (4) WIMPzillas of more than 10^{15} GeV (Albuquerque & Baudis 2003), and (5) primordial black holes of about 10^4 $M_\odot$, small enough that they don't tear up globular clusters but also uncommon enough that accretion on them does not exceed the X-ray background and they don't contribute many MACHO events (Afshordi et al. 2003).

Still darker and stormier than the dark matter is dark energy, for which quintessence, cosmological constant, and, most recently, phantom energy are alternative names, and for which there were some alternative ideas during the year. It is not clear that there is a "traditional" candidate, but the oldest is the cosmological constant, which is not a function of time or space and which has an equation of state $P = -w\rho$ with w precisely 1. Peebles & Ratra (2003) have provided a review from a relatively conservative point of view.

The standard puzzlement is that if you regard Λ as the sum of the zero-point energies of known fields, its value should be 10^{120} times larger than the best estimate (§ 3.1). Several explanations appeared during the year (Wetterich 2003; Jaikumar & Mazumdar 2003), and Thomas (2002) described a holographic quantum contribution that should always keep Λ smaller than the dominant matter component, though it doesn't seem to be smaller now. This reminds us that if you want to be puzzled all over the place, the standard model now includes dark energy, cold dark matter, hot (neutrino) dark matter, baryons, and electromagnetic radiation, all with significant energy densities now or within memory. Enqvist et al. (2003) address the approximate equality between baryons and CDM.

What are the alternatives to a cosmological constant? Parker et al. (2003) describe a vacuum metamorphosis that fits the Type Ia supernova data as well as does Λ, but makes different predictions for w and for number counts of sources versus redshift (one of those tests that always succeeds or always fails, depending on your point of view, because evolutionary effects always dominate over cosmological ones).

Alternatives to inflation are also alternatives to a cosmological constant, both after all being forms of exponential expansion. The triumphs of inflation appear in § 3.2, and it seems that "What came before inflation?" is no longer a silly question. Additional physics will be needed to describe the past boundary conditions of an inflating region say Borde et al. (2003), and Gratton & Steinhardt (2003) expand upon the point without (we think) entirely agreeing. In any case, please remember that not being able to say "what came before inflation" or "what came before the big bang" does not cast doubts upon the correctness of these pictures of the universe (though you may have reservations for other reasons) any more than not being able to name your 17 times removed great grandfather casts doubts upon your immediate parentage (though you may have reservations for other reasons).

The main alternative to inflation is the territory called brane theory and extra dimensions (Martis 2003 reports a conference covering these, variable speed of light, and some other variants on the standard model). In brane cosmologies, the analogs of early heating and exponential expansion are due to a four-dimensional field of a particle called the radion (Collins et al. 2003). The physics of the current epoch of exponential expansion is described by Townsend & Wohlfarth (2003) in $4 + n$

[1] We remind you that, while in Hollywood there is no such thing as bad publicity, within the sciences it sometimes seems as if there is no such thing as good publicity if you want your colleagues to take you seriously.

dimensional space, and by Ohta (2003) for S-brane cosmology. The latter requires our little 3D space to be either flat or hyperbolic. Saharian (2003) also mentions radions and describes brane cosmology as a Casimir effect between the two branes. We knew Casimir very slightly and are not quite sure what he would have thought of this, but are certain he would have been polite about it.

Even a conventional Λ bodes ill for the future. Large scale structure will cease to grow in comoving coordinates after about 2 more Hubble times; the Local Group will pull away from the Virgo cluster in real distance; and in due course nothing will remain in sight but the product of the merger of the Milky Way and M31 (Nagamine & Loeb 2003). Only structures with current density contrast greater than 17.6 will endure, a number that is attractively different from either zero, one, or infinity.

Phantom energy, with $w > 1$, is still worse. Observations say that it is not much larger than 1 (Schuecker et al. 2003b), but, if it is even slightly larger, then Ω_Λ will reach infinity in a finite time (35 Gyr for $w = 1.5$; Caldwell et al. 2003). First clusters and galaxies are torn up (at 1 Gyr and 60 Myr before the end), then the solar system (at $t = -3$ months) and the Earth (at -30 minutes), and by then we don't expect to care that the atoms are going to vanish at -10^{-19} seconds. For an observationally possible w of 1.1, the end is merely postponed, not ameliorated. We think it is time to switch over to term insurance.

3.7. Their Worlds and Welcome to Them

Prejudiced as always, we claim to live, until further notice, in a standard hot big bang universe, with *WMAP* parameters, nucleosynthesis, and all, preceded by inflation or something not readily distinguished from it. Brane theories do not produce the tensor signature of inflation, but data probably have to wait for *Planck*. A dozen or so other universes appeared in the 2003 literature, and any way that one might choose to order or classify them will offend someone. This list is, roughly, from the more familiar to the less familiar.

Quasi-steady state.—The purely cosmological aspects of this have come to look more and more like an evolutionary universe in accounting for $q_0 < 0$ (Narlikar et al. 2002) and the acoustic peaks in the CMB power spectrum (Narlikar et al. 2003). But it remains tied to (1) non-cosmological redshifts (Burbidge 2003 on gamma-ray bursts), which are also (2) quantized redshifts (not seen for QSOs around Virgo and Shapley-Ames galaxies in the 2dF survey say Hawkins et al. 2002, but also not falsified thereby say Napier & 2003), and (3) the need for some way of thermalizing random radiation. Li (2003a) notes the need for additional work on antenna theory if this is to be done with very elongated iron needles. One of us refereed one of these, non-anonymously, and we wish we could tell you to consult the acknowledgements sections to see which one, but no thanks did we get.

Brans-Dicke or scalar-tensor gravitation.—Limits on the tensor part have become monotonically snugger, now down to 1 part in 40, derived from small scale observations of the CMB (Amendola et al. 2003). This is equivalent to a limit on the extent (small!) to which the dark energy can couple directly to the dark matter and baryons. Scalar gravity would permit dipole gravitational radiation and reduce the tug of the Sun on the orbit of Mercury, and scalar-tensor gravity should not be confused with the scalar and tensor components to the CMB fluctuations that are predicted by inflation.

MOND (*MOdified Newtonian Dynamics*).—The core idea is that at very small accelerations, $\lesssim a_0$, gravitational forces fall less steeply than r^{-2}. This, says the originator (Milgrom 2002), yields a mass to light ratio near 1 for a large number of groups of galaxies, and the mass can then all be baryonic. Rich X-ray emitting clusters, however, still need some dark matter, according to Sanders (2003), though less than with Newtonian gravity. We were particularly struck by three giant elliptical galaxies (and being struck by three giant elliptical galaxies is a lot like being sat on by three elephants) described by Romanowsky et al. (2003). The velocity dispersions versus radius look almost Keplerian, which means that there is little or no dark matter. The result was presented with emphasis on the idea that such galaxies must be hard to form in a standard ΛCDM universe, but, perhaps more critically, if a few galaxies are exempt from the minimum acceleration requirement, a_0 cannot be a constant of the universe.

Conformal cosmology.—There must be more than one of these, because this year's authors (Papoyan et al. 2003) do not cite the authors we have mentioned in previous years, and no well-behaved astronomer would do this, would she? Anyhow, the 2003 model is a unification of general relativity and the usual model of the strong and electroweak interactions, in which the W and Z bosons are created from a vacuum and decay to the matter we see.

NUT space.—No! This is not a pejorative, or even an unsubtle reference to the quarrel perpetuated in the *Journal for Improbable Research*. N is Newman (and please see Newman et al. 1967 for U and T), and the point being made by Rahvar & Nouri-Zonoz (2003) is that microlensing in this space is only slightly different from that in the simplest general relativistic space (but it is weird nonetheless).

Gödel cosmology.—Did Puck put a Goedel around the world in 90 minutes? Only if your German diction is that of the elder author. Tarhan (2002) mentions the inclusion of shear and rotation, however, which ought to make the process easier.

Lyra geometry.—Ought, we feel, to depend on string theory in accordance with the ratio of small, whole numbers (Lyra 1951). But, says Rahaman (2002), the real difference from the geometry of general relativity is that domain walls do not influence the matter around them, which would presumably loosen limits on domain walls—two-dimensional singularities—as a dark matter candidate.

Complex topologies.—The suggestions are that the small (and aligned) quadrupole and octopole moments of the CMB (seen by *COBE* and confirmed by *WMAP*) could mean (1) that the universe is volleyball shaped (dodecahedral and misdescribed as a soccer ball by some nonplayers, but outside the index year by about 10 days), (2) that the initial power spectrum of density fluctuations was truncated on large scales, which also implies a closed universe (Efstathiou 2003), or (3) that we Earthlings, indeed all Local Groupians, simply picked a poor place from which to observe the universe. We asked about an upgrade, but were told that first class had checked in full, and looking at some of the people who travel that way, we believe it. Meanwhile, (1) is testable, because you should see the same things in opposite directions along key axes of the geometry. Examinations of the *WMAP* data are still in Astro-ph-istan, but Weatherley et al. (2003) looked for antipodal pairs of QSOs and concluded that the number is just about what you would expect from chance. The more antipodal author is betting on (3), and will ask to be born someplace else next time she contemplates a series like ApXX.

Quantized general relativity.—Gambini & Pullin (2003) say that quantizing GR on a lattice will eliminate the initial singularity of a standard big bang cosmology. This may not be quite the same as saying they know how to do it.

Cardassian expansion.—Is the sort where the Hubble constant is given by $H^2 = A\rho + B\rho^N$ (Freese & Lewis 2002). It has been declared a less good fit than ΛCDM to the angular diameters of compact radio sources and to the SN Ia brightness versus redshift relation (Zhu & Fujimoto 2002, 2003). We would like to hear from the original proposers or at least find out who Cardass was before declaring him dead.

Quantized everything.—In units of $\hbar c/R$, where R is something like the radius of curvature of a closed universe (10^{28} cm), leads to a prediction of typical particle masses that come out close to that of the pion (Massa 2002).

Self-creation cosmology.—With a semi-metric theory of gravity has no horizon or causality problems, and so no need for inflation, but photons fall with acceleration 50% larger than that of matter with non-zero rest mass (Barber 2002). The proposer believes that this could be tested in near Earth orbit, and we cannot help but feel that it probably somehow already has been, but will refer you to the owner of the address from which the paper was submitted for further information.

Cosmological synchronization.—Fedorov et al. (2003) opine that “cosmological factors affect many fluctuations processes observed on Earth,” and cite as an example correlations of the dark currents of photomultipliers located 2000 km apart (beyond the reach, we suppose, of single elements of the power grid, though just possibly not). The darker currented author hardly knows whether to be glad or sorry that the authors have not also claimed as an example the signals recorded by gravitational radiation detectors at widely separated locations.[2]

The backward universe.—The scenario presented by Harutyunian (2003) is more than just a nonstandard cosmology. Yes, the hydrogen abundance increases with time (from metal-rich QSO BLR clouds at large redshift to metal-poor intergalactic gas clouds here and now). In addition, cD galaxies produce the clusters in which we now find them, galactic nuclei make globular clusters, and the number of dwarf galaxies increases with time, owing to the “fragmentation of cosmic objects.” This paper was indexed under “Ambartsumyan lives,” which is objectively not true, but surely we would all rather have him still with us and let the ideas go.

3.8. Reionization

Only last year (§ 12.8.2) we trumpeted the long-anticipated discovery that at a redshift near 6, some sight lines are just about 100% opaque in Lyα (the Gunn-Peterson effect). Just about 100% opaque remains true with a Lyα optical depth larger than 20, but less than 10^6, so that some X-rays can get through, back to $z \approx 6.3$ (Bechtold et al. 2003a). During the year, there was on-going discussion of the possible sources of the ultraviolet photons at work back then, including globular clusters (Ricotti 2002), faint galaxies (Yan et al. 2003; Lehnert & Bremer 2003), and Population III stars (Sokasian et al. 2003). Also noted were small corrections arising from the correlations of neutral gas density and ionization sources (Nusser et al. 2002) and variations among sight lines to several SDSS QSOs (White et al. 2003a). Reionization of helium takes longer because it has more electrons, and Jakobsen et al. (2003) reported catching both the tail end of He II and the QSO responsible for removing a specific bit of it near $z = 3$. They described this as “the first detection of the transverse proximity effect.” You are expected to remember that the usual proximity effect is a deficiency of neutral absorbing gas just on our side of QSOs.

At this point, many others noticed before we did that “opaque in Lyα” does not mean 100% neutral hydrogen right back to $z = 1089$, but more like 10^{-4} to 10^{-2} (Oh 2002; Lidz et al. 2002) and that *WMAP* should see evidence for 50% ionization at much higher redshift (Kaplinghat et al. 2003; Gnedin & Shandarin 2002). These last two papers specifically mention $z = 20$ and, from the dates of their publications, have the status of predictions, assuming the *WMAP* data were truly embargoed.

Then, sure enough, the average scattering optical depth of the universe revealed itself as $\tau = 0.17 \pm 0.04$ (Bennett et al. 2003a). Now to do this with the present average baryon density (2.5×10^{-7} cm^{-3}) would require a path length of about 300,000 Mpc, a good bit larger than the Hubble radius (for any H larger than 1). But that’s OK, because there is a $(1 + z)^3$ factor to integrate in, and when that is done, significant ionization must set in by $z \approx 20$ (Yoshida et al. 2003), or, say

[2] Everything is forgotten sooner or later (Zwicky’s theorem) so perhaps this is the place to quote the senior author in a discussion remark at the December 2002 “Texas” Symposium on Relativistic Astrophysics: “Believe me, you do not know the meaning of the word ‘controversial’ unless you have been married to Joe Weber for 28 years.”

Fukugita & Kawasaki (2003), for some different history of H II/H I versus z, ionization must be 99% complete by $z \approx 18$.

A fresh opportunity then arises to consider where the ionizing photons come from and whether the total picture makes sense. Population III is important, say Somerville & Livio (2003). Stars in the first galaxies say Ciardi et al. (2003a). And the early start and late finish to reionization imply a slightly unexpected history of UV photon injection according to Haiman & Holder (2003). The injection could have been odd enough for significant recombination (this time deserving the name!) to have intervened in the range $z = 13$–6 (Cen 2003).

Lithium, which is nearly always more trouble than it is worth, was still only about half neutral at $z = 400$ (Stancil et al. 2002), when it was practically time to turn around and get ionized again. We are reminded of the spread of Christianity across Europe, which was only just reaching the more remote corners when some of the central bits turned around and decided to disagree with the established church.

Because reionization can only set in after the formation of stars and/or active galactic nuclei has begun, this section overlaps the beginning of § 9.

3.9. Observational Test of the Year

All you need to pin down Ω_m and Ω_Λ very well is a measurement of the redshift of a distant galaxy made from another distant galaxy, both of whose redshifts are known to us (Liske 2003). We would like to propose a colleague or two as members of this observing expedition.

4. THE GRB–SN Ic–WR CONNECTION

Because the editors of *PASP* (in Tempe, Victoria, and Chicago) are all such wonderful people, we will begin, without even being asked, by decoding GRBs into gamma-ray bursts (or bursters); SNe Ic into supernovae with no hydrogen features in their spectra near maximum light and progenitors likely to be massive stars stripped down for flight or fight;[3] and WRs into Wolf-Rayet stars, massive ones who, by the time they are classified this way, have indeed shed virtually all their hydrogen, perhaps by transfer to a close companion.

The WOW event of the year was undoubtedly the announcement of 80% ± 20% polarization of the gamma rays themselves from GRB 021206 (Coburn & Boggs 2003) as recorded by solar satellite *RHESSI*. This counts as truly serendipitous (unlike the original discovery of GRBs), because the front side of *RHESSI* was looking at the Sun, just as it was supposed to be, and it was the back side that got zapped by the gamma rays, a few of which scattered once in one detector and then either scattered again or were absorbed in a second detector. High energy photons Compton scatter preferentially perpendicular to their polarization vector. Thus, which two detectors were concerned for each gamma says something about their incident polarization. One might deliberately construct a gamma-ray (or X-ray) polarimeter along these lines. Eighty percent is just about the maximum polarization possible for synchrotron radiation, and contrasts with the 1%–10% seen in optical tails (Bersier et al. 2002; Barth et al. 2003a), for which there are already a good many models (Bjornsson et al. 2002; Granot & Konigl 2003).

Such extreme polarization would surely be trying to tell us something important about magnetic fields in the initial event (Waxman 2003), and you can perhaps already hear hesitation over whether WOW in this context might stand for Was Only a Wish. Nothing in print along these lines yet, but an impression from a GRB meeting in early September was that More Work Is Needed (or perhaps more luck). This may be an unfair impression; it was, for the participatory author, one of the most ghastly weeks of her life (the Faustian Acquaintance again) and nothing looked both true and certain.

Oh, and lest we forget to tell you later, the original discovery of GRBs was not (though it has often been so described) serendipitous. The authors had, in fact, set out very deliberately to show that nothing natural except solar flares could trigger two Vela satellites at the same time. That they proved themselves (Klebesadel, Strong, & Olson 1973) wrong changed their lives forever, but it was good intuition and hard work, not luck.

4.1. Now, About the Supernovae

You will surely (unless you are much younger than you look) remember GRB 980425 in the nearby galaxy ESO 184-G82 (Ap98, § 6.3). But it was a very puny GRB and the supernova an anomalous Ic. It might have been (1) seen from far off its jet axis and/or (2) related to the gamma-poor GRBs (Yamazaki et al. 2003b) of which more later.

The number of additional plausible associations has been nearer a handful than a pile: 980910, which could have been either of two nearby supernovae, both bright, slow, and broad lined (Rigon et al. 2003); 011121 = SN 2001kc, with a host at $z = 0.326$, making the GRB fairly normal (Garnavich et al. 2003b); 200405, which is the third of five GRBs at redshifts less than 0.7 to show a "late red bump" in the light curves, resembling the light curve of a supernova that went off at the same time but was not recorded as such (Price et al. 2003b); and 021211 = SN 2002lt (Della Valle et al. 2003a, 2003b), which showed definite traces of a Type Ic supernova in its postmaximum spectrum and had a redshift of 1.006 (for the host galaxy).

Those were the salad and rubber chicken of the SN/GRB conference dinner. Now here is the desert: GRB 030319 = SN 2003dh. It was the (apparently) brightest GRB spotted so far by *HETE* and among the brightest 1% of all time. And, given its $z = 0.169$, the corresponding supernova, identified

[3] We are still trying to figure out how to fit in here the curious fact that when Gretchen first encounters Faust, she has her skirts "kurz angebunden," tied up short. A Faustian Acquaintance says it is meant metaphorically, but what does he know about running in long skirts?

as a Ic from its spectrum as the GRB faded, was intrinsically a very bright one, to which the word hypernova has been applied by people more hyper than we.[4] The two events were essentially simultaneous (Garnavich et al. 2003a; Chornock et al. 2003; Uemura et al. 2003; Prince et al. 2003a; Hjorth et al. 2003; Meszaros 2003; Stanek et al. 2003; Kawabata et al. 2003).

These experts and others are inclined to feel that the association reduces GRBs to the previously-solved problem of very bright, hydrogen-deficient supernovae of the core collapse flavor. The official progenitor is then a massive, stripped star, whose core will collapse to a black hole. It must have sufficient angular momentum and magnetic field to collimate the jets needed for GRBs. Portions of this description are already known to apply to Wolf-Rayet stars, for which rotation is important and rapid rotation rare (Foellmi et al. 2003a). The presence of many solar masses of shed material around the events is suggested independently by analyses of afterglows (Reeves et al. 2003; Schaefer et al. 2003).

Calculations of massive star evolution and core collapse say that a hypernova/GRB type black hole can come only from very massive stars and will itself be a good deal bigger than ones left by mere supernovae, up to 14–23 $M_{\odot}$ (Fryer & Meszaros 2003). The requirements for both large mass and rapid rotation mean that only a small fraction of SN Ic's will have associated gamma-ray bursts, 1 in 300 says Norris (2002), with the observable universe populated by 10 SNe per second, but only 200,000 GRBs per year. This 1/300 fraction should not be confused with the fraction of all GRBs in the universe that have their jets aimed nearly enough at us to be seen. That factor is about 1 in 500 (van Putten & Regimbau 2003) and takes the 200,000 per year down to the few per day actually detectable by BATSE and all.

Only GRB 030329 and its implications are going to be on the exam, so you are free to wander off to another section, while we linger here over other aspects of these "greatest explosions since the big bang" (according only to those who have not seen the more explosive author at maximum wrath). Some of these are questions almost anybody might ask (e.g., what are the short duration events?), and some are answers that almost anybody might question. The last shall be first.

4.2. Answers Almost Anybody Might Want to Question

1. Long time delay between the supernova and the gamma-ray burst. This cannot be right for 030329 or the other associations, but could conceivably apply to some events (Guetta & Granot 2003; Lazzati et al. 2002). The GRB then goes off inside a pulsar wind nebula or young supernova remnant, where there can be lots of iron to reprocess gamma rays into X-ray emission features (Kallman et al. 2003), though it is possible to do something similar with simultaneous events (Kumar & Narayan 2003).

2. Energy source other than black hole formation. A fairly popular one has been the transformation of a neutron star into a strange quark star (Lugones et al. 2002; Berezhiani et al. 2003). New to us this year is the idea that the basic energy source is the shock from a supernova (possibly the second in a close binary) hitting a neutron star or white dwarf companion (Istomin & Kombert 2002).

3. A cannonball. This is an alternative to the relativistic jet and fireball model, in which a single plasmoid is ejected in a single direction, during the formation of a neutron star, which then acquires a very large recoil velocity. The original proponents (Dado et al. 2003a, 2003b) have picked up some additional support from Huang et al. (2003).

4. Nucleosynthesis is the answer to "what is there bound to be a bit of, but not very much, in GRBs?" (Pruet et al. 2002 and Beloborodov 2003 on deuterium; Inoue et al. 2003 on boron).

5. Noncosmological redshifts. Well, if active galaxies can have them, why not GRBs? The evidence is that the latter share the peaks in number versus redshift displayed by the former (Burbidge 2003).

6. Acceleration of ultra-high-energy cosmic rays. Nobody understands how this is done, and a plasma Wakefield accelerator in GRBs (Chen et al. 2002) might work as well as anything else. The mechanism is explained by Tajima & Dawson (1979). The cosmic rays will, however, have to find their way through a very long path length of intergalactic photons to get here.

7. At the end of the Ordovician. The demarcation lines in the fossil record when the name of the era or period changes are, by definition, levels where many species disappeared and others arrived. The end of the Ordovician was particularly notable for loss of shallow water inhabitants, and A. L. Melott (2003; private communication) has suggested that the cause might have been a GRB within about 1 kpc of the solar system, which has circled the Galactic center two or three times since. There are, however, warnings from the past (not before the Ordovician, just before the index year). The fullerenes at the Permian-Triassic boundary are not filled with extraterrestrial helium and argon (Braun et al. 2002), and nitrates in Antarctic cores are not correlated with the times of historical supernovae (Green & Stephenson 2003).

4.3. Questions Anybody Might Want to Answer

1. Are GRBs TeV sources? One, maybe, 0204179 in the Milagrito data stream (Atkins et al. 2003). This was the paper

[4] Hypernovae also provide evidence for closed, timelike world lines. We first heard the word in a phone call 5 or 6 years ago from Bohdan Paczynski, who asked who had invented it. All we could say was that it wasn't us. But this year several of the cited 030329 papers credit the coinage to Paczynski, apparently requiring the less timely author to locate a time machine, go back, and tell him.

that alerted us to something much stranger. In the *Astrophysical Journal* ordering of topics in each issue, the bursters come after interstellar medium and star formation. This is perhaps a relic of the days when they were almost universally thought to be events on the surfaces of old, nearby neutron stars.

2. Is there more still to be learned from statistical considerations several years after the BATSE inventory passed 2000 and ceased to grow? Hakkila et al. (2003) conclude that a previously-identified intermediate faint class between the long and short duration ones is a selection effect, due to the durations not being recorded correctly. On the other hand, Norris (2002) has pulled out a different subset, long duration events for which $N(S)$ has a slope $-3/2$, implying that they are close. A concentration of these toward the supergalactic plane also goes with distances less than 100 Mpc.

There are two correlations (small scale anisotropies for the long duration GRBs, Meszaros & Stocek 2003; and clustering of short duration GRBs on angular scales of 2°–4°, Magliocchetti et al. 2003) and one anticorrelation (of bursts with APM galaxies and Abell clusters; Williams & Frey 2003), any of which might marginally be attributed to very large scale structure and gravitational lensing, but which probably cannot all be simultaneously explained, or even true. And the strong BATSE events are (or were) concentrated in a fairly narrow redshift range, 1.8–3.6, if they were all like the few with measured redshifts (Mitrofanov et al. 2003, to whom the thirstier author is very much indebted for a glass of wine at that GRB conference where she really needed it).

3. What happens if you are in the beam of a GRB? Well, say Galama et al. (2003), if you are a dust grain, you will probably be sublimed out of existence, with Savaglio et al. (2003) and Perna et al. (2003a) concurring. And even gas won't have an easy time, say Guidorzi et al. (2003), noting that the amount of X-ray absorber in 010214 fell from 5×10^{22} H cm^{-2} to 3×10^{20} H cm^{-2} after about 6 s.

4. Are the optically-dark ones (meaning X-ray afterglows with good enough positions to search around, but nothing found) physically different, in the sense of being dust-shrouded or exceedingly far way? Perhaps, say Klose et al. (2003), but most of them are actually rather faint as X-ray sources, though not heavily absorbed, and were probably just too faint and fast to catch (De Pasquale et al. 2003), where we have mentioned just the last paper of many on each side of this issue.

5. Are the X-ray-rich, gamma-poor events part of a (baryon-overloaded?) continuum with the others, or something physically different? Mostly something different say Arefiev et al. (2003), including flare stars, anomalous GRBs, and a third class of unknown origin. The part of a continuum with small opening angle and off-axis viewing, say Yamazaki et al. (2003a). The part of a continuum with larger opening angles say Barraud et al. (2003), remarking upon the dearth of optical counterparts and redshifts, though these are long duration GRBs. Polluted, high redshift, off-axis, and photosphere dominated (thermalized) all remain possible, and more spectra and redshifts are needed say Zhang & Meszaros (2002).

You might also want to ask why these are not called X-ray bursters, but the name was already taken to describe nuclear explosions on the surfaces of accreting neutron stars.

6. Are the X-ray features real this time; and if so, what do they mean? You will be forgiven if you have forgotten, or tried to forget, the decade or more when cyclotron resonances in magnetic fields near 10^{12} G were part of the X-ray tails of many gamma bursts (Truemper et al. 1978; Ho, Epstein, & Fenimore 1992). These now live in some alternative astrophysical universe with Vulcan, the quadratic redshift-distance relation, and the canals of Mars.

Perhaps that experience had left us more skeptical than necessary when reports of iron features in X-ray tails (with the much higher spectral resolution of *Chandra* and *XMM*) began to appear a couple of years ago. There are still some doubters of the statistical significance in at least some cases (e.g., Rutledge & Sako 2003). What has changed recently is the presence of patterns of features consistent with K-alpha transitions of highly-ionized Mg, Si, S, Ar, and Ca in roughly reasonable ratios for the ejecta of a massive star (Reeves et al. 2003). It is perhaps not absolutely essential that the heavy element material be physically associated with the GRB event; close may be good enough (Kosenko et al. 2003).

A worrisome contradiction would be iron or other features so strong that they clearly require SN ejecta to have gotten out some astronomical units from the event in a burst where the SN Ic part of the light curve shows that the SN shock and the GRB jet started out at just about the same time. This has not so far happened.

7. What are the hosts? You already knew the answer to this one: star forming galaxies (Berger et al. 2003; Bloom et al. 2003) probably of modest metallicity (Fynbo et al. 2003; Le Floc'h et al. 2003). Whether these are truly a random sample of massive star formation we cannot swear, but have no reason to doubt.

8. And the question we would most like answered, what is making the events that last less than about 2 s? The best buy model probably remains binary neutron stars or neutron star+black hole mergers in low density environments in and around distant galaxies, though we are aware of at least one secret supporter of evaporation of primordial black holes in the galactic halo. Only one "short" BATSE event had even a probable optical counterpart, caught within 4 minutes of the 0.7 s burst, 000313 by BOOTES-1, and gone within the hour (Castro-Tirado et al. 2002). No redshift or host information could be derived. There has been one *HETE* localization of a short burst so far, but no optical counterparts. Stay tuned as *SWIFT* lifts off in 2004, with, we trust, *HETE* still on duty, since their wavebands and other properties are complementary.

9. It is worrisome that radio tails are rare? Apparently not, judging from the unhurried and unharried compilation of data

on 25 (Frail et al. 2003), which is one-third of the known optical ones.

4.4. Afterthoughts

Have you been wondering how to pronounce *RHESSI* since Ramaty was added to its name last year? A solar Goddardian friend who shares one of our birthdays confides that the "RH" is as in "rheology." That is, the satellite sounds like *RESSI*, unless you are an ancient Greek.

5. EXTRA-SOLAR-SYSTEM PLANETS

Most astronomers are probably only just beginning to recognize that this is a whole new major branch of astronomy that celebrated its eighth birthday soon after the end of the reference year (Mayor & Queloz 1995). That's "a recent result" to a mature astronomer, 56 in dog years, and more than 40 lifetimes to *Nothobranchius furzeri*, the shortest-lived vertebrate (Cellerino & Valdesalici 2003). Only 5 cm long, *N. furzeri* appears to take very little interest in exoplanets of any sort, but we attempt here to summarize current understanding of (1) the properties of the population found so far, (2) ways of finding more, characterizing them, and relating them to the great astronomical scheme of things, and (3) physical processes involved in their formation and evolution.

5.1. Known Exoplanets

Numbers.—There were, as we closed the books on the fiscal year, two triples, eight doubles, and about 100 single planets known (Fischer et al. 2003), the vast majority found by periodic oscillations in the radial velocities of the stars they orbit. The inventory does not increase quite monotonically, because planets are occasionally expelled from the lists (Henry et al. 2002 on HD 192263 as a rotating star with spots) and creep back in again (Santos et al. 2003b on HD 192263 as a rotating star with spots and a planet).

Periods.—The shortest is about 3 days (Masset & Papaloizou 2002), a real physical limit, and the longest 14 years (Marcy et al. 2002), a limit set by the durations of the searches in progress. The long one belongs to 55 Cnc (which also has a 4.65 day planet known since 1997) and has an orbital eccentricity of 0.16. The $a = 3.3$ AU ($P = 6$ yr) planet around HD 20692 has a somewhat smaller eccentricity near 0.1 (Carter et al. 2003), but none yet quite matches Jupiter at 12 yr and $e = 0.05$. The period distribution has a peak at less than 5 days, a relative minimum at 5–50, and a gradual rise back up in numbers beginning around 100 days (Jones et al. 2003b), which the authors attributed to migration stopping when the residual disk clears.

A claim has been published of periodicities or resonances in the semi-major axes of exoplanets, the solar system, and the moons of the Jovian planets, when the *X*-axis is $M(\mathrm{primary})/a^2$ (Vahia et al. 2003). This is the sort of thing, felt the referee, that should be made available to the community once, but only once, unless new, independent data reveal the same pattern. Adding in a sample with primary mass between solar and Jovian is frustrated by the rarity of brown dwarfs with planets (Guenther & Wuchterl 2003).

Masses.—The smallest so far (apart from companions of pulsars) is 0.12 M_J, orbiting HD 49674 in a short period orbit (Butler et al. 2003) and largest around 10–15 M_J. The former is a technological limit, and the latter a definition of where planets end and brown dwarfs begin. Nor do theorists seem to expect masses larger than about 10 Jupiters to form from circumstellar disks (Bate et al. 2003b). $N(M)$ currently has a sharp peak at the small mass end and a more or less monotonic decline into the brown dwarf desert (Chabrier 2003a). There is a period-mass correlation, in the sense that most of the (fairly complete) set of short period companions are less massive than Jupiter, and most of those with periods larger than 50–100 days are more massive than 1–2 M_J, which is again advertized as a product of the migration process (Masset & Paaploizou 2002; Gu et al. 2003; Udry et al. 2003).

Among the planet pairs, those with period ratios larger than 10 have the larger mass at the larger distance. Those with period ratios smaller than 10 have the larger mass at the smaller distance, as does the solar system (Mazeh & Zucker 2003). The authors discuss both formation processes and migration ones (with some systems getting stuck at 2 : 1 period resonances) as possible causes.

Radii and compositions.—Well, radius, since only that of the companion of HD 209458 has been measured, by timing the ingress and egress phases of its transits. It looks a bit larger than theorists had expected, which could be a signature of some heating process beyond irradiation (Baraff et al. 2003) or, more probably, of a radiative transfer effect that puts optical depth unity at a very low density in the atmosphere (Burrows et al. 2002). The atmosphere, which is currently being boiled away, contains hydrogen as well as sodium (Vidal-Madjar et al. 2003; Charboneau 2003), as one might well have guessed. Hydrogen dominance is assumed in the calculations of atmospheric structure and spectra predicted by Sudarsky et al. (2003). Indeed, modelers always seem to assume either solar or Jovian composition when asking about spectral signatures, the possibility of direct imaging, and so forth, and, while this may seem a bit Jovio-heliochauvinist, assuming the composition of Mercury or of a peculiar A star would probably be silly.

The primary stars.—Yes, some are themselves part of binary or even triple systems, in about the proportions you would expect (Patience et al. 2002), and with the planet orbiting only one star, with the exception of MACHO 97-BLG-047, whose planet seems to orbit both (Moriwaki & Nakagawa 2002). It may be a while before we can test the prediction that very few systems should have an outermost planet beyond 20 AU (Bate et al. 2003a), because the corresponding period is about 90 years, close to that of 70 Oph, host of not just one but two fictive planets (See 1896; Reuyl & Holmberg 1943).

Hosts are pretty much like other stars of the same spectral type in rotation (Bodaghee et al. 2003) and kinematics (Santso et al. 2003a).

And, as you may by now feel you have known since before 1995, the host stars are on the high end of the distribution of metallicities in the solar neighborhood (Zhao et al. 2002; Sadakane et al. 2002; Gonzalez 2003). We now feel confident in saying with Sadakane et al. and others that the stellar compositions are the ones they started with and not the result of back feeding by inwardly-migrating planets, for at least three reasons. First, Jupiters are not very metal rich in the first place. Second, the observed metallicities are not correlated with depths of surface convection zones. And third, helioseismology permits putting fairly tight limits on any difference in composition between photosphere and interior of the Sun, which is compositionally a very typical host. The presence of Li^6, which is destroyed in stellar interiors, is perhaps the most sensitive indicator of planetophagia. Its presence in HD 82943 has been disputed by Reddy et al. (2002, against) and Israelian et al. (2003, for).

5.2. Searches and Signatures

A prize-winning colleague once characterized the second half of the astronomical 20th century as being divisible into periods in which (1) everything was due to magnetic fields, (2) everything was due to mass transfer in close binaries, and (3) everything was due to black holes; and we noticed a termination shock to the century of magnetic material being transferred onto black holes in close binaries. The 2003 literature left a slight impression that everything was being attributed to planets. The result is a rough tripling in the inventory of techniques and phenomena that might conceivably reveal planetary presences beyond the six mentioned in Ap96 (§ 3.1). Here they all are, ordered very crudely from traditional to recent and from plausible to implausible, with references for the ones new (at least to us) this year and for the ones whose status has changed.

1. Direct imaging. This is sometimes described as impossible with current devices, but was, of course, the method by which Uranus was discovered, and, more recently, a set of orphan planets in Orion (Zapaterio Osorio et al. 2002; Martin et al. 2003), whose youth puts them above the "impossibly faint" limit and whose masses extend down to about 3 M_J. The use of a nulling interferometer will some day live in this section too.

2. Periodic residuals in proper motions. The early false alarms from See (1896), van de Kamp (1982), and all have left this approach somewhat in disrepute. There is, however, an astrometric orbit for Gl 876b, done with the Fine Guidance Sensor on *HST* (Benedict et al. 2002). The mass of the companion, originally discovered via strategy 4 below, is 1.89 M_J. And Neptune was discovered from residual proper motions of Uranus, though by whom is too complex for us to retell here (Kollerstrom 2003a).

3. Periodic residuals in pulsar timing. The one with three planets is B1257+12, in case you need to phone it. Interaction between the two larger planets permits measurements of their masses as about 4.3 and 3.9 Earth masses (Konacki & Wolszczan 2003). We like to think of them as being made of little bits of neutron star scrap material, but Keranen & Ouyed (2003) prefer quark star scraps.

Lightning has at least partially struck twice. The pulsar B1620−26 in the globular cluster M4 is orbited by a 0.34 $M_\odot$ white dwarf (with a cooling age of 340–620 Myr) and a planet as well, which the discoverers (Sigurdsson et al. 2003) believe was acquired in a somewhat complex star exchange. This implies that the planet is a gas giant, formed when the cluster was young and every bit as metal poor as it is now, a seeming contradiction to the planet-metallicity association, which garnered a good deal of attention in the secondary literature during the year.

And the best fit to a 7 year (1982–1989) interglitch stretch of timing of the Crab Nebula pulsar is blue noise plus a planet of about 3 $M_\oplus$ in a 568-day orbit (Scott et al. 2003). This is not the planet of Rees, Trimble, & Cohen (1971), which had a mass more like that of Neptune and a longer period.

4. Periodic residuals in optical radial velocities. Well, this has been the real winner (results in previous section), and no more needs saying here.

5. Periodic time residuals in pulsating white dwarfs. At least a few DA (ZZ Ceti) white dwarfs have periods so stable that they can be used as clocks the way pulsars are. Mukadam et al. (2003) report that ZZ Ceti itself is not orbited by a planet of mass larger than 38 $M_\oplus$ at a distance of less than 9 AU. G117-B15A is even more stable, with $P/\dot{P}$ larger than a Gyr, and so it must also be more or less planetless.

6. Transits. The first seen was by the companion of HD 209458, already known as a radial velocity variable. But OGLE-TR-56 is a transit discovery, or anyhow will be if confirmed by a radial velocity curve (Konacki et al. 2002). It has a period of 1.2 days (shortest so far), a mass of 0.9 M_J, a density of 0.5 g cm^{-3}, and, despite the small semi-major axis of 0.023 AU and large equilibrium temperature of 1900 K, is both tidally and thermally stable. OGLE-TR-3 is another short period candidate (Dreizler et al. 2003), and there are a good many others (Udalski et al. 2003). Why make a fuss about these? Because, if the confirmed yield is reasonably large, it is a way to survey hundreds or thousands of stars at a gulp, instead of tracking their velocities one by one. Aha! What we really need is an objective prism with a velocity resolution of a few meters per second. Meanwhile, transit searches from space (*Kepler* and all, when/if they fly) can push the sensitivity down to Earth-sized planets.

Earth itself was not discovered by the transit method, since sunrise and sunset also happen in a Ptolemeic universe. But Vulcan was, in the sense that a number of people reported seeing it cross the Sun soon after LeVerrier published the anomalous advance of the perihelion of Mercury. The Earth, if you wish, was discovered by periodic residuals in radial velocity around the turn of the previous century (unless you are prepared to count aberration of starlight as a proper motion method; that was 1729).

Transit searches normally use visible light, but anything that travels in straight lines and can be blocked would work. Thus the Earth has also been seen in transit against the background of cosmic-ray secondary neutrinos. Ptolemy might have been surprised by this one.

7. Variations in stellar line profiles during ingress, transit, and egress. The recognition of hydrogen and sodium in the atmosphere of HD 209458b happened this way.

8. Microlensing. What you get from a planet orbiting the lens, if it happens also to pass across the sight line to the target star, is a more subtle version of the blip that reveals a binary lens. OGLE event 2002-BLG-055 probably had one (Jaroszyński & Paczyński 2002). Like transit searches, microlensing can be used to patrol large numbers of stars at once and can be pushed to quite small companion masses.

9. Gaps in accretion disks around young stellar objects. Such disks are expected to be the formation sites of exoplanets of the future. As the planets form, they will sweep clean the dust and gas from annuli at their semi-major axes (and a good bit on either side, set by considerations like those in Bondi accretion). The disks are typically not resolved, and so the evidence comes from a careful analysis of the spectral energy distributions of the reradiated infrared. The idea is that there will be a temperature range missing appropriate to dust that would have been where the planet is (Rice et al. 2003b). This approach has moved rapidly up the plausibility ladder in the last year or two, mostly because of better data. That some disks show no evidence for such gaps (Macintosh et al. 2003 on σ Eri and Vega) means, we think, that something interesting is going on where they are found.

10. Warped disks. Detection of these requires resolving the disk, so if the warps imply nascent planets, these must have sizable orbits (Wahhaj et al. 2003; Weinberger et al. 2003, both on β Pic herself).

11. Disk structures caused by a dust clump in resonance with a large planet. Fomalhaut might have one (Holland et al. 2003).

12. Collimation of bipolar outflows. There is such of lot of this going on in the universe that we are not sure it can be evidence of anything, but Takami et al. (2003) suggest that planets may be relevant.

13. Detection of zodiacal light. This is a signature of old solar systems like ours, where comets, asteroids, Kuiper Belt objects, and all are grinding each other back down to dust. Mid-IR from our own should be the strongest signal seem from outside, and one expects the same from others (Moro-Martin & Malhotra 2002). On the other hand, if what you really want to do is direct imaging, what the experts call exo-zodi is the most serious background noise. The emission has probably not been seen, but Tamburini et al. (2002) attribute a (mild) correlation of polarization of scattered starlight with planet-hosting to zodiacal dust. We do not mean to imply that residents of the planets responsible pay special attention to the star patterns through which their host star passes each orbit period.

14. Formation in progress. The star KH 15D, as seen from our direction, currently displays 3^{mag} deep eclipses that last 40% of a 48.4 day period. The discoverers have blamed a swarm of 1–10 cm particles trapped in a giant vortex (Barge & Viton 2003). A search of Harvard College Observatory archival plates from 1913 to 1951 found no eclipses, which almost certainly means they were shallower, shorter, or both. As for what the authors found in another 1960s archive, the report is out of period, so you will have to look in the archives yourself.

15. Pollution of host atmospheres. This is the first item on the list where we think that the phenomenon exists (metal rich hosts) but planets are not the cause. They are probably not the cure either.

16. Pollution by oxygen-bearing molecules of evolved carbon stars. Remember that CO is so tightly bound that, in cool atmospheres, it soaks up all of the less abundant of C or O, leaving the other to dominate visible molecules (a discovery of Ralph H. Curtiss before even we were born).[5] IRC +10°216 is the archetypal carbon AGB star, in the spectrum of which Ford et al. (2003) have reported the detection of OH maser emission (supporting an earlier *ISO* report of water vapor in the star). The suggested source is the evaporation of comets as the star has brightened and expanded. And, we suppose, if comets then planets.

17. Pollution of a white dwarf. The ZZ Ceti star G29-38 has both an infrared excess and detectable calcium in its spectrum. Jura (2003) suggests that both might be coming from disrupted asteroid material. And if asteroids, then planets, we suppose.

18. Spin-up of evolved stars. Instead of the planets migrating inwards early on, stars may engulf them later. In addition to adding metals, this will add angular momentum. It therefore counts as one of several possible ways of accounting for relatively rapid rotation of subgiants (Lucatello & Gratton 2003) and metal-poor horizontal branch stars (Carney et al. 2003) in globular clusters.

19. Periodic residuals in timing of eclipsing binaries. The eclipses will seem to come early or late by an amount equal to the light travel time across the radius of the orbit of the binary around its center of mass with the planet. Where the third body is another star, this happens and is seen. For a planetary third body, the leads and lags are only a few seconds (which, unlike monotonic changes in orbit periods, do not accumulate as t^2).

20. Stellar masers as planetary phenomena. This is another somewhat generic idea from the past whose continuity with binary stars makes it somewhat untestable. The really interesting case would be microwave, light, or X-ray coherent amplifiers being used as weapons.

21. Mira variables. These undoubtedly exist and are gen-

[5] Curtiss described the cool stars as having either oxidizing or reducing atmospheres before 1926 and was dead before the stock market crash of 1929.

erally blamed on pulsation driven by the same opacity mechanism that applies to Cepheids. Berlioz-Arthaud (2003) would, however, like them to be engulfed planets in the giant atmospheres. The period would be about right, since anything dominated by gravity (breakup rotation, orbit, or pulsation) happens on the free-fall or dynamical timescale.

22. V838 Mon. This anomalous outburst with evidence for earlier ones in its surroundings probably belongs somewhere among the cataclysmic variables, but Retter & Marom (2003) would like it to be an expanding giant that has, so far, engulfed three Jupiters, all with semi-major axes less than 0.5 AU.

23. X-ray flashers or even gamma-ray bursts as planetary collisions. The collisions will be spectacular only if the doomed planets orbit in opposite directions; not very easy to achieve (Zhang & Sigurdsson 2003).

24. Gamma-ray bursts as trails of exhaust from interstellar spacecraft. At the time Harris (1990) looked into this, GRBs were generally thought to be galactic and to have 511 keV $e^{\pm}$ annihilation features. He looked for straight lines across the sky with bursts studded on them. He did not find any.

25. Incredibly good luck with the *Voyager* and *Pioneer* probes. They head ever outward, though now silent, and might some day come close enough to another planetary system to know about it. We probably won't.

26. A SETI WOW! event. There have been a few, but follow-up has found no indication of on-going or repeat emission (Gray & Ellingsen 2002).

27. Independent confirmation of panspermia. If the next epidemic comes equipped with some incontrovertible signature of extraterrestrial origin (Wickramasinghe et al. 2003), you might at least consider another Earthlike planet as its home base.

28. Arrival of Little Green Persons. LGMs are probably politically incorrect, and we are not quite sure about color, but if they say they come from some other planetary system, it is probably safest to pretend to believe them until you can get to a phone.

29. Something even more outlandish that was not published this past year.

5.3. Theoretical Considerations

While theorists have now had centuries to produce the solar system and at least 8 years to produce the rest, the actual processes lasted 10^7–10^8 years. Thus, one should probably not be surprised that they haven't yet quite completely finished imitating nature. Two items stand out as having changed in the last year or two. First is the increasing application of methods that had to be invented to look at migration of hot Jupiters and such being applied to the solar system. The second is the division of the dust-to-planets picture into four stages rather than three, with the intermediate objects being called planetesimals (up to 100 km or so, with solid body forces dominating), embryos (up to about 1000 km), and protoplanets (masses more or less the final ones but impacts still under way). Runaway growth slows to oligarchic growth at the embryo stage (Rafikov 2003a, 2003b). And the slower rate pushes formation timescales worrisomely close to the maximum lives of typical protoplanetary disks (Lyo et al. 2003; Armitage et al. 2003; Matsuyama et al. 2003a).

The main alternative to this gradualist process is a gravitational instability in the disk that can assemble something close to a protoplanet in a few orbit periods. The idea is particularly associated with the names of Alan Boss and his colleagues at the Department of Terrestrial Magnetism (Boss et al. 2002), though it is not supposed that the Earth or any other planet is held together by magnetic forces. There have also been converts, at least to the extent of other authors having noted that the instability process certainly circumvents the timescale problem (Mayer et al. 2002) and that it will happen most readily if the cooling time of the disk material is short (Rice et al. 2003a). Doubts about whether the condensations last long enough to form planets have been expressed by Pickett et al. (2003), who have quite properly discussed the issues with the proponents. Meanwhile, Haghighipour & Boss (2003) have begun to consider a sort of amalgamation of the two pictures, in which local maxima in the disk help planetesimals assemble into larger entities.

If we (or rather they) succeed in making some planetary systems, the properties will depend on the distribution of density in the initial disk (Kokubo & Ida 2002) and very probably on other physics that is still missing from the calculations (D'Angelo et al. 2003). And the next step is to make sure at least some of the planets survive until the remaining dust and gas disk is gone. The threat is called migration, and the losses could be substantial (Trilling et al. 2002) but can be halted either by gaps in the disk (Matsuyama et al. 2003b) or by magnetized zones (Terquem 2003). Migration should not in any case be regarded as the enemy, since it is probably responsible for some details of the solar system (Franklin & Soper 2003 on the 5 : 2 resonance of Jupiter and Saturn), the very existence of hot Jupiters, and the location of the Edgeworth-Kuiper belt slightly outside the official year. What do you mean, slightly? This all happened 4.56 Gyr ago.

Migration can also affect the eccentricities of planetary orbits, and we are glad we didn't invest too much time trying to figure out from first principles whether e should get larger or smaller, because the answer turns out to be "yes." Both are possible (Goldreich & Sari 2003; Chiang 2003).

The last two obvious questions concern stability, in two senses. First, should the systems we see still be around? The 2003 answers have been, on the whole, yes for the stars with two planets (Gozdziewski 2003b on HD 12661), but not with as much confidence as we had expected (Kiseleva-Eggleton et al. 2002, finding that same system marginal, HD 38529 and 37124 safe, and HD 160691 highly unstable). The planets with two stars have very similar problems, though the ones actually seen (Patience et al. 2002; Moriwaki & Nakagawa 2002) are probably OK. Life is, however, rather difficult for potentially habitable planets in most binaries (David et al. 2003; Benest 2003).

Second, on a more personal level, it would be good to know how many of the stars known to have one or two Jovian planets might also have a terrestrial one or two at 0.7–1.5 AU or thereabouts. One worries about this point because planets seem to prefer metal-rich stars, 20% or so of which already have Jovian planets, so the supply of other hosts is not infinite. The answer is not entirely straightforward. For six of the known systems with relatively long period Jupiters, the regimes of parameter space safe for an Earth are not simple to describe, though some exist (Levison & Agnor 2003). An Earth orbiting a very close star-Jupiter system perhaps finds life a trifle easier. Menou & Tabachnik (2003) say yes for at least a quarter, and Williams & Pollard (2002) say more. Gozdziewski (2003a) concludes that one might even be able to put an Earth with liquid water between the two massive planets of HD 37124. Squeezing inside the two planets of 47 UMa is probably impossible (Jones & Sleep 2002), or, even if we could live there, we couldn't have formed there (Laughlin et al. 2002). These analyses typically assume that three planets are coplanar, but this is not actually known even for the pairs observed.

Finally, we leave you with the thought that exoplanets have weather, as well as climates, typically with fewer bands but more polar vortices than are found on Jupiter and Saturn (Menou et al. 2003).

6. STAR DATES

Cognoscenti will recognize this as the plural of a long-running radio series (now called *Earth and Sky*), coordinated by the delightful Debbie Byrd out of Austin. The programs tend to run exactly 90 s, which may well be the right length for most of the items in a field that is widely said (sometimes by the wider author) to consist of solved problems. This is more or less true in the sense that the stars for which models are calculated and arranged into evolutionary tracks and isochrones are very much like the stars observed and plotted on color-magnitude, mass-luminosity, and similar diagrams. Some of the topics here tie up loose ends. A few others probably loosen previously tied up ends (along with Gretchen's skirt). But most are just progress reports on questions that have been tied and untied many times before.

Logically, this section should begin with star formation, but, despite having indexed 50 papers under that heading, we feel no wiser than last year, and so will begin with young stellar objects (YSOs), or rather with a minimalist primer on stellar activity, needed in several subsections. "Activity" means spots, flares, coronae, and related phenomena and is thought to be powered by magnetic field processes. If magnetic fields in most stars arise from on-going dynamos in the stars themselves, then activity should be encouraged by rapid rotation and deep (but not all the way to the center) convection zones. These in turn are favored by youth, close companions, and relatively cool photospheres.

6.1. Young Stellar Objects

The traditional classes are defined by an envelope mass larger than (Class 0) or smaller than (Class 1) the core mass (Ciardi et al. 2003b), and we are not sure whether we or the authors invented the name "Class -1" to describe sources even less evolved than the Class 0's (Lehtinen et al. 2003). YSOs go in for a good deal of activity, more so for massive ones still cool enough to have convective envelopes (Hofner et al. 2002), and still more when there is a lingering disk to provide another site for magnetic interaction (Preibisch et al. 2002; Beutter et al. 2003).

RCW 38 is so far unique as a synchrotron X-ray source (Wolk et al. 2002), but thermal X-rays from the hot corona are common (Feigelson et al. 2003, on Orion; Nakajima et al. 2003; Imanishi et al. 2003), but not ubiquitous (Preibisch 2003). Even radio YSOs have become common, and are largely powered by accretion shocks (Gonzalez & Canto 2002). Ultraviolet is also fueled by accretion (Brooks & Costa 2003). Infall and outflow both occur, sometimes in the same source (Mora et al. 2002 on UX Ori), as do spin-up and spin-down (Stassun & Terndrup 2003). β Pictoris is also a β Cephei star (Koen 2003). And much as we love the people for whom Herbig-Haro objects (Wang et al. 2003b; Rodriguez et al. 2002; Girart et al. 2002), Bok globules (Wolf et al. 2003), and FUors (Herbig et al. 2003) are named, they must go uncelebrated this year.

6.2. Brown Dwarfs

Formation.—This could either be like that of bigger stars, for which the signature will be accretion disks of their own, which some have (Natta et al. 2002 with IR data in the ρ Oph region, to Klein et al. 2003a, a millimeter detection, the first and last of many papers during the year), though they tend not to be big, fat, bright disks (Jayawardhana et al. 2003; White & Basri 2003). Or brown dwarfs could form as part of some more complex systems as adjuncts or companions to larger stars (Rauch & Werner 2003; Delgado-Donate et al. 2003a), for which the signature should be absence of binary BD pairs (but there seem to be many; Pinfield et al. 2003) and loss from clusters as they age (Sterzik & Durisen 2003), but the Pleiades seems to have its fair share (Moraux et al. 2003). Hmm. It sounds like the issue is settled, but we may have failed to index some papers on the other side.

Brown dwarf properties.—Well, they look strange in almost any color-magnitude diagram you try to draw, because the colors are not monotonic in either temperature or spectral type (Tinney et al. 2003), which is the fault of water and methane taking giant bites out of their continua (Burrows et al. 2003, and others). BDs show the usual sorts of activity signatures (X-rays, Hα flares, and radio flares), but even the best of them are very faint in quiescence (Fleming et al. 2003; Liebert et al. 2003a), and they are "on" for a much smaller fraction of the time than are true stars of similar age and rotation period (Martin & Bouy 2002; Mohanty & Basri 2003).

The nearest is a companion of ε Indi, which places it equal 14th in nearness to the Sun (Kaler 1994, from whom the more derivative author has cribbed a great many other numbers over the years, sometimes without credit. Thanks, Jim!).

Brown subdwarfs or sub-brown dwarfs.—The meaning is gas spheres that failed to become stars a very long time ago and show their age kinematically, compositionally, or thermally. We found a first one, 2MASS J05435346+8246465 (Burgasser et al. 2003a), which is metal poor, fast-moving, and fit by an evolutionary track 10–15 Gyr old,[6] and two candidates for second, 2MASS 0937+2931 (Burgasser et al. 2003b) and LSR 1610−0040S (Lepine et al. 2003a).

6.3. Oblate Stars

Achenar (α Eri) was said to be first in some press releases, but surely that dubious honor belongs to the Sun (though not by so much as Robert Dicke once thought). Achenar, with $a/b = 1.56$, is anyhow the most oblate, may well be rotating close to breakup, and has the Be trait to show for it (Domiciano di Souza et al. 2003). Zeng (2002) has calculated zero-age main-sequence models for stars rotating at up to 98% of breakup in the range 9–60 $M_\odot$. Temperature and luminosity are affected by at most 0.05 in the log, and the maximum a/b is only 1.25. Achenar is clearly overachieving. The consequences of rapid rotation for evolution of the star, especially mixing as it evolves, are more dire than one might have supposed (Vauclair & Theado 2003, and the two following papers).

6.4. Stellar Extrema

The most massive with real (binary orbit) numbers is the pair LH 54 in an OB association in the Large Magellanic Cloud at 100 + 50 $M_\odot$ (Ostrov 2002); and of course this belongs with the binaries in § 7, but how else do you measure stellar masses? With seismology, say Thoul et al. (2003a), getting 9.62 ± 0.11 $M_\odot$ with a β Cephei variable, and Handler et al. (2003) reporting 12, 12.7, and 13 $M_\odot$ for three others (an oddly tight grouping?).

The hottest main-sequence stars are not so hot as they used to be, with three groups pushing things down to 45,500 K for O3's (Herrero et al. 2002) and 34,000 K for O6–7 (Moore et al. 2002; Bianchi & Garcia 2002).

The stars of astounding small metallicity like the halo giant HE 0107−5346 (Christlieb et al. 2002) indeed display [Fe/H] values of less than −5.0, but light elements, especially carbon, fall below solar by a factor of only 30, and the pattern attracted many rather similar explanations during the year (Schneider et al. 2003; Umeda & Nomoto 2003; Bonifacio et al. 2003, all invoking Population III input). Shigeyama et al. (2003) prefer to think of the stars themselves as members of Population III later polluted by some interstellar accretion.

The lead stars of Van Eck et al. (2003) are noteworthy for having Pb/Ba larger than unity, not as competition for Elizabeth Taylor. The authors report stars numbered four to eight in the class.

β Lyrae is the first magnetic B giant (Leone et al. 2003). Babcock (1958) had suspected this. Early-type stars can apparently produce magnetic fields at the tops of their convective cores, the way later types do at the base of convection envelopes. It is not clear whether this is actually relevant to the ApBp phenomenon (MacGregor & Cassinelli 2003).

Stellar radii derived from single stars and eclipsing binaries as a function of spectral type do not entirely agree (Malkov 2003). This is probably the result of orientation and selection effects, but means that some recalibration of the mass-luminosity relation and the initial mass function (IMF) is needed.

The IMF of the year (Chabrier 2003b) peaks at slightly different masses in different populations, is fit by star formation described as compressible turbulence, and implies that brown dwarfs are about as numerous as single stars. Thus they contribute little mass to the Galactic disk, but there should be a dozen others closer to us than the companion of ε Indi.

6.5. Stellar Activity

The secret word is generally said to be dynamo (Bushby 2003, descending from the ceiling with a mustached duck that you are far too young to remember). The current primary task is to trace out how chromospheres and coronae, emission lines, spots, flares, and all depend on initial mass, composition, and rotation rate and on later evolution. In general, rapid rotation is good, but saturation occurs at some point (Flaccomio 2003a, 2003b; Pizzolato et al. 2003). For a given age and mass, high metallicity is good (Pillitteri et al. 2003). Age is bad (Guinan et al. 2003), presumably because of spin-down, since synchronized close binaries tend to be exempt (Audard et al. 2003 on UV Ceti).

Mercifully, the coronal cyclic periods for 61 Cyg A and B are the same as the chromospheric ones, 7 and 12 yr (Hempelmann et al. 2003). Alpha Cen A and B are both active (Raassen et al. 2003a), as are Castor A, B, and C (Stelzer & Burwitz 2003).

It was our intent to recommend a single "grand scenario" paper for the year, but we ended up with a pair, one (Barnes 2003a, 2003b) focusing on how aging changes one sort of field and spin-down to another, and a second (Berdyugina et al. 2002) that begins by reporting the behavior of LQ Hya, a young solar analog, but ends by introducing the Vaughan-Preston gap (Vaughan & Preston 1980) between stars with and without activity cycles. The systematics of the cycles also requires some clarification. Messina & Guinan (2002) indicate that the cycles get longer for shorter rotation periods and eventually kill themselves off (Micela & Marino 2003), but Paterno et al. (2002)

[6] Oh, all right. The track comes from 2001, but you know what we mean.

present models that seem to say the opposite, that cycle times should get shorter as rotation periods get shorter. They are kind enough to explain the Hale number (the time it takes star spot belts to migrate in latitude divided by the cycle time, which is 1.1 for the Sun and larger for more rapidly-rotating stars).

The latitude migration gives rise to the stellar equivalent of the solar butterfly diagram (Livshits et al. 2003; Alekseev & Kozlova 2003), and other stars also seem to have their own Maunder minima occupying 10% or so of their main-sequence lives (King et al. 2003a; a statistical argument, not the result of seeing spot cycles turning on or off).

Normal A-type stars are usually not a source of either coronal X-rays (Daniel et al. 2002; Stelzer et al. 2003) or ultraviolet emission lines (Simon et al. 2002). But the *Chandra* image of the young cluster NGC 2516, discussed by Damiani et al. (2003), records many of the Ap stars, which puzzles them and us.

Hot OB and WR stars are often X-ray sources, but the underlying physics is different, tied to radiation-driven winds (Raassen et al. 2003b; Oskinova et al. 2003).

6.6. The Chemically Peculiar Stars

Some of these may not be as peculiar as generally supposed. Stift & Leone (2003) point out that Zeeman broadening increases equivalent widths of many lines by factors of as large as 10, making abundances look larger by factors of 3–30 and introducing artificial correlations of abundances with patches of strong field on the stellar surfaces. This too was suggested by Babcock (1949) long ago. The argument from incidence in clusters of various ages that the anomalies take a fair fraction of main-sequence lifetimes to establish themselves (Poehnl et al. 2003; Paunzen et al. 2002) should not be affected by this, but the complex vertical abundance stratifications found by Bagnulo et al. (2003) may well be.

Surface abundance enhancements can also result from products of nucleosynthesis being mixed upward or dumped downward by companions. It is not surprising, perhaps, that the range of possibilities allows identification of four classes of barium stars, with different ranges of mass, composition, and orbit period (Liang et al. 2003). But we were a good deal surprised to hear that excesses of barium, the quintessential product of the *s*-process, are due to *r*-processing more often than to *s*-processing (Mashonkina et al. 2003).

6.7. Pulsating Stars

More than 80 papers ended up under this heading, despite the exiling of most Cepheids to "distance indicators" under cosmology, and ZZ Ceti stars to white dwarfs, and so forth. Some types that were excitingly new in earlier ApXX's now rate hardly more than a ho:

- sdB's, of which there is a new class, the driving mechanism for which is uncertain (Green et al. 2003a).
- The slowly-pulsating B stars, which seem to have no measurable physical characteristics different from the nonpulsating ones (Niemczura 2003).

Or a hum:

- The roAp star whose amplitude is strongly stratified with depth in the atmosphere (Balona & Lane 2003).
- γ Doradus stars, for which a newly-calculated instability strip agrees with observations, provided the depth of the convection zone is chosen correctly (Warner et al. 2003).

New classes of (probably) pulsating variables appear every year, and we will say about those presented by Mennickent et al. (2003a) and Mennickent et al. (2003b) only that both are blue and come out of OGLE searches from gravitational microlensing.

Some of these Star Dates must be sounding like one-night stands, but we have had long-term relationships with the R Coronae Borealis variables, which have been shown to have winds (Clayton et al. 2003) that come and go fairly unpredictably, and with the RV Tauri stars which form a two-dimensional set, in relative depth of adjacent minima and the number of cycles over which the alternation persists (Percy et al. 2003).

One Wolf-Rayet has quasi-periodic oscillations, but they may be due to an orbiting clump of dust obscuration, revealing affinities with the R CrB stars rather than with X-ray binaries. One Cepheid (T Ant) is crossing the instability strip for the third time and must be getting rather tired of the whole thing (Turner & Berdnikov 2003). Miras seem to have different radii at different wavelengths (Weiner et al. 2003). Their periods extend up to 2000 days (Knapp et al. 2003), but they cannot be put on a period-luminosity diagram because the dust has so far prevented measurement of their bolometric luminosities.

A fourth star, ζ Hya, has enough nonradial modes for the pulsations to be called oscillations and seismology (Frandsen et al. 2002). It is the first giant to be honored this way. Number five is α Cen B as well as A (Carrier & Bourban 2003). Number six is η Boo (Di Mauro et al. 2003). And number seven is HD 129929 (Aerts et al. 2003), one of the β Cep stars mentioned above under "masses." And seven is enough for there to have been a conference on the topic (Thompson et al. 2003a).

But the most striking pulsational item of the year is the conclusion that essentially all red giants are variable in both luminosity (Layden & Sarajedini 2003; Kopacki et al. 2003) and radial velocity (Setiawan et al. 2003).

6.8. Convection and Extra Mixing

Envelope convection in cool stars should overshoot into hotter regions, but it still does not do so sufficiently to provide a good explanation of the correlation of lithium depletion with main-sequence effective temperature (Ziegler & Ruediger 2003 and Oliveira et al. 2003, on M dwarfs; Xiong & Deng 2002, on the Sun). When you find that it is very difficult to explain something, this can mean that it isn't true, and Schuler et al. (2003) suggest that non-LTE effects may reduce the apparent lithium abundance for main-sequence stars in M34 (leaving less real reduction for convection to accomplish). Potassium is also affected.

Extra mixing close to the main sequence (affecting N and He, for instance) has been noted in more than half the previous ApXXs, and so it is a pleasure to report this year that (1) one of the very early proponents is now publishing in a highly-cited journal (Denissenkov & VandenBerg 2003) and that (2) a highly-cited evolver of stars is now including the effect (Maeder 2003).

6.9. The Böhm-Vitense Gap

The gap is in the distribution of stars on a color-magnitude diagram near the main-sequence turn-off. Santiago et al. (2002) record what may be the first one outside the Milky Way (for NGC 1868 in the Large Magellenic Cloud), but the cause could, alternatively, be the superposition of populations of two different ages or of single and binary stars.

6.10. Blue Hook Stars

These lie below the zero-age horizontal branch in the globular cluster ω Cen. Moehler et al. (2002) say the poor things have experienced unusually vigorous mass loss while they were red giants prior to helium core flash and predict excess helium and carbon in the atmospheres. The former is known to be true; the latter is hard to check. Cassisi et al. (2003a) say the cause might be a last helium flash, of which more in § 6.12.

6.11. Loops in HR Diagrams

The relevant ones are back to the blue for stars that have already been red giant stars but are not yet ready for promotion to post-AGB status. The cause is thought to be an encounter between an outwardly-moving fusion zone and a composition (or numerical) discontinuity. The stars of 4–5 $M_\odot$ in the SMC cluster NGC 458 are overachievers and loop hotter than either of two sets of models (Alcaino et al. 2003).

6.12. Real-Time Stellar Evolution

Well, IRC $+10°216$ began to deviate from spherical symmetry only 150 years ago (Murakawa et al. 2002), and we suspect the cause was asymmetric mass loss (Men'shchikov et al. 2002), not sudden spin-up. But you know perfectly well that this subject heading really means FG Sge (which recently dimmed by ejecting a small, dense dust cloud in our direction; Bogdanov & Taranova 2003), V 4334 Sge (which is turning into a bipolar planetary nebula; Kerber et al. 2002), and V605 Aql. Lawlor & MacDonald (2002) compare the three stars under the assumption that they (like 10–15% of 1 $M_\odot$ models) experienced a late helium flash when the envelope was already nearly transparent. The result is two returns each to the AGB: first a fast one, taking about 10 years (like V 605 and V 4334), and then a slow one, taking about 100 years (like FG Sge). Lawlor & MacDonald predict that FG Sge should heat up 1500–2000 K in the next 10–20 years and V605 Aql cool to the AGB in 50–70 years and then act like FG Sge. We expect to be able to check the former prediction ourselves, but will have to leave the latter one to you.

Since all of these are more or less carbon stars, it is probably OK to mention here that Blanco 26 in Baade's window turned on a pulsation (?) period of 344 days very suddenly (Glass & Schultheis 2002).

6.13. Planetary Nebulae

PNe are the last gasp of (most) stars up to the $8 \pm 2\ M_\odot$ required to go onward to heavy element burning and core collapse. There is some evidence that stars of less than 0.1 solar metallicity produce fewer or shorter lived PNe (Magrini et al. 2003). Very generally, more massive stars yield more massive planetaries, with more complex shapes, more evidence for nucleosynthesis, and more clinging to the Galactic plane (Phillips 2003a, 2003b; Otsuka et al. 2003; Lunyova & Kholtygin 2002; Pottasch et al. 2002; Sterling et al. 2002). Four types can be defined within these correlations (Peimbert 1990). The neutral mass can exceed the obvious, ionized mass by a large factor (Herald & Bianchi 2002), and the swept-up mass can be comparable with the ejected mass (Villaver et al. 2002).

Two old planetary questions are: (1) what are those comet-like things in NGC 7253 (the Helix)? The answer seems to be not a residual Oort cloud of comets belonging to the progenitor, but circumstellar stuff whose compression one can catch at earlier phases elsewhere (Speck et al. 2003; Huggins & Mauron 2002). And (2) why do many PNe have faint outer halos (Corradi et al. 2003) and multiple shells? One of us long ago tried to sell multiple shell flashes as the dominant mechanism (acting more or less as vendor for an overseas manufacturer). Variable mass loss rates still seem to be involved (Meijerink et al. 2003; Fong et al. 2003; Corradi et al. 2003), but an expert evaluation of the possibilities (Van Horn et al. 2003) favored instabilities triggered by luminosities close to the Eddington limit. Of the four alternatives discussed, none involved shell flashes. Bernetti et al. (2003) drew attention to the potential for recombination and reionization to produce the appearance of multiple shells.

And an answer to a question we had not thought to ask, the nucleus of BD $+30°3639$ has had a nova explosion in its past (Maness et al. 2003).

6.14. White Dwarfs

White dwarfs do not make up most of the dark matter in the halo of our Galaxy (Pauli et al. 2003 on kinematics; Afonso et al. 2003 presenting 5 years of data from MACHO and EROS). In fact they ought to constitute a couple of percent of the total halo, on the basis of chemical evolution models and searches for old, high velocity ones (Brook et al. 2003a). Curiously, old white dwarfs do make up most of the halo and thick disk dark matter in the galaxy of Mendez (2002).

The mean mass of a white dwarf has been decided by higher authority than ours to be 0.58 $M_\odot$ or some such, but new numbers for four cataclysmic variables are 0.36, 0.61, 0.62, and 1.17 $M_\odot$ (AM Her to IP Peg), according to Watson et al. (2003). This is very much like the situation for wider binaries and single stars a generation ago, when 40 Eri B was about 0.4, Procyon B was 0.6, and Sirius B was 1.2 $M_\odot$. Bigger stars make heftier white dwarfs (Althaus et al. 2003). Progress remains erratic on some other long-standing white dwarf questions.

Why are WDs such slow rotators? We still don't know, but one is not. The magnetic star RE J0317−853 displays a 725.7277 s period in photometry, spectroscopy, and polarimetry (Vennes et al. 2003), where hours to days is more typical. It is conceivably relevant that J0317 has the unusually large surface gravity $\log g = 9.5$ and so might be the product of a binary WD merger, though it is itself part of a wide binary.

Why are the pulsations always nonradial? Again, we have no new insights to offer, and most of them still are (Thompson et al. 2003b on the cool DA G29-38; Kepler et al. 2003 and Kotak et al. 2003 on the DB GD 358). But Mukadam et al. (2002) suggest that G30-20 might be displaying multiple radial modes, and we wish very much that they had said a bit more about how and why! The location of the instability strip is more or less understood (Fontaine et al. 2003).

Can sense be made of the sequence of spectral types as white dwarfs cool? A typical WD has a thin layer of hydrogen atop a thin layer of helium atop a core of carbon and oxygen (and perhaps heavier things), and the Balmer lines of hydrogen give it type DA. If the hydrogen is missing and it is hot, helium features lead to classification as DB. Cool helium is pretty featureless, hence type DC for continuum. If you look hard, especially in the ultraviolet, a good many WDs also show traces of calcium and other metals (Barstow et al. 2003; Jura 2003), for which no combination of radiative levitation, gravitational settling, and interstellar accretion is entirely satisfactory. As they age they must cool, having no other energy source to draw on. Calculations have incorporated better physics for the equation of state, electron conduction, and so forth (Prada Moroni & Straniero 2002; Deloye & Bildsten 2002). But the problem remains that there are no DAs as cool as the coolest DCs (Bergeron & Leggett 2002) and that there are no helium-dominated atmospheres at intermediate temperatures 5100–61,000 K (Dupuis et al. 2002; Carollo et al. 2003).

To *B* or not to *B*? About 10% of white dwarfs have magnetic fields in excess of 2 MG, with the percentage increasing as temperature goes down and age goes up (Liebert et al. 2003b). The increase with age does not sound like the usually advertized fossil fields. Strengths down to the kilogauss level are now detectable and fairly common (Valyavin et al. 2003), leading to another round of searches for coronal-type activity (Musielak et al. 2003). The less modest author has learned her lesson, and will send the next upper limit of this sort to a higher profile journal than the one in which Cavallo et al. (1993) appeared.

6.15. Numbers of Supernovae

There were 244 2003 events up to the end of September (IAUC 8212), minus a few retractions, and 292 in calendar 2002 (IAUC 8041). This is larger than ever before, and a modified system of nomenclature will be needed before the annual total reaches 703; number 702 will be 2006zz, or thereabouts. We have sporadically bemoaned the absence of direct evidence for the expected crowds of supernovae in starburst galaxies. Only a half-moan this year, because Mannucci et al. (2003) sat in the near infrared on 46 luminous infrared galaxies until four SNe had appeared. The implied rate is 7.6 ± 3.8 SNU (supernovae per century per 10^{10} solar luminosities), 10 times that in quiescent galaxies, but less than one-third of what they were expecting.

The fraction of intergalactic supernovae in two Abell clusters is about 20%, comparable with the fraction of intergalactic planetary nebulae and red giants (Gal-Yam et al. 2003). One would just as soon that the rate of supernovae very close to the solar system was close to zero. Gehrels et al. (2003) conclude that it is about one per 1.5 Gyr, where "close" is defined as nearer than 8 pc, where ionizing radiation and particles will deplete O_3 enough to double the UV flux reaching ground. Core collapse events are a larger risk than nuclear explosions.

6.16. Progenitors of Type II Supernovae

These are, we all say we know, massive stars ready for collapse of mostly-iron cores. Woosley et al. (2002) expertly review evolution up to that point, with lots of pictures of insides of stars (some of which rather resemble pictures of insides of more organic creatures). Pre-need imaging has set limits to the outsides of some stars that become SNe II, all in the range 12–15 $M_\odot$ (Smartt et al. 2003; Leonard et al. 2002a). SN 1993J was one of the events, and now that it has faded out of the way, recalibration of the field has allowed van Dyk et al. (2002) to say that the star had been a K giant with $M_v = -7.0$ and a mass of 13–22 $M_\odot$. It might have had a blue companion, but this is not required.

6.17. Mechanisms for Type II Supernovae

Notoriously, the out-going shocks in models of core collapse supernovae tend to stall so that no explosion occurs. Stars have evidently solved the problem, but it remains for the best one-dimensional (Thompson et al. 2003c) and two-dimensional (Buras et al. 2003) calculations, incorporating careful consideration of energy transport by neutrinos. Rampp & Janka (2002) review a large number of published calculations that either achieved explosions or did not and focus on where the successful ones may not have included sufficient details of the physics. Their better implementation of three-dimensional neutrino-driven convection does not encourage explosions. Variants include magnetic fields of 10^{15}–10^{16} G (Akiyama et al. 2003) and injection of vorticity (Blondin et al. 2003). Both look as if they force more symmetry into the calculations than the stars will.

Meanwhile, what modelers of the explosions, fallback, explosive nucleosynthesis, neutron star and black hole production do (Heger et al. 2003) is to deposit some number of ergs of kinetic energy, 10^{51} for instance, at the base of the envelop and see what happens. The regimes of total mass, helium, core mass, residual hydrogen mass, and initial metallicity that should yield Ib, Ic, IIp, or IIL events and NS or BH remnants are, to put it gently, complex.

6.18. Supernova Products

These include Strömgren spheres (Pynzar & Shishov 2003) and neutrinos, with a wide possible range of relative fluxes of the six flavors and antiflavors, though electron neutrinos are usually the most common (Keil et al. 2003). The expected nucleosynthesis continued to have product ratios (from carbon to molybdenum) not wildly different from solar system relative abundances (Limongi & Chieffi 2003), which is reasonable, given that half the stuff in the solar system was presumably made by events whose initial metallicity was at least half solar. And there is 100 kg yr^{-1} of supernova dust reaching Earth from the event that made Geminga, say Meisel et al. (2002). Interplanetary dust hitting us exceeds that by a factor of 30,000. The supernova was 660,000 years ago and not close enough to have done any (other) damage.

6.19. Hypernovae

These should perhaps have lived back in § 4 with gamma-ray bursters, but you may take back with you, next time you visit, a list of five SNe Ic and a couple of Type II's whose kinetic energy probably exceeded 10^{52} ergs (including 1998bw, Kinugasa et al. 2003). The newest one, 2002ac, was officially anisotropic (Kawabata et al. 2002; Yoshii et al. 2003; Wang et al. 2003d), which is an excellent thing in an explosion that aspires to kinship with GRBs.

6.20. Pulsars and Other Neutron Stars

And neutron stars we shall continue to call them, despite during the year having seen one vote for hyperon stars (Schaffner-Bielich et al. 2002), one vote for monopole stars (Wang & Tang 2002), and a whole flock of votes both for (Sedrakyan & Blaschke 2002; Spyrou & Stergioulas 2003) and against (Cottam et al. 2002; Ho & Lai 2003) quark stars. Even without the extra freedom arising from deneutronized centers, calculations of the maximum possible mass of a neutron star (Srinivasan 2003) and of the expected cooling rate (Potekhin et al. 2003 and Gusakov & Gnedin 2002 on Vela X-1 and a source in M81) cover a sizable range, dependent on the uncertain physics of superfluidity and other aspects of the equation of state.

Glitches are sudden decreases in pulsar periods, and they have been doing it since the year after they were discovered. Krawczyk et al. (2003) report events numbered 77–90 in objects 26–31. Most are small (parts in 10^9 vs. parts in 10^6 for glitches found in less systematic surveys), but 1930−22 dropped its P by 4.5 parts in a million, the second largest ever. Few pulsars show recovery to the previous period derivative in the length of time they were followed. We are not sure that two new glitch mechanisms published this year are numbers 77 and 78 (Andersson et al. 2003 on a superfluid analog of the two-stream instability, and Jones 2003 on a reconsideration of brittle fracture), but they must come close.

Giant pulses used to belong mostly to radio emission from the Crab pulsar. The associated optical ones are 3% brighter than others (Shearer et al. 2003), rather than hundreds of times as in the radio (Kostyuk et al. 2003). The radio ones have such narrow profiles that the implied brightness temperature rises to 10^{36} K, 100,000 larger than the value for the less well resolved, earlier data. There were two candidates for a fourth pulsar with giant pulses (two and three are 1937+21, a recycled millisecond source, and 1871−24). They are B1112+50 (Ershov & Kuzmin 2003) and B0540−69, the fraternal twin of the Crab in the LMC (Johnston & Romani 2003).

Magnetic fields are essential in pulsars, or, it is generally agreed, they would not pulse. The range overlaps that of the magnetars, with McLaughlin et al. (2003) reporting 9.4×10^{13} G for a Parkes survey object. Unlike the magnetars, it is not an X-ray source. The fields probably decrease with time (Geppert & Reinhardt 2002; Bhattacharya 2002), though the processes are not smooth nor so universal as they were when pulsars were supposed to turn off for that reason (Zel'dovich & Novikov 1971). The year's smallest field was an upper limit of 7×10^7 G for Aql X-1 (Maccarone & Coppi 2003).

Pulsars also slow down, though not so much as when we were children. The present periods haven't changed (much), but the estimated initial ones have gone up (Kramer et al. 2003, for instance, with an initial period of 0.139 s slowing to 0.143 in 30,000 years for the pulsar in the supernova remnant S147). There are also more processes involved than there used to be, so that the average pulsar leaves its SNR with a period of 0.3 s after 10^4 years, while the stronger fields of anomalous X-ray pulsars send them on their way with periods near 10 s (Li 2002).

Sizes and shapes. Pulsar 0652+14, which is close enough to have a radio parallax, is also a thermal UV and X-ray source. Thus, its radius can be measured to be 13–20 km (Brisken et al. 2003). A gravitational redshift measurement for a cyclotron feature in SGR 1806−20 yields 10.5–12.3 km (Ibrahim et al. 2003). Neither pulsars nor other neutron stars seem to pulsate, in the sense of oscillating radii. Haensel et al. (2002) say this is because of very strong damping, rather than the absence of driving.

Isolated, accretion-powered neutron stars are a good deal rarer than you would expect if their space velocities were the only thing impeding accretion (Romani & Ng 2003). Toropina et al. (2003) and Perna et al. (2003b) say that accretion is very considerably inhibited by even modest magnetic fields of 10^7–10^8 G, and we caught no contrary votes. The isolated neutron stars you do see as X-ray sources are merely misaligned pulsars, say Motch et al. (2003).

The slowing-down index, $\ddot{P}P/\dot{P}^2$, never takes on exactly the value 3.0 predicted for pure electromagnetic dipole radiation, but most are not far off either. Cusumano et al. (2003) announced 2.125 for the LMC Crab twin, whose pulse profiles and spectra are also very Crab-like (de Plaa et al. 2003).

6.21. Blue Stragglers

These are stars too hot and bright (hence too massive) for the population in which they find themselves. We can think of several ways to make this happen, but the most common seem to be mass transfer and mergers in close binary systems (Sandquist et al. 2003; Lucatello et al. 2003), so they occupy a sort of no-stars-land between the single and binary star sections. In crowded regions like the cores of globular clusters, direct stellar collisions and mergers probably also contribute (Ferraro et al. 2003). It seems that there are also yellow (F type) and red stragglers, above the turnoffs of clusters, but where no evolutionary tracks have boldly gone, or above and to the right, where the merged colors of binaries shouldn't really have put them either. Examples are to be found in NGC 6791 (Kaluzny 2003), M67 (Mathieu et al. 2003), several other clusters and the companions of the binary millisecond pulsar J1740−5340 (Orosz & van Kerwijk 2003), and among field stars with *Hipparcos* data (Griffin & Suchkov 2003). Again binary processes, some fairly complicated, are favored by most of the authors.

6.22. Type Ia Supernovae

The progenitors need to be able to explode a Chandrasekhar mass of degenerate carbon and oxygen to (mostly) iron. Van der Heyden et al. (2003) report 0.7–1.1 $M_\odot$ of iron and 0.1–0.15 $M_\odot$ of silicon in the remnant DEM L71 in the LMC, with similar numbers from Hughes et al. (2003). But Lewis et al. (2003) find 0.34 $M_\odot$ of Fe, 0.21 $M_\odot$ of Si, and 0.22 $M_\odot$ of S, as well as newly-formed argon and calcium in N103B. In both cases, the numbers come from X-ray spectra. Recent years have seen a good deal of enthusiasm for recurrent novae and/or supersoft X-ray binaries, where one sees both the accretion and the burning of hydrogen on massive white dwarfs as progenitor candidates (Hachisu & Kato 2003 on SNe; King et al. 2003 on supersofts). Our secret favorite has always been the merger of two white dwarfs, seriously impeded by the inventory not containing any systems that could actually do the job. But 2003 saw the announcement of the first double degenerate with total mass exceeding 1.4 $M_\odot$ and an orbit period short enough for gravitational radiation to bring the stars together in less than a Hubble time (Napiwotzki et al. 2003). The system has a period of about 7 hr and total mass of 1.45 $M_\odot$. It is so far unique in the radial velocity survey of 1015 WDs, though not all yet have even two spectra.

Livio & Reiss (2003) favor a double degenerate progenitor for SN 2002ic on spectroscopic grounds, but Marion et al. (2003) say there are no WDX2 mergers in their sample of 12 SNe Ia with near infrared spectra, because no carbon has been left unburned, though Mg, Ca, Si, Fe, Co, Ni, and Me are present.

What sets off the nuclear explosions? Well, there is detonation, deflagration, and various off-center and delayed variants of each. We caught one vote for convective deflagration (based on abundances in X-ray clusters; Buote et al. 2003) and a three-dimensional calculation in which deflagration starts at the core, works its way outward, and then triggers a central detonation, because large scale Rayleigh-Taylor instabilities put unburned material back in the core (Gamezo et al. 2003).

7. STAR DOUBLE DATES

Here live the binaries, of course, but also some multiple systems, star clusters, and an assortment of other topics in stellar dynamics, so the title might better have been Bob & Carol & Ted & Alice and the whole AARP. Don't worry, though, the dates will all be dutch treat, so the clusters won't cost you extra.

One might be interested in close (that is, interacting) binary systems for any (or none) of three reasons: for their role in the great scheme of things in stellar and galactic evolution, for their own dynamical sakes as the loci of things that are fun to calculate, or as the explanations of things we see and could not otherwise understand, like novae, the single most indexed topic of the year. The following subsections at least begin in roughly that order.

7.1. Binary Formation and Evolutionary Significance

Someone makes binaries every year (well, so does the Milky Way); in 2003 from an $m = 2$ perturbation in clouds (Nakamura & Li 2003). They also get some multiples, which Bate et al. (2002) say often get rid of a star or two to leave a close binary with mass ratio close to 1. And yes, there is such a population (Halbwachs et al. 2003; Goldberg et al. 2003), though the author who told you so 30 years ago is now of course much too old to say she told you so.[7] The official binary catalog in those days (Batten 1968) contained the best available orbits for 737 spectroscopic systems. Numbers roughly doubled within the paper era to 1469 orbits in Batten et al. (1989), and have increased another 50% in a catalog now, of course, available only on-line (Taylor et al. 2003).

In the great scheme of things, if you want to use spectrum

[7] She wishes she could claim to be too mature for this sort of thing, but this past year she did something that even Gretchen would have known better than to do.

synthesis to understand stellar populations in galaxies from integrated spectra, you must include the binaries (Belkus et al. 2003 on UV from aging populations). The example that is supposed to spring instantly to mind is the Type Ia supernovae, which really do come from binaries (and it would seem only from binaries) one way or another (Bitzaraki et al. 2003). They are important in nucleosynthesis and galactic chemical evolution just about back to the beginning, with progenitors forming no later than $z = 10$ (Yukoyama 2003; Barth et al. 2003b).

Type II supernovae are not exempt from binary effects, because loss of mass to a companion means that the star has to begin with more to reach a given end point, whether it is making a core collapse SN in the first place or having a black hole left over (Tutukov & Fedorova 2002; Clark et al. 2002).

Well observed, detached pairs of unevolved stars are the tightest handle we have on whether stellar structure and evolution calculations have all the physics they need incorporated. The answer invariably is "getting there" (Thoul et al. 2003b and Kervella et al. 2003 on α Cen A and B, Ribas 2003 on a low mass pair, and Duemmler et al. 2002 on a discordant pair, for which we think the spectral types must be wrong; a 0.995 $M_{\odot}$ star has no business being a late K dwarf, no matter what its brother is doing).

This is, therefore, perhaps as good a place as any to remind you that state-of-the-art calculations of stellar evolutionary tracks and isochrones are now carried out (more or less) independently by something like half a dozen groups. Yi et al. (2003), the Yonsei-Yale collaboration, is a new entrant in the field, and we caught at least the following comparisons of results from two or more of the earlier groups: Kotoneva et al. (2002), Gallart et al. (2003), Woo et al. (2003), Bertelli et al. (2003). This last focuses on convective overshoot (which, like the poor, is always with us) and on Population II and even III, occasioned both by the recent discovery of a number of very metal-poor stars and nearly-pristine intergalactic gas (Kim et al. 2002b, Schaerer 2003), and by the need to understand how much ultraviolet comes from these stars to contribute toward early reionization (§ 3.8). No one set of models for any stellar population is obviously superior to the others in all respects, and it is perhaps best simply to be content that there are no discrepancies of the glaring sorts seen a generation ago, when the very existence of loops back into the Cepheid instability strip seemed to depend on the computer you used.

7.2. The Calculating Binary

Close star pairs are supposed to circularize (North & Zahn 2003) and, meanwhile, to undergo apsidal motion, though we could do without the systematic excess of theoretical values over observed ones (Petrov & Orlov 2002), and we will never get used to the idea that the general relativistic component (Levi-Civita 1937) can be larger than the classical one for ordinary main-sequence stars (Volkov & Khaliullin 2002 on GG Ori). Periods and eccentricities are allowed to change because of tidal effects (Willems et al. 2003), activity cycles (Yang & Liu 2003), thermal relaxation oscillations (Qian 2003a), and perhaps other things (Qian 2003b).

But if there was one phenomenon we thought we understood, and apparently didn't, it is the Roche geometry. Bad enough that with a luminous accretion disk the Roche potential around a compact star can become hollow in the polar direction (Fukue & Hanamito 2002), but absolutely outrageous that, with sufficient irradiation by M_1, M_2 can be the first star to fill its Roche lobe and reach a potential surface that communicates with the outside world before transfer begins (Phillips & Podsiadlowski 2003). We do not mean to indicate disbelief but merely discontent with the general unexpectedness of such things. In the case considered by Phillips & Podsiadlowski, gas forms an excretion disk around M_2, leaves via the second Lagrangian point, L2, and takes enough angular momentum with it that the flow keeps going. They consider PSR 1957+20 (the "black widow"), Cen X-3, and a star orbiting the black hole at the center of an AGN as examples.

7.3. Specific Binaries

No one, Henrietta Leavitt is supposed to have said, will understand β Lyrae until we get a net and fetch the thing down, but Miroshnichenko et al. (2003) suggest that it may eventually look like HDE 327087, consisting of a B[e] and F supergiant pair, with total luminosity near 10^5 $L_{\odot}$ and most of the stray gas around the B star.

Eta Carinae ended up under several different subject headings. Explicit binary effects are discussed by Duncan & White (2003) and the 10^{50} ergs that have gone into ejecting some 12 $M_{\odot}$ at 1000 km s^{-1} by Smith et al. (2003b, 2003c). Remember that even a supernova gives you only about 10^{51} ergs in kinetic energy. But our favorite η Carinae paper of the year comes from Sallie Teames (Teames 2003), whom we really like anyway, and who has suggested that a particular Bolivian rock carving may record η Car as having been very bright a thousand years ago.

Wolf-Rayet stars, with their faces stripped down to helium and carbon, were the first sort we ever heard of as being easier to form in binaries. This remains true (Cherepashchuk & Karetnikov 2003) and makes them generous sources of carbon in the universe (Dray et al. 2003). But what is one to make of the observation that the fraction of LMC Wolf-Rayets that are radial velocity variables is 30%, about the same as for other sorts of stars there (Foellmi et al. 2003b). And as long as we are making things out of WR binaries, Benaglia & Romera (2003) would like to make the optical counterpart of the so-far unidentified EGRET source, 3EG J2022+4317. Incidentally, the unidentified class of gamma-ray sources remains large and seems to have a galactic component (Bhattacharya et al. 2003).

The hot subdwarfs, sdOB's, are another category easier to produce from pairs than from single stars, even when the subdwarf is itself single (Han et al. 2003; Morales-Rueda et al. 2003).

W Ursae Majoris stars or contact binaries are the quintessential interacting pairs. It is possible to catch them before contact (Zhang & Zhang 2003, Duemmler et al. 2003 on TW CrB and ER Vul, respectively) and to calculate that the observed ones will merge in about half a gigayear (Dryomova & Svechnikov 2002). In between, one star in 500 fainter than $M_v = +1.5$ is a W UMa (Rucinski 2002), a number which has, over the years, been both larger and smaller by a factor of four either way. Open clusters more than a Gyr old have their fair share (Mermilliod et al. 2003), though many globular clusters seemingly do not (von Braun et al. 2002).

7.4. Binaries with White Dwarf Components

The shortest period binary known is the X-ray emitting double white dwarf RX J0806+15, at 5.4 minutes. It is a unipolar inductor, making it the first electric star, and gravitational radiation is also important in its evolution (Hakala et al. 2003; Strohmayer 2003a), but accretion is hardly worth worrying about.

Binaries with one white dwarf plus a donor or potential donor now come in radio-selected (Bond et al. 2002) as well as X-ray selected (DiStefano & Kong 2003; Orio et al. 2003) flavors. The latter at least (well, there is only one example of the former) tend to have white dwarfs massive beyond the norm (Suleimanov & Ibragimov 2003). And we would remind you that this makes them plausible progenitors for Type Ia supernovae, but we are touting another brand this year (Napiwotzki et al. 2003).

Cataclysmic binaries or cataclysmic variables is the generic term once gas begins to flow onto the white dwarf, and 61 papers were indexed under the heading (yes, we read them all; no you don't have to). When not interacting, the systems are rather difficult to spot, but Schreiber & Gaensicke (2002) provide data on 30 systems, mostly hot, and SDSS should roughly double the current supply to 100 (Raymond et al. 2003). The former paper has the additional virtue of calling them V471 Tauri stars (for a prototype) rather than pre-CVs, which is dangerous flirting with the difficulties of making predictions about the future. Whether you think of that phrase as belonging to Yogi Berra or to Niels Bohr is probably a test for aculturation.

There are at least umpteen types of CVs (of which more shortly), and the basic evolutionary scenario seems to be more or less under control (Taam et al. 2003). "Burning" is probably too strong a word for the following items, but they might at least be oxidizing.

Is there still a gap in the period distribution at $P = 2$–3 hr? Yes, though it now has at least 37 systems in it, with magnetic ones over-represented (Katysheva & Pavlenko 2003).

Why aren't more symbiotic stars extrinsic S type stars? That's the sort with excesses of *s*-product elements scattered on the non-compact star by the compact star when it was a red giant. We don't know. Indeed, we had never thought of asking the question until Vanture et al. (2003) expressed puzzlement.

How many recurrent novae (the sort with two or more explosions in historic times) are there? Only a handful, but two additions this year. CI Aql (1917 and 2000) should according to Hachisu et al. (2003) grow to the Chandrasekhar limit in 20 million years, and IM Normae (1920 and 2002) is the second with a short period orbit (Woudt & Warner 2003). They are another route by which one might reach a nuclear (SN Ia) explosion.

How many novae are there per year per galaxy? In M87 200–300, but only 25–30 in the Milky Way, M31, and M81, and these can be modeled in terms of star formation rates and so forth (Matteucci et al. 2003). The Milky Way number has changed little since the estimate by Payne-Gaposchkin (1957).

Do novae hibernate? Yes, with a third example, say Kawka & Vennes (2003), and no, say Selvelli & Friedjung (2003), for HR Del (nova 1967), which has spent most of the past century near $M_v = +2.3$. But perhaps we just haven't waited long enough, since the scenario would be content with a century or two of relative brightness before fading into hibernation. GK Per (nova 1901) hasn't really gone anywhere either, but then it is (uniquely) both an intermediate polar and a dwarf nova, with accretion-driven outbursts every 2–3 years (Nogami et al. 2002; Bianchini et al. 2003).

Just how many types of CV are there? Well, novae (nuclear explosions) can arise from white dwarfs of different composition—C+O, ONeMg, NNeAl, and ONe at least (Shore et al. 2003 as a representative of half a dozen papers). As for the dwarf novae (whose energy source is variable accretion onto the white dwarf), let us quote: "At maximum light, several VY Scl stars are SW Sep stars" (Hameury & Lasota 2002). The answer, in other words, is "many," and we skip immediately to the last paper of the year on the topic (Nogami et al. 2003), which provides the additional information that 73 Dra is an SU UMa star with a time between outbursts almost as short as for the ER UMa stars. And if you just can't live without knowing what some of these subtypes are, Kato et al. (2002b, 2002c) will be happy to define.

And the one question that may actually burn: What is V838 Mon? Its first outburst appeared in Ap02 under "real time stellar evolution" (§ 3.1), in the belief that it was the prototype of a new sort of last shell flash. It has migrated to binary stars because Goranskii et al. (2002) said that a slow nova was a better fit to its light curve and spectral evolution than a helium shell flash. As the index year came to an end, it was the coolest supergiant ever observed (an LI presumably, say Evans et al. 2003b); its light echo (only about the third ever seen) was 52″ in radius (IAUC 8210); and it had very possibly at peak light been the brightest star in the Milky Way (Bond et al. 2003) at $M_v = -9.6$. Given that the senior author of that last paper commissioned the first member of this review series (Ap91), you might not think of him as a basically conservative bloke (fond of small telescopes, large stars, and so forth), but it is so, and his team opines that the new class of which V838 Mon is the best studied is different from all of novae, symbiotic stars, and last helium flashes. Crause et al. (2003) agree. But it is probably not so different as to deserve mention in § 5.2, where it also appears.

7.5. Neutron Star Binaries

As a rule, one associates binary processes with the production of millisecond radio pulsars, spun back up by a second phase of mass transfer (Willems & Kolb 2003). Tutukov & Fedorova (2003) suggest, however, that all true (rotation powered) pulsars form in close binaries. They have in mind the need to achieve both rapid rotation and large recoil velocities.

Many binary neutron stars announce their presence via X-ray emission fueled by transfer from the companion. Some old friends reappeared during the year. Traditional X-ray bursts are nuclear explosions of gas that accretes fairly steadily, and which systems do it when is fairly well understood (Cornelisse et al. 2003). The rapid burster remains unique with accretion-powered flare-ups as well. Mahasena et al. (2003) suggest a limit cycle mechanism.

Cygnus X-3 has again reported as a TeV source (Neshpor et al. 2003). The source is either sporadic or the detection spurious. Geminga really is a gamma-ray source, indeed the second brightest in the sky somewhat above 100 MeV. Its rotation period is, was, and ever shall be about 0.237 s, and we are sorry and embarassed to report that the period and period change recommended last year (Ap02, § 8.3) as something you could time the way Galileo did the lamp pendulum in the cathedral are not true (Jackson et al. 2002a).

Accretion-powered millisecond pulsars have, with the report of the fourth (Campana et al. 2003), passed beyond the sequence of "discovery, confirmation, well-known astrophysical class" recorded in the past couple of years. The primordial one, XTE J1757−305, has a featureless spectrum (Miller et al. 2003a). But there are times when one really wants optical data. Thus Jimenez-Garate et al. (2002) were able to show that HZ Her has a surface adulterated by CNO-processed material that came from what is now the neutron star.

Vela X-1 is one of those old-fashioned massive (companion) accretion-powered X-ray binaries, so its neutron star ought to have a strong magnetic field and display cyclotron resonance features. It does, but we do not know how to vote between Kreykenbohm et al. (2003) and La Barbera et al. (2003), who associate the 50 keV feature with fields of 2.6 and 6–7 × 10^{12} G, respectively.

Strong magnetic fields lead us inexorably on to soft gamma repeaters, anomalous X-ray pulsars (AXPs), and other magnetars. The SGRs were gradually separated out from the classical gamma-ray bursters because (1) they do it more than once, and (2) they are in the Milky Way and nearby galaxies. The AXPs distinguish themselves by very tight limits on the mass and luminosity of any companion, meaning that they must be rotation-powered or something, but also by rotation periods so long that the dipole mechanism would not extract even their X-ray powers unless their fields are somewhere around 10^{14} G. Both have rotation periods in the 6–12 s range (Psaltis & Miller 2002), but this is not a defining trait, since the ordinary LMXRB 4U 1626−67 has a rotation period of 7.7 seconds atop its 41.4 minute orbit period (Homer et al. 2002). Nor is the 6–12 s rotation even perhaps a necessary condition. Mori & Ruderman (2003) discuss a source (RX J1856 for short) with no pulsation and a thermal spectrum, which, they say, has been slowed to a rotation period longer than 10^4 s. The evidence for the strong field is that it is needed to accomplish the rotational braking. J1856 is perhaps an honorary AXP.

The SGR and AXP classes are not completely distinct. Kulkarni et al. (2003) report that RX J0526−6604 has metamorphosized from SGR to AXP. It is, or anyhow was, the original SGR of 5 March 1979, in case you don't recognize its URL address. And 1E 2259+586 is the second AXP to start showing soft gamma-ray bursts (Kaspi et al. 2003).

The evidence for the strong fields has been slightly indirect, but, in quick succession during the year:

1. Rea et al. (2003) announced what is probably the first cyclotron resonance feature in what is probably an AXP. At 8.1 keV it implies a field of 10^{15} or 10^{12} G for proton or electron cyclotron. If the latter, then the source must be accretion fed by a faint infrared companion.
2. Ibrahim et al. (2003) reported a 5 keV absorption feature in the better-known SGR 1806−20, which invites the same ambiguity of interpretation. Nishimura (2003) says it is not electron cyclotron which, we suppose, leaves the proton, higher field, alternative.
3. Haberl et al. (2003) associated a 300 eV feature in the spectrum of RBS 1223 with a field of 2–6 × 10^{13} G (that is, proton cyclotron).

We think that what is needed is a slowing-down rate and cyclotron features in the same source that imply the same field strength. This will surely happen if the basic idea is right.

Both X-ray binaries (Maccarone et al. 2003 on NGC 4472, and Irwin et al. 2003) and millisecond pulsars (Grindlay et al. 2002 and Freire et al. 2003 on 47 Tuc) display a remarkable affinity for globular clusters, which would lead us on inexorably to § 7.8 were it not for the need to stop at black holes on the way.

7.6. Black Hole Binaries

All of these found so far are X-ray sources. A millisecond pulsar with a black hole companion (signified by its mass) is presumably possible, but nobody reported any during the index year. The BHXRBs so far divide fairly cleanly into classes with high and low mass companion donors. Podsiadlowski et al.

(2003) affirm what you might well have expected, that is fairly easy to make HMXRBs with black hole primaries but much harder to make LMXRBs of that sort, and they put forward a triple star scenario.

Cygnus X-1 was the first of the persuasive BHXRBs, and Mirabel & Rodrigues (2003) have figured out how to make it without a supernova explosion, which they find desirable because of its lack of a visible supernova remnant and small space velocity. The first runaway BHXRB, J1655−40, in constrast, presumably has a supernova in its past (Mirabel et al. 2002).

Inventorying the black hole systems (confirmed by mass measurements) now just about requires removing your shoes, but there have been some laggards. GX 339−4 is firmly in the camp with a (first ever) mass function of 5.8 $M_\odot$ (Hynes et al. 2003). But the blackholedness of SS 433 was first affirmed, from radial velocity data for the secondary leading to a mass of 11 ± 5 $M_\odot$ (Gies et al. 2002), and then denied (Collins & Scher 2002).

The number of microquasars, that is BHXRBs with superluminal motion, is now about five. Chaty et al. (2003) added V4641 Sgr with radio jets moving out at an apparent speed near 10*c*. Other BHXRBs have honorable subluminal jets, like XTE J1550−564 at 0.34 and 0.93*c* (Tomsick et al. 2003; Kaaret et al. 2003a). Several of the BHXRBs display fairly steady periods of months, much longer than their orbits, which are perhaps disk precession periods (Smith et al. 2002; Rau et al. 2003).

The most complex topic in this subsection is the ultraluminous X-ray sources (or intermediate mass black holes), which have been with us for several years. The key question is whether these (1) are actually BHXRBs at the high end of the mass range with, perhaps, some beaming, or (2) a genuinely new class of (probably) single black hole, larger than is likely to be made from a single or binary Population I star. Therefore they get their own section.

7.7. ULXRSs and IMBHs

When we last saw this topic (Ap02, § 8.3), it meant ultraluminous X-ray sources and intermediate mass black holes, and the primary evidence was X-ray sources in several galaxies with luminosities in excess of 10^{39} ergs s^{-1}, the Eddington luminosity for a black hole of 8 $M_\odot$ (a fairly arbitrary limit). The definition has not changed. Thus an IMBH is still something larger than about 10 $M_\odot$ but not so hefty as the 10^6–10^{10} $M_\odot$ black holes at galactic centers, probably located away from the host nucleus.

The index year began with new, dynamical evidence for (1) a 2×10^4 $M_\odot$ compact object in the star cluster G1 in M31 (Gebhardt et al. 2002b, who also remarked that a similar object, made in a massive star cluster long ago, could be the seed for a larger, galactic center black hole) and (2) a 4×10^3 $M_\odot$ one in our own globular cluster M15 (Gerssen et al. 2002; van der Marel 2002). The evidence in each case was the radial profile of stellar velocity dispersion. Meanwhile, discoveries of very luminous X-ray sources in other galaxies, mostly in *Chandra* images, proliferated.

But, before the year was out, the dynamicists were having second thoughts. First, refined modeling with GRAPE-6 (Baumgardt et al. 2003b) applied to the optical images and spectra of G1 indicated that it is a very massive cluster, near 8×10^6 $M_\odot$ with a mass to light ratio of about 4, plausibly formed from the merger of two less extreme clusters, but with no real need for a large compact mass at the center.

More fun is the case of M15. It seems that the data on σ vs. r had been misinterpreted, with a horizontal axis that was really in arcminutes having been read in parsecs (Gerssen et al. 2003). This made the need for a central black hole much less acute. It is not possible to exclude one of up to 1000 $M_\odot$ (Baumgardt et al. 2003a), but the expected central concentration of white dwarfs and neutron stars would also do (Dull et al. 2003). And so say we all (McNamara et al. 2003).

Thus, we are back to the really bright X-ray sources and will consider them in order from “definitely not IMBHs” to “probably something else” to “uncertain” (more papers than can be cited) to “still a strong case for IMBH.” The alternatives remain as they were last year, (1) misidentifications or unresolved multiple sources, (2) beaming of the X-rays, or (3) nonspherical super-Eddington accretion and radiation, so that the photons don’t have to get out through the incoming gas. If you have ever tried to get off an elevator or the Atlanta airport train, while other people were trying to get on, you will appreciate the virtues of the last.

Two ULXRSs were revealed as background sources, a $z = 0.43$ BL Lac behind NGC 4698 (Foschini et al. 2002) and a $z = 0.217$ galaxy behind NGC 4168 (Masetti et al. 2003). Next, the optical identification of a ULXS in M81 with an O8 V star permits a mass estimate (23 $M_\odot$) and a radial velocity curve, yielding 18 $M_\odot$ for the black hole and a sub-Eddington luminosity (Liu et al. 2002a). The authors suggest that this may well be a common sort of source in star formation regions. The 2 hr (orbit) period for the ULXS in M51 implies a beamed, black hole X-ray binary (Liu et al. 2002b). And IC 342 X-1 must be an anisotropic emitter because it has lit up bright spots in a surrounding shell (Roberts et al. 2003).

NGC 4038−39 (The Antennae) has or have a bunch of ULXSs. It/they is/are a well-known star former, and the spectra and variability of at least seven of the nine ULXSs are like those of known Galactic BHXRBs (Zezas et al. 2002; Fabbiano et al. 2003a, and at least three other papers from the same group in various permutations). Similar considerations of spectrum variability and correlation with star formation rate apply to a number of other sources in the 10^{39}–10^{40} ergs s^{-1} range (Humphrey et al. 2003, and Dubus & Rutledge 2002, Roberts et al. 2002 on five sources in another interacting pair of galaxies, NGC 4485/4490).

Next come a number of cases for which the evidence does not strongly discriminate between an IMBH and a fairly hefty

BHXRB formed as usual from a binary system initially consisting of two stars of 50 $M_{\odot}$ or more. Let Kaaret et al. (2003b) on a source in NGC 5408 stand for a bunch, and Holt et al. (2003, on NGC 6946, in which six core collapse supernovae have been seen as well as a bunch of ULXSs) for some more.

This brings us to examples for which a black hole too large to have arisen from Roche lobe overflow and still have a live donor remains the best bet. Colbert & Ptak (2002) call attention to the large specific frequency of ULXSs in elliptical galaxies where massive binaries are unlikely still to be functioning. The black hole, of course, is forever, but the donors are not. Strohmayer et al. (2003b) have found quasi-periodic oscillations in the 4–5 $\times$ 10^{40} ergs s^{-1} source in M82 at a frequency of 54 mHz, consistent with a 100 $M_{\odot}$ black hole radiating at its Eddington luminosity. And the way the two bright sources in NGC 1313 light up the nebulae around them implies that the X-rays are not beamed (Miller et al. 2003b). One would, of course, really like to have optical identifications and radial velocity curves (or not, as the case may be) for these!

The last word on the subject goes to Burbidge et al. (2003b), who propose that the very bright sources are really local QSOs and BL Lacs with large intrinsic redshfits being ejected from nearly galaxies. Additional optical identifications would also help to test this hypothesis (which, of course, predicts the result reported for the NGC 4698 and 4168 sources mentioned a few paragraphs back).

7.8. Globular Cluster Dynamics

When we left the neutron star binaries at the end of § 7.5, it was with the thought that both the radio and X-ray sort are considerably over-represented in globular clusters. Why this should be so is suggested by the observations (1) that the number of sources per cluster is proportional to the estimated rate of stellar encounters there (Pooley et al. 2003) and (2) that there are lots of neutron stars and white dwarfs near the centers of the clusters (Lee et al. 2003b).

What about other sorts of binaries that might be formed by capture, star exchange, and all? Main-sequence contact systems (W UMa stars) are definitely not in excess (von Braun et al. 2002). In the field, they make up one star in a few hundred, while in M10 it is zero and in M12 one in perhaps 10^4. If anyone has estimated either the "one star in…is" or the total numbers in the whole galaxy for cataclysmic variables, RS CVn stars, or BY Dra variables, we have not seen the paper. But there are lots of each of these to be found among the fainter *Chandra* sources in various globulars (Gendre et al. 2003b, 2003a; Becker et al. 2003; Knigge et al. 2002; Heinke et al. 2003).

Other possible dynamical processes include mass segregation by position in the clusters (yes, it happens; Albrow et al. 2002) and core collapse. Yes, that happens too, but less often among the brightest clusters, although they are the ones with the strongest (pre-collapse) central concentrations (van den Bergh 2003). And we think the suggestion, not new this year, that the massive southern globular ω Cen began life as the core of a nucleated dwarf elliptical galaxy belongs in here somewhere (Tsuchiya et al. 2003; Mizutani et al. 2003).

The last dynamical experience clusters have is death. They are not generally expelled into intergalactic space (none in the case of the Coma cluster, Marin-Franch & Aparicio 2003), but they do get torn up. The definition of tidal disruption is not unique (Caimmi & Secco 2003), but the results are unmistakable. A distribution of masses and luminosities that was initially a power law (more little ones than big ones) ends up as some sort of Gaussian (Smith & Burkert 2002; de Grijs et al. 2003; Baumgardt & Makino 2003; Vesperini & Zepf 2003). And the clusters near the centers of galaxies are most at risk (Vesperini et al. 2003).

7.9. Globular Cluster Compositions and Ages

Dust exists, at least in NGC 7078, despite the paucity of gas and the shortage of heavy elements to make it from. So say Evans et al. (2003a) after a reanalysis of the far infrared emission recorded by *ISO*. A false alarm from *IRAS* (Gillett et al. 1988) was too early to have been mentioned in ApXX, but we think we believed it at the time.

Additional cluster topics that turned up during the year include (1) globular formation as an on-going process, (2) ages of the clusters, (3) the second parameter and other compositional items, and (4) cluster populations in various galaxies.

Taking these back to front, the gross properties (distributions of luminosities, ages, colors, compositions) of most cluster populations are remarkably similar, far more so than those of their host galaxies (Cohen et al. 2003; Larsen et al. 2002; Hempel et al. 2003; Eerik & Tenjes 2003). Some galaxies are remarkably well endowed, with Dirsch et al. (2003) reporting 6450 $\pm$ 700 clusters belonging to Fornax A and reminding us that the cluster system is more extended in radius than the general halo light, as is true for many galaxies, an item that much puzzled us when we first heard about it, but have had time to get used to (and so can expect some day to get used to the loss of the Faustian Acquaintance).

Our favorite second parameter this year is poor choice of color filters (Momany et al. 2003). But helium (Moehler et al. 2003), age (Beasley et al. 2002), and accretion from other stars in the cluster (D'Antona et al. 2002) or even from stars in the next galaxy (Kravtsov 2002) all had their supporters. Oh, sorry. The "second parameter" is what causes clusters of the same metallicity ("first parameter") to have very different horizontal branch morphologies.

To understand the surface compositions of the stars (which are definitely not the same for all the stars in a given cluster, the way we were taught in kindergarten), one must allow for the effects of primordial variation (Smith 2002), mixing in the stars themselves (Briley et al. 2002), pollution by neighbors (Yong et al. 2003), gravitational settling (Richard et al. 2002), and even Type Ia supernovae (Simmerer et al. 2003) to have any hope of coming out even. There may well be other relevant properties not emphasized in this year's indexed papers.

The oldest globular cluster did not come out older than the universe this year, but only 12 ± 1 Gyr (Grundahl et al. 2002; Schiavon et al. 2002a, 2002b). It would probably be churlish to continue to worry about how hard theorists over the years have worked to keep these ages down. The youngest globular clusters have not yet formed and are to be seen as giant star formation regions, for instance giant H II regions in the NGC 3256 merger (English & Freeman 2003) and an infrared cluster in NGC 5253 containing about 10^6 stars and expected to lose its gas as the stars evolve (Turner et al. 2003). The interacting pair NGC 3395–96 also has some candidates (Hanock et al. 2003). Our favorite, M33, has apparently been forming globulars at a roughly constant rate for most of the past 10 Gyr (Ma et al. 2002a), which is about as different as you can get from the traditional view that "they aren't making them any more," though that always had the qualification "at least in our galaxy."

7.10. Nuclear Star Clusters

Once upon a time, the bright stars very close to Sgr A* were valued primarily for probing the central gravitational potential. Indeed, the noose draws ever tighter, with two-thirds of the 15.2 year orbit period of one star observed (Schoedel et al. 2002). It could be orbiting either an isolated black hole of $3.7 \pm 1.5 \times 10^6\ M_\odot$, or a smaller black hole ($2.6 \pm 0.2 \times 10^6\ M_\odot$) and a star cluster with a core radius of 0.34 pc (Gebhardt 2002). Alternatives that can be ruled out include a star cluster alone (even if it is made of neutron stars and black holes) for which the collapse time would be only 10^5 yr, and a fermion ball. A boson ball is possible. The authors describe the $e = 0.87$ orbit as having a perinigricon. There are also OB stars within 1000 AU of Sgr A* (Ghez et al. 2003). Oh. Kepler's third law applied to a system with orbit period = 15.2 yr and total mass $3.7 \times 10^6\ (+1)\ M_\odot$ means a semi-major axis of 950 AU, in case your slide rule was confiscated at airport screening as a weapon of math instruction.

To a certain extent, however, interest has shifted to the star clusters themselves and their dynamical evolution (Freitag & Benz 2002). The main issue is the difficulty of forming massive stars in a region with such extreme tidal forces. Levin & Beloborodov (2003) suggest that the stars formed and remain in a very thin disk, with the left over gas swallowed by the black hole or nigricon. Portegies Zwart et al. (2003) propose that the central cluster formed about 5 pc from Sgr A* and has spiraled in. The stars do not have any collective measurable motion relative to the SiO maser location of Sgr A* (Reid et al. 2003b), but we don't think this rules out the inspiral. Ensslin (2003) concludes that both the central black hole (probed with polarization data) and the nearby stars are counter-rotating relative to the main galactic disk. Like painting a herring yellow and hanging it on the wall, this sounds like something that was just put in to make it more difficult.

Further out are several other young star clusters (Dutra et al. 2003), at least one of which (The Arches) has a normal, Salpeter initial mass function (Figer et al. 2002; Pindao et al. 2002), suggesting slightly that there is nothing very unusual about the star formation process there. But wouldn't it be more fun if there were somehow something in common between the young, massive stars around our own little black hole and the more impressive nuclear star clusters to be found in active galaxies (Torricelli-Ciamponi & Pietrini 2002), whose envelopes are perhaps stripped off to make the broad line emission region? QSO accretion disks are at risk of forming stars, but Goodman (2003) focuses on preventing it rather than encouraging it in parallel with the Sgr A* case of Levin & Beloborodov (2003).

7.11. Star Formation and Young Clusters

Star formation is one of the subjects that will get less attention than it deserves this year. Fragmentation lives (Bonnell et al. 2003; Cha & Whitworth 2003a, 2003b; Li et al. 2003), but so does coalescence (Takakuwa et al. 2003).

At least part of the difficulty in calculations of star formation is dynamic range. This is true not only in the three spatial dimensions, when events are happening in a 10 pc cloud to make 20 AU disks, but also in time, because interesting things happened from the dynamical on up to the Kelvin-Helmholtz timescales. Aspects of these problems are addressed by Elmegreen & Shadmehri (2003), Bate et al. (2003b), McKee & Tan (2003), Gomez & Mardones (2003), and Baume et al. (2003). And while you are at it, don't forget to include magnetic fields (Sarma et al. 2002), angular momentum and the need to get rid of it (Gammie et al. 2003), and turbulence (Padoan et al. 2002).

Rich clusters are born with mass segregation in place (Sirianni et al. 2002). Thus the only other really important dynamical thing they have to do is fall apart. The typical timescale for this depends on the density of stars around and is about 10^9 years locally but only 4×10^7 yr in the inner disk of M51 (Boutloukos & Lamers 2003). For permanent binding, about half of the originally-bound gas must be turned into stars (Vine & Bonnell 2003). Massive stars are the easiest to hang on to, and a good many of the local young F and G field stars have diffused from Perseus OB3 and other nearby OB associations (Wichmann & Schmitt 2003).

Is star formation triggered? One can only say with the moderator of *Twenty Questions*, "some of them are and some of them aren't," though we caught 11 votes for and 4 against (most applying to specific contexts and so not contradictory). One truly random sample of yes, yes around the rim of the H II region G308.70+0.60 (Cohen et al. 2002), and no near active regions in the M31 disk (Williams 2003).

7.12. Other Aspects of Stellar and Galactic Dynamics

Starting up close and moving outward, which direction the Sun seems to be going is a continuous function of the stars you choose to compare it to (Abad et al. 2003), but the local standard of rest is following a well-behaved circular orbit relative to the halo stars (Gould 2003a). The local angular velocity of the disk rotation is $\omega = +24.6 \pm 0.8$ km s^{-1} kpc^{-1} (Loktin & Beshenov 2003 from local measurements) or $\omega = 27.6 \pm 1.7$ km s^{-1} kpc^{-1} from absolute proper motions of stars near the Galactic center (Bedin et al. 2003). The agreement strikes us as extraordinarily good. The number is the difference of the Oort constants, A−B, or V_c/R_0 (where V_c is the local circular velocity and R_0 is our galactocentric distance), and is better determined than any of the four related numbers separately. Around the average of galactic rotation can be seen the effects of the arms, bar, and resonances (Sitnik 2003; Quillen 2003), showing that we indeed live in a barred spiral galaxy.

Direct detection of the bar in near-infrared star counts was reported by Picaud et al. (2003). The two votes on arms we recorded this year both said there are four (Russell 2003; Bissantz et al. 2003). The disk is warped (Lopez-Corredoira et al. 2002), though not by so much as that Faustian Acquaintance. Interaction with the Magellanic Clouds cannot be the cause of the disk warp (Garcia-Ruiz et al. 2002), but the dwarf spheroidal in Sagittarius (let us call you IGI, we're in love with you) could be (Bailin 2003). Despite the warp, the gas disk doesn't flare much, in either H I or H_2 (CO is the tracer), which puzzled Jan Oort back in 1962 (IAUS 15, 3) and continued to puzzle Narayan & Jog (2002) 40 years later.

The scale height of the stellar disk is puffed up through time by interactions with all the things you can think of (Haenninen & Flynn 2002; Sotnikov & Rodionov 2003); but the bulge is not just puffed-up disk, since it has its very own globular clusters (Goudfrooij et al. 2003).

There are at least two stellar disk populations and two halo ones (Siegel et al. 2002, who use methods which they credit to Hugo von Seeliger back in 1898). There are also two bulge populations, formed, say Nakasato & Nomoto (2003) before and after the last merger that assembled the Milky Way. The nuclear regions have a stellar population of their very own (van Loon et al. 2003). Any handful of stars you grab from anywhere is, however, likely to be a mix of all seven of these, which bedevils collection of the sort of data that you would like to have for testing models of galactic chemical and dynamical evolution.

The Milky Way is a big galaxy, with red giants extending out to a radius of 83 kpc (Morrison et al. 2003), nor are the outermost ones desperately metal poor, though that is surely part of the story in § 9. The total mass is 1–3 × 10^{12} $M_\odot$, with 5 × 10^{11} $M_\odot$ of it closer in than the Large Magellanic Cloud (Sakamoto et al. 2003). M31 is nearly enough the same (1.2 × 10^{12} $M_\odot$ out to 100 kpc; Evans et al. 2003) that there is no cause for jealousy on either side.

Looking for one sentence outside the Milky Way, one finds the motions in polar ring galaxies (Swaters & Rubin 2003), which the Milky Way definitely is not, and in galaxies with counter-rotating cores (Wernli et al. 2002), which the Milky Way just possibly is (Ensslin 2003). It would be very interesting to get some handle on the direction of rotation of the central black holes in some of each of these.

8. FUNDAMENTAL PHYSICS AND ASTRONOMY

"Fundamental" must, at bottom, be both a deep and shallow word, for our index page of fundamental physics includes items like CP violation and Planck foams of space and time (or, rather, turns out not to include either), while fundamental astronomy runs to coordinate systems and definitions of proper motion and radial velocity. We also picked up some less fundamental items like spectrographs of the future and laboratory production of craters and singing sands.

8.1. Fundamental Astronomy

The key point here seems to be that as measurements become more accurate, the definitions of what is being measured must become more precise. First you must establish a coordinate system, and the most nearly inertial one we currently have is tied to very distant extragalactic radio sources. It is stable to 6 μarcsec, provided that only the central cores of quasars and radio galaxies are used and not their moving jets (Feissel-Vernier 2003). Comparisons of the positions of bright stars that are also radio sources with those of the quasars show that the *Hipparcos* coordinate system is also inertial (Boboltz et al. 2003). These are good things.

The threatened upcoming decision to abolish leap seconds will, however, make it increasingly difficult to be sure that your telescope is actually pointing where you think it is (Klepczynski 2003). It will be a millenium or so, but only a millenium, until the Sun is setting at noon, since things like this pile up as t^2, unless you live in the sort of place where the Sun sometimes sets at noon anyhow.

With your coordinate system established, you are allowed to move around in it, but as the errors of radial velocity measurements are pushed below 1 m s^{-1}, definitions of both radial velocity and proper motion will need tidying up. Stars, or even centers of masses, do not actually move parallel and perpendicular to the celestial sphere. Thus, for constant velocity in inertial coordinate system, a star that is coming approximately but not exactly in our direction has its radial velocity gradually changed into proper motion (and will show only proper motion at its point of closest approach to us). The change is called secular acceleration of the radial velocity, and Kurster et al. (2003) report the first-ever detection of the phenomenon. The target was Barnard's star and the amount about 5 m s^{-1} yr^{-1}. Another product of their work is the conclusion that Barnard's star has no planet of more than 7.5 Earth masses within its habitable zone, which is, however, at $a = 0.034$–0.082 AU.

With just a little more precision in measurements, one has to start worrying about effects of special relativity and moving in and out of the Sun's gravitational potential (as space navigators must already), and, beyond that, the effects of gravitational radiation, gravitational lensing, and the potentials of other stars and the Milky Way as a whole (Lindegren & Dravins 2003). That these things must happen is not a new discovery. In his analysis of Barnard's star, Van de Kamp (1963) carefully allowed for secular acceleration of the proper motion (because the star is coming toward us), but the planet he reported, with a 20 year period, still isn't there.

Coordinate system in hand (or rather on the sky) and rules for describing parallax, proper motion, and radial velocity in your pockets (or rather in your computers), you are allowed to publish a catalog. More than 30 astronomers and teams did. Here are some of the ones in which precise positions are an important part of the content; others appear in § 11.

The USNO-B catalog (Monet et al. 2003) has positions of 1,042,618,261 objects, derived from more than 3 billion observations on more than 7000 Schmidt plates exposed over more than 50 years.

On-line editions now exist of (1) the Russian variable star catalog (Samus et al. 2003, with 13,480 variables in the Cygnus to Orion volume) and (2) a CHARA update of the Dominion Astrophysical Observatory catalog of orbits of spectroscopic binaries (Taylor et al. 2003). In each case, the information about the stars is the driver, but the positions are supposed to be good enough that you can find them. This also holds for the 308 new variables in the Yale Bright Star Catalog (Hoffleit 2002).

Tycho catalog stars with spectral types now number more than 2.5 million (Wright et al. 2003). Tycho is tied closely to *Hipparcos*, so you ought to be able to find these stars if you want them.

The 2dF survey so far includes 22,163 QSOs (Oguri 2003), which we presume establish an inertial frame for it. The FIRST (radio) sources so far in SDSS (Ivezic et al. 2002a) number about 30,000, dominated by quasars, and so again tied to fundamental coordinates.

X-ray sources toward the central region of the Milky Way include about 100 extragalactic ones out of 2357 (Muno et al. 2003), though X-ray positions are not (yet) the best way to establish a coordinate system.

Nearly 1200 extreme ultraviolet sources in the final catalog from the *Extreme Ultraviolet Explorer* (Christian 2002) include 35% late type stars and (the second largest category) 25% unidentified sources.

Stetson et al. (2003) reported 14,342 stars on 1764 CCD images of the old open cluster NGC 6791. With second epoch images these could be used to learn a great deal about stellar motions within the cluster, although the primary purpose was to obtain homogeneous photometry for color-magnitude diagrams and such. The paper initially got indexed as "humongous photometry," which seems not entirely inappropriate.

8.2. Fundamental Physics

The key point here is that a sizable number of exciting deviations from the conventional wisdom did not happen (though a few did), and most of the standard models remain in no worse shape than they were a year ago. First come things pertaining to the forces, ordered from strong (color, gluon, nuclear) to electromagnetic, weak, and gravitational before we descend into quantum foams and entangled photons.

Wildest of the "strong" products are the particles tentatively consisting of four quarks (Giorgi 2003) or even five (Goldman et al. 2003 discussing something that might be a baryon plus a meson). Other interpretations exist, which, we suppose, is why the particles (or anyhow their discoverers) are tentative. Element 116 probably exists though 118 does not (yet?), and the original report was fraudulent (Berry 2003a). Elements with $A = 5$ and 8 never did exist, but it really is touch-and-go, and getting the right theoretical answer requires that the calculation include spin, isospin, and tensor components of the nuclear force (Wiringa & Pieper 2002). Most prosaically strong (or strongly prosaic) is an astrophysical estimate of the rate of the reaction $C^{12}(\alpha, \gamma)O^{16}$ based on the carbon/oxygen ratio in white dwarfs (Metcalfe 2003). It agrees with the best laboratory measurement, or we probably would never have heard about it.

The electromagnetic core query remains whether to accept the evidence from QSO absorption lines for an increasing fine structure constant. No new data were caught this year, but Uzan (2003) reviewed what is out there. Bize et al. (2003) set a laboratory limit to $d\alpha/dt$ by comparing frequencies of excited and ground states of ionized Hg^{199} with a cesium clock. The limit (1 part in 10^5 over a Hubble time) is comparable to the QSO value. Last year there was an argument that the change had to be a decrease in c, the speed of light, rather than an increase in e, the charge on the electron. Carlip & Vaidya (2003) have explained that this is not true. Apparently h (and π if you use those sorts of units) remain exempt. Mbelek & Lachieze-Ray (2003) calculated that a time behavior of α that would agree with both the QSO positive detection and the Oklo natural reactor limit could be found from Kaluza-Klein coupling of gravity to electromagnetism.

Surprising only to those who know more advanced physics than we do were a new, tighter upper limit on the mass of the photon, 1.2×10^{-51} g from a rotating torsion balance experiment (Luo et al. 2003), and the absence of evidence that very energetic photons travel a bit slower than the customary c (Jacobson et al. 2003). The variation from c might have been seen, but was not, in 100 MeV synchrotron radiation from the Crab Nebula pulsar (cf. Amelino-Camelia et al. 2003). These two limits are different sorts of beasts, because a non-zero photon mass will make low frequencies slow down, not high frequencies.

The weak interaction was just a little scary this year. The KamLAND collaboration confirmed the neutrino oscillation among flavors and the masses recently fitted to observations of atmospheric and solar neutrinos by the very clever method of watching for changes in the neutrino flux reaching them from the sum total of nuclear power reactors in Japan as those reactors were turned on and off (Eguchi et al. 2003). When this was announced at a December 2002 conference, a participant asked whether the result could be checked by turning off all the reactors at once. He received a response along the lines that the consumers might object. Not long after, most of the power reactors in Japan were turned off, owing to potential cracks and leaks rather than scientific curiosity. We haven't heard what became of the neutrinos. Neutrinoless double beta decay is the sort in which the neutrino acts as its own antiparticle, so that the rate is a measure of neutrino rest mass. The majority opinion is that it has not been seen and should not have been for the masses (less than 0.1 eV) most likely in light of the oscillation data (Zdesenko 2002; Gonzalez-Garcia & Nir 2003).

Gravitation remains the weakest of the forces, and general relativity remains the best description we have of it. You might think it hard to make a headline item out of this,[8] but the 2003 repetition of the 1919 Eddington "deflection of light experiment" managed. Radio signals from *Cassini* as it passed behind the Sun were bent by the amount Einstein predicted to within 2 parts in 10^5 (Bertotti et al. 2003), improving by a factor of 100 the limit obtained from multiyear observations of 3C 273 and 3C 279, whose orbits around the Earth carry them behind the Sun each October. Damour (2003) provided a clear theoretical discussion of what deviations from GR would mean. Relativity, however, also beat out bimetric theories in describing the gravitational redshift from the surfaces of neutron stars (DeDeo & Psaltis 2003). And it did just fine in fitting the ongoing period changes of binary pulsars: Stairs et al. (2002) on B1534+12 (NS masses of 1.333 and 1.345 $M_\odot$), Splaver et al. (2002) on J0621+1002 (NS mass $= 1.7 \pm 0.3\ M_\odot$), and Bailes et al. (2003) on J1141−6545 (NS + WD $= 1.30 \pm 0.02 + 0.986\ M_\odot$). With these plus earlier results, it can be said that not all neutron stars have exactly the same mass.

The Newtonian constant of gravity does not vary measurably with time (Uzan 2003) or distance (Long et al. 2003; Chiaverini et al. 2003). These latter are beginning to approach the separation range, millimeters to micrometers, where (large) extra-dimension theories say some distance dependence might appear. *G* does, however, sometimes seem to vary from lab to lab. Schlamminger et al. (2002) report 6.66407×10^{-8} or 10^{-11} (whichever units you grew up with), which is more different from last year's values than the 0.00022 stated error would suggest. We continue to suppose that gravity travels at the speed of light (i.e., the mass of the graviton is *very* small) but would not presume to disagree with the pundits who say that this has not been established very precisely by direct observation (Will 2003; Samuel 2003).

Now that confidence in general relativity has been re-established, what can be done with it? Try to build a black hole tunnel for hyperspace travel, and probably fail (Burko 2003). Use one to reflect sunlight back into the solar system (Holz & Wheeler 2002), though the requirement for a 1 $M_\odot$ black hole at the edge of the solar system suggests that we might become aware of it in other ways first. Understand the 1.5 ms lower limit to neutron star pulsation periods as the effect of gravitational radiation (from quadrupole modes of the NS itself, not from orbital motion; Chakrabarty et al. 2003; Wijnands et al. 2003; Wagoner 2003). Generalize the laws of black hole mechanics to dynamical systems (Ashtekhar & Krishnan 2002).

And some more: Incorporate GR fully into calculations of black hole formation and find that it is rather difficult to get ones that rotate as fast as they could (Shapiro & Shibata 2002). Get back the standard BH entropy expression from loop quantum gravity (Dreyer 2003). Invent an alternative to black holes that has roughly a Schwarzschild radius but has negative pressure stuff inside (Abramowicz et al. 2002). Find that you have black strings as well as black holes in five-dimensional space (Sorkin & Piran 2003). Attribute an apparent close galaxy pair at $z = 0.46$ to gravitational lensing by a cosmic string and thereby derive a mass scale for symmetry breaking of 2×10^{15} GeV (Sazhin et al. 2003) leading in turn to predictions for CMB fluctuations below current limits of detectability.

And what must you not do with general relativity? Publish a positive result from a gravitational radiation detector that is not LIGO (Coccia et al. 2003). Gentlemen, what were you thinking of, and why didn't you come talk to us about it? (as Joe Weber used to say to the longer-married author as a warning against repeating the mistakes of others).

And so onward to the fundamentals of space-time and quantum mechanics. Space shows no evidence for anisotropy in an experiment with rotating, transversely-polarized Dy_6Fe_{23} (Hou et al. 2003, who did not say what the stuff is called). CPT violation (the product of charge conjugation, parity transformation, and time reversal) is neither seen nor expected (Ellis 2003). There was a little flurry of activity predicated on the thought that if you could still see interference effects in light that had come from very far away, then space-time must not be quantized on the Planck scale (Lieu & Hillman 2003). First the limits became less restrictive (Ragazzoni et al. 2003), and then they disappeared completely. The predicted effect is far too small to see (Ng et al. 2003). Photon entanglement could affect Zeeman measures of the solar field, but only at some observatories (Kotov 2003).

8.3. Less Fundamental Physics

Some things it seems quite reasonable to study in the laboratory, for instance properties of materials like polycyclic aromatic hydrocarbons (bombarded by cosmic rays, UV photons,

[8] No competition, however, with the headline of a recent press release (flagged by a secondary source): "NASA Official to Participate in Panel Discussion."

and Bernstein et al. 2003) and silicates (Colangeli et al. 2003), atomic transition rates (Quinet & Biemont 2003, comparing calculated and measured *gf* values for one of our favorite ions, Eu III), molecules found in meteorites (Blagojevic et al. 2003 on how to assemble glycine and propanoic acid), nuclear reaction rates, even for things with lives as short as the 2.6 yr of Pm^{147} (Reifarth et al. 2003), and natural radioactivity, though it is just 100 years since J. J. Thompson published a request for 2-gallon cans of deep well water to look for it (*Nature*, 30 April 1903). Bi^{209} used to be the heaviest stable nuclide, but now has a half-life against alpha decay of 1.9×10^{19} yr, with an energy release of 3.14 keV (de Marcillac et al. 2003). This does *not* make it the lightest unstable nuclide (which is tritium, or the free neutron, depending on taste). Nor did the authors watch one Bi^{209} nucleus for 10^{19} yr, but rather something more like 10^{19} nuclei for 1 year.

That some other things can be reproduced in laboratories remains astounding, for instance the supernova of Klein et al. (2003c), which hit a laboratory interstellar cloud and shocked it. No report on whether triggered star formation is under way. Dovady et al. (2003) have reproduced the Tibetan-horn sound of singing sands, and report that the underlying physics is Reynolds dilatency. And we meant to tell you that poor old Reynolds was always late for everything, but the word is cognate with dilate, not with dilatory. Burchell & Whitehorn (2003) have been making impact craters by slamming 2 mm stainless steel spheres into granite at 1–6 km s^{-1} at various angles of incidence. They find the same percentage of elongated craters as are seen on Venus, Mars, and the Moon. Incidentally, the angle has to be pretty close to glancing before the crater is noticeably non-circular.

8.4. Less Fundamental Astronomy

The buffet here is an awkwardly rich one. The notebooks contain 35 papers on specific observatories, telescopes, and other widgets, 8 on algorithms, 27 on radiation mechanisms and transfer, and 39 on items in the realm of acceleration, collimation, and instabilities. The difficulty in choosing is that the ones that look most intriguing may not be the most (g)astronomically satisfying. You may have had that problem with pickled sea squirt and chicken salad. Well, there is perhaps an answer. The operative author always goes for the sea squirt, so here are the items that you (or at least we) are least likely to have had before.

8.4.1. Widgets

Having spent most of our lives in a myopic blur, we love the idea of using adaptive optics to improve human vision (Williams & Roorda 2003). Probably additional brain circuits would be required to make interferometry work for human sight, but meanwhile, it is truly up and running for astronomy with the first use of as many as six telescopes (Hummel et al. 2003) and both Keck (Colavita et al. 2003) and the VLT (Segransan et al. 2003) using two big mirrors. Both resolved stars. The first attempt at optical interferometry goes back to 1873, with Eduard Stephan, Leon Foucault, and an 80 cm telescope (*Sky & Telescope*, May 2003, p. 32). It failed.

Is bigger better? Well, there are now CCD arrays large enough to fill $8'' \times 9''$ of the $14'' \times 14''$ image plane of the 48 inch (1.2 m) Oschin Schmidt telescope. They are being used for a survey program called QUEST, which will reach about the same depth as SDSS, and we are only guessing that the ST at the end is Schmidt Telescope. The biggest digital camera in use is the 340 megapixel MegaPrime at the Canada-France-Hawaii Telescope (Veillet 2003a). Some day there will, we trust, be a Square Kilometer Array (SKA) radio telescope. Indeed, there has already been one, constructed in the 1950s in Tasmania by Grote Reber. Because the operating frequency was 2 Mc/s, the surface was not required to be either as smooth or as densely filled as present SKA designs.

Some relatively opaque windows continue to clear. *ODIN* (Nordh et al. 2003 and 10 following papers) was a millimeter satellite (well, the satellite was bigger, and even the mirror was 1.1 m). It mapped a good many things in H_2O lines. *GALEX* (the *Galaxy Evolution EXplorer*) launched on 25 April will be doing the first most-of-sky UV survey. The gap in gamma-ray coverage below a fraction of a TeV is being filled in by pushing ground-based techniques to lower energy with a 50 GeV detection of Mkr 421 from STACEE near Albuquerque (Boone et al. 2002) while EGRET saw it up to 10 GeV.

Photographic plates live, both in fact (detection of new carbon stars with ammonia-sensitized Kodak I–N's; MacConnell 2003) and in memory, for it turns out that the band used in SDSS, whose name puzzled us last year, was lettered in honor of the Kodak I–Z plates sensitive near 1 μm.

And now for the brown rice of devices likely to nourish the future: (1) A new sort of tunable local oscillator being developed for ALMA and applied in this instance to look at the 98 GHz line of H_2O in the W51 star formation region (Takano et al. 2003); some more of the words are UTC-PD photomixer with an optical comb, where the initials are uni-travelling-carrier photodiode (and on our good days we can tell a sprocket wicket from a socket wrench), (2) a superconducting tunnel junction spectrograph for an 8 m telescope (Cropper et al. 2003 with a concept but no hardware yet), (3) a Michelson interferometer in series with an external grating spectrograph; this permits adding the signals from lots of lines to get a radial velocity (Erskine 2003), like the almost 40 year old radial velocity spectrometer (Griffin 1966), and was used to see the motion of the Earth around the Moon in the spectrum of sunlight, (4) an acousto-optical imaging spectrometer, a 30 year old idea still not much used in astronomy (Molchanov et al. 2002).

And now, as a reward, you may collect your non-conic-section mirrors (Willstrop & Lynden-Bell 2003), say boo to east-west aperture synthesis trans-equatorial ghosts (Robertson 2003), build that black hole tunnel (provided Visser et al. 2003 will loan you some matter that violates the averaged null energy condition), and go on to the next section.

8.4.2. Algorithms, Corrections, and Such

Malmquist bias affects the average brightness and other properties you will derive for sources too faint or too distant to be completely represented in your sample. Sadly, but predictably, the proper correction depends on the cosmological model you have in mind, and is particularly complex for a non-zero cosmological constant (Teerikorpi 2003).

The Lutz-Kelker correction is the same sort of beast, but for cases in which objects are selected and weighted by parallax rather than by brightness. Some samples (including *Hipparcos*) need both (Feast 2002). The correction is quite generally misunderstood and misapplied (Smith 2003b).

Eddington bias is mentioned in connection with recovering the distribution of flux densities of sources that are somewhat confused on the sky by Kenter & Murray (2003). It applies to sources near a sensitivity limit for which over- or under-estimates of something will wrongly push the source into or out of your sample (Eddington 1940). As in all the other cases, it seems to be a good deal easier to recognize that there is a problem than to deal with it correctly in any other way than by collecting data on many more faint, small, distant (or whatever) sources.

Delauney tesselation was a new one to us, perhaps useful for describing large scale structure in the distribution of galaxies (Marinoni et al. 2002). Just for a moment, it sounded like the authors were advocating a duel, but in fact it is merely the dual of Voronoi tesselation (the sort that you get by letting balloons expand around arbitrary points until they hit and stop each other).

Stäckel potentials caught the eye for two reasons this year. First, the three-dimensional ones provided by Famaey & DeJonghe (2003) for characterizing the Milky Way have five adjustable parameters, which, according to the late George Gamow, means that they could also be used to fit an elephant. Second, in a second consideration of triaxial galaxies, van de Ven et al. (2003) not only explain that they have found the first general solution of a system of equations formulated as a Ph.D. dissertation by Lynden-Bell (1960) but also follow the problem backward to Jeans (1915) and Stäckel (1891) himself. Eddington (1915) makes another cameo appearance.

8.4.3. Pushing Gas Around

Here is a collection of accretions, collimations, accelerations, instabilities, and so forth. In some cases, the interesting point is that two things thought to be different work in similar ways, or the converse.

Bipolar jets or outflows, slow to relativistic, and with or without strong magnetic fields, have been seen or inferred coming out of young stellar objects (Rodriguez et al. 2002), planetary nebulae (Lee & Sahai 2003), cataclysmic variables (Kato & Hachisu 2003), X-ray binaries (Tomsick et al. 2003; Kaaret et al. 2003a), active galactic nuclei (Gabuzda & Cawthorne 2003), and gamma-ray bursters (Vlahakis & Konigl 2003). Even a centipede would have to take off his shoes to count all the papers that produced jets for one or another of these, so we note only two (Price et al. 2003a; Lynden-Bell 2003b) that suggest rather similar things must be going on in all. The latter opines that a proper calculation must start with a series of static models and speaks of a "seriously deranged scientist" who, we are sure, is not the author.

Gas also sometimes flows inward. Where the sink is a black hole, the gas might take most of its accretion energy with it (Shimura & Manmoto 2003 say swallowing 98% is common), or most of the energy might be recycled to blow stuff out (Di Matteo et al. 2003; Fabbiano et al. 2003b), particularly in the case of our own Sgr A*, which must be accepting less than $10^{-7}\ M_\odot\ \mathrm{yr}^{-1}$, or the gas would impose a larger rotation measure on the out-going radio waves than is seen (Bower et al. 2003).

Young stellar objects in particular seem to manage to have gas flowing in and coming out at the same time (Mora et al. 2002 on UX Ori, for instance). For many years, the less collimated author thought this must be done by having gas spun off at a rapidly-rotating equator while it came in along the poles, until finally she grasped the meanings of the phrases "accretion disk" and "bipolar outflow." It was, therefore, a pleasant surprise to discover that she had been wrong only 99% of the time, not 100%, because stuff with small angular momentum can sometimes accrete through a polar funnel (Proga & Begelman 2003).

Roche lobe overflow has been happening to gas in binary stars at least since the time of Roche. This year, it can also happen to the gas in a small galaxy or globular cluster orbiting too close to a big one (Murray et al. 2003, who describe the Magellanic Stream as an example). Not surprisingly, this halts star formation in the donor (donor, hell; we was robbed!).

Quasi-periodic oscillations are another of those ills that afflict a range of astronomical objects. Periods range from days for Seyfert galaxies (Halpern et al. 2003) to minutes in cataclysmic variables to milliseconds in X-ray binaries of both neutron star and black hole varieties. Mauche (2002) suggests that at least all the stellar ones are the same sort of phenomenon and thereby rules out all timing mechanisms that require or forbid a solid surface. He is left with processes having to do with disk accretion on magnetized compact objects. We suppose this might do for the Seyferts as well.

Instabilities in in-, out-, and disk-flows are common, too. Rating a mention here is, first, the Kelvin-Helmholtz instability, because last year we couldn't remember what it was, and neither could the first couple of people we asked (after which we gave up asking). It is what happens when two large fluid volumes separated by an interface move in opposite directions. The instability makes waves that grow to plumes along the interface and lead to mixing. Malik & Matraver (2003) wrote on the subject to point out that the instability can still grow exponentially with time in an expanding universe, unlike density fluctuations, which grow only as power laws. Second is the instability responsible for the outbursts of dwarf novae. Received wisdom has located this in the accretion disk itself for many years, and for most theorists still does (Osaki & Meyer 2003). But we were pleased to see one vote for the Bath instability, which resides in the donor star, albeit for the black hole X-ray binary Cyg X-1 rather than for a dwarf nova (Tarasov et al. 2003).

Relativistic particle acceleration does not seem to be a good example of the advertizing aphorism, “the difficult we do with ease; the impossible takes a little longer.” Our inexpert opinion is that acceleration is in relatively good shape for the relativistic electrons that produce synchrotron radiation (e.g., Prieto et al. 2002 on details of 3C 445), and high energies take longer (Zhang 2002), as you might reasonably expect, but in much less good shape for relativistic protons (Lemoine & Pelletier 2003). Nevertheless, cosmic rays unquestionably exist, and some supernova remnants are likely sites for Fermi acceleration because they are TeV sources, implying π^0 production and thus relativistic protons in their bellies at present (Berezhko et al. 2003 on Cas A). There was a modest groundswell in favor of the local cosmic-ray population being derived largely from one or a few supernovae (e.g., Thorsett et al. 2003 on PSR B0656+14 and the Monogem ring). This does not, however, exempt the others, since evidence of exposure of meteoroids to cosmic rays supports the perfusion of the whole disk by relativistic protons.

The “impossible” category in this context is the acceleration of the ultra-high-energy cosmic rays, extending to 10^{20} eV per Dalton (formerly amu and a new word we just learned in this context). Suggestions that made it into the 2003 literature include (1) gamma-ray bursters (Chen et al. 2002), (2) active galactic nuclei (Gorbunov et al. 2002), (3) decay of dark matter particles (Yoshiguchi et al. 2003), (4) nearby galaxies (Glushkov 2003), (5) vacuum tunnelling, which is also responsible for the small non-zero cosmological constant we observe (Jaikumar & Mazumdar 2003), (6) magnetars (Arons 2003), (7) merging clusters of galaxies (Berrington & Dermer 2003), and (8) strangelettes, which have the advantage of being able to sail through the intergalactic photon sea with many fewer collisions than protons would experience (Madsen & Larsen 2003). None of these is actually new this year, which means, we trust, not an erosion of the enormous creativity of which theoretical astrophysicists are capable, but merely a focusing on some other set of problems.

Return currents are essential if charge is to be conserved (and if it isn’t, we want platinum American Express cards), and astronomers don’t normally worry about them much, but they were spotted this year for the first time in two contexts: pulsar magnetospheres (Ramachandran & Kramer 2003) and solar flares (Hénoux & Karlicky 2003), the latter it seems with sufficient energy to barrier penetrate all the way from § 2 here to § 8.

8.4.4. Pushing Photons Around

Pushing can be done only by charged particles. Well, so we had always thought from the time of Peter Scheuer’s radio astronomy course at Caltech in 1966 until spotting Heyl et al. (2003) on vacuum birefringence. The paper suggests that the first demonstration of the phenomenon might be the polarization of optical radiation from neutron stars. Perhaps virtual charge pairs are involved somehow. All the rest of the 2003 mechanisms appear to have real charges, though not always in familiar patterns.

Line locking of three absorption systems in the afterglow spectrum of GRB 021004 (Møller et al. 2003) caused a moment of puzzlement: surely half a day is not time enough to accelerate clouds into each other’s absorbed bands the way active galaxies do (Srianand et al. 2003). But it’s all OK. The accelerating would have been done over a long period of time in the wind of the progenitor star.

Raman scattering has been around a long time, though we always have to look up a definition (absorption of a photon followed immediately by the emission of a lower energy photon, where the intermediate state is not a true bound state of the atom), but its broadening of emission lines in planetary nebulae (Arrieta & Torres-Peimbert 2003) is new, at least to us.

Pulsars radiate, and the number of new ways of making this happen at radio frequencies appearing each year suggests that there has been some difficulty in converging on the right one. We caught (1) a non-resonant, beam-driven hydrodynamic instability in a one dimensional, highly relativistic, streaming pair plasma (Gedalin et al. 2003), (2) electron zero sound (Svidzinsky 2003, a prediction of Landau 1957, though not of course for pulsars), (3) an idea with testable predictions that we were unable to describe (Malov 2003), and (4) something whose intensity falls off less steeply than $1/r^2$ (Singeton et al. 2003, with both Anthony Hewish and Vitaly L. Ginzberg quoted in the same article as not thinking this can happen).

Maser and laser must be high prestige names (like Cholmondely-Marjoribanks) because they seem to be increasingly applied where they are at most marginally appropriate. The electron cyclotron maser proposed for 100% polarized radio outbursts of T Tau (South) by Smith et al. (2003a) probably deserves the name, because energy can be stored in inverted populations of the resonant levels of electrons in the 1.5–3 kG magnetic field of the source. The Alfvén wave maser in the Large Plasma Device at UCLA (Maggs & Morales 2003) sounds less deserving. The wave trapping between surfaces is like that in a laboratory laser or maser, but the energy does not seem to come from inverted populations of anything. The authors indicate that the effects they are seeing could be relevant to the heating of stellar coronae.

Lasing is harder, but Johansson & Letokhov (2003) suggest that the ultraviolet lines of Te II in η Carinae may be lased. The authors have worked out which levels are involved and, if they are right, this is probably the first clean astrophysical example. We were about to express equal enthusiasm for natural laser emission from magnetars (Eichler et al. 2002) but hesitate, having noticed that it is the equivalent of ordinary pulsar radio emission in weaker magnetic fields. AXP 441042+61 is the example considered.

Masers, lasers, synchrotron emission, and scattering (Harries et al. 2002) all happily polarize electromagnetic radiation, but Fender et al. (2002) worry that it may be necessary to invoke "some other poorly understood mechanism" to account for the large circular polarization in the radio emission from GRS 1915+105 (a microquasar) which is shared by Sgr A*, some AGNs, and SS 433. And yes, the "other" is justified, for they have carefully discussed several previous poorly-understood mechanisms.

Proton-electron bremsstrahlung is what happens when a power law distribution of suprathermal (high energy) protons hits electrons at rest. It can be calculated (Haug 2003), but the author is not sure if or where it happens.

Inverse Compton scattering has become fairly common, or anyhow recently been recognized to be fairly common, e.g., the TeV halo of galaxy NGC 253 (Ito et al. 2003) and the gamma rays from Cyg X-1 (Romero et al. 2002), though we can remember when it was a mechanism looking for a use, like Earth-bound lasers before bar code scanners. Barrio et al. (2003) consider the opposite, direct Compton (down) scattering of photons in Cyg X-1 but conclude it is fairly unlikely.

Zeeman broadening of spectral features unquestionably happens (and is invoked in § 6.6 in connection with the Ap stars). Zakharov et al. (2003) say that it does not happen to the X-ray emission features in the spectrum of Seyfert galaxy MCG −6-30-15 and thereby set an upper limit of 10^{10}–10^{11} G to the ambient magnetic field, which is not perhaps an enormous surprise.

9. SOME ASSEMBLY REQUIRED: FORMATION AND EVOLUTION OF GALAXIES

Every parent of a Christmas-toy age child will recognize the horror aroused by that phrase. The astronomical task is actually much worse, since we know less about the initial conditions and are required not only to achieve a given end point (the galaxies now seen, their properties, distribution in space, and all) but also to achieve it along a trajectory that is partially defined by observations of numbers, luminosities, compositions, and degree of clustering at large redshifts. And you must use the prescribed tools, including gravitational interactions of dark matter particles and feedback from baryons as they accrete onto supermassive black holes (wherever those come from) and form stars that spit back heavy elements and kinetic energy.

No one has ever doubted that these gaseous processes are important, but it has been only gradually possible, as N in N-body grew larger (e.g., a few $\times 10^6$ inside the virial radius of a typical halo; Power et al. 2003) to do much about them (Meza et al. 2003; Bell et al. 2003a; Shen et al. 2003).

The game plan here is to begin with local evidence for the complexity of galaxy formation, then skip to the distant in both time and space. Then, as the *Nature* instructions to authors used to say, the middle comes at the end.

9.1. Up Close and Personal

Some impression of the magnitude of the task of assembling galaxies comes with the realization that our supposed twin, M31, and the Milky Way were not put together the same way. The stellar halo of Andromeda is about 30% (by mass) 6–8 Gyr old stars with metallicities not less than one-third solar (Brown et al. 2003b). The Milky Way does not have such a population. One possibility is that M31 arose from the merger of two massive ancestral objects, while the Milky Way was made from a single one, both with the on-going addition of dwarfs. The idea can be traced back to Kenneth Freeman, who is not mentioned in the 2003 paper, and also appears in van den Bergh (2000, § 20.4) as an explanation of the extended $R^{1/4}$ profile of M31. The other 70% of the halo stars Brown et al. examined are the 12 $\pm$ 1 Gyr metal-poor ones that you were expecting.

The globular clusters in M31 are similarly dominated by a 10 Gyr old population, but with some a good deal younger (Jiang et al. 2003). Galactic globular clusters have a similar range of metallicities, but a much smaller range of ages (van den Bergh 2000, § 4.7). In other ways, the two galaxies are quite similar; for instance in their X-ray source populations, including extreme faintness of the central one (Kaaret 2002), and in their stellar bulge populations, according to Stephens et al. (2003). Nakasato & Nomoto (2003), however, distinguish two sets of Galactic bulge stars, having normal and reduced ratios of iron to alpha elements, which they attribute to formation after and before a major merger event respectively.

Returning to the halos, there may be some dynamical differences as well, in the sense that M31 shows evidence for a small number of very extended star streams (McConnachie et al. 2003), while the inner halo of the Milky Way either was not assembled from star streams at all, or there were more than 400, with no one making up more than 5% of the 4588 stars sampled by Gould (2003b). And none of the compositions of the Galactic halo, disk, or bulge stars (e.g., the ratios of iron, alpha elements, *s*- and *r*-process products) would allow them to have been made from the sum of dwarf spheroidal galaxies of the sort we now see in the Local Group (Shetrone et al. 2003). The Milky Way is still acquiring halo in small bites. Brook et al. (2003b) point to some metal poor stars in very eccentric orbits as indicating the recent acquisition of a dwarf in a polar orbit. And the outer ring of stars reported last year (Newberg et al. 2002) and by Yanny et al. (2003) in the index year was already being widely attributed to the on-going disruption of another dwarf (Ibata et al. 2003; Rocha-Pinto et al. 2003; Crane et al. 2003) even before the press-released discovery of the remains of the dwarf itself shortly after the end of the reference year.

While we are at it, the assembly of the Large Magellanic Cloud may also have been more complex than generally supposed, since it seems to have a metal-poor old halo population of stars with larger velocity dispersion than the rest of the galaxy (Minniti et al. 2003). Its bar is a lot like ours (no, they don't do pink ladies) and the method of its disassembly is guaranteed some 14 Gyr into the future (Hashimoto et al. 2003).

As for the rest of the Local Group, *FUSE* measurements of O VI (in a sight line to a QSO) may imply something like $10^{12}\ M_{\odot}$ of warm/hot intergalactic medium, enough to bind the Local Group (Sternberg 2003; Nicastro et al. 2003). Using heavy elements as an IGM tracer can be found in Spitzer & Zabriskie (1959) and the idea of binding the LG with hot gas in Kahn & Woltjer (1959). Curiously, all of the MW, M31, and M33 are significantly deficient in molecular gas for our types (Helfer et al. 2003).

9.2. Long Ago and Far Away: When Data Whisper Low, "You Must," the Theorist Says "I Can"

The story of galaxy, star, and QSO formation must begin well before the end of § 3.8 on reionization, because those UV photons had to come from somewhere. There are other indicators that star formation began early. QSOs at $z = 4$–6 already have black holes of 10^9–$10^{10}\ M_{\odot}$ (Bechtold et al. 2003b; Willott et al. 2003), and accretion on some of them started by $z = 11$ (Gupta et al. 2003). Mouri & Taniguchi (2003) connect the formation of these black holes directly to the first generation of stars made in dense clusters: stellar mass black holes merge to make intermediate mass black holes, which migrate to protogalactic centers and start accreting. This fits directly with another important set of observations which indicate that even at $z = 4$–6.5 the gas in QSO broad line regions has metallicity at least as large as solar (Dietrich et al. 2003a, 2003b). And the BLR is not a wimpish little thing that might have been enriched by one or two early supernovae. The gas mass is 10^3–$10^4\ M_{\odot}$, implying that a sizable fraction of a bulge-worth of stars have been feeding it (Baldwin et al. 2003). Even the gas in (intrinsic) broad absorption features further out from the AGN engine sometimes has more than solar heavy element content (Levshakov et al. 2003a).

Another way of saying these things is that the connections between star bursts and active galactic nuclei (Carilli et al. 2003 at $z = 4.1$; Van Bemmel & Dullemond 2003, Cyg A) and between bulges and black holes (Marconi & Hunt 2003, data; Wang et al. 2003g, mechanisms) that we see now go right back to the beginning. Shamefully, these are the only ones of 26 and 22 indexed papers on AGN/starburst and black hole/bulge connections from the year that will be mentioned.

Other things that got started early include Type Ia supernovae, since the most distant QSOs are not iron deficient (Freudling et al. 2003), and condensation of solid particles, since two of the three SDSS QSOs beyond $z = 6$ each have about $10^8\ M_{\odot}$ of dust (Bertoldi et al. 2003).

Now that the data have whispered, or even shouted, "We want early star formation," it is time to hand over to the theorists. A very informative and readable paper is that of Mo & White (2002) on the redshift evolution of dark matter halos and their clustering in a standard ΛCDM universe. The crucial points are (1) yes, there are some halos that should be capable of collecting baryons and letting them recool by $z \approx 20$, and (2) these are already strongly clustered so that, for instance, early metal production is very inhomogeneous, and the metallicity of Lyα forest clouds should not show a tight correlation with redshift, as in fact it does not (Telfer et al. 2002; Carswell et al. 2002). Indeed, a trend with z is hard to spot even in the more metal rich damped Lyα clouds (Prochaska et al. 2003), and the clumpiness in enrichment persists at least down to $z = 3$ (Adelberger et al. 2003).

Actually making stars in these halos is tackled (1) by Hirashita & Ferrara (2002), who conclude that during the period $z = 20$–5 a halo of $3 \times 10^{11}\ M_{\odot}$ (about one-third of the current mass of the Milky Way, but likely incorporated in a larger galaxy by the present time) can radiate 3–4 $\times\ 10^9\ L_{\odot}$ each in infrared and ultraviolet, with positive feedback from stars to dust to cooling of molecular gas to more star formation, and (2) by Mackey et al. (2003), who find that the ultraviolet from Population III stars made before $z = 30$ in minihalos will break up molecular hydrogen and temporarily turn off star formation until that first generation blows up and gives the remaining gas some metallic coolants. Then formation of, as it were, Population II.5 stars sets in at $z = 15$–20.

The peak star formation rate then still lies far in the future, at $z = 3$–6 (Maier et al. 2003). Just for a moment, this seems inconsistent with the equally-firm statement that half of all stars formed after $z = 2.2$ (Hernquist & Springel 2003). But remember that the rates are normally given in solar masses per cubic Mpc per year, and there are a lot more years between $z = 0$ and 2 than between $z = 4$ and 6. Incidentally, to put 1% of the closure density (25% of the baryons) into stars in 12 Gyr requires an average star formation rate of about $10^{-2}\ M_{\odot}\ \mathrm{Mpc}^{-3}\ \mathrm{yr}^{-1}$, not very different from the current value (Georgakakis et al. 2003; Perez-Gonzalez et al. 2003).

The structure and evolution of Population III stars, including their expected UV fluxes, have been considered by Kim et al. (2002b, extending up only to 20 $M_{\odot}$), by Schaerer (2003, masses to 500 $M_{\odot}$), and by Marigo et al. (2003, 120–1000 $M_{\odot}$). Cases can be made for any of these mass ranges. Flower & Pineau des Forets (2003) favor one not very different from star masses today, while Omukai & Palla (2003) retrodict more than 100 $M_{\odot}$. Lanz & Hubeny (2003) predict ultraviolet fluxes from stars as a function of composition (down to $Z = 0$), effective temperature, and surface gravity, rather than explicitly as a function of mass.

9.3. The Part in the Middle

In between the "first lights" plus "first nucleosynthesis" and the final assembly of the Milky Way and Local Group comes all the work on formation, structure, and evolution (chemical and dynamical) of galaxies and clusters. With one exception (§ 9.3.15), the following subsections look at questions that have been around for a while, not just in earlier ApXXs. So have many of the answers, but it doesn't hurt to have things one knows reinforced. However sure you may be that your Significant Other loves you, you don't really object to being told again, do you? The ordering is dynamical issues, galaxy types, and chemical evolution problems, though these cannot really be completely separated.

9.3.1. Who's on First?

The most distant QSO has $z = 6.43$ (Fan et al. 2003a) and comes from SDSS. The most distant galaxy at $z = 6.58$ (Kodaira et al. 2003) has it beat by a hare and is a Subaru discovery. Also from Subaru comes a gathering of Lyα emitters sprawled over a 20×50 Mpc (comoving) box, with a protocluster at the center and $z = 4.86$ (Shimasaku et al. 2003), which is at least a contender for most distant large scale structure. And if $z = 2$–4 red galaxies are more clustered than their observers (Daddi et al. 2003) had expected, an explanatory theorist will surely be along soon, with theory in hand (also in mouth and astro-ph).

9.3.2. Cores vs. Cusps

The question is whether the central mass profiles of galaxies and clusters are flat-topped or rising as power laws. A longstanding worry is that *N*-body simulations of ΛCDM models predict that most halos should be cuspy (de Blok et al. 2003), while most observed centers are corey (Borriello et al. 2003 on giant ellipticals; Laine et al. 2003 on blue compact galaxies). Two steps forward this year, one observational and one theoretical. When you probe the mass distribution (which is what the models calculate) rather than the light, at least some clusters do have cusps (Pratt & Arnaud 2002, Abell 1413 with *XMM*; Dahle et al. 2003, weak lensing by three) and so do some galaxies (Park & Ferguson 2003, strong lensing). In other words, perhaps the baryons did it.

On the theoretical side, both Mucket & Hoeft (2003) and Arieli & Rephaeli (2003) have blamed the cusps on inadequate spatial resolution in the simulations. Admittedly, a good many of the other 16 or so papers on the topic this year seemed to be steps back; for instance, neither black hole mergers nor accretion by central black holes, nor rotating bars make much difference, and we reference only the last, because the person who said bars don't help much (Sellwood 2003) very properly engaged in extended consultation with the people who had said bars were the solution (Weinberg & Katz 2002).

9.3.3. Missing Satellites

This is another possible small scale structure problem with ΛCDM *N*-body simulations of halo formation. You get an awful lot of little ones, far more than we see, for instance, as dwarf galaxies in the Local Group or nearby richer clusters. Recent calculations confirm that a big halo should have hundreds of associated small halos (Seymour & Widrow 2002; Helmi et al. 2003). But this time, it seems, the baryons didn't do it. That is, most of the small halos are too shallow to capture ionized gas (Tassis et al. 2003). Mo & White (2002) point out that half the dark matter today is in these shallow halos. Thus, the few satellites we do see in the Local Group are the massive end of the distribution (Stoehr et al. 2002), with their own dark matter and the maxima of their rotation curves outside their optical radii (Hayashi et al. 2003 on Draco and Carina). To find the rest, you must use gravitational probes, for instance Metcalf (2002) on bending of radio jets and gravitational lensing data that did not make it into the index year.

9.3.4. Cooling Flows and Preheating

These are not generally discussed together, but in each case the gas in X-ray clusters of galaxies has a larger energy content than can be accounted for by the gravitational potential energy available from cluster formation minus the losses in X-rays. The problem early in clusters' lives is reasonably called "preheating," because the correlations of gas temperature, X-ray luminosity, metallicity, and gas fraction with cluster mass were already in place by $z = 0.7$–0.8 (Maughan et al. 2003; McCarthy et al. 2003). Thus, there must have been nongravitational heating during formation or soon after (Novicki et al. 2002). Finoguenov et al. (2002) suggest galactic winds (powered, presumably, by supernovae and perhaps stellar winds, during rapid early star formation). Energy input from accretion on massive black holes could also help. Not all clusters were preheated, say Pratt & Arnaud (2003), so the energy source must be something that can vary from cluster to cluster.

The cooling flow problem is this. You can calculate how long X-ray emitting gas will last either from measured temperature and density (plus bremsstrahlung formulae) or by dividing energy content by luminosity. Either way, many clusters turn out to have central cooling times 10% or less of the Hubble time, so that 10's to 1000's of solar masses of cool gas should be piling up near the center. And yes, there is often a bit of CO (Edge & Frayer 2003), but rarely anything like as much as expected.

Peterson et al. (2003) have turned the problem into a pure X-ray one by using high resolution spectra from *XMM* to probe the amount of gas at each temperature downward from T_0, the ambient one at the edge of a cluster. There is some gas down to $T_0/2$, but nothing below $T_0/3$, and the masses and radial distributions are simply not those predicted by adiabatic cooling flow models of the X-ray emission. Either there must be some way to cool plasmas near T_0 (which is something like 10^8 K) without emitting any X-rays and to hide away the product, or the radiative cooling must be balanced energetically and stably by energy input in some form. Soker (2003) notes that some processes might be able to provide enough energy but will run away with no steady solution to match the clusters we see.

Probably no one heat source will work for all clusters. Ongoing mergers certainly heat, but will also destroy composition gradients that many (not all) clusters display. Fabian (2003) favored infalling, overdense blobs of gas for some (not all) cases. The specific case of the Perseus cluster, where a hot bubble of gas is also iron-rich (Schmidt et al. 2002) sounds like a galactic wind. In other cases, the central cD galaxy may not have settled down at the cluster dynamical center, and its sloshing around can add a good deal of kinetic energy (Dupke & White 2003).

The two main candidates have, however, been conduction of heat inward from regions of the clusters with cooling times longer than the age of the universe and deposition of energy near the center by jets and bubbles of relativistic plasma fed by a central AGN. Notice that neither of these has to be the same for all clusters. Conduction depends on magnetic field morphology (Cho et al. 2003), and not all clusters have central radio sources or traces of dead ones. This includes at least one classic, though mild, cooling flow cluster (Bayer-Kim et al. 2002).

Nor are the two mechanisms mutually exclusive. Heating from both outside and inside is less likely to become unstable than one alone (Ruszkowski & Begelman 2003). Some clusters seem to need both and have both available (Zakamska & Narayan 2003). More than a dozen other indexed papers advocated radio jets and blobs observationally (Kraft et al. 2003) or theoretically (Basson & Alexander 2003, whose radio lobes drive convection for faster energy transport).

The high profile paper of the topic year was Fabian et al. (2003), reporting that the Perseus cluster displays shocks and ripples in its X-ray image that seem to be driven by bubbles from the central radio source (and perhaps not iron-rich after all). This tells us both the source of the energy and how it is transported. The press release reported the wavelength of the ripples in light years and the frequency as a very small fraction of a Hertz, requiring the backs of two envelopes to make sure the implied speed was appropriate for a gas at $T =$ something $\times 10^7$ K. And yes, it's OK, faster than sound in air, but slower than light.

Tornatore et al. (2003) believe that there is still some physical process missing in the calculated balances between heating and cooling.

9.3.5. Classification of Galaxies

The Hubble types begin to fail rapidly beyond $z \approx 1$ (unless you are happy with everything being called Irregular). Conselice (2003) proposed a system tuned to morphologies seen near $z = 3$, with three variables: C is degree of central concentration (sensitive to bulge/total mass), A is the degree of asymmetry (sensitive to recent mergers), and S is the clumpiness (sensitive to recent star formation).

Two new sorts of dwarfs were featured during the year: faint fuzzies, reported last year and now attributed by Fellhauer & Kroupa (2002) to mergers, and ultracompact dwarfs in the Fornax cluster, a new category with scale lengths less than 300 pc (Deady et al. 2002). Both Bekki et al. (2003b) and Karick et al. (2003) describe them as what remains when an ordinary nucleated dwarf elliptical galaxy has been tidally stripped.

9.3.6. Galaxies in Voids

Perhaps if there were enough of these to do a good job of defining their statistical properties, there would be no voids. In practice, there seems to be some real disagreement. A simulation (Mathis & White 2002) says they are normal galaxies with no particular class favored, and Hogg et al. (2003), looking for H I sources, did not find an excess of dwarfs. But Gottloeber et al. (2003) report a very steep mass distribution, $N(M)$, including very few galaxies with circular velocities larger than the 100 km s^{-1} of M33. Sounds like an excess of dwarfs, No?

9.3.7. Faint Blue Galaxies

There used to be a lot of these, not so very long ago, where "not so very long ago" means redshifts near 1 and publications 10–15 years ago, when redshift surveys were just beginning to replace galaxy counts as the primary source of information on galactic evolution. What has become of them? Well, say Phleps & Meisenheimer (2003), FBGs have clustered and merged into the bigger, better, and generally redder galaxies we find around today, according to their redshift survey from $z = 0$ back to $z = 1$.

Do even dwarf galaxies have old stars? Well, obviously not those dIrr's that are just now being formed in tidal tails. But, say Delgado-Donate et al. (2003b), these are very rare, the number of candidates in a bunch of H I tidal tails being just about equal to the number of background galaxies. As for the dIrr's that do exist, many do have old stars (Hidalgo et al. 2003). I Zw 18, the least metal-enriched galaxy known to woman, seems not to (Papaderos et al. 2002), but the limit is really only less than about 25% (Hunt et al. 2002), because old stars have the tiresome habit of being faint. HS 1442+4250 is less famous, almost as metal poor, and apparently also lacking in old stars (Guseva et al. 2003). Some dwarfs have their own dark matter (Weldrake et al. 2003).

9.3.8. Production of S0 Galaxies

S0's (pronounced S-zeros) look like (early-type) spirals but have little or no gas or young stars. It takes only a junior-grade rocket scientist to deduce that some process removed the gas, automatically turning off star formation. Bekki et al. (2002), who are, however, senior-grade rocket scientists, deduce precisely that, noting that the intermediate stage between normal spirals and S0's should be the passively-evolving spirals of Dressler et al. (1997). Gnedin (2003a, 2003b, one of which was submitted in July 1999) ascribes the loss to tidal interactions, as proposed by Spitzer & Baade (1951). Gnedin locates the interaction at the time when galaxies enter clusters. Low surface brightness ones are wiped out completely at this point. Gas clearance must be an on-going process in S0's, for they have less than 10% of what must have been shed by their evolving stars in the past, according to a CO survey and archival H I data presented by Welch & Sage (2003).

9.3.9. Type Transformations (Dwarfs)

Do dwarf irregulars turn into dwarf spheroidals? We found a yes (Pasetto et al. 2003 on reshaping orbits around the Milky Way) and a no (Grebel et al. 2003 on metallicity and implied history of star formation). We don't want to have to cast the deciding vote, realizing that "no" is not falsified by the existence of "transition objects" (Skillman et al. 2003a, 2003b). These have properties between the two definitions, but could spend their lives in nomenclatural limbo rather than being en route from one to the other as a result of cessation of star formation.

9.3.10. Type Transformations (Ellipticals)

Are giant ellipticals made by mergers? Yes, and there is more than one way to do it, with Cen A having been made from two big spirals (Bekki et al. 2003a) and more like 50 smaller galaxies going into more typical gE's (Worthey & Collobert 2003). Evans et al. (2002) call attention to the ultra-luminous infrared galaxies with double nuclei as the process in action.

9.3.11. Chemical Evolution: Parameter Fitting

During the year, Chiappini et al. (2003) tackled spirals, including the Milky Way; Kawata & Gibson (2003) modeled ellipticals; and de Blok & Walter (2003) considered dwarfs. All found satisfactory agreement between calculations and observations, and all found it necessary to adjust several parameters to describe processes that cannot yet be calculated ab initio. Chiappini et al. introduce a temporal gap in star formation between the thick and thin disk populations. This causes a gap in the metallicity distribution, since no stars form while some enrichment is in progress. They allowed no gas to leave their galaxies. Kawata & Gibson found that feedback from Type Ia supernovae (as well as core collapse events, planetary nebulae, and all) is particularly important. And dwarfs systematically push out gas as they feed metals into it, and so systematically nourish their surroundings (Komiyama et al. 2003; Fragile et al. 2003). You don't need us, or even Gamow, to tell you that it would be nice if more of the processes could be "predicted."

9.3.12. What is $\Delta Y/\Delta Z$?

In a dictionary sense, it is the ratio of increase in helium to increase in metals as successive generations of stars pour out their heavy hearts (Hmm. They must have Faustian Acquaintances, too). The numerical value for the last half or more of nucleosynthesis has been close to 2 in both observations and calculations (Esteban et al. 2002 on giant H II regions in four spirals; Jimenez et al. 2003 on Milky Way stars with [Fe/H] $= -2.0$ to $+0.2$; Peimbert 2003 on 30 Doradus).

So long ago that the non-acid-free paper has crumbled, the less acid-free author participated in the opinion that the ratio would be larger for nucleosynthesis by massive Population II stars (Dearborn & Trimble 1980). For massive Population III stars it is apparently even larger, something like $\Delta Y/\Delta Z = 10$ (Marigo et al. 2003), but the total amount of either *Y* or *Z* made in these is very small.

9.3.13. The G Dwarf Problem: Or, High Velocity Clouds

This combination may sound like a Gilbert and Sullivan title (*Ruddigore: Or, The Baron's Curse*, for instance). But recall that the "G dwarf problem" is the rarity of metal-poor, long-lived stars in the solar neighborhood compared with the predictions of a model of chemical evolution (Tinsley 1968) that treats galaxies as homogeneous, one-zone, closed boxes with instantaneous recycling and constant initial mass function, and that fresh, unprocessed gas (one interpretation of high velocity clouds) violates the "closed box" part of the approximation.

We don't think anyone would today claim that real galaxies are closed systems, yet Lee et al. (2003a) say that the metal abundance vs. residual gas fraction in dwarf irregulars is described by closed box models. This seems particularly remarkable, since dwarf galaxies are just the sort that ought to be blowing out their enriched gas in supernova-driven winds (Garnett 2003), as the Carina dwarf has apparently done through several starburst episodes that have failed to enrich it, or her, if you prefer, since Carina is part of a ship (Rizzi et al. 2003). Larger galaxies with more supernovae can also have departing winds (McDowell et al. 2003 on Arp 220), and winds were probably more powerful in the past (Vermeulen et al. 2003).

Taking away the metal-rich gas is one way to keep on producing stars of the same composition over long periods of time, thus solving the G dwarf problem. Another way is to keep bringing in metal-free gas, diluting the products of stellar nucleosynthesis. A galactic fountain is gas that goes up and then comes back down at lower temperature. We do not at all question the existence of these (Irwin & Chaves 2003; Zsargo et al. 2003) but claim they are distractors in the present context.

What about fresh gas coming in? Well, yes, but for both the Milky Way and NGC 5128 (Cen A), the gas is not quite virgin, but slightly pregnant as a result of residence in dwarf galaxies (Geiss et al. 2002; Peng et al. 2002). What about the high velocity clouds themselves? We caught a total of five papers that collectively conclude that at least some of them are like dwarf Irr galaxies in having their own dark matter (Robishaw et al. 2002; Sternberg et al. 2002), but different in having made no stars (Willman et al. 2002; Hopp et al. 2003), though they perfectly well could have according to a standard criterion (Davies et al. 2002). HVCs are just not doing their astronomical duty. You may have some colleagues like that.

9.3.14. Gradients and Age-Metallicity Relationships

Given that heavy elements are produced in stars (Burbidge et al. 1957), star formation has gone on for 12 Gyr or thereabouts, and that the largest density contrasts got started first (Mo & White 2002), it would be astounding if there were no radial composition gradients or age-composition correlations in galaxies. Measuring them, or sometimes even finding them, has, however, been confounded over the years by the frequent need to use colors or integrated spectra as proxies for metallicities of individual stars, clusters, or gas clouds, by the tendency of stars to wander away from where they were born, neglecting to take their passports with them (Lepine et al. 2003b on wandering stars near the solar circle), and by a gradually increasing ratio of enrichment at the outskirts to enrichment near the center (Maciel et al. 2003; Ibukiyama & Arimoto 2002).

In practice as a result, 0.2 dex kpc^{-1} (Idiart et al. 2003 on ellipticals; Kennicutt et al. 2003 on the spiral M101) or 0.2 dex Gyr^{-1} (Davidge 2003)[9] are about as steep as you find and cannot be regarded as serious challenges to theorists, who are allowed to make their boxes as leaky as they wish. Leaky pipelines, on the other hand, deprive us of the scientists of the future (particularly for some reason female and minority scientists) and should be discouraged.

9.3.15. Search for the Missing Metals

Truth be told, we did not know there were any, except the silver rose lost by the Faustian Acquaintance, until Prochaska et al. (2003) pointed out that the metal content of the clouds responsible for damped Lyα absorption in QSO spectra adds up to less than what you would expect from the time integration of star formation at earlier epochs. Levashakov et al. (2003b) look at Lyman limit absorption systems, find them to resemble our own high velocity clouds, and decide that most of the metals produced at moderate redshift remain bound to the galaxies that made them, as is also implied by Mo & White (2002). Since the problem has been solved in the same year it was discovered, do not expect to see pictures of iron on the sides of milk cartons.

9.3.16. Search for the Missing Baryons

These, in contrast, have been missing for decades, though the average missing density has declined from something like 95% of the critical density (supposed to be in a smooth intergalactic medium of uncertain temperature) to about 3% at present (the rest being divided among stars, cold gas in galaxies, and hot gas in clusters; Bell et al. 2003b; Castillo-Morales & Schindler 2003). Back at $z = 2.5$, most of the baryons were in low density, low metallicity clouds responsible for the Lyα forest of QSO absorption features (Simcoe et al. 2002), and the next largest reservoir was somewhat denser, more enriched clouds traced by O VI absorption.

This latter stuff is now (meaning both $z = 0$ and 2003) called WHIM, for warm/hot intergalactic medium. It ranges from 10^5 K (UV territory) to 10^6 K (soft X-rays), and the strongest features are those caused by oxygen deprived of five to seven electrons. The case for the WHIM accounting for most of the missing baryons was made in a number of papers, including Mathur et al. (2003), Fang et al. (2003), and Otte et al. (2003), the latter two focusing on the Local Group. A good deal of the gas is to be found around clusters (Ettori 2003; Nicastro et al. 2003; Soltan et al. 2002; Bonamente et al. 2003). A very detailed balance sheet is given by Silk (2003), though it was not entirely clear to the less balanced author just where his “blown back out” component is now. A dissenting vote was cast by Binnette et al. (2003), who say that at most 30% of the current baryon density can now be in gas at about $10^{5.3}$ K, or *FUSE* spectra of QSOs would show a break at (slightly) redshifted 1216 Å from Lyα absorption. At large redshift this would be called the Gunn-Peterson effect.

9.3.17. Reality of Large Scale Clustering

Fesenko (2003) has said again that there is very little of this, with differential absorption in the Milky Way producing the impression of large scale structure far away. The more precipitous author incorrectly reported elsewhere last year that this view had disappeared from the community, for which apologies. If he is right, then you need not have read most of the rest of this section.

10. THE SOLAR SYSTEM

How did the astronomical objects closest to home end up in the middle of this review? We aren’t quite sure; but the Earth has also ended up in the middle of the solar system.

10.1. Major Planets and Modest Proposals

Attempting to march outward from the Sun, we almost tripped over the first step (heck, the senior author can trip over

[9] The dex is not, somehow, a terribly happy unit. It means a factor 10 (derived perhaps from “decimal exponent”) and so is the same as a Bel in acoustics. Thus, our gradients might be given as 2 dB per kpc and so forth. It is possible to structure sentences to avoid the need for either, saying, for instance, that the gradient in [Fe/H] is 0.2 per kiloparsec, since the [ ] notation already has powers of 10 build into it, but somehow we don’t always plan far enough ahead on the page to do this.

roses in a patterned carpet) for lack of any Mercurial news and are forced to turn to his Greek equivalent, who appears in *Science* 301, 902, as “the mythical god Hermes.” Real Gods, of course, are capitalized, but we wouldn’t dream of trying to cause problems for ASP (which already has several) by referring to any specific examples.

Venus is not noted for conspicuous visible markings. Percival Lowell, however, thought he had seen canals in 1896. These were very possibly a reflection of his ocular blood vessels in the telescope optics (Sheehan & Dobbins 2002). If so, we also understand his conclusion that Cytherean rotation was phased-locked to the Earth, since he never saw his eyeball from the other side. Well, it is sort of phase locked, but in a complex retrograde way, which is one of two possible stable conditions. The other is a 135 day prograde period (Correia & Laskar 2003). The rotation could have been prograde in the past, with halt and reversal, which would have pleased Venusian Joshuas and Velikowskies enormously. The atmosphere superrotates with a period of about 4 days (vs. 247 for the solid body). Bespalov & Savina (2003) have suggested a fourth possible mechanism, involving particle collisions. The first three appear in Hyde (1984).

Earth gets a whole subsection to herself (§ 10.2).

Martian matters were, as usual, dominated by H_2O. Water has three phases, so there should be at least three references. Ice there certainly is, even bare at the south pole (Titus et al. 2003). Bare water ice at the north pole was reported some years ago (Kiefer et al. 1976). And where there is ice, there can be ice ages (Feldman & Tokar 2003). But liquid water has perhaps never lasted long enough on the Martian surface to dominate the chemical processing (Christensen et al. 2003). No “steam” items were recorded, though Mars came closer to us on 26–27 August than at any time in the past 59,620 years, and will come closer on 28 August 2287 (this is not an IAU General Assembly year). The following three items all slightly surprised us.

Yoder et al. (2003) have suggested that Mars currently has a fluid core, based on the amplitude of its surface solar tides. Even more curious, the tides due to Phobos should be a bit stronger. Yes, it’s very small, but it is also a good deal closer than the Sun. No eclipses though.

The X-ray emission has contributions from both solar fluorescence and charge exchange (Dennerl 2002).

Martian meteors vaporize 120 km above the surface, just like terrestrial ones, because the atmosphere, though thin, has a large scale height. They are fainter than meteors seen from Earth only because of the smaller relative velocity (Ma et al. 2002c).

Jupiter is visible by day. Watching the bright near-point as the morning sky began to brighten (the easiest way to see Venus by day), we had often thought that this ought to be so and have now forgotten who said or wrote it was not so firmly that we never really bothered to try. The nay-sayer was not anyhow Sampson (2003), who has seen Jupiter by day and enabled students to do so. No, not binoculars, but near optimal geometry, with Jupiter near the zenith soon after sunrise and a nearby quarter Moon to help them focus at infinity. (This is also a big part of the problem for Venus; a distant building or trees help.)

Probably what you were expecting to hear about Jupiter was something from the *Galileo* mission. Young (2003) tells many things, including a new composition measurement, with Y very close to the solar primordial value, 0.234. Most molecules and noble gases are enhanced by factors of 2–4. Probably you were not expecting to hear various aspects of the solar cycle tied to the Jovial orbit period (Juckett 2003), though the idea can be traced back at least to 1965 (Jose 1965).

Saturn’s zonal wind flow pattern produces less conspicuous features than those of Jupiter (you knew that); but the wind speed varies more (Sanchez-Lavega et al. 2003). The changes, more than 200 m s^{-1} in a decade, may result from variable ring shadowing of the cloud tops.

Uranus was seen by Flamsteed in 1680, and so appears in Bevis’s *Uranographia Britannica* a century later. If you then conclude that this early Astronomer Royal was cheated and the planet should be called Flamsteed rather than Herschel (well, it was suggested), take consolation from the fact that “Flamsteed” numbers for stars were probably really selected by Lalande in 1783 or even by Bode in 1776, a year we find easy to remember because it saw the founding of Phi Beta Kappa (Kilburn et al. 2003).

Neptune also had to be discovered, and the story has been told many times, though for a number of years without access to the relevant files from the Royal Greenwich Observatory (which adhered to Olin J. Eggen when he departed). Returned, and now also available elsewhere, these materials are the basis for the conclusion that LeVerrier’s predictions were more useful than J. C. Adams’s, which changed several times, in such a way that Challis’s doubts were not entirely foolish (Kollerstrom 2003b).

Pluto has both a surface, on which ice/grains apparently blow around seasonally like dust (Grundy et al. 2002), and an atmosphere, which has expanded between 1988 and 2002 (Elliott et al. 2003). This latter was somewhat unexpected, since the object is now drawing away from the Sun. Still, southern California sometimes has its hottest days in October, and if you dare to tell us that the Earth is approaching the Sun then, we will send you back to teach Astro 100.

How did the solar system come into being? A traditional clue, often taken to imply triggering by a nearby supernova explosion, is the abundances and provenances of the daughter nuclides of various extinct radioactive nuclides with half-lives much less than 4.5 Gyr, for instance Be^{10}, I^{129}, Ca^{41}, Al^{26}, Fe^{60}, and Hf^{182}. Renewed support for the SN triggering hypothesis appeared in index 2003 (Marhas et al. 2002; Zinner 2003). Some of the other fossil radioactivities were, however, almost certainly produced in situ in the solar system by energetic particle bombardment during the X-wind phase (Shu 2003; Leya 2003). The protoplanetary nebula was well mixed, at least out to 3 AU (Becker & Walker 2003).

And where will it all end? The major planet orbits are chaotic in a technical sense (with characteristic time near 4 Myr for the terrestrials and perhaps 100 Myr for the Jovians; Varadi et al. 2003). But this does not mean that the semi-major axes or even the eccentricities are going to go flying all over the place, taking us with them, any more than they have in the past. Indeed, while the orbit of Mercury may become gradually more eccentric, and that of Neptune less resonant, basically we are all safe for about as long as the Sun will last, anyhow (Ito & Tanikawa 2002). Whether the Titius-Bode law has anything useful to say about such issues, or about the orbits of the Uranian moons, remains unclear (Lynch 2003).

10.2. Earth Works

With or without a space between syllables, the title is either a statement that all is well or a defensive measure. The latter is perhaps more appropriate, given the multitude of assaults on its lithosphere, biosphere, and philososphere, even if you are not worried about well-meaning engineers changing our orbit (McInnes 2002).

10.2.1. Interior

The anisotropy of the core in transmitting earthquake waves has been ascribed to progressively (with radius) tilted hexagonal close packed iron in the upper half of the solid core (Beghein & Trampert 2002). We would not dream of telling any of our colleagues to go there, even if they deserve a warmer place, and so are pleased that Stevenson (2003) merely wants to send a small communications probe to be carried downward by 10^8–10^{10} kg of liquid iron, which can open a crack through the mantle.

The outer liquid core is responsible for our magnetic field, which can change in as little as 400 years, owing, perhaps, to jets or waves in the fluid (Finlay & Jackson 2003; Johnson et al. 2003).

Next comes the mantle. Caro et al. (2003) have interpreted a $Sm^{147}-Nd^{143}$ chronometer to imply that solidification and differentiation of the mantle occurred as early as 4460 ± 115 Myr ago, at the end of the accretion phase, and so were completed in at most a few hundred million years. The hard-working mantle has been circulating ever since, with a typical upwell velocity of 2.5 cm s^{-1} (Bonatti et al. 2003; Asimow 2003) along the mid-Atlantic ridge.

Lava rises in intraplate plumes as well as along divergent boundaries. We spotted some disagreement about just how far down these can be followed—all the way to the core (Laske 2002), or only to 200 km in the case of Yellowstone (Anderson et al. 2002), or in most cases probably to the base of the crust (Dahlen et al. 2002). The plumes are perhaps also not tied so tightly to a core-centric coordinate system as we were taught as children (Tarcuno et al. 2003 on the classic plume responsible for the Hawaiian Islands and Emperor Seamounts). The mantle was last deeply disturbed by an impact whose debris formed the Moon 4533 Gyr ago (Muenker et al. 2003). Curiously, only about one-third of the atmosphere then present was ejected (Genda & Abe 2003), for which lovers of neon lights and kryptonite must be grateful.

The oldest protocrustal rocks crystallized 4.47 Gyr ago (Bizzarro et al. 2003) on the scale where the first solid grains now found in meteorites go back 4.567 Gyr (Jacobsen 2003).

Assault on the crust in the form of impacts is an on-going process. Big asteroids make big craters, with the ratio of crater-to-asteroid diameter ranging from 8 to 16 (Hughes 2003b). And Bowler (2003) says that bombardment is not periodic (“Wild theories…”) so firmly that we are puzzled about the source of his emotional involvement. The 3×10^7 kg of dust the Earth accretes each year (Moro-Martin & Malhotra 2003) does rather less damage. At 2×10^{-8} g cm^{-2} yr^{-1}, it is not the main reason your car needs washing.

10.2.2. Water and Air

These have changed on all timescales that can be measured. Atmospheric oxygen finally began creeping up about 2.4 Gyr ago (Farquhar et al. 2002), while CO_2 began to creep down from 10–20 times its present concentration a billion years later, after it was no longer needed to keep the Earth warm while the Sun was faint (Kaufman & Xiao 2002). And skipping rapidly to nearer the present, ENSO (the E1 Nino and Southern Oscillation phenomenon, known to Grandmother Farmer as “We’ve always had wet years and dry years.”) can be found as long ago as 900 A.D. and was already quite variable then (Cobb et al. 2003).

Ice is melting these days, enough around the polar regions to have increased the Earth’s moment of inertia since 1997 (Dickey et al. 2002), and also around Mt. Kilimanjaro (Thompson et al. 2002), with 80% lost since 1912 and zero (summer) coverage expected by 2015–2020, after which 20th Century Fox will have to go back in its files and retitle its film *The Mud Puddles of Kilimanjaro*. Indeed, climate, or at least weather, is changing all over the place (Nemani et al. 2003).

Do you have to be a weatherman to know which way the wind is blowing? Only those who were young in the 1960s would risk an answer. (We were always middle aged.) Perhaps it is too complicated even for them: a map published by Toon (2003) seems to show Sahel dust blowing west to Florida, and East Asian dust blowing east to California at more or less the same time.

Perhaps the atmosphere is just out to get us astronomers. The largest isoplanetic patch available from anywhere near ground level is 3″.3 just above the south pole (Travouillon et al. 2002), and yet there are correlations in atmospheric refraction on scales as large as 2°, which show up as residuals in SDSS astrometry (Pier et al. 2003). All too clearly, we, or at least our fellow human beings, are out to get the atmosphere. The spectrum of the sky background around the VLT in Chile is dominated by features of OH and O_2, neither of which you would really want to be without (Hanuschik 2003). But come north to Mt. Hamilton (Lick Observatory) and not only is there a strong sodium continuum in the night sky light, but more than half of the identified lines arise from Sc I and Sc II, escapees from high pressure halide lamps.

Aurorae can be observed both from ground and from above the atmosphere to be concentrated in ovals around the magnetic poles, but the energy is drawn from all over the Earth in the discharges upwards from clouds to the ionosphere (Keiling et al. 2003). Manifestations of aurorae come in red and blue, in X- and gamma rays, and even extremely-low frequency (ELF) radio (Norbert 2003; Su et al. 2003; Pasko 2003). The choice of ELVE as the as the singular of ELVES (they are related to Sprites, another upper atmosphere phenomenon) is distressing. We are uncertain whether it is an attempt to avoid confusion with ELF or a deliberate inversion of the irregular plural, as in Kleenices, sheriffim, and condominia. Incidentally, insects have antennae; radio astronomers have antennas, though we suppose any found sticking out of their heads would be called antennae. (Sorry, folks. Too much Gary Larson before breakfast.)

10.2.3. The Biosphere

A few of these items do have astronomical connections, for instance (1) the attribution of the Cambrian explosion to an impact 540 Myr ago that wiped out whatever had gone before (Trotzinger et al. 2002)—earlier life forms were not very well inventoried, because the only hard parts they left behind them were puzzles in the Burgess shale; (2) the association of SARS with "outer space" (Wickramasinghe et al. 2003); and (3) the happy news that only supernovae within about 8 pc are dangerous (Gehrels et al. 2003), provided that the only danger is ozone depletion. It should be about 1.5 Gyr between supernovae that close.

For the rest, the association is at best tenuous, and we have attempted to arrange them in contrasting pairs, in accordance with Newton's law of action and reaction. If your reaction to our action of bringing these into the room is to leave it, some conservation law will also be illustrated.

There are more than 100 species of tree frogs in Sri Lanka (Meegaskumbora et al. 2002), but a single "domestication event" in East Asia gave rise to (almost) all the pet dogs in the world (Savolainen et al. 2002).

It's a lot harder to determine the gender of dinosaurs that you thought it was going to be, even if, like Sue the Tyranosaurus Rex, they promise to stand still while you try (Brochu & Ketcham 2002), but mollusks are the sexiest invertebrates around, with estrogen receptors at the ready (Thornton et al. 2003).

There are lots of old hominid (Partridge et al. 2003) and hominim (Blumenschine et al. 2003) fossils around, but most of your colleagues have no Neanderthal genes (Klein et al. 2003b).

Squirrels can be as petite as 15 grams (Mercer & Roth 2003), but rodents of the past were as massive as 700 kg (Sanchez-Villagra et al. 2003). The latter (we mean Phoberomys, not the undoubtedly svelt Señor Sanchez-Villagra) was a contemporary of the world's largest turtle, *Stependemys geographicus*, which in turn rates a mention largely to provide an excuse for alluding to the hypothesis that the first Chinese pre-writing was done on the shells of much smaller turtles around 8400 B.P. (Li 2003). The shell ages are not in doubt, only whether what appears on them is a writing precursor.

Butterflies flirt with their wings (which polarize the light they reflect; Sweeney et al. 2003) and elephants run (Hutchinson et al. 2003), presumably with their feet, reminding us of the Transcendentalists who (according to Richard Armour) retired from the world to "work with their hands and think (presumably with their heads)."

Mice have IQs (Matzel et al. 2003), and some early birds had four wings (Xu et al. 2003). Meanwhile, the early worm is in even more trouble than usual, at least in Helgoland, because the birds are returning 2–12 days earlier than they did 40 years ago (Hueppop & Hueppop 2002).

"I eat anything except my stepmother's cooking." Genetic polymorphism for prion resistance suggests widespread cannibalism among many human populations (Mead et al. 2003, who remind us that BSE was spread by bovine cannibalism, though not with ritual intent); and, when the guardians of the ancient paintings as Lascaux attempted to preserve them from fungal damage, they attracted a bacterium that dines on the fungicide (Lasheras 2003). In this context, the near-certain conclusion that the way to live longer, even if you are a rat or a Faustian Acquaintance, is to eat less (Mair et al. 2003) no longer seems quite so unattractive as before.

10.2.4. Person or Persons Unknown

Fifty-six items pertaining to humans, individually and collectively, appear in the annual index, and we would not want to claim that any of them was totally irrelevant to astronomy. For instance, the 16 million male descendents of Genghis Khan (Zerjal et al. 2003) surely include a few of our colleagues. But the more obvious connections will appear first.

Women in science. The US National Academy of Sciences increased its female sector to 7.7% of its 2015 members this year (Berry 2003b), and women now make up about one-third of the youngest cohorts in the American Astronomical Society (Marvel et al. 2003). There is, however, still a good deal of grumbling in the ranks (Dupree 2003, on the situation at what is probably a representative institution). This is probably not related to women receiving only 9.3 minutes of fame for men's 15 minutes (Wagner & Caudill 2003, an analysis of lengths of appearances of individual scientists on PBS programs; there are, of course, also many fewer women who appear at all). The female of the species is said to be somewhat more sensitive to alcohol, though we believe it was a guy (Ridderinkhof et al. 2002) who assembled the title of "Alcohol-impaired detection of performance errors in medio frontal cortex" (and also probably in Ford SUVs).

Ap02 (§ 13) declined to comment on the gender of "those who have held Marie Curie Fellows," but the acknowledgements of Cassisi et al. (2003a) make clear that some of the fellows are male. Men, on the other hand, are more likely to be at least partially color blind, and Ito & Okabe (2002) have devised a magenta/green color coding to replace red/green that can be distinguished by most dichromats. The effect is dirty sunflower and blue gentian. It is probably irrelevant that one of each gender participated in a polite exchange on "what is white?" and "where does the solar spectrum peak?" (Hobson & Trimble 2003).

Astrology lives, and indeed apparently flourishes in UK universities, with four initiatives funded by a private donor as the Sapho Project (Evans 2002).

The *Carte du Ciel* survives as a source of historical photometry (Lamareille et al. 2003), but the 50th anniversary of the Watson & Crick double helix paper provided the occasion for the discovery that the young no longer even recognize a slide rule (Cram 2003). Other famous 50th anniversaries in 2003 included that of the first Urey-Miller atmosphere experiment (it made brown sludge) and of the uncovering of the Piltdown forgery (some of the bones and stone tools had been tinted with brown sludge). Incidentally, citations of the Watson & Crick paper peaked in 1963 and went through a minimum about 1975 (Strasser 2003).

Space opera. Philip Glass's *Galileo Galilei* was revived during the year and found lacking in memorable melodies (Pasachoff 2002). An operatic treatment of the life of J. Robert Oppenheimer by John Adams is scheduled for completion in fall 2005 (Nonymous 2003a), with an Einstein ballet due earlier the same year. These are part of a general blossoming of interaction between science and theatre (Lustig & Shepherd-Barr 2002), at least partly inspired by the success of *Copenhagen*, the Michael Frayn play about a wartime meeting between Bohr and Heisenberg.

We would propose as additional subjects, if a suitable composer or dramatist should appear: (1) "Night on Mauna Kea," as acquired by Walter Crittenden in an auction to benefit the Astronomical Society of the Pacific (Nonymous 2003b) at a price of $16,000, (2) "The Conversion of Constantine," which may have been caused by a meteor-meteorite whose impact crater has perhaps been found (Ormo et al. 2003), (3) "The Last Time Ball," set at the outset of World War II, when the Royal Greenwich Observatory suspended its dropping for the duration (Nonymous 2002), (4) "King Solomon's Dates" (with carbon-14, not with the daughter of Pharoah) as an approximate contemporary of Shosheq VII of Egypt (Bruins et al. 2003), and (5) "The Shrinking of Venice," a complete performance of which runs for many decades (Nosengo 2003). You might feel that this should be "sinking," but the population has declined by about 50% at the same time that seas have encroached. You are welcome to think of rats and ships, since there does not seem to have been a population of Venetian astronomers of late.

Maxwell in two, meaning James Clerk. Experienced players of "shaking hands with Shakespeare" (who died in 1616 and so could have looked through a telescope but probably did not) know that this takes at least six intermediaries. But Maxwell's student John Fleming (b. 1849) lived until 1945, so every pre-baby-boomer might, in principle, have met him (Hong & King 2003).

A very few people who actually met Alfred Wallace might still be living, since his lecture "Man's Place in the Universe" appeared in *Nature* on 9 April 1903 and is reproduced in volume 422 (p. 576). He put us at the center of the Milky Way (as did nearly all his contemporaries), which constituted the entire universe (as it did for about half his contemporaries), and he thought this location essential for the evolution of life (perhaps a less widespread view). He died in 1913.

Even post-boomers could have known Luis Alvarez, and his method of using cosmic-ray secondary muons to look for dense matter has reappeared as a way of catching uranium as it crosses international borders (presumably with human assistance; Nonymous 2003c). Alvarez himself looked for secret chambers in Cheops's pyramid.

Willem Luyten's carreer spanned most of the 20th century, and he still counts as a contemporary for many of us. His catalogs of stars with large proper motions are proving to be something like 90% complete (Pokorny et al. 2003; Lepine et al. 2003b, though one of these provided a description more like "10% incomplete"). The accuracy in positions is generally better than 1″, but the error is 11° for one star (Gould & Salim 2003).

Efforts at alphabetic completeness found no new Zwicky items this year, but there was a reference to a connection between H. C. Arp and H. G. Wells (McDowell et al. 2003) too complex to try to explain here. It involves bright lights on Mars. As near the middle of the alphabet as you can get comes Murphy, Edward Aloysius, the 1940 graduate of West Point for whom the law was named (Spark 2003). Because the USMA class of 1940 had joint alumni reunion Christmas dinner-dances with USNA until about 1980 (Murphy died in 1989), it is just barely possible that the author, who is now a "class of 40 widow," met him.

The constellations. The southernmost of those normally thought of as visible from northern sites must have been codified about 690 B.C.E. at northern latitude 33° ± 1° (Schaefer 2002). The last star chart to show them all in ecliptic rather than equatorial coordinates was probably the 1786 *Uranographia Britannica* of John Bevis (Kilburn et al. 2003).

The scientific literature. Would you prefer that your papers be cited or read? Impact factors (a particular journal-averaged sort of citation rate) sometimes figure in dossiers for promotions and tenure but can be very misleading, because the system under which they are compiled does not do a very good job of figuring out which journal is which (Sandqvist 2003). Scientists tend to cite themselves too much anyhow (Aksnes 2003). But we would like to take issue specifically with the claim that less than one-quarter of cited papers have actually been read by the citing authors (Simkin & Roychowdhury 2002). Their conclusion derives from statistical analysis of small errors in citations (page numbers, volume/year mismatches, initials, etc.) that propagate from paper to paper, plus the curious believe that reading the original paper protects you from this. Scout's honor, the (former) Scout author makes enough mistakes of this sort to reproduce accidentally every one that has ever appeared or will appear elsewhere. Only the heroic assistance of Editor Anne Pyne Cowley keeps you from knowing this. Particularly common is the paper you read last week or last century but do not have in hand and so very naturally assume that somebody else who cited it in between got the details right.

Breakthroughs of the century, as selected by the editors of *Science* (298, 2296) include neutrino astronomy as No. 2, the polarization of the CMB as No. 4, and adaptive optics with Keck and the VLT as No. 8.

Physics as a discipline. Wong & Wulfe (2003) report that the *Encyclopedia Britannica* had articles called "physics" from edition 1 (1768) to 8 (completed in 1860), "physical sciences" in 9 (by J. C. Maxwell) and 13 (by R. A. Millikan), but nothing in the 11th (1910) or 12th editions under those headings. By 1929, physics (by Oliver J. Lodge) was back in, though very much shorter than, say, "ceramics." Out of idle curiosity, we checked a contemporaneous, very much less prestigious encyclopedia (*Winston's Cummulative* for 1914) and found a short article called "physics," which referred the reader to separate articles on the principle branches, dynamics, hydrostatics, heat, light, sound, and electromagnetism. The sum of these was less than the five pages devoted to the Reformation.

The community. "Sometimes," says Colbert (2002), "all it takes is putting the food in the right place." We have been saying this for years about how to improve informal communication at conferences. Colbert is trying to encourage interdisciplinity and meant it figuratively.

Amateurs make up a productive part of the astronomical community in a way other scientists can only envy. Reid et al. (2003a) note the independent discovery of a very nearby star by J. P. Laurie, using a public archive. Two of five recent GRB afterglows were studied by an amateur group in Finland (Oksanen et al. 2002). Robert Evans is no longer by any means the only amateur who discovers supernovae, but 2003B (IAUC 8042) raised his total to a surely impossible target for others. He was also the discoverer of 1987B, which we have always thought of as the most undersung SN in history, victim of bad luck comparable with that of a distinguished scientist who happens to die the same day as a former president or rock idol. Supernova follow-up work by amateurs is discussed by Ripero et al. (2002), and the 2002 Edgar Wilson award for discovery of comets by amateurs was shared by five people from four countries (IAUC 8162).

And, contrary to anything you might ever have heard about horse-portions designed by committees, an SOC and its speakers have produced a perfectly splendid (though incomplete) history of astronomy (Duerbeck et al. 2002).

10.3. Small Stuff, Sweat Optional

The sum total of all of the solar system left-overs would not add up to even a Venusian mass, but if you print out the papers about each and add them to the balance pans, the small stuff will surely win.

10.3.1. Satellites

Luna, the moon of June, spoon, tune, and all, began the year with some ice at its poles that might have come from comet impacts (Berezhnoy et al. 2003). But (based on an out of period result from Arecibo radar reflections) we recommend that on your next trip you plan either to bring your own or drink your martinis warm. Could the Moon have a moon of its own? Well, not for long (Winter & Vieira Neto 2002), and the same probably holds for most other solar system satellites. Ours may have had a sufficiently fluid core for dynamo magnetism 3.6–3.9 Gyr ago (Stegman et al. 2003), but not lately.

As for everybody else's moons, Mercury and Venus have none; we caught nothing about Fear and Panic; that of Pluto is becoming less eccentric[10] with time (Stern 2003); and for the rest, all one can say is "more, more, more!"

At the instant of submission of Sheppard & Jewitt (2003), Jupiter had 60 (52 irregular), Saturn 31 (14 irregular), Uranus 22 (6 irregular), and Neptune 11 (5 irregular), where "irregular" means largish eccentricity and/or inclination (including retrograde orbits), and probability that they were captured (Astakhov et al. 2003). Most are small, though Triton of Neptune, despite its idiosyncratic orbit, is nearly as large as Luna. IAU Circulars 8193 (Neptune) and 8209 (Uranus) added a few more still within the reference year, and the stream has not yet choked off. The answer card for Trivial Pursuit (134) will surely be out of date by the time you get asked the question.

Some of the names (IAUC 8177) are a bit much and would appear to include a salad green (Kale) and a fractured poetic foot (Sponde). There were probably even more of these irregular moons in the past: prograde ones with large semi-major axes are ejected (Nesvorny et al. 2003b); some retrograde ones merge, but other encounters will result in more (but smaller) moons.

A few larger moons got whole papers to themselves. Titan (of Saturn) has weather in the form of transient clouds and

[10] A colleague recently described one of us in a newspaper interview as eccentric but lots of fun. Since the ideal female figure approaches a hyperboloid of revolution, we hope the eccentricity was negative.

perhaps precipitation (Brown et al. 2002b). Nereid (of Neptune) has a rotation period of 11.52 hr, which is totally lacking in weird resonances or chaos (Grav et al. 2003). Most attention went to the Jovian moons. Europa as well as Io is heated by its Jupiter-induced tides (Peale & Lee 2002), which may be the reason for its sub-European ocean and the contributions of both to the dust around Jupiter (Mauk et al. 2003). Callisto is a unipolar inductor (Strobel et al. 2002). And the volcanic ejecta of Io are salty (Lellouch et al. 2003), another reason it is the best place around Jupiter for cooking.

10.3.2. Interplanetary Material

The interplanetary gas and dust today are not left from the formation of the solar system. The gas is coming out in a solar wind (plus a bit from comets), and the dust is flowing inward from a variety of sources, when it isn't being pushed outward by the wind or being collected by planets (30,000 tons per year by the Earth alone). The dwell time of individual dust grains in the IPM is only about 10^5 yr, but the asteroid and comet supplies are enough to keep it up for more than 3 Gyr (Fixen & Dwek 2002).

Hydrated asteroids are the most common source (Tomeoka et al. 2003), followed by anhydrous asteroids. There is also some comet dust, which may preserve pre-solar grains with isotopic ratios characteristic of the evolved stars in whose environs they formed (Tielens et al. 2003; Messenger et al. 2003). About 1% seems to be interstellar dust not recycled through anything (Meisel et al. 2002). The dust from various sources is well mixed (Leinert et al. 2002).

The infrared light radiated by this dust (because it is heated by the Sun) has been remeasured from the *Midcourse Space Experiment* of the Department of Defense (Price et al. 2003c). It has a brightness of 10–30 mJy sr^{-1} in the anticenter direction. If this sounds awfully bright for something you have never seen, remember that there are still a lot of Hertz at 15 μm and a lot of square arcseconds in a steradian.

10.3.3. Meteors/oids/ites

Meteor showers must have been known to the ancients, but the earliest sightings we spotted this year were Korean ones from 918–1095 C.E. (Ahn 2003). Ahn's astronomical predecessors saw the Perseids, the Leonids, and some others. Lots of people saw the Leonids in 2002 (November). Especially striking is the package of two letters and six papers, beginning with Watanabe et al. (2003a), that was submitted on 16 November and includes data collected on the 18th (yes, both 2002). They and others (Welch 2003; Porubcan et al. 2002) report structure in the Leonid shower indicative of ejection events in 1767 and 1866 and semi-hollow dust streams. We had sworn to have a look this year, but it was (again) cloudy, and we never thought to emulate the Watanabe team by flying from Madrid to Lincoln, Nebraska, during the shower.

The Leonid parent body is a comet, 55P/Tempel-Tuttle. That of the Geminids is probably an old comet nucleus, though now cataloged as 3200 Phaethon, an asteroid (Beech 2002). And the Taurid parent body is a carbonaceous chondrite (Konovalova 2003). Future meteoroids are ejected from comets at a speed of about 100 m s^{-1} (Ma et al. 2002b), very close to the velocity calculated by Whipple (1951).

When pieces reach the ground, they are called meteorites. These come from parent bodies that have been chemically differentiated and layered (Trieloff et al. 2003). This could mean planetsimals as small as 30 km across, but size is not the whole story, since the much larger Ceres and Callisto are not differentiated (Yoshino et al. 2003). So far, a total of four meteorites have been photographed on the way down and later recovered (Spurny et al. 2003). The fourth started out at 300 kg, of which 1.75 kg was found at Neuschwanstein, near Mad[11] King Ludwig's Castle.

10.3.4. Comets

Comets have a long history in two senses. First, they remain relatively unprocessed since their formation, some near Jupiter and Saturn as well as out around Uranus and Neptune (de la Fuente Marcos & de la Fuente Marcos 2002). The "unprocessed" part is emphasized by Neslusan (2002, a review of archival data on molecular abundances in comparison with cold interstellar material), and the "relatively" part, even as far out as the Oort cloud, by Stern (2003a).

Second, people have been paying attention to them for a long time. Hasegawa (2002) reports orbits for 10 with perihelion passages between 126 and 1554 C.E. Most came within 0.8 AU of the Sun and 0.3 AU of the Earth. Remarkably, the discovery rate seems to have been nearly constant for the last 1600 years of pre-telescopic astronomy, with no obvious showers or clusters (Hughes 2003a). Comet 253P/Ikeya-Zhang returned for the first time since Hevelius saw it in 1666 (IAUC 7843). We missed it this year, but will keep eyes open in 2338.

Comets belong to families in three senses. First, there will be a set urged inward each time a star passes through the Oort cloud (with 99 times as many urged outward), and the members of the last few passage families can probably be picked out from their perihelion directions (Dybczynski 2002). Second, there are "capture" families that belong to the major planets, especially Jupiter at $R = 2.29$–5.72 AU (Lowry et al. 2003). Third, there are small groups with common origin in the breakup of a single larger comet. Sekanina & Chodas (2002a, 2002b) point out examples. Our favorite is the origin of C/1965 S1 (Ikeya-Seki, which the author born closer to its year of formation saw) and C1882 R1 ("Great September"; well, no, but Grandfather Trimble could have) in a breakup dated to

[11] According to the Faustian Acquaintance, all the Wittelsbachs were a bit eccentric. We hope in this case for a positive eccentricity, since the image of Ludwig himself with a figure like a hyperboloid of revolution is too horrible to contemplate.

1106 C.E. Ikeya-Seki and some of the others are also members of the Kreutz sungrazer family.

Comet C/2001 Q4 (NEAT) was discovered 10 AU from the Sun, a record (Tozzi et al. 2003), and Hale-Bopp remained active at least that far out (Gunnarsson et al. 2003) and detectable to 12.8 AU (Rauer et al. 2003). But the record belongs to Halley, now closer to aphelion than anyone would guess who does not carry Kepler's second law around in his backpack or frontal lobes. It has been seen at 28.06 AU and should remain detectable at 35 AU in December 2023 in the same sorts of VLT images (West 2003).

Comets are not forever. Half of the 110 currently known to have periods between 3 and 28 years will decay away in the next 7600 years (Hughes 2002).

10.3.5. Little Stars

We recorded about 30 papers and indexed 20, including a handful that occasionally spew off meteors and comae (Babadzhanov 2003; Bauer et al. 2003). We mean the asterets and comoids, not the papers, although….

Asteroids consisting of two chunks in more or less bound orbits have become sufficiently common, even in the Kuiper belt (Noll et al. 2002; Goldreich et al. 2002), that our first residual question was one of nomenclature. Why should (22) Kalliope and (45) Eugenia be described as having satellites (IAUC 8177) while Sekhmet (IAUC 8163) is a binary? Perhaps it has something to do with naming them. Kalliope's companion has been named Linus, we think for the little brother of Charlie Brown, rather than for the Homeric hero and harvest god or even for the New Testament character who may have been the son of Caractacus and younger brother of Gwladys (later Claudia) and may or may not have been identical with the second pope. Sekhmet was the Egyptian cat goddess, and even an IAU Working Group on Planetary System Nomenclature might shrink (from 12 members to 10?) at the thought of a cosmic object named Kitten.

Asteroids, like comets, come in families. Some of these arise from collisional break-ups and so have compositional as well as dynamical signatures (Nesvorny et al. 2003a; Michel et al. 2003; Ivezic et al. 2002b). Others, like the Trojans (Lagerkvist et al. 2002) belonging to Jupiter and the Centaurs belonging to Uranus (Masaki & Kinoshita 2003), have been captured into similar orbits without necessarily sharing origins. Plutinos belong to Neptune (Chiang & Jordan 2002), and if Pluto should ever capture any, its asteroid family might be called Americans.

Some of the single objects are rather bone-shaped (Hestroffer et al. 2003) and non-convex (D'urech & Kaasalainen 2003). Very large extraterrestrials snap them in half and make wishes at their family feasts.

Are collisions likely to damage asteroids? Well, the four that have been imaged so far have the distributions of crater sizes you would expect (Jeffers & Asher 2003), but the distribution of rotation periods (hours to days is typical) suggests that major collisions are not very common (Donnison 2003; Vokrouhlicky et al. 2003).

Are asteroids likely to damage astronomers? Well, certainly your reputation, if you announce something that proves untrue, perhaps most so if the something is an excessively close approach to Earth. The best estimates of numbers of Near Earth Objects (comets and asteroids) large enough to present some risk has varied by a factor of about 2 in recent years, down in 2003 (Brown et al. 2002c). The current count in the 1–10 m range implies one Tunguska every 1000 years (Jedicke 2002). But really serious damage comes only from larger objects, for which the inventory does not require so much statistical adjustment. Those numbers have not changed (Chapman & Morrison 2003). Your judgement of how one ought to react to these matters is surely at least as good as ours.

11. METHANE, ETHANE, PARAFFIN

This is, as you have heard before, the primitive chemist's equivalent of "one, two, many" in number theory and "hydrogen, helium, metals" in nucleosynthesis. In fact, we shall start with the "many" and work down to firsts and other extrema.

11.1. Many

- 1.6×10^{11} minutes of international phone calls in 2002 (Nonymous 2003d).
- 3×10^{7} stars from OGLE (the Optical Gravitational Lensing Experiment) around the Galactic center (Udalski et al. 2002).
- 16×10^{6} descendents of Genghis Khan (Zerjal et al. 2003).
- 4,318,486 radio bursts (Katz et al. 2003), of which 3898 came from the Sun and the rest were local interference.
- 500,000 archived plates at Harvard College Observatory, taken in the periods 1885–1953 and 1968–1989 (Schaefer 2003). What do you suppose they were doing between 1953 and 1968? Sonneberg is second, with 275,000, and Ondrejov third, with 110,000. The world total is close to 2 million.
- 200,000 asymptotic giant branch (AGB) stars in the Milky Way, including 10,000 *IRAS* candidates (Jackson et al. 2002b).
- 183,437 galaxies with colors, shape parameters, etc., from SDSS, a small fraction of the eventual total (Blanton et al. 2003).
- 107,765 radio sources in a 843 MHz survey (Mauch et al. 2003, about 43% of the eventual supply).
- 106,152 sources in ISOGAL, an infrared catalog compiled from the ground-based DENIS and satellite-based ISOCAM detectors (Schuller et al. 2003).
- 69,115 2MASS (infrared) sources in the Lockman hole (Beichman et al. 2003), which is a region of relative transparency in Galactic obscuration.
- 46,961 red giant stars from OGLE (Sumi et al. 2003).

• 43,000 galaxies in the DENIS galaxy *I*-band survey (Paturel et al. 2003).

• 18,811 bright *ROSAT* sources in the all-sky survey (Zickgraf et al. 2003).

• 17,129 *Hipparcos* stars (of 118,218 total) that could host habitable planets (Turnbull & Tarter 2003).

• 14,592 CO clouds in a stretch of Galactic plane not including the center (Brunt et al. 2003).

• 8155 candidate open star clusters in a portion of the digitized Palomar Observatory Sky Survey (Gal et al. 2003).

• 7612 RR Lyrae stars in the LMC found by OGLE I (Soszynski et al. 2003), including 5455 RRab stars, and 3 possible eclipsing binaries.

• 6450 globular clusters belonging to NGC 1399 (Dirsch et al. 2003).

• 4430 Å = 4428, a rethinking of the central wavelength of the first of the diffuse interstellar bands (Snow et al. 2002), discovered by Merrill (1934).

• 3126 variable stars in a southern sky survey with a 10 inch astrograph at Las Campanas (Pojmanski 2002).

• 3071 massive young stellar objects in the catalog from the *Midcourse Space Experiment* (Lumsden et al. 2002).

• 2810 emission lines in the spectrum of the sky background around the VLT site (Hanuschik 2003).

• 2580 eclipsing binaries in the LMC seen by OGLE, of which 36 should be useful for distance measurements, meaning that they are detached SB2/EB (Wyrzykowski et al. 2003).

• 1442 Galactic H II regions in a catalog compiled by combining 24 existing ones (Paladini et al. 2003).

• 1150 blue variable stars in the LMC and in the MACHO database (Keller et al. 2002).

• 1054 radio sources down to 0.1 mJy in a new VLA survey (Bondi et al. 2003). 1054 was also the year the Crab supernova was seen, though not by the VLA.

• 913 reflection nebulae in another of those merged catalogs (Magakian 2003).

• 780 Herbig-Haro objects (Reipurth et al. 2003).

• 748 double-lined spectroscopic binaries in the Henry Draper catalog (Wichmann et al. 2003).

• 715 young stellar objects in ISOCAM (Felli et al. 2002).

• 661 infrared star clusters and groups including new ones from 2MASS (Bica et al. 2003).

• 538 authors at 53 institutions, who take up 2.5 pages of *Phys. Rev. Lett.* 90, 081802.

• 399 Trojans in the preceding Lagrangian cloud (Lagerkvist et al. 2002), very probably more than fought against the Greeks.

• 313 stars within 10 pc (Burgasser et al. 2003c).

• 244 supernovae in the calendar year to 30 September 2003 (IAUC 8212).

• 204 X-ray sources in M31 (Kong et al. 2002a).

• 155 women in the US National Academy of Sciences (Berry 2003b).

• 150 narrow-lined Seyfert galaxies in the SDSS in a part of the sky where two were known before; 45 are *ROSAT* sources (Williams et al. 2002c).

• 142 variable stars in the Draco dwarf spheroidal (Rave et al. 2003). 113 were known to Baade & Swope (1961). Actually, they were probably all known to Baade, because he was dead by then.

• 142 X-ray sources in M31 as imaged by *Chandra* (Kaaret 2002).

• 142 YSOs with water maser data (Furuya et al. 2003). We have not attempted to assess the probability of there being exactly 142 each of three such different things. If it had been 137, one might have suspected a resurgence of Eddington's fundamental theory.

• 133 QSOs behind the Magellanic Clouds in the OGLE II database (Eyer 2002), or, we suppose, ejected from the Magellanic Clouds if the redshifts are intrinsic. Semi-serious thought—an investigation of correlation between the sky area covered and the number of background (?) QSOs ought at least to be able to put limits on numbers of ejectees from nearby galaxies.

• 129 lines of Ce III with oscillator strengths (Biemont et al. 2002).

• 100 features due to FeH seen in near-infrared spectra of M8 to L7 stars (Cushing et al. 2003).

• 100 supernovae discovered by UK amateurs up to 2003hi.

• 100 years since the Wright brothers' feat and feet left the ground at Kitty Hawk, NC; but remember that they were Ohio boys (like great-great-great-grandfather, governor Allen Trimble). It is also 100 years since the first transcontinental automobile trip. It took about 2 months and won a bet for the drivers, who were financed by a Wells of Vermont, who did not himself make the trip. And 100 years (in November) since the Metropolitan Opera debut of Enrico Caruso.

• 94 trans-Neptunian objects (Boehnhardt et al. 2003).

• 90 OH megamasers (Yu 2003). Most vary.

• 90 pulsar glitches, with data on numbers 77–90, in pulsars numbers 26–31 that do that sort of thing (Krawczyk et al. 2003).

• 87 *Chandra* X-ray sources brighter than 10^{39} ergs s^{-1} and not galactic nuclei culled from images of 54 galaxies (Colbert & Ptak 2002)

• 74 authors' addresses in *Phys. Rev. Lett.* 99, 091801.

• 53 elements that will superconduct under suitable circumstances (Shimozu et al. 2002). The new one is lithium, and if we could figure out the systematics in a periodic table, there might be a prize in it.

• 52 radio pulsars that also pulse in X-rays (McGowan et al. 2003).

• 50 years since "the publication of a famous discovery that, by elucidating a remarkable mechanism for preserving and conveying information, led to a better understanding of our human heritage. This feat was performed by a partnership between an unconventional newcomer from a different field and a Cambridge scholar with specialist knowledge. Their insights depended on careful observations made by another academic, whose premature death from cancer ended her chances of sharing in the ultimate accolade." The extended quote is from Searls (2003), and you have been saying for phrases, "Yeah, yeah. Watson and Crick and the double helix and Rosalind Franklin and all." And so you were meant to be saying, and so did we, equally led astray by the author, who is really talking about Michael Ventris and James Chadwick and the decoding of Cretan Linear B and Alice Kober and all. Yes, it is that 50th anniversary, making us feel very old, for the Cretan scripts were a childhood goal. Well, there is still Linear A. It is, of course, also the 50th anniversary of Watson and Crick, of the first "Urey atmosphere" experiment, carried out by Stanley Miller, and of the revelation that Piltdown man had never lived in England, at least not in one piece.

• 38 RR Lyrae stars found by OGLE to have two periods so nearly equal that the beat is their Blazhko period (Moskalik & Peretti 2003).

• 37 cataclysmic variables in the "period gap" between 2 and 3 hr (Katysheva & Pavlenko 2003).

• 31 carbon dwarfs (Lowrance et al. 2003).

• 23-skidoo. The worst typo of the year: "…solution to the problem of solar neutrinos (23 rotate to another flavor)" in a report from IAU Symposium 214 appearing in *PASP* 115, 142. It should have said "ν_e rotate to another flavor." The author? Oh, somebody named Trimble.

• 19 supernova remnants with OH masers, a new class just a few years ago. The cause is the SNR hitting a molecular cloud (Yusef-Zadeh et al. 2003).

• 15 QSOs around M82 (Burbidge et al. 2003a).

• 9 pulsars with pulsar wind nebulae detectable in X-rays (Gotthelf 2003).

• 9 ladies dancing (Partridge et al. 2003).

• 9C, the catalog (Waldram et al. 2003). We remember when 4C was new.

• 7 stars with proper motions in excess of $5'' \mathrm{yr}^{-1}$ (Teegarden et al. 2003).

• 7 Swans a Swimming (Partridge et al. 2003).

• 7 page ApJ Letter (Sneden 2003).

• 6 active galactic nuclei with TeV detections (Holder et al. 2003).

• 6 AM CVn stars (Podsiadlowski et al. 2003a). These are binary helium white dwarfs.

• 6 Geese a-laying (Partridge et al.).

• 6 element optical interferometer (Hummel et al. 2003).

• 6 degrees of separation? Well, maybe, but a sizable fraction of the 60,000 e-mails in the experiment never arrived at all (Dodds et al. 2003).

• 5 molecules of H_2O needed to dissolve one molecule of something else; a new, smaller definition of "many," which had previously been 8 (Hurley et al. 2002).

• 5 golden rings (Partridge, Wagner, & Tolkien 2003).

• 5 quarks in one particle (Aubert et al. 2003; Nakano et al. 2003).

• 4 quarks in one particle (Close 2003).

• 4 galactic center black holes whose masses have been determined from orbiting masers (Henkel et al. 2002).

• 4 types of barium star (Liang et al. 2003).

• 4 calling (or possibly colly, which means black) birds (Partridge et al. 2003).

• 4-armed spiral, meaning us (Russell 2003).

• 4th pulsar discovered, and the first after the pioneer Cambridge Three, has a new optical identification (Zharikov et al. 2002).

• 4th pulsar to show giant pulses (Ershov & Kuzmin 2003).

• 4th meteorite photographed on the way down (Spurny et al. 2003).

• 4th optical counterpart to isolated neutron star (Kaplan et al. 2003).

• 4th asteroid to be imaged (Jeffers & Asher 2003).

• 4th soft X-ray intermediate polar (Staude et al. 2003).

• 4th accreting millisecond pulsar in LMXRB (Campana et al. 2003). Its period is 5.25 ms.

• 3 X-ray binaries with precessing disks (Revnivtsev & Sunyaev 2003). It is KS 1731−260 and so is not previously famous like the first two, HZ Her and SS 433.

• 3 sources to show acetic acid, CH_3COOH (Remijan et al. 2003). It is G34.3+0.2 and so is not previously famous like the first two, Sgr B2 and W51. We propose to declare as our third law that the third source to display any newish phenomenon will not be a previously well-known one (and is unlikely to become famous thereafter). And what are our first two laws? Ah, they are already well known.

• 3 hibernating novae (Kawka & Vennes 2003).

• 3 French hens, to be called Freedom hens for the duration (Partridge et al. 2003).

• 3rd integral (Lynden-Bell 2003a).

• 3rd South African black to receive a Ph.D. in astronomy (Nonymous 2003g), Dr. Thebe Medupe; and one of the wonderful things about a Ph.D. is now your gender need matter only to your family.

• 2 spiral-dominated X-ray clusters (Fukazawa et al. 2002). It is HCG 55, and the first was HCG 92, so apparently compactness count. H is Hickson and G is group.

• 2 BAL FR II quasars (Brotherton et al. 2002). The second came from the LBQ Survey, and the first from FIRST.

• 2 neutron star X-ray binaries where the donor is a red giant (Galloway et al. 2002). The orbit period is 404 days.

• 2 turtle doves, voice of, to be heard in the land (Partridge & Solomon 2003).

• 2 anomalous X-ray pulsars that have turned into supersoft gamma repeaters, but not spectacular ones like 1979 March 5 (Kaspi et al. 2003).

• 2 subdwarf L stars (Lepine et al. 2003a).

• 1.74, Mach number of a shock in the merging cluster Abell 754 (Krivonos et al. 2003).

• zero minutes, the correct exposure time for measurements of seeing (Conan et al. 2002).

• zero, the best estimate of the number of intergalactic globular clusters in the Coma cluster (Marin-Franch & Aparicio 2003).

11.2. One

Some of these are firsts only by location—a previously known sort of thing has been seen further away than before. Others are new, somewhat unexpected combinations of previously-known phenomena. The last few items are things that you always knew had to be there, but for which evidence had previously been lacking. Please preface each item with the words "The first," or, for topics that particularly interest you, "The First!"

• Carbon stars outside the Local Group (Mouhcine et al. 2002).

• Eclipsing X-ray binary outside the Local Group (Pietsch et al. 2003). It is the high mass sort, reaches 4×10^{38} ergs s^{-1}, and was caught by *Chandra* in NGC 253.

• Extragalactic CO and XCN ice (Spoon et al. 2003).

• R Coronae Borealis star in the Small Magellanic Cloud (Morgan et al. 2003).

• Supernova remnant in M31 resolved in X-rays (Kong et al. 2002b).

• Catalog of variable stars in a giant elliptical galaxy (Rejkuba et al. 2003, with 1146 long period variables in NGC 5128). Variables were of course known there before, but not so many that you needed a catalog.

• RR Lyrae stars in NGC 6822 (Clementini et al. 2003), which also means that this classic dwarf irregular galaxy has an old stellar population.

• Spiral structure at redshift larger than 2 (Dawson et al. 2003), which says something about the progress of galaxy evolution long ago.

• Magnetic fields in pulsating B stars (Neiner et al. 2003, 335 G for Zeta Cas; Leone et al. 2003, on β Lyrae).

• Measurable magnetic field in a protoplanetary nebula (Bains et al. 2003, about 2–5 mG).

• Nova-like variable with a carbon star donor (Drew et al. 2003). The star, QU Car, is also probably the brightest NL known, with a bolometric luminosity of 10^{37} ergs s^{-1}, and this is presumably not a coincidence.

• Quasiperiodic oscillations in a Wolf-Rayet star (Kato et al. 2002a). It is WR 104, a WC9+OB binary with an orbit period of 241 days. The QPO period is not very different, and the authors suggest dust obscuration in the orbit as a likely cause.

• Oxygen-rich Mira to fade in the fashion of a carbon-rich R CrB star because of dust formation (Bedding et al. 2002). The timescale is a decade or so, vs. weeks for R CrB stars, and the pulsation period was unchanged afterwards, so this was not an example of a last helium flash like FG Sge.

• Runaway black hole binary (Mirabel et al. 2002). It is J1655−40, and the velocity (from *HST* images) is about 110 km s^{-1}.

• Diffuse synchrotron X-ray emission from a young stellar object, RCW 38 (Wolk et al. 2002).

• Photograph of the Horsehead Nebula, taken at Harvard on 11 December 1885 (Pound et al. 2003).

• US (high school) team to place first in the International Physics Olympiad, held in Taiwan in August. South Korea came in second, the hosts third, and Iran fourth. There was no team from mainland China, and whether SARS was the reason or the excuse, we have no idea.

• Human footprints, from the mid-Pleistocene, 385–325 kyr ago (Mietto et al. 2003). The foot was arched and the gait fully bipedal, except after a fall or two. We walk more or less that way ourselves, despite being a bit taller than her 1.5 m.

• Return currents (Ramachandran & Kramer 2003, on the magnetosphere of the pulsar J1022−61; Hénoux & Karlicky 2003 on a solar flare, which has unaccountably escaped from § 2 and is being sent to bed without its supper; solar flares eat Gauss as a rule, but will consume Tesla if no Gauss are available).

• And you cannot expect us to resist retelling the story of the misplaced comma (it is a book title), "Eats, Shoots and Leaves," the tale of a panda who enters a pizzeria, consumes his dinner, shoots the waiter, and departs. And your reward for listening to that, or at least not tearing the library copy of *PASP* into shreds, is what we think is perhaps the most important, or anyhow longest-awaited, first of 2003. Nobody really knows what the progenitors of Type Ia supernovae look like, though a "pre-need" image may someday tell us. Meanwhile, the longest-lived theoretical candidate has been binary white dwarfs with total mass exceeding the Chandrashekar limit and orbit periods short enough that gravitational radiation will spiral them together in less than a Hubble time. The chief difficulty has been the total absence of these in the real world, despite careful searches. Napiwotzki et al. (2003) report what is probably the first, and they have had to study more than 1000 WDs to get it.

11.3. Other Extrema

Unusually distant things come first (though the cosmological are in § 9), followed by other astronomical properties (temperature, age, dust), some slightly odd ones (mostly large or small), and human extremities at the end.

• The most distant TeV AGN is H1426+428 at $z = 0.129$ (Petry et al. 2002). It also has the steepest high energy spectrum, suggesting that the photons are having a hard time getting to us. The most distant radio supernova was 1988Z, at $z = 0.022$ (Williams et al. 2002a). The most distant stars with individually determined chemical compositions are super giants in NGC 300 (Pryzbilla 2003 on the AI's, and Urbaneja et al. 2003 on the BI's). The host galaxy is in the Fornax group at about 2 Mpc, or a redshift of 0.0004. The most distant comet at the time of its discovery was C/2001 Q4 (NEAT) at 10 AU (Scholz et al. 2003), a redshift of 10^{-14}, we think. And the most distant core collapse supernova so far was at $z = 1.006$ (LAUC 8197).

• *Dust*. The most highly reddened supernova was 2002cv at $V-K$ greater than 6 (Di Paola et al. 2002). The largest optical polarization due to scattering by dust is 31% per magnitude of $E(B-V)$ in NGC 3184 on the sight line to SN 1999gi (Leonard et al. 2002b).

• *Young and old*. The youngest moon crater was perhaps formed by an impact on 15 November 1953 (Buratti & Johnson 2003). We remember the date very well and had always wondered what had become of our 10th birthday present. The oldest pulsar with an optical identification has $P/2\dot{P} = 3 \times 10^6$ yr (Mignani et al. 2002).

• *High temperatures*. The hottest star with detectable H_2O in its spectrum is Arcturus (Ryde 2002). The highest brightness temperature is 10^{37} K for a bright spot only 1 m across on the Crab Nebula pulsar (Hankins et al. 2003). One of the three coherent radiation mechanisms they consider (plasma turbulence) could actually radiate the 2 ns subpulses involved.

• *Small*. The smallest groups of galaxies are set by the inability of a halo of 10^{12}–10^{13} $M_\odot$ to host as many as three (Heinamaki et al. 2003). The smallest counterrotating core was found in NGC 4621 and is 60 pc across (Wernli et al. 2002). Zero is, of course, possible.

• *Straight and narrow, crooked and wide*. The largest equivalent width is 705 Å for Hα emission in S Ori 71. Of course the continuum is very faint (Barrado y Navascues et al. 2003), and H II regions may achieve equivalent widths of infinity.

• The largest astrophysical rotation measure is $-14{,}800 \pm 1800$ rad m^{-2} for PSR B1259−63 at periastron, in the wind of its Be star companion (Connors et al. 2002). In combination with its dispersion measure, the RM reveals a field of 6 mG in the Be star wind.

• Narrowest feature on a star is the 150 = length/width ratio of a hot stripe on the companion of PSR J1740−5430 in globular cluster NGC 6397 (Sabbi et al. 2003).

• The smallest beaming angle of a gamma-ray burst is less than 1°.9 for 020813 (Covino et al. 2003).

• The most misaligned radio jet swings through 177° from a parsec to 20 kpc out from the nucleus (Homan et al. 2002). The real bend is only about 20°, and the rest is projection effect.

• *Humans, their institutions, and engineering achievements*. The fastest computer in 2002 managed 35,806 Gflops at the Earth Simulator Center in Japan (Keyes et al. 2003). Number 2 is at Los Alamos, numbers 3 and 4 at Lawrence Livermore National Lab.

• The biggest digital camera has 340 megapixels (Veillet 2003b).

• The university receiving the most patents last year (Nonymous 2003e) was inevitably the University of California, because they summed all nine campuses' contributions to get 431. MIT at 135 and Caltech at 109 are probably doing at least as well (if you approve of this sort of thing).

• The longest delay in awarding a prize stretched from 1910, when the Alexander O. Kowalevsky award of the St. Petersburg Society of Naturalists was established, to 2002, when the medal (for evolutionary and comparative embryology) was first awarded (Nonymous 2003f).

• The largest group of all male astronomers may well be the 19 advisory editors for the *Journal for History of Astronomy*, as published in their Vol. 33. This does not exceed the 44 men who made up the Swiss IAU delegation immediately after the death of Edith Mueller, but they have added a Kathrin, a Doris, and an Uli in the process of expanding to 88 members.

• The oldest star chart might be a carving of Orion on a sliver of mammoth tusk from 32,000 B.P. (Rappenglueck 2003).

• The most dilatory series may well be the one that began with Paper I in 1990 and has Paper IV (*A&A* 400, 421) in the index year. It is not by any means the longest-running series, which has reached paper 172 or thereabouts and appears in *Observatory*. Still to come in that series is the orbit for what the author describes as the longest spectroscopic-only orbital period, but the name of the star is a secret. The orbit is also quite eccentric. The author (e.g., Griffin 2003) is more nearly conical.

• The largest ratio of diacritical marks to letters in the name of a city with a population of astronomers must belong to Łódź, with ó, ź, and Ł, and a pronunciation that an American might attempt to render as Wudge.

These next few come from press releases and private communications.

• The first GRB afterglow discovered by an amateur astronomer was 030725, by South African Berto Monard, using a 12 inch (0.3 m). He is a member of AAVSO, and one might reasonably expect publication in their *Journal* as well as in some more obvious venue.

• The first Near Earth Object discovered by high school students was 2003QA. They were working at Visnjan School of Astronomy using plates from Mallorca Observatory's 0.3 m robotic telescope. The discovery appears in a Minor Planet circular.

• Harry Potter and his friends took an astronomy exam during which they were supposed to locate Venus after midnight. Impossible? Possibly not. If Hogwarts is at latitude 53° north, longitude 1°.5 west, on June 1, allowing for daylight savings time, Venus can set as late as 13 minutes after midnight. Orbit tilt and differential refraction can extend this a bit, but we are awfully glad that (1) the observations were done by Potter et al., and (2) the calculations were done by Kevin Krisciunas. We couldn't have done either.

• This latest possible sighting of Venus naturally brings us back to very old and very young lunar crescents (Ap02, § 6.2). Hoffman (2003) has looked into formulae going back to the

Babylonians (2500 B.P.) and Talmudic scholars like Maimonides, as well as recent Karaite and Moslem practice. The youngest (evening) crescent he found was 21.7 hr past new and set 48 minutes after the Sun. The oldest was 23.5 hr away from new and rose 63 minutes before the Sun. And, we are afraid, our Faustian Acquaintance still doesn't get up that early.

11.4. Methadone, Ethanol, Paragoric

No, we didn't spot any 2003 papers pertaining to these, but each surely has a place in astronomical life.

12. GOT MILK?

Here live the staples of astronomical meal planning that you must have thought we were going to forget. We didn't, but somehow couldn't find the right place for them in any of the earlier sections either.

12.1. The Interstellar Medium

So far, no molecules quite as complex as lactose, but Kuan et al. (2003) report the detection of glycine in Sgr B2, Orion KL, and the W51 star formation region, with 27 wavelength agreements. The gas ranges in temperature from 60 to 210 K, and the data were obtained with the repeatedly-threatened NRAO 12 m telescope. There have been tentative reports of this simplest (and only non-chiral) amino acid before, but this is somehow more persuasive. Other good, mostly new, molecules of the year include:

• Acetone $(CH_3)_2OH$ confirmed, with more lines after a 1987 detection (Snyder et al. 2002). And no, nail polish remover does not actually contain acetone, though they smell rather similar.

• NaC1 in a second source, the post-AGB star CRL 2688 (Highberger et al. 2003).

• D_2S, a first detection in two Class 0 protostellar sources, at a ratio to DHS of about 0.1 (Vastel et al. 2003).

• LAPHs, the locally-aromatic polycyclic hydrocarbons. No, they haven't been seen; it's a calculation, but we love the name, having been in some locally-aromatic places ourselves (Petrie et al. 2003).

• CH_3CHO (acetaldehyde) a familiar molecule, but newly found to mase (Chengalur & Kanekar 2003).

• Crystalline alumina and silver (ah! That's what happened to the rose) as possible carriers of so-far unidentified diffuse IR bands at 10–30 μm (Sloan et al. 2003), and a number of other proposed identifications for other unidentified features.

• Another new doubly-deuterated molecule, CHD_2OH, in an *IRAS* protostar (Parise et al. 2002). CH_2DOH and CH_3OD are already known there, and their sum is larger than the abundance of methanol. We strongly advise you not to drink any of these. Deuterated water is notoriously bad for fishes, and methanol not advised even in its lightest form

• C_4 or possibly C_4H in Sgr B2, where C_4H_2, C_5H, and C_3 are already known (Cernicharo et al. 2002).

A large fraction of neutral ISM resides in the unstable temperature range $T = 500$–5000 K (Heiles & Troland 2003), which continues to puzzle, though Sanchez-Salcedo et al. (2002) calculate that the gas needs a long time to discover that it is unstable.

Newly puzzling is the grey dust (up to several magnitudes worth out to 400 pc) reported by Skorzynski et al. (2003). We suppose that the dust must have known about its odd state all along, but why has it taken astronomers so long to notice? And 83 other ISM papers read, precised, and indexed about which their authors will surely feel that the greatest puzzle is why we did not understand their importance.

The last thing a given bit of interstellar gas gets to do is make stars. Kim et al. (2002a) provide a nuanced discussion of the first stage of this last gasp, where cloud complexes of about $10^7\ M_\odot$ can be assembled, as a result, it seems, of a combination of the Parker instability, self-gravity, the magneto-Jeans instability, and a swing amplifier. The composition of the stars made is not always equal to that of the gas and dust that went in. Andre et al. (2003) focus on oxygen deficiency in nearby B stars.

12.2. Supernova Remnants

Obviously it wouldn't be "astrophysics" without the Crab Nebula, which this year converted Poynting flux from the pulsar into particle flux by annihilation or recombination of the oscillating part of the magnetic field (Kirk & Skjaeraasen 2003). It also put (not very tight) constraints on the equation of state of dense nuclear matter from the need for the spin-down luminosity of the pulsar to be enough to power both the radiation and the acceleration of the thermal gas (Bejger & Haensel 2003). It was this very calculation, done successfully in the 1970s and seemingly intractable in 1985 during an Aspen workshop, that finally persuaded the less oxygenated author that she cannot do integrals above about 6000 feet (and yes, she can do integrals at sea level).

3C 58 was advertized as a pulsar wind nebula encountering the reverse shock of the real (ejected material) SNR, which is not seen (van der Swaluw 2003). He suggests that the Crab may also have a "real" SNR outside the part we see. Klinger et al. (2002) point out that NGC 206, an SNR in the LMC, has a jet rather like the one Sidney van den Bergh found to be sticking out of the Crab some comparatively large number of years ago. It probably still is, though we haven't looked lately.

The Vela SNR also has a younger one tucked inside one corner (Redman et al. 2002). They are disputing a "No, it's just substructure," from last year and supporting a first announcement of the young one from a few years before.

The X-ray Tycho remnant has its iron-rich bits segregated from its partly-burned Si, S, Ar, and Ca bits (Hwang et al. 2002), and we very much look forward to quantitative analysis of this and other relatively young SNRs as "ground truth" for models of supernova nucleosynthesis. Even RCW 86 at 10^4 yr is still somewhat iron rich (Rho et al. 2002).

SN 1006 remains the brightest on record. Winkler et al. (2003) have made the first measurements of its proper motion of expansion and obtained a dynamical parallax ($d = 2.2$ kpc). The expected apparent magnitude of a Type Ia supernova at that distance, -7.5, fits right into the interval (-7.3 to -7.6) implied by the contemporary records from when the full Moon, Venus, and the supernova were all visible together at the end of twilight on 15 May (1006, of course, and it must have been quite a sight).

SN 1987A was not a spherically symmetric explosion, judging from spectral and polarization behavior at the time. This has now been resolved in the ejecta (Wang et al. 2002b). A jet-induced explosion is thereby favored.

We were taught as children that the big loops out of the Galactic plane visible in radio continuum maps of nonthermal emission were large (e.g., 100 pc), old, nearby supernova remnants. Urosevic (2003) concurs. But Sofue (2003) attributed the great granddaddy of them all, the North Polar Spur, to a starburst at the Galactic center 15 Myr ago, and identifies other features with more recent starbursts there.

SN 1993J displayed light echoes in *HST* images between 1995 and 2001 (Sugerman & Crotts 2002). These are not useful for distance determination, but put the object into competition with V838 Mon (§ 7) for the third example of a light echo. One and two were Nova Persei 1901 and SN 1987A.

Cas A, adorned with a great deal of X-ray data, was the most-papered SNR of the year. We logged in a dozen and, most unfairly, mention only the first (Kargaltsev et al. 2002, advocating magnetar status for its compact core) and last (Chevalier & Oishi 2003, suggesting that the progenitor was still in its superwind stage when core collapse intervened, with the lumpy envelop as a signature). Kes 79 with a central compact Chandra core is older but similar (Seward et al. 2003).

Poor old SN 1885A isn't any of the 142 *Chandra* X-ray sources in M31 (Kaaret 2002).

12.3. QSOs, Radio Galaxies, Seyferts, and Other Active Galactic Nuclei

These are going to be the most neglected topics of the year, with 175 papers indexed under that heading and a good many more hiding under "X-ray background," "AGN/starburst," and so forth. Here is one (each) definitive answer to a number of questions that have been asked in previous years. The difference between "yes" and "no" is not always so large as you might suppose, and the logo for this section should probably be the two-headed eagle of the Duchy of Grand Fenwick, which says "Aye!" out of one beak and "Nay!" out of the other.

Yes, radio sources cluster (Overzier et al. 2003). No, there are no dwarf Seyferts (Ho et al. 2003). Yes, there are Type II (obscured) quasars (Derry et al. 2003 on the X-ray emission from 3C 257, at $z = 2.474$, the most distant radio galaxy in 3C, and other examples).

No, BAL (broad absorption line) QSOs are not physically special, but just an orientation effect (Aldcroft & Green 2003). And so yes, it is OK that some of them are FR II radio sources (Brotherton et al. 2002, with the second example, from the bright quasar survey).

Yes, there is more association on the sky of QSOs with nearby galaxies ($z = 0.15$–0.35 vs. 1.6) than gravitational lensing or other conventional models can account for (Gaztanaga 2003). And no, we don't really think that lensing by globular clusters (Bukhmastova 2003) is likely to be the answer either.

Yes, QSOs reveal a proper Hubble diagram (correlation of apparent magnitude with redshift) if you have enough of them to bin on both axes and use averages (Basu 2003).

No, most QSOs are not SCUBA (submillimeter) sources (Priddey et al. 2003), nor, indeed, conversely (Serjeant et al. 2003).

Yes, there are red (presumably dust-absorbed) QSOs, but only out to $z = 1.3$, and they are most common at $z \approx 1$ (White et al. 2003b).

No, blazars and flat spectrum radio sources are not an evolutionary sequence (Fan et al. 2003). Indeed, though there were more AGNs in the past, their properties have changed rather little with time (Vignali et al. 2003).

Yes, jets have counterjets, but you see both only when the bulk motion is not very relativistic (Saxton et al. 2002 on Her A) and many of them are in fact very relativistic, with even the optical emission beamed (Rokaki et al. 2003, the middle one of 13 jet/beaming papers).

No, microlensing is not the main cause of the rapid variability in the prototype lensed quasar pair 0957+561AB (Colley et al. 2003).

Yes, some are TeV sources, say Aharonian et al. (2003) on what is somewhere between the fifth and eighth example, 1ES 1959+650 at $z = 0.047$. They are in either case considerably outnumbered by the papers on the topic this year.

No, the first variable radio quasar, CTA 102, was not trying to signal to one of the participants at a SETI conference held the year of its discovery (Dent 1965), but yes, it was independently discovered east of the prime meridian (Sholomitski 1965).

Yes, unification (the sort that says what we see depends very much on viewing angle) is part of the story (Donato et al. 2003), but not the whole story (Panessa & Bassani 2002); the last and first of 14 indexed papers addressing the issue.

No, the whole story of why a minority of active galaxies are radio loud is not in (Woo & Urry 2002), but we caught a vote for rapidly-rotating Kerr black holes (Bian & Zhao 2003).

Yes, the central black hole sometimes eats a star (Gezari et al. 2003), and no, this has not resulted in the average AGN black hole being more massive now that it was at $z = 4$–6 (Bechtold et al. 2003a), though there is some correlation of types with mass (Liang & Liu 2003).

12.4. The Care and Feeding of Magnetic Fields

Actually, this is the easy part. Once there are seed fields on the scales of galaxies, they can be amplified by differential rotation and other large scale gas flows (Sokoloff 2002). Mininni et al. (2003) remind their readers that Hall currents (neglected in standard MHD calculations) may be important. We think these could occur in any room in the house.

The hard part is getting started. Historically, there have been two approaches, large to small (slightly exotic physics in the early universe, leaving extended very weak fields that are amplified when gas contracts into dark matter halos), and small to large (less exotic physics in galaxies or their nuclei producing stronger fields that are diluted by being spread around). Widrow (2002) discusses both. The other papers we caught during the year all seem to be of the small-to-large persuasion: Rydberg matter in clusters of galaxies (Badiei & Holmlid 2002), currents arising from collisions in partially-ionized plasmas as they collapse on the length scale of star formation (Birk et al. 2002), and a "cosmic battery" in accretion flow onto black holes arising from the radiation force on the electrons (Bisnovatyi-Kogan et al. 2002). But, just to be safe, next time you create a new universe, you might want to bring a few permanent magnets with you from home.

12.5. Spiral Galaxies

The class you assign to a particular spiral can depend on the rest wavelength of the image (Windhorst et al. 2002), though curiously only about half look later in UV than in visible light. It will certainly depend on when you look, because dense environments are turning S's into passive S's (Goto et al. 2003), and to S0's to E's all the time (Lubin et al. 2002). It can even depend on how hard you look, since grand design spirals also seem to have a flocculent component (Elmegreen et al. 2003), which is perhaps why the giant molecular clouds are not different in the two types (Tosaki et al. 2003).

A very few spirals have leading as well as following arms, but it is not so easy to tell which is which as you might suppose (Buta et al. 2003, reversing an earlier vote by the same group on NGC 4622).

The question of whether you can see right through the disk of a face-on spiral has been around for so long we have almost forgotten why it mattered (something to do with distance scales when the galaxy in question is the Milky Way and the evidence for dark matter in others). The answer is clearly no (Master et al. 2003). It is easier, however, in galaxies with little dust because they are metal poor (Morgan & Edmunds 2003).

How is mass in the inner parts of spirals divided between a disk and a spheroid (halo) component? The answer seems to be "with clenched teeth;" for instance, between Kranz et al. (2003) favoring halo mass, and Masset & Bureau (2003) favoring disk mass. The papers appeared sequentially (front-to-back, not back-to-back!) and fortunately do not pertain to the same galaxy. Given the propensity of baryons to dissipate and flow, we see no reason why all spirals should be the same in this respect.

The last gasp issue. A good many galaxies, including the Milky Way, seem to have only enough gas left to fuel their current star formation rates for a Gyr or less. Secretly, we think that this is probably evidence for continuing secret inflow (§ 9). But also the problem does not arise for all galaxies, even if you think of them as closed systems (Lee et al. 2002, observations), and maybe not even for most galaxies (Clarke & Oey 2002 calculations), period.

13. CLOCKS STRIKING THIRTEEN

A clock striking 13 is generally said to cast doubts upon all of its previous pronouncements.[12] And you may well feel similarly about this 13th section of the 13th ApXX. The responses from readers who feel this most strongly always begin, "Thank you for mentioning my work." And the next word is invariably "But." So here are some of the buts and butts we have collected during the year, beginning with errors and omissions from Ap02, ordered by section number, and continuing with items from other sources.

13.1. But One

Section 1: *MNASSA* is really *Monthly Notes of the Astronomical Society of South Africa*, the title Monthly Notices have been preempted by a larger journal. And the city in Sweden is Kiruna, not Karuna (but there is a Karungi in Sweden).

Section 3.4.5. The Cepheid with a 210 day period is HV 1956, and a colleague has written, most unusually, to report that he did not discover it (but he did publish a spectrum in *AJ* 89, 1705).

Section 4.3. The β Pictoris moving group is (at about 20 pc) the closest on average, but the somewhat more distant UMa moving group has at least one closer member. You may have seen it and asked, "Are you Sirius?"

Section 5.4. One of the authors quoted on interstellar absorption provided a clarification that starlight is indeed reddened in passage through interstellar space, but all interstellar grain models are wrong.

Section 6.2. The passage reading "The prototype of these these stars…" should have said, "The prototype of these three stars…." The original draft had said "these late helium flash stars…," which seemed like too many modifiers for one little noun to support, nouns not being paid extra as they were in

[12] Though pride of place surely goes to the clocks of London, which were striking ten past nine when Phileas Fogg returned from going around the world in 79 days.

the days of the 3 inch caterpillar. The correspondent who called attention to the problem suggested that, since the stars concerned are far along their evolutionary tracks, they might be experiencing celestial menopause. This is when stars stop…um…no.

Section 7.2. A distance to the Vela SNR of less than 300 pc appears in Jenkins & Wallerstein (1995), but they had been thinking about the issue since the 1970s.

Section 9.4. One of the authors whose work on accretion by black holes was mentioned points out that their calculation does not include radiation pressure but is pure MHD. We were going to pass on more of his explanation of magnetic effects in black hole accretion but gave up when it referred to MRI, which has already been recognized with a Nobel Prize this year.

Section 9.5. We foolishly said that if anyone had suggested that gamma-ray bursts were hollers from extraterrestrial intelligence, we had missed it. Yes, we had missed it. Harris (1990) looked for linear alignments of bursts (then thought to show positron annihilation features) along hypothetical interstellar spacecraft trajectories. He didn't find any.

Section 9.2. Interstellar matter in elliptical galaxies was studies by Minkowski & Osterbrock (1959), but we are taking a correspondent's word that they were first. And they explicitly joined Baade (1951) in denying the presence of dust and claiming only gas.

Section 12.3. The author cited denies that $z = 0.036$ is "a modest redshift," describing it as distinctly low. But the real point is that the Lyα clouds in voids are quite numerous but small, so that the total mass density there is less than that contributed by clouds that are part of various structures. "Modest" is one of those words that seems to get the less modest author into trouble fairly often. A fellow member of an advisory panel has never quite forgiven her for breaking into giggles when he spoke of "a modest number" (of dollars to be used for something), because she was imagining a blond, blue-eyed Three clutching a negligee around herself.

Section 12. Our decoding of the galaxy that "formed ≥4 Gyr since the redshift of the observation" was correct. The authors indeed meant "formed at least 4 Gyr before the photons we observe left the galaxy," but they continue to prefer their phrasing. The words "since," "until," and "before" apparently divide the territory of temporal relationships in some different fashion from the seemingly-similar words in other major European languages. More conference announcements than not urge potential participants to "register until the 15th of September."

References. These have become so numerous that a correspondent has started rearranging the names into potential co-authorships like Cold & Refrigier, Kennell & Hundhausen, and Walker & Jog.

13.2. Butt Two

The Flat Earth Society. Plotting missile ranges as circles on a Mercator projection will greatly over- or under-represent the truth, depending on the latitude at which 1° longitude $= N$ miles was normalized. In the case of a 3 May issue of *The Economist*, we think that the high northern latitudes need to worry a good deal more about North Korean missiles than you would guess from their rectangular grid map. And some other items that seem to misrepresent relationships among things:

- HPMS can unleash as much electrical power—2 billion watts or more—as the Hoover Dam generates in 24 hours (*Time*, 27 January, p. 27).
- Redshift is based on the assumption that the rate of the universe's expansion is slowing down (*Nature* 422, 109).
- The asymptotic spectral index s is not an asymptote (*ApJ* 591, 961; they mean that the function reaches its limiting values very quickly).
- [Spectroscopy] extends to wavelengths of 100's of km down to 10's of nm (*Nature* 425, 352, which excludes many X-ray and gamma-ray features, but takes in AM radio).
- Adiabatic and ionization losses…might be contributing significantly to the integrated electron spectrum (*A&A* 394, 71, abstract; and we think these processes may have been let loose on our checkbook).
- Most spheroids burn at redshift $z = 2$–3 (*MNRAS* 338, 623, abstract; "form" was perhaps intended).
- The only person in the world to be named after one of the universe's elements while still living (from a fund-raising letter for the World Innovation Foundation, noted in *Nature* 421, 473. They mean Glenn Theodore Seaborg, the only University of California Nobel Prize winner whose surname is an anagram of "Go Bears," the UC fight slogan, and who, together with Lyne Starling Trimble, constituted two-thirds of their graduating class in chemistry from UCLA roughly 70 years ago).

This brings us naturally to:

Missing persons. "In 1962, Giacconi loaded a sensitive version of a Geiger counter aboard a sounding rocket and for the first time saw X-rays from the sun." (*Science* 298, 527; and the missing person is Herbert Friedman, who did roughly that in 1949; Giacconi organized the first expedition above the atmosphere that saw non-solar-system X-rays). And some others:

- His grandfather gave him a telescope at age 8 (*Mercury* 32, No. 2, p. 5. This VERY precocious grandfather had a grandson named Jesse Leonard Greenstein).
- From first light to the Milkey Way (*IAU Bulletin* 93, 22; a conference title, and it would be most unfair to blame Robert Milkey, the AAS executive secretary).
- He invented a reflection goniometer and a new sort of sexton (from an unedited biography of William Wollaston, intended for the *Biographical Encyclopedia of Astronomy*; goniometers measure angles, and your guess is as good as ours what the sexton was supposed to measure).
- Gravity physics, a field that for decades consisted of a few

cheap table top experiments and a few theories (*Physics Today* 53, No. 11, p. 56. The missing person has to be strong enough to lift the many-ton 38 inch aluminum bar off Joe Weber's table. We have also not been able to locate the carpenter who built the table).

• Center of mass correction to an error-prone undergraduate (*American Journal of Physics* 71, 185, title; we suppose that pre-correction he often tipped over and could be found on the floor if you really needed him).

• The post–Herbig Ae/Be star HD 141569A (*ApJ* 585, 494, abstract. Never, we trust).

• van den Bergh, Clure, & Evans (*ApJ* 583, L71, text and references. Robert McClure was apparently in such a hurry he left his Mc behind)

• And our absolute favorite in this category, "JCMT, named after James Clerck, who discovered the equations describing electromagnetic radiation, and his wife Maxwell." (*Hawaii Tribune-Herald*, 22 June 2003, p. 46. We have not checked up on whether either James Clerk or Maxwell ever married.)

The modplaced misifier and other phrases that caused us to ponder whether they could have been said differently. Hard to pick a favorite in this class, but "a radiative flux relation which is about as well as to the stars derived from angular diameters" (*Ap&SS* 283, 226, abstract) is definitely in the running. And the runners-up:

• Less is known about numbered carbon chains (*ApJ* 58, L157, text).

• UV emission from Green et al. (*ApJS* 143, 257, abstract; requiring some blueshifting of the emitter).

• Polarization from the turbulent dynamo simulations (*ApJ* 585, 536, title).

• The A− bomb (from a referee's report we didn't see on a manuscript we don't know about by an anonymous author, all of whom received at best B+).

• A general theory of homeoidally striated density profile where no divergence occurs (*NewA* 8, 119).

• "Burning Plasma Assessment Committee" and "Burning Plasma Assessment Committee Report" from the December 2002 newsletter of the NAS Board on Physics and Astronomy. Conceivably this could be justified for the report, but it seems a bit harsh on the Committee.

• Cosmological models in cluster sized halos (*ApJ* 588, 674; the running head, but it must be very crowded).

• Models underestimate the rate of rotational breaking (*MNRAS* 336, 577, abstract), which automatically gets paired with, "brake frequencies of GRBs" (*MNRAS* 337, 1434, conclusion; and yes, it is a spectral break that is intended, though some of the models are at least slowed if not stopped).

• Thin domain walls with spherically symmetric following (*Ap&SS* 282, 391, introduction).

• This simple picture is much more complicated (*AJ* 125, 1795, introduction).

• The "dressed BH" which has choices of "wedding dress" and "see-through party dress" (*PASJ* 55, 155).

Detectives on the police farce. This supposed correction to a reference to "defectives on the police force" is the theme of the following:

• The dotted line marks a linear relation between the two properties and is not a fit to the data (*MNRAS* 337, 61, figure caption). Indeed, it is not a fit, since there is no dotted line.

• The labels in Fig. 3 were rendered illegibly in the print edition of the Journal. The figure is reproduced on the following pages (*AJ* 124, 3486; and the labels are still illegible).

• This article has been misprinted. Following this page, the article will be printed again (*A&A* 396, 429; but you must go back to the original to see how it was misprinted).

Rogue signs and capitals.

• The sensitivity achieved by various X-ray missions is given in units like 10^{16} erg cm^{-2} s^{-1} (for *XMM* in *Rev. Mod. Phys.* 75, 1029). This is the largest of the year, as far as we could tell.

• The jet density that turns out to be about 10^{10} g cm^{-3} is not a misprint but a model that probably doesn't work (*MNRAS* 338, 331), at least not for that object.

• Siding Springs (*New Scientist* 28 June, p. 36). Well, actually, there are several observatories, but only one Spring, the late Frank Kerr once gently corrected us, "It is, after all, Australia."

• CD galaxies (*Sky & Telescope*, June, p. 61), which presumably play the music of the spheres.

• AG Peg between phases 7.34 and 9.44 (*MNRAS* 339, 125, title and throughout). The numbers are surely right, but in what units, since phases normally fall between 0.0 and 1.0.

• A_v = absolute magnitude in *V* band; A_v = amplitude of variability in *V* band (*ApJ* 588, L85; both several places in the text). The colors *Z* and *z* vs. redshift in *ApJ* 587, 544 belong to the same tradition (which is not one we wish to encourage).

New words during the year included: perinigricon (*Nature* 419, 694; the part of the orbit nearest a black hole), surfatron (*ApJ* 579, 327; a radiation mechanism), the Dentist's Chair galaxy (*ApJ* 579, L79; no relation to the Keen Amateur Dentist of Ap02, § 9.4), logatropes (*A&A* 395, 321; not quite sure, but they ought to be cylindrical, like the author of The Longest Series), lumina (*Nature* 423, 17; approximately the equivalent of big bang or tremendous space kablooey), and Xallarap (*ApJ* 584, 278; it is parallax spelled backwards).

They are, properly speaking, acronyms only if they can be pronounced, but no one who spoke properly would have coined any of the following: YODA (yet another object detection application; *A&A* 395, 371), CHIANTI (an atomic database; *ApJS* 144, 71) SMAUG (spectral modeling and unfolding of galaxy clusters, *ApJ* 592, 62; and there is also a Hobbit diagram). LEGO (Lyα emitting galaxy-building object; *A&A* 407, 147).

And the coveted TAPFAAC (Trimble-Aschwanden prize for awkward acronym coinage) goes to ELHC (EROS LMC HAeBe Candidates; *A&A* 395, 829) because three of its four components are already abbreviations of various sorts.

The unclassifiable. These are truly our favorites. The first comes from the instructions for ordering a copy of the proceedings of an astrophysics conference: "Payments should be made by money transfer to the Bank Accounts below. Money transfer expenditures is paid by you. Once decont from the bank (the address below) the Proceedings Book will be sent immediately to the address(es) indicated."

From a request for a letter of recommendation: "I think only a few announcements [of positions] will appear in the next future." We would be glad of a next future, not being very optimistic about the one now looming. And from one of the responses to requests for input to the present paper, "I shall see this question some time but think that in my case it is very problematic."

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REFERENCES

Abad, C., et al. 2003, A&A, 397, 345
Abbett, W. P., & Fisher, G. H. 2003, ApJ, 582, 475
Abramowicz, M. A., et al. 2002, A&A, 396, L31
Adelberger, K. L., et al. 2003, ApJ, 584, 45
Aerts, C., et al. 2003, Science, 300, 1926
Afonso, C., et al. 2003, A&A, 400, 751
Afshordi, N., et al. 2003, ApJ, 594, L71
Aharonian, F., et al. 2003, A&A, 406, L9
Ahn, B. H., & Moon, G. H. 2003, JKAS, 36, 93
Ahn, S.-H. 2003, MNRAS, 343, 1095
Akiyama, S., et al. 2003, ApJ, 584, 954
Aksnes, D. W. 2003, Science, 300, 47 (quoted)
Albrow, M. D., et al. 2002, ApJ, 579, 660
Albuquerque, I. F., & Baudis, L. 2003, Phys. Rev. Lett., 90, 221301
Alcaino, G., et al. 2003, A&A, 400, 917
Aldcroft, T. L., & Green, P. J. 2003, ApJ, 592, 710
Alekseev, I. Y., & Kozlova, O. V. 2003, Astrofizika, 46, 28
Alexander, D., & Metcalf, T. R. 2002, Sol. Phys., 210, 323
Alexander, R. C., et al. 2002, Sol. Phys., 210, 407
Allen, S. W., et al. 2003, MNRAS, 342, 287
Aller, M. C., & Richstone, D. 2002, AJ, 124, 3035
Althaus, L. G., et al. 2003, A&A, 404, 593
Altrock, R. C. 2003, Sol. Phys., 213, 23
Altyntsev, A. T., et al. 2003, A&A, 400, 337
Amari, T., et al. 2003, ApJ, 585, 1073
Amelino-Camelia, G., et al. 2003, Nature, 423, 263
Amendola, L., et al. 2003, ApJ, 583, L53
Anderson, D. L., et al. 2002, Science, 299, 35 (quoted)
Andersson, N., et al. 2003, Phys. Rev. Lett., 90, 091101
Andre, M. K., et al. 2003, ApJ, 591, 1000
Antia, H. M. 2003, ApJ, 590, 567
Antia, H. M., & Chitre, S. M. 2002, A&A, 393, L95
Antiochos, S. K., et al. 1999, ApJ, 510, 485
———. 2003, ApJ, 590, 547
Arefiev, V. A., et al. 2003, ApJ, 586, 1238
Arieli, Y., & Rephaeli, Y. 2003, NewA, 8, 517
Armitage, P. J., et al. 2003, MNRAS, 342, 1139
Arons, J. 2003, ApJ, 589, 871
Arrieta, A., & Torres-Peimbert, S. 2003, ApJS, 147, 97
Asai, A., et al. 2003a, ApJ, 586, 624
———. 2003b, ApJ, 578, L91
Aschwanden, M. J., et al. 2002, Sol. Phys., 210, 383
Asensio-Ramos, A., et al. 2003, ApJ, 588, L61
Ashtekhar, A., & Krishnan, B. 2002, Phys. Rev. Lett., 89, 261101
Asimow, P. D. 2003, Nature, 423, 491
Astakhov, S. A., et al. 2003, Nature, 423, 264
Atkins, R., et al. 2003, ApJ, 583, 824
Aubert, B., et al. 2003, Phys. Rev. Lett., 90, 242001
Audard, M., et al. 2003, ApJ, 589, 983
Aulanier, G., & Démoulin, P. 2003, A&A, 402, 769
Baade, W. 1951, Publ. Univ. Mich. Obs., 10, 7
Baade, W., & Swope, H. H. 1961, AJ, 66, 300
Babadzhanov, P. B. 2003, A&A, 397, 319
Babcock, H. W. 1949, ApJ, 110, 126
———. 1958, ApJS, 3, 141
Bacon, D. J., et al. 2003, MNRAS, 344, 673
Badiei, S., & Holmlid, L. 2002, MNRAS, 335, L94
Bagnulo, S., et al. 2003, A&A, 403, 645
Bahcall, J. N., et al. 2003, Phys. Rev. Lett., 90, 131301
Bahcall, N. A., & Bode, P. 2003, ApJ, 588, L1

Bai, T. 2003a, Sol. Phys., 215, 327
———. 2003b, ApJ, 591, 406
———. 2003c, ApJ, 585, 1114
Bailes, M., et al. 2003, ApJ, 595, L49
Bailin, J. 2003, ApJ, 583, L79
Bains, I., et al. 2003, MNRAS, 338, 287
Baldwin, J. A., et al. 2003, ApJ, 582, 590
Balona, L. A., & Laney, C. D. 2003, MNRAS, 344, 242
Banerjee, S., et al. 2003, MNRAS, 340, 284
Baraffe, I., et al. 2003, A&A, 402, 701
Barber, G. A. 2002, Ap&SS, 282, 683
Barge, P., & Viton, M. 2003, ApJ, 593, L117
Barnes, S. A. 2003a, ApJ, 586, L145
———. 2003b, ApJ, 586, 464
Barrado y Navascues, D., et al. 2002, A&A, 393, L85
Barraud, C., et al. 2003, A&A, 400, 1021
Barrio, F. E., et al. 2003, MNRAS, 342, 557
Barstow, M. A., et al. 2003, MNRAS, 341, 870
Barth, A. J., et al. 2003a, ApJ, 584, L47
———. 2003b, ApJ, 594, L95
Basson, J. F., & Alexander, P. 2003, MNRAS, 339, 353
Basu, D. 2003, J. Astrophys. Astron., 24, 11
Basu, S., et al. 2003, ApJ, 591, 432
Bate, M. R., et al. 2002, MNRAS, 336, 705
———. 2003a, MNRAS, 339, 577
———. 2003b, MNRAS, 341, 213
Batten, A. H. 1968, Publ. Dom. Astrophys. Obs. Victoria, 13, 119
Batten, A. H., et al. 1989, Publ. Dom. Astrophys. Obs. Victoria, 17, 1
Battistelli, E. S., et al. 2002, ApJ, 580, L101
Bauer, J. M., et al. 2003, PASP, 115, 981
Baume, G., et al. 2003, A&A, 402, 549
Baumgardt, H., & Makino, J. 2003, MNRAS, 340, 227
Baumgardt, H., et al. 2003a, ApJ, 582, L21
———. 2003b, ApJ, 589, L25
Bayer-Kim, C. M., et al. 2002, MNRAS, 337, 938
Beasley, M. A., et al. 2002, MNRAS, 336, 168
Bechtold, J., et al. 2003a, ApJ, 588, 43
———. 2003b, ApJ, 588, 119
Becker, H., & Walker, R. J. 2003, Nature, 425, 152
Becker, W., et al. 2003, ApJ, 594, 798
Bedding, T. R., et al. 2002, MNRAS, 337, 79
Bedin, L. R., et al. 2003, AJ, 126, 247
Beech, M. 2002, MNRAS, 336, 559
Beghein, C., & Trampert, J. 2002, Science, 299, 552
Beichman, C. A., et al. 2003, AJ, 125, 2521
Bejger, M., & Haensel, P. 2003, A&A, 405, 747
Bekki, K., et al. 2002, ApJ, 577, 651
———. 2003a, MNRAS, 338, 587
———. 2003b, MNRAS, 344, 399
Belkus, H., et al. 2003, A&A, 400, 429
Bell, E. F., et al. 2003a, MNRAS, 343, 367
———. 2003b, ApJ, 585, L117
Bellot-Rubio, L. R., & Collados, M. 2003, A&A, 406, 357
Bellot-Rubio, L. R., et al. 2003, A&A, 403, L47
Beloborodov, A. M. 2003, ApJ, 588, 931
Benaglia, P., & Romero, G. E. 2003, A&A, 399, 112
Benedict, G. F., et al. 2002, ApJ, 581, L115
Benest, D. 2003, A&A, 400, 1103
Bennett, C. 2003, Science, 299, 991 (quoted)
Bennett, C. L., et al. 2003a, ApJS, 148, 1
———. 2003b, ApJ, 583, 1
Benoit, A., et al. 2003, A&A, 399, L19 and L25
Benz, A. O., & Grigis, P. C. 2002, Sol. Phys., 210, 431
Berdyugina, S. V., & Usoskin, I. G. 2003, A&A, 405, 1121
Berdyugina, S. V., et al. 2002, A&A, 394, 505
Berezhiani, Z., et al. 2003, ApJ, 586, 1250
Berezhko, E. G., et al. 2003, A&A, 400, 971
Berezhnoy, A. A., et al. 2003, PASJ, 55, 859
Berger, E., et al. 2003, ApJ, 588, 99
Berger, T. E., & Berdyugina, S. V. 2003, ApJ, 589, L117
Bergeron, P., & Leggett, S. K. 2002, ApJ, 580, 1070
Berlioz-Arthaud, P. 2003, A&A, 397, 943
Bernetti, S., et al. 2003, A&A, 400, 161
Bernstein, M. P., et al. 2003, ApJ, 582, L25
Berrington, R. C., & Dermer, C. D. 2003, ApJ, 594, 709
Berry, R. S. 2003a, Science, 300, 341
Berry, S. 2003b, Science, 300, 719 (quoted)
Bersier, D., et al. 2002, ApJ, 583, L63
Bertelli, G., et al. 2003, AJ, 125, 770
Bertoldi, F., et al. 2003, A&A, 406, L55
Bertotti, B., et al. 2003, Nature, 425, 374
Bespalov, P. A., & Savina, O. N. 2003, Astron. Lett., 29, 50
Beutter, H., et al. 2003, A&A, 395, 169
Beveridge, C., et al. 2002, Sol. Phys., 209, 333
Bewsher, D., et al. 2003, Sol. Phys., 215, 217
Bhattacharya, D. 2002, J. Astrophys. Astron., 23, 67
Bhattacharya, D., et al. 2003, A&A, 404, 163
Bian, W.-H., & Zhao, Y.-H. 2003, PASJ, 55, 599
Bianchi, L., & Garcia, M. 2002, ApJ, 581, 610
Bianchini, A., et al. 2003, PASP, 115, 474
Bica, E., et al. 2003, A&A, 404, 223
Biemont, E., et al. 2002, MNRAS, 336, 1155
Bilenko, I. A. 2002, A&A, 396, 657
Binnette, L., et al. 2003, ApJ, 590, 58
Birk, G. T., et al. 2002, A&A, 393, 685
Birn, J., et al. 2003, ApJ, 588, 578
Bisnovatyi-Kogan, G. S., et al. 2002, ApJ, 580, 380
Bissantz, N., et al. 2003, MNRAS, 340, 1190
Bitzaraki, O. M., et al. 2003, NewA, 8, 23
Bize, S., et al. 2003, Phys. Rev. Lett., 90, 151802
Bizzarro, M., et al. 2003, Nature, 421, 931
Bjornsson, G., et al. 2002, ApJ, 579, L59
Blackman, E. G., & Brandenburg, A. 2003, ApJ, 584, L99
Blagojevic, V., et al. 2003, MNRAS, 339, L7
Blanton, M. R., et al. 2003, ApJ, 594, 186
Bleybel, A., et al. 2002, A&A, 395, 685
Blondin, J. M., et al. 2003, ApJ, 584, 971
Bloom, J. S., et al. 2003, AJ, 125, 999
Blumenschine, R. J., et al. 2003, Science, 299, 1217
Boboltz, D. A., et al. 2003, AJ, 126, 484
Bodaghee, A., et al. 2003, A&A, 404, 715
Boehnhardt, H., et al. 2003, A&A, 395, 297
Bogdanov, M. B., & Taranova, O. G. 2003, Astron. Rep., 47, 535
Bonamente, M., et al. 2003, ApJ, 585, 722
Boothroyd, A., & Sackmann, I. J. 2003, ApJ, 583, 1004
Bonatti, E., et al. 2003, Nature, 423, 499
Bond, H. E., et al. 2002, PASP, 114, 1359
———. 2003, Nature, 422, 405
Bondi, M., et al. 2003, A&A, 403, 857
Bonifacio, P., et al. 2003, Nature, 422, 834
Bonnell, I. A., et al. 2003, MNRAS, 343, 413
Boone, L. M., et al. 2002, ApJ, 579, L5
Borde, A., et al. 2003, Phys. Rev. Lett., 90, 151301
Borriello, A., et al. 2003, MNRAS, 341, 1109
Boss, A. P., et al. 2002, Icarus, 156, 291
Boughn, S. P., et al. 2002, ApJ, 580, 672
Boutloukos, S. G., & Lamers, H. J. G. L. M. 2003, MNRAS, 338, 717
Bower, G. C., et al. 2003, ApJ, 588, 331
Bowler, P. J. 2003, Nature, 423, 384
Bradley, R., et al. 2003, Rev. Mod. Phys., 75, 777
Bradshaw, S. J., & Mason, H. E. 2003a, A&A, 401, 699

———. 2003b, A&A, 407, 1127
Braun, T., et al. 2002, Chem. Phys. Lett., 348, 301
Bridle, S. L., et al. 2003a, Science, 299, 1532
———. 2003b, MNRAS, 342, L72
Briley, M. M., et al. 2002, ApJ, 579, L17
Brisken, W. F., et al. 2003, ApJ, 593, L89
Brkovic, A., & Peter, H. 2003, A&A, 406, 363
Brkovic, A., et al. 2003, A&A, 403, 725
Brochu, A. A., & Ketcham, B. B. 2002, J. Vertebrate Paleontology, 22, 4
Brook, C. B., et al. 2003a, MNRAS, 343, 913
———. 2003b, ApJ, 585, L125
Brooks, D. H., & Costa, V. M. 2003, MNRAS, 339, 467
Brosius, J. W. 2003, ApJ, 586, 1417
Brotherton, M. S., et al. 2002, AJ, 124, 2575
Brown, J. C., et al. 2002a, Sol. Phys., 210, 373
Brown, M. E., et al. 2002b, Nature, 420, 795
Brown, M. L., et al. 2003a, MNRAS, 341, 100
Brown, P., et al. 2002c, Nature, 420, 294
Brown, T. M., et al. 2003b, ApJ, 592, L17
Browning, P. K., & Van der Linden, R. A. M. 2003, A&A, 400, 355
Bruins, H. J., et al. 2003, Science, 300, 315
Brunt, C. M., et al. 2003, ApJS, 144, 47
Brynildsen, N., et al. 2003, A&A, 398, L15
Buchlin, E., et al. 2003, A&A, 406, 1061
Bukhmastova, Y. L. 2003, Astron. Lett., 29, 214
Buote, D. A., et al. 2003, ApJ, 595, 151
Buras, R., et al. 2003, Phys. Rev. Lett., 90, 241101
Buratti, B. J., & Johnson, L. L. 2003, S&T, May, 10 (quoted)
Burbidge, E. M., Burbidge, G. R., Fowler, W. A., & Hoyle, F. 1957, Rev. Mod. Phys., 29, 547
Burbidge, E. M., et al. 2003a, ApJ, 591, 690
Burbidge, G. R. 2003, ApJ, 585, 112
Burbidge, G., et al. 2003b, A&A, 400, L17
Burchell, M. J., & Whitehorn, L. 2003, MNRAS, 341, 192
Burgasser, A. J., et al. 2003a, ApJ, 592, 1186
———. 2003b, ApJ, 594, 510
———. 2003c, AJ, 125, 850
Burko, L. M. 2003, Phys. Rev. Lett., 90, 121101
Burrows, A., et al. 2002, ApJ, 577, 986
———. 2003, ApJ, 594, 545
Bushby, P. J. 2003, MNRAS, 342, L15
Buta, R. J., et al. 2003, AJ, 125, 634
Butler, R. P., et al. 2003, ApJ, 582, 455
Cadavid, A. C., et al. 2003, ApJ, 586, 1409
Caimmi, R., & Secco, L. 2003, Astron. Nachr., 324, 491
Caldwell, R. R., et al. 2003, Phys. Rev. Lett., 91, 071301
Cally, P. 2003, MNRAS, 339, 57
Campana, S., et al. 2003, ApJ, 594, L39
Carilli, C. L., et al. 2003, Science, 300, 773
Carlip, S., & Vaidya, S. 2003, Nature, 421, 498
Carney, B. W., et al. 2003, AJ, 125, 293
Caro, G., et al. 2003, Nature, 423, 428
Carollo, D., et al. 2003, A&A, 400, L13
Carrier, F., & Bourban, G. 2003, A&A, 406, L23
Carswell, B., et al. 2002, ApJ, 578, 43
Carter, B. D., et al. 2003, ApJ, 593, L43
Cassisi, S., et al. 2003a, ApJ, 582, L43
———. 2003b, ApJ, 588, 862
Castillo-Morales, A., & Schindler, S. 2003, A&A, 403, 433
Castro-Tirado, A. J., et al. 2002, A&A, 393, L55
Cavallo, R., et al. 1993, J. Astrophys. Astron., 14, 141
Cellerino, A., & Valdesalici, S. 2003, Science, 301, 305 (quoted)
Cembranos, J. A., et al. 2003, Phys. Rev. Lett., 90, 241301
Cen, R. 2003, ApJ, 591, 12
Cernicharo, J., et al. 2002, ApJ, 580, L157
Cha, S.-H., & Whitworth, A. P. 2003a, MNRAS, 340, 73
Cha, S.-H., & Whitworth, A. P. 2003b, MNRAS, 340, 91
Chabrier, G. 2003a, ApJ, 586, L133
———. 2003b, PASP, 115, 763
Chae, J., et al. 2002, ApJ, 581, 726
———. 2003, JKAS, 36, 13
Chakrabarty, D., et al. 2003, Nature, 424, 42
Chaplin, W. J., et al. 2003, MNRAS, 343, 813
Chapman, C. R., & Morrison, D. 2003, Nature, 421, 473
Charboneau, D. 2003, Nature, 422, 124
Chaty, S., et al. 2003, MNRAS, 343, 169
Chen, D.-M. 2003, ApJ, 587, L55
Chen, P., et al. 2002, Phys. Rev. Lett., 89, 161101
Chen, Y. P., & Zhou, G. C. 2003, Sol. Phys., 215, 57
Cheng, H.-C., et al. 2002, Phys. Rev. Lett., 89, 211301
Chengalur, J. N., & Kanekar, N. 2003, A&A, 403, L43
Cherepashchuk, A. M., & Karetnikov, V. G. 2003, Astron. Rep., 47, 38
Chernov, G. P., et al. 2003, A&A, 406, 1071
Chevalier, R. A., & Oishi, J. 2003, ApJ, 593, L23
Chiang, E. I. 2003, ApJ, 584, 465
Chiang, E. I., & Jordan, A. B. 2002, AJ, 124, 3430
Chiappini, C., et al. 2002, A&A, 395, 789
———. 2003, MNRAS, 399, 63
Chiaverini, J., et al. 2003, Phys. Rev. Lett., 90, 151101
Cho, J., et al. 2003, ApJ, 589, L77
Chornock, R., et al. 2003, IAU Circ. 8114
Choudhuri, A. R. 2003, Sol. Phys., 215, 31
Christensen, P., et al. 2003, Science, 301, 1037 (quoted)
Christian, D. J. 2002, AJ, 124, 3478
Christlieb, N., et al. 2002, Nature, 419, 904
Christopoulou, E. B., et al. 2003, ApJ, 581, 416
Ciardi, B., et al. 2003a, MNRAS, 344, L7
Ciardi, D. R., et al. 2003b, ApJ, 585, 392
Cirkovic, M. M. 2003, Am. J. Phys., 71, 122
Clark, J. S., et al. 2002, A&A, 392, 909
Clarke, C., & Oey, M. S. 2002, MNRAS, 337, 1299
Clausen, J. V., et al. 2003, A&A, 402, 509
Clayton, G. C., et al. 2003, ApJ, 595, 412
Clementini, G., et al. 2003, ApJ, 588, L85
Cline, K. S., et al. 2003, ApJ, 588, 630
Cliver, E. W., et al. 2003, ApJ, 592, 574
Close, F. 2003, Nature, 424, 376
Close, R. M., et al. 2003, Sol. Phys., 212, 251
Cobb, K. M., et al. 2003, Nature, 424, 271
Coburn, W., & Boggs, S. E. 2003, Nature, 423, 415
Coccia, E., et al. 2002, Classical and Quantum Gravity, 19, 5449
Cohen, J. G., et al. 2003, ApJ, 592, 866
Cohen, M., et al. 2002, MNRAS, 336, 736
Colangeli, L., et al. 2003, A&A Rev., 11, 97
Colavita, M., et al. 2003, ApJ, 592, L83
Colbert, E. J. M., & Ptak, A. F. 2002, ApJS, 143, 25
Colbert, I. 2003, Science, 299, 1979 (quoted)
Colley, W. N., et al. 2003, ApJ, 588, 711
Collins, G. W., III, & Scher, R. W. 2002, MNRAS, 336, 1011
Collins, H., et al. 2003, Phys. Rev. Lett., 90, 231101
Conan, R., et al. 2002, A&A, 396, 723
Connors, T. W., et al. 2002, MNRAS, 336, 1201
Conselice, C. J. 2003, ApJS, 147, 1
Conway, A. J., & Matthews, S. A. 2003, A&A, 401, 1151
Conway, A. J., et al. 2003, A&A, 407, 725
Cooper, F. C., et al. 2003, A&A, 408, 735
Cornelisse, R., et al. 2003, A&A, 405, 1033
Corradi, R. L. M., et al. 2003, MNRAS, 340, 417
Correia, A. C. M., & Laskar, J. 2003, Icarus, 163, 24
Cottam, J., et al. 2002, Nature, 420, 51

Covino, S., et al. 2003, A&A, 404, L5
Craig, I. J. D., & Watson, P. G. 2003, Sol. Phys., 214, 131
Craig, I. J. D., & Wheatland, M. S. 2002, Sol. Phys., 211, 275
Cram, W. J. 2003, Nature, 422, 801
Cranmer, S. R., & Van Ballegooijen, A. A. 2003, ApJ, 594, 573
Crane, J. D., et al. 2003, ApJ, 594, L119
Crause, L. A., et al. 2003, MNRAS, 341, 785
Cropper, M., et al. 2003, MNRAS, 344, 33
Cushing, M. C., et al. 2003, ApJ, 582, 1066
Cusumano, G., et al. 2003, A&A, 402, 647
Daddi, E., et al. 2003, ApJ, 588, 50
Dado, S., et al. 2003a, A&A, 401, 243
———. 2003b, ApJ, 594, L89
Dahle, H., et al. 2003, ApJ, 588, L73
Dahlen, T., et al. 2002, Science, 299, 35
Damiani, F., et al. 2003, ApJ, 588, 1009
Damour, T. 2003, Ap&SS, 283, 445
D'Angelo, G., et al. 2003, ApJ, 586, 540
Daniel, K. J., et al. 2002, ApJ, 578, 486
D'Antona, F., et al. 2002, A&A, 395, 69
David, E.-M., et al. 2003, PASP, 115, 825
Davidge, T. J. 2003, PASP, 115, 635
Davies, J., et al. 2002, MNRAS, 336, 155
Dawson, S., et al. 2003, AJ, 125, 1236
Deady, J. H., et al. 2002, MNRAS, 336, 851
Dearborn, D. S. P., & Trimble, V. 1980, Nukeonicka, 25, 1441
de Blok, W. J. G., & Walter, F. 2003, MNRAS, 341, L39
de Blok, W. J. G., et al. 2003, MNRAS, 340, 657
DeDeo, S., & Psaltis, D. 2003, Phys. Rev. Lett., 90, 141101
de Grijs, R., et al. 2003, ApJ, 583, L17
de la Fuente Marcos, C., & de la Fuente Marcos, R. 2002, A&A, 395, 697
Delgado-Donate, E. J., et al. 2003a, MNRAS, 342, 926
Delgado-Donate, E. J., et al. 2003b, A&A, 402, 921
Della Valle, M., et al. 2003a, A&A, 406, L33
———. 2003b, IAU Circ. 8197, 2
Delmas, C., & Laclare, F. 2002, Sol. Phys., 209, 391
Deloye, C. J., & Bildsten, L. 2002, ApJ, 580, 1077
Del Zanna, G. 2003, A&A, 506, L5
Del Zanna, G., & Mason, H. E. 2003, ApJ, 406, 1089
Del Zanna, G., et al. 2003, A&A, 398, 743
de Marcillac, P., et al. 2003, Nature, 422, 875
DeMoortel, I., & Hood, A. W. 2003, A&A, 408, 755
DeMoortel, I., et al. 2003, Sol. Phys., 215, 69
Démoulin, P., et al. 2003, ApJ, 586, 592
Denissenkov, P. A., & VandenBerg, D. A. 2003, ApJ, 593, 509
Dennerl, K. 2002, A&A, 394, 1119
Dent, W. A. 1965, AJ, 70, 672
De Pasquale, M., et al. 2003, ApJ, 592, 1018
de Plaa, J., et al. 2003, A&A, 400, 1013
DePontieu, B., et al. 2003a, ApJ, 590, 502
———. 2003b, ApJ, 595, L63
DeRosa, M., et al. 2002, ApJ, 581, 1356
Derry, P. M., et al. 2003, MNRAS, 342, L53
Diaz, A. J., et al. 2002, A&A, 580, 550
———. 2003, A&A, 402, 781
Dickey, J. O., et al. 2002, Science, 298, 1975
Diego, J. M., et al. 2003, MNRAS, 344, 951
Dietrich, M., et al. 2003a, A&A, 398, 891
———. 2003b, ApJ, 589, 722
DiGiorgio, S., et al. 2003, A&A, 406, 323
Di Matteo, T., et al. 2003, ApJ, 582, 133
Di Mauro, M. P., et al. 2003, A&A, 404, 341
Di Paola, A., et al. 2002, A&A, 393, L21
Dirsch, B., et al. 2003, AJ, 125, 1908
DiStefano, R., & Kong, A. K. H. 2003, ApJ, 592, 884
Dobrzycka, D., et al. 2003, ApJ, 588, 586
Dodds, P. S., et al. 2003, Science, 301, 827
Dolphin, A. E., et al. 2003, AJ, 125, 1261
Domiciano de Souza, A., et al. 2003, A&A, 407, L47
Dominguez-Cerdena, I., et al. 2003a, ApJ, 582, L55
Dominguez-Cerdena, I., et al. 2003b, A&A, 407, 741
Donato, D., et al. 2003, A&A, 407, 503
Donnison, J. R. 2003, MNRAS, 338, 452
Dovady, S., et al. 2003, Science, 300, 47 (quoted)
Doyle, J. G., et al. 2002, A&A, 396, 255
Drake, A. J., & Cool, K. H. 2003, ApJ, 589, 281
Dray, L. M., et al. 2003, MNRAS, 338, 973
Dreizler, S., et al. 2003, A&A, 402, 791
Dressler, A., et al. 1997, ApJ, 490, 577
Drew, J. E., et al. 2003, MNRAS, 338, 401
Dreyer, O. 2003, Phys. Rev. Lett., 90, 081301
Dryomova, G. N., & Svechnikov, M. A. 2002, Astrofizika, 45, 158
Dubrovich, V. K. 2003, Astron. Lett., 29, 6
Dubus, G., & Rutledge, R. E. 2002, MNRAS, 336, 901
Duemmler, R., et al. 2002, A&A, 395, 885
———. 2003, A&A, 402, 745
Duerbeck, H. W., et al., eds. 2002, Astron. Nachr., 323, 6
Dull, J. D., et al. 2003, ApJ, 585, 598
Duncan, R. A., & White, S. M. 2003, MNRAS, 338, 425
Dupke, R., & White, R. E. 2003, ApJ, 583, L13
Dupree, A. 2003, Science, 299, 993
Dupuis, J., et al. 2002, ApJ, 580, 1091
D'urech, J., & Kaasalainen, M. 2003, A&A, 404, 709
Durrant, C. J., & Wilson, P. R. 2003, Sol. Phys., 214, 23
Durrant, C. J., et al. 2002, Sol. Phys., 211, 103
Durrer, R., et al. 2003, ApJ, 583, 33
Dutra, C. M., et al. 2003, A&A, 408, 127
Dybczynski, P. A. 2002, A&A, 396, 283
Eddington, A. S. 1915, MNRAS, 76, 37
———. 1916, MNRAS, 76, 572
———. 1940, MNRAS, 100, 354
Edge, A. C., & Frayer, D. T. 2003, ApJ, 594, L13
Eerik, H., & Tenjes, P. 2003, Astron. Nachr., 324, 242
Eff-Darwich, A., et al. 2002, ApJ, 580, 574
Efstathiou, G. 2003, MNRAS, 343, L95
Eguchi, K., et al. 2003, Phys. Rev. Lett., 90, 021802
Eichler, D., et al. 2002, ApJ, 578, L121
El-Borie, M. A. 2003, Astropart. Phys., 19, 549
El-Borie, M. A., & Al-Thoyaib, S. S. 2002, Sol. Phys., 209, 397
Elliott, J. L., et al. 2003, Nature, 424, 165
Ellis, J. 2003, Nature, 424, 631
Elmegreen, B. G., & Shadmehri, M. 2003, MNRAS, 338, 817
Elmegreen, B. G., et al. 2003, ApJ, 590, 271
English, J., & Freeman, K. C. 2003, AJ, 125, 1124
Enqvist, K., et al. 2003, Phys. Rev. Lett., 90, 091302
Ensslin, T. A. 2003, A&A, 401, 499
Ershov, A. A., & Kuzmin, A. D. 2003, Astron. Lett., 29, 91
Erskine, D. J. 2003, PASP, 115, 255
Esteban, C., et al. 2002, ApJ, 581, 241
Ettori, S. 2003, MNRAS, 344, L13
Evans, A., et al. 2003a, A&A, 408, L9
———. 2003b, MNRAS, 343, 1054
Evans, A. S., et al. 2002, ApJ, 580, 749
Evans, D. 2002, Nature, 420, 359
Evans, N. W., et al. 2003, ApJ, 583, 752
Eyer, L. 2002, Acta Astron., 52, 241
Fabbiano, G., et al. 2003a, ApJ, 584, L5
———. 2003b, ApJ, 588, 175
Fabian, A. C. 2003, MNRAS, 344, L27
Fabian, A. C., et al. 2003, MNRAS, 344, L43
Falcone, A., et al. 2003, ApJ, 588, 557

Falconer, D. A., et al. 2003, ApJ, 593, 549
Famaey, B., & DeJonghe, H. 2003, MNRAS, 340, 752
Fan, J. H. 2003, ApJ, 585, L23
Fan, X., et al. 2003a, AJ, 125, 1649
Fan, Y., & Gibson, S. E. 2003, ApJ, 589, L105
Fan, Y., et al. 2003b, ApJ, 582, 1206
Fang, T., et al. 2003, ApJ, 586, L49
Faraoni, V., & Cooperstock, F. I. 2003, ApJ, 587, 483
Fárnik, F., et al. 2003, A&A, 399, 1159
Farquhar, J., et al. 2002, Science, 298, 2369
Feast, M. W. 2002, MNRAS, 337, 1035
Fedorov, M. V., et al. 2003, Ap&SS, 283, 3
Feigelson, E. D., et al. 2003, ApJ, 584, 911
Feissel-Vernier, M. 2003, A&A, 403, 105
Feldman, W., & Tokar, R. 2003, Science, 300, 234 (quoted)
Fellhauer, M., & Kroupa, P. 2002, AJ, 124, 2006
Felli, M., et al. 2002, A&A, 392, 971
Fender, R. P., et al. 2002, MNRAS, 336, 39
Feng, J. L., et al. 2003, Phys. Rev. Lett., 91, 011302
Ferraro, F. R., et al. 2003, ApJ, 588, 464
Ferreira, S. E. S., et al. 2003, ApJ, 594, 552
Fesenko, B. I. 2003, Astron. Rep., 47, 531
Figer, D. F., et al. 2002, ApJ, 581, 258
Finlay, C. C., & Jackson, A. 2003, Science, 300, 2084
Finoguenov, A., et al. 2002, ApJ, 578, 74
Fischer, D. A., et al. 2003, ApJ, 586, 1394
Fitzpatrick, E. L., et al. 2003, ApJ, 587, 685
Fixen, D. J., & Dwek, E. 2002, ApJ, 578, 1009
Fixen, D. J., & Mather, J. C. 2002, ApJ, 581, 817
Flaccomio, E., et al. 2003a, A&A, 397, 611
———. 2003b, A&A, 402, 277
Fleishman, G. D., & Melnikov, V. F. 2003a, ApJ, 584, 1071
———. 2003b, ApJ, 587, 823
Fleishman, G. D., et al. 2003, ApJ, 593, 571
Fleming, T. A., et al. 2003, ApJ, 594, 982
Fletcher, L.& Hudson, H. S. 2002, Sol. Phys., 210, 307
Flower, D. R., & Pineau des Forets, G. 2003, MNRAS, 341, 1272
Fludra, A., & Ireland, J. 2003, A&A, 398, 297
Foellmi, C., et al. 2003a, MNRAS, 338, 360
———. 2003b, MNRAS, 338, 1025
Fogli, G. L., et al. 2003a, Phys. Rev. D, 67, 73001
———. 2003b, Phys. Rev. D, 67, 73002
Foley, C. R., et al. 2003, A&A, 399, 749
Fong, D., et al. 2003, ApJ, 582, L39
Fontaine, G., et al. 2003, ApJ, 591, 1184
Forbes, T. G., & Priest, E. R. 1995, ApJ, 446, 377
Ford, K. E. S., et al. 2003, ApJ, 589, 430
Foschini, L., et al. 2002, A&A, 396, 787
Foukal, P. V. 2002, Geophys. Res. Lett., 29, 2089
Fragile, P., et al. 2003, ApJ, 590, 778
Frail, D. A., et al. 2003, AJ, 125, 2299
Frandsen, S., et al. 2002, A&A, 394, L5
Franklin, F. A., & Soper, P. R. 2003, AJ, 125, 2678
Freese, K., & Lewis, M. 2002, Phys. Lett., B540, 1
Freire, P. C., et al. 2003, MNRAS, 340, 1359
Freitag, M., & Benz, W. 2002, A&A, 394, 345
Freudling, W., et al. 2003, ApJ, 587, L67
Friedland, A., & Gruzinov, A. 2003, Astropart. Phys., 19, 575
Fryer, C. L., & Meszaros, P. 2003, ApJ, 588, L25
Fukazawa, Y., et al. 2002, PASJ, 54, 527
Fukue, J., & Hanamito, K. 2002, PASJ, 54, 1057
Fukugita, M., & Kawasaki, M. 2003, MNRAS, 343, L25
Furuya, R. S., et al. 2003, ApJS, 144, 71
Fynbo, J. P. U., et al. 2003, A&A, 406, L63
Gabuzda, D. C., & Cawthorne, T. V. 2003, MNRAS, 338, 312
Gaizauskas, V. 2002, Sol. Phys., 211, 179
Gal, R. R., et al. 2003, AJ, 125, 2064
Galama, T. J., et al. 2003, ApJ, 587, 135
Gallagher, P. T., et al. 2002, Sol. Phys., 210, 341
———. 2003, ApJ, 588, L53
Gallart, C., et al. 2003, AJ, 125, 742
Galloway, D. K., et al. 2002, ApJ, 580, 1065
Gal-Yam, A., et al. 2003, AJ, 125, 1087
Gambini, R., & Pullin, J. 2003, Phys. Rev. Lett., 90, 021301
Gamezo, V. N., et al. 2003, Science, 299, 77
Gammie, C. F., et al. 2003, ApJ, 592, 203
Garcia-Ruiz, I., et al. 2002, MNRAS, 337, 459
Garnavich, P., Matheson, T., Olszewski, E. W., Harding, P., & Stanek, K. Z. 2003a, IAU Circ. 8114
Garnavich, P., et al. 2003b, ApJ, 582, 924
Garnett, D. R. 2003, ApJ, 581, 1019
Gary, D. E. 2003, JKAS, 36, 135
Gaztanaga, E. 2003, ApJ, 589, 82
Gebhardt, K. 2002, Nature, 419, 675
Gebhardt, K., et al. 2002, ApJ, 578, L41
Gedalin, M., et al. 2003, MNRAS, 337, 422
Gehrels, N., et al. 2003, ApJ, 585, 1169
Geiss, J., et al. 2002, ApJ, 578, 862
Genda, H., & Abe, Y. 2003, Icarus, 164, 149
Gendre, B., et al. 2003a, A&A, 400, 521
———. 2003b, A&A, 403, L11
Georgakakis, A., Georgantopoulos, I., Stewart, G. C., Shanks, T., & Boyle, B. J. 2003, MNRAS, 344, 161
Georgakilas, A. A. 2003a, A&A, 403, 1123
———. 2003b, ApJ, 584, 509
Geppert, U., & Reinhardt, M. 2002, A&A, 392, 1015
Gerrard, C. L., & Hood, A. W. 2003, Sol. Phys., 214, 151
Gerrard, C. L., et al. 2003, Sol. Phys., 213, 39
Gerssen, J., et al. 2002, AJ, 124, 3270
———. 2003, AJ, 125, 376
Gezari, S., et al. 2003, ApJ, 592, 42
Ghez, A. M., et al. 2003, ApJ, 586, L127
Gies, D. R., et al. 2002, ApJ, 578, L67
Gillett, F. G., et al. 1988, AJ, 96, 116
Gimeno, L., et al. 2003, Earth Planet. Sci. Lett., 206, 15
Giorgi, M. 2003, Nature, 423, 118 (quoted)
Girart, J. M., et al. 2002, Rev. Mexicana Astron. Astrofis., 38, 169
Gladders, M. D., et al. 2003, ApJ, 593, 48
Glass, I. S., & Schultheis, M. 2002, MNRAS, 337, 519
Glover, A., et al. 2003, A&A, 400, 759
Glushkov, A. V. 2003, Astron. Lett., 29, 142
Gnedin, N. Y., & Shandarin, S. F. 2002, MNRAS, 337, 1435
Gnedin, O. Y. 2003a, ApJ, 582, 141
———. 2003b, ApJ, 589, 752
Goldberg, D., et al. 2003, ApJ, 591, 397
Goldman, T., et al. 2003, Science, 301, 153 (quoted)
Goldreich, P., & Sari, R. 2003, ApJ, 585, 1024
Goldreich, P., et al. 2002, Nature, 420, 643
Gomez, M., & Mardones, D. 2003, AJ, 125, 2134
Gonzalez, G. 2003, Rev. Mod. Phys., 75, 101
Gonzalez, R. F., & Canto, J. 2002, ApJ, 580, 459
Gonzalez-Garcia, M. C., & Nir, Y. 2003, Rev. Mod. Phys., 75, 345
Goode, P. R., & Dziembowski, W. A. 2003, JKAS, 36, 75
Goode, P. R., et al. 2003, JKAS, 36, 83
Goodman, J. 2003, MNRAS, 339, 937
Goossens, M., et al. 2002, A&A, 394, L39
Gopalswamy, N., et al. 2003, ApJ, 586, 562
Goranskii, V. P., et al. 2002, Astron. Lett., 28, 691
Gorbunov, D. S., et al. 2002, ApJ, 577, L93
Goto, T., et al. 2003, PASJ, 55, 757
Gotthelf, E. V. 2003, ApJ, 591, 361
Gottloeber, S., et al. 2003, MNRAS, 344, 715

Goudfrooij, P., et al. 2003, MNRAS, 343, 665
Gould, A. 2003a, ApJ, 583, 765
Gould, A. 2003b, ApJ, 592, L63
Gould, A., &, Salim, S. 2003, ApJ, 582, 1001
Gozdziewski, K. 2003a, A&A, 398, 315
———. 2003b, A&A, 398, 1151
Grainge, K., et al. 2003, MNRAS, 341, L23
Granot, J., & Konigl, A. 2003, ApJ, 594, L83
Gratton, S., & Steinhardt, P. 2003, Nature, 423, 817
Grav, T., et al. 2003, ApJ, 591, L71
Gray, R. H., & Ellingsen, S. 2002, ApJ, 578, 967
Grebel, E. K., et al. 2003, AJ, 125, 1926
Grechnev, V. V., et al. 2003, ApJ, 588, 1163
Green, D. A., & Stephenson, F. R. 2004, Astropart. Phys., 20, 613
Green, E. M., et al. 2003a, ApJ, 583, L31
Green, L. M., et al. 2003b, Sol. Phys., 215, 307
———. 2003c, Sol. Phys., 208, 43
Griffin, R. F. 1966, Observatory, 86, 145
———. 2003, Observatory, 123, 286
Griffin, R. F., & Suchkov, A. A. 2003, ApJS, 147, 103
Grindlay, J. E., et al. 2002, ApJ, 581, 470
Grundahl, F., et al. 2002, A&A, 395, 481
Grundy, W. M., et al. 2002, AJ, 124, 2273
Gu, P.-G., et al. 2003, ApJ, 588, 509
Guenther, E. W., & Wuchterl, G. 2003, A&A, 401, 677
Guetta, D., & Granot, J. 2003, MNRAS, 340, 115
Guidorzi, C., et al. 2003, A&A, 401, 491
Guinan, E. F., et al. 2003, ApJ, 594, 561
Gunnarsson, M., et al. 2003, A&A, 402, 383
Gupta, N., et al. 2003, A&A, 406, 65
Gusakov, M. E., & Gnedin, O. Y. 2002, Astron. Lett., 28, 669
Guseva, N. G., et al. 2003, A&A, 407, 91
Haberl, F., et al. 2003, A&A, 403, L19
Hachisu, I., & Kato, M. 2003, ApJ, 588, 1003
Hachisu, I., et al. 2003, ApJ, 584, 1008
Haenninen, J., & Flynn, C. 2002, MNRAS, 337, 731
Haensel, P., et al. 2002, A&A, 394, 213
Hagenaar, H. J., et al. 2003, ApJ, 584, 1107
Haggerty, D. K., & Roelof, E. C. 2002, ApJ, 579, 841
Haghighipour, N., & Boss, A. P. 2003, ApJ, 583, 996
Haiman, Z., & Holder, G. P. 2003, ApJ, 595, 1
Hakala, P., et al. 2003, MNRAS, 343, L10
Hakkila, J., et al. 2003, ApJ, 582, 320
Halbwachs, J. L., et al. 2003, A&A, 397, 159
Halpern, J. P., et al. 2003, ApJ, 585, 665
Hameury, J.-M., & Lasota, J.-P. 2002, A&A, 394, 231
Han, Z., et al. 2003, MNRAS, 341, 669
Handler, G., et al. 2003, MNRAS, 341, 1005
Haneychuk, V. I., et al. 2003, A&A, 403, 1115
Hankins, T. H., et al. 2003, Nature, 422, 141
Hanock, M., et al. 2003, AJ, 125, 1696
Hanuschik, R. W. 2003, A&A, 407, 1157
Hara, H., & Nakakubo-Morimoto, K. 2003, ApJ, 589, 1062
Harra, L. K., & Sterling, A. 2003, ApJ, 587, 429
Harries, T. J., et al. 2002, MNRAS, 337, 341
Harris, M. J. 1990, J. British Interplanet. Soc., 43, 551
Harrison, R. A., et al. 2003, A&A, 409, 755
Harutyunian, G. A. 2003, Astrofizika, 46, 81
Harvey, K. L., & Recely, F. 2002, Sol. Phys., 211, 31
Hasan, S. S., et al. 2003, ApJ, 585, 1138
Hasegawa, I. 2002, PASJ, 54, 1091
Hashimoto, Y., et al. 2003, ApJ, 582, 196
Hathaway, D. H., et al. 2002, Sol. Phys., 211, 357
———. 2003, ApJ, 589, 665
Haug, E. 2003, A&A, 406, 31
Hawkins, E., et al. 2002, MNRAS, 336, L13
Hayashi, E., et al. 2003, ApJ, 584, 541
Heger, A., et al. 2003, ApJ, 591, 288
Heiles, C., & Troland, T. H. 2003, ApJ, 586, 1067
Heinamaki, P., et al. 2003, A&A, 397, 63
Heinke, C., et al. 2003, ApJ, 590, 809
Helfer, T. T., et al. 2003, ApJS, 145, 259
Helmi, A., et al. 2003, MNRAS, 339, 834
Hempel, M., et al. 2003, A&A, 405, 487
Hempelmann, A., et al. 2003, A&A, 406, L39
Henkel, C., et al. 2002, A&A, 394, L23
Hénoux, J.-C., & Karlicky, M. 2003, A&A, 407, 1103
Henry, G. W., et al. 2002, ApJ, 577, L111
Herald, J. E., & Bianchi, L. 2002, ApJ, 580, 434
Herbig, G. H., et al. 2003, ApJ, 595, 384
Hernquist, L., & Springel, V. 2003, MNRAS, 341, 1253
Herrero, A., et al. 2002, A&A, 396, 949
Hestroffer, D., et al. 2003, A&A, 394, 339
Heyl, J. S., et al. 2003, MNRAS, 342, 134
Hidalgo, S. L., et al. 2003, AJ, 125, 1247
Highberger, J. L., et al. 2003, ApJ, 593, 393
Hirashita, H., & Ferrara, A. 2002, MNRAS, 337, 921
Hjorth, J., et al. 2003, Nature, 423, 847
Ho, C., Epstein, R. I., & Fenimore, E. E., eds. 1992, Gamma-Ray Bursts: Observations, Analyses, and Theories (Cambridge: Cambridge Univ. Press)
Ho, L. C., et al. 2003, ApJ, 583, 159
Ho, W. C. G., & Lai, D. 2003, MNRAS, 338, 233
Hobson, A., & Trimble, V. 2003, Am. J. Phys., 71, 295
Hoekstra, H., et al. 2002, ApJ, 577, 595
Hoffleit, D. 2002, J. AAVSO, 30, 139
Hoffman, R. E. 2003, MNRAS, 340, 1039
Hofner, P., et al. 2002, ApJ, 579, L95
Hogg, D. W., et al. 2003, ApJ, 585, L5
Holder, J., et al. 2003, ApJ, 583, L9
Holland, W. S., et al. 2003, ApJ, 582, 1141
Holovatyy, V. V., & Melekh, B. Y. 2002, Astron. Rep., 46, 779
Holt, S. S., et al. 2003, ApJ, 588, 792
Holz, D. E., & Wheeler, J. A. 2002, ApJ, 578, 330
Homan, D. C., et al. 2002, ApJ, 580, 742
Homer, L., et al. 2002, AJ, 124, 3348
Hong, S., & King, J. 2003, Am. J. Phys., 71, 287
Hopp, U., et al. 2003, MNRAS, 339, 33
Hou, L.-S., et al. 2003, Phys. Rev. Lett., 90, 201101
Howe, R., et al. 2002, ApJ, 580, 1172
Huang, Y. F., et al. 2003, ApJ, 594, 919
Hudson, H. S., et al. 2003, Sol. Phys., 214, 171
Hueppop, O., & Hueppop, K. 2002, Proc. R. Soc. London A, B270, 233
Huggins, P. J., & Mauron, N. 2002, A&A, 393, 273
Hughes, D. W. 2002, MNRAS, 336, 363
Hughes, D. W. 2003a, MNRAS, 338, 999
———. 2003b, MNRAS, 339, 1103
Hughes, J. P., et al. 2003, ApJ, 582, L95
Hummel, C. A., et al. 2003, AJ, 125, 2630
Humphrey, P. J., et al. 2003, MNRAS, 344, 134
Hunt, L. K., et al. 2003, ApJ, 588, 281
Hurford, G. J., et al. 2003, ApJ, 595, L77
Hurlburt, N. E., et al. 2002, ApJ, 577, 993
Hurley, S. M., et al. 2002, Science, 298, 202
Hutchinson, J. R., et al. 2003, Nature, 422, 500
Hwang, U., et al. 2002, J. Astrophys. Astron., 23, 81
Hyde, R. 1984, Philos. Trans. R. Soc. London, A, 313, 107
Hynes, R. I., et al. 2003, ApJ, 583, L95
Ibata, R. A., et al. 2003, MNRAS, 340, L21
Ibrahim, A. I., et al. 2003, ApJ, 584, L17
Ibukiyama, A., & Arimoto, N. 2002, A&A, 394, 927

Idiart, T. P., et al. 2003, A&A, 398, 949
Imanishi, K., et al. 2003, PASJ, 55, 653
Inoue, S., et al. 2003, ApJ, 595, 294
Irwin, J. A., & Chaves, T. 2003, ApJ, 585, 268
Irwin, J. A., et al. 2003, ApJ, 587, 356
Israelian, G., et al. 2003, A&A, 405, 753
Istomin, Y. N., & Komberg, B. V. 2002, Astron. Rep., 46, 908
Ito, K., & Okabe, M. 2002, Science, 298, 115 (quoted)
Ito, T., & Tanikawa, K. 2002, MNRAS, 336, 483
Itoh, C., et al. 2003, ApJ, 584, L65
Ivezic, Z., et al. 2002a, AJ, 124, 2364
———. 2002b, AJ, 124, 2943
Jackson, B. V., & Hick, P. P. 2002, Sol. Phys., 211, 345
Jackson, M. S., et al. 2002a, ApJ, 578, 935
Jackson, T., et al. 2002b, MNRAS, 337, 749
Jacobsen, S. B. 2003, Science, 300, 1513
Jacobson, T., et al. 2003, Nature, 424, 1019
Jaikumar, P., & Mazumdar, A. 2003, Phys. Rev. Lett., 90, 191301
Jain, K., & Bhatnagar, A. 2003, Sol. Phys., 213, 257
Jain, R., & Yashiro, S. 2002, A&A, 394, 1111
Jakobsen, P., et al. 2003, A&A, 397, 891
James, S. P., & Erdélyi, R. 2002, A&A, 393, L11
James, S. P., et al. 2003, A&A, 406, 715
Jaroszyński, M., & Paczyński, B. 2002, Acta Astron., 52, 361
Javaraiah, J. 2003, Sol. Phys., 212, 23
Jayawardhana, R., et al. 2003, ApJ, 592, 282
Jeans, J. H. 1915, MNRAS, 76, 70
Jedicke, R. 2002, Nature, 420, 273
Jeffers, S. V., & Asher, D. J. 2003, MNRAS, 343, 56
Jenkins, E. B., & Wallerstein, G. 1995, ApJ, 440, 227
Jerjen, H. 2003, A&A, 398, 63
Ji, H. S., et al. 2002, Sol. Phys., 211, 221
———. 2003, ApJ, 595, L135
Jiang, L., et al. 2003, AJ, 125, 727
Jimenez, A., et al. 2002, Sol. Phys., 209, 247
Jimenez, R., et al. 2003, Science, 299, 1552
Jimenez-Garate, M. A., et al. 2002, ApJ, 578, 391
Jimenez-Reyes, S. J., et al. 2003, ApJ, 595, 446
Jing, J., et al. 2003, ApJ, 584, L103
Johansson, S., & Letokhov, V. 2003, Phys. Rev. Lett., 90, 011101
Johnson, C. L., et al. 2003, Science, 300, 2044
Johnston, S., & Romani, R. W. 2003, ApJ, 590, L95
Jones, B. W., & Sleep, P. N. 2002, A&A, 393, 1015
Jones, H. P., et al. 2003a, ApJ, 589, 658
Jones, H. R. A., et al. 2003b, MNRAS, 341, 948
Jones, P. B. 2003, ApJ, 595, 342
Jose, P. D. 1965, AJ, 70, 193
Juckett, D. A. 2003, A&A, 399, 731
Jura, M. 2003, ApJ, 584, L91
Kaaret, P. 2002, ApJ, 578, 114
Kaaret, P., et al. 2003a, ApJ, 582, 945
Kaaret, P., et al. 2003b, Science, 299, 365
Kahler, S. W., & Reames, D. V. 2003, ApJ, 584, 1063
Kahn, F. D., & Woltjer, L. 1959, ApJ, 130, 705
Kaler, J. B. 1994, Astronomy! (New York: HarperCollins), 335
Kallman, T. R., et al. 2003, ApJ, 593, 946
Kaluzny, J. 2003, Acta Astron., 53, 51
Kamio, S., Kurokawa, H., & Ishii, T. T. 2003, Sol. Phys., 215, 127
Kaplan, D. L., et al. 2003, ApJ, 588, L33
Kaplinghat, M., et al. 2003, ApJ, 583, 24
Kargaltsev, O., et al. 2002, ApJ, 580, 1060
Karick, A. M., et al. 2003, MNRAS, 344, 188
Karlicky, M., et al. 2002a, Sol. Phys., 212, 389
———. 2002b, A&A, 395, 677
———. 2002c, Sol. Phys., 211, 231
Karpen, J. T., et al. 2003, ApJ, 593, 1187
Kaspi, V. M., et al. 2003, ApJ, 588, L93
Kato, M., & Hachisu, I. 2003, ApJ, 587, L39
Kato, T., et al. 2002a, PASJ, 54, L51
———. 2002b, PASJ, 54, 1029
———. 2002c, PASJ, 54, 1033
Katsiyannis, A. C., et al. 2003, A&A, 406, 709
Katysheva, N. A., & Pavlenko, E. P. 2003, Astrofizika, 46, 114
Katz, C. A., et al. 2003, PASP, 115, 675
Kaufman, A. J., & Xiao, S. 2003, Nature, 425, 279
Kawabata, K. S., et al. 2002, ApJ, 580, L39
Kawabata, K. S., et al. 2003, ApJ, 593, L19
Kawata, D., & Gibson, B. K. 2003, MNRAS, 340, 908
Kawka, A., & Vennes, S. 2003, AJ, 125, 1444
Keil, M. T., et al. 2003, ApJ, 590, 971
Keiling, A., et al. 2003, Science, 299, 383
Keller, S. C., et al. 2002, AJ, 124, 2039
Kennicutt, R. C., et al. 2003, ApJ, 591, 801
Kenter, A. T., & Murray, S. S. 2003, ApJ, 584, 1016
Kepler, S. O., et al. 2003, A&A, 401, 639
Keranen, A., & Ouyed, R. 2003, A&A, 407, L51
Kerber, F., et al. 2002, ApJ, 581, L39
Kervella, P., et al. 2003, A&A, 404, 1087
Keyes, D., et al. 2003, Science, 301, 301 (quoted)
Khomenko, E. V., et al. 2003, ApJ, 588, 606
Kiefer, H. H., et al. 1976, J. Geophys. Res., 194, 1341
Kilburn, K. J., et al. 2003, J. Hist. Astron., 34, 125
Kim, E., & MacGregor, K. B. 2003, ApJ, 588, 645
Kim, W.-T., et al. 2002a, ApJ, 581, 1080
Kim, Y.-C., et al. 2002b, ApJS, 143, 499
King, A. R., et al. 2003, MNRAS, 341, L35
King, D. B., et al. 2003b, A&A, 404, L1
King, J. R., et al. 2003a, AJ, 125, 1980
Kinugasa, K., et al. 2002, ApJ, 577, L97
Kirk, J. G., & Skjaeraasen, O. 2003, ApJ, 591, 366
Kiseleva-Eggleton, L., et al. 2002, ApJ, 578, L145
Klebesadel, R. W., Strong, I. B., & Olson, R. A. 1973, ApJ, 182, L85
Klein, R., et al. 2003a, ApJ, 593, L57
Klein, R. G., et al. 2003b, Science, 299, 1525
Klein, R. I., et al. 2003c, ApJ, 583, 245
Klepczynski, W. 2003, Nature, 324, 671
Kliem, B., et al. 2004, A&A, 413, 23
Klinger, R. J., et al. 2002, AJ, 124, 2135
Klose, S., et al. 2003, ApJ, 592, 1025
Knapp, G. R., et al. 2003, A&A, 403, 993
Knigge, C., et al. 2002, ApJ, 579, 752
Ko, Y., et al. 2003, ApJ, 594, 1068
Kochanek, C. S. 2003, ApJ, 583, 49
Kodaira, K., et al. 2003, Science, 299, 1962 (quoted)
Koen, C. 2003, MNRAS, 341, 1385
Kokubo, E., & Ida, S. 2002, ApJ, 581, 666
Kollerstrom, N. 2003a, A&G, 44, 5, 23
———. 2003b, S&T, 106, 1, 26 (quoted)
Komiyama, Y., et al. 2003, ApJ, 590, L17
Konacki, M., & Wolszczan, A. 2003, ApJ, 591, L147
Konacki, M., et al. 2002, Nature, 421, 507
Kong, A. K. H., et al. 2002a, ApJ, 577, 738
———. 2002b, ApJ, 580, L125
Konovalova, N. A. 2003, A&A, 404, 1145
Kontar, E. P., et al. 2002, Sol. Phys., 210, 419
Kopacki, G., et al. 2003, A&A, 398, 541
Kosenko, D. I., et al. 2003, Astron. Lett., 29, 205
Kostyuk, S. V., et al. 2003, Astron. Lett., 29, 387
Kotak, R., et al. 2003, A&A, 397, 1043
Kotoneva, E., et al. 2002, MNRAS, 335, 1147
Kotov, V. A. 2003, A&A, 402, 1145
Kotov, V. A., et al. 2002, Sol. Phys., 209, 233

Kovac, J. M., et al. 2002, Nature, 420, 772
Kovacs, G. 2003, MNRAS, 342, L58
Kraft, R. P., et al. 2003, ApJ, 592, 129
Kramer, M., et al. 2003, ApJ, 593, L31
Kranz, T., et al. 2003, ApJ, 586, 143
Kravtsov, V. 2002, A&A, 396, 117
Krawczyk, A., et al. 2003, MNRAS, 340, 1087
Kreykenbohm, I., et al. 2003, A&A, 395, 129
Krijger, J. M., & Roudier, T. 2003, A&A, 403, 715
Krishan, V., et al. 2003, Sol. Phys., 215, 147
Krivonos, R. A., et al. 2003, Astron. Lett., 29, 425
Krivova, N. A., et al. 2003, A&A, 399, L1
Krucker, S., et al. 2002a, Sol. Phys., 210, 445
———. 2002b, Sol. Phys., 210, 229
Kuan, Y.-J., et al. 2003, ApJ, 593, 848
Kucera, T. A., et al. 2003, Sol. Phys., 212, 81
Kudritzki, R. P., et al. 2003, ApJ, 582, L83
Kulkarni, S. R., et al. 2003, ApJ, 585, 948
Kumar, P., & Narayan, R. 2003, ApJ, 584, 895
Kurster, M., et al. 2003, A&A, 403, 1077
Kuzanyan, K. M., et al. 2003, Chinese J. Astron. Astrophys., 3, 257
Kuznetsov, A. A., & Vlasov, V. C. 2003, Astron. Rep., 47, 129
La Barbera, A., et al. 2003, A&A, 400, 993
LaBelle, J., et al. 2003, ApJ, 593, 1195
Lagerkvist, C.-I., et al. 2002, Astron. Nachr., 323, 475
Laine, S., et al. 2003, AJ, 125, 478
Lamareille, F., et al. 2003, A&A, 402, 395
Landau, L. 1957, J. Exp. Theor. Phys., 5, 101
Landi, E., & Chiuderi-Drago, F. 2003, ApJ, 589, 1054
Lanz, T., & Hubeny, I. 2003, ApJS, 146, 417
Larsen, S. S., et al. 2002, AJ, 124, 2615
Lasheras, J. 2003, Science, 330, 245 (quoted)
Laske, G. 2002, Nature, 421, 10 (quoted)
Laughlin, G., et al. 2002, ApJ, 579, 455
Lawlor, T. M., & MacDonald, J. 2003, ApJ, 583, 913
Layden, A. C., & Sarajedini, A. 2003, AJ, 125, 208
Lazzati, D., et al. 2002, A&A, 396, L5
Leamon, R. J., et al. 2003, ApJ, 596, L255
Lee, C.-F., & Sahai, R. 2003, ApJ, 586, 319
Lee, H., et al. 2003a, AJ, 125, 146
Lee, J. C., et al. 2002, AJ, 124, 3088
Lee, K. H., et al. 2003b, AJ, 126, 815
Lee, S. W., et al. 2003c, JKAS, 36, 21
Lee, S. W., et al. 2003d, ApJ, 585, 524
Lee, S. W., et al. 2003e, JKAS, 36, 63
Le Floc'h, E., et al. 2003, A&A, 400, 499
Lehnert, M. D., & Bremer, M. 2003, ApJ, 593, 630
Lehtinen, K., et al. 2003, A&A, 398, 571
Leinert C., et al. 2002, A&A, 393, 1073
Leitch, E. M., et al. 2002, Nature, 420, 763
Leka, K. D., & Metcalf, T. R. 2003, Sol. Phys., 212, 361
Lellouch, E., et al. 2003, Nature, 421, 45
Lemoine, M., & Pelletier, G. 2003, ApJ, 589, L73
Leonard, D. C., et al. 2002a, AJ, 124, 2490
———. 2002b, AJ, 124, 2506
———. 2003, ApJ, 594, 247
Leone, F., et al. 2003, A&A, 405, 223
Lepine, J. R. D., et al. 2003b, ApJ, 589, 210
Lepine, S., et al. 2003a, ApJ, 591, L49
———. 2003b, AJ, 126, 921
Levi-Civita, T. 1937, Am. J. Math., 59, 225
Levin, Y., & Beloborodov, A. M. 2003, ApJ, 590, L33
Levison, H. F., & Agnor, C. 2003, AJ, 125, 2692
Levshakov, S. A., et al. 2003a, A&A, 404, 449
———. 2003b, ApJ, 582, 596
Lewis, K. T., et al. 2003, ApJ, 582, 770
Leya, I., et al. 2003, ApJ, 594, 605
Li, A. 2003a, ApJ, 584, 593
Li, K. J., et al. 2002a, Sol. Phys., 211, 165
———. 2003b, Sol. Phys., 215, 99
Li, X.-D. 2002, ApJ, 579, L37
Li, X. 2003b, Science, 300, 723 (quoted)
———. 2003c, A&A, 406, 345
Li, Y., et al. 2003, ApJ, 592, 975
Liang, E. W., & Liu, H. T. 2003, MNRAS, 340, 632
Liang, Y. C., et al. 2003, A&A, 397, 257
Lidz, A., et al. 2002, ApJ, 579, 491
Liebert, J., et al. 2003a, AJ, 125, 343
———. 2003b, AJ, 125, 348
Lieu, R., & Hillman, L. W. 2003, ApJ, 585, L77
Limongi, M., & Chieffi, A. 2003, ApJ, 592, 404
Lin, J., et al. 2003, NewA Rev., 47, 53
Lindegren, L., & Dravins, D. 2003, A&A, 401, 1185
Linton, M. G., & Antiochos, S. K. 2002, ApJ, 581, 703
Lionello, R., et al. 2002, ApJ, 581, 718
Liske, J. 2003, A&A, 398, 429
Litvinenko, Y. E. 2003, Sol. Phys., 212, 379
Liu, J.-F., et al. 2002a, ApJ, 580, L31
———. 2002b, ApJ, 581, L93
Liu, Y., et al. 2003, ApJ, 593, L137
Livio, M., & Riess, A. G. 2003, ApJ, 594, L93
Livshits, M. A., et al. 2003, Astron. Rep., 47, 562
Loktin, A. V., & Beshenov, G. V. 2003, Astron. Rep., 47, 6
Long, J. C., et al. 2003, Nature, 421, 922
Longcope, D. W., & Klapper, I. 2002, ApJ, 579, 468
Longcope, D. W., & Van Ballegooijen, A. A. 2002, ApJ, 578, 573
Lopes, I. P., & Silk, J. 2003, MNRAS, 341, 721
Lopes, I. P., et al. 2002a, MNRAS, 331, 361
———. 2002b, MNRAS, 337, 1179
López-Artiste, A., & Casini, R. 2003, ApJ, 582, L51
López-Artiste, A., et al. 2002, ApJ, 580, 519
Lopez-Corredoira, M., et al. 2002, A&A, 394, 883
López-Fuentes, M. C., et al. 2003, A&A, 397, 305
Low, B. C., & Berger, M. A. 2003, ApJ, 589, 644
Lowrance, P. J., et al. 2003, ApJ, 584, L95
Lowry, S. C., et al. 2003, A&A, 397, 329
Lubin, L. M., et al. 2002, AJ, 124, 1905
Lucatello, S., & Gratton, R. G. 2003, A&A, 406, 691
Lucatello, S., et al. 2003, AJ, 125, 875
Lugones, G., et al. 2002, ApJ, 581, L101
Luhmann, J. G., et al. 2003, Sol. Phys., 213, 367
Lumsden, S. L., et al. 2002, MNRAS, 336, 621
Lunyova, Y. V., & Kholtygin, A. F. 2002, Astrofizika, 45, 370
Luo, J., et al. 2003, Phys. Rev. Lett., 90, 081801
Luo, Q. Y., et al. 2002, A&A, 395, 669
Luridiana, V., et al. 2003, ApJ, 592, 846
Lustig, H., & Shepherd-Barr, K. 2002, Am. Sci., 90, 550
Lynch, P. 2003, MNRAS, 341, 1174
Lynden-Bell, D. 1960, Ph.D. thesis, Cambridge Univ.
Lynden-Bell, D. 2003a, MNRAS, 338, 208
———. 2003b, MNRAS, 341, 1360
Lyo, A.-Ran, et al. 2003, MNRAS, 338, 616
Lyra, G. 1951, Math. Z., 59, 521
Ma, J., et al. 2002a, Acta Astron., 52, 453
Ma, Y., et al. 2002b, MNRAS, 337, 1081
———. 2002c, A&A, 394, 311
Ma, Z. 2002, Sol. Phys., 211, 189
Maccarone, T. J., & Coppi, P. S. 2003, MNRAS, 338, 189
Maccarone, T. J., et al. 2003, ApJ, 586, 814
MacConnell, D. J. 2003, PASP, 115, 351
MacGregor, K. B., & Cassinelli, J. P. 2003, ApJ, 586, 480
Maciel, W. J., et al. 2003, A&A, 397, 667

Macintosh, B. A., et al. 2003, ApJ, 594, 538
Mackay, D. H. 2003, Sol. Phys., 213, 173
Mackay, D. H., et al. 2002, Sol. Phys., 209, 287
Mackey, J., et al. 2003, ApJ, 586, 1
Madjarska, M. S., & Doyle, J. G. 2003, A&A, 403, 731
Madjarska, M. S., et al. 2003, A&A, 398, 775
Madsen, J., & Larsen, J. M. 2003, Phys. Rev. Lett., 90, 121102
Maeder, A. 2003, A&A, 399, 263
Magakian, T. Y. 2003, A&A, 399, 141
Magara, T., & Longcope, D. W. 2003, ApJ, 586, 630
Maggs, J. E., & Morales, G. J. 2003, Phys. Rev. Lett., 91, 035004
Magliocchetti, M., et al. 2003, MNRAS, 343, 255
Magrini, L., et al. 2003, A&A, 407, 51
Mahasena, P., et al. 2003, PASJ, 55, 827
Maia, D., et al. 2003, A&A, 405, 313
Maier, C., et al. 2003, A&A, 402, 79
Mair, W., et al. 2003, Science, 301, 1731
Makarov, V. I., & Filippov, B. P. 2003, Sol. Phys., 214, 55
Malik, K. A., & Matraver, D. R. 2003, A&A, 406, 37
Malkov, O. Y. 2003, A&A, 402, 1055
Malov, I. F. 2003, Astron. Lett., 29, 502
Maness, H. L., et al. 2003, ApJ, 589, 439
Mann, G., et al. 2003, A&A, 400, 329
Mannucci, F., et al. 2003, A&A, 401, 519
Manoharan, P. K., & Kundu, M. R. 2003, ApJ, 592, 597
Marconi, A., & Hunt, L. K. 2003, ApJ, 589, L21
Marcy, G. W., et al. 2002, ApJ, 581, 1375
Marhas, K. K., et al. 2002, Science, 298, 2182
Marigo, P., et al. 2003, A&A, 399, 617
Marik, D., & Erdélyi, R. 2002, A&A, 393, L73
Marik, D., & Petrovay, K. 2002, A&A, 396, 1011
Marin-Franch, A., & Aparicio, A. 2003, ApJ, 585, 714
Marinoni, C., et al. 2002, ApJ, 580, 122
Marion, G. H., et al. 2003, ApJ, 591, 316
Marsh, M. S., et al. 2003a, A&A, 404, L37
———. 2003b, A&A, 393, 649
Martens, P. C. H., et al. 2002, ApJ, 577, L115
Martin, E. L., & Bouy, H. 2002, NewA, 7, 595
Martin, E. L., et al. 2003, ApJ, 593, L113
Martinez-Galarce, D. S., et al. 2003, ApJ, 585, 1095
Martis, C. J. A. P., ed. 2003, Ap&SS, 284, No. 4
Marvel, K., et al. 2003, Science, 301, 164
Masaki, Y., & Kinoshita, H. 2003, A&A, 403, 769
Masetti, N., et al. 2003, A&A, 406, L27
Mashonkina, L., et al. 2003, A&A, 397, 275
Mason, J., et al. 2002, ApJ, 580, L89
Massa, D. 2002, Ap&SS, 282, 471
Masset, F. S., & Bureau, M. 2003, ApJ, 586, 152
Masset, F. S., & Papaloizou, J. C. B. 2002, ApJ, 588, 494
Massone, A. M., et al. 2003, A&A, 405, 325
Masters, K. L., et al. 2003, AJ, 126, 158
Mathieu, R. D., et al. 2003, AJ, 125, 246
Mathis, H., & White, S. D. M. 2002, MNRAS, 337, 1193
Mathur, S., et al. 2003, ApJ, 582, 82
Matsuyama, I., et al. 2003a, ApJ, 582, 893
Matsuyama, I., et al. 2003b, ApJ, 585, L143
Matteucci, F., et al. 2003, A&A, 405, 23
Matzel, C. C., et al. 2003, J. Neurosci., 23, 6423
Mauch, T., et al. 2003, MNRAS, 342, 1117
Mauche, C. W. 2002, ApJ, 580, 423
Maughan, B. J., et al. 2003, ApJ, 587, 589
Mauk, B. H., et al. 2003, Nature, 421, 920
Mayer, L., et al. 2002, Science, 298, 1756
Mayor, M., & Queloz, D. 1995, Nature, 378, 355
Mazeh, T., & Zucker, S. 2003, ApJ, 590, L115
Mbelek, J. P., & Lachieze-Ray, M. 2003, A&A, 397, 803
McAllister, A. H., et al. 2002, Sol. Phys., 211, 155
McAteer, R. T., et al. 2003, ApJ, 587, 806
McCarthy, I. G., et al. 2003, ApJ, 591, 526
McConnachie, A. W., et al. 2003, MNRAS, 343, 1335
McDonald, L., et al. 2002, Sol. Phys., 211, 125
McDowell, J. C., et al. 2003, ApJ, 591, 154
McGowan, K. E., et al. 2003, ApJ, 591, 380
McInnes, C. R. 2002, Ap&SS, 282, 765
McIntosh, S. W., et al. 2003, A&A, 405, 769
McKee, C. F., & Tan, J. C. 2003, ApJ, 585, 850
McLaughlin, M. A., et al. 2003, ApJ, 591, L135
McNamara, B. J., et al. 2003, ApJ, 595, 187
Mead, S., et al. 2003, Science, 300, 540
Meegaskumbora, M., et al. 2002, Science, 298, 279
Meijerink, R., et al. 2003, A&A, 405, 1075
Meisel, D. D., et al. 2002, ApJ, 579, 895
Melnik, V. N. 2003, Sol. Phys., 212, 111
Melnikov, V. N., et al. 2002, ApJ, 580, L185
Mendez, R. A. 2002, A&A, 395, 779
Mendoza-Briceno, C. A., et al. 2002, ApJ, 579, L49
Mennickent, R. E., et al. 2003a, A&A, 399, L47
———. 2003b, A&A, 393, 887
Menou, K., & Tabachnik, S. 2003, ApJ, 583, 73
Menou, K., et al. 2003, ApJ, 587, L113
Men'shchikov, A. B., et al. 2002, A&A, 392, 921
Mercer, J., & Roth, V. L. 2003, Science, 299, 1165 (quoted)
Mermilliod, J.-C., et al. 2003, A&A, 399, 105
Merrill, P. W. 1934, PASP, 46, 206
Messenger, S., et al. 2003, Science, 300, 105
Messina, S., & Guinan, E. F. 2002, A&A, 393, 225
Meszaros, A., & Stocek, J. 2003, A&A, 403, 443
Meszaros, P. 2003, Nature, 423, 809
Meszarosova, H., et al. 2003, A&A, 407, 1115
Metcalf, R. B. 2002, ApJ, 580, 696
Metcalf, T. R., et al. 2003, ApJ, 595, 483
Metcalfe, T. S. 2003, ApJ, 587, L43
Meunier, N. 2003, A&A, 405, 1107
Meza, A., et al. 2003, ApJ, 590, 619
Micela, G., & Marino, A. 2003, A&A, 404, 637
Michal, R., et al. 2003, Science, 301, 449 (quoted)
Michel, P., et al. 2003, Nature, 421, 608
Miesch, M. S. 2003, ApJ, 586, 663
Mieske, S., et al. 2003, A&A, 403, 43
Mietto, P., et al. 2003, Nature, 422, 133
Mignani, R. P., et al. 2002, ApJ, 580, L147
Milgrom, M. 2002, ApJ, 577, L75
Miller, C. J., et al. 2002, ApJ, 579, 483
Miller, J. M., et al. 2003a, ApJ, 583, L99
———. 2003b, ApJ, 585, L37
Milvang-Jensen, B., et al. 2003, MNRAS, 339, L1
Minarovjech, J., et al. 2003, Sol. Phys., 213, 269
Mininni, P. D., et al. 2003, ApJ, 584, 1120
Minkowski, R., & Osterbrock, D. E. 1959, ApJ, 129, 583
Minniti, D., et al. 2003, Science, 301, 1508
Mirabel, I. F., & Rodrigues, I. 2003, Science, 300, 1119
Mirabel, I. F., et al. 2002, A&A, 395, 595
Miroshnichenko, A. S., et al. 2003, A&A, 406, 673
Mitrofanov, I. G., et al. 2003, ApJ, 584, 904
Mizutani, A., et al. 2003, ApJ, 589, L89
Mo, H. J., & White, S. D. M. 2002, MNRAS, 336, 112
Moehler, S., et al. 2002, A&A, 395, 37
———. 2003, A&A, 405, 135
Mohanty, S., & Basri, G. 2003, ApJ, 583, 451
Molchanov, V. Y., et al. 2002, Astron. Lett., 28, 713
Møller, P., et al. 2003, A&A, 396, L21
Momany, Y., et al. 2003, A&A, 407, 303

Monet, D. G., et al. 2003, AJ, 125, 984
Moon, Y. J., et al. 2002, ApJ, 581, 694
———. 2003, JKAS, 36, 37
Moore, B. D., et al. 2002, AJ, 124, 3305
Mora, A., et al. 2002, A&A, 393, 259
Morales-Rueda, L., et al. 2003, MNRAS, 338, 752
Moraux, E., et al. 2003, A&A, 400, 891
Mordvinov, A. V., & Willson, R. C. 2003, Sol. Phys., 215, 5
Mordvinov, A. V., et al. 2002, Sol. Phys., 211, 241
Morgan, D. H., et al. 2003, MNRAS, 344, 325
Morgan, H. L., & Edmunds, M. G. 2003, MNRAS, 343, 427
Mori, K., & Ruderman, M. A. 2003, ApJ, 592, L75
Morimoto, T., & Hiroki, K. 2003, PASJ, 55, 505
Moriwaki, K., & Nakagawa, Y. 2002, AJ, 124, 3364
Moro-Martin, A., & Malhotra, R. 2002, AJ, 124, 2305
———. 2003, AJ, 125, 2255
Morrison, H. L., et al. 2003, AJ, 125, 2502
Moskalik, P., & Poretti, E. 2003, A&A, 398, 213
Motch, C., et al. 2003, A&A, 408, 323
Mouhcine, M., & Lancon, A. 2003, MNRAS, 338, 572
Mouhcine, M., et al. 2002, A&A, 393, 101
Mouri, H., & Taniguchi, Y. 2003, ApJ, 585, 250
Mucket, J. P., & Hoeft, M. 2003, A&A, 404, 809
Muenker, C., et al. 2003, Science, 301, 84
Muglach, K. 2003, A&A, 401, 685
Mukadam, A. S., et al. 2002, ApJ, 580, 429
Mukadam, A. S., et al. 2003, ApJ, 594, 961
Muneer, S., & Singh, J. 2002, Sol. Phys., 209, 321
Muno, M. P., et al. 2003, ApJ, 589, 225
Murakawa, K., et al. 2002, A&A, 395, L9
Murray, S. D., et al. 2003, ApJ, 593, 301
Mursula, K., et al. 2003, Sol. Phys., 212, 201
Musielak, Z. E., & Ulmschneider, P. 2003a, A&A, 400, 1075
———. 2003b, A&A, 406, 725
Musielak, Z. E., et al. 2003, ApJ, 593, 481
Myers, S. T., et al. 2003, ApJ, 591, 575
Nagamine, K., & Loeb, A. 2003, NewA, 8, 439
Nagata, S. I., et al. 2003, ApJ, 590, 1095
Nakajima, H., et al. 2003, PASJ, 55, 635
Nakamura, F., & Li, Z.-Y. 2003, ApJ, 594, 363
Nakano, T., et al. 2003, Phys. Rev. Lett., 91, 012002
Nakasato, N., & Nomoto, K. 2003, ApJ, 588, 842
Napier, W. M., & Burbidge, G. R. 2003, MNRAS, 342, 601
Napiwotzki, R., et al. 2003, ESO Messenger, 112, 25
Narayan, C. A., & Jog, C. J. 2002, A&A, 394, 89
Narlikar, J. V., et al. 2002, PASP, 114, 1092
Narlikar, J. V., et al. 2003, ApJ, 585, 1
Natta, A., et al. 2002, A&A, 393, 597
Neiner, C., et al. 2003, A&A, 406, 1019
Nemani, R. R., et al. 2003, Science, 300, 1560
Neshpor, Y. I., et al. 2003, Astron. Lett., 29, 236
Neslusan, L. 2002, Contrib. Astron. Obs. Skalnaté Pleso, 32, 145
Nesvorny, D., et al. 2003a, ApJ, 591, 486
———. 2003b, AJ, 126, 398
Newberg, H. J., et al. 2002, ApJ, 569, 245
Newman, E. T., et al. 1967, Math. Phys., 11, 915
Ng, Y. J., et al. 2003, ApJ, 591, L87
Ngeow, C.-C., et al. 2003, ApJ, 586, 959
Nicastro, F., et al. 2003, Nature, 421, 719
Niemczura, E. 2003, A&A, 404, 689
Nindos, A., et al. 2003, ApJ, 594, 1033
Nishikawa, N., & Kusano, K. 2002, ApJ, 581, 745
Nishimura, O. 2003, PASJ, 55, 849
Nitta, S., et al. 2002, ApJ, 580, 538
Noël, F. 2002, A&A, 396, 667
Nogami, D., et al. 2002, PASJ, 54, 987
———. 2003, A&A, 404, 1067
Noll, K. S., et al. 2002, AJ, 124, 3424
Nonymous, A. 2002, Nature, 419, 894
———. 2003a, Nature, 423, 94
———. 2003b, Science, 299, 819
———. 2003c, Nature, 422, 277
———. 2003d, New Scientist, 17 November, 34
———. 2003e, Science, 299, 1561
———. 2003f, Science, 299, 343
———. 2003g, Science, 299, 343
Norbert, T. 2003, Science, 300, 747
Nordh, H. L., et al. 2003, A&A, 402, L21
Norris, J. P. 2002, ApJ, 579, 386
North, P., & Zahn, J.-P. 2003, A&A, 405, 677
Nosengo, N. 2003, Nature, 424, 608
Novicki, M. C., et al. 2002, AJ, 124, 2413
Nusser, A., et al. 2002, ApJ, 580, L93
Ofman, L., & Aschwanden, M. J. 2002, ApJ, 576, L153
Ofman, L., & Wang, T. 2002, ApJ, 580, L85
Oguri, M. 2003, MNRAS, 339, L23
Oh, S. P. 2002, MNRAS, 336, 1021
Ohki, K. 2003, Sol. Phys., 213, 111
Ohta, N. 2003, Phys. Rev. Lett., 91, 061303
Oksanen, A., et al. 2002, J. AAVSO, 30, 126
Oliveira, J. M., et al. 2003, MNRAS, 342, 651
Omukai, K., & Palla, F. 2003, ApJ, 589, 677
Orio, M., et al. 2003, ApJ, 594, 435
Ormo, J., et al. 2003, Antiquity, 77, 313
Orosz, J. A., & van Kerwijk, M. H. 2003, A&A, 397, 237
Osaki, Y., & Meyer, F. 2003, A&A, 401, 325
Oskinova, L. M., et al. 2003, A&A, 402, 755
Ostrov, P. G. 2002, MNRAS, 336, 309
Otsuka, M., et al. 2003, PASP, 115, 67
Otte, B., et al. 2003, ApJ, 586, L53
Overzier, R. A., et al. 2003, A&A, 405, 53
Özgüc, A., et al. 2003, Sol. Phys., 214, 375
Paczynski, B. 2003, Acta Astron., 53, 209
Padoan, P., et al. 2002, ApJ, 580, L57
Paladini, R., et al. 2003, A&A, 397, 213
Panessa, F., & Bassani, L. 2002, A&A, 394, 435
Papaderos, P., et al. 2002, A&A, 393, 461
Papoyan, V. V., et al. 2003, Astrofizika, 46, 92
Parfinenko, L. D. 2003, Sol. Phys., 213, 291
Parise, B., et al. 2002, A&A, 393, L49
Park, Y., & Ferguson, H. C. 2003, ApJ, 589, L65
Parker, L., et al. 2003, ApJ, 588, 663
Partridge, A., et al. 2003, The Twelve Days of Christmas (North Pole: Pear Tree Publications)
Partridge, A., & Solomon, King 2003, Additional Songs for the Holidays (London: King James Publications)
Partridge, A., Wagner, R., & Tolkien, J. R. R. 2003, A Catalogue of Curse-Bearing Jewelry (Netherworld: Mephistopheles Publications)
Partridge, T. C., et al. 2003, Science, 300, 607
Pasachoff, J. M. 2002, Science, 298, 1557
Pasetto, S., et al. 2003, A&A, 405, 931
Pasko, V. P. 2003, Nature, 423, 927
Paterno, L., et al. 2002, MNRAS, 336, 291
Patience, J., et al. 2002, ApJ, 581, 654
Patsourakos, S., et al. 2002, ApJ, 581, L125
Paturel, G., et al. 2003, A&A, 405, 1
Pauli, E.-M., et al. 2003, A&A, 400, 877
Pauluhn, A., & Solanki, S. K. 2003, A&A, 407, 359
Paunzen, E., et al. 2002, A&A, 395, 823
Payne-Gaposchkin, C. 1957, The Galactic Novae (Amsterdam: North-Holland), Ch. 2
Peale, S. J., & Lee, M. H. 2002, Science, 298, 593

Peebles, P. J. E., & Ratra, B. 2003, Rev. Mod. Phys., 75, 559
Peimbert, A. 2003, ApJ, 584, 735
Peimbert, M. 1990, Rep. Prog. Phys., 53, 1559
Peng, E. W., et al. 2002, AJ, 124, 3144
Penn, M. J., et al. 2003, Sol. Phys., 213, 55
Percy, J. R., et al. 2003, PASP, 115, 59
Perez-Gonzalez, P. G., et al. 2003, ApJ, 591, 827
Perna, R., et al. 2003a, ApJ, 585, 755
Perna, R., et al. 2003b, ApJ, 594, 936
Peter, H., & Brkovic, A. 2003, A&A, 403, 287
Peterson, J. R., et al. 2003, ApJ, 590, 207
Petrie, G. J. D., & Lothian, R. M. 2003, A&A, 398, 287
Petrie, S., et al. 2003, ApJ, 594, 869
Petrov, A. V., & Orlov, V. V. 2002, Astrofizika, 45, 334
Petrovay, K. 2003, Sol. Phys., 215, 17
Petry, D., et al. 2002, ApJ, 580, 104
Pevtsov, A. A., et al. 2003a, ApJ, 593, 1217
———. 2003b, ApJ, 595, 500
Phillips, J. P. 2003a, MNRAS, 340, 883
———. 2003b, MNRAS, 344, 501
Phillips, S. N., & Podsiadlowski, P. 2002, MNRAS, 337, 431
Phleps, S., & Meisenheimer, K. 2003, A&A, 407, 855
Picaud, S., et al. 2003, A&A, 408, 141
Pickett, B. K., et al. 2003, ApJ, 590, 1060
Pier, J. R., et al. 2003, AJ, 125, 1559
Pietrzynski, G., et al. 2003, AJ, 125, 2494
Pietsch, W., et al. 2003, A&A, 402, 457
Pillitteri, I., et al. 2003, A&A, 399, 919
Pindao, M., et al. 2002, A&A, 394, 443
Pindor, B., et al. 2003, AJ, 125, 2325
Pinfield, D. J., et al. 2003, MNRAS, 342, 1241
Pizzolato, N., et al. 2003, A&A, 397, 147
Podsiadlowski, P., et al. 2003a, MNRAS, 340, 1214
Podsiadlowski, P., et al. 2003, MNRAS, 341, 385
Poehnl, H., et al. 2003, A&A, 402, 247
Pohjolainen, S. 2003, Sol. Phys., 213, 319
Pojmanski, G. 2002, Acta Astron., 52, 397
Pojoga, S., & Cudnik, B. 2002, Sol. Phys., 208, 17
Pokorny, R. S., et al. 2003, A&A, 397, 575
Pontieri, A., et al. 2003, Sol. Phys., 213, 195
Pontin, D. I., et al. 2003, Sol. Phys., 212, 319
Pooley, D., et al. 2003, ApJ, 591, L131
Portegies Zwart, S. F., et al. 2003, ApJ, 593, 352
Porubcan, V., et al. 2002, Contrib. Astron. Obs. Skalnaté Pleso, 32, 132
Potapov, V. A., et al. 2003, Astron. Lett., 29, 241
Potekhin, A. Y., et al. 2003, ApJ, 594, 404
Pottasch, S. R., et al. 2002, A&A, 393, 285
Pound, M. W., et al. 2003, AJ, 125, 2108
Power, C., et al. 2003, MNRAS, 338, 14
Prada Moroni, P. G., & Straniero, O. 2002, ApJ, 581, 585
Pratt, G. W., & Arnaud, M. 2002, A&A, 394, 375
———. 2003, A&A, 408, 1
Preibisch, T. 2003, A&A, 401, 543
Preibisch, T., et al. 2002, A&A, 392, 945
Price, D. J., et al. 2003a, MNRAS, 339, 1223
Price, P. A., et al. 2003b, ApJ, 589, 838
Price, S. D., et al. 2003c, AJ, 125, 962
Priddey, R. S., et al. 2003, MNRAS, 339, 1183
Prieto, M., et al. 2002, Science, 298, 193
Prince, T. A., et al. 2003a, Nature, 423, 849
Prochaska, J. X., et al. 2003, ApJ, 595, L9
Proga, D., & Begelman, M. C. 2003, ApJ, 582, 69
Pruet, J., et al. 2002, ApJ, 580, 368
Pryzbilla, N. 2003, PASP, 115, 502
Psaltis, D., & Miller, M. C. 2002, ApJ, 578, 325
Pulido, J. O. 2002, Astropart. Phys., 18, 173
Pynzar, A. V., & Shishov, V. I. 2003, Astron. Rep., 47, 288
Qian, S. 2003a, MNRAS, 342, 1260
———. 2003b, A&A, 400, 649
Quillen, A. C. 2003, AJ, 125, 785
Quinet, P., & Biemont, E. 2003, MNRAS, 340, 463
Raassen, A. J. J., et al. 2003a, A&A, 400, 671
Raassen, A. J. J., et al. 2003b, A&A, 402, 653
Rafikov, R. R. 2003a, AJ, 125, 906
Rafikov, R. R. 2003b, AJ, 125, 942
Ragazzoni, R., et al. 2003, ApJ, 287, L1
Ragusa, S., & Céleri, L. C. 2003, Gen. Relativ. Gravitation, 35, 1125
Rahaman, F. 2002, Ap&SS, 282, 625
Rahvar, S., & Nouri-Zonoz, M. 2003, MNRAS, 338, 926
Ramachandran, R., & Kramer, M. 2003, A&A, 407, 1085
Ramesh, R., et al. 2003, ApJ, 591, L163
Rammacher, W., & Ulmschneider, P. 2003, ApJ, 589, 988
Rampp, M., & Janka, H.-T. 2002, A&A, 396, 361
Rappenglueck, M. 2003, Science, 299, 817 (quoted)
Rau, A., et al. 2003, ApJ, 590, L37
Rauch, T., & Werner, K. 2003, A&A, 400, 271
Rauer, H., et al. 2003, A&A, 397, 1109
Raulin, J. P., et al. 2003, ApJ, 592, 580
Rave, H. A., et al. 2003, ApJS, 145, 245
Raymond, S. N., et al. 2003, AJ, 125, 2621
Rea, N., et al. 2003, ApJ, 586, L65
Reale, F. 2002, ApJ, 580, 566
Reddy, B. E., et al. 2002, MNRAS, 335, 1005
Redman, M. P., et al. 2002, MNRAS, 336, 1093
Rees, M. J. 2003, Our Final Hour (New York: Basic Books)
Rees, M. J., Trimble, V., & Cohen, J. M. 1971, Nature, 229, 395
Reeves, K. K., & Warren, H. 2002, ApJ, 578, 590
Reeves, J. N., et al. 2003, A&A, 403, 463
Reid, I. N., et al. 2003a, AJ, 125, 354
Reid, J. M., et al. 2003b, ApJ, 587, 208
Reifarth, R., et al. 2003, ApJ, 582, 1251
Reipurth, B., et al. 2003, ApJ, 593, L47
Reis-Neto, E., et al. 2003, Sol. Phys., 212, 7
Rejkuba, M., et al. 2003, A&A, 406, 75
Remijan, A., et al. 2003, ApJ, 590, 314
Rempel, M. 2003, A&A, 397, 1097
Rempel, M., & Dikpati, M. 2003, ApJ, 584, 524
Retter, A., & Marom, A. 2003, MNRAS, 345, L25
Reuyl, D., & Holmberg, E. 1943, ApJ, 97, 41
Revnivtsev, M., & Sunyaev, R. 2003, A&A, 399, 699
Rho, J., et al. 2002, ApJ, 581, 1116
Ribas, I. 2003, A&A, 398, 239
Rice, W. K. M., et al. 2003a, MNRAS, 339, 1025
———. 2003b, MNRAS, 342, 79
Richard, O., et al. 2002, ApJ, 580, 1100
Ricotti, M. 2002, MNRAS, 336, L33
Ridderinkhof, K. R., et al. 2002, Science, 298, 2209
Rigon, L., et al. 2003, MNRAS, 340, 191
Riley, P., et al. 2002, ApJ, 578, 972
Ripero, J., et al. 2002, J. AAVSO, 30, 130
Rizzi, L., et al. 2003, ApJ, 589, L89
Roberts, T. P., et al. 2002, MNRAS, 337, 677
———. 2003, MNRAS, 342, 709
Robertson, J. G. 2003, Ap&SS, 284, 1063
Robinson, F. J., et al. 2003, MNRAS, 340, 923
Robishaw, T., et al. 2002, ApJ, 580, L129
Rocha-Pinto, H. J., et al. 2003, ApJ, 594, L115
Rodriguez, M., et al. 2002, Rev. Mexicana Astron. Astrofis., 38, 161
Rodriguez-Pacheco, J., et al. 2003, Sol. Phys., 213, 121
Rokaki, E., et al. 2003, MNRAS, 340, 1298
Romani, R. W., & Ng, C.-Y. 2003, ApJ, 585, L41

Romano, P., et al. 2003, Sol. Phys., 214, 313
Romanowsky, A. J., et al. 2003, Science, 301, 1696
Romero, G. E., et al. 2002, A&A, 393, L61
Roth, M., et al. 2002, A&A, 396, 243
Rouppe van der Voort, L. H. M. 2003, A&A, 397, 757
Roussev, I. I., et al. 2003, ApJ, 588, L45
Rubiño-Martin, J. A., et al. 2003, MNRAS, 341, 1084
Rucinski, S. M. 2002, PASP, 114, 1124
Ruderman, M. S. 2003, A&A, 409, 287
Rüdiger, G., et al. 2003, A&A, 406, 15
Russell, D. 2003, A&A, 397, 133
Rust, D. M., & Kumar, A. 1996, ApJ, 464, L199
Ruszkowski, M., & Begelman, M. C. 2003, ApJ, 581, 223
Rutledge, R. E., & Sako, M. 2003, MNRAS, 339, 600
Rutten, R. J., & Krijger, J. M. 2003, A&A, 407, 735
Ryde, N. 2002, ApJ, 580, 447
Ryutova, M., & Tarbell, T. 2003, Phys. Rev. Lett., 90, 191101
Ryutova, M., et al. 2003, Sol. Phys., 213, 231
Sabbi, E., et al. 2003, ApJ, 589, L37
Sadakane, K., et al. 2002, PASJ, 54, 911
Saharian, A. A. 2003, Astrophysics, 46, 103
Saint-Hilaire, P., & Benz, A. O. 2002, Sol. Phys., 210, 287
Sakamoto, T., et al. 2003, A&A, 397, 899
Sakurai, T., & Hagino, M. 2003, JKAS, 36, 7
Sakurai, T., et al. 2002, Sol. Phys., 209, 265
Salvaterra, R., & Ferrara, A. 2003, MNRAS, 340, L17
Sampson, R. D. 2003, JRASC, 97, 144
Samuel, S. 2003, Phys. Rev. Lett., 90, 231101
Samus, N. N., et al. 2003, Astron. Lett., 29, 468
Sánchez Almeida, J., et al. 2003, ApJ, 585, 536
Sanchez-Lavega, A., et al. 2003, Nature, 423, 623
Sanchez-Salcedo, F. J., et al. 2002, ApJ, 577, 768
Sanchez-Villagra, M. R., et al. 2003, Science, 301, 1708
Sanders, R. H. 2003, MNRAS, 342, 901
Sandquist, E. L., et al. 2003, AJ, 125, 810
Sandqvist, A. 2003, A&A, 402, E1
Santiago, B., et al. 2002, MNRAS, 336, 139
Santos, N. C., et al. 2003a, A&A, 398, 363
———. 2003b, A&A, 406, 373
Sarma, A. P., et al. 2002, ApJ, 580, 928
Saunders, R., et al. 2003, MNRAS, 341, 937
Savaglio, S., et al. 2003, ApJ, 585, 638
Savolainen, P., et al. 2002, Science, 298, 1611
Saxton, C. J., et al. 2002, ApJ, 579, 176
Sazhin, M., et al. 2003, MNRAS, 343, 353
Schaefer, B. E. 2002, J. Hist. Astron., 33, 313
———. 2003, S&T, 105, 42
Schaefer, B. E., et al. 2003, ApJ, 588, 387
Schaerer, D. 2003, A&A, 397, 527
Schaffner-Bielich, J., et al. 2002, Phys. Rev. Lett., 89, 171101
Schatz, H., et al. 2002, ApJ, 579, 626
Schiavon, R. P., et al. 2002a, ApJ, 580, 850
Schiavon, R. P., et al. 2002b, ApJ, 580, 873
Schlamminger, S., et al. 2002, Phys. Rev. Lett., 89, 161102
Schmahl, E. J., & Hurford, G. J. 2002, Sol. Phys., 210, 273
Schmelz, J. T. 2002, ApJ, 578, L161
Schmidt, R. W., et al. 2002, MNRAS, 337, 71
Schmieder, B., et al. 2003, A&A, 401, 361
Schneider, R., et al. 2003, Nature, 422, 869
Schoedel, R., et al. 2002, Nature, 419, 694
Scholz, R.-D., et al. 2003, A&A, 398, L29
Schreiber, M. R., & Gaensicke, B. T. 2002, A&A, 406, 305
Schrijver, C. J., & DeRosa, M. L. 2003, Sol. Phys., 212, 165
Schrijver, C. J., et al. 1997, ApJ, 487, 424
———. 2002, ApJ, 577, 1006
Schuecker, P., et al. 2003a, A&A, 398, 867
———. 2003b, A&A, 402, 53
Schuler, S. C., et al. 2003, AJ, 125, 2085
Schuller, F., et al. 2003, A&A, 403, 955
Scott, D. M., et al. 2003, MNRAS, 344, 412
Searls, D. B. 2003, Nature, 426, 391
Sedrakyan, D. M., & Blaschke, D. 2002, Astrofizika, 45, 166
See, T. J. J. 1896, AJ, 16, 17
Segransan, D., et al. 2003, A&A, 397, L5
Sekanina, Z., & Chodas, P. W. 2002a, ApJ, 581, 760
Sekanina, Z., & Chodas, P. W. 2002b, ApJ, 581, 1389
Seljak, U., et al. 2003, MNRAS, 342, L79
Sello, S. 2003, NewA, 8, 105
Sellwood, J. A. 2003, ApJ, 587, 638
Selvelli, P., & Friedjung, M. 2003, A&A, 401, 297
Serjeant, S., et al. 2003, MNRAS, 344, 887
Setiawan, J., et al. 2003, A&A, 397, 1151
Seward, F. D., et al. 2003, ApJ, 584, 414
Seymour, M. D., & Widrow, L. M. 2002, ApJ, 578, 689
Shanmugaraju, A., et al. 2003, Sol. Phys., 215, 185
Shapiro, S. L., & Shibata, M. 2002, ApJ, 577, 904
Share, G. H., et al. 2002, Sol. Phys., 210, 357
Shearer, A., et al. 2003, Science, 301, 493
Sheehan, W., & Dobbins, T. A. 2002, S&T, 104, 12
Shen, S., et al. 2003, MNRAS, 343, 978
Sheppard, S. S., & Jewitt, D. C. 2003, Nature, 423, 261
Shetrone, M., et al. 2003, AJ, 125, 684
Shigeyama, T., et al. 2003, ApJ, 586, L57
Shimasaku, K., et al. 2003, ApJ, 586, L111
Shimozu, K., et al. 2002, Nature, 419, 597
Shimura, T., & Manmoto, T. 2003, MNRAS, 338, 1013
Sholomitski, G. B. 1965, AZh, 42, 673
Shore, S. N., et al. 2003, AJ, 125, 1507
Shu, F. 2003, New Scientist, 17 May, 28 (quoted)
Siegel, M. H., et al. 2002, ApJ, 578, 151
Sievers, J. L., et al. 2003, ApJ, 591, 599
Sigalotti, L. Di.G., & Mendoza-Briceno, C. A. 2003, A&A, 397, 1083
Sigurdsson, S., et al. 2003, Science, 301, 193
Silk, J. 2003, MNRAS, 343, 249
Simcoe, R. A., et al. 2002, ApJ, 578, 737
Simkin, M., & Roychowdhury, V. 2002, Nature, 420, 594
Simmerer, J., et al. 2003, AJ, 125, 2018
Simnett, G. M. 2003, Sol. Phys., 213, 387
Simnett, G. M., et al. 2002, ApJ, 579, 854
Simon, T., et al. 2002, ApJ, 579, 800
Singeton, J., et al. 2003, Science, 301, 1463 (quoted)
Sirianni, M., et al. 2002, ApJ, 579, 275
Sitnik, T. G. 2003, Astron. Lett., 29, 311
Sivaraman, K. R., et al. 2003, Sol. Phys., 214, 65
Skartlien, R. 2002, ApJ, 578, 621
Skillman, E. D., et al. 2003a, AJ, 125, 610
Skillman, E. D., et al. 2003b, AJ, 125, 593 & 610
Skorzynski, W., et al. 2003, A&A, 408, 297
Sloan, G. C., et al. 2003, ApJ, 594, 483
Slocum, P. L., et al. 2003, ApJ, 594, 592
Slosar, A., et al. 2003, MNRAS, 341, L29
Smartt, S. J., et al. 2003, MNRAS, 343, 735
Smith, D. M., et al. 2002, ApJ, 578, L129
Smith, G. H. 2002, PASP, 114, 1097
Smith, G. R. 2003a, MNRAS, 341, 143
Smith, G. H., & Burkert, A. 2002, ApJ, 578, L51
Smith, H., Jr. 2003b, MNRAS, 338, 891
Smith, K., et al. 2003a, A&A, 406, 957
Smith, N., et al. 2003b, AJ, 125, 1458
———. 2003c, ApJ, 586, 432
Sneden, C. 2003, ApJ, 582, L3
Snow, T. P., et al. 2002, ApJ, 578, 877

Snyder, L. E., et al. 2002, ApJ, 578, 245
Socas-Navarro, H., & Sanchez-Almeida, J. 2003, ApJ, 593, 581
Sofue, Y. 2003, PASJ, 55, 445
Sokasian, A., et al. 2003, MNRAS, 344, 607
Soker, N. 2003, MNRAS, 342, 463
Sokoloff, D. D. 2002, Astron. Rep., 46, 871
Solanki, S. K. 2002, Astron. Geophys., 43, 9
Solanki, S. K., et al. 2002, A&A, 396, 1029
Soltan, A. M., et al. 2002, A&A, 395, 475
Somov, B. V., et al. 2002, ApJ, 579, 863
Somerville, R. S., & Livio, M. 2003, ApJ, 593, 611
Song, L., et al. 2002, Sol. Phys., 211, 315
Sorkin, E., & Piran, T. 2003, Phys. Rev. Lett., 90, 171301
Soszynski, I., et al. 2003, Acta Astron., 53, 93
Sotnikov, N. Y., & Rodionov, S. A. 2003, Astron. Lett., 29, 321
Spadaro, D., et al. 2003, ApJ, 582, 486
Spark, N. T. 2003, J. Improb. Res., 9.5, 4
Speck, A. K., et al. 2003, PASP, 115, 170
Spitzer, L., & Baade, W. 1951, ApJ, 113, 413
Spitzer, L., & Zabriskie, F. R. 1959, PASP, 71, 412
Splaver, E. M., et al. 2002, ApJ, 581, 509
Spoon, H. W. W., et al. 2003, A&A, 402, 499
Spruit, H. C. 2003, Sol. Phys., 213, 1
Spurny, P., et al. 2003, Nature, 423, 151
Spyrou, N. K., & Stergioulas, N. 2003, A&A, 395, 151
Srianand, R., et al. 2003, MNRAS, 336, 753
Srinivasan, G. 2002, Bull. Astron. Soc. India, 30, 523
Stackel, P. 1891, Math. Ann., 35, 91
Stairs, I. H., et al. 2002, ApJ, 581, 501
Stancil, P. C., et al. 2002, ApJ, 580, 29
Stanek, K. Z., et al. 2003, ApJ, 591, L17
Stassun, K. G., & Terndrup, D. 2003, PASP, 115, 505
Staude, A., et al. 2003, A&A, 406, 253
Stegman, D. R., et al. 2003, Nature, 421, 143
Steiner, O. 2003, A&A, 406, 1083
Stelzer, B., & Burwitz, V. 2003, A&A, 402, 719
Stelzer, B., et al. 2003, A&A, 407, 1067
Stepanov, A. V., & Tsap, Y. T. 2002, Sol. Phys., 211, 135
Stephens, A. W., et al. 2003, AJ, 125, 2473
Sterling, N. C., et al. 2002, ApJ, 578, L55
Stern, S. A. 2003a, Nature, 424, 639
Stern, S. A., et al. 2003, AJ, 125, 902
Sternberg, A. 2003, Nature, 421, 708
Sternberg, A., et al. 2002, ApJS, 143, 419
Sterzik, M. F., & Durisen, R. H. 2003, A&A, 400, 1031
Stetson, P. B., et al. 2003, PASP, 115, 413
Stevenson, D. J. 2003, Nature, 423, 239
Stift, M. J., & Leone, F. 2003, A&A, 398, 411
Stoehr, F., et al. 2002, MNRAS, 335, L84
Strasser, B. J. 2003, Nature, 422, 803
Strobel, D. F., et al. 2002, ApJ, 581, L51
Strohmayer, T. E. 2003a, ApJ, 593, L39
Strohmayer, T. E., et al. 2003b, ApJ, 586, L61
Sturrock, P. A. 2003, ApJ, 594, 1102
Su, H. T., et al. 2003, Nature, 423, 974
Sudarsky, D., et al. 2003, ApJ, 588, 1121
Sugerman, B. E. K., & Crotts, A. P. S. 2002, ApJ, 581, L97
Sui, L., et al. 2002, Sol. Phys., 210, 245
Suleimanov, V. F., & Ibragimov, A. A. 2003, Astron. Rep., 47, 197
Sullivan, M., et al. 2003, MNRAS, 340, 1057
Sumi, T., et al. 2003, MNRAS, 340, 1346
Suzuki, T. K. 2002, ApJ, 578, 598
Svidzinsky, A. A. 2003, ApJ, 590, 386
Swaters, R. A., & Rubin, V. C. 2003, ApJ, 587, L23
Sweeney, A., et al. 2003, Nature, 423, 31
Sykora, J., et al. 2003, Sol. Phys., 212, 301
Szalay, A. S., et al. 2003, ApJ, 591, 1
Taam, R. E., et al. 2003, ApJ, 592, 1124
Tajima, T., & Dawson, J. M. 1979, Phys. Rev. Lett., 43, 267
Takakuwa, S., et al. 2003, ApJ, 584, 818
Takami, M., et al. 2003, A&A, 397, 675
Takano, S., et al. 2003, PASJ, 55, L53
Tam, S. W. Y., & Chang, T. 2002, A&A, 395, 1001
Tamburini, F., et al. 2002, A&A, 394, 675
Tarasov, A. E., et al. 2003, A&A, 402, 237
Tarcuno, J. A., et al. 2003, Science, 203, 1964
Tarhan, I. 2002, Astron. Nachr., 323, 494
Tassis, K., et al. 2003, ApJ, 587, 13
Taylor, S. F., et al. 2003, PASP, 115, 609
Teames, S. 2003, J. AAVSO, 31, 54
Teegarden, B. J., et al. 2003, ApJ, 589, L51
Teerikorpi, P. 2003, A&A, 399, 829
Telfer, R. C., et al. 2002, ApJ, 579, 500
Temmer, M., et al. 2003, Sol. Phys., 215, 111
Teriaca, L., et al. 2003a, ApJ, 588, 566
———. 2003b, ApJ, 588, 596
Terquem, C. E. J. M. L. J. 2003, MNRAS, 341, 1157
Terradas, J., et al. 2002, A&A, 393, 637
Testa, P., et al. 2002, ApJ, 580, 1159
Thejappa, G., et al. 2003, ApJ, 592, 1234
Thomas, S. 2002, Phys. Rev. Lett., 89, 081301
Thomas, J. H., et al. 2002, Nature, 420, 390
Thompson, C. G., et al. 2002, Science, 298, 279
Thompson, M. J., et al., eds. 2003a, Ap&SS, 284, 1
Thompson, S. E., et al. 2003b, ApJ, 589, 921
Thompson, T. A., et al. 2003c, ApJ, 592, 434
Thornton, J. W., et al. 2003, Science, 301, 1714
Thorsett, S. E., et al. 2003, ApJ, 592, L71
Thoul, A., et al. 2003a, A&A, 402, 293
———. 2003b, A&A, 406, 287
Tian, L., & Liu, Y. 2003, A&A, 407, L13
Tian, L., et al. 2002, Sol. Phys., 215, 111
Tielens, A. G. G. M. 2003, Science, 300, 68
Timmes, F. X., et al. 2003, ApJ, 590, L83
Tinney, C. G., et al. 2003, AJ, 126, 975
Tinsley, B. M. 1968, ApJ, 151, 547
Titov, V. S., & Démoulin, P. 1999, A&A, 351, 707
Titov, V. S., et al. 2003, ApJ, 582, 1172
Titus, T. N., et al. 2003, Science, 299, 1048
Tokhchukova, S., & Bogod, V. 2003, Sol. Phys., 212, 99
Tomeoka, K., et al. 2003, Nature, 423, 60
Tomsick, J. A., et al. 2003, ApJ, 582, 933
Tonry, J. L., et al. 2003, ApJ, 594, 1
Toon, O. B. 2003, Nature, 424, 623
Tornatore, L., et al. 2003, MNRAS, 342, 1025
Török, T., & Kliem, B. 2003, A&A, 406, 1043
Török, T., et al. 2004, A&A, 413, L27
Toropina, O. D., et al. 2003, ApJ, 593, 472
Torricelli-Ciamponi, G., & Pietrini, P. 2002, A&A, 394, 415
Torsti, J., et al. 2003a, A&A, 408, L1
———. 2003b, Sol. Phys., 214, 177
Tosaki, T., et al. 2003, PASJ, 55, 605
Townsend, P. K., & Wohlfarth, M. N. 2003, Phys. Rev. Lett., 91, 061302
Tozzi, G. P., et al. 2003, A&A, 398, L41
Travouillon, T., et al. 2002, A&A, 400, 1163
Trieloff, M., et al. 2003, Nature, 422, 502
Trilling, D. E., et al. 2002, A&A, 394, 241
Trotzinger, J., et al. 2002, Science, 298, 1547 (quoted)
Truemper, J., et al. 1978, ApJ, 219, L105
Tsiklauri, D., et al. 2002, A&A, 395, 285
———. 2003, A&A, 400, 1051

Tsuchiya, T., et al. 2003, ApJ, 589, L29
Tu, C. Y., et al. 2002, J. Geophys. Res., 107, 1291
Turnbull, M. C., & Tarter, J. C. 2003, ApJS, 145, 181
Turner, D. G., & Berdnikov, L. N. 2003, A&A, 407, 325
Turner, J. L., et al. 2003, Nature, 423, 621
Tutukov, A. V., & Fedorova, A. V. 2002, Astron. Rep., 46, 765
Tutukov, A. V., & Fedorova, A. V. 2003, Astron. Rep., 47, 600
Uchida, Y., et al. 2003, PASJ, 55, 305
Udalski, A., et al. 2002, Acta Astron., 52, 217
———. 2003, Acta Astron., 53, 133
Udry, S., et al. 2003, A&A, 407, 369
Uemura, M., et al. 2003, Nature, 423, 843
Uitenbroek, H. 2003, ApJ, 592, 1225
Umeda, H., & Nomoto, K. 2003, Nature, 422, 871
Uralov, A. M., et al. 2002, Sol. Phys., 208, 69
Urbaneja, M. A., et al. 2003, ApJ, 584, L73
Uzdensky, D. A. 2003, ApJ, 587, 450
Urosevic, D. 2003, Ap&SS, 283, 75
Uzan, J.-P. 2003, Rev. Mod. Phys., 75, 403
Vahia, M. N., et al. 2003, Bull. Astron. Soc. India, 31, 37
Valyavin, G. G., et al. 2003, Astron. Rep., 47, 587
Van Bemmel, I. M., & Dullemond, C. P. 2003, A&A, 404, 1
van de Kamp, P. 1963, AJ, 68, 515
———. 1982, Vistas Astron., 26, 146
van den Bergh, S. 2000, The Galaxies of the Local Group (Cambridge: Cambridge Univ. Press), § 4.7
———. 2003, ApJ, 590, 797
van der Heyden, K. J., et al. 2003, A&A, 406, 141
van der Marel, R. P., et al. 2002, AJ, 124, 3255
van der Swaluw, E. 2003, A&A, 404, 939
van de Ven, G., et al. 2003, MNRAS, 342, 1056
VanDriel-Gesztelyi, L., et al. 2003, ApJ, 586, 579
van Dyk, S. D., et al. 2002, PASP, 114, 1322
Van Eck, S., et al. 2003, A&A, 404, 291
Van Horn, H., et al. 2003, ApJ, 585, 983
van Loon, J. T., et al. 2003, MNRAS, 338, 857
van Putten, H. M. P. M., & Regimbau, T. 2003, ApJ, 593, L15
Vanture, A. D., et al. 2003, ApJ, 587, 384
Varadi, F., et al. 2003, ApJ, 592, 620
Vastel, C., et al. 2003, ApJ, 593, L97
Vauclair, S., & Theado, S. 2003, ApJ, 587, 777
Vaughan, A. H., & Preston, G. W. 1980, PASP, 92, 385
Veillet, C. 2003a, Nature, 422, 543 (quoted)
———. 2003b, Nature, 424, 634 (quoted)
Vennes, S., et al. 2003, ApJ, 593, 1040
Vergados, J. D., & Owen, D. 2003, ApJ, 589, 17
Vermeulen, R. C., et al. 2003, A&A, 404, 861
Veronig, A. 2003, Observatory, 123, 58
Veronig, A., et al. 2002, A&A, 392, 699
Vesperini, E., & Zepf, S. E. 2003, ApJ, 587, L97
Vesperini, E., et al. 2003, ApJ, 593, 760
Vidal-Madjar, A., et al. 2003, Nature, 422, 143
Vignali, C., et al. 2003, AJ, 125, 418
Villaver, E., et al. 2002, ApJ, 581, 1204
Vilmer, N., et al. 2002, Sol. Phys., 210, 261
Vine, S. G., & Bonnell, I. A. 2003, MNRAS, 342, 314
Vinko, J., et al. 2003, A&A, 397, 115
Visser, M., et al. 2003, Phys. Rev. Lett., 90, 201102
Vlahakis, N., & Konigl, A. 2003, ApJ, 596, 1104
Vocks, C., & Mann, G. 2003, ApJ, 593, 1134
Vokrouhlicky, D., et al. 2003, Nature, 425, 147
Volkov, I. M., & Khaliullin, K. F. 2002, Astron. Rep., 46, 747
von Braun, K., et al. 2002, AJ, 124, 2067
Vrsnak, B., et al. 2002, A&A, 396, 673
———. 2003a, A&A, 404, 1117
———. 2003b, ApJ, 580, L177
Wagner, J. D., & Caudill, S. R. 2003, Science, 300, 1875
Wagoner, R. V. 2003, Nature, 424, 27
Wahhaj, Z., et al. 2003, ApJ, 584, L27
Waldram, E. M., et al. 2003, MNRAS, 342, 915
Walker, M., et al. 2003, ApJ, 589, 810
Walton, S. R., et al. 2003, ApJ, 590, 1088
Wanajo, S., et al. 2002, ApJ, 577, 853
Wang, H., et al. 2002a, ApJ, 580, L177
———. 2003a, ApJ, 593, 564
———. 2003b, AJ, 125, 842
Wang, L., et al. 2002b, ApJ, 579, 671
———. 2003c, ApJ, 591, 1110
———. 2003d, ApJ, 592, 457
Wang, T. J., et al. 2003e, A&A, 402, L17
———. 2003f, A&A, 406, 1105
Wang, Y., & Tang, Z. 2002, Ap&SS, 282, 363
Wang, Y. M., & Sheeley, N. R. 2003a, ApJ, 590, 1111
———. 2003b, ApJ, 591, 1248
Wang, Y. M., et al. 2002c, Sol. Phys., 211, 333
Wang, Y. P., et al. 2003g, ApJ, 588, 113
Warner, D. B., et al. 2003, ApJ, 593, 1049
Warren, H. P., et al. 2002, ApJ, 579, L41
———. 2003, ApJ, 593, 1174
Watanabe, J., et al. 2003a, PASJ, 55, L23
Watanabe, K., et al. 2003b, ApJ, 592, 590
Watson, C. A., et al. 2003, MNRAS, 341, 129
Watson, P. G., & Craig, I. J. D. 2003, ApJ, 590, L57
Waxman, E. 2003, Nature, 423, 388
Weatherley, S. J., et al. 2003, MNRAS, 342, L9
Weinberg, M. D., & Katz, N. 2002, ApJ, 580, 627
Weinberger, A. J., et al. 2003, ApJ, 584, L33
Weiner, J., et al. 2003, ApJ, 589, 976
Welch, G. A., & Sage, L. J. 2003, ApJ, 584, 260
Welch, P. G. 2003, MNRAS, 342, 971
Weldrake, D. T. F., et al. 2003, MNRAS, 340, 12
Welsch, B. T., & Longcope, D. W. 2003, ApJ, 588, 620
Wernli, F., et al. 2002, A&A, 396, 73
West, R. M. 2003, ESO press release, 2 September 2003
Wetterich, C. 2003, Phys. Rev. Lett., 90, 231302
Wheatland, M. S. 2002, Sol. Phys., 208, 33
———. 2003, Sol. Phys., 214, 361
Wheatland, M. S., & Craig, I. J. D. 2003, ApJ, 595, 458
Wheatland, M. S., & Litvinenko, Y. E. 2002, Sol. Phys., 211, 255
Whitelam, S., et al. 2002, Sol. Phys., 211, 199
Whipple, F. L. 1951, ApJ, 113, 464
White, R. J., & Basri, G. 2003, ApJ, 582, 1109
White, R. L., et al. 2003a, AJ, 126, 1
———. 2003b, AJ, 126, 706
Wichmann, R., & Schmitt, J. H. M. M. 2003, MNRAS, 342, 1021
Wichmann, R., et al. 2003, A&A, 400, 293
Wickramasinghe, N. C., et al. 2003, The Lancet, 361, 1832
Widrow, L. M. 2002, Rev. Mod. Phys., 74, 775
Wiegelmann, T., & Inhester, B. 2003, Sol. Phys., 214, 287
Wiehr, E., & Bianda, M. 2003, A&A, 404, L25
Wijnands, R., et al. 2003, Nature, 424, 44
Wilhelm, K., & Kalkofen, W. 2003, A&A, 408, 1137
Will, C. M. 2003, ApJ, 590, 683
Willems, B., & Kolb, U. 2002, MNRAS, 337, 1004
Willems, B., et al. 2003, A&A, 397, 973
Williams, B. F. 2003, MNRAS, 340, 143
Williams, C. L., et al. 2002a, ApJ, 581, 396
Williams, D. M., & Pollard, D. 2002, Int. J. Astrobiol., 1, 61
Williams, D., & Roorda, A. 2003, Science, 299, 1654 (quoted)
Williams, D. R., et al. 2002b, MNRAS, 336, 747
Williams, L. L. R., & Frey, M. 2003, ApJ, 583, 594
Williams, R. J., et al. 2002c, AJ, 124, 3042

Willman, B., et al. 2002, AJ, 124, 2600
Willott, C. J., et al. 2003, ApJ, 587, L15
Willstrop, R. V., & Lynden-Bell, D. 2003, MNRAS, 342, 33
Windhorst, R. A., et al. 2002, ApJS, 143, 113
Winebarger, A. R., et al. 2003a, ApJ, 587, 439
———. 2003b, ApJ, 593, 1164
Winkler, P. F., et al. 2003, ApJ, 585, 324
Winter, O. C., & Vieira Neto, E. 2002, A&A, 393, 661
Wiringa, R. B., & Pieper, S. C. 2002, Phys. Rev. Lett., 89, 182501
Wolf, S., et al. 2003, ApJ, 592, 233
Wolk, S. J., et al. 2002, ApJ, 580, L161
Wong, M.-L., & Wulfe, A. 2003, Nature, 423, 805
Woo, J.-H., & Urry, C. M. 2002, ApJ, 581, L5
Woo, J.-H., et al. 2003, AJ, 125, 754
Woodard, M. F., & Libbrecht, K. G. 2003, Sol. Phys., 212, 51
Woosley, S. E., et al. 2002, Rev. Mod. Phys., 74, 1015
Worthey, G., & Collobert, M. 2003, ApJ, 586, 17
Woudt, P. A., & Warner, B. 2003, MNRAS, 343, 313
Wright, C. O., et al. 2003, AJ, 125, 359
Wunnenberg, M., et al. 2002, A&A, 395, L51
Wyrzykowski, L., et al. 2003, Acta Astron., 53, 1
Xiong, D. R., & Deng, X. L. 2002, MNRAS, 336, 511
Xu, X., et al. 2003, Nature, 421, 335
Yamazaki, R., et al. 2003a, ApJ, 593, 941
———. 2003b, ApJ, 594, L79
Yan, H., et al. 2003, ApJ, 585, L93
Yang, Y., & Liu, Q. 2003, PASP, 115, 748
Yanny, B., et al. 2003, ApJ, 588, 824
Yasnov, L. V., & Karlicky, M. 2003, A&A, 408, 737
Yi, S. K., et al. 2003, ApJS, 144, 259
Yoder, C. F., et al. 2003, Science, 300, 299
Yong, D., et al. 2003, A&A, 402, 985
Yoshida, N., et al. 2003, ApJ, 591, L1
Yoshiguchi, H., et al. 2003, ApJ, 586, 1211
Yoshii, Y., et al. 2003, ApJ, 592, 467
Yoshino, T., et al. 2003, Nature, 422, 154
Young, R. E. 2002, NewA Rev., 47, 1
Yousef, T. A., & Brandenburg, A. 2003, A&A, 407, 7
Yu, Q., & Tremaine, S. 2002, MNRAS, 335, 965
Yu, Z.-Y. 2003, MNRAS, 338, 745
Yukoyama, J. 2003, PASJ, 55, L41
Yusef-Zadeh, F., et al. 2003, ApJ, 585, 319
Zakamska, N. L., & Narayan, R. 2003, ApJ, 582, 162
Zakharov, A. F., et al. 2003, MNRAS, 342, 1325
Zapaterio Osorio, M. R., et al. 2002, ApJ, 578, 536
Zaritsky, D., & Gonzalez, A. H. 2003, ApJ, 584, 691
Zdesenko, Y. 2002, Rev. Mod. Phys., 74, 663
Zel'dovich, Ya. B., & Novikov, I. D. 1971, Relativistic Astrophysics (Chicago: Univ. Chicago Press) 1, 437
Zeng, Y. R. 2002, A&A, 394, 965
Zerjal, T., et al. 2003, Am. J. Human Genetics, 72, 717
Zezas, A., et al. 2002, ApJS, 142, 239
Zhang, B., & Meszaros, P. 2002, ApJ, 581, 1236
Zhang, B., & Sigurdsson, S. 2003, ApJ, 596, L95
Zhang, J., & Huang, G. L. 2003, ApJ, 592, L49
Zhang, J., et al. 2003, ApJ, 582, 520
Zhang, K. K., & Liao, X. H. 2003, Chinese J. Astron. Astrophys., 3, 12
Zhang, M., & Low, B. C. 2003, ApJ, 584, 479
Zhang, X.-B., & Zhang, R.-X. 2003, AJ, 125, 1431
Zhang, Y. H. 2002, MNRAS, 337, 609
Zhao, J., & Kosovichev, A. G. 2003, ApJ, 591, 446
Zhao, G., et al. 2002, AJ, 124, 2224
Zharikov, S. V., et al. 2002, A&A, 394, 633
Zhou, G., et al. 2003, A&A, 397, 1057
Zhu, Z.-H., & Fujimoto, M.-K. 2002, ApJ, 581, 1
———. 2003, ApJ, 585, 52
Zickgraf, F-J., et al. 2003, A&A, 406, 535
Ziegler, U., & Ruediger, G. 2003, A&A, 401, 433
Zinner, E. 2003, Science, 300, 265
Zsargo, J., et al. 2003, ApJ, 586, 1019