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Invited Review

Astrophysics in 1999

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ABSTRACT. The year 1999 saw the arrival of a star with three planets, a universe with three parameters, and a solar corona that could be heated at least three ways. In addition, there were at least three papers on every question that has ever been asked in astrophysics, from "Will the Universe expand forever?" to "Does mantle convection occur in one or two layers?" The answers generally were, "Yes," "No," and "None of the above," to each of the questions. The authors have done their best to organize the richness around centers defined by objects, methods, and madnesses.

1. INTRODUCTION

You hold in your (real or virtual) hands the successor to "Astrophysics in 1991, 1992" and so forth, cited below as Ap91, Ap92, etc., and appearing somewhere near the beginnings of volumes 104 to 111 of PASP. In accordance with the policy that allows the old century and millennium to end on 31 December 1999, "Astrophysics in 1999" clearly ends a decade of reviews. Accordingly, we have taken some liberties with the format, dismissing a great many important, but long-standing, questions with a single answer, provided by a single paper. Not always the first, or the last, or even the most correct, but one that has the sound of a horn blowing at midnight.

The journals scanned were the issues that reached the library shelves between 1998 October 1 and 1999 September 30 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 *Supplements* and *Reviews*), *Solar Physics*, *Acta Astronomica*, *Revista Mexicana Astronomia y Astrofisica*, *Astrophysics and Space Science*, *Astronomy Reports*, *Astronomy Letters*, *Astrofizica*, *Astronomische Nachrichten*, *Journal of Astrophysics and Astronomy*, *Publications of the Astronomical Society of Japan*, *Bulletin of the Astronomical Society of India*, *Baltic Astronomy*, *New Astronomy*, *IAU Circulars*, the solar physics portions of *Astroparticle Physics*, *Journal of Geophysical Research*, and *Geophysical Research Letters*, and, of course, *Publications of the Astronomical Society of the Pacific*.

1.1. Hale

You might feel this heading should be "Hail," but we have in mind George Ellery, who started so many astronomical entities which still flourish (and see also Ap98, § 10.8, on the "tale" of Comet Hale-Bopp). The American astronomical community welcomed something like 150 new Ph.D.s, roughly a third of the world total. This number has crept very slowly up over the past decades, but, in a strong converse trend, the number of American astronomers applying for membership in the International Astronomical Union in 1999 was about 85, down from 182 in 1987.

Happy anniversaries were celebrated by the American Astronomical Society and the American Physical Society (both 100 in 1999), the *Astronomical Journal* (with publication at the beginning of Volume 117 of the papers from an AAS session honoring its 150th), and the public planetarium, the first of which was built by Zeiss in Munich in 1924 and opened in 1925. It may or may not be a coincidence that a number of planetarium refurbishments are in progress or just completed, including the Adler (Chicago), Hayden (New York), Griffith (Los Angeles), and Stonehenge (Salisbury). Mt. Stromlo Observatory also turned 75 in 1999. If you want to spell out the full acronym, MSSSO, it is essential to keep in mind that, because it is a dry country, there is only one Siding Spring, but several Observatories.

Inauguration and/or first light (not always in that order) came for Subaru, Gemini North, the first mirror of the Very Large Telescope (now called Antu; the others will be Kueyen, Melinal, and Yepun), the Sudbury Neutrino

Observatory (well, perhaps not quite light), the new (single) mirror of the (formerly) Multi-Mirror Telescope, and NODO, the largest liquid mirror telescope. CHARA helicoptered the first of its telescopes to Mt. Wilson on January 22, and the Green Bank Telescope is coming along. Indeed, in a photograph stapled into NRAO Newsletter No. 81, it looks very much as if it were trying to scratch its head.

Reaching out into space, the reasonably happy fliers were the *Submillimeter Wave Astronomy Satellite* (*SWAS*, on 5 December 1998), *Deep Space 1* (October 1998), the *Far Ultraviolet Spectroscopic Explorer* (*FUSE*, June 1999), and the X-ray satellite *Chandra* (formerly *AXAF*) in late July of 1999.

Carrying on with firm upper lips were *Cassini* (swinging past Venus and Earth with its nuclear power source still intact), *Galileo* (safed through most of a fly-by of Europa, but back on the ether), *NEAR* (irresistibly, *NEAR* miss, which misfired on 20 December 1998; but it passed close enough to Eros to measure its mass and size, and it gets another chance to pass *NEAR*er next year). And the Hubble Deep Field South joined its northern predecessor as a source of curious faint things for the whole community.

Our younger-sister publication, the *Astrophysical Journal*, acquired a new editor under far happier circumstances than those attending the changing-of-the-guard at *New England Journal of Medicine* (Angell 1999).

1.2. Farewell

Surely the saddest of the institutional departures was that of the Royal Greenwich Observatory, which closed its fourth and last set of doors on 31 October 1998. The National Radio Astronomy Observatory 140 foot correlated its last fringes on 17 June 1999. Kitt Peak National Observatory closed its 0.9 meter reflector and coudé feed. Mostly it needs to be fed money, and catering arrangements could conceivably be made.

Above the atmosphere, *MIR* still orbits, but no one now lives there. *ROSAT* did its last X-ray astronomy on 23 October 1998. And some missions were still-born, or nearly so. A successful launch of *ABRIXAS* (an all-sky X-ray survey instrument) was followed by battery failure. *WIRE* (the *Wide-Field Infrared Explorer*) also rose on schedule, in March, but lost the coolant essential for infrared sensitivity. Its 2″ tracker telescope is, however, being used for very high precision study of rapid variability of bright stars. *Zhamya 2.5* went to a watery Pacific grave on February 5. And winner of the "bad publicity award" for 1999 was the *Mars Climate Observer*. Well launched on 10 December 1998, it failed the math part of its SAT and self-destructed in late September.

Colleagues who left us during the year (in the order in which the news was received) included American Astronomical Society members William Markowitz, Leonida Rosino, Patrick Fleming, Irving Segal, William Mesrobian, Barry Lasker, G. Edward Langer, Thomas Ogburn, William Blitzstein, Gerhard Herzberg, Heinrich Eichhorn, Ken Willcox, Rebecca Elson, Arne Slettebak, Boris Garfinkel, Margaret Russell Edmondson (elected a patron posthumously), Richard A. White, Oscar Monnig, Cornelis Zwaan, Arthur Hoag, Paris Pishmish, Sidney Kastner, Daniel Magnes Popper, Dorothy N. Davis Locanthi, and Henry W. Spreitzer. Special friends from abroad who departed during the year included Carlos Jaschek and Wilhelmina Iwanowska.

2. SOLAR PHYSICS

The almighty electronic search engine of the Astrophysics Data System (ADS) reveals to us in a split second over 1000 papers that have been published during the time frame of 1998 October–1999 September on solar topics. A specified search according to various subfields of solar physics reveals a breakdown of the forefront interests (Table 1). In the following we summarize the highlights in each subfield in the same order. The total number of solar publications is somewhat less than the sum of items given in Table 1 (because of the many overlaps), but the percentages should approximately reflect the relative weight of activities in each field.

2.1. The Musical Art of Solar Helioseismology

Like the celebrated cellist Yoyo Ma exploring all kinds of magic internal resonances of his musical instrument, solar helioseismologists continue to develop new acoustic sounding techniques to probe the convective and radiative zones of the solar interior. The art of full-disk helioseismology has also been dubbed "repetitive music and the question of gap filling" (Fossat et al. 1999), something that J. S. Bach mastered ingeniously 300 years ago.

The accuracy of "global helioseismology" is continuously refined, providing crucial constraints on the helium abundance (27.3%–27.7%, Brun et al. 1998; 24.8% ± 0.2%, Richard et al. 1998, Basu, Däppen, & Nayfonov 1999b), the inversion of the radial density structure of the solar/stellar interior, or the solar age (4.66 ± 0.11 Gyr, Dziembowski et al. 1999). Deviations from standard solar models have recently been employed to derive anomalous solar energy losses by the Primakoff emission of axions (Schlattl et al. 1999; Cebrian et al. 1999).

Increased effort was spent on the inversion of the "tachocline" (Hujeirat & Yorke 1998), a thin zone at the base of the convection zone which exhibits a high radial gradient of the rotation rate, having a width of < 0.05 (Corbard et al. 1999) or < 0.02 solar radii (Elliott & Gough

TABLE 1

DATA ON SOLAR PHYSICS PAPERS PUBLISHED BETWEEN 1998 OCTOBER AND 1999 SEPTEMBER

Solar Field	Articles in Refereed Journals	All Bibliographic Sources	Percentages (%)
2.1) Solar helioseismology	39	101	9
2.2) Solar neutrinos	32	49	4
2.3) Solar photosphere	160	281	23
2.4) Solar chromosphere	109	182	15
2.5) Solar corona: quiet	38	63	5
2.6) Solar corona: active regions	69	130	11
2.7) Solar corona: flares	97	149	13
2.8) Solar corona: mass ejections	50	99	8
2.9) Solar corona: holes	54	84	7
2.10) Solar wind and heliosphere	48	63	5

1999). Mixing and overshooting effects at the bottom of the convection zone are also studied with seismic methods (Schlattl & Weiss 1999), which are thought to be essential to solve the lithium problem of the standard solar model.

New techniques emerged also that focus on "local helioseismology," e.g., the *time-distance technique* or *ring diagram analysis* around localized inhomogeneities, such as sunspots or emerging active regions. The time-distance technique allows us to probe the vertical extension of active regions (Chou et al. 1999) or acoustic halos around active regions ("acoustic glory"; Braun & Lindsey 1999), as reconstructed from absorption features of acoustic waves. The ring diagram analysis reveals meridional circulation patterns, e.g., poleward flows at 0.97–1.00 solar radii (Gonzalez Hernandez et al. 1999; Lindsey & Braun 1998), with a velocity of about 10–30 m/sec (Braun & Fan 1998; Basu, Antia, & Tripathy 1999a). The most variable seismic phenomenon is, of course, a solar flare, whose "sunquakes" are now quantified with "egression power maps" (Donea et al. 1999). Furthermore, transitions from one 11-year solar cycle to the next one also leaves seismic fingerprints, which are different for "old" and "new" magnetic flux (Benevolenskaya et al. 1999).

2.2. Solar Neutrinos

The latest studies on the solar neutrino flux concentrate on its time variability. If a clear correlation of the neutrino flux with the solar cycle could be established, we could probe the interaction of the neutrinos' magnetic moment with the solar dynamo. The tentative results, however, appear to be mixed. The dynamic solar model suggests that the GALLEX data may show an anti-correlation, while the SuperKamiokande data may show a correlation with the activity cycle (Grandpierre 1999). However, the Homestake data analysis (Sturrock, Walther, & Wheatland 1997) was described as not revealing a significant correlation with the monthly sunspot number (Walther 1999), contradicting by the same token a new analysis of GALLEX data (Sturrock et al. 1999a, 1999b).

A new correlation of the neutrino flux with solar wind particles was found by Basu (1999a), suggesting that the two may have a common cause of origin in the solar atmosphere! Sturrock, Walther, & Wheatland (1998) found evidence for a dependence of the variance of the neutrino flux upon latitude and suggest that these effects may be attributed to resonant spin-flavor precession of left-hand-helicity electron neutrinos in the magnetic field of the solar radiative zone. We can be assured that the neutrino problem will stay with us in the next millennium; we need a couple more generations of trained astronomers who await satisfactory neutrino statistics.

2.3. Solar Photosphere

Because the solar photosphere provides the only firm ground where the magnetic field strength can be measured directly (via Zeeman effect and Stokes polarimetry), it still provides an ideal laboratory for studying magnetically driven phenomena in astrophysical plasmas.

A new buzzword is "magnetic helicity," which is supposed to control the evolution of magnetic fields, the twisting and braiding deformations that lead to magnetic reconnection, with subsequent eruption in the solar corona that also affects our "space weather." A simple *sign rule* was established, i.e., the sign of helicity is mainly negative in the northern hemisphere of the Sun and positive in the southern hemisphere (Zhang & Bao 1998, 1999). The current helicity was also found to be scale-invariant over a range of 1000–15,000 km, suggesting a fractal nature of the vortical field structure (Abramenko 1999; Consolini et al. 1999). Theoretical models relate the helicity to the rise of subphotospheric flux tubes which become kink-unstable and form delta-spot active regions (Linton et al. 1998).

Another motivation of numerous recent photospheric studies is the coronal heating problem. The ultimate energy source for coronal heating must lie in the turbulent convection zone below the photosphere, which buffets magnetic flux tubes and generates transverse MHD waves that propagate upward to coronal loops and can be dissipated there. Also the random motion of the footpoints produces twisted and braided coronal field lines which generate field-aligned DC electric currents that can be dissipated resistively. Numerous studies were therefore devoted to investigation of the photospheric drivers, such as the dispersal or diffusive dynamics of magnetic flux elements (van Ballegooijen et al. 1998; Sigwarth et al. 1999; Hagenaar et al. 1999; Berger et al. 1998; Lawrence et al. 1999; Cadavid et al. 1998, 1999; Srikanth et al. 1999), horizontal velocity fields (Roudier et al. 1999), vertical flow characteristics (Berrilli et al. 1999; Schlichenmaier & Schmidt 1999), granular shear flows (Nesis et al. 1999), and velocities in solar pores (Keil et al. 1999) and in sunspots (Sigwarth et al. 1998; Sobotka et al. 1999). Many of these observational measurements were performed for the first time with new high-resolution capabilities down to subarcsecond scales (LaPalma Observatory, THEMIS, *TRACE*, *SOHO*/MDI). Theoretical models and numerical simulations of the dynamics of (sub)photospheric flux tubes explored convective instabilities (Takeuchi 1999), interacting and reconnecting magnetic flux tubes (Kondrashov et al. 1999), oscillations of photospheric flux tubes (Hasan & Kalkofen 1999; Mashnich & Bashkirtsev 1999; Sutmann et al. 1998), torsional waves (Ploner & Solanki 1999), and resonantly damped flux tube modes (Stenuit et al. 1999).

Another focus of recent photospheric studies addresses the fundamental topology and geometric height variation of the magnetic field through the photospheric-chromospheric interface. The spatial magnetic field boundaries of active regions were found to scale with a fractal dimension of $D \approx 1.5$–1.7 (Meunier 1999). However, even in simple short-lived active regions, the photospheric magnetic field is found to be highly fragmented, creating a very complex connectivity pattern (Deng et al. 1999). The magnetic topology of 3D reconnection, requiring singularities, null points, and separatrices, has only recently been considered for the understanding of photospheric fields (Inverarity & Priest 1999; Tongjiang et al. 1999). Extrapolating the photospheric field allows testing the nonpotentiality of the magnetic field by comparison with Hα filaments (Woodard & Chae 1999) or with radio maps (Lee et al. 1999).

More detailed work has also been devoted to determine photospheric elemental abundances, which serve as a standard candle for solar observers to normalize coronal elemental abundances. The disparity between the two abundances provides important clues on the selective heating and chromospheric evaporation process during flares. New calculations of photospheric and/or coronal abundances have been presented for sulfur, calcium, iron (Fludra & Schmelz 1999), iron (Grevesse & Sauval 1999), and boron (Cunha & Smith 1999).

2.4. Solar Chromosphere

Research on the solar chromosphere entered center stage. The unprecedented attention comes mainly from new observational EUV capabilities, such as the EIT, SUMER, and CDS instruments on *SOHO*, as well as the recently launched *TRACE* telescope. While earlier theoretical models dealt with the chromosphere as a stratified plane-parallel sphere with a vertical extent of some 2500 km, the new picture of the chromosphere became extremely inhomogeneous in temperature and density (e.g., Feldman et al. 1999a), with fuzzy spicular extensions up to $\approx$7000 km. A bewildering variety of terms were coined for dynamic phenomena in the chromosphere, such as spicules, macrospicules, explosive events, bi-directional EUV jets, blinkers, tornados, nanoflares, etc., which all are believed to be more or less direct witnesses of magnetic reconnection processes.

The structure of the chromosphere did undergo a major revision by a discovery made with the *TRACE* telescope. It revealed a "spongy" chromospheric fine structure in certain active region plage areas, which has been characterized with the analogy to "moss" (Berger et al. 1999; Fletcher & DePontieu 1999; Schrijver et al. 1999). The "moss" emission is visible at temperatures of $\approx$0.6–1.5 MK and is located at altitudes of $\approx$2000–4000 km above the photosphere at the footpoints of hotter coronal loops with typical temperatures of 3–5 MK. The punctuated structure of the "moss" is believed to be caused by the extinction of cooler spicular jets that form dark inclusions in front of the bright (hotter) EUV emission. Theoretical models show that the small-scale loops. Rather it represents "moss" is not composed of small-scale loops. Rather it represents the high-temperature end of large-scale coronal loops in the chromosphere/transition interface (Martens et al. 1999), where the temperature gradient dT/dh and thus conductive losses are largest. The physics of the "moss" dynamics is not understood; it could be an interaction of spicular jets from the chromosphere with the ambient hotter transition region plasma, or alternatively a secondary by-product of the downward heat conduction of coronal loops.

The coronal heating problem can probably not be understood without first decrypting the dynamics of the chromosphere. There appears to be a paradigm shift from coronal large-scale to chromospheric small-scale magnetic reconnection processes. Magnetic flux elements are thought to appear randomly within supergranulation cells, are carried into the network according to a prescribed velocity field, and cancel in the network by collisions between elements of opposite polarity (Sturrock et al. 1999a, 1999b). Litvinenko (1999) finds that the physical conditions for chromospheric reconnection are most favorable at an altitude of 600 km above the photosphere. Chae et al. (1999) observe chromospheric upflows in Hα during explosive EUV events and interpret the Hα signature as cool inflows into the magnetically diffusive region, while the EUV jets represent the hotter outflows from the same region. Theoretical models of bi-directional EUV jets ejected from a Petschek reconnection region can actually explain the observed Doppler-shifted components of the EUV line profiles (Innes & Tóth 1999). The underlying reconnection process is thought to create a sling-shot effect that generates complex 3D surface shock waves, which can heat the plasma and produce EUV jets (Tarbell et al. 1999). Alternative models consider Alfvénic resonances (Sterling 1998), torsional Alfvén waves (Kudoh & Shibata 1999), or weakly-damped Alfvén waves (DePontieu 1999) as drivers of chromospheric jets (called "spicules" at the limb and "dark mottles" on the disk). Wang (1999) suggested that jets seen in He II 304 Å are triggered by magnetic reconnection during flux submergence (or cancellation). Chromospheric reconnection events have also been associated with macrospicules (Wang 1998), with "heating events," "network flares," and "microflares" (Benz & Krucker 1999). Their thermal energy and occurrence rate have been compared with the radiative loss rate of the corona and it was concluded that microflaring could potentially account for a significant fraction of the coronal heating requirement (Benz & Krucker 1998).

Another line of attack on the coronal heating problem is the detection of waves. Although the efficacy of coronal heating by AC waves is generally ruled out by the two simple arguments that (1) subphotospheric acoustic waves are reflected at the photospheric discontinuity and (2) Alfvénic waves are dissipated too far out in the heliosphere, so that no suitable wave dissipation mechanism seems to be at hand to heat the intervening corona, several recent studies concentrated on the detection of wave-like oscillations in the chromosphere. Ireland et al. (1999) performed a wavelet analysis with *SOHO*/CDS data in a wide range of temperatures ($T = 2 \times 10^4$ to 2×10^6 K) and found significant periods. Brynildsen et al. (1999) analyzed the 3 minute oscillations in the sunspot chromosphere (see also Fludra 1999; Gelfreikh et al. 1999) and find support for the hypothesis that the oscillations are upward-propagating, nonlinear acoustic waves. This underscores a fundamental recent finding made by Carlsson & Stein (1995) that the dynamics (of H_{2v} bright points) in the nonmagnetic chromosphere is caused by propagating acoustic waves—and not the standing waves demanded by the resonant-cavity model. Numerical simulations show that the leakage or transmission strongly depends on the relative orientation of the "waveguides" (i.e., flux tubes) to the source of acoustic waves (Huang, Museliak, & Ulmschneider 1999b; Nocera & Ruderman 1998; Sutmann et al. 1998) and that nonlinear transverse waves carry ≈ 30 times more energy than longitudinal tube waves (Ulmschneider & Museliak 1998). However, it was also argued that the dynamical model of Carlsson & Stein (1995) uses only about 1% of the supplied acoustic energy, and that chromospheric heating also requires acoustic waves of short period (< 2 minutes) which form shocks and produce the persistent outward temperature increase observed in UV (Kalkofen et al. 1999).

In summary, from present observations it is still not clear whether the chromosphere conveys more energy to the corona by waves or mass flows. Since waves are harder to detect (because a high cadence and contrast are required to detect wave-like modulations in solar images), most of the observations are biased towards the more easily detected phenomenon of mass upflows, which can simply be studied (besides the more difficult detection of blueshifts) from emission measure increases (which generally also go along with temperature increases) in EUV and SXR wavelengths. The latter manifestation is most dramatic in flares, where "chromospheric evaporation" increases the ambient coronal electron density by factors of ≈ 10–1000, with a temperature increase up to a factor ≈ 10. A number of recent studies are devoted to this phenomenon of chromospheric evaporation (Karlicky 1998; McDonald et al. 1999; Czaykowska et al. 1999; Podgorny & Podgorny 1999; Gan 1998) or the associated white-light and Hα emission (Abbett & Hawley 1999; Fletcher & Brown 1998; Ding et al. 1999; Matthews et al. 1998). However, accumulating all the thermal energy input that is observed from the chromospheric-evaporated plasma in soft X-rays (flares, transient brightenings) and EUV (microflares, nanoflares) down to the detection limit (corresponding to energies of $\approx 10^{25}$ erg per event), the input rate falls short of the coronal heating requirement by about 2 orders of magnitude. Only by the argument of extrapolating the (power-law) frequency distribution of heating events several orders of magnitude below the detection threshold (using the powerful argument of scale-invariance that is inherent in systems with self-organized criticality) was a solution of the coronal heating problem via chromospheric evaporation conjectured (Benz & Krucker 1998). This fundamental problem reminds us a bit of the issue of the closed universe, which requires stretching the observed amount of luminous baryonic matter by about two orders of magnitude.

2.5. Solar Quiet Corona

In contrast to active regions, where flares occur, stronger magnetic fields prevail, and closed magnetic field lines control the corona, the rest of the corona was historically designated as "quiet corona." The "quiet corona" may further be subdivided into closed-field regions and open-field regions (coronal holes). A remarkable advance that was achieved in recent years is the discovery that flare-like phenomena are not exclusively bound to active regions (e.g., Shimojo & Shibata 1999), but happen also as miniature versions (microflares, nanoflares) in the quiet-Sun network (Berghmans et al. 1998; Krucker & Benz 1998; Benz & Krucker 1999; Prés & Phillips 1999; Chae et al. 1998; Gallagher et al. 1999; Wang 1998), demonstrated also by nonthermal (relativistic) particle signatures (Benz & Krucker 1999; Nindos et al. 1999). This is a significant discovery, because it opens up heating and energy release mechanisms for the quiet corona, where much less magnetic flux (and thus less magnetic energy) is available than in active regions. By the same token, the term "quiet Sun" has also become a misnomer!

A great deal of quantitative work on electron density and temperature diagnostics for the quiet-Sun corona has been conducted over the last year, conveying valuable puzzle pieces that incrementally add up to a detailed understanding of its structure: comprehensive measurements of EUV emission line intensities made with CDS (Brooks et al. 1999; Landi et al. 1999; Fredvik & Maltby 1999) and Koronas-I (Zhitnik et al. 1998), cross-calibration of iron lines between SERTS and CDS (Brosius et al. 1998), element abundance variations with height (with SUMER) and gravitational settling (Feldman, Widing, & Warren 1999b), differential emission measure distributions from SUMER and CDS (Griffiths et al. 1999; Landi & Landini 1998), electron density measurements with line ratios from the same ions with SUMER (Doschek et al. 1998), first-ionization-potential (FIP) element enhancements with SUMER (Feldman et al. 1998; Laming et al. 1999), blueshift measurements of the quiet Sun with SUMER (Dammasch et al. 1999; Peter 1999b), and expansion factors of network boundaries with temperature using CDS (Patsourakos et al. 1999).

A concerted effort to understand the structure of the quiet corona was undertaken with the so-called "Whole Sun Month Campaign" (IACG Campaign 4), with the primary objective of understanding the large-scale, stable structures that dominate the solar corona at solar minimum: specifically, the equatorial helmet streamers and polar coronal holes that can persist for several solar rotations during this phase of the solar cycle. The scientific results were published together in Volume 104, No. A5 of the *Journal of Geophysical Research*, containing some 20 papers (Galvin & Kohl 1999; Biesecker et al. 1999; Gibson et al. 1999; Alexander 1999; Fludra et al. 1999; Panasyuk 1999; Zidowitz 1999; Zhao et al. 1999; DelZanna & Bromage 1999; Gopalswamy 1999; Gopalswamy et al. 1999; Warren & Hassler 1999; Dobrzycka et al. 1999; Guhathakurta et al. 1999; Linker et al. 1999; Clegg et al. 1999; Breen et al. 1999; Riley et al. 1999; Posner et al. 1999; Torsti, Anttila, & Sahla 1999a, 1999b). This joint venture tackled (and answered) fundamental questions on how the large-scale global magnetic field on the Sun is related to the solar wind, addressing the boundaries between open versus closed coronal field lines, the source of the slow solar wind, the radial expansion and deviations from it, the importance of the solar wind in the coronal force balance, and the heliospheric location of the sonic surface.

2.6. Solar Coronal Active Regions

The three-dimensional geometric, density, and temperature structure of active region loops, the most suspicious smoking guns of the elusive coronal heating mechanisms, have been explored in much more detail. Progress has been made thanks to the powerful multitemperature discrimination and spatial resolution of EUV (EIT/*SOHO*, *TRACE*, *CORONAS*, SERTS) and soft X-ray (*Yohkoh*) instruments. Pioneering 3D reconstructions have been achieved with new methods such as *dynamic stereoscopy* or *potential field stretching*. The relatively "cool" ($T \approx 1.0$–1.5 MK) active region loops seen in EUV seem to exhibit significantly different properties from the "hotter" ($T \approx 2$–8 MK) loops seen in soft X-rays: (1) they are close to isothermal equilibrium (as opposed to hotter loops that exhibit a temperature maximum at the loop top); (2) radiative loss dominates conductive loss in the coronal part (as opposed to balanced loss rates in hotter loops, or dominant conductive loss; Prés & Phillips 1999), so they do not fulfill the steady-state energy balance equation, i.e., the Rosner-Tucker-Vaiana law (e.g., Neupert et al. 1998). *TRACE* observations show that active region loops consist of thin loop threads which continually evolve, i.e., are intermittently heated for time periods of a few minutes, followed by rapid cooling as evidenced by the occurrence of downflows and EUV extinction (Schrijver et al. 1999).

The ominous coronal heating problem has been tackled from various angles. New clues have been sought by investigating global correlations in active regions, e.g., between magnetic flux parameters and soft X-ray luminosity, revealing best correlation in the case of the total unsigned magnetic flux; but the result did not allow discrimination between different coronal heating theories (Fisher et al. 1998). Coronal heating is definitely more intense in new active regions, because younger active regions were found to contain high-temperature loops (>5 MK), which are absent in older active regions (Sterling 1999). But what is the source of coronal heating? The presence of Alfvén waves in coronal loops has been investigated by examining the relationship between the nonthermal line width and the loop orientation relative to the line-of-sight. Although a systematic difference in the line width was found between face-on and edge-on loops, as expected for propagating Alfvén waves, it was concluded that the Doppler shift was too small to explain all nonthermal velocities reported so far (Hara & Ichimoto 1999; Harra-Murnion et al. 1999). Besides dissipation of resonant Alfvén waves, alternative heating mechanisms have been studied in terms of MHD turbulence (Dmitruk et al. 1998). A radically different concept of active region loop heating is the model of energy dissipation along magnetic separators, which assumes that the location of the heated plasma is confined to the topological boundaries of magnetic separators, instead of being spread along dipolar field lines (Welsch & Longcope 1999; Milano et al. 1999). Observationally, however, no conclusive tests have determined whether the heated plasma is distributed along field lines or separators.

An exciting discovery in the dynamics of active region loops is the phenomenon of global MHD oscillations. Some active region loops were found to oscillate with a period of ≈ 5 minutes after a flare, for which the MHD mode was identified as fast kink mode. Nakariakov et al. (1999) interpreted the damping of the loop oscillations in terms of viscous dissipation of resonant Alfvén waves and inferred a stunningly low Reynolds number of $\approx 10^6$, which is 8–9 orders of magnitude smaller than the classical value of $R = 10^{14}$ assumed in the corona! Such an over-efficient dissipation mechanism has profound implications for flare heating and makes the coronal heating problem even harder, not easier (Hudson & Kosugi 1999)!

New techniques have been developed to infer the coronal magnetic field strength with radio (polarization) measurements (Ryabov et al. 1999). A 3D magnetic null point in the center of a saddle was identified with *SOHO*/EIT images (Filippov 1999). Radial stretching of a potential field has been found to match magnetic field tracers (i.e., loop structures) observed in soft X-rays (Gary & Alexander 1999).

Elemental abundances, differential emission measure distributions, density, and temperature measurements in active regions have been greatly refined, making use of cross-calibrations between SERTS and CDS (Brosius et al. 1998), SERTS and SXT (Schmelz et al. 1999), SERTS and *CORONAS I* (Zhitnik et al. 1999), CDS observations (Landi & Landini 1998), as well as *SMM*/FCS observations (Saba et al. 1999). These studies brought also some new light into the issues of chromospheric versus coronal abundances, or the role of resonant scattering in the corona.

2.7. Solar Flares

There is a growing consensus in the understanding of particle acceleration mechanisms in solar flares: wave-resonant stochastic acceleration is considered as the most likely candidate that can reconcile both electron and ion distributions up to the highest observed (gamma-ray) energies, while shocks or DC electric fields may play a role for low-energy (≈ 100 keV) bulk acceleration. Interestingly, high-energy (> 1 MeV) electrons seem not only to be produced in large flares but also to be present in weak flares when no hard X-ray emission is detected, according to nonthermal radio emission observed at millimeter wavelengths (Raulin et al. 1999). There is an old controversy whether particle acceleration in interplanetary space (*solar energetic particle events* [*SEP*]) is decoupled from the coronal flare site. Timing measurements with the *WIND* spacecraft show that there are two types of electron acceleration sources: flare-related (type III bursts) and interplanetary (up to half an hour later; Krucker et al. 1999). Klein et al. (1999) find evidence that the bow shock of a coronal mass ejection (CME) in interplanetary space is NOT the main accelerator of the high-energy (> 20 MeV) protons, because their timing can be traced back to coronal acceleration sites. On the other side, high-energy particles are accelerated sometimes in a fully confined magnetic geometry, so that no particles escape into interplanetary space, as evident from radio-silent gamma-ray flares (Rieger et al. 1999).

Overall, the magnetic reconnection scenario (e.g., simulated by Magara & Shibata 1999) as prime driver of solar flares becomes established by an increasing number of complementary observations that fall in place like puzzle pieces. The first direct evidence for observed high-speed flows in the region immediately above a flare arcade, indicative of plasma outflows from a cusp-type reconnection point, has been brought forward by McKenzie & Hudson (1999). The reconnection outflows are also thought to coincide more or less with the particle acceleration sites, a location that has been consistently verified with electron time-of-flight measurements, although the energy-dependent hard X-ray time delays theoretically could also be interpreted in terms of spectral variations (Brown et al. 1998c). New evidence for trapping of electrons in the above-the-loop-top acceleration site (known as *Masuda sources*) comes from comparison of footpoint versus loop-top hard X-ray spectra, found to be consistent with magnetic reconnection models in which energetic particles are trapped between MHD slow-mode shocks attached to the reconnection region and a fast-mode shock formed by the reconnection outflow jet (Metcalf & Alexander 1999). While single-loop models with cusp geometry can account for many flares, there is also clear evidence for multiple-loop interactions in numerous other flares (e.g., Falewicz & Rudawy 1999). The next level of complexity is exercised with theoretical models of 3D fan reconnection geometries (Craig & McClymont 1999). A statistical approach of small-scale magnetic reconnection events that pile up to a macroscopic flare was attempted with a cellular automaton model, predicting a power-law slope of $\alpha = 3/2$ in the frequency distribution, which is consistent with observed values (Litvinenko 1998).

Analysis of gamma-ray lines shows strong enhancements of ^{3}He/^{4}He in chromospheric plasma with respect to photospheric values (Mandzhavidze et al. 1999; Share & Murphy 1999). Soft X-ray line studies reveal that calcium and iron are also enhanced in flares, but sulfur is depleted (Fludra & Schmelz 1999). The altitude of 0.5 MeV gamma-ray emission seems to be confined below a height of $\approx 10^4$ km, according to observations of occulted electron-dominated flares (Vilmer et al. 1999; Murphy et al. 1999).

The basic mechanism of chromospheric evaporation in flares is nicely confirmed by observed blueshifts that trace upflows (Czaykowska et al. 1999; Jianqi et al. 1998), by observed redshifts that trace the subsequent downflows (Gan 1998), as well as by the Neupert effect (Tomczak 1999). However, in small flares, the percentage of nonthermal electron beam energies was found to be insufficient to power chromospheric evaporation, requiring an additional energy source (McDonald et al. 1999). New hydrodynamic simulations of the chromospheric evaporation process focus on differences in line shifts and optical emission before (gentle evaporation) and after (explosive phase) flares begin (Abbett & Hawley 1999; Ding et al. 1999).

2.8. Solar Coronal Mass Ejections

Coronal mass ejections (*CME*) became an integral part of flare phenomena (if you listen to the flare folks), or, vice versa, flares are considered as a possible by-product of CMEs (if you pay your membership dues to the Geophysical Union). Since true astrophysicists are only interested in fundamental physics, these chicken-or-egg statements do not explain the primary physical mechanisms of the little-understood coronal magnetic reconfigurations and instabilities that drive those secondary phenomena that we observe as flares and CMEs.

A new model for the coronal initiation of solar CMEs was proposed by Antiochos et al. (1999), the so-called "*magnetic breakout*" model. (The French love this model because it fits nicely the *TRACE* observations of the holiday 1998 July 14 flare, which occurred on the French national holiday, when the storming of the Bastille during the French Revolution is celebrated.) Antiochos's magnetic breakout model reproduces two difficult properties of CMEs and eruptive flares: (1) very low-lying magnetic field lines, down to the photospheric neutral line, can open toward infinity during an eruption, and (2) the eruption is driven solely by magnetic free energy stored in a closed, sheared arcade. Observationally, an event has been studied where magnetic field reconnection near one footpoint of a loop system triggers reconnection near its other footpoint and this way destabilizes the loop system and gives rise to the CME (Innes et al. 1999), or even to multiple CME events (Lyons & Simnett 1999). While the launch of CMEs was characterized with 2D geometries of "*disconnection events*" in the past, new *SOHO*/LASCO studies show clearly that the core of CMEs consists of 3D helical flux ropes (Dere et al. 1999), which can be propelled outward with a suitable high current (Chen 1989). The kinematics and morphology of CMEs were successfully modeled with this erupting flux rope model (Wood et al. 1999).

The solar mass loss due to CMEs is estimated to be of order 10% of the total solar wind mass loss, averaged over a solar cycle. A clear signature of this coronal mass loss can be seen in *dimming* regions behind the launch of a CME. This new phenomenon of *coronal dimming* is now observed in EUV and soft X-rays (Zarro et al. 1999; Sterling & Hudson 1997).

Another frequent manifestation of CMEs is the propagation of circular wave fronts that originate at the CME launch site and propagate radially across the entire solar surface (e.g., with a speed of ≈250 km/sec; Thompson et al. 1999). This wave phenomenon now discovered in EUV wavelengths (called *EIT waves*) has been associated with Moreton (or Ramsey) waves discovered earlier in Hα. Injection of >10 MeV protons have also been observed in association with such coronal Moreton waves (Torsti et al. 1999c).

A new finding that triggered a NASA press release is the relation of sigmoidal morphology in eruptive CMEs (Canfield et al. 1999). The authors find that the sigmoidal (magnetic structures with S-shaped twist) are more likely to erupt (probably via kink instability) than non-sigmoidal ones. The predictional power of this key observation raised many hopes that we are now in the position to forecast the solar-terrestrial *space weather*, and this way can promptly alert space astronauts, electric power plants, mobile phones (and perhaps hospital beepers!).

A number of recent CME studies are devoted to the properties of CME-associated radio emission, which are manifested as type II shock fronts (Reiner et al. 1998; Reiner & Kaiser 1999; Cliver et al. 1999; Dulk et al. 1999; Gopalswamy et al. 1999; Bale et al. 1999), type III burst electron beams (Aurass et al. 1999), and other metric/decimetric radio emission (Maja et al. 1999).

2.9. Solar Coronal Holes

Coronal holes demarcate magnetic open-field regions, which occupy not only the solar north and south poles (as expected for an ideal dipolar field), but occasionally also extend to low-latitude regions, which, depending on their morphological shape, were named, e.g., "the Italian boot," or "elephant trunk" (Zhao et al. 1999; DelZanna & Bromage 1999; Gopalswamy et al. 1999). Interesting physics arises from questions like how a trans-equatorial coronal hole manages to maintain its morphological shape without being wound up by differential rotation, or what is different in the conditions of particle acceleration that boost the solar wind from coronal holes by a factor of about 2, compared with the solar wind from the rest of the (closed-field) corona.

Elemental abundances are different in coronal holes and the rest of the Sun. While low first ionization potential (FIP) elements (Na, Al, Ca, Mg, Ni, Fe, Si) are enriched by about a factor of 4 in the quiet-Sun corona (compared with the underlying chromospheric values), little or no enrichment exists in polar coronal holes (Feldman et al. 1998).

First magnetic field measurements in a coronal hole were achieved with RATAN-600 radio observations by Borovik et al. (1999), yielding a field strength of $B \approx 0.2$ G at the photospheric level and $B = 7$–10 G at the height level of $\lambda = 18$ cm emission. Combined radio and EUV observations of an equatorial coronal hole yield a temperature of $T_c \leq 0.9$ MK and a density of $n_e \approx 3 \times 10^8$ cm^{-3} (Chiuderi-Drago et al. 1999; DelZanna & Bromage 1999).

Combined coronal hole density measurements confirmed that the solar wind reaches an asymptotic velocity within 10–15 solar radii, placing the acceleration region of the fast solar wind very close to the Sun (Guhathakurta et al. 1999). The electron densities in polar coronal holes were found to be consistent with a constant pressure of $p_e = 1.6 \times 10^{14}$ cm^{-3} K (Warren & Hassler 1999).

The dependence of coronal hole boundaries on height has important consequences for the solar wind speed (just apply the law of mass flux conservation to a bottleneck). New evidence for super-radial geometries was found from H I Lyα and O VI emission (Dobrzycka et al. 1999; Cranmer et al. 1999), while the radial geometry was defended by others (Woo et al. 1999; Woo & Habbal 1999).

SUMER observations in coronal holes have shown that the blueshift measured in He I 584 Å is not consistent with a uniform outflow (Peter 1999a). Peter & Judge (1999) find a higher filling factor of blueshifted material in polar holes ($\approx$70%) compared with equatorial coronal holes ($\approx$30%), while the respective blueshifted regions show comparable outflow velocities. However, there is still some controversy about the accuracy of rest wavelength (laboratory) measurements that affects the inferred velocities (Peter & Judge 1999; Dammasch et al. 1999).

Spectral line profile measurements in coronal holes have been studied in more detail to quantify the anisotropy of solar wind acceleration (Kohl et al. 1999; Cranmer et al. 1999). It was concluded that MHD waves responsible for the excess line broadening tend to become non-linear as they reach 1.2 solar radii (Doyle et al. 1999). Esser et al. (1999) show for the first time that collision times between protons and minor ions are small compared to the solar wind expansion time in the inner corona, leading to a heating mechanism that acts faster than minutes.

New model calculations can explain that the solar wind from coronal holes is completely determined by Alfvén wave acceleration (Tziotziou et al. 1998). Also Si VIII observations are in agreement with undamped radially propagating Alfvén waves (Banerjee et al. 1998). The first nonlinear, two-dimensional MHD simulations of magnetosonic waves show that outward-propagating slow magnetosonic waves are trapped, and nonlinearly steepen in polar plumes, possibly contributing to heating of the lower corona by compressive dissipation (Ofman et al. 1999).

Coronal holes clearly modulate the solar wind: a close relationship of coronal hole extensions to recurrent proton events associated with Corotating Interaction Regions (CIR) was found by Posner et al. (1999). Evidence for a 17-year cycle variation was found in the coronal hole topology and the interplanetary magnetic field (Juckett 1998). An intense geomagnetic storm was found to be associated with a filament eruption near a varying low-latitude coronal hole (Srivastava et al. 1998).

Coronal holes are far from uniform; they are “peppered” with vertical radial structures (“plumes”), which sometimes reveal flare-like dynamics at their footpoints. Wang et al. (1998) discovered 27 correlated white-light and EUV jets (with speeds of 400–1000 km s^{-1}) in a polar coronal hole and interpreted them in terms of magnetic reconnection between magnetic bipoles and neighboring unipolar flux. They find that the bulk of the jet plasma travels with $\approx$250 km s^{-1} (at 2.9–3.7 solar radii) and suggests that these lower velocities may represent the actual outflow speed of the background polar wind. Similar velocities were observed in an explosive event occurring in a region within a polar coronal hole (Pérez et al. 1999).

2.10. Solar Wind and Heliosphere

Remote sensing and in situ measurements of the solar wind with instruments on the *SOHO* (SUMER, LASCO, UVCS, SWAN, CELIAS, COSTEP, ERNE), *ACE*, *Wind*, *Ulysses*, and *Geotail* spacecraft have substantially contributed to a more comprehensive understanding of solar wind acceleration and propagation. The high-speed wind has the following characteristics (Cranmer 1999): (1) the dominant proton-electron plasma flows outward more slowly than other, less numerous positive ions such as He^{2+}; (2) the proton temperature exceeds the electron temperature by about a factor of 2, and the temperatures of other positive ions are greater than the proton temperature by at least their mass ratio, $(T_{\rm ion}/T_p) \gtrsim (m_{\rm ion}/m_p)$; (3) protons and other ions have higher temperatures in the direction perpendicular than in the direction parallel to the magnetic field ($T_\perp > T_\parallel$). The acceleration region of the solar wind is localized in a shell of 1–15 solar radii (e.g., Guhathakurta et al. 1999). Most measurements agree that the high-speed solar wind is accelerated rapidly to about 100–200 km/sec in the first solar radius and reaches a peak of $\approx$700 km/sec at a distance of 5–10 solar radii. The broadened line width of coronal emission lines (e.g., H^0, O^{5+}, O^{6+}) is attributed to MHD waves and MHD turbulence in the solar wind. It is believed that the characteristics of the high-speed wind are controlled by dissipation of high-frequency Alfvén waves, with periods in the millisecond regime (Cranmer et al. 1999). Thus high-frequency Alfvén waves could be generated in coronal magnetic reconnection events, by a turbulent cascade from lower-frequency modes or by kinetic plasma instabilities. Ions can then gain high perpendicular energies ($T_\perp \gg T_\|$) by gyro-resonant wave-particle interactions. A number of recent studies are therefore devoted to measurements and modeling of line widths and temperature anisotropies of various ions in the solar wind (Marsch et al. 1999; Dammasch et al. 1999; Zangrilli et al. 1999; Banerjee et al. 1998).

Other topics studied in the solar wind and heliosphere include, to name a few: shocks in the heliosphere (Whang & Burlaga 1999), mass ejections in the interplanetary medium (Gothoskar & Rao 1999), heliospheric radio emission (Gurnett et al. 1998; Mann et al. 1999a), solar-cycle variations in the heliosphere (Veselovskii et al. 1999; Juckett 1998), the heliospheric termination shock (Exarhos & Moussas 1999a, 1999b; LeRoux & Fichtner 1999), and interactions of cosmic rays with the heliospheric current sheet (El-Borie 1999).

While remote-sensing measurements are still terribly useful, vigorous progress is expected in the future with new in situ instruments, such as the upcoming *Solar Probe* mission, which will sample the inner heliosphere down to 4 solar radii.

3. PLANETARY SYSTEMS AND RELATED TOPICS

We are attempting to avoid the grammatical eccentricity of a Large Astronomical Organization, which recently declared itself to have a Division of Planetary Systems Sciences. Just in case you find it difficult to explain why this sounds funny, the English custom is that, no matter how many tents you propose to erect, you still use tent poles. We thought of giving a number of other examples, but kept wandering off into slight impropriety. If you want everything plural, it has to be the Division of Sciences of Planetary Systems, or poles for erecting tents. Alors, zut. And the less said about "extra-solar planets" the better. We have yet to see even one inside the Sun.

3.1. Theirs

The headline of the fiscal year was, of course, the discovery of three planets orbiting Upsilon And (Marcy 1999). All three are in the Jovian category by mass but have much shorter orbital periods. Unless you want to count the two or three little things orbiting PSR 1257+12 (Ap92, §3 and thereafter), this is the first true system of planets found apart from our own. Ap9x, not having reported the discovery of two planets orbiting PSR 0329+54, is in the happy position of not having to withdraw them (Konacki et al. 1999). Peter van de Kamp's conclusion that he had seen the effects of two planets orbiting Barnard's star long predates this series, as does the non-replicability of the result. But use of the Fine Guidance Sensor on *HST* has pushed the limits for Barnardettes lower in mass and longer in period (Benedict et al. 1999).

And, before we forget, the most important question in this territory is whether the discovery of increasing numbers of companions of large mass but short period makes the existence of other earths more or less likely. Pundits have pontificated and pontiffs punditized on both sides.

Additional planetary companions found in radial velocity searches continue to orbit through the literature (Delfosse et al. 1998 on Gl 1876; Butler et al. 1998 on HD 187123, and others). Other techniques (proper motions, transits, microlensing) are not yet competitive, though you would not immediately guess this from the numbers of papers published. Transits seem to be winning at the moment (Krisciunas 1999 on 51 Peg was within the index year, a press release on HD 209458 well outside, but there is always next year).

As the numbers of radial velocity companions increase, additional systematics appear. All nine with $a = 0.9$–2.5 AU have eccentricities larger than 0.1 (Marcy et al. 1999). It is 0.05 for Jupiter. The preponderance of above-solar metallicities in the hosts (noted last year) is holding up (Gonzalez et al. 1999; Sadakane et al. 1999). None of the planets has been seen directly. The limit is interesting (albedo less than 0.3) only for Tau Boo (Charbonneau et al. 1999). You will surely remember the publicity connected with a putative run-away planet imaged with NICMOS. The paper has now appeared (Terebey et al. 1998); but the grapevine quivers with rumors suggesting that the models formulated to account for it (Lin et al. 1998; de La Fuente Marcos & de La Fuente Marcos 1998) now have the status of predictions.

And, indeed, the rest belongs to the theorists. Their general strategy seems to be "make" (Godon & Livio 1999, who use vortices in disks) and then "migrate" (Papaloizou & Terquem 1999, with disks again important). Hahn & Malhotra (1999), applying the same considerations to our own system, conclude that Jupiter moved in, and Saturn, Uranus, and Neptune out by 30% or more. Most serious removal was that of the Oort comet supply from the region of Saturn, Uranus, and Neptune to Way Out.

The expectation that massive planets in other systems will also be, like ours, made mostly of hydrogen and helium, but with modest rocky cores (Guillot 1999) should make you feel right at home, if you are a Jovian.

3.2. Protoplanetary Disks

Yes, other stars have them, including 55 Cnc, which has already done its planetary thing (Trilling & Brown 1998). But then so does the Sun. It is called the zodiacal light and bears some resemblance to what other disks might fade into

(Gehrz et al. 1999). Otherwise, we note only the remarks of Men'shchikov et al. (1999), who believe they have seen evidence for a wide range of dust particle sizes in the disk around HL Tau, as if agglomeration into planetesimals were underway. Luckily the process is a slow one, because the paper spent about two years from submission to acceptance. BF Ori is perhaps making comets out of some of its detritus (de Winter et al. 1999), but we fear there will be nobody to admire them.

3.3. Ours

There is no unique, reasonable way to order this material. So, the previous section having ended with comets, this one begins with them.

3.3.1. Comets

The first recorded sungrazer was C/1680V, on November 14 (recorder Gottfried Kirch; Biswas 1999). Biswas also notes that Halley was recovered on 25 December 1758 by Johann George Palitsch, and that, in our own time, Elizabeth Roemer has recovered the largest number of comets (79). The record for discoveries is still held by Eugene Shoemaker, with 14 solos and 18 shared.

Hale-Bopp remained the most published comet of the year, holding steady at $m \approx +12$ into the spring (IAU Circ. 7226). It had two active nuclei (Sekanina 1998), two comparable sources of CO gas (frozen CO and break up of more complex molecules; DiSanti et al. 1999), radio emission (Altenhoff et al. 1999) in the tradition established by Kahoutek, and a high ratio of deuterium to light hydrogen in its HCN as well as in its H_2O. That is, some of the molecular fractionation produced in interstellar gas has been preserved intact, and such comets were not the main source of water or hydrogen for the Earth. Hale-Bopp had, however, none of the carriers of the standard diffuse, unidentified bands found in the ISM (Herbig & McNally 1999).

Some of our favorite comets (and discoverers) of the year were *SOHO* (IAU Circ. 7234), ODAS (IAU Circ. 7067), LINEAR (IAU Circ. 7035), Spacewatch (IAU Circ. 7127), and CATALINA (IAU Circ. 7148). Still more former asteroids are now officially comets, including 1940QB (IAU Circ. 7069), Chiron (IAU Circ. 7179), and 1999 DN_3 (IAU Circ. 7167). This last is particularly notable because it won a share of the Edgar Wilson Award for the discovery of comets by amateur astronomers for Korado Korlevič and Mario Jurič of Visnjan Observatory in Croatia (IAU Circ. 7223), whom you have met previously in these pages, if not in person (sadly, neither have we, so far). Incidentally, the renaming must always be in the direction asteroid becomes comet, because once something has shown a tail, you can't pretend it didn't!

Do not worry about the supply of comets running out in the near future. Nearby stars will perturb the Oort cloud a few times every million years, according to data from the *Hipparcos* satellite (Garcia-Sanchez et al. 1999).

3.3.2. Meteors, Meteorites, and the Interplanetary Medium

The Lyrids are said to be the oldest known shower, dating back to 687 B.C. They were spectacular in 1803, producing lots of electrophonic sound (Beech & Nikolova 1999). It is not clear how the parent comet made so many meter-sized chunks, unless it was originally more like a Lyttleton rubble pile than a Whipple dirty iceberg (Lyttleton 1948, 1951).

But the shower to watch in 1998–1999–2000 has been the Leonids of November 17–18. They go back to 899 and represent material lost by Comet 55P/Tempel-Tuttle. They were truly spectacular in 1833 (Olson & Jasinski 1999 on the visual observations by Abraham Lincoln) and in 1966, when material ejected in 1800 and 1899 reached us (Asher 1999). 1998 was not a particularly great year. Indeed, at the expected time of shower peak, as seen from Japan, the rate of sporadic meteors exceeded the rate of Leonids by a factor nearly two (Watanabe et al. 1999). The actual peak came 16 hours earlier (Asher et al. 1999). The forecasts for 1999 and 2000 are similarly rather uncertain as to peak time and peak rate (Ferrin 1999), so it is not much use planning a meteor expedition unless you have a time machine.

Most impressive meteorite of the year has to be the fireball and one-ton fall in Turkmenistan near Kun'-Urgench (Mukhamednazarov 1999). It left a crater 5 m across and 3.5 m deep. By the way, we did find Turkmenistan in our office-size Rand-McNally, but only 11 towns are shown, not including Kun'-Urgench. There is, however, a Kizyl-Aryat on the main railroad line, not to be confused with Kyzyl, the (former) capital of (former) Tana Tuva. Only the capital, Ashchabad, has an airport, but you can fly there nonstop from Birmingham (UK) and various other places.

Most of the other meteoritic news concerned grains that preserve fossil radioactivities and other evidence of presolar-system composition. We note only the grains (probably) from Type II supernovae and from AGB stars described by Choi et al. (1998), mostly because the meteorites have such nice names, Bishunpur and Semarkone, and the minority report from Lee et al. (1998). They ascribe many of the extinct radioactivities and chemical oddities to nuclear reactions and melting caused by solar flares rather than to survival from before the solar system formed. The conventional wisdom is that partial melting and assorted chemical processing occurred in asteroid-sized bodies before the future meteorites broke off (Hutcheon et al. 1998), but that the future chondrites were exempt, which is why we study them to learn how and when the solar system formed.

The dust of the interplanetary medium has a good deal in common with the dust of the interstellar medium (Bradley et al. 1999), but in fact the source is material knocked loose from various asteroids and comets, as for the larger grains that become meteorites. Some of the stuff can be associated with specific asteroids, on the basis of infrared reflectivity and implied chemical composition (Ishguro et al. 1999; Michel et al. 1999). Vesta is so big that its broken off pieces include another named asteroid, Braille, as well as the meteorites called eucrites (Soderblom 1999).

Surprisingly, the Earth-crossing asteroids (of which 1036 Ganymede is the largest) are not the primary local sources of IPM dust, because they live such a short time after first crossing the 1 AU line (Michel et al. 1999).

3.3.3. Asteroids

The more Sherlockian author has been wanting for years to write an essay "On the Dynamics of an Asteroid," in the hopes that it might have European vogue. This is clearly the year. Eros has a future dynamic lifetime of only 50–100 Myr and a 5% chance of hitting the Earth (Michel et al. 1998). Its present orbit has presumably then also not been stable for much longer than that. The up-coming *NEAR*er encounter is probably not designed to reveal what the previous orbit was, but data from the *NEAR* miss has already told us about mass and size, setting the density at 2.5 ± 0.8 g/cm^3 (Yeomans et al. 1999; Veverka et al. 1999). Eros is, in other words, rocky.

Some other asteroid dynamical issues include (*a*) how Jupiter captured its Trojans (by trading i for e; Marzari & Scholl 1998), (*b*) the recognition of 2–4 asteroids that have Trojan-type orbits (that is, they live at Lagrangian points L4 and L5) but with respect to Mars, not Jupiter (Tabachnik & Evans 1999), (*c*) the future of 1997 XF11, which will not hit us in 2028 or 2042 and will gradually wander away over the next 1000 years (Sitarski 1999), (*d*) the future of 1999 AN10, with a possible close approach in 2027 and some potential hazard until 2600, though each passage close to Earth disturbs the orbit enough to make the next fairly unpredictable (Milani et al. 1999), (*e*) the long range future of Chiron, whose orbital semi-major axis could be anything from 10 to 70 AU 10^5 years from now (Lissauer 1999), (*f*) the simulated future of Fatum, which approximates 4179 Toktakis and can be counted on to give us a 10-year warning of its simulated impact on Earth (Sitarski 1998): Fata Morgana might have been a more suitable name, (*g*) another snark/boojum, Minor Planet 1997 CU21, which is really a Centaur working its way inward from the Kuiper Belt (McBride et al. 1999), not precisely the same as working one's way through school, and (*h*) another look at how they were put together from planetesimals and such (Kenyon & Luu 1999); you expect a few Plutos and 10^5 things larger than 50 km, more or less like the real solar system.

We aren't quite sure whether rotation is a dynamical process, but big and little asteroids have different distributions of rotation period (Donnison & Wiper 1999). The range is 2.27 to 1150 hours. Rotation properties of objects in the Kuiper belt (KBOs) apparently constitute a third set, somewhat difficult to describe, because only the small (or dark?) ones are strongly non-spherical or spotted (Romanishin & Tegler 1999).

1998 KY26 has the shortest rotation period in the solar system, at 10.6 minutes (Ostro et al. 1999). Its surface composition is like that of the carbonaceous chondrites. Both Centaurs and KBOs have a range of surface types, including water ice and hydrocarbons (Brown et al. 1999; Brown & Koresko 1998). Wickramasinghe & Hoyle (1998) go further and attribute the red colors of KBOs to biological processes.

3.3.4. Rings

None of the ring systems belonging to the Jovian planets can last the age of the solar system, and all must be replenished either continuously or sporadically from disrupted moons. The rings of Jupiter, at least, are being currently fed (Burns 1998). Ganymede and, probably, Callisto and Europa have dust around them now (Kruger et al. 1999) which is on its way to help the rings and to replenish zodiacal light.

The sharp-edged rings of Neptune, like those of Saturn, must have shepherd satellites, though these are too small to see (Salo & Hanninen 1998). The Neptune rings are, in fact, really just arcs. They are close to but not at a resonance location relative to Galatea (Sicardy et al. 1999; Dumas et al. 1999). Thus their confinement in both azimuth and radius remains something of a mystery.

3.3.5. Moons

The moons of our solar system should clearly be discussed in order from those of Mercury on out.

We therefore begin with two very short paragraphs.

Moving on to Luna brings us to two issues much discussed during the year. One is the relatively new question of whether there is ice at the poles. The answer seems to be, none on the 31st of July, at least not where the Lunar Prospector crash-landed, more or less as planned (Anon. 1999). The other is the much older question of whether our Moon formed from the joint debris of Earth and intruder after a major impact. Pros, cons, and variations are presented by Halliday & Drake (1999, who are fairly positive about the idea) and by Podosek (1999, less positive). An interesting variant is that of Canup et al. (1999), who first produce a bunch of moons, which then collide with each other or the Earth until only one is left.

Next comes Mars, orbited by Phobos in such a complicated orbit that you need to allow for the effects of Sun, Jupiter, Deimos, and a whole bunch of moments of Mars to match it (Waz 1999). At least the acceleration is not so large that you suspect Phobos of being hollow, as seemed to be the case some years ago.

Asteroid Eugenia has a moon of its own (IAU Circ. 7129), not quite the first asteroid of which this can be said.

Galileo has been hanging around Jupiter for several years, returning images and other data from the vicinity of the moons. In a tidy summary, Showman & Malhotra (1999) remind us that Io has volcanoes (as predicted by Peale et al. 1979), Ganymede has its own magnetic field, and Callisto and Europa apparently have subsurface oceans under dirty ice. The effects of tidal heating are most obvious for Io, but also important in warming the ice and water layers of Europa (Chapman 1999). Callisto also has a tenuous atmosphere of CO_2, which must be transient (that is, resupplied), unless we and *Galileo* happened to arrive at an unusual time (Carlson 1999).

The methane clouds of Titan come and go. That is, it has weather (Griffith et al. 1998) and probably rain as well. It is not instantly obvious what sort of umbrella you need to carry in methane rain, but we suspect that the reassurance offered by the mother of the less sweet author, "It's all right; you aren't made of brown sugar." (Meaning that, unlike the Wicked Witch of the West, you won't melt in the rain), may not be applicable.

Uranus has probably added three new, small moons in 1999 (IAU Circs. 7171, 7230, and 7248). We don't really mean that it has just captured them (though this is presumably not impossible), but only that they have just been recognized. They do not, on the other hand, go back the full 4.5 Gyr either (Lissauer 1999). The additions transfer the title of Mooniest Planet from Saturn to Uranus.

Nereid belongs to Neptune, though seemingly only just. Its orbit has both large inclination and large eccentricity, suggestive of a captured asteroid. But its infrared spectrum shows features of surface water ice (Brown et al. 1998), which sounds more like a real moon. Some years ago, Goldreich et al. (1989) suggested everything would fit together if indeed Nereid were a proper moon, but its orbit had been disturbed when Triton in turn was captured.

As if Triton hadn't already done enough damage, Woolfson (1999) has revived the suggestion that its arrival also kicked out a previous Neptunian moon, now called Pluto. Pluto, of course, has its own moon, Charon. We can't see that it is much use to the Plutonians (for whom June is too cold for spooning anyhow, not to mention 20 years long). But its transits have enabled Young et al. (1999) to map the planetary surface. There is one bright, largish feature that could be condensation around a geyser. This probably is also wasted on the Plutonians, who, if they ever got into hot tubs, could never be persuaded to get out.

3.3.6. From the System Back to Earth

The Sun at 4.66 Gyr is slightly older than the meteorites, which began at 4.57 Gyr B.P. (Dziembowski et al. 1999). This seems to be altogether a Good Thing. The solar number comes from imposing results of helioseismological investigations onto models. The orbits of all the real planets have lasted that long and will still be more or less the same when the Sun becomes a white dwarf (Lissauer 1999). Concurrence comes from Murray & Holman (1999), whose description of solar system dynamics is "overlap of components of a mean motion resonance among Jupiter, Saturn, and Uranus."

Innanen (1998) proposed that the Earth-Moon system stabilizes the orbits of Mercury and Venus by suppressing an 8.1 Myr resonance. Namouni & Murray (1999) think they would be stable anyhow. Hamilton (1998) comments in a conference report that it is not clear why the orbits of Venus and Earth are as nearly circular as they are.

Staying within the inner solar system (indeed, who of us has ever left it), we are reminded that Venus has volcanoes, but that neither its terrain nor the processes responsible are very Earth-like (Solomon et al. 1999). Mars has been cycling between "more like Earth" and "less like Earth" depending on what you think of its magnetic stripes and its water supply. The stripes are both wider and deeper than the ones found, for instance, in mid-Atlantic (Acuna et al. 1999; Connerney et al. 1999). Only for the terrestrial ones can we say with some confidence that the cause is reversals of a dipole magnetic field and plate spreading. A couple of *Mars-Orbiter* results indicate that the northern topographic depression is probably not an old ocean and that the reservoir of water ice in the polar caps would fill, at most, a thousand square kilometers of terrestrial ocean (Smith et al. 1999).

Back on Earth, a number of old conclusions were reemphasized, including (*a*) something that hit about 65 Myr ago left non-terrestrial isotope ratios and little bits of carbonaceous chondrite material at the K-T (Cretaceous-Tertiary—C is needed for Cambrian) boundary (Kyte 1998; Shukolykhov & Lugmain 1998), (*b*) the salinity of the ocean implied by fluid inclusions in old quartz plus chemical modeling has changed; the surprise is that oceans were saltier than now for the first 3 Gyr or so (Knauth 1998), (*c*) the rotation of the Earth is slowing, though the mechanism proposed by Gu (1998) is a new one on us—interaction with the solar wind, (*d*) what hit Tunguska in 1908 was probably a stony asteroid, about 60 m across (Foschini 1999), (*e*) the 11-year solar cycle modifies the ozone content of the upper atmosphere and various others of its parameters (Shindell et al. 1999), interestingly a case where the monotonic decline and seasonal changes in O_3 are part of the noise rather than the signal, (*f*) there is such a monotonic decline as the dominant time dependence in 1979–1999 (Randel et al. 1999; McKenzie et al. 1999), (*g*) 1998 was the warmest year in the millennium, and the future is likely to include increasing numbers of Interesting Times (Tett et al. 1999), (*h*) convection in the Earth's mantle takes place in two separate layers, but the dividing line is a good deal deeper than previously advertised, at 1600 km rather than 660 (Kellogg et al. 1999; van der Hilst & Karason 1999; Kaneshima and Helffrich 1999), (*i*) ice ages come and go in response to cycles in the Earth's orbit parameters, to which the response is not linear (Rial 1999), (*j*) nutation of the Earth is complicated, but theory is once again catching up with data (Getino & Ferrandiz 1999), (*k*) the lightening-fed structures called sprites are almost as cute as their name (Uppenbrink 1999), and (*l*) evolution happened (a number of articles in *Science* for 25 June 1999).

There were also some surprises: (*a*) the East African Rift Valley is still spreading (Chu & Gordon 1999), at about 6 mm per year, (*b*) the wind speed got up to 318 mph, the fastest ever officially measured, during the May 1999 Oklahoma tornado, (*c*) the fact that some people cannot make bread rise does not mean that there is no "yeast effect" (Rauscher 1999, concerning effects of exposure to good music on various kinds of learning), (*d*) there really is an island of Beta Stability near $Z = 114$ (or near Dubna, depending on your point of view), with an isotope that lasts 30 seconds (Oganessian et al. 1999); elements 116 and 118 have also been made (Gregorich 1999), and (*e*) there are only 10 "esthetically pleasing" ways to tie a tie (Fink & Mao 1999), most rather more complex, and requiring a thinner tie, than the Windsor and four-in-hand knots within the capability of the author who wears ties less often (or is this a stand-off?). We are reminded of an old Dirac story, in which he supposedly watched the wife of a colleague knitting for some time, and then, in an independent rediscovery of purling, announced that there was only one other way to achieve the same end product.

4. HARDWARE, SOFTWARE, UNDERWARE

Another title for this section might be "widgets, pure theory (meaning cases where you have more confidence in the essential correctness of a calculation than of its applicability to any particular astronomical system), and you don't say."

4.1. Hardware

The award for widget of the year goes to the two solid state detectors that have begun the process of recording simultaneously the direction of arrival, time of arrival, and energy of photons. Perryman et al. (1999) used a superconducting tunnel junction (STJ—you won't need the abbreviation again here, but watch for it in the future). Romani et al. (1999) employed a "cryogenic transition edge sensor spectrophotometer" (TES for short, thank heavens). Both groups looked first at the Crab pulsar, the former reporting that the color in visible light does not change through the pulse and the latter reporting that the infrared turnover varies slightly through the pulse, presumably a self-absorption effect as you look through different amounts of magnetosphere.

Fairly new physics (by astronomical standards) is also employed in the super-conducting hot electron bolometer (HEB), whose first submillimeter data are just appearing (Kawamura et al. 1999).

It was a pleasant surprise to learn that several optical observatories we had thought of as being "historical" are still producing publishable data. These include San Fernando in Spain (admittedly a re-reduction of their zone of the turn-of-the-century Astrograph Catalogue, putting it on the *Hipparcos* coordinate system; Abad et al. 1998); Zo-se in China (again turn-of-the-century data applied to proper motions in star clusters; Balaguer-Nunez et al. 1998); and the US Naval Observatory station in Washington, DC (Douglass et al. 1999). *IUE* continues its periodic recalibrations (Smith 1999a). And the pre-fix *HST*, whose papers still roll out (Stanghellini et al. 1999), probably also belongs in this category. Bless et al. (1999) record a sort of hail and farewell for the High Speed Photometer, which was still in good condition when returned in December 1993.

The Mt. Maidanak site in Uzbekistan is reported as having seeing comparable with that in La Silla and Paranal (Il'yasov et al. 1998), though the facilities are currently in need of considerable maintenance. We will take their word for both points. You can fly to Tashkent non-stop from Amsterdam, but after that you're on your own. Mt. Maidanak is, on the other hand, easier to reach than the bar antenna for gravitational radiation described by Mohanty et al. (1998) as being able to reach a strain of $h = 10^{-25}$, since so far it exists only on paper. Heck (1999) has attempted to provide data on ages and conditions of the full range of astronomical observatories and other institutions. We were, to put it gently, surprised that there is something in North America supposedly dating back to 1478 that is not an archaeoastronomy site. The continuity of Beijing Observatory from 1279 to the present also feels a bit tenuous.

The VLT, with one of its four mirrors in operation, and another nearly so, is among the newest of optical observatories. The first package of results appears as Giacconi et al. (1999, and 8 following Letters). Some measurements made with the Palomar testbed interferometer appear elsewhere, but the instrument is described by Colavita et al. (1999).

Adaptive optics is being implemented more and more places. Still under discussion is whether one does better with laser guide stars near the center of the field of view or with off-axis real ones (Ragazzoni 1999; Ragaozzini & Rigaut 1998 on "tomographic turbulence analysis"). Meanwhile, ALFA (on the Calar Alto 3.5 m telescope) is the only laser AO system open to guest observers (Davies et al. 1999). Clearly it is a rugged system.

Global warming will presumably be good for some sites (desert mountains that become even drier?) and bad for others. Most at risk must be the meter-wave 2 × 0.8 km interferometer on Mauritius (Gulap et al. 1998). It is at latitude $-20\overset{\circ}{.}14$, longitude about 58° east, and elevation something like 3 meters.

New devices are the last, best refuge of the cute acronym. In addition to ALFA just above, we note VERITAS, whose construction is on hold pending resolution of a conflict with an Amerind sweat lodge (Weekes & Boone 1999), suggesting the slogan, "in aqua veritas." The immersed echelle (Szumski & Walker 1999) probably involves neither water nor wine, but something with a larger index of refraction, since the goal is to match the slit width of a spectrograph to the size of a seeing disk of a large telescope.

MOMI is designed to look at faint, circumstellar stuff (O'Conner et al. 1998). ORFEUS II (the EU is Extreme Ultraviolet) has looked at O IV and H_2 in the Milky Way and the Magellanic Clouds (Widmann et al. 1999; de Boer 1998), but not, we hope, abandoned Euridice II in the Second Underworld. LASE is a balloon-borne hard X-ray detector, applied, so far, to X-ray transients (Manchanda 1999).

Moving away from acronyms, we find the Stokesmeter, which does just what it says, measuring stellar magnetic fields in the range 1–10 G with a little help from Plachinda & Tarasoava (1999). They have been looking at F–G main-sequence stars with modest activity, like Procyon.

QMAP is a balloon-borne mapper of the microwave background. It picks out angular frequencies on the sky between the *COBE* (low) and Saskatoon (high) ones, and finds a level of fluctuation that fits smoothly in between at $l = 40$–200 (Devlin et al. 1998 and two following papers).

The remarkable brightness of the soft gamma repeater on 1996 August 27 was noted last year. No, it wasn't quite as bright as the Sun, but it was seen by a solar X-ray photometer, the Czech-Polish collaboration on the *Interball-Tail* satellite (Sylwester et al. 1998).

A number of devices and projects commissioned in 1998 or earlier continue to soldier on, providing ever-larger catalogues and data bases. The first SCUBA (submillimeter) source catalog appears in Eales et al. (1999). EGRET has completed the first seven years of its two-year design life (Esposito et al. 1999). Infrared observations collected by *ISO* have been condensed down into a conference (Waters et al. 1998).

All of the surveys for gravitational lensing by stars (or whatever) in the Milky Way were alive and well. Sutherland (1999) reviewed MACHO. Ansari et al. (1999) presented another AGAPE candidate in M31. There were no new candidate lens events in the second year of operation of EROS, but it logged in lots of short-period Cepheids in the LMC and SMC (Afonso et al. 1999; Bauer et al. 1999). And spin-offs from OGLE now include eclipsing binaries in LMC star clusters (Pietrzynski & Udalski 1999).

The calibration of colors determined with the Sloan Digital Sky Survey onto color systems used elsewhere has rediscovered the gradient of metal abundance perpendicular to the Galactic plane (Newberg et al. 1999). Calibration of astrometric results from *Hipparcos* is also still underway. Narayanan & Gould (1999a) conclude that some parts of the sky are better than others. You can trust Hyades data, for instance, but not Pleiades.

And, if your Large Optical Telescope proposal has been rejected yet again, take comfort from the fact that 23 of the 51 papers in *Nature* (1993–1995) presenting optical and/or near-IR results came from telescopes with mirrors 2.5 meters or smaller in diameter (Gopal Krisha & Barve 1999).

4.2. The Beaker and Spectrograph Brigade

More and better laboratory data on atomic and nuclear energy levels and cross sections, on chemical reaction rates, molecular spectra, properties of potential astrophysical solids, and so forth are both frequently needed and frequently published. Not, of course, always the same ones, and we mention only a subset with some slightly cockeyed aspect.

Guillois et al. (1999) have associated some particular unidentified infrared bands with laboratory spectra of diamond dust. The band strength in HD 97048 implies that the atmosphere of the star must contain 10^{23}–10^{24} carats of diamond (sadly, not of gemstone quality).

The behavior of extended red emission vs. temperature of the emitter is not matched by laboratory behavior of any of the suggested materials (Fauré et al. 1999).

^{180}Ta, the rarest of all naturally-occurring isotopes, has an excited state whose lifetime exceeds 10^{15} years. If you can afford to wait that long, the product ground state then has a lifetime of only 8 hours before it beta-decays to ^{180}Hf or ^{180}W (Bikit et al. 1999).

Better laboratory wavelengths are needed for the Si IV doublet features observed in QSO spectra in order to improve the upper limit on temporal changes of the fine structure constant. It is currently $|\dot{\alpha}/\alpha| = 3 \times 10^{-14}$ per year (Ivanchick et al. 1999). When CH meets NH_3, the best calculations of the reaction rate and the best lab measurements disagree (Fauré et al. 1999a). Presumably the interstellar medium knows which to use.

Theory notoriously fails equally well for laboratory and astrophysical turbulence. The curious fact about the experiments on turbulence arising in fluid flows with differential rotation discussed by Richard & Zahn (1999) is that the experiments date from 1890 to 1946. Admittedly the astrophysical systems to which they are applied go back still further in time.

Finally there are the laboratory supernovae of Remington et al. (1999) and of Ryutov et al. (1999). No, they don't make whole ones (or you would have heard about it earlier, just before the Earth vanished). But the possibility of carrying out any experiment scalable to astrophysical conditions by factors of 10^{54} (for collisional mean free path) and other spectacular numbers is impressive.

4.3. Software and Algorithms

"Theory" to a practicing scientist (when are they going to learn?) means that we understand what is going on quite reasonably well. The items following (some of which are actually analytic rather than numerical calculations) have generally not yet reached that status. Call them models, scenarios, processes, or whatever appeals to you.

Convection continues to be described by ever more complex equations, e.g., Wuchterl & Feuchtinger (1998), who are concerned about pulsating and other rapidly changing stars. They include radiation from the eddies and truncate velocities at the sound speed. Hofner et al. (1998) apply similar equations to dynamical atmospheric models for pulsating AGB stars. Later in the year Gardiner et al. (1999) are still struggling to fit line profiles with mixing length theory. They find no use for convective overshoot, but need a mixing length that is 25% longer than the local pressure scale height for their F stars.

Collimation of jets is another problem that nature has solved more completely than have astronomers. Allowed ingredients include rotation, disks, magnetic fields, and pressure of surrounding material. Three papers discussed self-collimation and what might constitute a set of sufficient conditions for it to occur. But the only item we could find in common among Okamoto (1999), Vlahakis & Tsinganos (1999), and Lery et al. (1999) was that they all cited Ostriker (1997).

Dynamical relaxation processes: Tremaine & Ostriker (1999) have found a new one with properties between those of two-body and violent relaxation. (The latter involves the whole potential of the system.)

Angular momentum transport in disks is done very efficiently by MHD turbulence (Hawley et al. 1999a).

Nameless, but very clever, is the method used by Barnes et al. (1998) to obtain Doppler imaging of stars previously thought too faint. They add up the profiles of a bunch of lines and find, for He 699, that star spots live less than 30 days. The idea of Doppler imaging first came from Deutsch (1958).

Among the problems that we thought had been solved, but about which there is apparently still new stuff to be discovered, are (*a*) Keplerian orbits, at least in projection (Sato 1998), (*b*) aberration of starlight (Liebscher & Brosche 1998, who note that Flamsteed probably saw it in 1699, but Cassini disagreed because the direction was wrong by 90° for parallax, leaving it to Bradley to get things right and the credit), (*c*) scattering of light in various regimes of wavelength, magnetic field strength, particle size, and so forth (Stenflo 1998), (*d*) Faraday depolarization in the case where it is due to light rays taking different paths through the stuff between the source and us (Melrose & MacQuart 1998), (*e*) Bondi-Hoyle-Lyttleton accretion when the accretor is quite luminous or rotating (Fukue & Ioroi 1999), and it is gas being accreted, not distinguished senior astrophysicists!, (*f*) the Kerr (rotating compact object) solution for neutron stars (Sibgatullin & Sunyaev 1998), because a rapid rotator develops a quadrupole moment, and (*g*) the basic equations of general relativity, which can be reformulated as a hyperbolic system of differential equations, more suitable for the study of evolving spatial metrics (Anderson & York 1999).

And, in between, are dozens of processes and systems where "more work is needed" and some was performed in index year 1999. We note only the Blandford-Znajek process and ambipolar diffusion. The former is a process for extracting energy from rotating, magnetized black holes which, according to Cavaliere & Malquori (1999), turns itself off as BL Lac sources evolve to radio-loud quasars, where mass flows disturb the ordered magnetic field you need. The latter is a popular way of getting magnetic field out of star-forming regions, so that cores can contract. Greaves & Holland (1999) suggest an observational test for its occurrence that involves alignment of grains and velocity differences between ionized and neutral species. The process passes the test, they say.

As a logical(?) introduction to the next section, we offer the numerical collimation of jets (Ustyugova et al. 1999) and numerical diffusion (Kercek et al. 1999). Both are caused by inappropriate choices of coordinate system, time or space step size, and such.

4.4. Underware

Here live some candidates for the "letting it all hang out" award of 1999. They were originally indexed as rediscoveries of the obvious and unlikely-to-weird. You decide which is which. Incidentally, the original lists included roughly twice as many items as are listed below.

◦ Galaxy collisions are harder on the little ones (Tsuchiya et al. 1998).

◦ Some spiral galaxies, probably including the Milky Way, have perfectly straight portions to their arms (Berdnikov & Chernin 1999). The suggestion goes back to Vorontsov-Velyaminov (1951), and some of the images they show look quite persuasive.

◦ The constant of gravity is a good deal bigger than the number you learned in college (Schwerz et al. 1998) and is once again at risk of being a function of length scale (Anderson et al. 1998).

◦ Infrared-selected stars are redder than optically-selected ones, even of the same spectral type (Iyengar & MacConnell 1998).

◦ H I selected galaxies have unusually large ratios of neutral hydrogen mass to optical luminosity (Spitzak & Schneider 1998).

◦ The polarized components of the broad emission lines in NGC 1068 are redshifted relative to the parent galaxy by about 900 km/sec due to gas outflow. Alexander et al. (1999) explain how it happens—think of the photons as seen by the gas; but it still seems funny.

◦ When spiral arms are due to interaction with a companion, retrograde orbits result in a single leading arm, and prograde orbits in two trailing arms according to Karanis et al. (1998). Whatever you thought the question was, this does not seem to be the answer.

◦ The galaxies most luminous in Hα have the largest emission line regions (Crawford et al. 1999).

◦ The limit on the mass of the photon that comes from seeing eclipses of close binaries in the LMC at the same time at all wavelengths is 10^{-44} g (Pritchard et al. 1998).

◦ The most recent definition of magnitudes is not precisely logarithmic, but uses inverse hyperbolic sines (Lupton et al. 1999). It is apparently more suitable in the presence of certain kinds of noise, as in the Sloan Digital Sky Survey.

◦ BL Lac now has broad emission lines (since its 1997 outburst, Madejski et al. 1998) and so is no longer a BL Lac object. We wonder if there are other prototypes that no longer belong to their classes.

◦ Rapid rotation makes things non-spherical (Alimi et al. 1999).

◦ Triple stars are unstable (Kiseleva et al. 1998).

◦ Clouds containing dark matter can collapse at larger redshift than do ones made of pure baryonic material (Oliveira et al. 1998).

◦ Gravitational waves can be gravitationally lensed, providing a possible signature for a black hole at the Galactic center (Ruffa 1999). Actually this item probably belongs in the "first catch your rabbit" section.

◦ Neutron star kick velocities are a result of parity violation (in VERY strong magnetic fields; Arras & Lai 1999).

◦ "Germinate recombination of photoexcited electron hole pairs" (Seahra & Duley 1999). Contemplation has persuaded us that "germinate" is an adjective, not a verb, and that very probably the intended meaning is the one that would have been suggested by putting a hyphen between electron and hole.

◦ Faster than light motion requires negative energy density (Olum 1999). Even quintessence has only its pressure negative, and if we had a stock of negative energy density, we would be truly torn between going back in time to influence the stock market to make our fortunes and opening a weight loss clinic to make our fortunes.

◦ Radio sources evolve (Artyukh & Tyul'bashev 1998), meaning the populations as a function of redshift, not the individual sources, though they, of course, also change with time.

◦ Neutron star magnetic fields are a result of the polarized spins of all the baryons inside (Kutschera 1999).

And this imaginative solution to the origin of neutron star magnetic fields (which have generally been supposed to be relics of an earlier, dynamonic youth) gives renewed hope for a solution to the general problem of "origin of cosmic magnetic fields." There will be a special session on this at the April meeting of the American Physical Society (April in Long Beach; Palm trees in blossom ...). Meanwhile, you may wish to contemplate the summary provided by Eugene Parker at the June 1999 centennial meeting of the American Astronomical Society. "There are two kinds of magnetic fields. Dynamos and primordial fields. This means that I don't know where they came from, but they've been there a long time." And we are inclined to think that the first means, "You could do it in the lab. If you had a big enough lab."

5. SOME BRIGHT PARTICULAR STARS

Under a heading stolen first hand from Payne-Gaposchkin (1979) and second hand from Shakespeare (*All's Well that Ends Well*, Act I) are gathered an assortment of stars that are reasonably bright in either apparent or absolute magnitude.

5.1. Supernovae: Progenitors and Events

The traditional cliches are that we recognize the progenitors of Type II supernovae (which occur among Population I stars) but do not understand the physics of the explosions, and understand the physics of Type I supernovae (which occur among Population II stars) but have never found any plausible progenitors. Something has happened on three of these four fronts in the last year.

Progenitors for Type Ia's (powered by nuclear explosions of carbon and oxygen to iron peak elements) have in the past been supposed to include an assortment of intermediate mass single stars, some subtypes of cataclysmic variables, and binary white dwarfs with short orbital periods and total mass in excess of the Chandrasekhar limit. The supersoft X-ray binaries are the most recent addition to this inventory. Their main virtues are that (*a*) the white dwarf mass is very close to the Chandrasekhar limit, at least for some of them (Hoshi 1998) and (*b*) the mass is growing, because the white dwarfs burn the hydrogen supplied by their companions steadily and keep the products (Kato & Hachisu 1999). Ordinary novae, in contrast, flash their hydrogen and often throw off more than they have gained (Schwarz et al. 1998).

Some at least of the recurrent novae are known to share the first advantage (Hachisu & Kato 1999; Kato 1999). And in 1999 came the sixth recorded outburst of recurrent nova U Sco (also 1863, 1906, 1936, 1979, 1987). Its peak luminosity was modest, but, more to the point, its post-outburst spectrum showed no signs of ejected gas, and, on its way down, the nova spent a month or so as a supersoft XRB, meaning the extra accreta were staying put and fusing (Munari et al. 1999; Kahabka et al. 1999). Neither paper gives an estimated date for the supernova, but apparently the snark is a boojun. Some of the symbiotic stars (CVs with giant donors) are also promising candidates (Corradi et al. 1999; Hachisu et al. 1999). Iben & Tutukov (1999) prefer triple stars.

Meanwhile, back on the burning front, detonation (a front that advances supersonically), deflagration (a front that advances subsonically), and combinations thereof all continue to have both good and bad features when it comes to agreeing with observations. Conceivably not all observed events do the same thing (Gamezo et al. 1999; Imshennik et al. 1998; Li et al. 1999; Niemeyer 1999). It is a little ominous, but not unprecedented, that including more physics in the calculations has made computational explosions less like astronomical ones (Reinecke et al. 1999).

Progenitors for Type II supernovae have long been supposed to be massive stars evolved to the point of iron (really nickel) core collapse. Additional data published during the year continued to be consistent with this point of view (Van Dyk et al. 1999; Benetti et al. 1999). Do the computed core collapses actually make explosions? Not always, as has been true for many years, but at least the stage has been reached where putting in more of the relevant physics makes things better, not worse (Hannestad & Raffe1t 1998; Fryer 1999). Imshennik & Zabrodina (1999) sounded surprised that rapid rotation did not result in their SNe IIs exploding. But a little bird recently whispered at a conference that rotation is actually a disadvantage because it messes up the neutrino-driven convection that really does the job.

5.2. Particular Supernovae

The Crab Nebula is the only possible starting place. Sadly, the wonderful *Chandra* X-ray image did not make it on to paper by the end of the official year, but you have surely seen the bright rim where energy is being deposited in the wisps studied by Lampland (1921) and Scargle (1969). A couple of prequels make clear that the X-ray details should also change fairly rapidly (Greiveldinger & Aschenbach 1999; Begelman 1999). According to Atoyan (1999) the initial period of the pulsar could have been as short as 3–5 msec, so there has been lots of energy to play with over the years.

The next most interesting Crablet of the year is the assortment of possible European sightings before July 4, 1054 (Collins et al. 1999a). The authors suggest that these might have been downplayed because of simultaneous ructions in the Western church.

Among other favorite supernovae, S Andromeda (1885) may have made only about 0.22 $M_\odot$ of ^{56}Ni, accounting for its faintness and rapid fading (Fesen et al. 1999a). There may or may not have been an event in 386 A.D. which may or may not have produced a pulsar (which really is seen) with $P = 0.54$ sec now (Torii et al. 1999). Ditto, more or less, for SN 185 and SNR RCW 86 (Petruk 1999). The number of "probably associated" neutron stars (mostly pulsars) and SNRs is now large enough we have stopped counting in cold weather (when you have to take your shoes off to do it).

Also firmly on the shelf marked "maybe" are (*a*) a supernova only 30 pc away but 5 million years ago, responsible for a deep ocean crust layer that is rich in ^{60}Fe (Knie et al. 1999), (*b*) a supernova that made a black hole in X-ray binary GRO J1655−40 and simultaneously deposited some of its metal-rich ejecta into the atmosphere of the companion star, which is still enriched in O, Mg, Si, and S (Israelian et al. 1999), (*c*) a neutron star at the center of SNR Cas A as the interpretation of the central point source in the *Chandra* image (IAU Circ. 7246). The difficulty is that the emission, if thermal, is at too high a temperature for a neutron star that old (IAU Circ. 7170). The radio remnant Cas A itself has faded some 26% since its 1948 discovery (Stankevich et al. 1999), and the radio shell, radio knots, and optical knots are all moving outward, but all at different speeds (Agueros & Green 1999).

Unquestionably present are (*a*) a younger little SNR in the corner of Vela, which was responsible for most of the ^{44}Ti and ^{26}Al made in that part of the Milky Way (Aschenbach 1998; Chen & Gehrels 1999), (*b*) at least a dozen cases with evidence for "SNR hits ISM," where once there was only IC 443, (*c*) and a good many unidentified EGRET gamma-ray sources; the evidence that some of them are SNRs is essentially statistical (Romero et al. 1999), (*d*) a supernova at $z = 0.95$ in the Hubble Deep Field, revealed when the patch of sky was imaged a second time (Mannucci & Ferrara 1999); actually there were two HDF supernovae, but we've lost the other one.

SN 1987A remains in a class by itself, with more than a dozen papers during the reference year. None of them provides an indisputable answer to the decade-old question, "Did 87A make a neutron star or a black hole?" unless you are prepared to accept the answer, "Yes." On the other hand, continuing changes in morphology and brightness of the surrounding stuff present all sorts of possibilities for trying to figure out what Sk $-69°202$ was doing before February 1987 (Collins et al. 1999; Soker 1999; IAU Circs. 7056, 7102). A reanalysis of speckle imaging from March and April 1987 (Nisenson & Papaliolios 1999) was prompted by the probable connection between SN 1998bw and gamma-ray burst 980425 and raises the possibility that the so-called mystery spot was real after all and came from a relativistic jet of the sort that might have looked like a GRB from some direction other than ours.

At last count, there were at least five sorts of supernovae, Ia, Ib, Ic, II-L, II-P, and probably IIb. There are, according to Williams et al. (1999), five kinds of supernova remnants in the Large Magellanic Cloud (excluding 1987A) but no reason at all to suppose they are the same five types.

5.3. Eta Carinae, FU Ori, and Their Weaker Brethren

Eta Carinae is, at least some of the time, the brightest non-terminal star in the Milky Way, and its 1843 event is the largest explosion whose basic mechanism is fundamentally not understood (Humphreys et al. 1999). A handful of probably similar events have been recognized, including P Cygni (at its best in 1600), SN 1961V (Zwicky's prototype Type V), and Variable 12 in NGC 2403. Enhancement of nitrogen (but no other obvious chemical anomalies) in its surrounding nebulosity indicates that Eta is neither very close to birth nor very close to death (Lamers et al. 1998).

The Hubble-Sandage or luminous blue variables are arguably poor relations, and their erratic behavior is also not at all well understood (van Genderen et al. 1998). Langer et al. (1999) and Stothers (1999) point out, however, that these stars are perilously close to an instability involving the balance among gravity, radiation pressure, and rotation, and so fairly likely to blow portions of their stacks at any time (Eta perhaps quite soon).

At the next level down in vigor, we find some Wolf-Rayet stars that are doing similar things, though with less violence and later in life (Crowther & Smith 1999).

FU Orionis or FUOR variables are, in contrast, pre–main-sequence stars where the cause of the outburst is a thermal instability in an accretion disk (Kley & Lin 1999). Infall is delivering more stuff to the accretion disk of most pre-MS stars than they can handle, so that they must all occasionally have such an outburst to get rid of the extra (Muzerolle et al. 1998). Somewhere between botany ("bad") and unification ("good"), we find the UX Ori variables, which also have unstable accretion disks and so are rather like FUORs, and, in turn, probably include all the Herbig Ae/Be stars (Herbst & Shevchenko 1999). And, to close the loop, the massive pre-MS binary Z CMa includes one FUOR and one Ae/Be star (Garcia et al. 1999). It has been on duty quite recently, since its microjet has a dynamic age of only 10 years. There are also EXORs; and EC 53 in Serpens, at least, bursts periodically (Hodapp 1999).

On the subject of the Ae/Be (Herbig) stars themselves, we noted about 10 papers, but cite only the *Hipparcos* result that the earlier types are closer to the main sequence, confirming their status as pre-MS stars (Wichmann et al. 1998), and a sample of LMC stars which are, on average, 10 times as bright as the Ae/Be's in the Milky Way (Lamers et al. 1999). This could be an interesting result of lower metallicity or merely a selection effect.

5.4. FG Sge, R CrB, and Other Real Time Stellar Evolution

FG Sge now seems to be attracting more attention in the eastern hemisphere than the western. In summary, its luminosity, color, pulsation period, and surface composition all continue to change indecently fast (Tatarnikov & Yudin 1998; Arkhipova et al. 1998; Kipper & Kochkova 1999). No alternatives have been suggested to the now-standard model of a late helium flash in the shell of a star that thought it was on its way to becoming the nucleus of a planetary nebula. Just think how many competing models there would be if a quasar did this sort of thing!

The more recent mimic, V4334 Sgr, must have experienced a very late shell flash indeed, since ionization of the surrounding stuff suggests a pre-gallop effective temperature of 98,000 K (Kerber et al. 1999). We are not sure whether the lateness is responsible for the recent increase in surface lithium abundance in the star or not (Asplund et al. 1999). It has also experienced its first R CrB type fading episode. Let there be, however, no doubt that this is a bright star— about 10^4 $L_\odot$ despite a mass of a mere 0.8 $M_\odot$ (Kipper & Klochkova 1999a). Asplund et al. (1999) are not quite sure whether the newly-visible Li is newly manufactured or just newly dragged up. But they think it was made by the nuclear processes discussed by Cameron & Fowler (1971) from ^{3}He in a hydrogen-burning shell. The source of the lithium in a few red giants that must long ago have fused their primordial supply is an old question as well. The majority of the dozen or so papers on the subject this year also point to nuclear mechanisms in thin burning shells (e.g., Sackmann & Boothroyd 1999). Hill & Pasquini (1999), however, favor accretion. Siess & Livio (1999) also look at swallowing of a planetary (or brown dwarf) companion as a lithium source for aged stars. Rapid rotation might be a signature of the process. The continuing deficiency of beryllium in some Li-rich giants is presumably a vote for nuclear reactions and against child swallowing (Castilho et al. 1999).

The FG Sge and R CrB stars are somewhere between closely related and incestuous. On the one hand, well studied FG Sge stars (all two of them) seem to be turning into carbon-rich, fade-prone R CrBs. Conversely, there is some evidence that the R CrB called UW Cen had a last shell flash (Clayton et al. 1999). The authors are sufficiently ambitious to want to go on and understand the connection between R CrBs and planetary nebulae. So were the authors of at least 19 other papers. We note only the remark by Trams et al. (1999) that evolution never goes backwards. That is, you do sometimes see a star with oxide dust in its wind and carbon molecules in its photosphere, but never one with graphite grains blowing in the wind and oxides on the surface. An alternative interpretation of oxidy winds is that the stuff has been knocked off comets by recent ejecta (Cohen 1999).

And, returning once more to the R CrBs themselves, one should probably not have been surprised to hear that they are the only cool, non-degenerate stars whose atmospheric continuous opacity is not dominated by the H^- ion (Pavlenko 1999). Instead, C I, CNO II, and He^- are all comparable sources.

A quite different sort of real time stellar evolution appears to have been experienced by V439 Cygni, which was a Mira in 1941 and is now a luminous blue variable (Polcaro & Norci 1998). A rapid increase in effective temperature over the past 25 years in the nucleus of a planetary nebula shows up in the changing ionization and excitation of its nebula (Kostyakova 1999). That planetaries change in general was first remarked up by Liller & Aller (1957). An assortment of young stellar objects also refused to sit still over the past few years, but for them it seems less surprising.

5.5. The Apparently Bright Stars

Alpha Centauri, the second to fourth nearest stars, still does not have very well determined masses or distances, partly because the main, AB, orbit was not well covered by *Hipparcos* (Pourbaix et al. 1999).

If the temperature of Arcturus is as well known as the 4290 ± 30 K given by Griffin & Lynas-Gray (1999), then the spectral type–color–temperature relation for giants is not a tight one. Arcturus also does not have the advertised *Hipparcos* companion (Turner et al. 1999).

Alpha Aql and Alpha Cep, both A7 V stars, both have chromospheres and chromosphere-corona transition regions, close to the record high temperature for these phenomena (Gouttebroze et al. 1999).

The orbit period of Beta Lyrae has been increasing at 19 seconds per year, and mass transfer between the two stars is a likely cause (Wilson & Van Hamme 1999). This is, therefore, probably as good a place as any to mention some other period changes whose causes may or may not be understood. Examples where the responsible physics is probably also the expected mass transfer between stars include the early-type (radiative envelope) systems discussed by Simon (1999) and the contact binary AW UMa and a couple of others with longer periods, addressed by Pribulla et al. (1999).

A common, or at least commonly-blamed cause of binary period changes is magnetic cycles in the component stars, which change various moments of inertia and lever arms. XY UMa is a typical example, according to Erdem & Gudur (1998, outside the index year), but Chochol et al. (1998) say this cannot be the right answer, because deviations from a flat $O-C$ curve are not correlated with absolute magnitude. Albayrak et al. (1999) invokes a third, otherwise undetectable star, for his six systems. The required orbit periods are years (not decades) and the hypothesis therefore falsifiable with only modest patience.

Gamma Doradus has been officially dubbed the prototype of a class of pulsating variables with 1–5 modes each, periods of 0.3–4 days, and amplitudes less than 0.1 mag (Kaye et al. 1999). The mechanism is high order, low degree (i.e., big n, little l) non-radial, gravitational mode pulsation. The class received a good many recruits from *Hipparcos* data (Aerts et al. 1998).

Fourth-brightest brings us to Delta Scuti stars, many of which have many modes, some of which come and go if you have a sufficiently long data train (Alvarez et al. 1998). No explanation was offered and we do not, off hand, think of one. The more unstable author was surprised to hear that some Delta Scutis have [Fe/H] as low as -2.0 (Hintz et al. 1998). Should she have been?

And of course there are Delta Cephei and its tribe. Given their importance to the cosmic distance scale (see also § 12.1), Cepheids appearing in several dozen papers is to be expected. We note only a fairly random subset. De Zeeuw et al. (1998) have noticed that Delta Cephei itself belongs to an OB association. The lateness of this discovery in the great scheme of things is not the result of observers neglecting to cross-correlate catalogs (though this was the cause of the claim through the 1950's and 60's that there were no Cepheids in clusters or associations). In this case, the association itself has just been discovered in *Hipparcos* data. It is called Ceph OB6. Similarly the Wolf-Rayet binary γ^2 Vel is newly in the new Vela OB2 association.

Cepheid masses derived from binary orbits, pulsation theory, and evolutionary tracks are still not in wildly good agreement (Böhm-Vitense et al. 1998). A contributing factor may be that it is not always clear which mode a given Cepheid favors (Mantegazza & Antonelli 1998, modifying some assignments originally made by the Gaposchkins). Bono et al. (1999) remark that the separation between fundamental and first overtone pulsators is clearer in observations than in their calculations. There are, of course, also two populations of Cepheids. Remarkably, Type II's occur among Population II stars, but light curves alone are not enough to tell you which you are looking at (Fernie & Ehlers 1999).

"Which mode" is not a question confined to the Cepheids. Miras, or rather observers of Miras, have been asking it for decades, and firmly finding discordant answers. Perrin et al. (1999) had hoped to clarify the situation for R Leo (advertised variously as fundamental and first overtone) by a direct, interferometric study of how the radius changes with time through its period. Their $R(t)$ curve falls between the expected values for the two modes. RR Lyraes have the habit of switching modes without advance notice. Clement & Goranskij (1999) is probably not the definitive paper, but it does organize the confusion nicely.

Non-radial modes, driven by opacity, exist over the whole range of parameters of both RRab and RRc stars (Dziembowski & Cassisi 1999). One feels vaguely that they have just been put there to make things more difficult!

6. SOME FAINT PARTICULAR STARS

The more etymological author still feels vaguely that most astronomers ought to think about stars. This may have been conditioned by the fact that five of the six women who made up the first cohort of female astronomy graduate students at Caltech published their first papers on assorted, mostly faint, stars. The section includes a small subset of the interesting individuals, types, and issues that could not reasonably have been described as "bright," and you will find references to those five first papers tucked in various corners. (The sixth is under dwarf galaxies.)

6.1. Sharpness of Traditional Spectral Types

We have been roundly taken to task by Philip C. Keenan for having noted in Ap98 several papers in which standard spectral types and luminosities or temperatures measured in other ways were not well correlated. He is, after all, one of the K's of MKK (Morgan, Keenan, & Kellman 1943). The main points of his letter are that the luminosity classes are not well separated at early types; that one could do very much better with only slightly higher wavelength resolution than in standard classification spectra; and that CCD plots are actually easier to classify than photographic spectra. We therefore return to the issue, which was addressed one way or another in about a dozen papers.

Di Benedetto (1998) found clean relations of color to spectral type for A to K main sequence stars, but much more scatter among the giants. Richichi et al. (1999) have calibrated K0–M0 III temperatures from radii based on lunar occultations. Most of the sample is quite tidy, but seven stars are cooler by about 900 K than the average for their spectral types. This is, needless to say, not understood (though misidentification comes to mind).

Verdugo et al. (1999) have again pushed into the difficult territory of bright, early type stars, and find that subtypes Ia, Ib, etc., are not very good luminosity indicators. Straizys et al. (1998) find a spottier correlation of types with temperatures and surface gravities determined from colors, with good results for late B, late F, early G, and all M type stars. Finally, returning whence we came, Keenan & Barnbaum (1999) have reassessed spectral types for cool giants with *Hipparcos* parallaxes. They find it possible to improve greatly the calibration of types IIIb, III, and IIIa, and, in particular to modify the criteria for IIIb slightly so that members of the class are nearly all clump stars, while III's largely belong to the main giant branch.

6.2. Brown Dwarfs

Given that we remember (Ap92, § 4) when the number was precisely 0 (or may be 0 ± 1, since occasionally candidates seemed to be removed from the inventory before they had been added), the most important thing to say about BD in 1999 is MANY! Tinney (1999) includes a nice review of how the change happened. Indeed the numbers are now large enough to say that their initial mass functions in the field (Reid et al. 1999b) and in at least some clusters (Hambly et al. 1999 on the Pleiades) are roughly a continuation of the IMF for low mass M dwarfs (of which there are not so many as was once suspected; Weistrop 1972).

Apart from anything else, the continuity suggests that star formation is "blind" to the potential for nuclear reactions, as indeed it should be. The contribution of brown dwarfs to the local mass density can also be assessed: it is neither negligible nor dominant, amounting to perhaps 10% of the total (Reid et al. 1999; Fuchs et al. 1998), though admittedly the total retains error bars of nearly 50% (Stothers 1998). Han & Chang (1998) suggest that BDs are 50% of the mass in the Galactic bulge, on the basis of properties of gravitational lensing events. If true, there are major implications for star formation theory. Some clusters seem to have less than their fair share, including IC 348 (Luhman et al. 1998) and the Hyades (Gizis et al. 1999; Harris et al. 1998; Reid & Hawley 1999). Apportionment of the blame between the processes of star formation and of dynamic evolution of clusters remains to be determined.

The second most important issue is probably *spectral types*. These are now officially L (in fact L0 to L9) and T, with a dividing line near 1300 K (Kirkpatrick et al. 1999). Even the long-solitary T dwarf, Gl 229B, now has company from the Sloan Digital Sky Survey and 2MASS (Strauss et al. 1999; Burgasser et al. 1999). The prototype is relatively young (or you wouldn't see it at all), near 0.5 Gyr, and has $T \approx 900$ K and $M \approx 25\ M$(Jupiter) according to Leggett et al. (1999), who have fit the data with models computed by Burrows et al. (1997). The spectral types are presented definitively by Kirkpatrick et al. (1999; see also Lodders 1999).

The type L sequence is defined by metal hydrides and neutral alkali metals. The outstanding features in type T are due to methane, so that one feels we are at last really making contact with Jupiter. An important contributor is the settling out of dust grains, so that one sees quite deep (Tinney et al. 1998; Martin et al. 1998b). The resulting colors could be dominated by organic aerosols (Griffith et al. 1998a).

Detailed atmospheric modeling is under way (Burrows & Sharp 1999; Tsuji et al. 1999). When dust opacity cuts in, new convection zones appear, possibly layered with radiative ones (Tusji et al. 1999). As a result, brown dwarfs should have vertical mixing and "weather" driven by convection, much like Jupiter (Tinney & Tolley 1999; Griffith & Yelle 1999).

The Sun, of course, also has weather, but it is magnetically driven. It seems probable that serious brown dwarfs do not go in for anything so frivolous as magnetism. Supporting evidence includes the singularly inactive rapid rotator CP 944−20 (Tinney & Reid 1998) and the flarelessness of VB 10 compared to VB 8 (Martin 1999). Meyer & Meyer-Hofmeister (1999) point out that this probably means that there are no AM Her stars (cataclysmic variables with strong fields) that have BD secondaries, though some non-magnetic CVs do (van Teeseling et al. 1999). Comeron et al. (1999) and Neuhauser et al. (1999) nevertheless report a few X-ray emitters in their brown dwarf samples and at least one radio emitter. All are, however, very young.

And we end this section with a sort of drizzle of other members of the BD set and their implications.

a. A visual binary system made of two brown dwarfs, sadly with too large a separation to yield astrometric masses in our lifetimes (Martin et al. 1998).

b. Another pair, found in the DENIS survey, where a mere 12-year wait should see us through most of the 5 AU orbit (Martin 1999a).

c. Brown dwarfs in star formation regions with their very own disks to make them feel like real stars (Wilking et al. 1999).

d. Generically, presence among young stellar objects, where, though they can be as much as 8 mag fainter than the T Tauri stars (Tamura et al. 1998), they are brighter and warmer than they will ever be again, and so relatively easy to find (e.g., Bejar et al. 1999). The BDs and T Tauri stars are about equally likely to be found in binary systems, with an incidence of 22% according to Itoh et al. (1999). This probably also has implications for star formation.

e. There ought to be oodles of brown dwarfs that have formed from the ultracold gas in M31, where the Jeans mass is close to 0.01 $M_\odot$ (Allen et al. 1995). Unfortunately, at an apparent magnitudes close to +30, they may be a little difficult to find (Elmegreen 1999a).

f. A BD in close orbit with a brighter star may reflect more than it emits for itself, though the albedo is (not surprisingly) a strong function of the presence or absence of clouds in the BD atmosphere and of the spectral type of the companion. Marley et al. (1999) report that $a = 0.05$–0.4 is likely.

g. And, finally, something must be said about lithium. They have it (Rebolo et al. 1998), though not reliably enough to count as a defining trait for type L (Kirkpatrick et al. 1999).

6.3. Faint, High Latitude B Stars

Humason & Zwicky (1947) provided an early inventory of these. Their list included a remarkable grab bag, ranging from white dwarfs to QSOs. The inventory from Greenstein & Sargent (1974) made clear most of the issues that are still with us. Some are white dwarfs nearby; some an assortment of blue horizontal branch stars and post-AGB stars (a term not then yet in use); and some were seemingly normal, main sequence, Population I stars too far from the Galactic plane to have got there in their lifetimes, unless they are moving very fast or did not start out in the Galactic plane. The sample presented by Magee et al. (1998) have at least the rotation speeds of young, Population I stars; most are not binaries, and their mode of transport is not obvious.

Rolleston et al. (1999) believe that their 21 stars of solar metallicity from the Palomar Green survey have distances, ages, and velocities consistent with escape from the Galactic plane. They do not distinguish between ejection by clusters and liberation by supernovae in binaries. Ryans et al. (1999) focused on one runaway star probably thrown out by a cluster. Twenty-five years downstream, we are aware of more diffuse matter in Galactic halos, both gas (Veilleux et al. 1999) and dust (Howk & Savage 1999a), than was known to Greenstein & Sargent (1974), but the stuff is in no condition to form stars at the present time.

6.4. The Chemically Peculiar Stars

Whole books and conferences have been devoted to these. Thus finding more than two dozen interesting papers on them during the year is no surprise. Some still use the traditional designations Ap, Bp, Am, λ Boo, Hg-Mn stars, and so forth. Other papers, especially European ones, have adopted CP (for chemically peculiar) numbered subclasses for all (and we can never remember which is which). Cohen, Deutsch, & Greenstein (1969) presented line identifications and variability through the 5.26 day rotation period for α^2 CVn. Their conclusion, that no set of nuclear reactions could produce the observed peculiaries, and that some atmospheric process must be able to make transient europium spots and such, is now so generally accepted that it is not thought necessary to mention it. Even for lithium, beryllium, and boron, whose preferential destruction in stars shows up early on the main sequence, nuclear reactions are not the answer (Burkhart & Coupry 1998 on Li abundances uncorrelated with age, and Stephens & Deliyannis 1999 on greatly enhanced Be in combination with little or no Li).

Chi Lupi is a well known Hg-Mn star. Its mercury is essentially pure ^{204}Hg (Proffitt et al. 1999). Other stars have other isotope mixes, though none include the lightest, ^{196}Hg and ^{198}Hg (Woolf & Lambert 1999). In fact, it seems that no two are the same, and the mix is never solar (Hubrig et al. 1999, who also note that accurate laboratory wavelengths are just as important now for detangling elemental and isotopic compositions as they were for Cohen et al. 1969).

How are these anomalies produced and maintained in photospheres and parts of photospheres? It has to be something that happens quickly enough for the 1.7 Myr old cluster Orion OB6 to have at least two Hg-Mn stars (Woolf & Lambert 1999a). Part of the story is radiative levitation, possible because the lines of different isotopes are systematically shifted in wavelength. But Woolf & Lambert (1999), Proffitt et al. (1999), and Leckrone et al. (1999) conclude that this is not enough for Chi Lupi, which must also have some outward gas flow that carries away the lightest isotopes. We are pretty sure that the diffusion calculation discussed by Seaton (1999) incorporates a good deal more physics than did earlier ones, and that we should be encouraged by his remark that the results after 10^8 years (star time, not computing time) "are not discouraging." Kuschnig et al. (1999) have concentrated on which elements should puddle in parallel versus vertical magnetic fields, and also feel that there is some resemblance between models and reality.

The magnetic fields are complex and not all the same in strength or morphology. Among the descriptions, we noted "not just a dipole" (Bagnulo et al. 1999), "tangled" (Hubrig et al. 1999a), "not dynamo" (Strassmeier et al. 1999a from a rather indirect argument), and "-1408 G" from Nd II lines is Przybylski's star (Cowley & Mathys 1998). One cannot help noticing both the number of significant figures and the difficulty of pronouncing Przybylski, which may have been keeping you from working on this star. Start out as if it were written "Pshib ..." and you will come out OK. Getting an equally accurate magnetic field value is harder.

The double line spectroscopic binary 66 Eri is the first double CP star whose components are not Hg-Mn stars. They are peculiar in different ways (Yushchenko et al. 1999). *Hipparcos* picked out a bunch of new variable CP stars. Confirming earlier correlations, the Ap's are all oblique rotators, and the Am's are all eclipsing systems (that is, short period binaries), except for the Gamma Dor stars, which pulsate (Paunzen & Maitzen 1998). Leone & Catanzaro (1999) point out that short period, circular orbits (implying synchronized rotation) remain rare among all types of CP stars, including the helium weak and helium strong ones.

Even the globular clusters can have chemically peculiar stars. Caloi (1999a) concludes that they are killed by the onset of convection, which naturally mixes in all the carefully saved pots of Eu, Nd, and so forth. Gaps in the distribution of globular cluster stars in the HR diagram arise from the same cause. Behr et al. (1999) describe 13 horizontal branch stars in M3 as having atmospheric helium abundances depleted by factors of 10 to 1000 and some metals enhanced by 3–100 times above the average low metallicity found for the main sequence and red giant stars. These are clearly "peculiar" if not CP in the strict definition. Ditto for V1291 Aql (Kato & Sadakane 1999).

6.5. White Dwarfs

Greenstein & Trimble (1967) concluded that the average white dwarf has a mass near 0.75 $M_{\odot}$ on the basis of gravitational redshifts measured for large enough numbers that the space velocities could be dealt with statistically. That average has crept down over the years and long ago ceased to be a hot topic (Ap92, § 13.6). The author concerned notes, however, with some interest, the three WD + MV binaries studied by Vennes et al. (1999), in each of which the spectroscopic log g implies a smaller mass for the white dwarf than the one that comes from the "gold standard" of binary orbit analysis. Among cataclysmic variables, Smith & Dhillon (1998) found an average of 0.69 $M_{\odot}$ for systems with orbit periods shorter than 2 hours and 0.80 $M_{\odot}$ for longer period systems. The error bars, however, overlap, and there are selection effects in favor of more massive WDs, which are likely to have more vigorous outbursts.

Topics of greater recent interest include the range of surface compositions and the processes that might account for them, cooling rates (often as a measure of the age of the Galactic disk, star clusters, or companions), magnetic fields, rotation periods, and pulsations.

For the hottest WDs, whether you see hydrogen, helium, or both on the surface is set by a (calculable) balance between diffusion and mass loss (Unglaub & Bues 1998). It has been traditional to invoke accretion of interstellar material to account for the hydrogen atmospheres with calcium and other metal contamination. Dreizler & Wolff (1999) conclude that this is not necessary after all, when the effects of radiative levitation and stratification are properly computed. Barstow et al. (1999) concur, but Zuckerman & Reid (1998) note with some puzzlement that detectable calcium is correlated with the presence of an M dwarf, brown dwarf, or planetary companion, which would seem to favor some sort of accretion process. Accretion clearly is responsible for the patchy hydrogen on the surface of the DAO component of the CV RE J0271$-$318 (Dobbie et al. 1999). A larger sample of hot pre-white-dwarfs suggests that the H and He rich atmosphere stars may constitute two separate sequences over their entire history (Rauch et al. 1999).

Globular clusters are old enough that you see only the warmest, brightest white dwarfs. This is not a 1999 discovery. M4 is, however, the first cluster to have its WD sequence mapped in both visible light (Ibata et al. 1999a) and the near infrared (Pulone et al. 1999). That the stars have a range of 1.1–1.8 μm colors, but all nearly the same 1.1 μm brightnesses was a bit of a surprise.

Cooling calculations have been applied both to dating the Galactic disk (oldest stars = 10–12 Gyr would suit both Knox et al. 1999 and Hansen 1999a, but not Benvenuto & Althaus 1999) and to judging the ages of binary pulsars whose companions are WDs. For the millisecond (spun-up, small magnetic field) systems, Burderi et al. (1998) conclude that either WD cooling or neutron star spin-up (or, of course, both) is not understood. That is, they cannot get consistent ages for the two stars.

That some white dwarfs are very magnetic indeed was a highlight of the 1970s. Attractive is another question. In fact, we think a couple are almost repulsive, including RE J0317−853, where the combined effects of electricity and magnetism render permitted an otherwise forbidden $S_0 \rightarrow S_0$ transition (Burleigh et al. 1999) and LHS 2229, with $B \approx 100$ MG and a strong absorption feature due to C_2H or some other C−H bond (Schmidt et al. 1999). If you want to do detailed spectrum synthesis, it may be helpful to know that LP 790−29 has about the same temperature and magnetic field but instead shows Zeeman-shifted Swan bands of C_2, while ESO 439−162 has the same spectral features as LHS 2229 but is non-magnetic.

White dwarfs could rotate at periods as short as 0.5 sec (Geroyannis & Papasotiriou 1999). But, in fact, they don't. Livio & Pringle (1998) blame angular momentum loss during explosions for the slow rotation in dwarf novae, but, in fact, the single ones are mostly also much slower than they need to be, with $v \sin i$ less than 15 km/sec for most DAs (Koester et al. 1998).

Pulsating white dwarfs apparently now come in at least four classes. The longest-known are called ZZ Ceti stars, have hydrogen dominated atmospheres, and can be modeled reasonably well, although the maximum computed pulsation periods are about twice the observed 1200 sec maximum (Wu & Goldreich 1999). The second group has only seven members and helium-dominated atmospheres. The temperatures at which the stars should pulsate are very sensitive to even small amounts of hydrogen in the atmosphere (being hottest for pure He). This is presumably the reason that pulsating and non-pulsating stars seem to mingle in the HR diagram (Beauchamp et al. 1999). After a long period as "pulsating DB stars," they are now V777 Her stars.

Third are the PG 1159 stars, again named for a prototype. They are the hottest, and the dominant atmospheric opacity is that of CNO. They are thought to be cooling so rapidly that period changes should be detectable. Early attempts led to the "wrong" sign for dP/dt, and this at least seems to have been sorted out, but the amplitude is still too big for theory to interpret (Costa et al. 1999). The PG 1159's do not all have exactly the same surface composition. H1504+65 is the most massive, the hottest at 170–200,000 K, and apparently unique in being completely devoid of H and He but having oodles of neon (made by helium burning out of the nitrogen left from CNO cycle hydrogen burning; Werner & Wolff 1999). The 20 or more frequencies of HS 2324+3944, a PG 1159 with some residual hydrogen, include non-radial g-modes, rotation, and linear combinations of these. The periods range from 1000 to 3000 sec (Silvotti et al. 1999).

Handler (1999) suggests that he has about two examples of a fourth class, found among nuclei of planetary nebulae (young or pre-WDs) and characterized by longer periods of hours. Feibelman's (1999) new class of variable stars may or may not be the same thing. Both are anyhow very hot.

Whether WDs are born at the same rate their precursors die and whether either integrates to the accumulated supply are old questions. Smith (1998) finds that 4.6×10^{-13} white dwarfs are born per year, per cubic parsec, locally.

6.6. White Dwarfs in Binaries

Dozens of papers discussed various aspects of cataclysmic variability. We record only a set of "one-liners" pertaining to novae, dwarf novae, and the rest.

The nova Sgr 1991 (V4332 Agr) acted more like a single star than a binary (though it could have been a virgin nova; Martini et al. 1999).

An apparent spiral structure in the disk of IP Peg was a highlight a year or two ago. Bobinger et al. (1999) say it's really just a couple of hot spots, while Harlaftis et al. (1999) say the pattern is a two-armed spiral and repeats from outburst to outburst, and Steeghs & Stehle (1999) believe that two-armed spiral CVs should actually be rather common, though hard to detect.

AE Aqr continues to excrete, though Ikhsanov (1999) says that it used to be an accretor (presumably not as recently as 1956 when it was first described that way). EX Hya needs a narrow line region and a broad line region, as if it thought it was an active galactic nucleus (Mauche 1999). CD Boo and a couple of other putative variable stars really are AGNs (Margon & Deutsch 1999).

The VY Scl stars or anti-dwarf novae also have quasi-periodic oscillations and much other finery, and at least one is a super-soft X-ray source (Greiner et al. 1999; Pavlenko & Shugarov 1999; Leach et al. 1999). We wonder whether it might do to describe them as ordinary dwarf novae that spend more time bursting than not. Then, if we understood the burst mechanism, their lifestyles would be clear. Hameury et al.'s (1999) conclusion that there are several kinds of such mechanisms is not likely to get anybody into serious trouble. According to Smak (1998), different processes can look rather similar, e.g., the ultraviolet will brighten ahead of visible light whether the outburst goes through the disk from inside out or outside in.

Much has been written over the years about V471 Tauri, the first WD + MV binary recognized before the components have started interacting. But the saddest word is that it is no longer the prototype of V471 Tauri stars; they are now just pre-CVs (Nicholls & Storey 1999).

6.7. So Doth the Greater Glory Dim the Rest

Eighteen other stars and types get only one line, idea, or reference each. This is not meant to indicate that they aren't important. Indeed we have published on a few of them ourselves, making them a priori important.

◦ The Maia class of variable stars defined by Struve (1955) includes some real variables (Gamma CrB, Gamma U Mi, etc.), but is not a well-defined class (Scholz et al. 1998).
◦ The latest member of the class of slowly pulsating B stars (periods of 1–5 days; Aerts et al. 1999a) is a member of the open cluster NGC 7652 (Choi et al. 1999).
◦ Concave stars haven't actually been observed, but the more massive component of some contact binaries must be so (Morris 1999).
◦ The former Delta Scuti star V879 Aql is really a W UMa contact binary, whose discoverers had originally called it an RR Lyrae (Kopacki & Pigulski 1998). While we're at it, RR Mic and V1711 Sgr are not Type II Cepheids (Berdnikov & Szabados 1998).
◦ RS CVn stars do all sorts of things rather better than most others, including flaring in the extreme UV (Oster & Brown 1999) and making plages (Zhang & Zhang 1999).
◦ SX Phe stars (pulsating blue stragglers, roughly) are found in the Carina dwarf spheroidal galaxy, but the period-luminosity-mass relation is different from the Galactic one (Poretti 1999).
◦ R CMa is no longer hollow, but both stars are still "overluminous" (Varricatt & Ashok 1999).
◦ The rapidly rotating ($P = 5.5$ days) G5 giant FK Comae still has a good deal of adolescent spottiness (Strassmeier et al. 1999; Korhonen et al. 1999).
◦ We admit that it is occasionally a little difficult to get excited about some of the more subtle composition anomalies displayed by late-type stars, but admire particularly Shetrone et al. (1999) for describing their subject as "an insipid CH star."
◦ Carbon stars appeared in about 10 papers. We note only that the ratio of ^{12}C to ^{13}C can range a factor of three either direction around the equilibrium value for CNO cycle hydrogen burning (Ohnaka & Tsuji 1999).
◦ S-type stars come, as many have remarked before, both with and without Tc. The two sorts differ systematically in mass loss rates and pulsation periods (Groenewegen & de Jong 1998). These ought to make sense relative to the belief that the Tc-rich stars are *s*-processing right now, while the non-Tc stars have been polluted by companions, but we haven't quite figured out all the details.
◦ No, we are not going to try to tell you whether RV Tauri stars have the maxima or the minima in their light curves of alternating large and small amplitudes, but only that the ones previously advertised in globular clusters are not really RV Tau's (Zsoldos 1998). This leaves the calibration of their absolute magnitudes in some disorder.
◦ Seemingly anomalous X-ray stars of spectral types that should have neither coronae nor boisterous winds continue largely to be blamed on otherwise undetectable M dwarf companions (Panzera et al. 1999). The radio emission from Algol has opposite circular polarization at the two poles (Mutel et al. 1998). And 15 or so other papers on X-ray and radio stars, including LSI +61°303, which is both, and a Be star as well. Curiously the radio comes from neither star but from between or around (Lestrade et al. 1999, who have compared VLBI and *Hipparcos* positions). The star is also periodic all over the place (Gregory et al. 1999). Such radio and X-ray emission quite often comes from colliding winds, on which we recorded at least 10 papers. There used to be a Pygmi who came from V444 Cygni; now there is merely colliding-wind X-ray emission (Maeda et al. 1999). If you have begun to notice that astronomers aren't as frivolous as they used to be (present company excepted), you probably also remember when "radio star" meant Jack Benny or Rosemary Clooney.
◦ The hot subdwarf stars have always been a sort of leftover category, including at times inactive CVs, pre-white-dwarfs, and various members of the extended horizontal branch. The four sdO's studied by Peterson (1969) seem to have been of the pre-WD type (log g at least 5.5, helium making up 40%–90% of the atmosphere, and lots of nitrogen). Both nuclear processes and gravitationally-driven diffusion contribute to the atmospheric abundances. The pulsating sdB star PG 1605+072 has 55 periods and chemical diffusion in its atmosphere, despite a rotation period shorter than 8.7 hours (Heber et al. 1999). Some rather similar stars don't have any pulsation periods at all (Kilkenny et al. 1999). Maybe they could share?
◦ Nuclei of planetary nebulae do not make up as large a fraction of the really hot white dwarfs as you might expect (Rauch 1999).
◦ B[e] stars are not the same as Be stars, being forbidden, but nevertheless existing in at least five classes (Lamers et al. 1998a). We tried to enforce a moratorium on Be stars this year and actually found a bit of help from Porter (1999), who says that they turn into B stars when they swallow their disks.
◦ Star spots seem to be ubiquitous where envelopes convect. Rapid rotation apparently makes high latitude spots (Stout-Batalha & Vogt 1999) and inhibits activity cycles (Kitchatinov & Rudiger 1999).

◦ The roAp (rapidly oscillating) stars should probably have appeared earlier with the other Ap's, but the ghastly question "Should roAp stars get WET; and will they make a splash?" (Matthews 1998) does not invite either a response or any future discussion.

7. GAMMA-RAY BURSTS

The number of these with X-ray tails and/or optical and/or radio counterparts is now "many." All conform more or less to the first such (Ap97, § 11), to the extent of having happened well outside the Milky Way. Topics still under discussion are the nature of the host galaxies, the extent of the association with supernovae, detailed models of the emission versus time and wavelength to be expected from various likely processes, the amount of beaming needed to match observations (not just total energy), and are they really all the same sort of beast? The last is a possible hot topic for 2000, as various statistical studies continue to show what seem to be several populations in duration, evolution of spectral hardness, substructure, and so forth.

First the hosts. One way to describe the data would be to say that most of the events since 1997 February have occurred in galaxies (most often relatively faint, star-forming ones, of moderate redshift by modern cosmological standards), while most of the events before that did not. That is, when an optical flash has been caught and followed down, a galaxy often reveals itself: (*a*) Bloom et al. (1998) on 970508 in a $z = 0.835$, $L = 0.12L^*$ galaxy; (*b*) Djorgovski et al. (1998) and Bloom et al. (1998a) on 980703 in a $z = 0.966$ galaxy, a couple of magnitudes brighter than earlier hosts and with 0.9 mag of internal absorption, as you would expect from a star-forming region; (*c*) Fruchter et al. (1999a) on 970228, the first optical counterpart, and 971214. GRB 990519 showed more optical polarization than previous events (Wijers et al. 1999) and faded very rapidly (Stanek et al. 1999a). The current limit on the host is fainter than $R = 26.6$ (Covino et al. 1999).

In contrast, for many of the earlier events with good positions from satellite triangulation, there isn't much of anything in the error box (Schaefer 1999). This implies, if the host is simply too faint to see, quite large total energies or considerable beaming (Band et al. 1999). A couple of recent events, 980329 (Reichart et al. 1999a) and 980519 (Halpern et al. 1999), also faded very quickly below the brightness that would have been caught by standard surveys.

But the event to watch was 990123, at a record redshift of 1.6 (the sixth to be measured). The discovery package (Kulkarni et al. 1999; Akerlof et al. 1999; Galama et al. 1999; Meszaros 1999) mentions the rapid radio fading, the redshift, the peak apparent magnitude ($m = +9$), and the sizable energy required if beaming was not significant. The burst deposited 3×10^{-4} erg/cm^2 at the top of the Earth's atmosphere (GRB power anyone?). It could have been gravitationally lensed, though this is unlikely to buy you more than about a factor of two in energy (Blandford & Helfand 1999). Bloom et al. (1999a) and Fruchter et al. (1999) draw attention to its probable association with a star formation region.

GRB 980425 and SN 1998bw got their positions together just in time for Ap98 (§ 6.3). The official package appeared in November (Kulkarni et al. 1998; Galama et al. 1998; Iwamoto et al. 1998). Theoretical comments naturally followed. In particular, the fraction of archival supernovae and GRBs close enough in position and time to be likely associations is at most 1% of bright BATSE events (Kippen et al. 1998).

The latter part of the index year has seen a handful of additional associations suggested. Reichart (1999a) fits the light curves of 970228 and 980326 with rapidly fading burst counterparts and longer lasting SN light curves. SN 1999eb = 991002 (IAU Circ. 7269) is the most recent candidate as we go to copier. And the rest belongs to the theorists, with 30+ papers in the journal literature. Our favorite (Pugliese et al. 1999) predicts that SS 433 will someday become a GRB. No date given.

Historical accident is largely to blame for the custom of discussing the soft gamma repeaters together with the classical GRBs, though if both should turn out to be variants of what supernovae do, a unified presentation could some day make sense. Last year was the year of the magnetar or strong magnetic field model (Ap98, § 6.4). Naturally someone this year has expressed doubts about whether the spin-down of one of them (1900+14) is really due to a pulsar-type process and concluded that we have no firm evidence for the strong field (Marsden et al. 1999).

Initial data on the fourth SGR (1627−41) are given by Woods et al. (1999), Hurley et al. (1999), Smith et al. (1999a), and Mazets et al. (1999). It is perhaps the first magnetar to have a star-quake-type burst. An indirect argument yields $B = 10^{14}$ G, but the decrease of the 6.41 sec period needed to check this had not then yet been measured.

The period derivative and implied magnetic field of the perhaps-related anomalous pulsar 4U 0142+61 ($P = 8.7$ sec) have held steady for the past 19 years (Israel et al. 1999), but who knows what the millennium will bring for it.

And next year, if the subscribers and editors permit this series to continue, we promise to bite the fireball bullet and try to make some sense out of competing emission mechanisms.

8. WHEN FOND RECOLLECTION PRESENTS THEM TO VIEW

This is our longest section. It is also the densest, addressing questions and issues familiar enough to need no prolonged explanation. We have tried hard to put the questions and statements of the puzzles in some logical order and also to put key concepts at the beginnings of paragraphs, but we will undoubtedly have failed in places. The title comes from a 19th century nostalgic song called "The Old Oaken Bucket." There are, otherwise, relatively few examples of terminal cuteness in the section, clarity having been valued over comedy (but feel free to skip to § 13).

8.1. Active Galaxies

Are they "unified"? That is, can you account for a large sector of the observations of everything with a few basic food groups, like black hole mass and rotation, host galaxy type, and, especially, the orientation from which we see the sources (Ap92, § 7)? The issues could be different for Seyfert 1 versus Seyfert 2 galaxies and the various sorts of radio galaxies, quasars, and blazars. We counted 32 papers making some point in favor of unification in this sense and (truly a coincidence) 32 against. About six said both, neither, or something unclassifiable. On the "pro" side comes the first detection of polarized broad line emission in a LINER (NGC 1052; Barth et al. 1999) and the elongated, polarized UV images of narrow line radio galaxies (Hurt et al. 1999). A balancing pair of cons is Dultzin-Hacyan et al. (1999) drawing attention to the fact that only Seyfert 2's have an excess of companions less than 100 kpc away, and the report of cooling flow gas in a BL Lac that is not seen in FR I radio galaxies (Hardcastle et al. 1999).

What is the nature of the connection between active nuclei and starbursts, and does one sort evolve into the other? The conclusion that there is always an AGN contribution above some cut-off luminosity near 10^{12} $L_\odot$ (Dudley 1999; Veilleux et al. 1999a) does not actually answer either part of the question, but it has the merit of being tidy. Lutz et al. (1998) go on to speak against AGNs as being systematically the later evolutionary phase, based on images. Collin & Zahn (1999) appear to be suggesting the converse, that an AGN accretion disk can cause lots of star formation and supernovae.

Are there radio quasars with broad absorption lines? Yes (Brotherton et al. 1998a), but they are not the big, strong, lobe-dominated objects that you see in 3C (Kuncic 1999) (Ap97, § 9.5).

What are the masses of the central black holes? Can you trust the answers, and are they correlated with the mass of the bulge component of the host galaxy? Fan et al. (1999a) find black hole masses for Blazars (based on the timing of flares) that are only (1–7) × 10^7 $M_\odot$. Other indirect arguments lead to numbers more like 10^9 $M_\odot$, even for mildly active nuclei (Cappellari et al. 1999). Among normal galaxies, Colbert & Mushotzky (1999) conclude that central, modest X-ray sources imply 10^2–10^4 $M_\odot$ in half of both E and S galaxies, while Burderi et al. (1998a) find statistical support for ubiquitous big ones. We are tempted to vote with the moderates, Bischoff & Kollatschny (1999) who use reverberation time arguments to put a 6×10^7 $M_\odot$ black hole in Mrk 110. As for the bulge/BH connection, Wandel (1999) finds that there is a range of at least a factor 20 in the ratio, with brighter sources having bigger BHs (denied by others). We are slightly tempted to call the suggested constancy of the ratio the Cattaneo effect, since he seems to be the last to have mentioned it during the year (cf. Stigler 1980 on multiple discoveries and eponyms). Cattaneo et al. (1999) suggest that the ratio is determined by the efficiency of black hole accretion.

Do quasars and QSO's have host galaxies? Yes, of course they do. They had, as it were, ground-based hosts long before *HST* was ever launched (and indeed the first *HST* contribution? to the topic was a negative one of failing to see them; Ap95, § 10). And they still do, though the preprints have rolled over their heads. *HST* (or rather astronomers who use it) is finally firmly on the right side (Kirhakos et al. 1999; Urry et al. 1999; Lehnert et al. 1999). All note that the hosts of radio loud ones are nearly all giant elliptical or interacting (i.e., future gE's?) galaxies, answering another hoary question.

Do radio galaxies age? Don't we all? (Jones et al. 1999, who calculate many of the details).

Do populations of radio sources evolve? Same answer, but it is remarkably difficult to get clean, comparable samples to determine luminosity functions at different redshifts (Bershady et al. 1999). The dichotomy between luminosity evolution (the same percentage of galaxies were active in the past, perhaps even the same ones, but they were brighter) and density evolution (more galaxies were active in the past, and none lasts very long) was always a false one unless AGNs are remarkably unimaginative about living and dying.

Do we ever actually see stuff falling into the black hole, as opposed to the jets coming out? Could be, say Nandra et al. (1999), looking at the profile of the Fe-K line in NGC 3516.

Why don't we see a spectral feature associated with the Lyman edge in accretion disks? Non-LTE, say Hubeny & Hubeny (1998, one of the few father-daughter pairs in astronomy). Disk coronae, say Rozanska et al. (1999). It's an interesting problem, say Koratkar & Blaes (1999).

Are the radio and optical emission regions of active galaxies aligned with each other? Yes, say the first and last papers indexed during the year (De Young 1998; Simkin et al. 1999). The latter present what seems to be the nearest example, Pictor A (the phenomenon was once confined to large redshifts; Ap92, § 10.6). It has all the possible alignments of optical continuum, emission lines, core radio jet, and extended radio emission. The jet hitting gas clouds in the galaxy is at least part of the story.

How fast do AGN jets move? Only 0.1*c* in many Seyferts (Ulvestad et al. 1999) even on the smallest, parsec scales.

Sometimes with gamma factors up to 100, say Crusius-Waetzel & Lesch (1998), after discussing sub-day variability of Blazars and such, whose brightness temperatures would otherwise be a sobering 10^{16}–10^{20} K. At some point, however, a coherent radiation mechanism, allowing truly enormous values of T_b, begins to seem more attractive (Benford & Lesch 1998). And a dozen 1999 papers with speeds in between.

Does the Milky Way have its very own black hole? Nobody really said no, so just one paper that said yes (Ghez et al. 1998).

Can you map out accretion disks with the time intervals by which various emission line fluxes lag the variable ionizing continuum? Again nobody said no, but O'Brien at al. (1998) say "sort of" rather than Yes!

Is advection-dominated accretion flow a good thing? No (Blackman 1998, because it does not produce fast enough variability in M87, etc.). Yes (Quataert & Narayan 1999, even when you see outflows in sub-Eddington sources). Sometimes (Lu et al. 1999). But we are not prepared to listen to any further discussion of who deserves credit for the original idea (Ap97, § 13.1).

Do some galaxies have two black holes? Could be—there were at least 13 papers on double nuclei of various sorts. But not M31. Kormendy & Bender (1999) present spectra and photometry showing that there is really one BH of $3 \times 10^7\ M_\odot$ plus an eccentric disk of stars orbiting it.

Do active galaxies vary rapidly? Is the Pope Catholic? (Actually we have no first hand information on this point.) Just the first and last papers of the year, without any effort to pick "fastest." At 408 MHz, yes, but not all of them, in years (Riley & Green 1998). Gamma-ray blazars at visible wavelengths, virtually all, many in hours (Xie et al. 1999).

8.2. The Milky Way and (Other) Normal Galaxies

Each year since 1991, as the last leaves fall from the trees of College Park and the last shreds of patience from the editors of PASP, the continuing author has become conscious that some topic was going to be slighted. This is the one for 1999. There were (honest count) 137 papers that got (*a*) read, (*b*) recorded, and (*c*) indexed, representing about twice as many in the journals scanned, of which 250 were read and about 200 recorded.

8.2.1. The Milky Way

We live in a spiral galaxy. It rotates, though different tracers persist in revealing slightly different rotation curves (Ali & Sharaf 1998). It has spiral arms, either two (Normandeau 1999) or four (Engelmaier & Gerhard 1999), in H I, and the 3 kpc arm is one of them. It has a bar, though just how far out this extends depends on the tracer you use (Sevenster et al. 1999 with OH/IR stars; Fux 1999 with gas dynamics; Tiede & Terndrup 1999 on an inner disk); a magnetic field of uncertain topology (Han et al. 1999); and a halo which, in the good old days either was or was not a radio source, and now either is or is not a gamma-ray source (Parmar 1999; Pohl & Esposito 1998; Dixon et al. 1998; Kinzer et al. 1999). The situation is actually a bit clearer than we have made it sound. For instance, Galactic gamma rays in the EGRET band come partly from the halo (Dixon et al. 1998), while OSSE gamma are mostly from the plane (Kinzer et al. 1999). The Galactic gradient of metallicity with radius is a lot like that of other spirals (Gummersback et al. 1998).

Our vantage point is just a little closer to the co-rotation radius than Copernicus might have expected, if he had been interested in such issues (Mishurov & Zenina 1999, and several others).

8.2.2. Everybody Else

Other galaxies also rotate, even some of the ellipticals (Arnaboldi et al. 1998 on the planetary nebulae in Fornax A), especially the fainter ones (Rix et al. 1999). Lots of them have bars (Greve et al. 1999 on NGC 1530, a rather extreme case where the bar mass is 12% of the whole galaxy). In elliptical circles, the polite word is triaxiality (Theis & Spurzem 1999) rather than bars. Most galaxies have halos, with some evidence for a typical size of 50 h^{-1} kpc (Honma 1999), though disk-only spirals may also exist (Fry et al. 1999 on NGC 4244). A significant subset of galaxies have dynamically and/or chemically decoupled cores (Sil'chenko 1999), and a good many others are otherwise messy or asymmetric (Rubin et al. 1999).

A moderately serious issue is the extent to which basic Hubble types evolve into other types. Dutil & Roy (1999) suggest evolution to later types with bar formation as the driver. Zhang (1999) has in mind the same direction for evolution but a different mechanism, which also accounts for the Tully-Fisher relation, the Faber-Jackson relation, and, conceivably, the Great Red Spot on Jupiter.

Actually, you can see the galaxies of long ago evolving into something more like the modern types just by adding infrared data to the images of those in the Hubble Deep Field (Thompson 1998), or, of course, by simulating suitably on your computer (Takamiya 1999a).

8.3. Dwarf Galaxies

Most of us, counting dwarf galaxies in the Local Group, will say Large Magellanic Cloud, Small Magellanic Cloud, Other. But the first one shown to be extragalactic was NGC 6822, where Hubble first reported Cepheid variables. It was the topic of Susan Kayser's Caltech Ph.D. dissertation (Kayser 1967), the first astronomical one completed by a woman there. The advisor was Halton C. Arp, who had then not yet quite focused on discordant redshifts as his main interest. NGC 6822 should be amenable to a search for stellar populations of various ages of the sort already pursued in the Magellanic Clouds (Olsen 1999 on the LMC, Mighell et al. 1998 on the SMC, whose oldest stars go back about 11 Gyr, with numerous burstlets thereafter).

How many are included in that Local Group "Other?" The inventory continues to grow, with occasional setbacks from entities that turn out not to be dwarf galaxies at all or not within 1 Mpc of the LG center of mass (e.g., Karachentsev et al. 1999, who place the dwarf Irregular Cam A at 1.6 Mpc). But the definitive number is 30, that is, 35 Local Group members, minus MW, M31, M33, LMC, and SMC (Courteau & van den Bergh 1999).

Quite unexpectedly, Klypin et al. (1999a) conclude that we really ought to have about 300, most with circular velocities of only 20–50 km/sec. This is based on simulations of dynamical evolution, however, not on counts in other groups, where we have no information on anything that puny. Armandroff et al. (1999) present a less copious deficit, but also conclude that some LG dwarfs are missing through either physical or selection effects, and that the MW and M31 populations are not the same either.

And here we list a handful of other dwarf problems (yeah, 7 or 8 of anything is likely to be a handful).

Do they have dark matter? Yes, or at least something that acts a lot like it (Mateo et al. 1998), though the data are still not as complete as one might like (Kleyna et al. 1999). Or, alternatively, there is none in the dwarf spheroidal in Sagittarius, which is currently being disrupted (and this is causal; Gomez-Flechoso et al. 1999), but we think the ayes have it in the 15 or so relevant papers of the year.

Do they have central black holes? No, observationally (Haiman et al. 1999), and none expected (Sellwood & Moore 1999).

Do they have composition gradients? Well, in general, the smaller and fainter the galaxy, the more subtle the gradient, if any (Smoker et al. 1999).

Does some subset of distant ones correspond to one or more of the categories of absorption lines in QSOs? All possible answers have appeared, but we particularly like that of Kepner et al. (1999a), which is, "Yes, but you can't tell which ones."

What is the ratio of CO to H_2 compared to that in the Milky Way? Small, nigh unto zero, perhaps (Taylor et al. 1998). Well, what did you expect?

Is there a dwarf spheroidal second parameter, and, if so, what is it? Majewski et al. (1999) say that, in Sculptor, there are age differences and composition differences, but that [O/Fe] is +0.5 for both old stars with low Fe/H and young stars with high Fe/H. So there!

Is there a separate class of dwarf S0's between the earlier and later types? Ryden et al. (1999) quote Sandage & Binggeli (1984) as saying "This is a new class, if indeed it exists," and conclude that it does not, in the sense that, at least in Virgo, the candidates are not statistically separable from the dE's.

There are also blue compact dwarf galaxies, low surface brightness galaxies, and faint blue galaxies. The BCDGs include ones with exponential profiles, de Vaucouleurs profiles, and complex profiles (Doublier et al. 1999). Some faint blue galaxies are merely irregulars that have not yet been well imaged (Teplitz et al. 1998). And at least some of the low surface brightness galaxies differ from high surface brightness galaxies only in surface brightness (Heller et al. 1999). The cause, not unexpectedly, is less current star formation.

Do dwarf irregulars evolve into dwarf spheroidals? No, the shapes are different (Sung et al. 1998). Well, maybe, and the Phoenix dwarf is in the process of doing it, turning its gas into stars from east to west (St-Germain et al. 1999). And we end by quoting Knezek et al. (1999) who draw attention to some star-forming dwarfs that will not fade into dE's or dSph's even in a Hubble time, and another dwarf with no H II regions for which no known galaxy is an appropriate precursor.

8.4. Nucleosynthesis and Chemical Evolution

At least one or two papers during the year addressed each of the standard nucleosynthetic processes identified by Cameron (1957) and Burbidge et al. (1957, B^2FH), and their modern equivalents (e.g., Trimble 1996). This will be much less complete.

Spallation is the break up of big nuclei into little ones. It happens in solar and stellar flares, presumably in active galactic nuclei and supernovae and their remnants, and most notably in the interaction between cosmic rays and interstellar gas. Normally the process involves one heavy nucleus and a proton (because there are so many of them, like beetles), and either can be the relativistic particle in our rest frame.

Spallation is best known as the major source of Li, Be, and B over galactic history. But most of the papers we caught drew attention to the need for at least one other source. Fields & Olive (1999) mention boron from a neutrino process in supernovae. Smith et al. (1998) suggest alpha-alpha reactions (where one is a cosmic ray and the other is not), as a source of ^{6}Li. Parizot & Drury (1999) favor making beryllium in superbubbles. And Guessoum & Kazanas (1999) have explored spallation in another context, X-ray novae, where it should make the lithium excess actually seen in five systems. The more processes you can think of to add up, the easier it becomes to accept the conclusion of Cunha et al. (1999) that there is real scatter in the amounts of beryllium and boron, even over small ranges of stellar age, location, and total metallicity.

But the highlight of 1999 under this heading is a retraction. Early data from the COMPTEL telescope on the *Compton Gamma Ray Observatory* had seemed to show a significant flux from the Orion region of gamma rays emitted by the decay of excited states of ^{12}C and ^{16}O, implying lots of low energy particles there. They would also have contributed to nuclear processing. A more thorough analysis of the data leads to an upper limit at about 1/3 of the flux level originally suggested (Bloemen et al. 1999).

Here are a few other elderly and perhaps honorable questions in the general area of nucleosynthesis. (1) Is nitrogen a primary or a secondary product? The answer is yes (Henry & Worthey 1999; Pilyugin 1999; and a number of other papers). (2) Is much ^{26}Al produced by novae? No (Jose et al. 1999) or Yes (Wanajo et al. 1999). The reason you care is that it is supposed to be the major heat source to melt meteorite parent bodies. (3) How much helium is added to the cosmic inventory by the stars producing metals? $dY/dZ = 2$–4 seems to cover all the values published during the year (Esteban et al. 1999a; Fernandez et al. 1998; and others), and this is a larger ratio than models of chemical evolution easily encompass (Fields & Olive 1998). (4) To what extent are old, metal poor stars less deficient in oxygen than in iron? According to Fulbright & Kraft (1999), the answer depends on which oxygen feature you look at, and they conclude that the one yielding the smallest abundance, so that $[\mathrm{O/Fe}] \approx 0$, could well be right. Israelian et al. (1998) in contrast find that all the indicators agree and that $[\mathrm{O/Fe}]$ rises to $+1.0$ at $[\mathrm{Fe/H}] = -3$.

The last question has taken us from individual processes to the realm of gross chemical evolution of the universe. The topic remains a gross one for a couple of reasons. First, we have some of the essential data (e.g., metal abundance vs. age vs. location) for individual stars only in our own galaxy. Given a method of rapid intra- and inter-galactic communication, the question we would most like to ask is, "Do you guys have a G dwarf problem?" That is, how many other populations share with that in the solar neighborhood a deficit of old, metal poor stars sufficient to force one to invoke gas inflow, metal-enhanced star formation, or other tooth fairies? Henry & Worthey (1999) think that such deficits occur in all large galaxies. These are also the ones that have abundance gradients (more heavy elements at the core). It would be nice if the same gas flow processes could account for both. Henry & Worthy (1999) do not explicitly suggest this, but Angeletti & Giannone (1999) seem to.

The second source of grossness is the "curse of the adjustable parameter." That is, your model can include infall and outflow of gas of various compositions, a wide range of initial mass functions, assorted prescriptions for star formation, and much else. It is possible to fit any sort of galaxy you happen to be interested in with some combination of these (e.g., Chiosi et al. 1998 on giant ellipticals), but your fit will not be unique (e.g., Ng 1998 on the degeneracy of star formation rate vs. time and the slope of the initial mass function, $N(M) = N_0 M^{-x}$). In principle, it should be possible to break the degeneracy of population ages and metallicities in other galaxies by matching enough different spectral features, but not yet (Ronen et al. 1999).

Even QSO absorption line gas has a sort of G dwarf problem, unless you can manage to exclude newly-formed heavy elements from the ionized gas (Pitts & Tayler 1999). But we emerged merely confused from what Ciammi (1998) calls "a Lagrangian picture of the G dwarf problem."

If you nevertheless end up with a model that doesn't fit the population you started out to match, do not worry. At least 15 1999 papers pointed out that, even within the Milky Way, there is not a universal trend of metallicity versus time, and that the distribution of the heavy elements is by no means the same in all stars of a given, low metallicity. The first and last we saw were Ponder et al. (1998, on globular cluster and field stars in M31, giant elliptical galaxies, and the Milky Way), and Ikuta & Arimoto (1999) saying that you shouldn't have expected any such uniformity anyhow.

But, lest you feel inclined to give up on the whole enterprise, we (or rather Hughes et al. 1998) hasten to assure you that enrichment must be going on right now, at least in the LMC, where the smaller supernova remnants have a larger percent of heavy elements than do the big ones that have swept up lots of old, less-enriched, interstellar gas.

8.5. Interstellar Matters

Our index alone for this topic occupied two full pages, meaning a couple of hundred papers read, recorded, and indexed. Ap98 (§ 5) counted up the phases from cold to hot, so we'll go the opposite direction, sticking close to the Milky Way and galaxies like it. For each item, please mentally insert "and umpteen other papers just as good or better" including perhaps your own.

X-ray emitting gas is found in the bulge region of the Milky Way (Park et al. 1998) and the halo of NGC 891 (Devine & Bally 1999).

Ionized hydrogen does not destroy all the dust in it (Howk & Savage 1999). It also tolerates existence of molecules (Koo 1999), not to mention being chock full of free electrons, whose primary purpose in life appears to be to allow us to probe interstellar turbulence using pulsar scintillation data (Spangler 1999). Presumably H II also contains all the elements from H to Ur that come out of or go into stars, but not always in the same proportions (Esteban et al. 1999, comparing M8 with Orion).

Ultracompact H II *regions* can be thought of as an evolutionary phase between non-star and star, with well-defined signatures for several intermediate stages (Walsh et al. 1998). In fact, a good many regions catalogued this way are not paricularly compact, and are resolved at radio wavelengths (Testi et al. 1999a). Only massive stars do it (Phillips et al. 1998)

The local bubble has hydrogen 10–90% ionized (most toward C Ma, whose stars may be the source of the ionizing radiation), but the helium 40% ionized throughout (Wolff et al. 1999). This is not understood, at least by us, though Wolff et al. suggest that the ionized helium could be a fossil of a supernova shock that passed by some time ago.

Phaselessness? Wada & Norman (1999) model an ISM that is nearly a continuum in both temperature, from 10 up to 10^8 K, and in surface density, from 10^5 down to 0.1 $M_{\odot}/\mathrm{pc}^2$. Admittedly, stars still form where the stuff is coldest and densest, but we feel their result entitles us to ignore the varying degrees of warmish, translucent, transparent, and diffusish gases and hurry right on to:

Neutral hydrogen, which, when we were children, came in Average Interstellar Clouds with $n(\mathrm{H}) = 100\ \mathrm{H/cm}^3$ and $T(\mathrm{spin}) = 125$ K. It mostly now seems to come in shells around other things, apparently Strömgren spheres (Cappa & Benaglia 1998), whether big (Skelton et al. 1999) or little (Basu et al. 1999). All are, of course, honorably magnetized (Gray et al. 1999). And, before you know it,

Molecules are forming (Weiss et al. 1999, on the process in cirrus clouds outside the Galactic plane), large numbers of different ones, and not always in the proportions you would expect. Bell et al. (1999) report that HC_9N and $HC_{11}N$ are actually more abundant than C_6N, C_7N, and C_8N in Taurus molecular clouds number 10. Truthfully, we would not have guessed there would be a lot of any of these.

Many more molecules are probably still missing from the inventory, since bands and features of uncertain identity remain common and, occasionally, of considerable importance in energy budgets. Szczerba et al. (1999) find that a 30 μm band carries about 10% of the total flux from *IRAS* sources associated with carbon-rich, post-AGB stars. It could be due to MgS on graphite grains.

The conversion factor from CO (easily observed) to H_2 (impossible when cold) is needed for a variety of studies. The two scale differently with the amount of dust present (Shuping et al. 1999), which is not a good start toward a universal relation (Ap97, § 7.2)

The ratio of deuterium to ordinary hydrogen can be measured in both molecular and atomic regions, though you must understand the chemistry to learn much from the former. And selective that chemistry can be! The ratios of H_2CO to DHCO and DHCO to D_2CO are both 2–3 in the Orion Belt (Ceccarelli et al. 1998). Whether there are real D/H variations in the Galactic interstellar (atomic) gas remains in some dispute. Vidal-Madjar et al. (1998) say yes, over the range at least of $(1.1–1.6) \times 10^{-5}$, and the Orion region in particular is deuterium poor, in both atomic (Jenkins et al. 1999; Bertoldi et al. 1999) and molecular (Wright et al. 1999) phases. So it appears is the Galactic center (Jacq et al. 1999). Mullan & Linsky (1999) say that there should be real variations, caused by stellar flare production of deuterium, but we feel vaguely that this ought to make more deuterium in regions of vigorous star formation like Orion, not less.

Whether the continuing non-detection of amino acids should surprise or not remains unclear. Rajtog (1999) says they might be mostly polymerized, in which case you should look at infrared rather than radio wavelengths. Polymerized amino acids are more or less proteins, and Bernstein et al. (1999) describe how alcohols, quinones, ethers, and other organic molecules might be produced from polycyclic aromatic hydrocarbons in ices that have been exposed to ultraviolet radiation. And we will tiptoe away from this one, before Sir Fred Hoyle tries again to convince that plagues come from comet tails, repeating as we go, however, that eventually it will turn out that there are complicated organic molecules in space (maybe even chlorophyll and porphyrins) but that Fred Johnson (1970), who started saying it back in the 1960s, won't get any credit.

Dust grains exist in some uneasy and dynamical balance with the molecular gas (Willacy et al. 1998). If you look around enough places, you will find that the grains differ in distribution of sizes (Men'shchikov et al. 1999a on the red rectangle, which has millimeter rather than micrometer grains), chemical compositions (Cesarsky et al. 1998, on the process they call graphitization, which has gone further in the Milky Way than in Andromeda because there are more UV photons), and temperatures (Kramer et al. 1999 on the core of IC 5146, where both dust and gas are very cold according to the ratios of $O^{16}:O^{17}:O^{18}$. The cold dust (at $T < 15$ K, seen by SCUBA) can outweigh the warm, "*IRAS*" dust by as much as ten to one, especially far from the centers of galaxies (Alton et al. 1998). Dust filaments can also extend up to 2 kpc from a galactic plane, 10 times the molecular extension (Alton et al. 1998). The variations in grain size, composition, and temperature naturally add up to differences in extinction curves. We remain fascinated by the still-unidentified feature at 2175 Å (formerly 2200 Å before UV wavelength resolution reached modern standard). It is correlated with various other things when you compare Milky Way and SMC sight lines (Misselt et al. 1999).

Dust polarizes as well as extinguishing light. The UV polarization is not very well understood (Martin et al. 1999). And we were more than a little surprised to hear that ferromagnetic grains at moderate temperature can emit radio waves as well as infrared. The process is magnetic dipole (Draine & Lazarian 1999), and it has probably been seen in the band 14–90 GHz.

Dust comes mostly from stars, including cool post-AGB stars, protoplanetary nebulae, and novae (Chiar et al. 1998). One feels vaguely that it is suitable to remark, "Dust thou art, to dust returneth," but to whom is not so clear.

8.6. Star Formation

The heading "a star is born" had to be resisted, because one of the few things we know with some confidence is that they almost never do it alone. Stars are born in clusters, most of which then gradually fall apart. Theory of star formation continues to progress by rather small steps, invoking concepts like gravitational instability (Karachentsev et al. 1999a), turbulence (Sellwood & Balbus 1999), self-regulation (Churchill et al. 1999), though not in the deep wells where bulges form, says Elmegreen (1999b), inner Lindblad resonance (Elmegreen et al. 1999a), fragmentation (Testi & Sargent 1998), magnetic induction (Totani 1999), magnetic delaying (Boss 1999), magnetic flattening (Galli et al. 1999), and a scale determined by a pulsational mode of gravitational collapse with gravitational and electrostatic coupling (Dwivdei et al. 1999, a paper originally indexed under "Eh?").

We focus here on several continuing issues, primarily observational. The first is the time (or redshift) history of star formation over the life of the universe. Collectors of data at submillimeter and infrared wavelengths tend to find more than collectors of optical and ultraviolet data at all redshifts (Blain et al. 1999). Perhaps as a result, of the 52 papers on the subject we read, 22 emphasized early formation, 18 late formation, and 12 both or neither (with the continuing worry that, if you aren't careful, you end up with more stars now than we actually see). One paper must represent each camp. Early: Some groups of galaxies must form before $z = 15$ and include the brightest galaxies (Cohen et al. 1999). Late: Cowie et al. (1999) find that the density of ultraviolet luminosity is rather flat with redshift. Complicated: Rownd & Young (1999) report that the main controller of star formation rate is the amount of available gas (whose correlations with galaxy type, size, and degree of clustering are not tidy).

Is the Milky Way typical? Fields (1999) suspects that the Milky Way either does not trace the cosmic SFR(z) or that our initial mass function is not the common one. Untypical in either case. Taking a close-up view, Boissier & Prantzos (1999) decide that the solar neighborhood is not even a good proxy for the whole Galaxy. They make the important additional point that agreement between their multiparameter model and a bunch of observations does not guarantee that this is how the galaxy really did it.

When and in what order do stars form? Well, spirals have younger ones than ellipticals (Peletier & de Grus 1998, with no dissenting opinions). Bulges form before disks (Abraham et al. 1999). Bulges form after disks (Noguchi 1999). Stars are forming right now, before your very eyes (White et al. 1999 on the Eagle Nebula), except the best part is over before you can see it (Brown & Chandler 1999). High and low masses form together (Preibisch & Zinnecker 1999), but perhaps by different mechanisms (Flaccomio et al. 1999, interpreting a supposed break in the slope of the initial mass function near 1 $M_\odot$).

Where do stars form? In tidal tails, according to Fritz Zwicky (1958) and many others since, but not in all tidal tails (Smith et al. 1999c on Arp 215, where there is enough molecular gas to make a dwarf irregular galaxy, but few young stars). In cooling flows of X-ray clusters (Hansen et al. 1998 on Hydra A), but never enough to use up all the gas that is trying to flow in. In places where they are hidden by dust (Calzetti & Heckman 1999), even in very metal-poor galaxies (Thuan et al. 1999). Perhaps in cD galaxies, which are not just the sums of little ones (Hilker et al. 1999), or conversely (Carter et al. 1999). In some very small star formation regions (Mizuno et al. 1998). In Gould's (1879) belt, which can be traced in the distribution of weak lined T Tauri stars as well as in B stars (Wichmann et al. 1999). We had somehow almost forgotten that he is the same Benjamin Apthorpe Gould who founded the *Astronomical Journal.*

Is star formation important? If this is not to be a completely silly question, then the answer cannot just be the obvious yes. Dominguez-Tenreiro et al. (1998) find that models of the development of disk galaxies come out better if you allow stars to form as you go, to prevent overmerging (Wiel et al. 1998). On the other hand, other things are at least as important according to Nusser & Sheth (1999).

Efficiency of star formation must generally be rather low in galaxies that are still doing it, but Veltchev et al. (1999) note that NGC 206 in M31 has apparently used up all the available diffuse material (100% efficiency?) and is, as a result, a region of unusually low extinction. Whether there is a universal initial mass function is not up for discussion this year.

And, finally, the question for which you have all been waiting: *Is star formation triggered?* In Ap92, § 5, we replied (well, really, Bruce Elmegreen replied), "On the largest scales, most star formation is triggered, while on the smallest scales most of it is not." The first half still stands firmly, and lots of 1999 papers praised the star-forming abilities of interacting galaxies, with Fujita & Nagashima (1999), dissenting just a bit. But we would like to reconsider the second half of the answer. At least 25 papers in index year 1999 presented data or theoretical arguments suggesting triggered and/or propagating star formation on small to medium scales of single clouds and cloud complexes.

Step one is the compression of gas by a potential trigger. Reach & Rho (1999) describe the case of supernova remnant 3C 319. Benaglia & Cappa (1999) have found 10^3–10^4 $M_\odot$ of neutral hydrogen collected around four bubbles, each apparently due to the wind of a single of star. And Ogura et al. (1998) have mapped the CO near HH 135/136 and find radiation-driven implosion of the molecular gas.

Several examples of "second generation stars" in the Milky Way appeared. Walter & Brinks (1999) addressed IC

2574, where H-alpha is being radiated from around the edge of an H I shell, implying new star formation on the edges of a bubble blown by the old. The second generation of stars in the Trifid Nebula, found by Cernicharo et al. (1998), are still young stellar objects, perhaps of class 0, mapped with *ISO* (the *Infrared Space Observatory*). Come back in 10^6 years or so to see a really big H II region there. Ditto, roughly, for the Perseus molecular cloud region mapped by Barsony et al. (1998). Patel et al. (1998) suggest that the familiar association Ceph OB2 is part of a second generation triggered by the Cepheus bubble.

On a finer length scale, the "pearl necklace" of OB stars and compact H II regions in G45.5+0.06 appears also to be propagating star formation. And the authors (Feldt et al. 1998) call attention to other examples. Six or more papers pointed out similar phenomena in the Large Magellanic Cloud. We note only the case of outward propagation of star formation in 30 Doradus (Walborn et al. 1999; Rubio et al. 1998). Efremov (1999) was not alone in pointing to some arcs and rings of young stars as possibly coming from episodes of star formation triggered by gamma-ray bursters. He was also not alone in neglecting to cite the work of Schmidt-Kaler (1968) a generation earlier on rings of young stars formed in some secondary process.

Theorists of triggered or sequential star formation are under-represented by Nomura et al. (1998) on low mass stars and Scalo & Chappell (1999) on more massive ones with strong winds.

8.7. Star Clusters

Like wine, they are either red (globular) or white (open). Unlike wine, they typically do not improve with age (de la Fuente Marcos 1998, on the faint-star remnants of old, open ones). If you would like to pour a glass of Mosel or Chianti before continuing this section, we will wait for you.

8.7.1. Open Clusters and Star Associations

The distance to the Hyades is still a rung on some ladders leading to the far reaches of the universe. It was 46.6 pc this year, according to Narayanan & Gould (1999), who derived a statistical parallax from *Hipparcos* data for 43 members. *Hipparcos* distance moduli for 18 other clusters (Robichon et al. 1999) differ from ground-based determinations by up to 0.2 mag, but the average is zero.

There are no young, open clusters less than 6 kpc from the Galactic center according to Dzigvashvili et al. (1998). We were surprised, but did not instantly think of a counter-example.

Different ways of measuring cluster ages yield different numbers (Basri & Martin 1999; Barrado y Navascuez et al. 1999). Both were looking at young clusters, and both found that lithium depletion makes clusters look older than other methods. No open cluster is older than 8–9 Gyr (Carraro et al. 1999). The youngest is presumably zero, or 0 ± 10^7 yr, if you allow for dense cores in giant molecular clouds. But the nearest young one of the sort called a T association is now advertised as surrounding TW Hya (Webb et al. 1999; Lowrance et al. 1999; Low et al. 1999; Jayawardhana et al. 1999, 1999a). Jensen et al. (1998), outside the index year, disagreed. Mamajek et al. (1999) have put in a bid for a young cluster of *ROSAT* sources far from any molecular cloud and centered around Eta Cha as a competitor.

Some open clusters contain Be stars (Maeder et al. 1999, more of them in metal-poor clusters), Delta Scuti stars (Li & Michel 1999), radio stars (Clark et al. 1998, both thermal and non-thermal) clump stars (Keenan & Barnbaum 1999), and Herbig Ae/Be stars (Testi et al. 1999). In fact all Be's of this sort still have clusters around them, though most of the Ae's do not, with a mass cut near 10–20 $M_\odot$ (Testi et al. 1999).

Clusters are born with mass segregation in place (Bosch et al. 1999, on 30 Dor), but aging clusters do experience recognizable dynamical evolution. The binaries may sink to the center (Gim et al. 1998) and produce horizontal branch blue stragglers). Later, stars depart and become merely parts of an associated moving group (Odenkirchen et al. 1998 on Coma Berenices). The final stage is called a star stream. The idea goes back to Proctor (1869), but in recent years has been largely associated with the name of Olin J. Eggen (e.g., Eggen 1998 and references therein). *Hipparcos* data have confirmed that many of these really do consist of stars at the same distance and with the same space motion (Chereul et al. 1998; de Bruijne 1999; Hoogerwerf & Aguilar 1999; Asiain et al. 1999). But they can also consist of stars with very different ages (Chereul et al. 1999), and the author who has experienced the wider range of ages still finds this puzzling.

Given initial mass segregation and the virial theorem, the direction of evolution of the stellar content of clusters is always in the direction of losing small, faint ones. Effects of this are seen many places (Sagar & Griffiths 1998; von Hippel & Sarajedini 1999; Hawley et al. 1999). Stellar collisions can even remove some little ones by merging them into more massive stars (Portegies Zwart et al. 1999, a simulation that begins with no primordial binaries in its initial conditions), Simultaneously, of course, the more massive stars are sequentially dying, and we suppose that a terminal 10^{10} year old cluster should consist exclusively of 0.9 $M_\odot$ K dwarfs and 0.6 $M_\odot$ white dwarfs. No candidates for this phase were reported during the year.

Questions of the correlations and evolution of stellar rotation, magnetic fields, and activity are particularly appropriate tasks for cluster astronomers. We caught a couple dozen papers supporting the standard correlation of fast rotation (either from youth or synchronicity in a close binary system) plus convection = strong field and lots of activity. Guenther & Ball (1999) is a random sample. Micela et al. (1999) provide evidence that the process can saturate with deep convection zones (etc.). Dupree et al. (1999) heat their coronae (or rather those of the stars in M67) with both acoustic and magnetohydrodynamic energy, and Cuntz et al. (1999) do the same for chromospheres.

Binary open clusters are common in the Large Magellanic Cloud (Leon et al. 1999, not a new result) and not unknown in the Milky Way (Subramaniam & Sagar 1999).

8.7.2. Globular Clusters

The globulars have a certain number of things in common with open clusters. The mass segregation of their stars is a birth defect (Peikov & Rusen 1999). They contain variable stars, though not all of the same sorts. M55, for instance, has just revealed the first RR Lyraes anywhere with non-radial pulsation (Olech et al. 1999). Most globulars have blue stragglers, probably not all made the same way (Sills & Bailyn 1999 on M3). They contain chemically peculiar stars (Caloi 1999a). And they can be destroyed, though with greater difficulty than open clusters and associations. The Milky Way, for instance, now has only about half the number it started with (Vesperini 1998), and the dynamical processes are such that almost any initial distribution of cluster masses would have evolved to the present log-normal one. Internal and external processes both contribute to disruption and can leave quite complicated correlations of kinematics and stellar populations (Dinescu et al. 1999).

Since nothing lives forever, it must also be the case that globular clusters formed. The powers that be are not, however, making them any more, at least in our Galaxy (contrary to the open cluster case). One of the longest-bearded questions in this territory is whether clusters now being formed elsewhere will look like globulars 10 Gyr down the river of time. We noticed a dozen or so papers. None took an "all or nothing" approach. But several pointed to some candidates whose masses (of little stars) seem to put them in the running (Sternberg 1998; Schweizer & Seitzer 1998), while others found some previously advertised candidates for young globular clusters were really something else (Ryder & Knappen 1999; Chandar et al. 1999a).

Globular clusters come with an assortment of initial mass functions or stellar luminosity distributions (Piotto & Zoccali 1999), and even if you allow for effects of stellar and dynamic evolution it is not clear whether the ranges are the same as for open clusters. They also have a range of chemical compositions, definitely different from the open cluster range. The assortment of correlations between abundances of CNO and other elements is exceedingly complex, and assignment of various anomalies to various processes is by no means complete (Cohen 1999; Ivans et al. 1999).

Stellar populations in globular clusters are unique in some ways. The cataclysmic binaries in NGC 6397 (all four of them, and this is a record) are not like the field sort and may arise from blue stragglers (Edmonds et al. 1999). Globulars have far more than their fair share of binary pulsars and X-ray binaries (though only the sort with neutron stars and low-mass companions; Davies & Hansen 1998). Another thing in very short supply is gas. After many years of debate on why, Smith (1999) has put forward the interesting suggestion that most stellar winds are fast enough that the gas just flows on through, instead of remaining in the clusters.

Globular clusters were once advertised as differing from open ones in having few or no binary stars, This is no longer thought to be the case (Rubenstein & Bailyn 1999). Binaries should not, however, be blamed for effects that are really due to sloppy photometry (Walker 1999).

Finally, there is the Oosterhoff dichotomy (Oosterhoff 1944). The approximate idea is that, if you measure periods of all the RR Lyrae stars in all the clusters, then the medians or means fall mostly into two bins. Lee & Carney (1999) say unambiguously that the difference is in age. Type II clusters were formed in protogalaxies, are older, and have the brighter stars. The Type I's date from mergers that assembled the Milky Way and have the fainter RR Lyraes (not what we would have guessed). Clement & Shelton (1999) reject composition differences as the cause in favor of an evolutionary explanation which is, however, not as transparent as that offered by Lee & Carney.

8.8. Binary Stars

A bunch of old double (or even duplicitous) issues arose again and reminded us of things we have said and unsaid many times before.

Frequency of binaries. More than 50% of Cepheids are, according to Szabados & Pont (1998). All of the W UMa stars are, of course, but they in turn add up to one star in every 130 in Baade's window (Rucinski 1998; data by OGLE), a denominator that has dropped monotonically with time (Ap94, § 9.6). Among the Trapezium region stars, binaries with $a = 132–264$ AU are about as common as in the much older solar neighborhood (Simon et al. 1999), but over the larger region of the Orion Nebula cluster, where you might expect 135 of 894 stars to be binaries with $a = 1000–5000$ AU, if they were like the solar neighborhood (Duquennoy & Mayor 1991), Scally et al. (1999) find none. Duchene et al. (1999) report that the fraction of stars that are in bound pairs is smaller in more dense regions, and this could be the effect either of binary destruction or of initial conditions (data on IC 348). Binaries in clusters would seem to probe which is which, so we go there next.

Binaries in clusters (and, since you know it is going to be horned in somewhere, the distribution of binary system mass ratios). According to Kahler (1999), 60%–70% of Pleiades are in binaries. This is at least equal to the field value, implying that the fate of the Pleiades is to fall apart into an underdense region). Their distribution of M_2/M_1 is bimodal, with a peak at $M_2/M_1 = 1$ and a rise toward values less than 0.3–0.5. Elson et al. (1998) reported an open cluster in the LMC that has a larger fraction of binaries (35%) in its core than at the edges (20%), opposite to the Duchene et al. (1999) correlation. It sounds like mass segregation, which in turn could also be primordial or evolutionary. This same cluster has lots of binaries with $M_2/M_1 >$ 0.7, and this is not just a selection effect.

We take heed of the warning of Hurley & Tout (1998) that using only an HR diagram to determine the percentage of binaries and their mass ratios (from distances above the main sequence) can lead you astray into the bimodal camp because of color effects, at least for stellar masses larger than 3 $M_\odot$.

Fortunately, Abt & Willmarth (1999) made use of radial velocity data to examine binary populations in clusters of different ages. They find that as clusters get older (from Orion to Praesepe and Coma) the fraction of pairs with M_2/M_1 larger than 0.5 increases from none to 43%. The distribution of periods does not change significantly, while the total fraction of binaries increases a bit. They suspect that you will need three-body interactions, captures, and disruptions to account for all the evolutionary changes.

Dynamical issues. That binary systems circularize with time has been both seen and expected ever since the death of Sir James Jeans (who got it backwards). The circularization process, based on the shortest period systems that have eccentric orbits in systems of different ages, remains more efficient than standard theory (10–12 days at 10^{10} years, versus 3–5 days expected; Goodman & Dickson 1999). Rotation and orbit periods also synchronize, and some advertised non-synchronous Algols turn out to have been a misinterpretation of the effects of gas spun up by accretion (Glazunova 1999). Whether rotation and orbit axes should align with time we are not sure, but at least the process has somewhere to start, since, according to Terquem et al. (1999) young stellar binaries are frequently non-coplanar.

Changes in binary periods are mostly what you would expect (Simon 1999a) or not (Chochol et al. 1998) as the case may be. But also what you might expect ranges from magnetic cycles in the components and third stars to mass transfer and secular evolution of the components (in, approximately, order of increasing time scale).

Mass transfer and loss. Loss through the second Lagrangian point is most efficient for the smallest ratios M_2/M_1 (Pribulla 1999), which is not particularly surprising. Less expected were the particular regimes of stellar and binary properties that manage to avoid a common envelope binary phase, including donors in the Hertzsprung gas (King & Begelman 1999), when you might think they were most anxious to expand. If a CEB phase has happened recently, however, you will notice it (Ferguson et al. 1999) on BE UMa, an sdO or DAO nucleus of a planetary nebula, where the M dwarf companion has not yet come into thermal equilibrium, following a CEB phase that ended only 10^4 years ago.

And, in the oldies but goodies department, we note that it was Wyse (1934) who first interpreted the changes through eclipses in the line profiles of Algol systems as indicating that there is a disk around the star we would now call the accretor.

Formation and evolution. Some calculations of star formation make binaries (Vanhala & Cameron 1998; Boss 1999) and some do not (Bate 1998). Pre-main-sequence stars in pairs have disks like everybody else (Koresko 1998, on HK Tau B, where the disk is not co-planar with the orbit). Even the first stage of mass transfer changes the surface composition of the accretor (Marks & Sarna 1998). And some of the stranger outcomes of binary evolution include (*a*) systems where the measured masses differ significantly from those implied by evolutionary tracks (Penny et al. 1999), (*b*) massive contact systems in M31 of a sort not found in the Milky Way (Rucinski 1999), (*c*) single-line spectroscopic systems with the orbit parameters of barium stars, but no barium, hence presumably no late-life transfer from a pre-WD to the star we now see (Zacs et al. 1999), (*d*) a binary pulsar whose companion is a white dwarf that was initially the more massive star in the system (van Kerkwijk & Kulkarni 1999), and (*e*) black hole X-ray binaries from a scenario in which kick velocities are important in inducing mergers (Bethe & Brown 1999). This last takes us naturally to § 8.9.

8.9. Neutron Stars, Black Holes, and X-Ray Binaries

Once again, some oft-asked questions are provided with, at most, one right answer each, since, if two papers are cited, they disagree.

Formation rates. Bethe & Brown (1998) make binaries with both neutron star and black hole components, but the rate for BH + NS is 10^{-4} per year in the Milky Way and that for NS + NS only 10^{-5} per year. This is odd because it was the middle of the night. Oops, sorry, wrong poem. This is odd because the observed pulsar inventory includes a few double neutron stars, and, so far, none with companion masses in the black hole range. At most 0.1% of Galactic neutron stars are made by accretion-induced collapse of white dwarfs. Otherwise we would be drowning in *r*-process material (Fryer et al. 1999). And no, we don't really believe that any *r*-process product is liquid at STP.

Neutron star pulsation. It is still not clear which modes exist or how to classify them (Lockitch & Friedman 1999). None have been seen, either.

Kick velocities of neutron stars as they form. Yes, for a subset of the single pulsars (Cordes & Chernoff 1998) and ones at least as large for neutron stars that remain bound in binaries (Sutantyo 1999). Indeed very few Wolf-Rayet stars now have neutron star companions (Vanbeveren et al. 1998), though this must at least partly reflect some coupling between retention of a neutron star and whether the secondary looks O-ish or WR-ish.

Quasi-periodic oscillations, up to kHz, in fluxes from low-mass and other X-ray binaries. The main contenders for official explanation seem to be beats between neutron star rotation and Keplerian orbits around the NSs and the general-relativistic effect called Lense-Thirring precession or dragging of inertial frames. Miller (1999) concludes that the latter is less likely than you thought and Psaltis et al. (1999) conclude that the former is less likely than you thought. Incidentally, the lead authors were then at the same institution. We indexed 18 other papers on the topic.

Spin-up and -down of neutron star rotation in XRBs. Normally they are supposed to spin up during episodes of rapid accretion and down in between. 4U 1636−57 did the opposite, with its 580 Hz period spinning down during an X-ray burst (Strohmayer 1999 and 11 other relevant papers).

Pulsar radiation mechanisms. We understand why they pulse, but not why they radiate (at such low frequencies), said S. M. Faber long ago. This must still be true, or there would not have been 15+ papers addressing the subject this year. The more popular scenarios include production of electron-positron pairs in the electric potential induced by the spinning magnetic dipole as the pulsar rotates. If so, the PSR 2144−3933, with $P = 8.51$ sec, $B = 2 \times 10^{12}$ G, and a spin-down age of 2×10^8 yr turned off when dinosaurs still roamed the Earth (doing very little radio astronomy; Young et al. 1999a, Wolszczan 1999). We won't attempt to tabulate all the alternatives, some of which are less weird than others, but merely note that recycled (millisecond) and normal pulsars probably do different things (Kijak & Gil 1998, and many others).

Pulsar glitch mechanisms. Somehow, formation of nuclear rods along vortex lines (Larson & Link 1999) sounds less main-stream, if better aligned, than crustal effects (Sedrakian & Cordes 1999). Even star quakes were riding again (Link et al. 1998), along with half a dozen or so other riderless horses and horseless riders in the field.

Neutron star masses and the nuclear equation of state. A case can be made that the masses of all (radio) pulsar neutron stars in binary systems are the same (Thorsett & Chakrabarty 1999) at $1.35 \pm 0.04\ M_\odot$, while some of the X-ray binary ones are bigger (Orosz & Kuulkers 1999). Accretion produces at least a qualitatively plausible explanation. But no interpretation makes sense to us of the apparent statement by Cheng & Zhang (1998) that the equations of state are not all the same.

Temporal evolution of NS temperatures, rotation rates, and magnetic fields. About 30 relevant papers during the year left a strong impression that these all get smaller with time if left to their own devices, but that they usually are not, especially in binary systems. In many scenarios, two or all three of the temporal trends are associated. Here we note (*a*) all the multipoles of the magnetic field should die away together, so that pulsar pulse shapes won't evolve (Mitra et al. 1999), which seems to be true, (*b*) initial spin-down to periods of 10–20 msec can happen really fast and in a way such that the energy is not all left hanging around in relativistic particles in the Crab Nebula (Andersson et al. 1999), though Atoyan (1999) would just as soon it was, (*c*) no observation of the surface temperature of any neutron star really requires weird, accelerated cooling from quark nuggets or whatever (Yakovlev et al. 1999), though admittedly there are not an enormous number of measured temperatures or even upper limits, and (*d*) when it comes to making pulsars, more magnetic field is not necessarily better (Baring & Harding 1998).

Special friends. The orbit period of X Per has been revised upward from the classic 580 days to 20–30 years (Smith & Roche 1999). Geminga has become the first pulsar to announce its magnetic field out of two mouths—spin-down rate and frequencies of spectral emission features. If the latter are ion cyclotron lines, then both say $(3–5) \times 10^{11}$ G (Jacchia et al. 1999). GRO J1655−40 (one of the Galactic "superluminal" sources) has a black hole with its ratio of angular momentum to mass at most 0.7 of the maximum allowed by general relativity (Sobczak et al. 1999). This may be generically true of black holes in accreting X-ray sources (Gammie 1999). CM Cam is a sub-luminal ($v \approx 0.15c$) optical counterpart to the X-ray transient XTE J0421+560 (Ueda et al. 1998). The name does not mean that the counterpart is a previously-known variable star, but only that the process of assigning variable star names has recently been much accelerated (compare CM Tau = SN 1054).

8½. PLUS ÇA CHANGE, PLUS C'EST LA MÊME CHOSE

Yes, of course the universe has changed with time. The evidence lies about in heaps and piles of microwave photons, helium atoms, distant quasars, and Hubble Deep Field images. And dozens of papers during the year called specific attention to ways in which $z = 1$ or 2 or 3 or 6 differs from $z = 0$ in everything from chemical composition and the average mass of stars to the largest scale structure that existed. Here, perversely, we focus on a smaller number of papers reporting conditions rather less different from here and now than you might have expected. Examples are gathered around a few, fuzzily-edged subtopics. Collectively, they perhaps carry a message to modelers of galaxies and larger scale structures: form early, and form often. Both the section heading and the contents are intended to remind you slightly of the Fellini film of the same number.

Metal abundances and dust. The Fe/Mg ratio in QSO emission lines was much the same at $z = 0.8$, 3.35, and 4.47, meaning that something (whether Type Ia supernovae or not) started making lots of iron early, or that the universe was more than 1 Gyr old at $z = 4.47$ (Thompson et al. 1999). Dust had begun to form by a redshift of 5 (Armus et al. 1998, based on finding $A_v = 0.5$ mag for a $z = 5.34$ galaxy); most of it was in place by $z = 1$–3 (Barger et al. 1999); and the dust distribution in high redshift active galaxies is much like that in low redshift, less active, ones (Zheng & Fang 1998).

Individual galaxies and their components. There should be lots of low-surface-brightness galaxies at large redshift (O'Neil et al. 1998), which is rather difficult to check, but the general run of higher surface brightnesses hasn't changed much since $z = 1$ (Simard et al. 1999; Evstigneeva & Reshetnikov 1999). The star formation rate was much the same at $z = 3$ and $z = 4$ in galaxies whose redshifts come from the spectral break at the Lyman limit (Steidel et al. 1999). The brightest infrared bright galaxies (*IRAS* galaxies, at low redshift) have about the same maximum luminosity at $z = 1.8$ to 4.7 as here and now, though you must look to 350 μm to find this out (Benford et al. 1999). Closer to home, the range of ultraviolet excesses in giant elliptical galaxies at $z = 0.375$ is the same as for $z = 0$ (Brown et al. 1998a).

Looking down inside some galaxies, we find that the phases and structure of their interstellar media are much the same at $z = 3.5$ as at present (Rauch et al. 1999a, Churchill & Charlton 1999). The relationship between galaxies and the gas clouds responsible for lines of the Lyman alpha forest remains confused, but the average line width doesn't change much with redshift from $z = 3$ down to $z = 1$ (Savaglio et al. 1999), though you might have expected it to on the basis of available sources of heating and ionization. And the blazar 1428+4213 at $z = 4.72$ (probably a record) tells us that at least some really big black holes formed by $z = 5$ (Fabian et al. 1999).

X-ray-emitting clusters of galaxies. At least two with redshifts a bit in excess of 0.8 were described during the year (Gioia et al. 1999; Tran et al. 1999). They are, of necessity, bright enough to see at that distance, but their temperatures and velocity dispersions (masses) are what you find for the same luminosities today. There are population samples of X-ray clusters from $z = 0.6$ downward (Rizza et al. 1998; De Grandi et al. 1999; Ebeling et al. 1998). Apart from a slight deficit of the highest luminosities at the largest redshifts, there has been very little evolution of the population. The clusters have arguably formed over a very wide range of redshift (Fujita & Takahara 1999).

Large scale structures. Such things should happen late in a universe where the primary assembly method is bottom up, by hierarchical gravitational clustering. Rosati et al. (1999) have reported the first supercluster at $z > 1$. It consists of a pair of *ROSAT* clusters at $z = 1.26$, with a comoving separation of 2.4 h^{-1} Mpc (for $q = \frac{1}{2}$, and more for smaller q). A structure at $z = 0.546$ probably has at least three clusters (Ostrander et al. 1998). And there seems to be a megaparsec-long filament of gas that emits Lyman alpha stretching past a QSO at $z = 2.5$ (Campos et al. 1999).

Finally, if you prefer not to think of Fellini, feel free to conclude that the author with more pairs of shoes simply miscounted.

9. PLEASE, SIR, MAY I HAVE SOME MORE?

Are there many or few of these astronomical entities, or is the number just what you might have expected but the inventory interesting for some other reason? You be the judge as we count down from many to few and on to zero. Lovers of Dickens will already be aware that one bowl of porridge is not enough.

9.1. Many

700,000 galaxies so far in the ESO imaging survey (Benoist et al. 1999). This is, they point out, far fewer than SDSS is finding, but they say the images are better.

12,925 galaxies now with good redshifts and coordinates in the CfA survey (Falco et al. 1999).

3030 equations (Liperovsky et al. 1999). "Have your computer call my computer, and we'll do mid-day input."

2338 H II regions in M33 (Hodge et al. 1999). The peak of the luminosity function is at 6×10^{35} erg/sec, but there are, of course, sizable selection effects.

2249 catalogued white dwarfs with spectral types (McCook & Sion 1999). The paper includes 21 references to papers by J. L. Greenstein, and even a couple by the present darker author.

1800 Cepheids in the Large Magellanic Cloud (Alcock et al. 1999b), another MACHO by-product, naturally.

1655 flat-spectrum, compact radio sources (Augusto et al. 1998). Most have core-jet structure on the scales probed by MERLIN or the VLBA (very long baseline array).

1637 BATSE gamma-ray bursts through the end of 1996 August (Paciesas et al. 1999). One of the things we love about the archival literature is that it's so archaic.

1459 eclipsing binaries in the Small Magellanic Cloud (Udalski et al. 1998). This is one of many spin-offs from the OGLE search for gravitational microlensing, and, believe it or not, they show ALL the light curves.

1252 *ROSAT* detections among the Gliese Third Catalogue of nearby stars (Hunsch et al. 1999). This is about one-third of the stars.

1121 spectra of type A stars (Wilhelm et al. 1999). Of them there are 416 main sequence stars, 140 Am/Ap stars, and about 10% are unclassifiable.

708 elliptical galaxies with accurate values for the velocity dispersion and the strength of the Mg II lines (Wegner et al. 1999).

659 S and S0 galaxies whose profiles have been fit by an assortment of standard functions (Baggett et al. 1998). Most are some combination of de Vaucouleurs power laws and truncated (exponential) disks.

478 Herbig-Haro objects (Ziener & Eisloffel 1999), but what we really want to know is who is in charge of assigning the numbers. Not Haro, we are pretty sure. Occasionally one ought to be removed from the inventory, when it turns out not to be a separate entity (Rodríguez et al. 1998, on HH 110, which is just the grazing collision of HH 273 with a nearby cloud core).

309 catalogued gamma-ray sources (Macomb & Gehrels 1999). Many are unidentified, and the process of finding optical counterparts is a slow one (Combi et al. 1999).

271 EGRET sources (Esposito et al. 1999). Again, lots are unidentified.

258 solar flares seen in 1980–1989 at energies above 300 keV with *SMM* (Vestrand et al. 1999)

156 supernovae to the end of 1998 (IAU Circ. 7082) and 153 to the end of 1999 September (IAU Circ. 7268). To put this into perspective, remember that SN 1987A received its designation because it was the first caught that year ... on 23 February. The real rate probably does not vary.

140 stages of stellar evolution, according to Liu et al. (1999). This is probably a lower limit, since they are using the 140th evolutionary phase of a 1.9 $M_\odot$ star to interpret a Delta Scuti variable. In truth, we suspect they meant the 140th time step on an evolutionary track, but this is still a lot for a star that hasn't yet managed to get off the main sequence.

139 Wolf-Rayet galaxies (Schaefer et al. 1999).

134 Wolf-Rayet stars in the LMC (Breysacher et al. 1999). The similarity of these two numbers strikes us as strange and wondrous.

35 new galaxies in a deep *ISO* survey of a 0.1 square degree patch of sky (Lopez-Corredoira 1999). Only two were previously known, and the galaxies greatly outnumbered the 13 stars in the same field.

31 radio-emitting X-ray binaries (Marti et al. 1998).

26 type L dwarfs, most found by 2MASS (Kirkpatrick et al. 1999). These are important enough to be discussed elsewhere (§ 6.2).

23 pulsating Lamba Boo stars (Martinez et al. 1998).

19 QSOs seen by the far-UV detector on *ROSAT* (Edelson et al. 1999).

15 pulsating sdB stars (Koen et al. 1999).

15 QSO's at redshifts exceeding 3.6, found in the commissioning phase of the Sloan Digital Sky Survey by 89 authors (6 leads and 83 alphabetized; Fan et al. 1999b). This amounts to 0.17 QSO/author and is very close to what was expected.

14 entities needed to model the infrared-to-millimeter spectrum (including molecules) of Gl 2591 (van der Tak et al. 1999). Under the general heading of "too many parameters spoil the soup" we noted also the non-uniqueness of synthetic stellar populations (Pelat 1998) and the many components that can be invoked to match various data concerning the cosmic microwave background radiation (Pierpaoli & Bonometto 1999).

12 massive contact binaries (Lorenz et al. 1999), with some cut on the quality of the data.

12 carbon-rich post-AGB stars (Hrivnak & Kwok 1999; Garcia-Lario et al. 1999)

11 QSOs associated with NGC 1068 (Burbidge 1999). The redshift range is 0.26 to 2.8, while NGC 1068 is a nearby Seyfert galaxy, about which conventional things were also written during the year (Lumsden et al. 1999a).

11 Lyman-limit components in a range of 200 km/sec around $z = 1.9$ (Kohler et al. 1999). The range of carbon abundances suggests "halo" and "disk" contributions, that is, a bunch of clouds in a single galaxy, but the ionizing radiation is harder than would be provided by stars.

10.4 the ratio by number of helium to hydrogen in M17, according to the radio recombination lines (Tsileva & Krasnov 1999). This is a perfectly reasonable number, but later in the same paper, they describe it as $y = 10.4\% \pm 1\%$, which sounds like fractional abundance rather than ratio.

10 new compact infrared sources (from an IRTF survey) helping to power the Orion BN/KL nebular complex (Gezari et al. 1998). IRTF is the infrared telescope facility and we think BN/KL is Becklin & Neugebauer, Kleinmann & Low. The total luminosity of the region is about 10^5 $L_\odot$. The Circinus complex is powered by at least four such sources (Dobashi et al. 1998).

10 radio components in the gravitationally lensed active galaxy B1933+503 (Sykes et al. 1998).

10 millisecond pulsars detected as X-ray sources (Becker & Trumper 1999).

9 parameters in a model for spectra of gamma-ray bursters, where the dominant process is synchrotron emission from a dirty fireball (Dermer et al. 1999).

6 O I–III stars with non-radial pulsation in the form of prograde *p*-modes (De Jong 1999). The author predicts that many or most O stars have these, but they have gone unseen because you need very precise line profiles with very high signal-to-noise ratios to see the amplitudes of 5–7 km/sec. The periods are 3–12 hours, and the pulsation is probably not the cause of cyclic wind variability in these stars.

6 different systems in which the names are given of candidates for class zero (collapsing) YSOs (Choi et al. 1999a).

Four of the 8 candidates stand up. The very existence of YSOs still in the collapse phase was an issue until quite recently. Of the 1999 examples, we note only the condensations within MC 27 in Taurus, which are apparently within 10^3–10^4 years of forming initial proto-stellar cores (Onishi et al. 1999).

5 candidates for X-ray emitting, isolated neutron stars with no optical identification (Schwope et al. 1999).

A fifth cornerstone mission in the European Space Agency's Horizon 2000 program (Straitzys 1999). The mission is *Gaia*, a follow-on to *Hipparcos*, and thinking that things should have only four corners is obviously shear prejudice, derived from living in a rectangular coordinate system, and would be firmly denied at the Pentagon.

Four are (*a*) the two-phase instabilities (Hunter et al. 1998), (*b*) the asynchronous polars (cataclysmic variables with strongly magnetized white dwarfs whose rotation period is not equal to the orbit period; Ramsey et al. 1999). The resulting beat periods are days to weeks and some of the systems probably oscillate around synchronicity (Campbell & Schwope 1999), (*c*) the stars that really belong to an apparent quintet near the Galactic center; the fifth is an interloping Wolf-Rayet star along the line of sight (Glass et al. 1999, and one thinks immediately of Stefan's quintet and various other extragalactic examples), (*d*) separate but interacting causes of variability in T Tauri stars (Smith et al. 1999b; they are magnetic flares, variable accretion, rotation, and obscuration by circumstellar material), (*e*) components to fit the X-ray spectrum from four pulsars (Cheng & Zhang 1999, including Geminga but not the Crab pulsar), (*f*) the maximum number of cyclotron frequencies found in the spectrum of a single X-ray binary (Santangelo et al. 1999). The system is X0115+63; the data come from *BeppoSAX*; and the frequencies are in the ratios 1:1.9:2.8:3.9. The Fourth Astronomical Olympiad was held in September at the Crimean Astrophysical Observatory; we don't know who won.

3.8 and 2.4, the slopes of the mass-luminosity relation as newly calibrated on stars in close binary systems (Gorda & Svechnikov 1999).

9.2. Twosies and Threesies

Does anybody but the California-born author remember when these words meant how you picked up the jacks in a game that was played only in the spring?

Threes, thirds, and triples can sometimes complete the definition of a new class of systems or events, or sometimes just confuse the previous one. Here is a subset of the 15+ that appeared during the year.

◦ Three candidates for triple-barred spirals, though only two, NGC 4371 and 2681, meet the criteria (Erwin & Sparks 1999).

◦ A triple galaxy interaction for Mrk 8 (Esteban & Mendez 1999).

◦ A third integral of motion for galaxies with central black holes (Sridhar & Touma 1999; Emsellem et al. 1999); the first two are total energy and angular momentum about some one axis, and you must ask Ehrenfest to explain what the third one is.

◦ The third reported equivalent of a Lyman alpha forest in the corresponding line of He II, shortward of the 304 Å rest wavelength (Anderson et al. 1999); and you see the same clouds as in Lyman alpha.

◦ Three stars with spectral type WN9ha (Bohannan & Crowther 1999); we looked several times through the paper for a definition of the type.

◦ A three-ring galaxy, IC 4214 (Buta et al. 1999); it does not seem to be the third example.

◦ The third-shortest period of apsidal motion in a close binary, 36.3 years for V606 Cen (Wolf et al. 1999).

◦ Three kinds of coronae belonging to accretion disks around black holes (Esin 1999).

Among the third types and mechanisms, one was added (a third type of flare in M dwarfs, between impulsive and long duration; Katsova et al. 1999), and one was deleted (the "intermediate line region" between broad and narrow in active galaxies, which Sulentic & Marziani 1999 have decided isn't needed after all to match data).

The two's are divided into confirmations, repetitions, second types and classes, second parameters, and "both please." The distinctions among the last three categories are rather subtle, meaning we are not quite sure we understand them ourselves, so if you don't find your favorite "me too" under one, try the others.

A second example, discovery of, has confirmed the existence of (*a*) radio galaxies with megaparsec-scale structure but spectra nevertheless peaked in the GHz range (Schoenmakers et al. 1999), (*b*) globular clusters containing dust (Hopwood et al. 1998, presenting SCUBA data on NGC 6356, with about 0.01 $M_\odot$ of dust; the first was 47 Tuc), (*c*) white dwarfs in orbit with B-type main sequence stars (Burleigh & Barstow 1999, on θ Hya; the first was HR 2875 reported last year), (*d*) SCUBA-selected galaxies at high redshift with lots of CO and very high star formation rates (Frayer et al. 1999). It is a lot like the first one, and both have star formation rates near 10^3 $M_\odot$ per year and telephone numbers with prefix SMM J, (*e*) Be star with an $m = 1$ prograde arm in its disk (Berio et al. 1999 on Gamma Cas; the first was Zeta Tau).

Repetitions. Three classic surveys or catalogues have been repeated after long enough that you may have forgotten the first. They are

(*a*) The Second Cambridge Pulsar Survey (Shrauner et al. 1998). It found no new objects. The first survey was by Bell, Hewish, and others in 1967, and the objects they found were very new indeed.

(*b*) The Second Cape Photographic Catalogue (Zacharias et al. 1999). We suspect the first (non-photographic) one may have come from the younger Herschel.

(*c*) The Second Byurakan Survey (Stepanain et al. 1999). Judging by what was found (white dwarfs, QSOs, and such), it must have been a survey for blue objects.

Second types, classes, and mechanisms. Layden et al. (1999) have reported a new class of long-period (0.5–0.9 day) RR Lyrae stars in NGC 6441 and a few other metal-rich globular clusters. This is a second class only if you have grouped the shorter period RRa, b, c, and d's together. The authors suggest upward mixing of core helium as the cause; this could also be a "second parameter" for HR diagrams of globular clusters. The second commonest molecule in protostellar ices is CH_3OH (Dartois et al. 1999).

Two catalogues of compact groups of galaxies have been published, associated with the names of Hickson and Shakhbaizian. Statistically, at least, the two contain rather different types of compact groups (Tovmassian et al. 1999). They differ in morphology (chains vs. spheres) and in ratio of infrared to optical brightness.

The QSO SBS 1542+541 has absorbing gas with two different levels of ionization (Telfer et al. 1998), but that is OK, since it has to do two jobs, making the broad absorption lines and acting as the "warm absorber," a topic that we had decided was going to get only one bite this year. It was supposed to have been Petitjean & Srianand (1999).

The phrase "second parameter" is most often associated with globular clusters that have different horizontal branch morphologies despite having the same metal abundance (the first parameter). You have just met helium mixing. Another usual candidate is age, which either is (Stetson et al. 1999) or is not (Borissova et al. 1999) a or the second parameter. The upturn into the UV of continuous spectra of E and S0 galaxies is not a unique function of their metallicity (Ohl et al. 1998). In so far as generic horizontal branch stars are responsible for this upturn, we seem to have another "second parameter," which could be the same as one of the globular cluster ones.

"*Both please*," is the situation where competing mechanisms have been suggested to account for something, often in a somewhat confrontational way, but the data are easier to account for if you allowed some of each (like honey and condensed milk on your bread, or lemon and milk in your tea, depending on whether you associate the phrase with Pooh or Richard Feynman). Examples include (*a*) two ways of making blue stragglers in globular clusters, via binary interactions and mixing in single stars (Sills & Bailyn 1999), (*b*) two sources of the gas in nebulae surrounding Wolf-Rayet stars, recent ejecta and left-over O-star material (Pasquali et al. 1999), (*c*) two ways of polarizing the radiation of Seyfert 2 galaxies, with scattering and dichroism (Lumsden et al. 1999a), and (*d*) [Listen up, guys, this is probably the important one] formation of galaxies, where both monolithic collapse and hierarchical assemblage may be involved (Kepner 1999).

9.3. One Alone

Quite a number of papers described items that are of the general form, "Lincoln's Doctor's Dog's First Book of Jewish Recipes." Some effort has been made to limit this list (which is intended to run monotonically outward from your desk to the distant universe) to examples requiring not more than two or three qualifiers to make it unique. Insert "the first" in front of every item.

Issue of an archival journal with a cD attached to its cover. The content is a video of the 1996 June 14 Spanish bollide (Docobo & Ceplecha 1999).

Two-body solution on a non-flat space-time (Mann et al. 1999). It uses lineal gravity, however, not general relativity.

Data from LIGO (Allen et al. 1999). They didn't see anything, which is why it is listed as close to home. The limit corresponds to at most one neutron star binary pair spiraling together every half hour in the Milky Way.

Extensive astronomical data from a liquid mirror telescope (Cabanac et al. 1998).

Extra-solar granulation (Kjeldsen et al. 1999) on Alpha Cen A. They perhaps also recorded *p*-mode oscillations.

Stellar flare discovered by amateur astronomers (Overbeek & Toldo 1999). The star is the soft gamma repeater 1900+14, and you will perhaps recall having heard that solar flares were discovered in 1859 (on September 1) by the English amateurs Carrington and Hodgson.

Astrometric parallaxes for cataclysmic variables (Harrison et al. 1999 on SS Aur, U Gem, and SS Cyg, and McArthur et al. 1999 on RW Tri). All were done with the Fine Guidance Sensor on *HST*, and all are between 100 and 300 pc from us.

Recovery of a nova in X-rays. Balman & Ogelman (1999) have detected thermal emission from shocked knots and clumps in the nebula surrounding GK Per (Nova Persei 1901).

Angularly resolved interacting binary. Beta Cen, with $a \approx 0\farcs05$ (Robertson et al. 1999). The *Hipparcos* data are, understandably, a mess.

Thermal emission from OH and H_2O in a supernova remnant (Reach & Rho 1998). It is 3C 301.

A bunch of things in X-ray binaries whose relative distances we have not tried to figure out: Quasi-periodic oscillations lasting for as long as a year (Ubertini et al. 1999); CV-style disk instability in an X-ray binary with a neutron star (Shahbaz et al. 1998a); high mass X-ray binaries where the non-compact component looks like a Be star (Clark et al. 1999).

And then, moving gradually outside the Milky Way:

Cepheid in the LMC that pulsates only in the second overtone (Alcock et al. 1999c). If you start out to describe this as "first second overtone Cepheid" we will get confused.

Extragalactic circumstellar olivine, also in the LMC (Voors et al. 1999).

Blue stragglers in an extragalactic (SMC) globular cluster (Shara et al. 1998).

HR diagram for a globular cluster in an elliptical galaxy (Reid & Gizis 1998). The host is NGC 5128 (Cen A), and the cluster is more metal deficient than the field stars at the same radius.

Starburst triggered by a galaxy encountering intergalactic stuff (Xu et al. 1999). The galaxy is, however, the intruder into Stefan's quintet, which doesn't seem entirely fair.

Detection of CO in a Fanaroff-Riley type II radio galaxy (Evans et al. 1999). It is 3C 293.

EGRET detection of the TeV blazar Mrk 501 (Kataoka et al. 1999).

X-ray selected, optically-obscured AGN that is a large classical double radio source (Barcons et al. 1998). It also has a good recipe for kosher paella.

Submillimeter detection of the Sunyaev-Zeldovich effect (Lamarre et al. 1998).

Luminous objects in the universe (Yamada & Nishi 1998). They were about $10^8\ M_\odot$. This is not the first time this mass scale has been suggested as a good starting point for hierarchical merging, but the present authors appear to have reached it by a more difficult method than usual.

9.4. All or Nothing

Every triangle we examined this year had precisely three sides, and none of the pentagons as few as four. The items here seemed, at the time they appeared, rather more surprising.

All planetary nebulae probably have comet-like clumps like those in the Helix (Redman & Dyson 1999). The numbers are 600 to 60,000 clumps per PN. All QSOs, at least all those in the Palomar-Green sample, vary at least 10% in a year or so (Giveon et al. 1999).

None of 9 DAO type white dwarfs showed pulsation (Handler 1998). It is expected, with driving from the hydrogen-burning shell (the epsilon mechanism, in contrast to the kappa mechanism, where stellar pulsation is driven by atmospheric opacity).

Ortiz et al. (1999) saw no optical flare on the Moon caused by meteorite impacts. They looked for only 4.3 hours, and distinguished astronomers of the past have occasionally reported something of the sort.

No failed galaxies or masses of neutral hydrogen larger than $10^8\ h^{-2}\ \mathrm{M}_\odot$ turned up in a survey of the CVn region by Kraan-Korteweg et al. (1999). Zero also is the number of persuasive examples of gravitationally lensed pairs of gamma-ray bursts (Komberg et al. 1999).

W. P. Bidelman was quoted as saying that there are no normal A0 stars (Woolf & Lambert 1999). We had a letter from him just as this was going to typewriter, on Dan Popper and the fastest star in the galaxy (next section). The letter was signed "Billy," but, cowardice intact from Ap98 (Acknowledgments), we wrote back our thanks to Prof. Bidelman.

More discussed than seen is the category of stars being disrupted and swallowed by large, galactic-center black holes. The rate should be about 1% of the supernova rate (Ulmer 1999 and several other papers), implying 1.5 in the 1999 data base. If so, it (or it-and-a-half) has not been recognized.

A classic "existence" question is Type II quasars and QSOs, meaning edge-on, obscured ones, recognizable only in scattered or polarized light. Kay et al. (1999) have withdrawn a particular *IRAS* source from the candidate list. But the clearest statement on the subject came from Oksuga & Umemura (1999), who remark that a true QSO nucleus is so much brighter than a Seyfert one that it is really rather difficult to hide it completely. We are much reminded of the "boner" answer to "Where are elephants found?" which is, "Please teacher, elephants are such large animals that they hardly ever get lost."

A few more "existence" topics include

(*a*) Population III (zero metallicity) stars. Norman (1999) and Nakamura & Umemura (1999) have revived the suggestion that the answer should be to "when" rather than "where." That is, all were very massive and died a long time ago, though the two suggested mass ranges don't overlap.

(*b*) Periodicity in the redshift distribution of QSOs. No, just selection effects says Basu (1999, of interest because he used to take the opposite point of view).

(*c*) Cosmic chirality. We still think the answer is no, but in addition several processes can produce "false positives," including disalignment of polarization and structure by gravitational lensing of distant sources (Surpri & Harari 1999), changes with position along a jet of magnetic field direction (Gabuzda et al. 1999), and changes of jet orientations on time scales that are likely to intervene between gathering of data at different wavelengths (Gomez et al. 1999).

(*d*) Real physical disks that act like the alpha-disks (viscosity proportional to pressure) of model quasars, X-ray binaries, and so forth (Balbus & Papaloizou 1999).

(*e*) Red obscured quasars and QSOs whose loss from various samples would lead to misunderstanding of AGN birth and evolution. Obscuration, yes (Kim & Elvis 1999). Big deal, no (Masci & Webster 1999).

10. EXTREMA

Like Pearl Mesta, "the hostess with the mostest on the ball," we continue to seek out ever more exotic tidbits. This year, they are ordered from far (cosmology, active galaxies) to near (Earth, people).

10.1. Far and Few

The largest redshift published for a galaxy was 6.68 (Chen et al. 1999). It was found in a STIS slitless spectrum survey in parallel mode use of *HST*, and beats out 5.34 and 5.60 in the Hubble Deep Field (Fernandez-Soto et al. 1999). The record for a radio galaxy is 5.19 (van Breugel 1999), and the galaxy is a sizable one for its age. The most distant supernova has $z = 1.9$ (IAU Circ. 7228). The most distant radio halo is perhaps that of Abell 1300 at $z = 0.31$ (Reid et al. 1999a).

The deepest dip in the microwave background caused by gas in an X-ray cluster (Sunyaev-Zeldovich effect) belongs to RX J1347−1145 (Pointecouteau et al. 1999) The y parameter is 1.27×10^{-3}. 1E 0657−56 is not, after all, the hottest X-ray cluster at 17 keV. It is merely cozy at 11–12 keV, when corrections for absorption are made correctly (Yaqoob 1999). MS 1124.7+2007 does, however, seem to be the darkest cluster, with $M/L = 640 \pm 140$, winning the Oscar for performance as a gravitational lens (Fischer 1999).

The closest of generally distant classes are (*a*) cluster that strongly lenses a background galaxy, Abell 2124 at $z = 0.066$ (Blakeslee & Metzger 1999; the lensee is at 0.57), (*b*) damped Lyman alpha line of lowest redshift in optical data, $z = 1160$ km/sec for Ton 1480 seen through NGC 4203 (Miller et al. 1999), and (*c*) ditto with radio data, $z = 0.91$, an early result from the Giant Meter Radio Telescope (Chengalur & Kanekar 1999). The gas has a spin temperature of 1000 K.

10.2. Active Galaxies

The fastest (or at least most accelerated) AGN flare afflicted PHL 1092, whose X-ray luminosity rose at 5×10^{42} erg/sec^2 (Brandt et al. 1999). Apart from anything else, we like the units! The closest spaced pair of quasars (as opposed to lensed images) has $z = 0.58$, a separation of $2\farcs3$ on the sky, and a ratio of radio luminosities of 40 or more (Brotherton et al. 1999).

For some reason, the faintest Seyfert galaxy (which is also the closest to us) attracted considerable attention under the name either NGC 4395 or 4359 (Moran et al. 1999). Mercifully, all the sources agreed that it has a black hole mass of a few $\times\ 10^5\ M_\odot$ and optical and X-ray variability in weeks to months, like brighter Seyferts (Kraemer et al. 1999; Lira et al. 1999), so called, of course, because the first one, NGC 1068, was recognized by Fath (1909). Stevens et al. (1999) suggest NGC 1365 as a close runner-up. It has a proper Seyfert 2 nucleus, but with luminosity only about 5% that of NGC 1068, and most of what we see is starburst activity.

A QSO with broad absorption lines and $L = 5 \times 10^{15}\ L_\odot$ (for some combination of H and q) is the brightest of its type, at $z = 3.87$ (Lewis et al. 1998). About half the luminosity is infrared, but reprocessing by dust does not provide a good fit to the spectrum.

10.3. Passive, or at Least Less Active, Galaxies

The most vigorous star formation is $10^3\ M_\odot$/yr for the SCUBA galaxy 02399−0136 (Frayer et al. 1998). A galaxy pair UGC 2866+2855 is advertised as potentially the next star burst (Huttermeister et al. 1999). No date was given for the event. We were briefly inclined to doubt the statement of Colbert et al. (1999) that M82 is the brightest infrared galaxy in the sky, but then realized they meant "apparent brightness," not absolute.

The X-ray cluster with the smallest amount of cool gas is Abell 1030, based on the absence of ultraviolet absorption lines in the spectrum of its central QSO. The limit for $T < 10^6$ K is, at most, 10^{-8} of the total gas required to produce the X-rays (Koekemoer et al. 1998).

Some Shakhbazian compact groups are prolate systems with axial ratios of 0.3. Oleak et al. (1998) describe them as the most prolate systems known in the universe. Tovmassian et al. (1998a), however, enter a caveat having to do with incompleteness of the sample.

Lo et al. (1999) have examined galaxies from $z = 0.8$ to 1.06 (not all of them, of course) and conclude that none has a molecular gas mass greater than $10^{11}\ M_\odot$, and, therefore, that the largest possible total mass of a galaxy is $10^{12}\ M_\odot$. They attribute the limit to more massive gas masses having cooling times longer than the age of the universe (not a new argument).

10.4. Star Clusters and Interstellar Stuff

Gallagher & Smith (1999) propose a star cluster with $L = (3–4) \times 10^8\ L_\odot$ ($M_v = -16.5$) and age ≈60 Myr as the brightest known. It is in M82. An *HST* image of a small part of M33 found 60 star clusters (some mix of open and globular, arm, inter-arm, and halo populations) implying a total of 690 for the whole galaxy. Eleven were previously known, and we had indexed this under "most missing clusters" (Chandar et al. 1999).

The 305 blue stragglers in M80 constitute the largest and most concentrated population so far found in a globular cluster (Ferraro et al. 1999). The cluster has no obvious excess of primordial (lower main sequence) binaries, and the authors attribute the plethora to collisions as the cluster "attempts to undergo core collapse."

NGC 6881 is a candidate for the messiest planetary nebula (Guerrero & Manchado 1998). It has a ring collimating two sets of lobes 23° apart and a precessing jet. Su et al. (1998) point out that such complexity is likely to be fairly common, but lost in two-dimensional projections. We see no way to avoid this loss from current observatory sites.

Herbig-Haro objects 80 and 81 have the highest ionization level (that is, strongest [O III]) to date (Heathcote et el. 1998). If it is shock ionization, then the velocity is in excess of 600 km/sec, so they may also be the fastest.

10.5. Cosmic Rays

The highest energies pushed above 10^{20} eV a few years ago, presenting, as we saw last year, a major problem if they are known particles and need to travel through more than 60 Mpc of intergalactic photons (Stecker & Salamon 1999). Fighting at the front are both observers and theorists. On the issue of isotropy, Bird et al. (1999) report that particles between 2×10^{18} and 2×10^{19} eV are slightly concentrated toward the Galactic plane, but they see no supergalactic or other concentrations at higher energy. In contrast, Gorchakov & Kharchenko (1999) perceive an anisotropy at 10^{18}–10^{19} eV suggestive of sources in the Galactic halo. Takeda et al. (1999) have a somewhat larger Akino data base of 581 events exceeding 10^{19} eV. The total ensemble is isotropic on the parts of the sky surveyed, but there are a few triple and pair events, several of which lie close to the Galactic plane, but there is also one near the Cygnus Loop or PSR 2053+36. In a pattern whose statistical significance is difficult to evaluate, Farrars & Biermann (1998) found that the directions to the five events they knew about exceeding 10^{20} eV are all directions to radio loud quasars with redshifts of 0.3 to 2.2 (that is, distances very much in excess of 60 Mpc).

Among the theorists, you can find Medina-Tanco (1999) getting to 5×10^{19} eV in local galaxies, Gallant & Achterberg (1999) associating the highest energies seen with gamma-ray bursts made by merging pairs of neutron stars, and Boldt & Ghosh (1999) concluding that even QSOs will give up around 10^{21} eV. At least three papers favored some sort of neutrino collision mechanism. If both supplies are isotropic, then you presumably get isotropic cosmic-ray events (Yoshida et al. 1998). But if there is a local supply and streams coming from quasars and such (Gelmini & Kusenko 1999; Fargion et al. 1999), then you get one or more of the reported anisotropies.

The most imaginative hypothesis comes from Kifune (1999) who suggests that the speed of light differs from *c* at very high energies and processes are no longer Lorentz invariant, so that particles can reach us from much further away.

And, while we're at it, a few other cosmic ray issues, at the "one each" level. The ultimate reservoir is not the chromospheres of M dwarfs exhibiting a first ionization potential (FIP) effect, because lead comes out wrong (Westphal et al. 1998). Ordinary interstellar gas and grains plus some fresh supernova ejecta are a better bet. Higdon et al. (1998) pick out the centers of superbubbles blown by supernovae as the right place.

Confinement time in the Galaxy is 18 Myr at an average density of 0.28 atoms/cm^3, based on the production of ^{36}Cl while the CRs are on their way to us (Connell et al. 1998). Consideration of ^{36}Cl and other secondaries like ^{10}Be, ^{26}Al, and ^{14}C, lead Ptuskin & Soutoul (1998) to conclude that the corresponding confinement volume extends 5 kpc into the halo on either side of the Galactic disk. Yet another discussion of similar data yields the conclusion that CRs must be reaccelerated from time to time while they remain in the Milky Way (Strong & Moskalenko 1998).

10.6. Compact Stars and Their Binaries

The largest possible central density for a white dwarf is (5.5–6.0) $\times 10^9$ g/cm^3 (Bravo & Garcia-Senz 1999), beyond which it quickly becomes a neutron star. The largest mass ever expelled in a nova explosion is $4 \times 10^{-4}\ M_\odot$ from QU Vul, if the infrared flux is free-free emission (Shin et al. 1998). The white dwarf GD 229 may have a magnetic field in the range 4–9 GG, which would be a record with considerable margin. 0.7 to 1.6 GG is also possible, if the spectral features are due to He I and He II (Jones et al. 1999a). Some additional WD properties appear in § 6.5.

The strangest neutron stars are those made of strange quark matter (e.g., Xu et al. 1999a, who suggest that PSR 0943+10 may be an example, and at least three other papers earlier in the year). Benvenuto & Lugone (1999) have in mind the object left by SN 1987A, with the transmogrification from ordinary neutron matter responsible for structure in the associated neutrino burst. If you use such a strange star as the core of a red giant (instead of the normal neutron star that lives inside a Thorne-Żytkow object, also not yet identified in the real world), then you shorten the lifetime by a factor 500 (Hajyan 1998).

What is stranger than strange quark stars? Well, maybe stars made of Higgs particles (Dehnen & Gensheimer 1998) or Skyrmions (Ouyed & Butler 1999) or WIMPS (Zakharov 1999). Additional variants are possible if general relativity is not the right theory of gravity. Grigorian et al. (1998) have in mind their own scalar-tensor theory, which is only distantly related to Jordan, Brans-Dicke, Rosen, and other bimetric theories. Robertson (1999) has in mind a metric due to Yilmaz (1958), which postpones horizon formation until the central compact mass is above 10 $M_\odot$, in case this strikes you as desirable.

Geminga is the faintest radio pulsar (Kuz'min & Losovskii 1999), assuming you believe it has been seen at all. If not, then many other non-detections are competitive. Gilfanov et al. (1998) conclude that the details of behavior of the bursting pulsar require a magnetic field less than a few $\times 10^7$ G. Again, lots of zeros are in the running for weakest neutron star magnetic field. If the 2.7 hour period in the X-ray light curve of HMXRB 2S 0114+650 (optical counterpart a B1 Ia) is the rotation period of the neutron star, then it is the longest known (Corbet et al. 1999).

The oldest radio supernova, or, alternatively, one of the youngest radio supernova remnants, is the tentative recovery of SN 1923A in M83 (Eck et al. 1998). Six supernovae have been catalogued in this galaxy, which is also a record. The oldest X-ray SN (or again youngest SNR) is 1979C in M100, recovered by *ROSAT* in 1994 (Immler & Pietsch 1998). And similarly in the optical we find SN 1980K at 17 years (Fesen et al. 1999). It looks a lot like the youngest previously known SNRs, which should not require a fundamental rethinking of the evolutionary relationships.

The brightest X-ray binary is perhaps the off-center variable source in the radio galaxy NGC 1365, at more than 2×10^{40} erg/sec (Komossa & Schulz 1998), unless it is somehow associated with the active nucleus. The least well localized XRB would seem to be the one Cusumano et al. (1998) describe as the *BeppoSAX* source 1SAX J0544.1−710 and the *ASCA* source J0448−70.4.

In the realm of XRB astrometry, we find the most accurate stellar parallax to date for something outside the solar neighborhood. It is $0''.00036 \pm 0''.00004$ for Sco X-1, using VLBA data for the corresponding radio source (Bradshaw et al. 1999). The total space velocity is about 240 km/sec, so Sco X-1 is not part of Gould's belt (we never thought it was), and, at a distance of 2.8 kpc, its luminosity must sometimes reach the Eddington limit.

10.7. Stars

This section was originally "normal stars," but clearly if they were completely normal, they wouldn't be extrema. The ordering is, as best we could figure out, from early evolutionary phases to later ones.

The youngest YSO? Well, probably not, but IRAM 04191+1522 (which is still dissociating H_2) and L1544 Tau, whose inflow is still in progress, must be strong candidates (Andre et al. 1999; Williams et al. 1999a).

The X-ray brightest YSO is probably EC 95 in Serpens at 10^{33} erg/sec, with flares to twice that (Preibisch 1998). Ones that exceed 10^{31} erg/sec are actually fairly common (Carkner et al. 1998). Wolf 630 was described as having the brightest X-ray flares of any single main sequence star, also reaching 10^{33} erg/sec (Kellett & Tsikoudi 1999). The star has at least three other names (and RS CVn slightly evolved binaries get much brighter).

The latest spectral type recorded for a flare star is M9.5, with the second example identified in the 2MASS survey by Liebert et al. (1999). Still cooler stars of types L and T are less active. The bluest star in the Hyades with a chromosphere (or at least with the D3 line of He I at 5876 Å) has $B-V = 0.26$. This limit varies among clusters and between clusters and the field (Rachford 1998). Hotter stars, with radiative envelopes, are deprived of the opportunity for this sort of activity.

The fastest known runaway B star is HIP 60350, with $V = 417$ km/sec in the local standard of rest. It was probably expelled from the Galactic plane 20 Myr ago, by the action of a star cluster, not a supernova, and is apparently single (Maitzen et al. 1998). It cannot compete with the later type star CoD $-20°2277$, with a radial velocity of 500 km/sec (Popper 1943). It also has a large (Luyten) proper motion. And no, we haven't checked the *Hipparcos* catalogue for this star, just in case the speed has been downsized while the author born in 1943 was busy growing up (and out). Incidentally, Bidelman (1999, private communication) records the day on which that velocity was measured as the only occasion he ever saw Popper really excited.

The most precisely determined stellar masses appear to be 1.326 ± 0.016 and 0.819 ± 0.009 $M_\odot$ for the components of ι Peg, which is both a visual and a double line spectroscopic binary (Boden et el. 1999). The optical orbit was resolved with the Palomar Test Bed Interferometer. The spectral types are F5 V and G8 V, and the conspicuous lithium lines, temperatures, and radii suggest a very young system. RR Caeli cannot compete for accuracy, but the 0.095 for its secondary is the smallest star mass with a direct, spectroscopic-eclipsing binary determination (Bruch 1999). The spectrum is later than M6.

The largest stellar masses still come from combining models with observed colors and luminosities. New evolutionary tracks from Ishii et al. (1999) indicate that the zero-age main sequence turns back toward the red for stars of 100–200 $M_\odot$. Thus there are none bluer than $\log T = 4.6$ for solar composition and OPAL opacities, and you might get the mistaken impression that you were seeing only evolved stars among the most massive ones and that the ZAMS stars were still hidden in placental dust (indeed we think that is the general impression).

The patchiest stellar magnetic field may be that of HD 119419, which has a dipole of 17 kG, a dominant quadrupole of 48 kG, and patches ranging between 50 and a few kG (Bagnuolo & Landolfi 1999).

HDE 31685 is, as it were, more P Cygnish than P Cygni, with a ratio of wind momentum to photon momentum that is 30 times higher. It will lose 20 $M_\odot$ in the next 10^5 years if nothing intervenes (Hillier et al. 1998), like exhaustion. De Koter et al. (1998) have been modeling such stars. They conclude that both mass loss rates and initial masses are a good deal larger than you would have supposed, owing to earlier neglect of multiple photon momentum transfer.

Along the same lines, Figer et al. (1998) suggest that the initial mass of the star powering the "Pistol Nebula" near the Galactic center may have been 200–250 $M_\odot$. It is possibly the brightest luminous blue variable known. A peak absolute visual magnitude near $M_v = -10$ appears to characterize the stars of NGC 2403 along with a number of other galaxies, including M81, M33, and M31 (Sholukhova et al. 1998), but the bluer galaxies have a larger *fraction* of really massive stars. No persuasive twins of SS 433 appear in any of them, say the authors.

On the theoretical side, Stothers & Chin (1999) conclude that all stars with initial masses in excess of 100 $M_\odot$ converge quickly via mass loss to a common evolutionary track. The size of the convective core adjusts continuously to go with the new mass, unlike the case of donor stars in close binaries, which typically continue on as if they were still fully clothed.

The oldest star spot? V711 Tau (an RS CVn binary) has a polar one that has been around for at least 11 years (Vogt et al. 1999). V410 Tau, with a spot at a constant longitude for 12 years beats it out just a bit (Grankin 1999).

The spottiest star seems to be HD 12545, whose light amplitude is 0.63 mag, because a cool spot $12 \times 20\ R_\odot$ on one side is augmented by a warm spot on the other side (Strassmeier 1999). It is a K0 III RS CVn system, and only the weak-lined T Tauri star, V410, just mentioned, has a larger light amplitude due to spots (Strassmeier et al. 1999a). There are, however, apparently a number of stars whose spots cover 10% to as much as 68% of their surfaces (Alekseev 1998; Alekseev & Bondar 1998). Their light amplitudes are much smaller.

The brightest possible red giants and asymptotic giant branch stars are not to be found in Baade's window or elsewhere near the core of our Galaxy. It is at least possible that close interactions strip extended atmospheres and truncate evolution to larger luminosities, but actual two-body capture formation of binaries is unlikely (Glass et al. 1999a; Bailey & Davies 1999).

Some extreme periods: The fastest RR Lyrae is V2109 Cygni at 0.18605 day. It is probably a second overtone RR*c* (Kiss et al. 1999) and was a *Hipparcos* discovery. The shortest known precession period for a nucleus of a planetary nebula is 500 years for NGC 6884. This is dependent on the author's interpretation of the double-S shape of the nebula as the product of a precessing bipolar jet outflow (Miranda et al. 1999). Monnier et al. (1999) report that the M supergiant VY CMa has a rotation period between 1200 and 2400 years, based on the distribution of circumstellar dust. The period could, alternatively, be that of a binary companion to the visible star. The evidence for many supergiants would, of course, be consistent with rotation periods of infinity.

10.8. Earth, Earthlings, and Their Activities

The most precise age for a meteorite is 4.566 Gyr for Piplia Kalan. It is probably a fragment of Vesta (Srinivasan et al. 1999).

The first photosynthesis (by cyanobacteria) can now be traced back to 2.5 Gyr (Summons et al. 1999). People came later, but, by 1999 October, are supposed to have crossed the 6 billion mark ("the most people ever"). Perhaps this is why there seem to have been more astronomy- and astronomer-connected oddities than ever before (see also §§ 13 and 11).

The highest observatory still attached to the ground is probably Cerro Toco at 5200 m, from which high-order moments of the cosmic microwave background are being studied (Torbet et al. 1999). Without the qualification, *Pioneer* and *Voyager* probes will contest the title.

The fastest computer in the world was briefly (1995–1997) GRAPE-4, developed in Japan to study formation of large scale structure in the universe, black hole mergers, and other complex dynamical processes (Hut & Makino 1999).

The oldest astronomical photographic plates archived were taken in 1879-1889 by Ostwald Lohse (Tsvetkov et al. 1999). They are housed in Potsdam.

The oldest stellar evolution code presumably belonged to one of the Schwarzschilds, but the oldest still in use (Staritsin 1999) appears to be Paczynski (1970). The paper deals with rotational broadening of the upper main sequence.

The oldest author publishing in 1999 was, by a wide margin, Carl O. Lampland (fourth author of Hollis et al. 1999). This is, however, slightly unfair, since he (like "Mozart by the time he was my age") had been dead for 47 years. The paper addresses motions in the jet of the symbiotic CV R Aqr, which, retrospectively, can be traced back to images from 1921 exposed by Lampland.

"Have you read the last Cepheid distance paper by the *HST* Key Project Team?" Well, they had planned to look at 18 galaxies, and Paper XVIII has appeared (Macri et al. 1999), but we make no absolute promises. Meanwhile, what is probably the last of the ApJ papers originally handled by the more editorial author has finally appeared (Burles et al. 1999).

On the theoretical front, the largest possible (calculated) gravitational redshift increases from $z = 1.95$ to $z = 3$ if you are prepared to permit anisotropic pressure (Bondi 1999). Probably the least efficient process published during the year is the acceleration of particles in young stellar objects by Alfvén waves, for which Mao (1999) finds a conversion efficiency of 10^{-11}. Admittedly, we can think of processes for which the efficiency must be even lower, like ionization of hydrogen from its ground state by radio waves.

There are two candidates for "most difficult method." Dravins et al. (1999) describe what is necessary to get a radial velocity measurement from purely astrometric data. You need the change in parallax, the change in proper motion, and the size of the moving cluster (Hyades or Pleiades for instance) being used. The idea appears to have been put forward by Seeliger (1901). We would have guessed Bessell or a colleague whose initials are…

Second contender is a way of measuring distances to globular clusters from the gravitational radiation emitted by close binary systems in them (Benacquista 1999). Another process invoking very extreme conditions is "magnetic lensing" by neutron stars (Shaviv et al. 1999). It becomes comparable with gravitational lensing at $B \approx 5 \times 10^{14}$ G and dominates above 5×10^{16} G.

And the following also scored high on the weirdmeter, though we would be hard pressed to select a single winner.

—The blueshifted galaxies reported by Basu (1998), with $\Delta\lambda/\lambda = 0.1$–$0.3$.

—The extraction of energy for active galactic nuclei from nuclear decay induced by magnetic monopoles (Peng & Chou 1998).

—The production of the Great Red Spot on Jupiter, and the differential rotation of latitude zones on all the Jovian planets, by electric currents driven by magnetic torques between ring systems (Kundt & Luttgens 1998).

—The following radiation mechanisms: (*a*) inverse Compton scattering by protons in AGN jets to make the gamma rays (Huang et al. 1999a), (*b*) "inverse" or proton bremsstrahlung as the source of Galactic diffuse gamma rays (Pohl 1998, who concludes that this one is not a major player), and (*c*) a positron cyclotron maser for pulsars (Ma et al. 1998).

—The book reviewed by its own author, A. V. Ambartsumian (1998). He thinks quite highly of it and of the subject matter, V. A. Ambartsumian. Indeed the influence of the late elder Ambartsumian on research at his home institution is palpable. We noted at least 8 papers emphasizing ideas of expansion from very dense, singular, or nonstandard conditions to account for stellar, galactic, and cosmological phenomena as now seen. All appeared in *Astrofizica*, and we note only the last, Sahakyan & Grigoryan (1998) on neutron stars as the first stage of stellar evolution.

11. EPONYMS ON PARADE

From Abell to Zipf, here are people who have lent their names (not all of them willingly) to things astronomers find useful. Feel free to drop in at any letter that appeals to you, or to return to trying to come up with something that will, in due course, be named for you. Where the authors' names are not given, the eponymous author has not been explicitly cited. The second part of the section deals with acronyms, strange words, and other twists and turns of literary style.

11.1. But He Who Robs Me of My Fair Name

Abell (George Ogden) identified a whole catalogue full of clusters of galaxies (also one of planetary nebulae). Its reliability has been at issue for many years. Recent words say there is about a 75% overlap between Abell and *ROSAT* clusters (De Grandi et al. 1999a). Richness tends to be overestimated beyond $z = 0.1$ (Yee & Lopez-Cruz 1999), and this is mostly a matter of contamination (David et al. 1999).

Alfvén (Hannes) had waves and turbulence that continue to be important in the interstellar medium (ApJ, 517, 226; ApJ, 523, 315).

Arrhenius (Svante) calculated the global warming to be expected from increasing CO_2 in the atmosphere (*Nature* for 1899 June 22 issue). He got it just about right (*Nature*, 399, 735), and "Arrhenius effect" might sound less threatening than global warming!

Barnett relaxation (and we are already giving up on first names) affects the way interstellar grains align in magnetic fields (ApJ, 520, L67, and MNRAS, 305, 615).

Blandford-Znajek mechanism extracts energy from magnetized, rotating black holes. Its existence and importance have been debated often over the years. This year, Armitage et al. (1999) found contexts where it dominates energy from accretion, and Livio et al. (1999) did not.

Blazhko had an effect seen in the light curves of RR Lyrae stars; it is an extra period that is not just rotation of the star (AJ, 118, 572).

Bondi accretion, or sometimes Bondi-Hoyle or Bondi-Hoyle-Lyttleton, seems to be an upper limit to what actually happens if the accretor is rotating or magnetized (Toropin et al. 1999) or the situation not spherically symmetric (Mastrodemos & Morris 1999).

Brans-Dicke gravitation has both scalar and tensor parts and was originally proposed to make the universe more Machian (and the Sun less spherical). It also makes white dwarfs cool faster (Benvenuto et al. 1999).

Burgers had both a vector and an equation. A modified form of the latter is useful for calculating the formation of large scale structure in the universe (MNRAS, 307, 376).

Butcher-Oemler effect is the blueness of galaxies in rich clusters at even moderate redshifts compared to local ones. X-ray data may or may not have anything to say about why it happens (Henriksen et al. 1999).

Cederblad 201 (title of ApJ, 515, 649) is a reflection nebula.

Cerenkov is rarely cited for his radiation, perhaps because of the difficulty in spelling his name if you don't own a ˇ (hacek) . In any case, a modified, helical version may be relevant for the insides of neutron stars (AN, 320, 141).

Chandrasekhar is credited with several things every year, this time dynamical friction (roughly, the slowing of a body by the gravitational force of its wake as it moves though some system). There are contexts where his version is a good approximation (Velazquez & White 1999) and contexts where it is not (Ostriker 1999).

Cowling (1934) had an anti-dynamo theorem which attracted an anti-anti-dynamo paper last year (Lorrain & Koutchmy 1998). Moss & Brandenburg (1999) have now provided an anti-anti-anti-dynamo paper. That is, Cowling was right, and a stationary axisymmetric MHD dynamo cannot be driven by strictly axisymmetric motions.

Drake's equation estimated the probability of radio-communicating civilizations in the Galaxy. He also did the first, 1959, search, examining Epsilon Eridani and Tau Ceti. He didn't find anything. A&A, 348, 133 suggests that Epsilon Eri would be a good target for a search, but does not mention that one has already been done.

Evershed effect is the outward horizontal flow of gas in the penumbrae of sunspots. It is still not well understood (A&A, 348, L37).

Faraday (Michael) flourished long enough ago that his effects are bound to have suffered from incorporation (not exactly that his ne'er do well nephew stole his best jacket and wore it without credit, but that sort of thing). Anyhow, they continue to depolarize radio sources in active galaxies (ApJ, 519, 108).

Fath galaxies are more often called Seyfert galaxies, but Shields (1999) correctly records that Fath found the first one in 1909. It was NGC 1068.

Fermi (Enrico) acceleration is something we always thought should happen only to charged particles, but apparently photons can suffer too (Binette et al. 1998).

Ferraro's (1937) theorem deals with angular rotation along magnetic field lines and is important for that wondrous region of the Sun called the tachocline (MacGregor & Charbonneau 1999). The latter name came from Spiegel & Zahn (1992), and one might have preferred them to name it for themselves (Zahn-Spiegel surface somehow sounds better than Spiegel-Zahn).

Feynman's (Richard Phillips) (1948) path integral method has been applied to the motion of cosmic rays in the heliosphere by Zhang (1999a), who, however, loses brownie points by noting that it is also a Markov process, without citation.

Fowler (William Alfred), Caughlan (Georgeanne), and Zimmerman (Barbara) perhaps never quite made it as an eponym, but they kept track for so many years of the rates of nuclear reactions important for astrophysics that we wondered whether anyone else would ever take up the task. Arnould et al. (1999) have done so. The project is called NACRE (another word for Mother of Pearl, or Hester Prynn).

Fredholm had an integral of interest in the structure of thin stellar disks (MNRAS, 300, 83).

Gleisberg's solar cycle is the one with period of 90–110 years. Pipin (1999) has modeled it using variable differential rotation.

Hall (whose middle name is well known to be Quantum) usually has an effect. But he also has a conductivity, which is important to how interstellar cloud cores collapse against magnetic support (MNRAS, 303, 239). His first name? Oh, that is Fractional.

Hatchett-McCray effect has been discussed by someone else (Georgiev et al. 1999). It has to do with periodicities of high ionization lines in binary systems, we think (Hatchett & McCray 1977).

Hessian of the Hamiltonian is H_{ik}, a fairly complex assortment of partial derivatives (MNRAS, 307, 878). One could not reasonably expect a citation of Hamilton. "Hess(e?) we are not so sure about.

Hill of the "double averaged Hill problem" was not cited in the paper (Astron. Lett., 25, 544) that uses the phrase in its title. In accordance with biblical principles, one supposes that a double-averaged Hill is a Valley.

Hubble-Sandage variables were not so-called by Hubble (1929). In fact King et al. (1998) concur in calling them luminous blue variables, whose inventory in M31 they roughly double.

Jose in colloquial American English used to be the second half of the phrase beginning, "No way." But the list of authors of A&A, 339, 638 is much more impressive.

Kaluza-Klein is a way of including a scalar field in your theory of gravity, different from Brans-Dicke (above). AN, 320, 97 suggests such a field as a form of (or alternative to) dark matter.

Kartunen-Loeve transforms are more or less the same thing as principal component analysis (though the latter sounds much more modern somehow). They go back to 1947 and 1948 and are duly cited by Connolly & Szalay (1999), who apply them to noisy galaxy spectra (can't you just hear the spirals hissing and the ellipticals rumbling?).

Knudsen number is somehow important for making whistlers in places besides the Earth's atmosphere, but it is neither defined nor cited in MNRAS, 301, 49.

Kurucz model (stellar) atmospheres are the world standard for a variety of applications. Thus we thought it a bit odd of the authors of AJ, 118, 527 to thank someone else for sending them the models without citing the originator. Incidentally, the less-well-spelled author once found herself appointed to a six-year term on an editorial board as the result of pointing out to an editor-in-chief that his publication had misspelled Bob's last name throughout the text of an article announcing his receipt of the Van Biesbroeck Award for service to the astronomical community.

Landau (Lev) damping is the alternative to Chandrasekhar-type dynamical friction when a stellar system responds to an external perturber (Nelson & Tremaine 1999). Hermitians, or rather anti-Hermitians, come into it too. Landau and Lagrange also appear as more relevant than Lindblad to a new class of spiral disk instability (MNRAS, 307, 1).

Marlot wavelets have been applied to trace the 11-year solar cycle back into the 1400s, using ^{10}Be in ice cores (A&A, 346, 131). Maunder of the minimum appears too, because the cycle continued through it, though with its period apparently lengthened to 20–25 years.

McIntyre of the McIntyre Bequest (Turk 1999). Only someone who has been involved in trying to sort out some similar well-meaning, but poorly executed, gift to a nonprofit society can appreciate this in all its full glory, but getting a driver's license in Massachusetts used to be rather similar. (You needed to pass a driving test, for which you needed a car, for which you needed insurance, which you needed a driver's license to get.)

Moreton waves appear in the title of ApJ, 510, 460 (and we pause mid-alphabet to remind you that if no author is given in our citation, you won't find the eponymous scholar cited in the paper at hand).

MyCn18 is Mayall (Margaret, not Nicholas) and Cannon (Annie Jump, 1940) discussed by Sahai et al. (1999). We could not have guessed otherwise. It is a planetary nebula.

Oosterhoff and his dichotomization of globular clusters have been discussed seriously in §8.7.2, but the less European author still wishes that someone would answer the question, "Of the various ways that Americans could mispronounce his name, which did he find least offensive?"

Peclet had a number (A&A, 348, 933). When it is small, it means that the time scale of motion in a radiative zone is small compared to the time scale of thermal diffusion.

Plaskett's map of the Milky Way, which is essentially the one we all still sketch in introductory courses, first appeared in Plaskett (1935).

Raman scattering appeared in at least five papers. Schmid et al. (1999), who have been thinking about the issues since 1989, apply it to the interpretation of features in the spectra of symbiotic stars, where one sees the direct emission of O VI at 1032 and 1038 Å, but also the scattered features at 6825 and 7082 Å.

Rankine and Hugoniot were cited by Truelove & McKee (1999), who are studying the evolution of early supernova ejecta to the Sedov-Taylor (also cited!) phase. The remnants of 1006, 1572, 1604, and whenever Cas A was made are probably at this stage.

Rayleigh and Taylor in reality were probably a lot less unstable than many of their contemporaries, though they themselves never had to live at the edge of an expanding supernova remnant, where their instability is likely to occur (ApJ, 519, L177).

Razin effect, in the context of pulsars, would suppress synchrotron emission only at very low magnetic field intensity, in which case there isn't much synchrotron anyhow (Fransson & Bjornsson 1998).

Ritter's approximation to the onset of stellar convective instability at $\Gamma_1 = 4/3$ is still pretty good (Stothers 1999a). The idea is now 120 years old, like Moses at his death.

Rossby waves that propagate inward from an entropy maximum at the edge of an accretion disk contribute to a new instability (ApJ, 513, 805).

Scott effect cannot be the entire explanation of the fact that the luminosity of the brightest star in a galaxy is correlated with the luminosity of the whole galaxy (Lee & Byun 1999). Or is it? Elizabeth Scott (1956) pointed out (in a cosmological context) that the bigger your sample, the more likely you are to catch an example of a very rare sort of beast, including the brightest.

Serendip, the Three Princes of, were supposed to have gone about making "fortunate discoveries by accident." These are not to be confused with fishing expeditions (except, perhaps, when You are the PI and They are the Reviewers, or conversely). Some examples from various massive searches currently in progress include: novae from supernova searches (IAU Circs. 7236, 7208); a nova in the EROS microlens data base (7239), and one from MACHO (7121); a lensed QSO in the OGLE microlensing survey (7240); a supernova from EROS (7092), after which it went after them on purpose (7136); an X-ray transient seen by OGLE (7105), and a couple of CV outbursts (7068, 7159); a comet in the Lick supernova search (7126) and one from the SDSS (7194). The nova found on images taken with Kodak Tech Pan film by Liller (7242) was clearly not an accidental discovery, just a very classic technology.

Shannon entropy (Cincotta et al. 1999) comes from a 1949 book by, curiously, Shannon & Weaver (1949).

Sobolev approximations are a way of modeling radiative transfer, not always well enough for the particular problems you happen to be interested in (Owocki & Puls 1999).

Stachel potentials may or may not describe the shapes of elliptical galaxies. It was already several years ago when the longer-eared author heard one colleague say to another roughly, "Can you remember the last time anyone seriously used a Stachel potential to describe an elliptical?" and received the answer, "Well, yes, actually, I did, last week." We are not sure whether either of the parties was one of the authors of Mathieu & Dejonghe (1999), but clearly they did, last year, if not last week.

Strehl, as in fraction of the available light that lands within the nominal diffraction circle of an optical system, was Karl, and the operative paper seems to have been Strehl (1902).

Strouhal's number, one of many that can be used to characterize convection, is much less than unity in star formation regions (Astron. Rep., 43, 805).

Taylor-Proudman balance is relevant to the latitude variations of solar differential rotation and convection (ApJ, 511, 945).

Weyl focusing and Ricci focusing might both apply to gravitational lensing, but in fact the shear (Weyl) part is normally negligible (MNRAS, 302, 801).

Wilson-Bappu effect (Olin & Vainu) is the correlation of emission line cores of strong absorption lines with stellar brightness. Wallerstein et al. (1999) report that *Hipparcos* parallax brightnesses are well predicted by Wilson-Bappu brightnesses over the range $M_V = +7$ to $+2$. For brighter stars, Reed (1998) reports a sort of anti W-B, in which stars with H-alpha emission are less likely to be supergiants than stars without.

Yarkovsky effect is distinguished from Poynting-Robertson by Vokrouhlicky & Farinella (1998). It seems, however, that the effect was first discovered by Ernst Opik (1951), who chose the name of a not-very-well known Russian engineer rather than his own (Vokrouhlicky 1998). Indeed it strikes us that, while Opik was first on a remarkably large number of astronomical playing fields, there doesn't seem to be an Opik effect, Opik equation, or Opik reaction (except, readers *d'un certain age* may remember, sometimes a fairly explosive reaction when others disagreed with him).

Yilmaz metric is shown explicitly by Robertson (1999). But to paraphrase Anne B. Underhill, you can write more metrics that aren't spaces than there are spaces that don't have metrics.

Zipf is, of course, best known for his fastener, or Zipfer, but he is also one of the honorees connected with the concept that, if you rank order something (frequency of words in text, numbers of citations to papers, numbers of genera having precisely n species, numbers of people with particular incomes, authors by the numbers of papers they publish in a fixed interval of time, and a good many other things), item N on your list is about $1/N$ as common or as good as the first one. Lotka (1926), Bradford, Pareto, Willis, and undoubtedly others also have laws, distributions, etc. of similar purport. The same pattern probably applies to the numbers of names carried by a particular law/effect/phenomenon. We would, therefore, like to declare that the distribution of eponymns obeys the Merton-Trimble-Krisciunas conjecture, thereby slightly bumping up the number of three's (Merton 1973).

11.2. Acronyms, Metonyms, and Catachreses

These are the words you love to hate, and the abbreviations made by stringing bits of them together.

NICE is a way of mapping extinction in a molecular cloud from the Near Infrared Color Excesses of stars seen through it (Alves et al. 1998). SHARC is a Submillimere High Angular Resolution Camera (Lis et al. 1998). In order to appreciate it fully, you have to remember that it is to a certain extent a rival of SCUBA. CABS (A&A, 337, 729) were originally recorded under the heading "stop that acronym," until we realized that we had never been very good at stopping cabs (in California, they are a product, which you order by telephone, not a process with which you interface on the street). CENBOL (MNRAS, 308, 201) you must figure out for yourself.

HAEBE (A&A, 346, 604, many places). It is easy to understand the temptation, since even we get just a little tired of writing "Herbig Ae/Be stars" ourselves (though not of crediting George Herbig, 1962). But it sounds like the potential cause of a case of the HAEBE-JAEBES. We asked the discoverer for advice on an alternative abbreviation or perhaps a prototype. He expressed immediately willingness to have them designated as just Ae/Be stars; but this invites confusion with emission line stars in later evolutionary phases. Work continues on this important issue.

And here are a good many words that you probably wouldn't have at any price.

- Albanian, meaning resident of Albany (AJ, 117, 3).
- Animals, assorted—the Kookabura (reference lost, but it was Australian), the W50 seashell (AJ, 116, 1846), the Pelican (Lang et al. 1999), and Mosquitoes (MNRAS, 307, 918) are not all the same sorts of beasts. The first three describe shapes of features in the sky (rather better than Crab describes NGC 1952); the last were killed in the preparation of the manuscript, according to the acknowledgments and without further explanation. While we are at it, here are some plants—the Cauliflower (AJ, 117, 1952, actually Eta Carinae) and the Upper Banana (ApJ, 503, L122).
- Antonym (Ap97, p. 241) is presumably the opposite of syninym.
- Astrosphere (Izmodenov et al. 1999) is perfectly reasonable by analogy with heliosphere, but still it sounds like it must be lined with Astroturf © and when cut in half would make two Astrodomes.
- Balnicity (ApJ, 505, L9, table) is not new. It means, roughly, like broad absorption lines or having them and applies to quasars.
- Cumulation (ApJ, 514, L47, title). It is indeed a dictionary word, but not separable from accumulation just from a dictionary definition.
- Dyadosphere (Preparata et al. 1998) in a black hole model of gamma-ray bursts, where the electromagnetic field is strong enough to make $e^{\pm}$ pairs, an idea to be found in Heisenberg & Euler (1930).
- Heteroscedastic (ApJ, 117, 1942, title) is the opposite of homoscedastic; and yes, they do define it.

◦ Maculation (MNRAS, 305, 966). It means starspots, not macular degeneration on the part of the observer.
◦ Phothospheric (A&A, 347, 973, several times in the discussion) is perhaps just a misprint, but where was Shpellcheck ©?
◦ WCFIELDS and WCField models mean wind compression and apply to Wolf-Rayet stars, though not ones of the subtype WC (Ignace et al. 1998). After all, anyone who dislikes accretion disks and Be stars can't be all bad.

11.3. The Right of Response

A (mercifully) few published papers consist largely of an attack on some previously published paper. The more quarrelsome author has published two of these, but it was more than 25 years ago and she is not proud of them. The well-behaved way to handle such things is surely for the "attacking" author to communicate with the "attacked" author in advance of submission, and if the author didn't, then the editor should. If no resolution is achieved then, at minimum, the "attackees" deserve an opportunity to present a brief rebuttal as soon as possible. A thumb up, therefore, to Hazlehurst (1999), which is something like round three in a continuing dispute about the topology of streamlines in contact binaries. No guesses here on what the right answer is, but hearty approval of how the discussion in being handled by all parties. In contrast, cases where an attacking paper seems to have been published without consultation or opportunity to respond include MNRAS, 299, 811 and ApJ, 514, L25 (though, in fairness, the authors could not have known that one attackee would be dead before the year was out).

Disagreement is presumably impossible for Nature 399, ix (where the same paper is advertised twice on one page) and A&A, 343, 697, which cites itself. We wonder how Science Citation Index is going to handle this one! ApJ, 512, 564 has a similar self-citation.

12. UNIVERSES NEAR AND FAR

More than half of the kindly contributors thanked at the end of § 13 mentioned among the highlights of the year "the accelerating universe," "the cosmological constant," "supernovae and cosmology," or some variant thereof. So be it, though the sets of numbers promulgated through the year were very close to the one still standing on the floor at the end of the IAU Symposium on cosmology in Kyoto, Japan, in August 1997. The numbers are in § 12.2.

By modern standards, the Friedmann-Robertson-Walker solutions to Einstein's equations almost count as warm, fuzzy, and familiar. Thus, voting with Sidney van den Bergh, who once said, "You'd be amazed how often the conventional wisdom turns out to be right," we begin with efforts to establish accurate values for the numbers that define the standard models; pass on to related issues of large scale structure, backgrounds, and dark matter candidates; and end with an appetizer platter stocked from the largest-ever annual assortment of cosmological pickled eels' tongues.

12.1. Hubble's Variable Parameter and Distance Indicators

After several years of monotonic decline (Ap98, § 11.1), the median value of the 26 values of H_0 published during the reference year rose back up to 62 km/sec/Mpc. The mean value was 63.9, significantly affected by the 119 derived from surface brightness fluctuations in the dwarf elliptical galaxies in the Sculptor group (Jerjen et al. 1998). Not quite the smallest number, but surely the most imaginative was $H = 27.08$ to 53.13 km/sec/Mpc, from "bidirectional relativistic proper motions of radio components of nearby" AGNs (Qin 1999). Trend tracers with long memories will have noted that even the Sandage-Tammann value has levitated a bit, to 60 ± 2 (internal error only; Saha et al. 1999). It comes from the now-standard combination of Cepheid variables and Type Ia supernovae.

You could probably argue that, in the end, you have to understand all of astronomy to be able to measure H_0 properly. At any rate, many dozens of papers addressed more than a dozen ways of estimating distances outside the Milky Way, without reporting specific values of the Hubble constant. The following list largely adheres to the "one bite per dog" policy, except where the present authors can't quite decide who to believe, in which case it is "one bite on each side of the dog."

◦ NGC 4258. This probably attracted the most public notice. A geometric (but not assumption-free) distance based on its Keplerian disk of water masers has put this weakly active galaxy 10% closer than is calculated from its Cepheid variables on the current scale (Herrnstein et al. 1999 vs. Maoz et al. 1999).
◦ The distribution function of the luminosities of planetary nebulae in the light of [O III]. Jacoby & Ciardullo (1999) maintain, not for the first time, that this is a good standard (or at least standardizable) candle because the cause of the range of line luminosities is physically understood.
◦ Detached, double-line, spectroscopic, eclipsing binaries. The project is called DIRECT, which is fair enough. It should also be qualified as "difficult," but is coming along on schedule, with samples of suitable systems identified in M31 and M33 (Stanek et al. 1999).
◦ The Large Magellanic Cloud has wandered from 42 to 57 kpc in the last few years (Madore et al. 1999). A single eclipsing binary (Guinan et al. 1998) and a large sample of

stars monitored by the OGLE gravitational lensing program (Udalski et al. 1998) both put it at the short end of the stick, near 45 kpc.

◦ Red clump stars. These are the ones that, at least approximately, would have been horizontal branch stars, if they had had the good luck to be born in globular clusters. Paczynski et al. (1999) describes them as "not only the best calibrated but also the best understood standard candle." Girardi et al. (1998) conclude that they are not reliable. Twarog et al. (1999) refrain from quality judgments, but their LMC distance, 48 kpc, is rather larger than the ones under the previous bullet.

◦ Stars at the tip of the red giant branch. They are declared to be pretty good distance indicators by Geisler & Sarajedini (1999), though you must have enough color information to be able to correct for stellar ages and metallicities.

◦ RR Lyrae variables. Gould & Popowski (1998) who "sing the praises of the central limit theorem," like them, at least when handled with statistical gloves. Kovacs & Walker (1999) start off with equal enthusiasm, but conclude that pulsational analysis applied to the RRd's (double mode variables) leads to distances that differ systematically by 10%–15% from those found by statistical parallax or the Baade-Wesselink method applied to RRc's in the same clusters.

◦ Reduced parallaxes and statistical parallaxes applied to *Hipparcos* data for RR Lyraes and Cepheids are similarly discrepant (Groenewegen & Salaris 1999). The distances from statistical parallax are the smaller of the two in this case as well as in the previous bullet.

◦ Soft X-ray transients. On the assumption that the cause of the flare-ups is the same sort of disk instability that produces dwarf novae, Shahbaz et al. (1998) suggest they might be good standard candles for the future (when some have been found outside the Local Group, for instance).

◦ Surface brightness fluctuations at infrared wavelengths. Jensen et al. (1998a) clearly want this to work, but they caution, first, that you must correct for bright points due to globular clusters, and, second, that the dominant stellar populations are different in blue and red elliptical galaxies.

◦ The Tully-Fisher relation is the (observed) correlation among spiral galaxies of the widths of H-alpha, 21 cm, or other emission lines (due to rotation) and the total luminosity in some wavelength band or other. Calibrating this for use at large distances was one of the stated goals of the *HST* Key Project on the cosmic distance scale. Unqualified praise for it was thin on the ground, with about a dozen papers directed toward how you might improve the correlation by greater understanding of how galaxies form and a variety of other correction factors. All found residual scatter. At the cheerful end of the range, we find Willick (1999) with a small scatter, achieved by using only the brightest galaxies and circular velocities measured at large radii. At the other end were Borchkhadze & Kogoshvili (1999), who found a scatter of 0.56 mag among the Virgo spirals.

◦ The fundamental plane is the elliptical galaxy equivalent of Tully-Fisher. Here too one can only say, "scatter happens." (Forbes et al. 1998.)

◦ The Sunyaev-Zeldovich effect is the up-scattering of photons from the cosmic microwave background by the same electrons that emit X-rays in clusters of galaxies. Since the two processes depend on different powers of distance, fitting everything tells you how far away the electrons are. Unfortunately, including more physics to get a better fit to the X-ray spectrum increases the error bars on H (Cannon et al. 1999).

◦ Type Ia supernovae (the nuclear explosion kind) are being used to estimate both the Hubble constant and the higher-order cosmological parameters. The latter task does not require you to know absolute brightnesses, but only to know that they are all the same or can be brought onto a uniform scale by some calibration method. Considerable success has been claimed in recent years, and one should probably feel a bit better about it all given that the observed range in maximum luminosity can be modeled fairly well. The general principle is that small ratios of C/O in the degenerate (white dwarf) material that explodes result in lower luminosities and will happen in stars that are initially metal poor (Umeda et al. 1999).

◦ The peak in the luminosity function of a population of globular clusters. The concern raised in this series and elsewhere is that all large galaxies seem to have bimodal populations, peaking at two absolute brightnesses and having different metallicities and locations. Inivitably, one will sample different proportions of the two populations in trying to get $\Psi(L)$ for a bunch of galaxies. The one unimodal galaxy we read about during the year, NGC 7457, has a very broad range of cluster brightnesses (Chapelon et al. 1998), and one suspects that the two peaks have simply not been resolved.

◦ Cepheid variables remain the gold standard of distance measurement in most astronomical value systems, partly because we think we understand them and perhaps also a bit out of prolonged exposure. Shapley and Hubble, after all, used them to put us 20 kpc from the center of the Milky Way and to derive a velocity-distance slope of 500 km/sec/Mpc. Feast (1999) is undoubtedly pro-Cepheid (and should be, given how much of the work is his own) but honorably raises a number of pink-to-scarlet flags concerning differences in metallicity, stellar populations, and much else.

12.2. The Other Cosmic Numbers

Now that the Hubble constant is firmly established, you are allowed to choose two, and only two, from the following menu: real age in years; global spatial curvature ($K = 0$ is flat space); the deceleration parameter q [which is not the same as long-range future, but just the current second derivative of $R(t)$]; the density (and pressure if you wish) in all forms of matter in units of the density that would just stop universal expansion in infinite time if there were no cosmological constant, Λ; and, of course, Λ itself. From the two you choose, all the others can be calculated, though not easily, and the more pedantic author is inclined to feel that the most valuable long-range product of the current rush to $\Lambda = 0.7$ may be all the diagrams that have been published, which, if you ignore the data, allow you to see just how t, K, q and all fit together.

In any case, you did not need to come here to be told for the first time, not even the first time this month, that there has been a large bandwagon, pulled by supernovae, pushed by fluctuations on the sky of the brightness of the cosmic microwave background, and steered somewhat erratically by large scale deviations from smooth Hubble expansion and gravitational lensing. Analyzers of lensing data alone hasten to add that these are consistent with any Λ between -1.0 and $+0.7$ or thereabouts (Quast & Helbig 1999). The bandwagon is flat and carries a matter density about 30% of the critical density (with a tenth of that, in turn, in baryons) and a Λ of about 0.7. The expansion time so far is 12–15 Gyr, and the universe should expand forever.

Of the 59 relevant papers (plus 32 primarily addressing baryon supplies) read and recorded during the year, we note (*a*) one with original data from supernova observers (Perlmutter et al. 1999), (*b*) two overviews that have the advantage of being reasonably accessible, clearly written, and brief (Lineweaver 1999; Bahcall et al. 1999), and (*c*) by way of redressing the balance, a few of the most discouraging and discordant results that saw light of print:

Popov & Kovalev (1999) found $q = 0.5 \pm 0.15$ from the angular diameter versus redshift relation for VLBI quasars. The problem remains that evolutionary effects compete with cosmological ones, and typically win, for this and other traditional tests (Takamiya 1999). Large values of matter density, more consistent with 1.0 than 0.3, were reported by Reichart et al. (1999, from statistics of X-ray emitting clusters) by Szapudi et al. (1999, from non-linear clustering), and by Croom & Shanks (1999, from a particular interpretation of how quasar counts are affected by gravitational lensing). There are ways around all of these, but also, of course, around the bandwagon, if you aren't afraid to walk that far alone after dark. For instance, Aguirre (1999a) suggests carbon needle dust as an alternative to Λ to account for the faintness of distant Type Ia supernovae. Valdarnini et al. (1999) tried to match data on the redshift dependence of the population of X-ray emitting clusters with a bunch of cosmological models and found that cold dark matter plus cosmological constant gave the worst fit.

All this being said, it remains true that embracing Λ is a very Bayesian process—easy enough if it had high probability in your "priors" and much harder if it did not. Presumably Starkman et al. (1999) are telling the truth in saying that *global* exponential expansion can be established only with data that reach most of the way to the Hubble radius, that is, redshifts larger than about 1.8. These are not (yet) available, though the record SN redshift stands at 1.9 this week (IAU Circ. 7228).

As for the cosmic baryon content, the number of boxes you are required to search grows ever larger. They are labeled (1) "brown dwarfs" (out of fashion this year, and thus stored on the top shelf, so that Gilmore & Unavane 1998 quite properly looked in the halo), (2) "QSO absorption clouds" (e.g., McIntosh et al. 1999, who report that standard methods slightly over-weigh that box), (3) "very filamentary but otherwise diffuse gas" at 10^5–10^7 K, a box only really opened in the last couple of years but one that outweighs all the others according to Cen & Ostriker (1999), and (4) "Gunn-Peterson absorption gas," which comes dangerously close to overbalancing the total amount allowed by big bang nucleosynthesis, according to Levshakov & Kegel (1998) who find $\Omega_b = 0.08$ if $H = 70$ km/sec/Mpc. The ratio of gas mass to total mass in the X-ray clusters (a fifth box) remains fairly uncertain. It goes down if the recently-advertised excesses of extreme ultraviolet and soft X-ray emission are actually produced by inverse Compton scattering rather than by intermediate temperature gas (Lieu et al. 1999), or if there are small-scale fluctuations in gas density inside a typical cluster (Mathiesen et al. 1999).

But, for the moment, there do not seem to be serious objections to betting, with Burles & Tytler (1998) that all is for the best in the best of moderately deuterated worlds, with $\Omega_b h^2 = 0.019$ (though their stated error, ± 0.001, is not generous).

12.3. Very Large Scale Structure and Streaming

This topic, which always appears as VLSSS in the more acronymical author's notebooks, means fluctuations around the mean density of the universe and deviations from linear (Hubble) flow on scales larger than clusters of galaxies. The answers you get depend very much on the questions you ask, though even the simplest Q's may have complex or disputed A's. Some examples follow.

How big are the largest scales with detectable fluctuations? More than 200 h^{-1} Mpc (Basilakos & Plionis 1998), but less than 500 h^{-1} Mpc (Kalinkov et al. 1998), or perhaps as large as $z = 3$ (Tipler 1999).

What is the topology? There was a vote for pancakes (Demianski & Doroshkevich 1999) and at least six for filaments (Sathyaprakash et al. 1998; Batuski et al. 1999; Shandarin & Yess 1998, this last interesting as coming from an old pancake man).

Have you accounted for the local streaming (known as "dipole" when seen in the microwave background) from the gravitational effects of the lumpy matter, and, if so, how far out do you have to look to do it? Yes, but only beyond 40 h^{-1} Mpc (Giovanelli et al. 1998). Yes, by around 200 h^{-1} Mpc (Dale et al. 1999). Or, apparently, no (Hudson et al. 1999; Willick 1999a).

Does a luminosity fluctuation of a given size and amplitude imply a density fluctuation of the same diameter and amplitude? In other words, roughly, is there bias? The most optimistic plausible answer is that of Croft et al. (1999) who say that the spectrum of fluctuations derived from the Lyman alpha forest of absorption lines in the spectra of quasars "has no unknown bias factor." But the majority of the 20+ papers on the subject seem to be saying something more like, "Yes, there is bias, not to mention anti-bias, and, no, light does not perfectly trace mass, and, what is more, the relationships are complex, and depend on, at least, the length scale on which you look (Fang et al. 1998) and the epoch at which you look (Colin et al. 1999; Kauffmann et al. 1999)." Inevitably, other things you want to measure will be messed up (Dekel & Lahav 1999).

Do we see the backflow on the other side of the largest lumps near us, which are usually blamed for a good deal of the local streaming? No (Branchini et al. 1999). Yes, but it may be an artefact (Schmoldt et al. 1999), or Yes, but only for one of them (Thereau et al. 1999).

Even at this point, it seems like only a raging optimist would attempt to simulate formation of VLSSS from some set of initial conditions (inflation, cosmic strings, cold dark matter, or whatever) and to compare his results with the real world. Thus we mention only the calculation of Hu (1998), who considers limiting forms of the set of all possible initial conditions (well, anyhow, all the ones popular in the last few years) and gallops with them, like Lord Ronald, madly off in all directions.

Arguably, however, the worst is yet to come. Klypin et al. (1999) suspect that almost none of the calculations really has adequate spatial resolution to find many of the features important in the data. In addition, a number of people have focused on why the answers to the set of observational questions listed above do not converge better. It is, frankly, not even clear that there is agreement on this point. Even a single, long-studied sample like that of *IRAS* galaxies says different things to different people, depending on which mathematical estimators they use and on whether they regard density fluctuations or velocity fluctuations as fundamental (Baker et al. 1998; Kerscher 1998), while use of different samples guarantees disagreement (Hui & Gaztanaga 1999), especially if someone else has already done some pre-processing (Einasto et al. 1999).

Some of the answers (?) nevertheless make at least qualitative sense. Active galaxies should, for instance, be more biased than star burst ones (Magliocchetti et al. 1999). And the Lyman alpha forest clouds with high surface densities are clustered like galaxies, while those with low surface densities act like the general run of larger scale structure (Davé et al. 1999).

We turn final attention in this section to the profound-sounding question of whether the universe is hierarchical or fractal on the largest scales probed. This makes it sound more important than if you just ask whether samples taking in more volume find bigger structures. Attentive ears heard two fairly firm no's (Wu et al. 1999; Martinez 1999), with Treyer et al. (1998) explicitly pointing out that fluctuations in the X-ray background nicely fill in the length and amplitude scales between redshift surveys and the microwave background as seen with *COBE*, crossing the regime where "fractal" gives way to homogeneous and isotropic.

The fractal fort continues to be held most strongly by Joyce et al. (1999). They believe that apparent homogeneity in the largest galaxy surveys arises from improper *K*-corrections to the data. This is the correction you must make because if you observe at a fixed wavelength from Earth, you are taking in shorter and shorter source wavelengths as you look to higher redshifts. The author who goes further back in redshift is inclined to vote with the "homogeneous" party, while readily admitting that, on sufficiently small scales, even the Earth looks flat.

12.4. Fractals for Rent

But if the universe on large scales is not fractal or hierarchical, something else must be, or all that hard work would go to waste. The entities identified most often as one or both in 1999 were insterstellar cloud structure and star formation regions. We tried to catch all the relevant papers and apologize to anyone missing from the following list (indeed to anyone appearing who would have preferred not to): Maragouait et al. (1998), Westpfahl et al. (1999), Gorbatskii & Tarakanov (1998, 1999), Elmegreen & Salzer (1999), and Elmegreen (1999).

The only other candidate seems to have been the light curve of OJ 287 (He & Xie 1998). But they did not recover the 12-year period that others have reported for many cycles in the past. Tateyama et al. (1999) see a time scale of about one year between radio outbursts in OJ 287, and 3C 345 has a similar longer radio quasi-periodicity in its ejection of new jet components (Lobanov & Zensus 1999, though the 1995 August submission date is now a whole period ago).

Other AGN periodicities advertised during the year included 65 days (and gradually slowing) for 3C 66a in 1993–1998 (Lainela et al. 1999, who suggest it may be a shock in a helical jet); 14 years in BL Lac itself over 199 years of observations from Yunnan Observatory (Fan et al. 1998; the period does not leap out at you from the raw data); and probably some others that we missed.

12.5. Backgrounds

Honestly now, aren't you getting awfully tired of reading about the 2.7 K thermal isotropic microwave cosmic relict background radiation? Apparently, at least, your colleagues are getting tired of writing about it, for we caught many fewer papers than in any recent past year that addressed what it looks like and what it is trying to tell us (apart from the countably infinite number on cosmological parameters).

The iconoclastic limit was reached by Lopez-Corredoira (1999), who suggested that all the fluctuations on the sky (except, presumably, the dipole) could be contamination from the Milky Way. The author regards it as a bad sign that the main *COBE* lumps are about the same angular size as giant molecular clouds. Efstathiou & Bond (1999) challenged the current bandwagon by saying that even infinite precision in measuring CMB fluctuations will not tell you everything you ever wanted to know about the universe. You must also look at clusters of galaxies, optical distance indicators, and so forth. Lasenby et al. (1999) are really saying the same thing, but more gently. The Mrs. Beeton award for optimism ("first catch your rabbit") goes to Lopez et al. (1999) who believe the power spectrum near $l = 3000$ will harbor covert information about the temperature and number of species in the cosmic neutrino background.

In the infrared, the first question is whether we finally have a good characterization of the smoothed sky at a few to 1000 μm. The answer is yes, though it has been a very long haul, described in a set of papers beginning with Hauser et al. (1998, and see Dwek & Arendt 1998, for a possible number at 3.5 μm). The second question is whether the sum of known galaxies or at least known types of galaxies is likely to add up to the background so characterized. Again the answer seems to be yes—no warm spooks need apply—and SCUBA has been enormously helpful in finding enough sources that we can see how to add them up (Puget et al. 1999; Eales et al. 1999, and others). The third question, for which some not-exactly-answers are suggested in § 10 is how do the highest energy cosmic rays and gamma rays manage to get to us through that sea of photons.

In the ultraviolet, there are two or three fluxes that might be described as backgrounds. Just longward of the Lyman limit (912 Å), nearly all the photons we see come from nearby hot stars (Murthy et al. 1999, using 17 years of data from the *Voyager* probes). At shorter wavelengths, there are the photons that ionize QSO absorption line clouds and whatever else gets in their way. Huang et al. (1999) have looked at how likely these are to get out of the various kinds of galaxies where they are made. And there is perhaps something in the wavelength band between these (Henry 1999) which, in the most interesting case, might be photons from the decay of unstable dark matter particles.

Once the tidy black body spectrum of the black body background ($T = 2.75 \pm 0.002$ K; Mather et al. 1999) ruled out hot intergalactic gas as the main source of the smooth X-ray background, the main question became just which known (or unknown) classes of discrete sources could be made to add up to the total. This has been addressed a number of times before (e.g., Ap97, § 9.1) and gets only one nibble here, from Ueda et al. (1999) who say that all is well. The main problem has always been that the background X-rays are harder than most sources. Watanabe et al. (1998) say that all is also well for the gamma-ray background up to about 1 MeV, though admittedly they use mostly nuclear gamma rays from Type Ia supernovae, which have never been observed.

12.6. Dark Matter Candidates

There is proverbially[1] no new thing under the Sun. Dark matter candidates are, however, by definition, not illuminated, and so we are not prepared to swear whether any of the following is making its first appearance. The ordering is not exactly "unlikely" to "likely" but (probably correlated) "few papers" to "many papers," because it's easier to write that way.

Supermassive particles, meaning much larger than the 100 GeV scale of weak interactions (Chang et al. 1998). These could even be charged or strongly interacting if they are massive enough.

Axinos (Covi et al. 1999). They would come from the decay of the lightest neutralino (WIMP, lowest-mass supersymmetric particle, or LSP) and quite naturally contribute a density close to the critical one.

Axions. These are definitely not new to the inventory, but some relatively new limits have been put on their properties from their propensity to interact with the stuff in stars (Gnedin et al. 1999; Dominguez et al. 1999).

Quark nuggets are "not impossible" say Alam et al. (1999).

Cold dark matter from B-ball decays (Enquist & MacDinah 1998).

Decaying neutrinos with a rest mass near 23 eV (Adams et al. 1998). The authors do not emphasize likelihood, but note that photons among the decay products have the potential for totally spoiling acoustic peaks in the 3 K background as a signature for anything else.

Hot, *low-mass WIMPS* from decay of a scalar particle (Brustein & Hadad 1999). Their contribution to formation of large scale structure would presumably resemble that of "normal" non-zero-rest-mass neutrinos.

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[1] The author who keeps a copy of *Tanach* in her office freely admits to having started this sentence thinking that the quote is from the book of Proverbs. It is, in fact, Ecclesiastes I.9, but "There is ecclesiastically no new thing ... " didn't seem like a very good jumping off point.

Ordinary neutrinos. These of course remain in the potential inventory (Croft 1999), and a new entry is the sort of sterile neutrino implied if you want to fit simultaneously all the data on atmospheric, solar, and Los Alamos neutrinos. But, just to make life more interesting, these (even if of low mass) would be made cold from the regular neutrino flavors by MSW oscillation (Shi & Fuller 1999). So, to recap, we can now have hot WIMPs and cold neutrinos as well as the converse.

Brown dwarfs could still be of some importance in our own and other disks (Binney 1999), but most of the dark matter is not in the disk (Bienayme 1999) and the halo dark matter in most other galaxies is not even as bright as M, L, or T dwarfs (Uemizu et al. 1998; Gilmore & Unavane 1998a).

Gas in various forms. Stothers (1998) suggests that about a third of the local density might be cold, giant molecular clouds. Kalberla & Kerp (1998) want clouds of only 10^{-3} $M_\odot$ and 3 K, but suggest that they could add up to a large fraction of the dark matter. And De Paolis et al. (1999) believe that there is actually positive evidence for much of the Galactic halo dark matter being cold molecular gas, if the Galactic diffuse gamma-ray halo seen by EGRET is produced by cosmic rays hitting gas. M31 has no such halo (Blom et al. 1999), hence, apparently, either less halo gas or fewer cosmic rays. Sanchez-Salcedo (1999) puts a component of massive molecular clouds specifically in the thick disk of the Milky Way.

Black holes could do it all, but the dominant masses had better be quite small, at least within galaxies, less than a few solar masses in disks and less than 10^3 $M_\odot$ in halos, or you disrupt binaries and clusters, puff up the disks, and do other dynamically bad things (Carr & Sakellariadou 1999; Arras & Wasserman 1999).

The Sackett et al. (1994) halo apparently doesn't have to be made of M, L, and T dwarfs or anything else, because it probably isn't there (Zheng et al. 1999). Contributions from a stellar ring and from poorly removed foreground stars are to blame for the Ap94 (§ 5.8) highlight.

X-matter or quintessence (the sort with negative pressure) after a year or two in the inventory is practically an old friend and, as such, gets only a single reference (Perlmutter et al. 1999a, who point out that if it is to replace a cosmological constant in fitting the redshift-distance relation for Type Ia supernovae, the constant, $-w$, in $P = -w\rho$ must be less than about -0.6).

MaCHOs, meaning whatever Compact Objects are responsible for the gravitational lensing of stars in the Small and Large Magellanic Clouds. Two questions arise. First, where are they? In the SMC itself for the first, 1998, event seen there by the MACHO, OGLE, EROS, and PLANET searches (Udalski et al. 1998b) and probably also for the second SMC event (Alcock et al. 1999). In the LMC itself for at least some of those events (Zaritsky et al. 1999; Aubourg et al. 1999), or in the disk of the Milky Way (Gyuk & Gates 1999), although the required masses drop only slightly and not into the invisible brown dwarf range. Thus we get little help compared to the standard "in the halo, stupid; that's why they're called Ma*CH*Os or Massive Compact *Halo* Objects."

Second, and only if you believe the H part, does it make sense to worry seriously about what they are. It is fine to say cold white dwarfs, if all you are concerned about is not seeing them directly. They could either have been born cold (Hansen 1999) or have achieved coldness (Hansen 1999a).Lovers of Shakespeare may note that this leaves an opportunity for some brand new physics, under which WDs might have coldness thrust upon them. A large population of cold white dwarfs would be exceedingly interesting in the contexts of galactic evolution and the census of baryons in the universe (Chabrier 1999). Actually, most would say "impossible" rather than merely "interesting." Meanwhile, however, Ibata et al. (1999) have caught some faint, rapidly-moving point sources in the repeat of the Hubble Deep Field images, which could be the bright end of the luminosity distribution of the putative white dwarfs.

Finally, it may be possible to decide whether the dominant dark stuff on cosmic scales is neutrinos, WIMPs, or MaCHOs from future studies of gravitational lensing of galaxies and distant supernovae (Cooray 1999; Metcalf & Silk 1999).

12.7. Brave New Universes

The oldest of these goes back almost as far in the literature (and much further back in time!) as the conventional evolving model. It is, of course, steady state cosmology. The primordial version (Bondi & Gold 1948; Hoyle 1948) succumbed long ago to some combination of the microwave background, the uniform abundance of helium, and counts of radio sources and quasars. But a modified, quasi-steady-state maintains a precarious hold on life (Banerjee & Narlikar 1999; Burbidge & Hoyle 1998). The proponents say it combines the virtues of a conventional model (agreeing with observations) with the virtues of steady state (bringing the process of creation within the realm of scientific inquiry). The difficulties are left as an exercise for the reader. (In case more details of Dirac's method might help, the complete text of "Lion Hunting in the Desert" appeared in the October 1999 issue of the *Newsletter* of the American Physical Society.)

A cold big bang, with an initial ratio of photons to baryons of $10^{0 \pm 2}$ can make at least the cosmic helium and some CNO, but not the deuterium, lithium, or background radiation (Aguirre 1999). This idea also has the dignity associated with moderate antiquity, for instance the paper of Zeldovich (1962), which deals with nucleosynthesis in a cold big bang.

MOND (modified Newtonian dynamics) is only about a third as old as steady state. Its primary original trait was the elimination of the need for dark matter. On the scale of average sized galaxies, it still does this (Brada & Milgrom 1999), but it needs help on the scale of clusters of galaxies in order to match observed velocity dispersions and gravitational lensing. Sanders (1999) says that the requisite dark matter must be purely baryonic.

Making the 3 K radiation dipole with inhomogeneous expansion does not require new equations, but only different initial conditions. If you also want to solve the "horizon problem," then the observer needs to be rather near the center of the inhomogeneity (Schneider & Celerier 1999).

And here is the threatened appetizer tray of less familiar alternative universes, in the order they reached libraries, characterized by their most obvious differences from Friedmann-Robertson-Walker. Some probably carry salmonella, but it is not clear which ones. You might be tempted to try to decide from the name of the journal in which each appeared. Remember, however, that even Homer nods (Flaccus, 30 B.C.) and, once in a while, conversely.

Quasars that are bright because their own light is focused back onto their nuclei (Rozgacheva & Charugin 1998).

Octahedral geometry due to magnetic fields (Battaner & Florido 1998).

Ether (Tomaschitz 1998).

A Higgs field absorbed by the spatial metric, so that particles have mass from $t = 0$ (Papoyan 1990).

Baryons made with isocurvature (non-adiabatic) fluctuations in their density through the universe (Koyama & Soda 1999).

A truly enormous speed of light at $t = 10^{-32}$ sec (Albrecht 1999).

Quantized rotation curves for galaxies (Roscoe 1999).

Radiation and matter alternate as the dominant mass density near $t = 1$ sec (Kawasaki et al. 1999).

A non-singular big bounce in the past (Overduin et al. 1999).

A non-relativistic fractal universe ($D = 2$; Abdalla et al. 1999).

Warm inflation (Berera et al. 1999).

String-based inflation (Berera & Kephart 1999).

A quantized distribution of QSO redshifts (Lokanadhar et al. 1998).

Adiabatic creation in a FRW model (Lima & Alcaniz 1999). This is not steady state although the required rate of creation is similar.

Projective Unified Field Theory (PUFT) with no initial singularity (Schmutzer 1999). This is very much in the tradition innaugurated by Pascal Jordan (Schucking 1999).

After contemplating many of these, about all one can say is a paraphrase of the remark of a clergyman who specialized in baptisms. "My, that is a baby, isn't it?" Substitute "telescope" or "experiment" when visiting labs whose purpose may not be clear to you, and "universe" in the present context. But, before passing on to the less lofty peculiarities of § 13, call to mind the rest of the (mis)quotation that heads this subsection ("that has such people in it") and that it was originally spoken in real, if misplaced, admiration.

13. BLACK AND WHITE AND RED ALL OVER

No, not a newpaper. An embarrassed zebra. As usual, this 13th section commemorates things that didn't turn out quite as intended, beginning with our own blunders and continuing with those of other contributors to the field.

13.1. Ours

For the first time, the references of Ap98 were subjected to an assortment of automated and on-line checking processes. Thus the misspelling of colleagues' names was greatly reduced. One email correspondent reported that we had not correctly reproduced the surname of Philip Iadevaia (of Pima College). He did not actually appear in Ap98, but it is exactly the sort of name we would have misspelled given the opportunity. Alfonso XII (r. 1875–1886) should have been Alfonso X (r. 1254–1282) "el Sabio" (and the person who told us is at Alfonso X el Sabio University!). One happy update: D. H. Kelker is to be found in a Canadian mathematics department.

And just because we don't know where else to mention it, the star in the *Hipparcos* data base that is supposed to be SU Tau (HIP 027465) is actually a perfectly nice comparison star called C by Bailey & Howarth (1979). But the chap who called it to our attention was kind enough to say that it did not change "the interesting conclusions" of PASP, 109, 1089.

By way of compensation, neither author saw the normal set of proofs, which provided opportunity for a whole different class of errors. Most are worth at most a small giggle. One or two genuinely might mislead. Herewith a subset of each.

◦ That well-known molecule "H-2 zero" (p. 410, left column).

◦ Similarly, spectral type "zero" in the sequence "zero-B-A" etc. (p. 418, right column).

◦ "Ralston et al. 1998 do agree" (p. 403, right column), where we had written "Ralston et al. 1998 disagree." Luckily they probably never saw it.

◦ The symbol for luminosity distance "d-sub-el" (p. 421, right column), came out "d-sub-one," whatever that means.

◦ "Binary lenses are much commoner than binary lensees" (p. 401, right column), came out "Binary lenses are much commoner than binary lenses," violating some deep mathematical theorem about the transitiveness of equality. Moral: Never try to coin a word if you aren't going to see the proofs.

◦ Authors "X. X. Moruzzi and Y. Y. Strumia" (p. 434) never got upgraded to G. Moruzzi and F. Strumia. But if they didn't complain, why should anyone else?

◦ A black hole of 19^9 solar masses (p. 426, right column). This happens often enough that you might find it useful to know that 19^9 is about 3×10^{11}.

◦ And a sizable number of orthographic and grammatical infelicities, resulting in pseudosyllables like "toev," "oion," and "deex" where hyphens were removed and an odd verb tense or two, like "fitted" for "fit."

There were also some errors achieved by the authors all by themselves, to which colleagues have gently called our attention. They are ordered by section number.

Sect. 3.1.3. Gamma Cygni should probably have been P Cygni, but then it wouldn't have fit in that section.

Sect. 4. (Neutrinos). The mixing angle, θ (which describes mixing between neutrino mass and flavor eigenstates), was confused with the Weinberg angle (which describes the degree of symmetry breaking between the electromagnetic and weak interactions). This sort of error is described by the Trimble angle.

Sect. 7.4. The slow nova in M31 made it only to $B = 17.25$, not 12.25 (a copying error).

Sect. 8.3. The connection between RV Tauri stars and type II Cepheids was earlier pointed out by Arp (1955).

Sect. 9.4. There are indeed two types of S stars, and apparently also a third type, born that way from material locally contaminated, and found in Omega Cen (Lloyd Evans 1983).

Sect. 10.8. Our approval of "diskoseiology" stands, but one of the authors involved in the coinage reports that he would have preferred "diskotromicity."

Yet another category of error involves the authors having believed a cited paper, most often on issues of priority and other extrema. Yes, of course these should all be sorted out. And no, we are generally not going to be the ones to do it. Take comfort from Stigler (1980). True pioneers never get credit for anything.

13.2. Theirs

As usual, no authors are cited, since they are often not to blame for the words that seem to have come out of their keyboards.

Here is a triumph of misinformation that must have come from enforcement of a "house style" requirement to spell out acronyms and abbreviations plus a limited dictionary. It appears in both abstract and text of ApJ, 514, 844. "We set an upper limit of 0.012 h_{50}^{-2} solar neutrino units (SNU) for the SN Ia rate at $r > 50$ kpc." It was supposed to be supernova units (SNU), which, last we heard, meant 1 SN per century per $10^{10}\ L_{\odot}$ in galaxy brightness.

NO Ser really is a star (it is BD $-1°$ 3438 and was discussed in at least one paper this year). But the potential for a form of low humor is endless. The prototypes are RU Lupi and Nu Bootes. We offer NO Mus (no fuss) and LO And (behold) and invite you to continue the list. Incidentally, a few stars are, in effect, nameless, through no fault of their own (Griffin 1999).

Topological impossibilities are not limited to the four-sided triangles and pentagons of § 9.4, above. Try following these instructions from the *AAVSO Newsletter* No. 21 (1998 December), p. 15. "What I especially look out for is that warm clothing is worn in a way that cold bridges are reduced, i.e., socks over trousers, trousers over shoes ... " (and presumably, shoes over socks?).

Ghost authors and papers: The best known is probably Einstein & Preuss (1917), where the spectral co-author is actually part of the name of the journal, *Sitz. Ber. Preuss. Akad. Berlin*, in which Albert published some of his general relativistic papers. We ourselves were rescued this year by the editor from creating a paper by "Barrado and Navascuez." But the following is from *Meteoritics and Planetary Science*, Vol. 34, No. 4, A156, footnote 1: "Three Germans, Otto Haxel, J. Hans, D. Jensen, and Hans E. Suess, who co-authored the Physical Review paper ... " Reassembled, J. H. D. Jensen (who normally used the middle name Hans) later won a Nobel Prize for the work.

Bargain basement funding, from *Science*, 287, 627 (Letter to the Editor), "Tenet will contribute up to in its first fiscal year, and $32 million in addition in its second year." One wouldn't mind matching the first year contribution oneself.

"BL Lacs that have been pointed by *BeppoSax*" (A&AS, 132, 362, abstract) presumably meant "targeted" or "pointed at," but given the continuing discussion of the significance of the angle from which we see active galactic nuclei (§ 8.1), it would be nice if we could orient them to suit.

"Stability of small-scale Kelvin-Helmholtz Instability" is a title (ApJ, 506, 289).

A brand new source of excess metallicity is revealed in MNRAS, 299, 1119 (abstract): " ...classical Be stars made from the Australia Telescope Compact Array."

The perils of SI: The abstract of ApJ, 507, L177 describes "the UV interstellar extinction band at 4.6 μm." Presumably they intended 4.6 μm^{-1}, or 2175 Å (in the units we grew up with).

Looking backward, the conclusions of ApJ, 508, 74 tell us that "the model gives predictions for past and future events," and remind us that Thomas Gold pointed out many years ago the need for a word of the general form retrodict or hindcast.

Looking up and down at the same time? We believe the authors of A&AS, 132, 45 (abstract) and Acta Astron., 49, 389 (discussion), but wish they had described their results in some fashion slightly different from: "The irradiation enhances the emission in the line, although the equivalent width reduces considerably," and "a slower decline corresponding-by-definition-to a higher rate of decline."

Names of the radio bands. One paper this year mentioned that K = 1.2 cm, U = 2 cm, X = 3.6 cm, Q = 0.7 cm. Rumor hath it that the letters were supposed to be meaningless and, therefore, difficult to decode, but we suspect the selector was Hungarian.

Missing pieces: In AJ, 118, 1261, the table has components called purple, orange, red, green, and blue. But the drawings are in full black and white. The figure caption in ApJ, 518, 860 says that "the halfway tick mark between G0 and G1 indicates type G0.5" But the figure extends no bluer than G5. ApJS, 121, 231 (results), explains itself as containing "a series of self-explanatory figures (Figs. 1–10) more or less familiar to people studying relevant issues." Of which we are not two, or even one.

Are you sure this paper was ready for publication? In the conclusions of AN, 320, 103, we find that "The main result of this manuscript [equation (??)]." Elsewhere occur Fig. [??] and Table [??].

Imperfect English is clearly not a fair target when the authors are doing so very much better than either of us would in anything except English or German (though we have assembled a fine collection). The acknowledgement of A&A, 348, 592 is, however, irresistible: "thank X who carried out the observations in serviced mode." The meaning of the verb "service" which makes this most interesting is found only in larger dictionaries.

Finally, the authors of the following two papers must be those guys you see ahead of you in the supermarket express checkout line ("6 items maximum") pushing carts full enough to feed a herd of graduate students (did you ever try to herd graduate students?). A&A, 344, 421 is paper II according to the title, but III in the running head. ApJS, 122, 81, is paper III in the title, but the abstract begins, "This is the fifth and last such paper..."

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