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Invited Review

Astrophysics in 2002

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ABSTRACT. This has been the Year of the Baryon. Some low temperature ones were seen at high redshift, some high temperature ones were seen at low redshift, and some cooling ones were (probably) reheated. Astronomers saw the back of the Sun (which is also made of baryons), a possible solution to the problem of ejection of material by Type II supernovae (in which neutrinos push out baryons), the production of R Coronae Borealis stars (previously-owned baryons), and perhaps found the missing satellite galaxies (whose failing is that they have no baryons). A few questions were left unanswered for next year, and an attempt is made to discuss these as well.

1. INTRODUCTION

Astrophysics in 2002 completes a round dozen in the series. The previous 11 reviews are cited here as Ap91, Ap92, etc., to Ap01, and appear in volumes 104–114 of *PASP*. The game plan has been more or less as usual. The authors read a good deal more than they take notes on and take notes on many more papers than can be mentioned here.

Section 2 was assembled using papers found on the Astrophysics Data Service, maintained with support from NASA. The journals scanned for sections 3–13 were the issues that reached library shelves between 1 October 2001 and 30 September 2002 of *Nature*, *Physical Review Letters*, *Science*, the *Astrophysical Journal* (plus *Letters* and *Supplement Series*), *Monthly Notices of the Royal Astronomical Society*, *Astronomy and Astrophysics* (plus *Reviews*), *Astronomical Journal*, *Acta Astronomica*, *Revista Mexicana Astronomia y Astrofisica*, *Astrophysics and Space Science*, *Astronomy Reports*, *Astronomy Letters*, *Astrofizica* (happily back among the living), *Astronomische Nachrichten*, *New Astronomy*, *Journal of Astrophysics and Astronomy*, *Publications of the Astronomical Society of Japan*, *Bulletin of the Astronomical Society of India*, *Baltic Astronomy*, *Contributions of the Astronomical Observatory Skalnate Pleso*, *IAU Circulars*, and, of course, *Publications of the Astronomical Society of the Pacific*. Some of the journals we read for fun, without systematic note-taking, were *Observatory* (occasionally so much fun it should be rated PG for Professorial Guidance suggested), *Journal of the American Association of Variable Star Observers*, *Astronomy and Geophysics*, *Mercury*, *Sky and Telescope* (until they terminated our subscription, which magically reappeared a few months later), and *Monthly Notices of the Astronomical Society of South Africa*.

In accordance with the long-standing principle that our own works are not to be regarded as highlights of the year, any paragraphs containing citations to papers by V. Trimble should be deemed to have been written by M. J. Aschwanden, and conversely (some of them actually were).

It was a year of ups and downs, especially for satellites, *HESSI*, the *High Energy Solar Spectroscopic Imager*, after a successful launch, became *R* (for Ramaty) *HESSI* when it started collecting data in February 2002. The CASLEO 2.15 meter telescope is now the Jorge (pronounced, he insists, George) Sahade telescope. A Cerenkov detector for high energy cosmic rays is now operating in Namibia (Steenkamp 2002). And ARCHEOPS (a balloon-borne device to look at the cosmic microwave background) traveled from Karuna, Sweden, to Siberia on 7 February 2002. This trip cannot (yet) be made by ship, but opening of a Northwest Passage (see the Earth section, § 11.3) must surely someday be followed by a Northeast Passage, though ships will probably still not be the best platform for microwave telescopes.

Genesis lives at L1 and has been collecting solar wind since November 2001. *MAP* lives at L2 and has been collecting cosmic microwave photons for about the same length of time. The LDEF (Long Duration Exposure Facility) lived in near Earth orbit for much longer than had been planned, since it went up before the Challenger explosion and could not come down until long after. Its much-battered surfaces collected no measurable SIMPS (strongly interacting massive particles, Javorsek et al. 2002), but the implications for their (non)-contribution to dark (?) matter are infinitely model dependent.

MINISAT was launched in April 1997 and completed operation in April 1999. We're embarassed at having missed it completely until workshop proceedings were published (Gimenez 2001). It was a Spanish mission that mapped diffuse emission at 300–1050 Å and monitored sources at 10–100 keV.

The European Space Agency decided in May not to carry on with *Venus Explorer*, but kept *GAIA* (an astrometric mission) and *Solar Orbiter* (which, we think, is probably supposed to orbit the Sun) in their queue. *GAIA* has an estimated launch date in 2012 and may have to work very hard, since the American precursor, *FAME* (the AM part stands for Astrometric Mapping) has slipped from budgets and the German precursor *DIVA* has slipped to 2007–2008 at the earliest.

Pioneer 10 can no longer be counted upon to call home, but 30 years after its March 1972 launch, it responded when called.

The Very Large Telescope began operation with two-to-four 8-meter mirrors in an interferometric mode, and adaptive optics with a laser guide star began at Keck on 23 December 2001. We have not come up with a good enough remark about the Laser of Bethlehem to bother but would be grateful for suggestions.

And some good things came down during the year, which counts as bad news. These include *EUVE* (*Extreme Ultraviolet Explorer*), with atmospheric re-entry on 30/31 January 2002, and *BeppoSAX* on 30 April 2002. *HETE-I* and *SAC-B* returned to Earth in early April 2002, still locked face to face, without having ever done any of the science for which they were intended. *Contour* (COMet Nuclear TOUR) broke into three pieces as it was being boosted out of near Earth orbit in August 2002. Apparently all three pieces went off in roughly the right direction.

Yohkoh, the Japanese solar satellite, was lost on 13 December 2001 because an erroneous command was uploaded by accident. Well, you might think, surely no one would load a "self-destruct" command on purpose; but remember what happened to the *Compton Gamma Ray Observatory* (*CGRO*) not so very long ago.

They are still launching rockets at Baikonur, Kazhakstan, from whence *Sputnik* went up in 1957, but the intention is for it to wind down by 2005. Saddest of all, the paper version of *Astronomy and Astrophysics Abstracts*, successor to *Astronomische Jahresberichte*, founded in 1898, has ceased to exist, with only an on-line version surviving. Something that two World Wars could not kill has succombed to friendly fire.

2. SUN MICROSYSTEMS

When you search for information about the *Sun* with your website browser, you are likely to be swamped first with products from the *Sun Microsystems Inc.* computer company. Here, however, we highlight the products of solar astronomers, which also dissect our astronomical Sun into microsystems from inside to outside, such as micropores (Lites et al. 2002), the microstructure of solar magnetic fields (Sanchez-Almeida 2001), and coronal microflares (Shimizu et al. 2002), or propose a *reconnection and microscale (RAM)* mission (Bookbinder et al. 2002).

2.1. Solar Neutrinos and WIMPs

There are good and bad news in solar neutrino physics. The good news: Raymond Davis, Jr., deservedly, was awarded the 2002 Noble Prize in Physics for his 40-year-long ^{37}Cl solar neutrino measurements. The bad news: On November 12, 2001, about 60% of the photomultipliers used for the Super-Kamiokande detector were destroyed in an accident that happened as a chain reaction following the implosion of a faulty photomultiplier. On the bright side, the solar neutrino problem has been pretty much settled by the Sudbury Neutrino Observatory (SNO) experiment, from which a ^{8}B neutrino flux of $\Phi(^8\mathrm{B}) = (5.44 \pm 0.99) \times 10^6\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$ was inferred (Ahmad et al. 2001), which agrees well with the predictions of the best standard solar models and is consistent with the trinity of the electronic, muonic, and tauonic neutrinos. This boron neutrino flux constrains also the metallicity of the accretion of our protosolar cloud, which can be tested now with *p*-mode oscillation data, yielding an upper limit of ≈2 solar masses of iron, or ≈40 solar masses of meteoric material (Winnick et al. 2002).

A still unknown property of solar neutrinos is their magnetic moment. If they have a nonzero magnetic moment, variability of the neutrino flux by an inhomogeneous magnetic field in the solar interior could result. Recent histogram analysis of GALLEX-GNO and SAGE data indicates that the solar neutrino flux, in the energy range of gallium experiments, varies on a timescale of weeks. A "resonance statistic", which takes the depth dependence of the internal rotation rate into account, yields strong evidence that modulation of the neutrino flux is occurring in the convection zone, and no evidence that modulation is occurring in the radiative zone (Sturrock & Weber 2002).

Even more exotic, helioseismology can now be used to infer the presence of dark matter in the solar neighborhood. If *weakly interacting massive particles* (*WIMPs*) accumulate in the center of the Sun, they transfer additional energy from the solar core and change the luminosity of the Sun up to ≈0.1%, which is now within the reach of helioseismic detection. This limit implies for WIMPs a mass of 60 GeV and an annihilation cross section of $10^{-32}\ \mathrm{cm}^3\ \mathrm{s}^{-1}$ (Lopes et al. 2002).

2.2. Seismology inside and behind the Sun

2.2.1. p-, f-, g-, and r-Modes

Helioseismology reaches now, after decade-long sampling, unprecedented precision for *p*-mode oscillations (Chaplin et al. 2002; Di Mauro et al. 2002). The latest analysis of 3456 days of BISON data yielded fractional frequency precision levels of $\approx 10^6$ for many low-l p-modes (Chaplin et al. 2002). Changes in the p-mode frequency in the order of $\delta\nu = 251 \pm 7$ nHz for the maximum of the solar cycle 23 could now be predicted (Jain et al. 2002). Since such high levels of precision have been achieved for the global frequencies, the helioseimic analysis focuses now more and more on second-order effects, such as suppression of p-mode power by local magnetic fields (Jain & Haber 2002), e.g., the power and lifetime were found to be reduced by about 40% by an active region (Komm et al. 2002; Rajaguru et al. 2001), on the splitting of f- and p-mode frequencies due to presence of magnetic fields (Pinter et al. 2001) or due to coupling to slow resonant MHD waves (Vanlommel et al. 2002), on the subsurface rotation rate gradient (Corbard & Thompson 2002), but also on systematic differences between MDI and GONG measurements (Schou et al. 2002).

Searches for gravity waves (g-modes) continued, using 5 years of GOLF data, yielding new upper limits of $\lesssim 6$ mm/s (Gabriel et al. 2002), but still no real detection of gravity waves.

Rossby-like modes (r-modes), which essentially are surface deformation waves, are controlled by the differential rotation rate on the solar surface, and thus strongly anisotropic like *Rossby waves* in geophysics. New theoretical work, based on the most unstable modes with periods of ≈1–3 yr, 18–30 yr, and 1500–20,000 yr, with growth times of $\approx 10^2$, 10^3, and 10^5 years, considers r-modes as drivers of the convective zone, which could explain short-term fluctuations of the rotation, the variability of the solar cycle, and abrupt changes of the terrestrial climate in the past (Dzhalilov et al. 2002).

2.2.2. Meridional Flows

Not enough, besides the non-coupling components, the spheroidal p-, f-, and g-modes (for which the main restoring forces are pressure gradient and buoyancy), the r-modes (surface deformation waves), there are also toroidal modes (Unno et al. 1989), which we might call *t-modes* (why not?). Torsional oscillations, in which the entire convective envelope appears to be involved, with the phase propagating poleward and equatorward from midlatitudes at all depths throughout the convective envelope, have been observed in form of *meridional flows*, i.e., migrating bands of slower and faster rotation during the last 11-year solar cycle (Vorontsov et al. 2002; Beck et al. 2002; Chou & Dai 2001; Haber et al. 2002; Petrovay & Forgacs-Dajka 2002). The meridional flows were found to exhibit a striking asymmetry in the northern and southern hemispheres, which might have a profound impact on the transport of angular momentum and magnetic field in the surface layers (Haber et al. 2002). Torsional oscillations have been reproduced with models that incorporate the nonlinear feedback between the magnetic field and the rotational profile via the Malkus-Proctor feedback mechanism (Phillips et al. 2002).

2.2.3. Where Is the Solar Dynamo?

Where is the solar dynamo located, ask the dynamo modelers (Dikpati et al. 2002). After all this success with flux transport dynamo models which can reproduce the correct cycle length as well as the phase relationship between the toroidal and poloidal components (α-Ω dynamo), it is suddenly not clear anymore whether the driver is rooted just below the photospheric surface, where a radial gradient of the angular velocity was found (Corbard & Thompson 2002), or whether the driver is buried deep down in the overshoot layer between the radiative and convective zone, in the highly-sheared tachocline (where the latitudinal differential rotation above shrinks to solid rotation below). New dynamo simulations were attempted with the subphotospheric driver without involvement of the tachocline, but it was found that such a model violates the observed polarity relationship with polar fields (Dikpati et al. 2002). Therefore, the tachocline is still a key player for the generation of strong magnetic fields, which ultimately are observed at the photospheric surface in sunspots, and thus a number of theoretical studies focused on the dynamics of the tachocline (Brun et al. 2002; Gilman & Dikpati 2002; Forgacs-Dajka & Petrovay 2001, 2002; Garaud 2001, 2002; Miesch 2001; Xiong & Deng 2001), which might oscillate with a period of 22 years (Forgacs-Dajka & Petrovay 2001). Equally interesting is the dynamics of magnetic flux tubes that emerge from the tachocline to the surface (way more complicated than the hydrodynamics of an emerging submarine), where effects like heat diffusion and thermal shadows (Moreno-Insertis et al. 2002), excitation of transverse flux tube oscillations and metallicity of the ambient medium (Musielak & Ulmschneider 2002a, 2002b; Musielak et al. 2002a), turbulent convection (Rubinstein & Zhou 2002), mesogranulation patterns (Cattaneo et al. 2001), the exact inversion of the internal rotation rate (Eff-Darwich et al. 2002), and the boundary conditions of torsional oscillations matter (Tavakol et al. 2002). It is amazing that the knowledge of the internal rotation rate relative to the surface rotation rate differs from 20% (Eff-Darwich et al. 2002) up to factors of 10–50 in some theoretical hydrodynamic models.

2.2.4. Backside Imaging of the Sun

The most impressive achievement of recent helioseismology is perhaps the first seismic images of the solar interior at the far side (or back side) of the Sun (Braun & Lindsey 2001). What could be less accessible in our solar system? The trick is to apply phase-sensitive helioseismic holography to MDI or Gong+ data. This way Braun & Lindsey (2001) demonstrated how acoustic travel-time perturbations could be mapped over the entire portion of the Sun facing away from Earth. Needless to say that this method fills the otherwise invisible data gap to forecast the appearance of active regions at the east side of the Sun and the related space weather effects. Of course, the accuracy is limited by the spatial resolution of the low-order *p*-modes, but fat active regions probably cannot fall through the fishing net.

2.3. Photosphere

2.3.1. *Are Granular Flows Self-organized or Random?*

From the longest (11 hr) uninterrupted movies of solar granulation, taken with the Swedish Vacuum Solar Telescope (La Palma, Canary Islands) with a cadence of 21 s, photospheric flow structures were studied with local correlation tracking. The transport of granules was found to exhibit a hierarchical structure of mesogranular and supergranular flows, similar to the self-organizing structures in *curved convection rolls experiments* (Getling & Brandt 2002). The same results, however, were also claimed to be consistent with a completely random and changing flow pattern that does not require any self-organization of the granular flows (Rast 2002). Other studies find that the temporal coherence time of granulation is consistent with a turbulent Kolmogorov spectrum (Hirzberger 2002; Abramenko et al. 2001, 2002), that some recurrently fragmenting granules survive by means of their descendants for more than 3 hr (Müller et al. 2001), but that only large granules with size scales of $\gtrsim$2500 km and lifetimes of $\gtrsim$0.5 hr represent reliable tracers of the surface velocity field (Rieutord et al. 2001). It was reassuring to hear that supergranulation flows measured in white light could also be recovered by simultaneous measurements in UV with *TRACE* (Krijger et al. 2002). From Doppler-shift measurements, radial flows for typical supergranules were found to have speeds of ≈10% that of their associated horizontal flows, or about $v \approx 30$ m s^{-1} (Hathaway et al. 2002).

2.3.2. *Elementary Building Blocks of the Magnetic Field*

Interest is focused on the smallest magnetic flux concentrations, such as "micropores" in intergranular lanes (with sizes of 1″-2″ and lifetimes of 10–100 s), in the belief that they are the elemental "building blocks" of the magnetic field of which large-scale structures in active regions are formed. An underlying question is whether weak internetwork fields dominantly represent remnants of active region flux that is recycled by granular and supergranular convection, or is a local dynamo the dominant agent for production and maintenance of the internetwork flux? At an angular resolution of ≈1″, half of the magnetic flux in the quiet Sun resides in the weak internetwork flux, but these regions occupy over 90% of the area (Lites et al. 2002). The flux imbalance of the internetwork region is considerably smaller (1/3) than that of the network, suggesting that internetwork flux arises primarily from a local dynamo, not from the continual recycling of network flux (Lites et al. 2002). Far below a resolution of $\ll$1″, the average magnetic flux of $B \approx 10$–30 measured in the network and internetwork of the quiet Sun, can be decomposed into a significant fraction of kilogauss fields with very small filling factors, as inferred from a novel *principal component analysis* of the observed Stokes profile (Socas-Navarro & Sánchez-Almeida 2002). Hunting for the smallest magnetic flux concentrations was pursued with pixel sizes down to 0″.2 × 0″.5 (Hartj & Kneer 2002). Quite a number of authors worried about systematic errors in weak-field measurements, such as calibration issues related to the majority polarity bias (Berger & Lites 2002), accuracy due to limited wavelength sampling (Graham et al. 2002), projection effects (Li 2002a), and modeling of line profile asymmetries and wings (Miller-Ricci & Uitenbroek 2002; Sigwarth 2001), or tried to stretch the spatial resolution to the limits with phase diversity or speckle imaging methods (Loefdahl et al. 2001; Suetterlin et al. 2001). A wealth of new detailed measurements were reported from the newly commissioned THEMIS telescope on the island Tenerife (Bommier & Molodij 2002; Mein 2002; Berrilli et al. 2002; Faurobert et al. 2001; Lepreti 2001). Weak magnetic fields manifest themselves also in the Hanle effect, which has been for the first time spatially mapped together with the Zeeman effect through Stokes polarimetry with a narrow-band universal filter (Stenflo et al. 2002). It was concluded that the weak depolarizing magnetic field has still unresolved mixed polarities on subarcsecond scales (Stenflo et al. 2002).

2.3.3. *How Do Elementary Flux Tubes Die?*

There are two competing models about the origin of the solar magnetic field: (1) flux tubes are generated at the base of the convection zone and transported to the surface by convective flows of a turbulent dynamo; (2) small-scale (fast) dynamos that operate near the surface, where turbulent granular and supergranular flows generate small-scale, highly-intermittent magnetic fields, e.g., as simulated by Emonet & Cattaneo (2001). Can the observations distinguish between the two theories? A 3-hr observation revealed that flux concentrations that recently emerged in the internetwork are rapidly (within 10–15 minutes) dispersed after emergence, and that the initially quite concentrated (≈0″.5) magnetic flux gets spread out and shredded by the granular flows, rather than cancelled by opposite polarities (DePontieu 2002), and thus seem to favor small-scale fast dynamos near the surface. Other studies report that emerging flux tubes are passively transported by the supergranular flow to the magnetic network where they eventually meet oppositely directed fields and are annihilated (Simon et al. 2001; Chae et al. 2002a). The subtle answer to our initial question seems to hinge on the observational capability to distinguish whether an emerging small-scale flux tube dies by shredding or by annihilation! Additional complications of the not-understood dynamics are upward-propagating acoustic waves in internetwork grains (Hoekzema et al. 2002; Rosenthal et al. 2002), horizontally undulating moving features (Bernasconi et al. 2002), and helicity transport (Chae 2001; Grigoryev & Ermakova 2002).

2.4. Sunspots

2.4.1. *Omnipresent Oscillations*

The 3-minute oscillations in sunspots are now detected in almost every wavelength and by every instrument that is capable of a cadence of a minute or so. The multi-wavelength detection helps then to probe the oscillation amplitude as function of temperature, and is was found that the oscillation amplitude above the umbra increases with temperature, reaches a maximum in emission lines forming at $T \approx 100{,}000$–$200{,}000$ K, decreases with higher temperature (Brynildsen et al. 2002a), reaches a minimum at a temperature of $T \approx 1.0$ MK (O'Shea et al. 2002), and increases again towards higher coronal temperatures. Observations with high signal-to-noise ratios show deviations from pure linear oscillations. The power spectra, however, show a single peak close to 6 mHz, and thus do not support the sunspot filter theory (Brynildsen et al. 2002a), which would predict multiple resonant peaks produced by a chromospheric resonator, equally spaced ≈1 mHz in frequency. However, a number of oscillation frequencies were found to exist cospatially and simultaneously, i.e., at 5.40, 7.65, and 8.85 mHz (O'Shea et al. 2002). Instead, the 3-minute sunspot oscillations rather seem to be modulated by global *p*-mode oscillations that originate beneath the sunspots and are modified by the magnetic field (Zhukov 2002), while propagating upward into the corona. The disturbances travel outward into the corona with a propagation speed of $v \approx 122 \pm 43$ km s^{-1}, which corresponds to the expected sound speed in the corona, and thus identifies the oscillatory disturbances as longitudinal slow magnetoacoustic waves (De Moortel et al. 2002a, 2002b, 2002c; O'Shea et al. 2002). Lower down, as observed in Ca II 8542 Å, running penumbral waves propagate with an average phase velocity of 16 km s^{-1} (Tziotziou et al. 2002), which corresponds to the sound speed in the temperature minimum ($T \approx 10{,}000$ K) region. At a height that corresponds to the second and third harmonic gyrofrequency, the same sunspot oscillations were also detected in radio wavelengths, with peak frequencies of 6.25–6.45 mHz and 4.49–5.47 mHz (Nindos et al. 2002).

2.4.2. *Magnetoconvection of "Complete" Sunspots*

The flow dynamics and thermodynamic structure of sunspots can now be understood pretty well with MHD models that mimic the magnetoconvection of "*complete sunspots,*" which includes the subphotospheric layers as well as the coronal volume above sunspots (Hurlburt et al. 2002). The formation and stability of sunspots appears to be controlled by the large-scale convection cell flowing inward beneath the penumbral surface and rolling back outward below some shallow depth of 1500–5000 km, as reconstructed with helioseismic tomography (Zhao et al. 2001) and reported in Ap01. The new "*complete*" MHD simulations by Hurlburt et al. (2002) produce pore-like solutions with small total magnetic flux as well as magnetoconvective traveling wave solutions at large total flux, which accordingly feed back different Poynting fluxes to heat the overlying corona. Observations, however, display always more complexity than the best theoretical models can handle: a "fluted" field geometry in the convergence zone and oppositely directed flows that slip past one another (Lites et al. 2002), penumbral grains (Sobotka & Suetterlin 2001), umbral dots (Tritschler & Schmidt 2002), redshifts in sunspot plumes (Brynildsen et al. 2002b), the azimuthal (Schlichenmaier et al. 2002) and height dependence of the Evershed effect in the penumbra (Rouppe van der Voort 2002; Hirzberger & Kneer 2001), asymmetric Stokes profiles (Schlichenmaier & Collados 2002), persistent slow plasma flows around sunspots (Georgakilas et al. 2002), possibly caused by the proper motion of sunspots (Yurchyshyn & Wang 2001).

2.5. Chromosphere

2.5.1. *How Cool Is the Chromosphere?*

While the traditional standard model of the chromosphere contains a temperature minimum region bottoming out at 4400 K in an altitude of ≈500 km above the photosphere, observations of the 4.7 μm rotation-vibration bands of the CO molecule display much cooler brightness temperatures of $T_B =$ 3700 K (Ayres 2002). Thus the somewhat controversial proposal was made that the low chromosphere is not hot but instead permeated by CO-cooled clouds. In a recent study (Ayres 2002), the arguments are reiterated that traditional chromospheric models fail at least two key tests: (1) the center-to-limb behavior of 4.7 μm CO $\Delta v = 1$ fundamental rotational-vibrational bands, and (2) off-limb emissions of the same species. Even state-of-the-art, spatially and temporally intermittent, radiation-hydro models of Carlsson & Stein (1997) are considered to be *not cold enough* to reproduce the ubiquitous ultraviolet emission, which constitutes a *full-time cold COmosphere* (Ayres 2002).

2.5.2. *How Wild Is the Chromosphere?*

The time of hydrostatic models of the chromosphere is definitely over. Most state-of-the-art models contain some time-dependent behavior, which in the time average cannot be reproduced by a hydrostatic model. Even steady-state models include at least flows, which strongly affect ionization and radiative losses of H and He (Fontenla et al. 2002). New radiation-hydro models include, e.g., dynamic hydrogen ionization (Carlsson & Stein 2002) or the effects of coherent scattering on radiative losses (Uitenbroek 2002). *TRACE* movies confirm a lot of dynamic features reproduced by radiation-hydro codes: the dichotomy in oscillatory behavior between network and internetwork, upward propagation above the cutoff frequency, the onset of acoustic shock formation in the upper photosphere, phase-difference contrast between pseudo-mode ridges and the interridge background, enhanced 3-minute modulation aureoles around network patches, a persistent low-intensity background pattern largely made up of internal gravity waves, ubiquitous magnetic flashers, and low-lying magnetic canopies with much low-frequency modulation (Krijger et al. 2001). Velocity oscillations in He I 10830 Å are seen in chromospheric heights of 1100–1800 km (Muglach & Schmidt 2001) and in inter-plume regions (Banerjee et al. 2001a, 2001b). Chromospheric oscillations (4–15 minutes) in network bright points suggest not acoustic waves, but rather magnetoacoustic or magnetogravity wave modes (McAteer et al. 2002). *Magnetic shadows* were also discovered, which for some unknown reason suppress the characteristic 3-minute oscillations in internetwork regions (McIntosh & Judge 2001). Another puzzle is the excess of Lyman alpha emission measured with the *VAULT* sounding rocket, which exhibits a detailed correlation with the moss seen in 171 Å EUV emission by *TRACE*, but requires another mechanism besides classical heat conduction from the corona (Vourlidas et al. 2001). The "wild" chromosphere and transition region continues to dazzle and challenge the imagination of theoretical modelers.

2.6. Corona

2.6.1. Hydrodynamic Controversies

Although the stunning time-lapse movies from *TRACE*, *SoHO*, and *Yohkoh* give us the illusion that everything is highly dynamic in the solar corona, many brightness changes in coronal loops actually evolve on time scales that are much longer than the sound crossing time, and thus their pressure balance is still close to hydrostatic equilibrium. Recent studies scrutinize the hydrostatic energy equation, which, in principle, is able to quantify the unknown coronal heating function, since the rate of the energy input can be calculated by balancing it against the observable energy losses by radiation and thermal conduction. However, different authors obtained contradicting results, depending on what terms they neglected in the energy equation, how good they resolved individual loops, how good they subtracted the background corona, whether they neglected the hydrostatic weighting bias, whether they used narrow-band or broad-band temperature instruments, or whether they determined the temperature by inversion of filter ratios or by forward fitting. The *TRACE* instrument has the highest spatial resolution ($0''.5$ pixel size), being most powerful to resolve individual loops and to subtract the correct background, and yields consistently a heating function concentrated in the lowest 10 Mm of the solar corona (Ap01). *Yohkoh*/SXT has a broadband temperature response and is highly biased towards the hottest plasmas, which favors looptop heating (Priest et al. 2000), because of the notorious hydrostatic weighting bias resulting from the background corona, but can be reconciled with footpoint heating if the cooler background is subtracted (Aschwanden 2001). *SoHO*/CDS has many temperature filters, and thus the potential for more comprehensive temperature modeling, but the poor resolution (degraded now to $\approx 10''$) shows only blurred fat loop bundles, which consist of tens or hundreds of loopstrands with different temperatures, and thus produced the puzzling result that (unresolved) loops seen with CDS appear to have a very broad temperature distribution (Schmelz et al. 2001; Schmelz 2002; Martens et al. 2002), but multi-loop simulations clearly demonstrated that the near-isothermal temperature structure of individual loop strands, established with triple-filter data (Chae et al. 2002b), can be determined with a *TRACE*-like instrument (Aschwanden 2002a).

Footpoint-heated loops have hydrostatic solutions with an almost isothermal temperature structure in the coronal segments, but have a significantly larger base pressure than uniformly heated loops (RTV model), characteristics that can be used as a diagnostic for solar (e.g., Landini & Landi 2002; Brkovic et al. 2002b) as well as for stellar coronae (Peres et al. 2001; Schrijver & Aschwanden 2002; Orlando et al. 2001). Coronal loops with short heating scale heights ($s_H/L \lesssim 1/3$), however, create the problem that they are thermally unstable, and thus cannot stay in hydrostatic equilibrium. One possible solution is that they could be stabilized by steady-state or siphon flows. Flows have indeed been detected in coronal loops with speeds of $v = 5$–40 km s^{-1} (Winebarger et al. 2001, 2002b), as jets in interconnecting loops (Farnik & Svestka 2002), and are included in more sophisticated hydrostatic loop models (Petrie et al. 2002). Another possible solution is that active region loops consist of a number of small-scale strands that are impulsively and consecutively heated, and this way exhibit a prolonged cooling time, as demonstrated with hydrodynamic simulations (Warren et al. 2002)

2.6.2. The Birth of Coronal Seismology: Loop Oscillations

Bernie Roberts from St. Andrews University in Scotland made it clear in several review talks that we entered a new field, namely the new-born discipline of "*coronal seismology.*" While the sister field of *helioseismology* studies global oscillations in the solar interior, *coronoseismology* is focused on local oscillations of resonant systems, such as coronal loops that are excited in (transverse) sausage modes, kink modes, or (longitudinal) slow magneto-acoustic modes (e.g., Roberts 2001a). Such oscillations are usually triggered by a destabilizing filament or a flare (Schrijver et al. 2002). *TRACE* discovered a sizable number of coronal loops oscillating in (transverse) kink mode, with typical periods of $P \approx 2$–33 minutes, all strongly damped after a few oscillation periods (Aschwanden et al. 2002). *SoHO*/SUMER discovered also a large number of oscillating hot ($T \approx 7$ MK) loops with periods of $P \approx 10$–30 minutes, which exhibited a stronger oscillatory signal in the Doppler shift than in the (phase-shifted) flux amplitude (Wang et al. 2002c), and were interpreted in terms of (longitudinal) slow magneto-acoustic waves (Ofman & Wang 2002). Coronal oscillations were even detected in white light during eclipses, with periods down to $P \approx 6$ s (Williams et al. 2002; Pasachoff et al. 2002). A major theoretical challenge is the interpretation of the physical damping mechanism of coronal loop oscillations. Arguments were brought forward pro (DePontieu et al.

2001) and contra wave leakage (Ofman 2002), for phase mixing (Ofman & Aschwanden 2002), for resonant absorption (Goossens et al. 2002; Ruderman & Roberts 2002), and for thermal conduction (Ofman & Wang 2002).

The detection of oscillating loops requires high spatial resolution in the order of ≈1″, which explains the successful detections by *TRACE* and *SUMER*, while searches with CDS were less successful (Harrison et al. 2002). Changing periods are more suitably explored with wavelet methods (De Moortel et al. 2002d; Ireland & De Moortel 2002).

2.6.3. Coronal Seismology Part Two: Propagating Waves

Standing waves have fixed nodes, propagating waves have moving nodes, the physics textbook says. Alas! Same thing with coronal seismology. Propagating waves have been detected in the solar corona in a large variety: Moreton waves, EIT waves, shock waves, blast waves, magneto-acoustic waves, acoustic waves, etc. While the first five wave types were preferentially detected after flares or CMEs, the last type, i.e., acoustic waves, are less conspicuous and harder to detect because of their low contrast. Nevertheless, a systematic search with wavelet analysis brought a larger number of events to daylight where acoustic waves (with coronal sound speeds of $v \approx 122 \pm 43$ km s^{-1}) propagate along the lowest coronal scale height of loops rooted near sunspots, with typical periods of $P = 4.7 \pm 1.5$ minutes (De Moortel et al. 2002a, 2002b). However, a careful distinction of the location of the footpoints revealed that loops rooted inside sunspots have periods of $P = 172 \pm 32$ s, while loops rooted outside of sunspots have periods of $P = 321 \pm 74$ s, which is the familiar pattern of 3-minute and 5-minute global oscillations inside and outside of sunspots. It was therefore concluded that the observed longitudinal coronal oscillations are not flare-driven, but rather excited by the global (subphotospheric) oscillations that leak through the transition region upward into the corona (De Moortel et al. 2002e).

EIT waves are the most spectacular waves, they propagate concentrically over the entire solar surface. A recent review of 173 EIT waves revealed that all are triggered by a *coronal mass ejection* (*CME*) event, while flares and type II radio bursts are less frequently associated, in some contradiction to the belief that EIT waves are related to Moreton waves, which are flare-associated (Biesecker et al. 2002). Moreton waves were simultaneously observed in Hα and/or in soft X-rays (Narukage et al. 2002; Khan & Aurass 2002). A clearer picture of the relation between Moreton and EIT waves (Vrsnak et al. 2002) was obtained with an MHD simulation of the CME phenomenon: the legs of the shock produces Moreton waves, while the slower moving front ahead of the shock is interpreted as EIT wave (Chen et al. 2002). However, another study confirms the cospatiality of Moreton and EIT wave fronts, but interprets the observed characteristics—deceleration, broadening, and decrease of intensity of the profiles—in terms of a fast-mode shock ("blast wave") rather than a CME-associated magnetic field evolution (Warmuth et al. 2001). Another study goes as far as to simulate with a full three-dimensional MHD code how an EIT wave slams into an active region, finding that the current-carrying active region is destabilized by the impact of the wave (Ofman & Thompson 2002).

2.6.4. Small-Scale Variabilities and the End of the Nanoflare Story

While a single hot water droplet cannot heat a cool rock, a geyser can. The same question still lingers among solar observers: Is the sum of all small-scale variabilities detected in EUV and soft X-rays enough to supply the heating budget of the solar corona. One kind of small-scale variabilities are *soft X-ray microflares* (also called *active region transient brightenings*). They behave like small flares, in form of multiple- or single-loop structures, which become filled with heated plasma, accompanied by a small-scale magnetic flux emergence in 50% of the cases (Shimizu et al. 2002). A different kind are *blinkers*, mostly detected in the cool (transition region temperature) O v line, but rarely at coronal temperature lines of Mg ix or x, which were statistically studied in the quiet Sun (Bewsher et al. 2002; Brkovic et al. 2002a) as well as in active regions (Parnell et al. 2002), and it was proposed that they are produced by granular compression of a network junction, causing subtelescopic fibril flux tubes to spend more of their time at transition-region temperatures and so to increase the filling factor temporarily (Priest et al. 2002a). Another kind of small-scale variabilities is called *EUV explosive events*, which were found to be related to blinkers (Madjarska & Doyle 2002), but because of their chromospheric origin seem not to be directly connected to the corona and thus not relevant for coronal heating (Teriaca et al. 2002). Their correlated variability in 171 Å could be due to contamination by the cool O vi line ($\lambda = 172$ Å) rather than due to the hotter coronal Fe ix/x line (Winebarger et al. 2002c). Their size distribution was found to have a steep power-law slope of $\alpha = 2.9 \pm 0.1$ (Winebarger et al. 2002a). Also *Ellerman bombs* (short-lived small-scale events detected in Hα) were found to have a size-distribution with a slope of $\alpha \approx 2.1$, and their clustering revealed a fractal dimension of $D \approx 1.4$ (Georgoulis et al. 2002). In principle, steeper slopes than the critical limit of $\alpha = 2$ imply a divergence of the energy distribution at their lower limit, and thus could boost the energy budget of the smallest events above the requirement for coronal heating. Some of the delicate biases that enter nanoflare statistics were reviewed by Benz & Krucker (2002), but the biggest biases were found in the temperature incompleteness of narrowband filters and in the negligence of the fractal geometry of nanoflares, which after correction, produce a consistent power-law slope of $\alpha \approx 1.5$–1.6 at all scales from large flares down to the smallest EUV nanoflares, making nanoflares entirely insignificant for coronal heating (Aschwanden & Parnell 2002).

2.6.5. What Does Really Heat the Corona?

Although Parker's nanoflare hypothesis did not work out to explain the heating of the solar corona, at least not from the statistics of small-scale brightenings observed in EUV and soft X-rays, the basic physical process of magnetic twisting and braiding could still be at work and heat the corona, if the energy is dissipated in form of slowly-changing processes that gradually fill coronal large-scale structures with heated chromospheric plasma. Promising new three-dimensional MHD simulations of this process including the transition region have been performed by Gudiksen & Nordlund (2002) which reproduce slender coronal loops, the observed heating scale heights, and upflows of heated plasma. Other (two-dimensional) MHD simulations reproduced more realistically magnetic reconnection in the chromosphere by including the gravitational stratification and found a slower reconnection rate than the classical two-dimensional reconnection (Galsgaard & Roussev 2002; Roussev & Galsgaard 2002; Roussev et al. 2002). Also other variants of three-dimensional MHD simulations that include the gravitational stratification and the chromosphere consistently can reproduce the observed footpoint heating and upflows in coronal loops, such as slingshot magnetic reconnection during two-loop interactions (Sakai et al. 2002a), formation of multi-thread loops driven by chromospheric up- and downflows (Sakai & Furusawa 2002), a generalized magneto-Bernoulli mechanism (Mahajan et al. 2002), or slowly-evolving double Beltrami two-fluid equilibria (Ohsaki et al. 2002). One driver of these footpoint braiding models is the emergence (Seaton et al. 2001; Parnell 2002; Shimizu et al. 2002) and migration of photospheric magnetic flux tubes to supergranule boundaries, where they form myriads of coronal separatrix surfaces (Schrijver & Title 2002), where dissipation of energy occurs along sharp boundaries, analogous to geophysical plate tectonics (Priest et al. 2002b). The statistics of these processes was also explored with cellular automata models (Krasnoselskikh et al. 2002; Podladchikova et al. 2002).

The alternative to slowly-changing currents (DC models) are fast-changing currents (AC models), e.g., high-frequency Alfvén waves, which can be excited by outflows from coronal reconnection events (Voitenko & Goossens 2002) or by azimuthal footpoint motions (De Groof & Goossens 2002a, 2002b). Alfvén waves, however, have in the homogeneous corona a dissipation length of at least a solar radius, and thus cannot explain the observed footpoint heating of coronal loops. They may, however, contribute to the heating of the open-field (solar wind) or diffuse large-scale corona within 1–2 solar radii, e.g., by MHD turbulent cascades (Dmitruk et al. 2002). Other waves, like ion-cyclotron waves, may contribute to the heating of coronal funnels (Li 2002c) and the solar wind, as evident from the ion temperature anisotropies. In addition, although acoustic waves have been ruled out to contribute to coronal heating, a wideband spectrum of slow magnetoacoustic waves with a suitably low cutoff in wavenumber was found to be able to explain the footpoint heating of coronal loops (Tsiklauri & Nakariakov 2001).

To summarize, DC models seem to become the workhorse for heating processes of coronal loops, which generally show upflows and heating near the footpoints, while AC models seem to dominate the heating in the outer corona (1–2 solar radii), in form of Alfvénic or ion-cyclotron resonant absorption.

2.6.6. Magnetic Field Modeling

Still we are reading the following sentence in solar physics papers: *At the present time there is no general method available which allows the direct and accurate measurement of the magnetic field at an arbitrary point in the corona*, which becomes more and more alarming the closer we move to the launch date of the *STEREO* mission. Regardless what theoretical models say, based on extrapolating the photospheric magnetic field, the ultimate judge are the observed magnetic structures, e.g., the thin crispy coronal loops seen in EUV. A faithful attempt was undertaken to fit linear force-free field lines to the three-dimensional geometry of stereoscopically observed EUV loops (Wiegelmann & Neukirch 2002), of course requiring a different α-value for each loop. Other new attempts include the inference of the magnetic scale height from free-free emission polarization measured in radio and EUV (Brosius et al. 2002), from gyroemission (Huang & Nakajima 2002), or tomographic reconstructions (Frazin & Janzen 2002).

The non-potential character of the magnetic field was studied in terms of twisted and sigmoid structures which exhibit various degrees and changes of magnetic helicity and chirality (Bao et al. 2002; Kusano et al. 2002; Kusano 2002; Gibson et al. 2002; Liu et al. 2002b; Portier-Fozzani et al. 2001; Regnier et al. 2002). One controversial result is that the photospheric shear motion and the flux emergence process were found to equally contribute to the helicity injection of an active region (Kusano et al. 2002), while others concluded that shearing motions are a relatively inefficient way to bring magnetic helicity into the corona (Demoulin et al. 2002a), and that the helicity transferred to the corona comes mainly from continuous emergence of twisted flux tubes (Demoulin et al. 2002b). The helicity removed by a CME from an active region was estimated to be a factor of 4–64 larger than the helicity injected by horizontal shearing motion, and thus the source of helicity was attributed to the emergence of twisted flux tubes from the convection zone (Nindos & Zhang 2002). Theoretical efforts focused on the minimum energy state of the solar corona with null-point reconnection and current sheets (Antiochos et al. 2002; Zhang & Low 2002; Choe & Cheng 2002; Uzdensky 2002), the orientational relaxation of active region bipoles (Longcope &

Choudhuri 2002; Mackay et al. 2002), or analytical solutions of reconnecting magnetic fields (Watson & Craig 2002). Gary (2001) was rethinking the paradigm of the plasma β-parameter, which is generally assumed to have a low value in the solar corona, but made a quantitative argument that it is likely to exceed the critical value of unity in coronal heights of $\gtrsim$0.2 solar radii, and this way might explain the curious cusps observed above active regions, or streamers (Suess & Nerney 2002).

Another mystery is the magnetic field at coronal hole boundaries. In a first systematic morpholocigal study of coronal hole boundaries in soft X-rays, it was concluded that continuous magnetic reconnection is necessary to maintain the coronal hole integrity, which would otherwise be wound up by differential rotation, but strangely, no direct signs of reconnections were found (Kahler & Hudson 2002)!

A quite novel method was demonstrated to probe the magnetic field in the solar corona by birefringence effects of the two magnetoionic (X and O) modes, for which the frequency-dependent time delay (in the order of $\approx$1 ms) in both polarizations could be measured as function of the radio frequency (Fleishman et al. 2002a, 2002b).

2.6.7. *Elemental Abundances and Atomic Physics*

Simultaneous radio and EUV measurements can now be used to constrain the coronal abundance of Fe relative to H, because the EUV emissivity is proportional to the Fe abundance, while radio free-free emission is proportional to the H abundance. With this novel method, pioneered by Stephen White (Ap00), the absolute Fe abundance was measured in the corona to be 7.8×10^{-5}, which has an enrichment factor of 2.4 relative to the standard photospheric Fe abundance (Zhang et al. 2001). Even larger enhancement factors were measured in a CME-producing active region, i.e., first ionization potential enhancements of 7–8 compared with the usual factor of 3–4 (Ciaravella et al. 2002).

Atomic physics parameters used in solar physics have been steadily improved, by measurements of the resonance strengths and energies for dielectronic recombination (Savin & Laming 2002), high-lying electronic shells (Doron et al. 2002), escape probabilities and absorption factors (Fischbacher et al. 2002), modeling of observed S XII and Fe XXI lines (Keenan et al. 2001, 2002a, 2002b), Fe XIII lines (Landi 2002), and Fe XXV (Dzifcakova & Kulinova 2001). Major progress cumulated in the fourth release and update of the atomic database CHIANTI (Landi et al. 2002a, 2002b), which contains atomic data over the entire wavelength range of $\lambda = 1$–1700 Å. Needless to say that this most comprehensive astrophysical atomic database contains many thousands of soft X-ray and EUV lines, way more than you need to describe the flavor of the Italian wine after which the database was named.

2.6.8. *Filaments and Prominences*

Filaments and prominences are just two sides of the same coin, masses of cool and dense gas embedded in the hot coronal plasma, which can be observed in emission above the limb (as prominences) or in absorption against the solar disk as dark filaments (Chiuderi-Drago & Landi 2002). The filaments, however, appear to be much more extended in EUV lines than in Hα, because the ratio of the Lyman continuum to Hα opacity reaches factors of 50–100 (Heinzel et al. 2001). The three-dimensional magnetic field topology often involve separators and *bald patches* (Mandrini et al. 2002), sigmoidal field lines (Marque et al. 2002; Pevtsov 2002), but it is often not clear whether magnetic reconnection occurs *before* or *after* eruption (Deng et al. 2002; Sterling et al. 2001a). The dynamics of filaments was studied in terms of proper motion (Ambroz & Schroll 2002) and non-radial motion (Filippov et al. 2001). Some filaments were observed to disappear suddenly in a coronal hole (Chertok et al. 2002) and automated filament disappearance detection systems were designed promptly (Gao et al. 2002), since CMEs are often associated with erupting magnetic structures or disappearing filaments (Yurchyshyn et al. 2001).

Prominences are dynamically interesting because they show oscillatory MHD behavior (Diaz et al. 2001; Oliver & Ballester 2002; Terradas et al. 2002) as well as instabilities that result into eruption. The question arises how exactly a prominence becomes unstable. Is it initiated by the magnetic field support (Ashbourn & Woods 2002), magnetic dips in three-dimensional sheared arcades (Aulanier et al. 2002), the interaction between a flux rope and an overlying sheared arcade (Chae et al. 2001; Yurchyshyn 2002), the removal of a strapping electric field above a sheared arcade (Hansen & Bellan 2001), magnetic reconnection accompanying photospheric flux cancellation (Wang 2001b), or magnetic flux emergence and magnetic flux injection (Shakhovskaya et al. 2002). A prominence may be heated during eruption and thus can brighten in emission (Filippov & Koutchmy 2002; Karlicky & Simberova 2002). Radio tracking of eruptive prominences show constant acceleration at heights $\gtrsim 0.5$ solar radii (Klein & Mouradian 2002), and 92% of eruptive prominences were found to be associated with CMEs (Hori & Culhane 2002). Prominence plasma is only partially ionized and the draining of hydrogen lasts typically a day, much longer than for helium (Gilbert et al. 2002). A nice review of the *SoHO* contributions to prominence science can be found in Patsourakos & Vial (2002).

2.7. Flares and CMEs

To be politically correct, we cannot treat flares and CMEs separately anymore, so we try to marry them in one joint Section. Subsections that address flare and CME aspects separately should be read with stereo glasses.

2.7.1. What Leads up to a Flare or CME?

Priest & Forbes (2002) write in their new review on flares: "*Two major advances in our understanding of the theory of solar flares have recently occurred. The first is the realisation that a magnetohydrodynamic (MHD) catastrophe is probably responsible for the basic eruption and the second is that the eruption is likely to drive a reconnection process in the field lines stretched out by the eruption.*" The fundamental role of the magnetic reconnection process as primary driver and energy source of flares and CMEs remained nearly unchallenged, except for a single alternative review with more emphasis on electric currents (Feldman 2002). The concept of three-dimensional magnetic reconnection and associated particle acceleration was even successfully reproduced with a laboratory experiment (Brown et al. 2002a).

A number of studies concentrated on the magnetic topology before the occurrence of flares and CMEs, finding sigmoid formation along quasi-separatrix layers (Fletcher et al. 2001; Gibson et al. 2002), sigmoid formation in the shear *between* active regions (Glover et al. 2001), inter-active region triggering of sympathetic flares (Wang et al. 2001b), magnetic helicity injection by photospheric horizontal motions that triggers homologous flares (Moon et al. 2002b; Zhang & Wang 2002a), rapid magnetic field changes before flares (Wang et al. 2002a; Spirock et al. 2002; Kim et al. 2002a), cancellation of magnetic flux just prior to a flare (Jennings et al. 2002), intrusion of a adjacent magnetic region (Ulrich et al. 2002), magnetic flux emergence before homologous flares and CMEs (Zhang & Wang 2002a, 2002b; Kurokawa et al. 2002), *EIT crinkles* that appear at well-separated locations magnetically connected with a coronal nullpoint (Sterling et al. 2001b) and thus being consistent with the *magnetic breakout model* of Antiochos, or changes in the helical structure leading up to eruption (Yan et al. 2001).

Numerical simulations reproduced the twisting of loops by photospheric vortex motion, resulting into kink instability and releasing of 35%–50% of the free magnetic energy (Gerrard et al. 2002), the twisting of flux tubes à la Gold-Hoyle (Ali & Sneyd 2002), the catastrophic evolution of a flux rope in a changing background field (Hu & Jiang 2001), or the accumulation of magnetic energy in a flare current sheet, which amounted to 5×10^{32} ergs in the 14 July 2000 flare (Bilenko et al. 2002).

2.7.2. Particle Acceleration, Gamma Rays, and Hard X-Rays

An extensive review summarized all what we learned about particle acceleration and kinematics in solar flares over the last decade, which is dominated by high-resolution imaging with *Yohkoh* and *TRACE* and by high-precision timing measurements with *CGRO* (Aschwanden 2002b). New trends start to apply three-dimensional magnetic reconnection scenarios instead of the traditional two-dimensional models of the Carmichael-Sturrock-Hirayama-Kopp-Pneuman-Tsuneta type. One of the most challenging tasks is still the inference of the electromagnetic fields in the reconnection region that are responsible for particle acceleration. Analytical models of magnetic reconnection were used to derive the scaling of high-energy particles as function of the electric resistivity in a current sheet (Craig & Litvinenko 2002; Heerikhuisen et al. 2002). A notorious problem of stochastic particle acceleration is the strong anisotropization, requiring additional pitch-angle scattering. This problem can now be solved by isotropization through the electron firehose instability (Messmer 2002). An interesting effect that was theoretically predicted is the formation of a bump-in-tail in the velocity distribution of collisionally stopped electron beams and the consequent beam-driven wave generation (Haydock et al. 2001). Particle acceleration seems also to be periodically modulated by oscillating loops, e.g., a period of $P = 6.6$ s was found in a flare (Asai et al. 2001). The period corresponded to the longitudinal Alfvénic transit time of the flare loop, and thus suggests the involvement of the fast kink mode. Sub-second pulses in gamma rays were also detected for the first time in correlation with sub-millimeter pulses (Kaufmann et al. 2002). Detailed reconstruction of the particle injection, trapping, and precipitation function in another flare did lead to a model of two interacting loops, where the larger serves as an efficient trap while the smaller provides the impulsive source (Lee et al. 2002a).

Gamma-ray observations of solar flares from the pre-*RHESSI* era still reiterating that the extended emission of the June 1991 flares are more likely to be produced by continuous particle acceleration than by long-term trapping (Rank et al. 2001). Line width and redshift measurements of nuclear de-excitation lines of ^{12}C, ^{16}O, and ^{20}Ne as function of the heliocentric angle provide information on the ions directionality, but current measurements are compatible with both downward isotropic distributions as well as with distributions with significant pitch-angle scattering (Share et al. 2002). Anisotropic velocity distributions could also be detected by Hα line polarization (Karlicky & Henoux 2002), but have not yet been detected in the pre-*RHESSI* era. New theoretical calculations of the cross-sections of nuclear deexcitation lines (Kozlovsky et al. 2002) and neutron lines (Hua et al. 2002) were performed, but a more dramatic improvement of gamma-ray line diagnostic is expected from the new *RHESSI* data. The selective ^{3}He acceleration in impulsive flares was explained in terms of reduced collisional energy losses by pre-acceleration of heavy ions (Litvinenko 2002).

Hard X-ray observations of the 14 July 2000 Bastille Day flare revealed for the first time a clear two-ribbon structure in >30 keV hard X-rays, that the first reconnecting loops are low-lying and highly sheared, while the later reconnecting loops are high-lying and less sheared, and that the hard X-ray spectrum at the outer edge of the flare arcade tends to be harder than at the inner edge (Masuda et al. 2001). The EUV double-ribbon structure was found to show a good cospatiality with the hard X-ray ribbons, as expected, but there were also surprises: deviations from the underlying magnetic field, bifurcations of the EUV ribbons, and magnetic flux imbalance (Fletcher & Hudson 2001). An analysis of nine flares revealed that UV flare footpoints brightenings precede the onset of hard X-ray emission, but in different loops than those which lighten up later in hard X-rays (Warren & Warshall 2001). The search for Masuda-type above-the-loop-top hard X-ray sources was extended to 18 flares and was successful in 15 events, so that it was concluded that this is a common feature of all flares (Petrosian et al. 2002). Hard X-ray emission was also for the first time detected from a CME-related fast ejection with a speed of $v \approx 1000$ km s^{-1} in heights of 200,000 km above the limb at energies of 23–53 keV, probably resulting from electrons trapped in expanding loops that form a part of the CME (Hudson et al. 2001).

2.7.3. Flare Multi-wavelength Observations

Many flare multi-wavelength studies include radio observations, among them the first *Siberian Solar Radio Telescope (SSRT)* radio images, taken at 5.7 GHz (Altyntsev et al. 2002), and the first *Solar Submillimeter-wave Telescope (SST)* 212 and 405 GHz observations at El Leoncito in Argentina (Kaufmann et al. 2002; Trottet et al. 2002), which show the first evidence of the gyrosynchrotron spectrum to extend above 200 GHz. Other imaging radio observations, benefitting from cospatial soft X-ray imagery of the flare plasma, disentangled the multi-loop structure of flares (Kundu et al. 2001; Garaimov & Kundu 2002), the trapping properties of flare loops (White et al. 2002), the cusp shape of flare loops (Grechnev & Nakajima 2002), the reconnection rate in a long duration flare (Isobe et al. 2002), a pulsating radio source above flare loops (Khan et al. 2002), moving gyrosynchrotron sources ($v \approx 6000$ km s^{-1}) and streaming electrons with a speed of $v \approx 90{,}000$ km s^{-1} (Yokoyama et al. 2002), shock-excited radio bursts from reconnection outflow jets (Aurass et al. 2002a), the motion of flare loop footpoint sources (Qiu et al. 2002), or the location of millisecond spike sources, which were found to be 20″–400″ away from primary flare sites (Benz et al. 2002). In non-imaging radio observations, modelers generally make use of the dynamic spectrum to substitute for the missing spatio-temporal information, i.e., to model turbulent reconnection outflows (Barta & Karlicky 2001) or the vertical motion of radio sources and shocks (Wang et al. 2001c). Theoretical studies on radio emission were concerned with electron cyclotron maser millisecond spikes (Vlasov et al. 2002), beam-driven plasma emission (Vasquez et al. 2002; Alves et al. 2002), radio scattering by plasma turbulence (Ledenev et al. 2002), or combinations thereof, i.e., maser-driven type III emission (Yoon et al. 2002) or type III emission via direct amplification (Wu et al. 2002b). Other worthwhile multi-wavelength studies dealt with unusual cases like an X-class flare *without* a CME (Green et al. 2002), an X-class flare with helically rotating spray ejecta (Pike & Mason 2002), or flares where the peak time of line broadening occurs *before* the hard X-ray peak (Ranns et al. 2001). Last but not least, human detection of solar flares becomes soon obsolete, new automated detection algorithms are now developed based on neural network concepts with back-propagation algorithms (Fernandez-Borda et al. 2002).

2.7.4. Thermal Flare Plasma Dynamics

While the previous sections about gamma rays, hard X-rays, and radio signatures all involve nonthermal particles, we deal in this section with the thermal flare plasma, which is seen in soft X-rays and EUV and is modeled with hydrodynamics (HD) or MHD. There is pretty much a consensus that the coronal flare plasma originates from chromospheric evaporation (upflows), as a result of heating by precipitating (nonthermal) electrons and ions. In a small flare, the chromosphere undergoes a strong upward motion already 1 s after the maximum of the hard X-ray spike, while downflows can begin as early as 6 s later (Falchi & Mauas 2002). The temporal evolution of the heated flare plasma ($T \approx 10^7$ K) and the cool ($T \approx 10^4$ K) coronal material has been shown for the first time to be highly correlated, revealing oscillatory Doppler shifts, which imply a more complicated dynamics than the usually assumed passive cooling (Kliem et al. 2002). The chromospheric response to electron bombardment was studied from modeling of the hydrogen Balmer lines (Kasparova & Heinzel 2002), the Ca XIX line (Gan & Li 2002), the Ni I line (Ding et al. 2002a), the Hα and Ca II lines (Ding et al. 2002b), and the Hβ line (Gu et al. 2001).

Peculiar high-speed soft X-ray jets were observed with *Yohkoh*/SXT, with speeds up to ≈1700 km s^{-1}, much faster than previously reported. In radio wavelengths, an even faster collimated ejection was observed with a speed of ≈3000 km s^{-1}. The associated microwave emission was identified to be nonthermal, probably caused by an apparent motion driven by successive injections of high-energy electrons into preexisting, higher elongated loops (Nakajima & Yokoyama 2002; Kim et al. 2001). Because some of the ejected matter falls back to the surface, Shibasaki (2002) proposed that a part of the potential energy of the falling matter can be converted into thermal energy and heat itself up to temperatures of several million Kelvins, and this way can provide energy and mass supply for long duration flares, rather than by magnetic reconnection.

The cooling of the flare plasma can now be tracked all the way from initial temperatures of ≈40 MK down to 1 MK, using *Yohkoh*/HXT, SXT, *GOES*, and *TRACE* measurements. The thermal emission during the Bastille Day flare of 14 July 2000 was found to peak in different temperature bands successively with systematic time delays that correspond to a cooling time of 7 minutes from 40 MK down to 1 MK (Aschwanden & Alexander 2001). A hydrodynamic simulation of the plasma cooling was performed for the same flare using a composite of hundreds of individual loops, which was found to reproduce the observed temperature evolution much better than a single-loop model (Reeves & Warren 2002). Taking the multi-loop approach to the ultimate extreme, Reale et al. (2002) modeled a fully unconfined flare plasma, which was thought to apply to some stellar flares.

2.7.5. Flare Statistics

Statistics of flares energies is of special interest because it demonstrates the power-law behavior of nonlinear dissipative processes, which is governed by self-organized criticality. This power-law behavior is, however, so universal that one could not tell a distribution of solar flare events apart from a distribution of Californian earthquakes. Attempts were therefore undertaken to put some real physics into these cellular automata models that were used to mimic flare power-law distributions (Vlahos et al. 2002), e.g., a discretization of MHD equations (Isliker et al. 2001), or RTV scaling laws and the fractal geometry of flare models (McIntosh & Charbonneau 2001; Aschwanden & Parnell 2002). New developments explored the Olami-Feder-Christensen (OFC) model, which is not a self-organized criticality (SOC) state, but at the edge of SOC and displays a new range of physical properties (Hamon et al. 2002). Other pursued approaches are the statistics of waiting time distributions, which was found to be Poissonian (Moon et al. 2002c), but multi-Poissonian when analyzed with a Bayesian procedure for individual active regions (Wheatland 2001). For sympathetic flares in particular, which occur in neighbored active regions, an overabundance of short waiting times was found (Moon et al. 2002a).

Statistics of flare parameters enjoys increasing popularity, it can be used to test the scaling laws predicted by various flare models. Studies were performed on statistics of the timing between hard X-rays, soft X-rays, and Hα onset (Veronig et al. 2002a), on fluxes, durations, rise times, and decay times of 50,000 *GOES* flares (Veronig et al. 2002b), on the Neupert effect in 1114 BATSE and *GOES* flares (Veronig et al. 2002c), and on (whether you believe it or not) 518,606 solar radio bursts from over 40 years (Nita et al. 2002). Statistics of flare parameters can even be used to verify whether the same magnetic reconnection scaling law holds for both solar and stellar flares (Yamamoto et al. 2002), or whether they belong to the same Hertzsprung-Russell diagram (Shibata & Yokoyama 2002).

2.7.6. CMEs Observed from Cradle to Grave

Now we have a good idea about the fatherhood and birth circumstances of CMEs. A statistics of 32 CMEs revealed that 41% of the observed CME-related transients are associated with active regions and have no prominence eruptions, 44% are associated with eruptions of prominences embedded in active regions, and 15% are orphans associated with eruptions of prominences outside active regions (Subramanian & Dere 2001). One observer actually witnessed the birth of a CME, which he describes as a disappearing filament disrupted a helmet streamer, which resulted in the restructuring of coronal field and causing the mass in the helmet to form the CME (Wu et al. 2002f). The first spectroscopic and imaging observations of the acceleration experienced by an erupting and untwisting flux rope that launches a CME was reported by Foley et al. (2001). Very fast acceleration of a CME was observed simultaneously in optical (with LASCO) and in soft X-rays (with *Yohkoh*), reaching peak acceleration values of $\lesssim 5000$ m s^{-2} and peak velocities of $\lesssim 1100$ km s^{-1} in ≈ 500 s at a height of only 280 Mm (Alexander et al. 2002). Bulk velocities of CMEs were measured over the entire LASCO field of view from 2 to 30 solar radii (Lewis & Simnett 2002). The detailed kinematics of individual strands of CMEs is however rather complex, so that spectroscopic UVCS measurements find a very irregularly distributed plasma at temperatures of $10^{4.5}$–$10^{5.5}$ (Ventura et al. 2002). The expulsion of CMEs is sometimes accompanied by flare sprays (Li et al. 2002a), blobs emitted from the tips of helmet streamers (Eselvich & Eselvich 2001; Aurass et al. 2002b), falling-back cores (Wang & Sheeley 2002a), and coronal inflows (Sheeley & Wang 2001). One signature of expulsion of CMEs is the intensity dimming in the evacuated regions, which was proven with Doppler measurements now (Harra & Sterling 2001). CME masses and densities can also be estimated from radio imaging at metric frequencies and ray-tracing methods. One CME was found to have a 17 times higher density compared with the ambient medium, a line-of-sight depth of 160,000 km, and the radio estimate of the CME mass was 4 times less than the white-light value (Kathiravan et al. 2002).

Flares are found to be integral to the early development of *fast* CMEs, where flares tend to happen within half an hour of the CME onsets, while the relative timing is very loose for *slow* CMEs (Zhang et al. 2002c). It was also found that the global nonpotentiality of the magnetic field in an active region is significantly correlated with the CME productivity (Falconer et al. 2002).

The most intimate radio signature of CME shocks are still type II bursts. A total of 1051 radio bursts were detected during 3557 CMEs (Dougherty et al. 2002). An analysis of 63 metric type II radio bursts revealed that the radio emission is generated either at flare-related blast wave shocks (30%), at shocks driven by the leading edge of the CME (30%), or at shocks driven by internal parts of the flanks of CMEs (29%) (Classen & Aurass 2002). But type II bursts are also highly associated with soft X-ray flares (Das & Sarkar 2002). In some type II bursts, shock wave speeds of 1100-2300 km s^{-1} were inferred, comparable with the CME speed (Chertok et al. 2001). The speed of the soft X-ray ejecta were found to be lower (>400 km s^{-1}) than the accompanying type II bursts (1000–2000 km s^{-1}) in the 13 January 1996 event, so it was concluded that the soft X-ray ejecta are supersonic in the lower corona and drive a shock that produces the type II bursts (Gopalswamy et al. 2001). Comoving with the type II radio burst sources, the coronal shock wave was also for the first time detected in soft X-rays (Khan & Aurass 2002). Bandsplitting of type II bursts, which is evidence for upstream and downstream beams in shocks, was detected out to 2–4 solar radii (Vrsnak et al. 2001). The propagation of CMEs was tracked and detected as heliospheric shocks out to 2 AU (Dryer et al. 2001) and all the way out to 63 AU, arriving at *Voyager II* 6 months later (Burlaga et al. 2001; Wang et al. 2001a).

2.7.7. CME Modeling

Two types of CMEs (fast and slow ones) can be distinguished not only observationally (e.g., Zhang et al. 2002c; Gopalswamy et al. 2002a), but also theoretically. Fast CMEs are proposed to result from a *catastrophic loss of equilibrium* in a configuration with a twisted flux rope, while slow CMEs do not involve a true catastrophe, but merely a fast evolution of a changing system (Lin & Ballegooijen 2002). An alternative interpretation explains the dual speed-height profiles of CMEs in terms of the flux tube orientation, i.e., whether the flux rope magnetic field circulates in the same or opposite sense relative to the surrounding coronal magnetic field (Low & Zhang 2002). Theoretical modeling of the erupting flux rope dynamics has been extended to 11 CMEs and excellent agreement between theory and observations was found, but only for this special selection of CMEs with flux rope-like morphological features, while the model could not match other CME species (Krall et al. 2001). There are at least two groups of three-dimensional models of CMEs: (1) highly twisted structures called flux ropes and (2) sheared magnetic arcades. New theoretical modeling involves also spheromak-type MHD solutions, which show that the three-part structure of CMEs can satisfactorily be explained by projection effects of such solutions (Tokman & Bellan 2002). The large-scale magnetic field of a halo CME was modeled with the transequatorial connection of two distant active regions in the two hemispheres, similar to the *magnetic breakout model* (Wang et al. 2002b).

The three-dimensional topology of the magnetic field of CMEs is one branch of the modeling industry, while other branch concentrates on hydrodynamic and MHD modeling, starting from mass-loading of CMEs from filament dips (Aulanier & Schmieder 2002), all the way to propagation of related heliospheric shocks and predictions of their arrival times at Earth and at spacecraft further out in the heliosphere (Dryer et al. 2001).

2.8. Interplanetary Meteorology

Since we started to adopt meteorological terms in solar and space physics, such as *solar wind*, *SoHO tornados*, or *space weather*, we can easily guess where this will lead us in future: *coronal taifuns*, *chromospheric hurricanes*, *sunspot cyclones*, *flare geysers*, *interplanetary thunderstorms*, etc.

2.8.1. Space Weather on Bastille Day

Since the day when the communication satellite *Galaxy IV* got knocked out, leaving 90% of North America's pagers and several major broadcast networks dead, being just one of the several hundred spacecraft anomalies registered every year (Carlowicz & Lopez 2002), energetic particles and induced ionospheric currents that make the *space weather* definitely became a concern and subject of enhanced interest. In this regard, a large number of papers concentrated on the geoeffective 14 July 2000 flare, the so-called *2000 Bastille Day* event (not to be confused with the Bastille Day event on the same day a year later). Many of these studies were published in the topical issue of *Solar Physics*, volume 204, nos. 1-2, covering modeling of the coronal nonpotential magnetic field (Deng et al. 2001; Yan et al. 2001), gamma-ray, hard X-ray, soft X-ray, and EUV observations (Share et al. 2001; Masuda et al. 2001; Fletcher & Hudson 2001; Aschwanden & Alexander 2001), radio type II, III, and IV emission (Reiner et al. 2001; Chertok et al. 2001; Wang et al. 2001c; Caroubalos et al. 2001; Maia et al. 2001a; Manoharan et al. 2001), the Earth-directed halo CME (Andrews 2001; Reiner et al. 2001; Manoharan et al. 2001), the solar energetic particles detected in interplanetary space (Maia et al. 2001a; Mäkelä & Torsti 2001; Smith et al. 2001a; Bieber et al. 2002), the heliospheric shocks and magnetic clouds (Dryer et al. 2001; Lepping et al. 2001; Whang et al. 2001), the interplanetary magnetic field (Raeder et al. 2001; Chen et al. 2001), the response of the Earth's ionosphere and geomagnetic field (Liu et al. 2001; Araujo-Pradere & Fuller-Rowell 2001; Chen et al. 2001), transatlantic geopotentials (Lanzerotti et al. 2001), the ring current dynamics (Jordanova et al. 2001; Brandt et al. 2001), atmospheric drag on satellite orbits (Knowles et al. 2001), and detection in the outer heliosphere (Burlaga et al. 2001; Wang et al. 2001a). The 14 July 2000 Bastille Day flare was characterized with a number of superlatives: It was the third largest proton event >10 MeV since 1976, but the energy in >1 MeV ions was found to be only about 1% of the energy in >20 keV electrons (Share et al. 2001). It ranked with its *GOES* class X5.7 as the 33rd largest flare in history (recorded with *GOES* since 1975), as the fourth largest solar energetic proton event since 1967 (with 24,000 peak proton flux units), the interplanetary disturbance had the sixth fastest transit speed of $\gtrsim 1400$ km s^{-1} recorded in history, the 27th largest geomagnetic Ap index of 164 and the 24th largest Kp index of 9, or the largest geomagnetic disturbance since 1989 (Watari et al. 2001). Although it did not rank as number one in any of these physical parameters recorded in history, we can safely conclude that it ranks first in the number of papers that have ever been blown out of printers by a solar storm.

2.8.2. Solar Energetic Particle Events

Large *solar energetic particle (SEP)* events are known to be closely related to CMEs, which tells you something about their origin. Fast CMEs drive MHD shocks, which in turn accelerate the SEPs (protons and minor ions), which are longer-lived than those accelerated during flares. Statistics shows that SEP production is most efficient when faster CMEs cannibalize slower CMEs, which happens within a heliocentric distance of ≈20 solar radii for most of the SEP events (Gopalswamy et al. 2002a). The collision of two CMEs apparently creates a new shock, which is also detectable in interplanetary radio emission (Gopalswamy et al. 2002b). Hybrid events place the acceleration in both the coronal flare site as well as through re-acceleration in interplanetary CMEs (Kocharov & Torsti 2002; Torsti et al. 2002a).

The origin of interplanetary electrons is often unclear, it can be either due to flares or CMEs. Recent studies on four events with 0.25–0.7 MeV electrons showed that acceleration in the lower corona is minimal, but that they became accelerated later in coronal shock waves that produce also type II bursts (Klassen et al. 2002). On the other hand, 2–19 keV impulsive interplanetary electron events could be tracked back to the corona and were found to originate in densities similar to flare-associated type III bursts (Benz et al. 2001). Another series of well-collimated electron events with energies >60 keV was found to be inconsistent with the starting times of electrons with lower energies, but two different injections could be distinguished with radio data (Maia et al. 2001b). Nevertheless, flare-accelerated SEP particles suffer more trapping (Reames 2002) than those accelerated in outward-propagating shocks and CMEs (Gomez-Herrero et al. 2002; Klassen et al. 2002). Energetic particle abundances, e.g., Fe/O and He/H, were found to change drastically during the passage of an interplanetary shock at a spacecraft, and thus can be used as probes (Reames & Tylka 2002; Reames & Ng 2002). From the interplanetary shocks downstream of Earth, a magnetic bottleneck was found to reflect a major fraction (≈85%) of the protons emitted during the 14 July 2000 flare back to Earth (Bieber et al. 2002). Surveys of ^{3}He-rich SEP events were found to favor stochastic acceleration in MHD-turbulent cascades (Mason et al. 2002). Exceptionally high ^{3}He enhancements have been reported for the first time up to 50 MeV/nucleon (Torsti et al. 2002b). While SEP events are generally classified into impulsive and gradual SEP events, Kahler et al. (2001) reported about the first observation of a CME clearly associated with an impulsive SEP event.

2.8.3. Solar Wind

What is the source of the solar wind? According to model a by Fisk et al., a plasma-filled loop emerges in the center of a supergranule, reconnects with the overlying canopy, and the upward reconnected part becomes an open field line and drains its plasma upward into the solar wind (Fisk & Schwadron 2001). Upflows were measured in form of blueshifts mainly in the temperature range of 80,000–600,000 K (Stucki et al. 2002). Polar coronal jets with velocities of 200 km s^{-1} at temperatures of 530,000 K were analyzed by Dobrzycka et al. (2002) and white-light jets with speeds of 600 km s^{-1} by Wang & Sheeley (2002b). Polar plumes were found to be episodic, lasting perhaps 24 hr but recurring for up to weeks a time (De Forest et al. 2001), and can also be detected in radio (Moran et al. 2001). Substantial acceleration of the solar wind from protons and O VI speeds was measured mainly in the range of 1.4–2.6 solar radii (Zangrilli et al. 2002). The solar wind could be accelerated and heated by high-frequency magnetosonic waves (Joarder 2002), damping of low-frequency Alfvén waves (Lou 2002), by MHD turbulence (Spangler et al. 2002), as well as by shocks at the *corotating interaction regions* (*CIR*) between fast and slow solar wind zones (Mann et al. 2002). Relationships between solar wind speeds and the expansion rate for the coronal magnetic field were also measured with interplanetary scintillation observations (Hakamada et al. 2002; Spangler et al. 2002; Lotova et al. 2002). Oddly, extremely high ion kinetic temperatures (exceeding 10^8 K) were reported at the North Pole in 2001, nearly simultaneously with the polarity change of the Sun's magnetic field (Miralles et al. 2001). Farther out in the heliosphere, solar wind electron distributions were found to have halo depletions, probably from mirroring of back-scattered strahl and/or shock-heated electrons from far out in the heliosphere (Gosling et al. 2001). The fast and slow solar winds were found to exhibit different pick-up ion spectra (Chalov & Fahr 2002; Fahr 2002).

2.9. Solar Cycles

The 11-year solar magnetic cycle modulates not only the radiation output in all wavelengths, it is also the lifetime cycle of solar NASA missions, which meticulously adhere to a ≈10-year lifespan: *SMM* 9.8 yr (February 1980–December 1989), *CGRO* 9.1 yr (April 1991–May 2000), *Yohkoh* 10.3 yr (August 30, 1991–December 14, 2001). This coincidence might not be entirely accidental, since each solar cycle maximum causes also an expansion of the Earth's upper atmosphere and this way maximizes the frictional air drag on satellites.

Solar cycle variations have been found in surprisingly many phenomena, such as in the classical sunspot number (Kane 2002b, 2002c; Li et al. 2002c, 2002d, 2002e; Vernova et al. 2002; Letfus 2002; Crane 2001; Mavromichalaki et al. 2002), in chromospheric UV irradiance (Lean 2001), in coronal green line (Rusin & Rybansky 2002), in coronal soft X-ray flux (Benevolenskaja et al. 2002) and soft X-ray bright points (Sattarov et al. 2002), in coronal streamer temperatures (Foley et al. 2002), in coronal hole areas (Maravilla et al. 2001), in coronal radio emission (Gelfreikh et al. 2002), in the solar wind (Prabhakaran-Nayar et al. 2002), in the interplanetary magnetic field (Lockwood 2002), in helioseismology data (Antia et al. 2001; Chou & Dai 2001), but also in less obvious phenomena such as in tree-ring-based climate reconstructions (Ogurtsov et al. 2002), in the cloud behavior and sunshine records in Ireland (Pallé & Butler 2002a, 2002b), or in the sky brightness observed at Norikura, Japan (Sakurai 2002). The solar-cycle-induced regular variation of the UV irradiance can be used to identify additional UV changes due to anthropogenic influences, such as climate forcing by industrial aerosols (Lean 2001). Forecasting of solar cycles, which show irregular dynamics possibly due to a low-order chaotic process, is now attempted with genetic algorithms (Orfila et al. 2002), nonlinear dynamics (Sello 2001), and wavelet decomposition (Rigozo et al. 2001).

Shorter periodicities, mainly related to the solar rotation were investigated in the sunspot number (Zieba et al. 2001), in chromospheric He I (Henney & Harvey 2002) and UV emission (Kane 2002a, 2002c), in coronal green line (Rybak & Dorotovic 2002) and radio emission (Kane 2002a), in the solar wind (El-Borie 2002), and even in Flamsteed drawings during the Maunder minimum (Vaquero et al. 2002). The previously found 160-day periodicity in flare rates was linked to photospheric flux variations (Ballester et al. 2002).

On the long-term side, secular variations of the Sun's magnetic flux were tracked over the last 300 years, and it was concluded that the total cycle-related magnetic flux, and thus the interplanetary magnetic flux, doubled in the first half of the last century (Solanki et al. 2002). The same effect, however, was explained by an increase of the area of polar caps (Makarov et al. 2002). Solar cycle studies can be extended backward much further than to the Maunder minimum, some sunspots were reported from Arabian sources in A.D. 939 (Vaquero & Gallego 2002). Another study analyzed the ^{10}Be production in the Earth's atmosphere, which is believed to be modulated by the galactic cosmic-ray influx and the solar surface magnetic activity, and this way solar activity could be traced back over 200,000 years (Sharma 2002).

3. THE STARS: THEIR FACTS AND LEGENDS

This was the title of a children's book from the 1940s. The legends—Andromeda, Cassiopia, Why the Little Bear's Tail Is So Long—were easy to remember; the facts (mostly about positional astronomy and navigation) more difficult. Life hasn't really changed very much, and today for every three astronomy students who remember about Eddington and "let him go and find a hotter place," you will find at most one who can reproduce the arguments for central temperatures of stars that led to the encounter.

3.1. Stellar Structure and Evolution

In comparison, at least, with formation and evolution of galaxies, these are solved problems. That is, the stars one calculates correspond reasonably well in measurable properties to the stars one sees, particularly for the main sequence and phases not too far beyond. Thus it makes sense to start there. Several groups have been in the business of calculating evolutionary tracks and isochrones for a number of years. The Padova group has recently provided isochrones in a wide range of color systems, like HST, ESO, Washington, Johnson-Cousins-Glass, etc. (Girardi et al. 2002). Yale has also updated theirs (Yi et al. 2001). And no, they do not precisely agree, nor, notes Guenther (2002, another Yale paper) is either exactly like the third, Geneva, set (Meynet & Maeder 2002 and references therein) or the fourth set from Victoria (VandenBerg et al. 2002).

Nor do all or even any necessarily match the details of, for instance, the properties of binary pairs with good data from Torres et al. (2002), who, however, note that each of the four sets they looked at has at least one assumption, not the same for all, that could be relaxed and probably lead to agreement with measured masses, luminosities, temperatures, and radii for pairs of stars with the same initial composition and age. Treatment of convection remains the most serious of these assumptions (e.g., Brummell et al. 2002 on three-dimensional, turbulent, compressible convection, within which overshoot is common and penetration rare).

You can even have evolutionary tracks for Population III ($Z = 0$) stars if you want them (Siess et al. 2002), though there are no Pop III binary systems to compare them with. Now, what are some of the things we do not understand so well as the basic evolutionary scenarios?

a. Stellar rotation. Either why young stars have the distributions of surface velocities they do (Abt et al. 2002 on B stars) or how and why angular momentum redistributes itself over the life of the star. Abt et al. report that $v \sin i$ peaks at 25% of break-up, excluding the chemically peculiar Ap/Bp stars, which are very slow rotators and also have strong surface magnetic fields in complex patterns that sort of tell patches of anomalous abundances where they should be (Kochukhov et al. 2002 on α^2 CVn). Localized overabundances of elements past the iron peak by factors up to 10^5 are not uncommon (Dulk et al. 2002 on bismuth in HD 7775). As for redistribution, even the sign can depend on the isotropy or anisotropy of mass loss (Maeder 2002 on normal OB stars and Stepien 2002 on rapidly rotating Be stars).

b. Mass loss. Some years ago (Ap93, § 4) we collected 11 mechanisms that could contribute. Doppler heating (Krticka & Kubát 2001), which expels certain ions at very high temperature and lets the others fall back got left out, though the idea has been around for a while (Gayley & Owocki 1994). Anyhow, the real point about mass loss is that there is nearly always a bit more of it than you expected (Bono et al. 2002a on Cepheid evolution), except when there is less (Origlia et al. 2002 on red giants in globular clusters).

c. The mass cut between stars that become white dwarfs and stars that become neutron stars. Somewhat above 7 $M_\odot$ (von Hippel et al. 2002, from the WD in open cluster M35). Make that 9 $M_\odot$ (Giorgi et al. 2002 on NGC 2571). Make that 12 $M_\odot$ in binaries (Dewi et al. 2002, but a calculation, not an observation). The cut between stars that leave neutron stars and those that leave black holes is less well known and, perhaps more important, mass is not the only determinant (Morley & Schmidt 2002).

d. Production mechanism for the R CrB stars and others with no hydrogen to speak of left in their atmospheres and small total mass. We voted long ago for thorough mixing and burning, but were outvoted by advocates of vigorous mass loss. The index year, however, saw a firm push for mergers of CO + He white dwarf pairs (Saio & Jeffery 2002). The product will initially be a hot, extreme helium star, of which the 17 known may be a fairly complete galactic census, which gradually readjusts to a red giant structure, with cool, extended envelope. There could be 200–1000 of these in the Milky Way, of which 33 are known.

e. Planetary nebulae. We flagged down 27 papers on these without being entirely sure what the main unanswered questions were. To one of them, however, the answer is that there are at least 100 evolutionary routes to bipolar planetaries, most (but not all) of which involve binary stars (Soker 2002). In most cases, the asymmetries are established early (Imai et al. 2002), within 10^3 yr of the onset of rapid mass loss.

A perhaps more interesting question (which, however, we have not perfectly formulated either) is the one to which the answer is no, the sequence AGB → PN → WD is not invariant, even in the mass range where it dominates in introductory textbooks. Not all the hot stars in globular clusters went through an AGB phase (Moehler 2001) and some post-AGB stars that are still fairly cool are not going to be uncovered in time to illuminate PNe before the shell is gone (Fujii et al. 2002). Castro-Carrizo et al. (2002) present a star that looks like it might just barely make it, having reached 20,000 K at a dynamical age of 1300 yr. It answers to M2-56.

f. The brown dwarfs or substellar mass objects (but you must not try to call them SMOs, because this will bring the supermassive objects running; and when that sort of SMO runs, the floor really shakes). At least no one now doubts the existence of brown dwarfs, though there is ongoing debate about whether they form like stars (Natta & Testi 2001) or like planets in disks around other stars (Reid 2002). Bate et al. (2002) say some of each, which is nearly always our favorite choice. Most of the BDs still bright enough to be in observed samples have the kinematic properties of relatively young stars (Reid et al. 2002). At least within the Pleiades, the number as a function of mass is still rising at 0.03–0.04 $M_\odot$, but the total contribution to the cluster mass is at most a few percent (Dobbie et al. 2002; Jameson et al. 2002).

Brown dwarfs have weather in the sense of transient clouds and such (Gelino et al. 2002; Burgasser et al. 2002b) in atmospheres that are in some sense purple at $T = 600$–1300 K (Burrows et al. 2002), but the colors change again below 600 K (Marley et al. 2002), because water clouds start to form. The spectral types have been defined by several groups (Burgasser et al. 2002a; Leggett et al. 2002a; Geballe et al. 2002 all for types T0 to T8). But if you want to be truly discouraged on this subject, Tsuji (2002) indicates that it is not at all clear that the spectral sequence L0 to T5 is fully determined by effective temperature.

Brown dwarfs occur both as companions to "real" stars (Leggett et al. 2002b) and in pairs of their own (Lane et al. 2001). And Bedin et al. (2001) provide a considered description of the comparison between isochrones and observed properties of very low mass stars. The fit is lousy.

g. Real-time stellar evolution, that is, stars whose locations on an HR diagram change in centuries or less. The FG Sge stars, attributed to last flashes of the thin, helium-fusing post-AGB star, are the best known, and have appeared here before (Ap 97, § 8.4). The other classes are imaginatively entered in our notebook as "other," and include:

- OH/IR stars, whose maser emission dies off in 1700 years, so that four were lost from a set of 328 in 12 years (Lewis 2002).
- A Be star that heated from 22,000 to 40,000 K in 20 years (Kondratyeva 2001).
- The contact binary RY Scu, which ejected a nebula in about 1876 (Smith et al. 2001d), the year Grandfather Trimble was born.
- An AGB star, CIT3, whose shell has been interferometrically resolved and whose mass loss rate dropped rather suddenly 87 years ago (Hofmann et al. 2001).
- The peculiar supergiant IRC + 10420, which is evolving toward the Wolf-Rayet corner of the HR diagram at +120 K/yr (Klochkova et al. 2002).
- The luminous blue variable HR Car, whose photosphere has cooled from 15,000 K to 10,000 K in 5 years (Machado et al. 2002). We suppose it is now an LWV or luminous white variable.
- Some hot (15–20,000 K) analogs of R CrB stars, not all of which are the same sort of beast, but at least three of which have had $T_{\rm eff}$ increase by a few thousand Kelvin in 70 years (De Marco et al. 2002). No masses have been measured, and even the luminosities are poorly known (Demers et al. 2002 on the SMC/LMC populations).
- A potential new class of stellar outburst, with prototype V 838 Mon, plus V 4332 Sgr and one example in M31 (Munari et al. 2002). The prototype had spent some years near $M_V = +4.45$, not obviously variable and with an F-ish color. In January to April 2002, it decided to brighten to $M = -4.35$ and its color reddened to M. The outburst spectrum has P Cygni features and strong barium and lithium, but the event is not quite like either a slow nova or an FG Sge star.
- The post-AGB star HD 161796, which lost 0.46 $M_\odot$ between about 670 and 1570 CE (Hoogzaad et al. 2002). The departing material has formed water ice and three kinds of silicates—amorphous, forsterite, and enstatite.
- Convection and extra mixing. Since we started with this, let's end with it. Many stars have been stirred rather more than mixing length theory would lead you to expect. This is reflected, for example, in the N/O ratio in OB stars near the main sequence (Daflon et al. 2001), the lithium abundances in M67

stars (Randich 2002), and the C^{13}/C^{12} ratios in AGB stars (Abia et al. 2001).

3.2. Young Stellar Objects

Young stellar objects are best seen in some band that penetrates the shrouds of dust in which they are typically found. Infrared is an obvious good choice (hence SOFIA, *SIRTF*, *JWST*, and all), but so, it turns out, are X-rays, because protostars (etc). are typically rapid rotators, with accretion disks, magnetic fields, and all sorts of activity (of which more in the next section).

If you are new to the topics, Tsujimoto et al. (2002a, 2002b) provide a great tutorial. Not only have they found a large number of *Chandra* sources in the Orion molecular clouds and shown that X-ray properties vary systematically with evolutionary stage as defined in other wave bands, they tell you what the definitions are. There are four classes of YSOs, 0, I, II, and III from least evolved to most evolved. The 0's and I's are also called protostars, while II and III are pre-main-sequence stars, also called T Tauri stars, of which there are, in turn, two subtypes, classical with lots of junk still around and naked T Tauri stars. More massive analogs are called Herbig Ae/Be stars, and for them also the amount of stuff around declines as age goes up from 100 or more solar masses to less than 0.1 for ages 10^4 to 10^7 years (Fuente et al. 2002). The residual bits might (or might not) then make a small companion star or a handful of planets (Li 2002d).

Back to the X-rays. Academic year 2002 saw the first announcement of X-ray emission from a Herbig-Haro object. Well, actually two first announcements: Pravdo et al. (2001) on HH 2 and Favata et al. (2002) on HH 154. Raga et al. (2002) have modeled both. In case you weren't there in 1951–52 when they were discovered, a Herbig-Haro object is a compact knot of emission line gas located at some considerable distance from anything that might reasonably ionize and excite the gas. Everyone (we think) now agrees that they are, in effect, the "beam dumps" of jets from YSOs, though the actual exciting source remains unidentified for at least 60% (Avila et al. 2001). There are also disagreements about the details of how the energy is converted to the forms we see, via shocks (Thiele & Camenzind 2002), stagnation (Lim 2001), and magnetic fields (Matt et al. 2002). And, if you like closed circles, you will be pleased to hear the some HH's may themselves in turn trigger additional star formation (Girart et al. 2001).

The "converse would be worrying" prize of the year goes to Rhode et al. (2001) for the first direct, geometrical demonstration that stars shrink as they approach the main sequence. The authors combined temperature, luminosity, and $v \sin i$ data (for Orion protostars again).

Some of the variability of T Tauri (etc.) objects arises from the rotation as measured plus spots on the stars. But everything else you can think of also contributes (Barcza 2002 on pulsation and mixing; Eiroa et al. 2002 on changes in disks, spots, and obscuration).

We are going to leave roughly 40 additional "must-see" YSO papers uncited and note only a couple more items that are just what you expected, provided, of course, that what you expected was total confusion, as surely you did if you have read any of the previous papers in this series. First, something like 85% of the "Eagle's Eggs" of M16 do not actually have YSOs at their centers (McCaughrean & Anderson 2002), and, in the future, stars will eventually form in lots of them (Williams et al. 2001) or almost none (Thompson et al. 2002b).

The second concerns the Class 0 or infall sources. The signatures of infall where accretion hits the disk (and the excrement hits the air-circulating device) are now seen more or less routinely, which was not the case a few years ago (Velusamy et al. 2002; Narayan et al. 2002), the first disks actually resolved by a nulling interferometer are very much smaller than expected, with 90% of the 10 μm emission coming from inside 20 AU (Hinz et al. 2001). In addition, the gory observational details of the disks at both centimeter (Harvey et al. 2002) and submillimeter (Shirley et al. 2002) wavelengths are not actually very well fit by the "inside out" collapse that we have been led to expect for the last quarter-century or so (Shu 1977).

Third, and not obviously the charm, the calculated brightnesses of YSO in their first 10^6 years remain very dependent on the initial conditions chosen for the calculations (Baraffe et al. 2002), with corresponding considerable uncertainty in the masses of protostars (Classes 0 and I, remember) derived from photometry (Wuchterl & Klessen 2001). There is also a systematic discrepancy, in the direction of models being fainter than real stars early on, even if you choose the most favorable initial conditions (Boss & Hartmann 2001). Is it obvious that this most favorable case starts with self-gravitating collapse? In any case, tracks initiated from various ICs do converge after about 10^7 yr (Baraffe et al. 2002), meaning, we suppose, that derived masses and ages should be reliable beyond that point … or that everybody is wrong together.

3.3. Stellar Activity

Stellar activity means things like spots, flares, chromospheric and coronal emission (including X-rays and radio as well as optical emission lines), and winds. En route to trying to answer the question "how does it work?" the community has collected much information on correlations of activity indicators with the other things that we (think we) know about stars. None of the (copious) 2002 collection upset our prejudices badly, and so we note just one (or one per side) discussion on each of some of the long-considered issues. Other things being equal, the latest paper to appear during the year is selected.

Cycles. Many active stars are cyclic, but the most vigorous not obviously so (Bruevich et al. 2001).

Coronae have to be heated, and it seems to take the sum of all the processes you can think of (Aschwanden 2001; Schrijver & Aschwanden 2002; Aschwanden & Charbonneau 2002; Hey guys! This paragraph really was written by VT).

Chromospheres have to be heated, and it seems to take three sorts of input, acoustic waves, magnetic waves associated with flux tubes, plus magnetic reconnection (Fawzy et al. 2002a, 2002b, 2002c).

The dividing line in the HR diagram between giants with coronae and giants with chromospheres is fairly sharp, and the cause is trapping of the flux loops made in a dynamo at the base of the convective envelop when that base is more than 80% of the radius of the star away from the surface (Holzworth & Schüssler 2001).

The chromosphere of one star (besides the Sun!) has been resolved because it was microlensed (Alfonso et al. 2001). They saw Hα emission and noted that the limb of the star is redder than the center of the disk.

Binaries tend to be more active (Makarov 2002). Normally one thinks of this as resulting from rapid co-rotation (Sung et al. 2002), but both this paper and Sokoloff & Piskunov (2002) suggest more complex mechanisms involving resonance and such. The products of close binary mergers do even better (Rocha-Pinto et al. 2002).

Some binaries also have activity cycles, and the resulting changes in stellar moments of intertia can change the orbit periods a bit (Yang & Liu 2002, the Applegate 1992 mechanism). In the case of Capella, however, we think that Johnson et al. (2002) are saying that intrinsic changes in the depth of the convective envelope (that is, changes in the moment of intertia) are the cause of the cycling. You are all too young to remember, but Capella was the first X-ray star (besides the Sun).

Brown dwarfs. The nature of stellar activity changes somewhere around the boundary between spectral types M and L, but it is too simple just to say that activity turns off or declines. Hα declines, as do persistent X-ray fluxes, but flares hold up, and persistent radio emission may even increase (Berger 2002). Very young brown dwarfs form a continuum with very young stars of small mass. That is, the pre-main-sequence dynamo doesn't know whether the proton–proton chain is going to turn on later or not (Feigelson et al. 2002b).

Very young solar type stars, like those in Orion, are spitting out high energy particles so fast that they can make a whole flock of unstable nuclides like those whose daughters are found in meteoritic inclusions, including Ca^{41}, Cl^{36}, Mn^{53}, La^{138}, and maybe Al^{26} (Feigelson et al. 2002a).

Beta Pictoris has a *FUSE* chromosphere, but arguably should not (Bouret et al. 2002).

FK Comae stars are sometimes spotted (Korhonen et al. 2002).

Gamma Cassiopeiae has a disk dynamo driven by the Balbus-Hawley instability according to Robinson et al. (2002).

Population II stars should have the flux available to heat their chromospheres reduced by a factor of ten for each factor of ten reduction in metallicity from solar, and this is not enough to power what we see (Musielak et al. 2002a).

UXORs are mostly binaries (Grinin et al. 2002), and EXORs apparently are not (Herbig et al. 2001, and the prototype is EX Lupi, not EX Ori!).

The RS CVn stars were originally defined partly by their chromospheric emission (Popper 1970). They still have it (Gu et al. 2002), and it is often spotty (Fransca et al. 2002). Indeed there can be activity from each star separately and from the gas in between (Kjurkchieva et al. 2002), which brings us to one last activity point.

Sometimes the magic phrase is "colliding winds" rather than magnetic activity (Watson et al. 2002).

3.4. Pulsating Stars

There are lots of these, both types (we have notes on 22) and individual stars. The Russian Variable Star Catalogue, containing all those pulsators with some reasonable information on types and periods and individual names of the form MY Constellationis (as well as eclipsing binaries, supernovae, and so forth), is now appearing in its fourth, electronic edition (Samus et al. 2002). Most of the coordinates are now given to better than 1″. Still to be incorporated are the 68,000 variables (many pulsational) found in 7 square degrees of the LMC and SMC by the OGLE II project (Zebrun et al. 2001) and other comparably large numbers turning up in other automated photometry programs.

The following subsections highlight a subset of important/amusing/puzzling types and an even smaller subset of the papers that discussed them during the index year.

3.4.1. Cepheid Variables, Both I and II

These are the pulsators used in the cosmological distance ladder, which makes them intrinsically the most important to those who have forgotten that "aster" means star. The distance calibration remains fairly sensitive (at 0.15 mag or so) to whether the period-lumosity relation changes with metallicity. Udalski et al. (2001, another OGLE paper) enunciate a firm no, based on 138 Cepheids in the Local Group dwarf irregular IC 1613, which is somewhat more metal poor than the Magellanic Clouds at $[\mathrm{Fe/H}] = -1$. But, say Dolphin et al. (2002), the Cepheids in another dwarf, Leo A, with $[\mathrm{Fe/H}] = -1.8 \pm 0.3$, extend to shorter periods (in the fundamental mode) and lower luminosities than do Milky Way samples, which they describe as a composition effect. Sharpee et al. (2002) fill in the territory between with the following values for the absolute magnitudes of the shortest-period Cepheids in other galaxies, in order of decreasing metallicity: $M_V = -2.6$ (LMC), -1.4 (SMC), -1.3 (IC 1613), and -0.7 (Leo A).

Pulsational models, in any case, are still in need of minor repairs, because star masses derived from bumps on the light curves and double modes remain about 15% smaller than the masses for the evolutionary tracks that run through the mean luminosities and temperatures of the same stars (Bono et al. 2002). Not so long ago, however, the difference was a factor of two, and the answer was some combination of evolutionary mass loss and convection. It probably still is (Bono et al.). But the largest discrepancy between observations and theory this year is in the range of period coverage. The main Cepheid populations in the Milky Way, M31, and M33 have bimodal period distributions, with peaks at 5 and 13 days (Antonello et al. 2002), which is more or less where the models are concentrated. But recent surveys have found Cepheid-like light curves as long as 210 days, while the models stop at about 80 (Pietrukowicz 2002).

Polaris is probably the favorite Cepheid of people who have never heard of Cepheids. It pulsates in an overtone mode with decreasing amplitude (not a new result), but is moving into, not out of, the instability strip (Evans et al. 2002); which is odd!

Type II Cepheids are found among Population II stars (unlike the case of supernova types!). They have correspondingly smaller masses and luminosities, but similar-looking light curves and evolutionary phase (helium fusion), and similar, but off-set, period-luminosity relations. We will advise you to read only one paper from the year (Wallerstein 2002), because it was so good that we neglected to record any others. The author clarifies the relationships among the BL Her ($P = 1$–5 days), W Vir ($P = 10$–20 days), and RV Tau ($P = 20$–100 days) stars, how they fit into the various galactic stellar populations (all except thin disk), chemical compositions, horizontal branch vs. asymptotic giant branch status, and much else. He notes that the non-identity between W Vir and classical Cepheids of the same period was known to Joy (1937).

3.4.2. Be Stars

The long-running discussion on whether most of these variable emission line stars are showing us rotation periods or pulsation periods continues. Balona & James (2002) vote for rotation for λ Eri. But δ Scuti became a Be star for the first time during its 2000 periastron passage (Miroshnichenko et al. 2001). And we think we know that it is a (non-radial) pulsator. Indeed the authors suggest that the pulsations were amplified by the tidal effect of the companion, lifting off the shell that made it a Be. But Percy et al. (2002), candidates for the Noble Prize in astronomical peacemaking, point out that there are five or more causes of Be variability, including transient disks, density waves in the disks, close companions, rotation, and non-radial pulsation. They refer readers to a recent conference volume (Smith et al. 1999) for additional details and models.

Some, though not most, B [e] stars are also pulsators, with 2–3 periods of days to years (van Genderen & Sterken 2002).

3.4.3. R Coronae Borealis Variables

The more heavily carbonized author continues to be exceedingly fond of these low mass, hydrogen-poor stars, whose sudden fadings result from formation of carbon grains in their atmospheres, with recoveries when radiation pressure blows the grains away. Some out-of-period papers promise that they will be an exciting topic for Ap03. This year, however, we noted a reiteration that the range of absolute magnitudes is very large (Bergeat et al. 2002a, 2002b, who also discuss a range of other types of carbon stars and their properties, many unfortunately hiding in undecoded acronyms). The ejecta from a third star has been resolved (V854 Cen; Clayton & Ayres 2001), while a second-epoch observation of R CrB itself revealed the dust from the most recent episode of fading (Ohnaka et al. 2001). Indeed some of the details of the fadings seem to require more than one dust shell per episode (Rosenbush 2000).

3.4.4. Period Changes

As a star evolves across the instability strip for its own particular breed, its period ought to change, quite rapidly near the strip edges say Buchler & Kollath (2002). Shell flashes can also change periods drastically, from 445 to 397 days in 17 years for the Mira S Ari (Merchan Benitez & Jurado Vargas 2002) and 495 to 385 days from 1662 to 1950 for another Mira, R Hya (Zijlstra et al. 2002). These both, you will notice, indicate shrinkage of radius. Mira itself has just, once again, been put forward as the explanation for some of the properties of the Laser of Bethlehem (Signmondi 2001).

Monotonic evolutionary change is not, however, the only possibility. Stellar activity cycles can change effective radii and densities and so pulsation periods. This year we caught two votes for sudden interior mixing events, for T Tauri (Barcza 2002) and for an RR Lyrae star in the globular cluster M15 (Paparo et al. 2002). RR Lyraes may also show systematic evolutionary changes, though the evidence derived by Corwin & Carney (2001), from 207 light curves in M3, is, at best, underwhelming.

There are several discrete populations of RR Lyrae stars in the Milky Way whether you look at kinematics or chemistry (Borkova & Marsakov 2002). We don't understand the Blazhko effect in any of them. Neither do Jurcsik et al. (2002), but at a much high level, for they have discovered that the light curves don't look like normal RR Lyraes at any phase of the Blazhko cycle.

3.4.5. Stellar Oscillations

We expressed puzzlement last year on just how these differ from other, more easily detected stellar pulsation types. Stochastic excitation, say Christensen-Dalsgaard et al. (2001) reporting on AAVSO data, which is also stochastic, that is, no individual frequencies are derived. Lots of individual frequencies have been reported for β Hyi (Carrier et al. 2001) and for ζ Her (Morel et al. 2001). There are both acoustic (or p, with pressure as the restoring force) and g (with gravity as the restoring force) modes.

The standard reference oscillator remains, however, the Sun, which lives back up in § 2. Only one note here: the editor of a Major Journal (not the one who denied exponential expansion on his publication on the grounds that it was growing at only about 5% a year) asked a while back how you can know what the back of the Sun is doing so as to fit global modes. Braun & Lindsey (2001) provide the answer, in case it has ever bothered you.

3.4.6. Not Pulsating After All

We found two rejected categories this year. First, K–M III giants with improbably short advertized periods of 2–20 days. One is a close binary with underestimated temperature, and many actually have longer periods (Koen et al. 2002b). Special kudos to the authors, who include some of the people who had originally advocated the class. Second are the B stars with excessively long periods, a couple of which turned out to be rotation (Kallinger et al. 2002 on HD 208727 and Briquet et al. 2001 on HD 131126).

3.4.7. Subdwarfs, White Dwarfs, and Hot Helium Stars

You could have a whole conference on these (and people have), but we note only one pulsating sdB factoid. A mode analysis for PG 1047+003 leads to a rotation period of 11 days (Kilkenny et al. 2002), meaning that it is well on its way to becoming a slowly-rotating white dwarf, as so many of them are. In case you had forgotten this (the break-up period, after all, is a few seconds), Dufour et al. (2002) discuss a couple of DBs previously described as rapid rotators which are not (acknowledging consultation with the original authors, for which bravo!). And Beuermann & Reinsch (2002) have shoved LP 790-29 into a period range around 25 years by ruling out most possible alternatives. Jordan & Friedrich (2002) show the evidence for a 24–28 year period.

As for white dwarf pulsators, there are (at least) three types associated with the (at least) three types of atmospheres. First in order of recognition and numbers are the DAs with atmospheres of nearly pure hydrogen. Benvenuto et al. (2002) find that G117-B15A has a hydrogen envelope of at least $10^{-3.8}\ M_{\odot}$ and a pulsation mass of $0.525\ M_{\odot}$, equal to the mass implied by its spectroscopic surface gravity (Koester & Allard 2000). Second are the DB or He-rich atmospheres, for which the calculated pulsation strip extends too far to the red if you leave out convection (Gautschy & Althaus 2002). Third are the hottest, PG 1159 stars with atmospheres of mostly carbon and oxygen. From their multimode mode structures, you can extract good values for mass, luminosity, residual helium fraction, and much else. Vauclair et al. (2002) find $10^4\ L_{\odot}$ for RX J2117+3412 (which seems bright for a white dwarf!) and $0.56\ M_{\odot}$.

The arrays of modes in pulsating He stars are rather similar, and much can also be learned from them (e.g., Brassard et al. 2001). We especially like the discussion of V652 Her (Jeffery et al. 2001) because it makes use of data collected by the under-recognized astronomer of the year (Landolt 1975, § 7.2). The unsurprising mass is $0.6 \pm 0.2\ M_{\odot}$. Some of the helium stars share with Cepheid variables the quirk of having masses derived from pulsation properties smaller than the masses of the evolutionary tracks leading to them (Montanes-Rodriguez & Jeffery 2002 on BX Cir). Extra mass loss during evolution approaches tautology as an explanation, while mass accretion from a companion would be wrong headed.

3.4.8. The Chemically Peculiar and Still More Peculiar Stars

At least 70% of the λ Boo stars pulsate, but only in high overtones relative to those excited in δ Scuti stars (Paunzen et al. 2002). Some roAp (rapidly oscillating peculiar A) stars are not detectable oscillators, despite falling within the calculated instability strip. Cunha (2002) suggests the name “noAp” stars for these and an alternative explanation of why the pulsations might not be detectable, which we do not understand.

What remains unmentioned? The SX Phe stars (Pop II, pulsating blue stragglers), one at least of which was not chemically mixed during merger of a binary system, if that is how it formed (Templeton et al. 2002).

The β Cep stars, whose instability strip grows ever narrower in mass as you look at smaller metallicities, a case where observations and theory agree. Pigulski & Kolaczkowski (2002) report the first three outside the Milky Way (in the LMC, of course) and remark on their scarcity relative to galactic populations, while Deng & Xiong (2001) watch the unstable range of 8–15.5 $M_{\odot}$ at solar metallicity shrink to no instability strip at all for $Z = 0.005$.

The δ Scu stars, of which we note three pre-MS examples, V751 Ori, a Herbig Ae star (Balona et al. 2002), a star in IC 348 (Ripepi et al. 2002), and BI Cyg, which is probably also a γ Dor star (Breger et al. 2002).

The γ Dor stars themselves, of which there are now a bunch, which show no correlation of period with luminosity or color (Henry & Fekel 2002). At least one, HD 209295, in a mirror image of the previous paragraph, is also a δ Scu star (Handler & Shobbrook 2002).

And we have left unmentioned this year, though recognizing in the past, an assortment of other pulsation behavior types in the RV Tauri stars, OH/IR stars (no period-luminosity relation; Engels 2002), other post-AGB stars, long-period variables, and probably some others.

4. WHERE TWO OR THREE ARE GATHERED: BINARIES AND STAR CLUSTERS

Like beetles and the common person, the creator must have loved binary stars, since she made so many of them, indeed perhaps almost exclusively binaries and multiples at the earliest stages of formation according to Larson (2002), who is concerned about what you do with spare angular momentum (go around in circles and attempt to become known as wheels, in our case). Several other lines of argument during the year concurred anyhow on “many” if not “all” (Nakamura & Li 2002; Patience et al. 2002; Boss 2002b), and even more among young stars (Shatsky & Tokovinin 2002; Bosch et al. 2001), though with a dissenting vote from Sigalotti & Klapp (2001).

Intriguingly, the ratio of triples to binaries is close to unity in at least one star formation region (Koresko 2002). A catalog for the LMC also shows that triples and multiples are commoner among the very young stars (Dieball et al. 2002). Contrary to some earlier negative results, there are binary brown dwarfs (Close et al. 2002a, 2002b).

And all the rest is, we suppose, binary star evolution, though with a few details still to be worked out between main-sequence pairs (Qian 2001 on W UMa oscillations) and binary white dwarfs (Bergeron & Liebert 2002 on a DAB star that is really a close DA + DB pair; Maxted et al. 2002 on the systems with known mass ratios, all six of them, and all with small total mass).

4.1. The Pisgah View

The picture painted with the broadest brush is that of the “scenario machine,” in which the investigators started (now 15 or so years ago) with a reasonable-sounding distribution of initial masses and separations, let it chug away for varying parts of a Hubble time (especially for the computational phase), and then asked whether the product range of cataclysmic variables, Algols, blue stragglers, W UMa stars, X-ray binaries of various sorts, RS CVn stars, Type Ia supernovae, and all the rest, was one that you might want to buy. The original machinery is still chugging away in the hands of its originators and can predict the expected numbers of about 100 types of products expected either from on-going star formation or from a burst (Tutukov & Yungelson 2002). It is being adapted by others, e.g., Raguzova (2002) who concludes that 70% of Be stars should have white dwarf companions.

The machine now has company. Hurley et al. (2002a) are at work on a similar program, in which single star evolution, an assumed initial population of binaries, mass loss and accretion, magnetic breaking, supernova kick velocities (and, for all we know, the great red spot on Jupiter) are all taken into account, and the predicted numbers of systems of each of many types from blue stragglers to SNe Ib/Ic more or less agree with actual Milky Way populations. The Russian work is not cited.

Third up at bat is the team Belczynski et al. (2002a), who predict that there should be 40% as many black hole plus neutron star binary systems as neutron star plus neutron star ones. None of the former and about six of the latter are known. They also predict that the ratio of quark stars to neutron stars should be close to one, and cite neither of the previous two groups.

The time would seem to be ripe for a very brave, young, but tenured person to corral copies of all three codes, start them off with as nearly as possible identical initial conditions, and see how similar the results are. (This has actually been done for codes that follow structure formation from the early universe.) The person should be young because this might take a while, and tenured because there is a good chance that someone will be displeased by any possible answer. If they all come out the same, why did we need three? But if they all come out very different, then apparently we know nothing about binary population evolution!

4.2. A Few Binary Close-Ups

If you hike along the trail marked out with broken twigs and arrows drawn on rocks by any of these three scouting teams, you will inevitably encounter most of your, and our, favorite sorts of binaries, including:

Population II, which are not so very different from Population I, in numbers and periods, but are circularized up to orbit periods of 20 days (Latham et al. 2002), vs. 7.56 days for pre-main-sequence systems (Melo et al. 2001) and 16 days for ages near that of our solar system (Savonije & Witte 2002).

Beta Lyrae, which is generally advertized as being in the stage of first, rapid mass transfer from M_1 to M_2, but some aspects of whose light curve are not yet well understood (Linnell 2002). Incidentally, models can now handle transfer as rapid as 10^{-5} of the system mass per orbit, but the computation will take you about 30 hours per orbit (Motl et al. 2002), which may well be longer than the actual orbit period.

Blue stragglers. The metal-poor, field ones are consistent with a population consisting entirely of close binaries, in which M_1 is a white dwarf and M_2 is the star you see (Carney et al. 2001).

Products of common envelop binary evolution. Bleach et al. (2002) discuss the enhancement of chromospheric activity, flares, and such in systems like HZ 29 (which used to be a QSO and so should be active!). Eggleton (2002) however notes that a system can get rid of lots of envelop material with pulsations and radiation pressure without ever going through a CEB phase.

Subdwarf B stars are often the product of binary evolution (Heber et al. 2002).

The cataclysmic variables have white dwarf mass recipients and a range of non-degenerate donors. We put 37 X’s on the map for them, but are going to stop at only four, each a site of considerable antiquity. The most recent estimate of the nova rate in M31 is 37^{+12}_{-7} per year (Shafter & Irby 2001). The events trace the bulge light, as do, more or less, galactic novae, though the census is less complete. Dwarf novae with long recurrence times do indeed have very light weight secondaries (Mennickent et al. 2001). WZ Sge, the prototype of the class, blew its stack again in July 2001 (Cannizzo 2001). The previous occasions were 1913, 1946, and 1978; this last event led to the system being moved from the class of recurrent novae (nuclear explosions) with short recurrence times to that of dwarf novae (accretion outbursts) with long cycle time (cf. Smak 1993).

The recurrent nova inventory is always small and subject to losses (as per WZ Sge), but has just been topped back up again to nine with IM Nor (1920 and 2002; Kato et al. 2002c). The actual discoverer was Liller (2002).

X-ray binaries with neutron star accretors. Somehow, the more indexed author could not decide this year whether these counted as "binaries" or as "neutron stars," so you get some specific systems here, and a discussion of some new-ish types in § 8. Black hole XRBs appear in § 9. If your itinerary includes only one night in Belgium, perhaps you should spend it with Grimm et al. (2002), who provide an overview of the X-ray binary population of the Milky Way for comparisons with other galaxies. The low mass XRBs are brighter (in X-rays, not in visible light) than the high mass XRBs, and at any given time, 5–10 bright sources dominate our entire X-ray output. If you have time to meet some of them individually consider

1. Sco X-1, the very first (1962) XRB, whose secondary, donor star has finally been seen (Steeghs & Casares 2002).

2. What *may* (yet again) be the first TeV XRB, Cen X-1 (Atoyan et al. 2002), although neither the 2.1 day orbit period nor the 4.8 second rotation period are in evidence to enhance the identification.

3. SS 433. There was a time when whole books and conferences were devoted to this source with its $v = 0.26c$ jets. Lest it be forgotten entirely, Gies et al. (2002) have looked again, but are still not sure whether the accretor is a neutron star or a black hole.

4. Systems, called Z-sources, which display quasi-periodic oscillations whose frequencies vary with source luminosity and spectral hardness in well-defined (but very complicated) fashion. We had all been used to thinking that the parameter that varied and drove the others was mass accretion rate, but Homan et al. (2002) say that this may not be so.

5. 4U 1620−67, in which the gas being accreted contributed emission lines with Ne/O = 4–6, telling us that the donor must be a neon-rich white dwarf (Juett et al. 2001; Yungelson et al. 2002).

6. The precursors of LMXRBs, that is, the neutron star equivalent of V471 Tau, where Roche lobe overflow has not yet begun. None of these are actually known, though they must exist, and we are not quite sure whether zero is an awkwardly small number for this case or not (Bleach 2002).

7. KS 1713−260 whose sixth or so burst was the longest ever (12 hours). Degenerate carbon burning is apparently a good bet for this phenomenon (Kuulkers et al. 2002; Strohmeyer & Brown 2002), while the commoner, shorter X-ray bursts are powered by helium burning.

8. RX J185635−3754, which had a brief flirtation with being a quark star last year. But better astrometry has increased the distance, so that the measured luminosity and temperature now imply a radius of 12–16 km, appropriate for an ordinary neutron star (Walter & Lattimer 2002).

9. EXO 0748−675, which is one of six LMXRBs with measured changes in their orbit periods. Three are positive and three negative, and Wolff et al. (2002) present a recent data set and give the impression that more than enough models are available to account for both signs. This one is slowing down, and they suggest changes in the structure of M_2 as the cause. The most popular slowing down mechanism, however, remains the propellor, and Ikhsanov (2002) will be happy to re-introduce you to it if you have not lately tried to spin down a neutron star in the wind of its companion.

10. The confused source X2127+119 in the globular cluster M15. No, no. We keep telling you that "confused" is a technical term, meaning more than one source per beam width. This one is now resolved into two, $2\farcs7$ apart, of which the brighter is the one that bursts and the fainter is the one whose optical counterpart is AC 211 (Smale 2001).

4.3. Star Clusters

Very probably you took Astro 100 at some point in the past. If not, you have surely taught it, and so can be presumed to know that most stars form in clusters or groups, but do not die there, that the Milky Way has two types, open (or galactic) and globular, and that there are at least approximate analogues in most other $z = 0$ galaxies (Kissler-Patig et al. 2002). Our open clusters are found in the disk and have formed continuously down to the present time. Most are not gravitationally bound (Meibom et al. 2002), and a typical half life locally is 600 Myr (Bergond et al. 2001; Bekki & Chiba 2002; Yoon & Lee 2002).

The globular clusters are found in two or more populations, associated with the galactic halo, bulge, and thick disk and have been around a long time, though even they have suffered disruptions past, present, and future. The effect of these is, more or less, to produce the distribution of luminosities and such that we actually see from a somewhat different initial population (Whitmore et al. 2002 on $N(L)$; Fall & Zhang 2001 on $N(M)$).

The properties of populations of globular clusters belonging to other galaxies are not very strongly correlated (apart from specific frequency) with the Hubble type or other properties of the galaxy (Harris et al. 2002). Only the largest galaxies with lots of clusters have examples of the rare, largest masses, and this is probably a manifestation of the Scott effect (Larson 2002).

On beyond the Astro 100 level, here are some items that looked new, or at worst, previously owned, this year.

a. There are also moving groups. The closest of these has β Pic as a conspicuous member and might be a good place to look for warm planets (Zuckerman et al. 2001). Ortega et al. (2002) say its formation may have been triggered by ejecta from the Sco-Cen OB association 11–12 Myr ago. Moving groups of this sort form a continuum with OB associations, which, in turn, form a continuum with open clusters. Much stranger in our view are the moving groups identified many decades ago by Olin Jeuck Eggen, as a rule on purely kinematic grounds, whose members do not share a single age or chemical composition. Montes et al. (2001) have found additional members of a couple of these.

b. There are also nuclear star clusters, meaning ones associated with nuclei of galaxies. Boeker et al. (2002) described 59 of these in 77 galaxies, and the Milky Way has its own (Launhardt et al. 2002).

c. Brodie & Larsen (2002) have found what may be a genuinely new kind of star cluster on the outskirts of a couple of S0 galaxies. They have $[\mathrm{Fe/H}] \approx -0.6$, $[\alpha/\mathrm{Fe}] = +0.3$ to $+0.6$, ages of at least 7–8 Gyr, and absolute magnitudes near $M_V = -7$. But, and here is the distinction, they also have effective radii of 7–15 pc, rather than the 2–3 pc you would expect for massive, old, metal poorish clusters. They are roughly in the planes of their galaxies and share the disk rotation.

d. Globular clusters used to come in two types, Oosterhof I and II, defined by the mean periods and luminosities of their RR Lyrae stars. But some of our Milky Way globulars fit into neither of the boxes (Pritzl et al. 2002).

e. You might reasonably argue that the second parameter (which gives clusters of the same metallicity—which is the first parameter—horizontal branches that are either red or blue) also defines two classes, whatever that parameter is. We caught votes this year for age (Bellazzini et al. 2001) and mass loss (Catelan et al. 2001), both of which have been suggested before (along with helium abundance and CO/Fe ratio). But oddest is the suggestion from Soker et al. (2001) of free-floating planets, which crash into red giant stars and mess up their further evolution. What makes this odd is that, locally at least, having lots of planets is associated with stars of larger than average metallicity, while the second-parameter clusters are not just Population II but at the low metallicity end.

f. Also productive of a double take through the bus window is the suggestion that our heftiest, most chemically complex cluster, ω Cen, is the product of a merger of two unequal clusters (Ferraro et al. 2002). About 5% of the stars show coherent bulk motions relative to the rest, as well as larger metal abundance. We would love to see a calculation of the encounter and merger of two globular clusters that leaves them joined rather than both dismembered.

g. Richer et al. (2002) have obtained the deepest ever HR diagram of a globular cluster, M4 (from *HST*), and used proper motion data to clean it up. There are stars right down to the hydrogen burning limit and white dwarfs very possibly right down to the end of the cooling sequence (Hansen et al. 2002a) at 12.7 ± 0.7 Gyr on the scale where disk white dwarfs extend back to 7.3 ± 1.5 Gyr. There is a crowd of stars at the faint end of the WD sequences, indicative of production in a star burst. Both MS and WD sequences hook back to the blue in $V-I$ at the faint end, as expected. And there is a sprinkling of stars between the main sequence and white dwarf loci which, say the authors, could be the evolutionary products of cataclysmic variables, now consisting of pairs of helium WD plus small mass main sequence star.

4.4. Stellar Dynamics

Only a couple dozen papers landed at this tour stop, which is surely a failing of our "nose for news," rather than of the subject. Most of them actually dealt with globular clusters, for instance the question of whether some have their very own dark matter halos, and their relationship to the dwarf spheroidal galaxies (maybe, and incestuous, say Bromm & Clarke 2002 and Fellhauer & Kroupa 2002).

The thick disk stellar component of the Milky Way has, over the years, been attributed first to stars formed intermediately in time, location, and metallicity between those of halo and thin disk and, later, to stars made some time ago in the thin disk and scattered to a larger velocity dispersion by encounters with giant molecular clouds. Kroupa (2002a) puts forward the interesting alternative that the thick disk is the product of star evaporation from an original population of objects that are now to be found both as compact dSph galaxies and as ω Cen-like globular clusters.

Runaway stars are always good for a quick visit. It has to be quick, because, even if you feel like staying around, they don't. At least some OB stars get kicked out of their clusters or associations (de Grijs et al. 2002) and travel far enough and fast enough to make up many or most of the high latitude B stars (Ramspeck et al. 2001). Some actually leave their galaxies (Barkov et al. 2002), although the most surprising aspect of this particular paper is the model used for the galaxy, which consists of a central black hole and two shells of point particles (Spitzer & Hart 1971).

5. GOINGS ON BETWEEN THE STARS: THE INTERSTELLAR MEDIUM(S)

Interstellar gas and dust (whose ratio is nearly constant at fixed metallicity; Edmunds 2001) make up less than 10% of the galactic baryons and a considerably smaller fraction of the total mass, but seem to generate a considerably larger fraction of the papers in Some Journals. Far more of these have at least one important conclusion than can be mentioned here. It isn't exactly true that the gassier author looked hard for the unimportant things, but that may have been the result.

5.1. Too Cold?

Just how cold can the ISM get? Not very, you might suppose, noting the discovery of interstellar ethylene glycol (anti-freeze; Hollis et al. 2002). This has not, however, prevented some of the neutral hydrogen in the envelope of IRC +10216 from being cold enough to be seen in absorption against the 2.7 K cosmic microwave background radiation (Le Bertre & Gerard 2001).

It was, all around, a good year for new molecules. Some others of our favorites are (*a*) ND_3 (Lis et al. 2002), the first triply deuterated, about which a moment's thought will reduce the surprise that its spectrum is more like that of NH_3 than like that of NDH_2, (*b*) $C^{13}O^{17}$, the rarest form of CO, though not quite so rare where it was seen (the ρ Oph cloud; Bensch et al. 2001) as it would be with terrestrial isotope ratios, (*c*) O_2, a tentative first detection, also in the cloud around ρ Oph (Goldsmith et al. 2002), of what is probably the dominant reservoir of oxygen during part of the life of a typical young stellar object, but homopolar, and so incapable of producing strong spectral features, (*d*) vinyl alcohol or CH_2CHOH, the simplest enol and an important intermediary in organic chemical reactions, but probably not one of the alcohols you want to drink (Turner & Apponi 2001), and (*e*) AlCN, which joins MgNC, MgCN, and NaCN among the interstellar cyanides found around IRC +10216 (Ziurys et al. 2002, who are in fact kindly folk, unlikely to employ their discoveries in the most obvious fashion).

5.2. Too Hot?

The local bubble of ionized material that surrounds us is hot enough and extensive enough that it must have been fed by several supernovae (Berghoefer & Breitschwerdt 2002), approximately six, says Maiz-Apellaniz (2001). The papers also concur that the bubble is extended perpendicular to Gould's belt (of B stars) rather than perpendicular to the local Milky Way disk, suggesting a connection between those supernovae 10–20 Myr ago and the belt stars, which would have been ready for something of the sort at the time. Some of the dust in the bubble has evaporated (Slavin & Frisch 2002), and what remains has a small enough albedo (about 0.1) that a good deal of ultraviolet light can pass through it (both directions) letting us peer through to the extragalactic background (Henry 2002).

Some fraction of the rest of the ISM volume is also made of old SNRs, but not most of it concur Maiz-Apellaniz (2001) and Shelton et al. (2001). How far does such material extend beyond the obvious plane of a galaxy? Quite a ways and hotter further out for NGC 891 (Otte et al. 2001). In the case of the Milky Way, beyond 5 kpc (Howk et al. 2002b) and far enough to provide pressure confinement of part of the Magellanic Stream (Wakker et al. 2002), and more or less all over the LMC as well, as traced by O VI absorption (Danforth et al. 2002). If we instruct you to connect this up with the prevalence of WHIM (warm/hot intergalactic medium) in § 12 (well, actually most of it is further away than that), we will feel we are telling our uncles how to find their olive groves. But if we don't, we will feel that we are not doing our duty. All very difficult, this business of writing review articles.

5.3. Too Medium?

Just a few more numbers, please, that surprised either the original authors or us as readers. A star as cool as 3500 K can illuminate a detectable reflection nebula (Li & Draine 2002b, who were a bit surprised; we had no previous opinion). Up to 25% of interstellar gas is likely to be in temperature/density phases generally regarded as thermally unstable, observations of which surprised us last year (Ap01, § 8.1), according to models calculated by Kritsuk & Norman (2002). Five different sight lines examined with *FUSE* yielded an average value for D/H of $1.52 \pm 0.08 \times 10^{-5}$ (Moos et al. 2002 and five following papers). Only the local bubble is being probed.

Local cosmic rays are confined to the galaxy for 15.0 ± 1.6 Myr and pass through about 10 g/cm^2 of material with average density 0.34 H/cm^3 (Yanasak et al. 2001). The data are abundances for the unstable nuclides Be^{10}, Al^{26}, Cl^{36}, Mn^{54}, and a limit on C^{14} collected by the *Advanced Composition Explorer* satellite. The local GCR spectrum (and therefore presumably the local composition, confinement time, etc.) may, however, not be typical of the Milky Way as a whole (Buesching et al. 2001). There remain some interesting uncertainties in the rate at which GCRs diffuse through the galaxy (Lerche & Schlickeiser 2001), much slower when turbulence is parallel to the magnetic field, which we suppose would encourage the persistence of regional fluctuations.

5.4. Too Dusty?

All late-type galaxies, from Milky Way clones to ultraluminous infrared galaxies have lots of dust at temperatures as low as 20–25 K say Dunne & Eales (2001), who aimed SCUBA at 104 of them. We think it is a coincidence that this is just about the number of Messier objects, most of which are not galaxies.

Some dust spins with rotational kinetic energy a good deal larger than the local temperature would produce and radiates accordingly, say Finkbeiner et al. (2002), reporting what they describe as the first tentative detection of such emission in one H II region and one dark cloud. The original theory came from Erickson (1957).

Dust, wherever you look, seems to be made mostly of silicates, carbonaceous grains, and PAHs (Li & Draine 2002c on the SMC), but we also caught sight of ammonia ice (Guertler et al. 2002) and nanodiamonds formed near Herbig Ae/Be stars (van Kerckhoven et al. 2002). There were votes against long carbon chains, C_4 and C_5 (Maier et al. 2002) and C_7 (McCall et al. 2001), and silicon nanoparticles (Li & Draine 2002a). And one of (MANY) unidentified diffuse interstellar absorption bands, at 2.895 μm, has turned out to be made by neutral oxygen, a common, usually easy to identify atom, but doing something strange called $4p\,^3P \rightarrow 4s\,^3S^0$ (shoo, shoo; get back where you belong with laboratory astrophysics).

One of the major early discoveries of UV astronomy from above the atmosphere (yes, this is a tautology) was extended, in both wavelength and space, excess extinction at 2200 Å refined to 2175 Å as resolution improved. This has been seen as far away as $z = 0.83$ (satellite no longer required; Motta et al. 2002). Zagury (2002) however denies the existence of the feature and says that the true galactic extinction curve is a straight line in suitable coordinates, presumably A_λ vs. λ, which is already a bit logarithmic, since A_λ is absorption in magnitudes.

5.5. Too Turbulent?

Turbulence is fed into the interstellar medium by supernova shocks and remnants (Koyama & Inutsuka 2002; Maron & Blackman 2002; Brunt & Heyer 2002). According to Ossenkopf (2002) the resulting models have more velocity structure in them, at least for cool clouds, than is revealed by line profiles. He calls this intermittency, and one would normally suppose it to mean that the models were in poor shape. Boldyrev et al. (2002) note, however, that the data are in pretty poor shape too, though their model fits what information is available.

Lithwick & Goldreich (2001) have modeled the sort of turbulence that is seen in partially ionized gas as the cause of pulsar scintillations. The same structures show in *FUSE* data for lines produced by ions like O VI (Sterling et al. 2002, Bhat & Gupta 2002). We turn, finally, parochial and cite the measurement of the local bulk gas flow by Frisch et al. (2002), partly for the pleasure of recording that they credit the general idea to Münch (1957), who looked at the gas around an OB association. The Frisch et al. value is 17 km/sec relative to the local standard of rest, coming from $l = 2.^\circ3$, $b = -5.^\circ2$, confirming the number given by Bzowski (1988).

5.6. Too, Too?

We mean the high velocity (and intermediate velocity) clouds. Their characteristics are (*a*) primary discovery as emitters of 21 cm radiation, and (*b*) velocities seriously inconsistent with disk rotation for their directions and distances (though they do not come labeled with distances, and the average and range are both topics of ancient dispute). The two primary scenarios that accomodate them are (1) freshly inflowing, metal-poor intergalactic material (helpful for the G dwarf problem and in keeping up the star formation rate in the future) and (2) return flows in a fountain picture of interstellar gas perpendicular to the disk. One would expect clouds of the former sort to be both more distant and less enriched in heavy elements than clouds of the latter sort. In light of the range of available data, we are voting “both of the above,” and maybe one or two other scenarios as well. This is not, perhaps, terribly helpful if what you need is a definitive answer on how to include HVCs in your global model of galactic chemical and dynamical evolution (§ 10).

Several extensive data sets appeared during the year. Wakker et al. (2001a, 2001b) concluded that the highest velocity clouds are at least 6 kpc outside the galactic plane, have metallicities of 10%–30% solar, and masses of $\gtrsim 10^6\ M_\odot$. The intermediate velocity clouds are closer at 0.5–2.0 kpc, of solar metallicities, and smaller masses. The compositional difference cannot be blamed on heavy elements being more depleted onto grains in one class than the other. Such differences exist, but they are always in the direction of the higher velocity gas having less depletion (Contini et al. 2002 on NGC 4151; Cartledge et al. 2001; Walborn et al. 2002 on the Carina Nebula). The last of these papers reminds us that this should be called the Routly-Spitzer effect for its discoverers (Routly & Spitzer 1952).

Quite a lot of the high velocity cloud stuff is associated with the Large and Small Magellanic Clouds in some way (Lockman et al. 2002; Richter et al. 2001; Danforth et al. 2002). Neither of the above is then the answer to the principal scenarios for these gas clouds, but they are entitled to their moderate metallicities and intermediate locations, as are the ones directly illuminated by UV from the Milky Way, so that they glow in Hα (Tufte et al. 2002).

Other galaxies are not so helpful as you might expect (surely we have said this before). Very few have detectable high velocity clouds, and what is there seems largely to be part of fountain-like circulation (Lee et al. 2001a on NGC 5725; Lee et al. 2002; Fraternali et al. 2001 on NGC 2403). Each of the Magellanic Clouds is apparently cycling fountain material at a rate of about 0.02 $M_\odot$/yr/kpc^2 (Howk et al. 2002a on the LMC; Hoopes et al. 2002 on the SMC).

Yet another data set provides a possible answer to a question that we decide a few sections down stream (§ 12) doesn’t need answering, the issue of missing satellite galaxies. De Heij et al. (2002) have found about 200 compact, apparently H I-only (virgin gas) HVCs concentrated around the Milky Way and around M31. These have, they say, small dark matter halos of their own, and are arguably the “missing satellites” of Λ-CDM models for structure formation. In any case, HVCs in general are not satellite *galaxies*, since tight limits can be put on the surface brightnesses of the stellar populations in many of them, below the surface brightnesses of even the most feeble of the known Milky Way companions (Simon & Blitz 2002).

6. I DID IT MYSELF

If you want something done right, do it yourself, said Mae Nightingale of the Le Conte Junior High School music department (yes, really, but her birth name was Wheeler). This advice is generally supposed to be more difficult for astronomers to take than for other sorts of scientists. We are not 100% sure that this is true—with something × 10^{11} stars in the Milky Way, there is quite likely to be one with the properties you want to investigate. The only problem is to find it, but pharmaceutical chemists looking for new drugs have much the same problem. In any case, here are some of the recent successes and failures in the continuing struggle to bring astronomy down to Earth.

6.1. Difficult Elements

There is probably no point in looking for elements 116 and 118 among the nearly one half of all solar spectral features that remain unidentified (Kurucz 2002), since they haven't been produced on Earth after all (Ninov et al. 2002).

Hassium (Hs) on the other hand now exists in a generous sample of seven atoms. Do not disparage these seven atoms, though they lasted for less than a second. Five is enough to show collective properties for superfluid helium (Tang et al. 2002) and for water as a solvent (Hurley et al. 2002). The enthalpy of absorption of the oxide HsO_4 is roughly equal to that of OsO_4, meaning that it belongs to group 8 in the periodic table (Duellmann et al. 2002). We do not, however, expect that astronomers will switch from using [Fe/H] to [Hs/H] as the standard indicator of metallicity in the near future. The authors prepared isotopes 269 and 271 by bombarding Cm^{248} with Mg^{26}.

Thorium, in contrast, has been seen in stars, and improved oscillator strengths of Th II transitions (Nilsson et al. 2002) will help to make it a better chronometer for the oldest galactic stars.

We are not quite sure what you might want to use Dy IV for, but it is found in both Przybylski's star and in the laboratory of Zhang et al. (2002), who have provided the first measured transitions probabilities for it. The temptation to tell you that it is chemically like neutral europium is very great, but truthfully we are not sure that all three electrons are removed from the N shell.

Iron must surely have been measured to death, you might suppose. But no, existing line lists were incomplete by factors of 2–3 for Fe XVIII to XXIV L-shell transitions (Brown et al. 2002). These are, of course, X-ray transitions, and the situation for lithium-like (three electrons) to fluorine-like (nine electrons) ions of Ne, Mg, Al, Si, S, and Ar is not much better, with both wavelengths and transition probabilities in need of calculation (Behar & Netzer 2002). That these have become urgent is a tribute to the energy resolution of the *XMM-Newton* and *Chandra* spectrographs. We remember when there were two blobs, one around 6.6 keV and one at lower energy, which were called "iron" and "oxygen" in a very generic sense. No data were reported during the year for Fe XXVII.

6.2. Not in My Lab You Don't!

Herewith a trio of great moments (and dreadful half hours) of cutting-edge attempts at laboratory simulation of large-scale phenomena.

A supernova in every home? Drake et al. (2001) have produced "a spherically diverging hydrodynamically unstable system," in which a millimeter size capsule of germanium doped with CH expands into a lower-density foam when zapped by a laser. We didn't catch whether this makes a Type I or and Type II supernova.

Collimated jets are found (or at least postulated) in astronomical objects from young stars to old quasars, the collimation generally being achieved with some combination of rotation, magnetic fields, and optimism. Lebedev et al. (2002) have made a supersonic jet with conically convergent flows. The next steps they intend are studies of stability and interaction with a cloud. The jets of Hsu & Bellan (2002) show collimation, helicity, and plasma detachment, in a plasma gun experiment. It sounds as if most of the geometry was put in with a disk-annulus electrode and injected magnetic helicity, but the instabilities seem to be emergent phenomena, and the best of the pictures looks like a long-stemmed mushroom that has just shot off its cap at an intrusive mycologist.

Laboratory black holes (in addition to the one that swallowed our budget surplus for the year). The first two are analogies, an acoustic black hole (Unruh 1981) and, this year, a dielectric one that arises when the velocity of a medium with finite permittivity exceeds the speed of light in that medium (Schützhold et al. 2002). Apparently neither has been constructed, carried out, fallen into, or whatever the right phrase is. Neither, of course, has been the Large Hadron Collider, which, just possibly, might produce mini black holes (Dimopoulos & Landsberg 2001), but this should not be the main thing that keeps you awake over the next few years. If the process is possible at all, then galactic cosmic rays have been doing the same thing in the upper atmosphere for gigayears (Feng & Shapere 2002) with no ill effects of which we are aware. Only Rabinowicz (2001) believes he has seen mini black holes (about 1 gram) up close, in the form of ball lightning. They are, he says, primordial, but radiate much less efficiently than Hawking/Beckenstein black holes of similar mass and so have survived to the present time.

Returning again to analogies, we come upon Leonhardt (2002) and his event horizon, from which photon pairs are emitted in resemblance to Hawking (etc.) radiation.

6.3. Serious Physics

Further analysis of the solar neutrino data from the Sudbury Solar Neutrino Observatory (Ahmad et al. 2002) indicates that the neutrino with which the outcoming solar electron ones are mixed differs from ν_e by $(\Delta m)^2 = 10^{-4}$ eV^2. The most straightforward interpretation is that all three species have masses of a few hundredths of an eV, so that the neutrino contribution to the cosmic matter density is comparable to the stellar contribution. This is by no means so certain that further data would be willingly foregone, thus the news that SuperKamiokande will rise again to look at solar, atmospheric, and reactor neutrinos (not to mention supernova neutrinos when available) was good indeed (Totsuka & Sobel 2001). And indeed they were back on at least the higher energy lines soon after the end of the index year.

Deviations from the standard model of particle physics. Votes during the year were, roughly, yes, from McFarland et al. (2001) on the mixing angle that connects the weak and electromagnetic forces; no, or anyhow not enough to account for the excess of baryons over anti-baryons in the early universe, according to Smith et al. (2002c) on CP violation at BaBar, and maybe, according to Roberts et al. (2002) on the magnetic moment of the muon.

6.4. Dust and Ashes

Dust grains and molecules (unlike say, supernovae and black holes with jets) are about the right size to fit into the sorts of laboratories most of us can afford. Herewith, some recent measurements relevant, perhaps, to what all is to be found beyond confines of Earth.

The year of silicon? Extended red emission means extended in wavelength. It comes from dense regions of the interstellar medium, like the Red Rectangle. Ledoux et al. (2001) have explored laboratory photoluminescence of silicon nanoparticles as a promising candidate, while Koike et al. (2002) prefer thermoluminescence from silicates like forsterite irradiated by cosmic rays. Crystalline silicates are optically anisotropic (Suto et al. 2002). We don't think that Schutte (2002) are claiming that such crystals can't form at low temperature, but only that it isn't done as previously advertized (Moore et al. 1994).

Solid H_2 turns black at a pressure of 320 GPa (Loubeyre et al. 2002). If you have had this happen to bananas, you may not think it is anything to brag about, but in the hydrogen case, it is evidently a promise of a metallic state to be reached near 450 GPa. No, we have never had any metallic bananas, but can think of several things the Three Stooges might have done with them.

Molecules, like atoms, have Landé *g* factors, which determine how they will react to magnetic fields, emit polarized radiation, and such, but one's intuition is a very poor guide to whether the factors will be large or small, or, if large, what the sign will be (Berdyugina et al. 2002; Berdyugina & Solanki 2001).

A great deal of terrestrial biochemistry occurs in liquid water solution. This cannot be typical of interstellar chemistry, and we spotted four papers in which complex things were assembled in other ways. (1) a racemic mixture of amino acids from UV-irradiated ices (Bernstein et al. 2002a), (2) the PAH coronene (Oomens et al. 2001), (3) H_2CO and CH_3OH produced by shooting a hydrogen beam at an ice made of CO and H_2O (Watanabe & Kouchi 2002), and (4) solid amino formate from simpler molecules in the presents of an HCl catalyst (Khanna et al. 2002). When you do this sort of thing with water, the process is often called a Urey atmosphere experiment, so we were astounded to learn that the versions with electricity and ultraviolet radiation as the energy sources had both been carried out in 1913, when Urey was celebrating his 20th birthday (Yockey 2002). In fact, water must be feeling a bit neglected, since the lists of "steam lines" are still quite incomplete (Jones et al. 2002), despite the assignment of quantum numbers to no fewer than 5589 features between 1 and 2 μm by Tereszchuk et al. (2002).

Putting it all together. From dust to planets still seems like a long ways to go, but shadowing pressure, which enhances clumping and induces a gravitational-like instability, has been seen in the lab (Bingham & Tsytovich 2001). Differential charge effects can also accelerate coagulation of grains, according to an experiment carried out on the International Space Station (Morfill 2001).

Can you talk to it? What one really wants to know about interstellar chemistry is just how far does it go? Pendelton & Allamandola (2002) have apparently gone just about as far as you can go with a mix of aromatic and aliphatic compounds subjected to both plasma processes and energetic particle impacts on ice residues. The former is a better fit to measured 2.5–10 μm interstellar absorption spectra. They have also looked at a haze of *E. coli*, which has 5–10 μm spectral features not seen in the ISM, and conclude that there is no evidence for biological origin of the 3.4 μm feature, claimed by others in earlier years. Indeed they say that the presence of the CH-stretch feature in spectra of distant galaxies implies a universal reservoir of pre-biotic carbon.

6.5. Radiation Mechanisms

We continue to hold the opinion, enunciated by the late Peter A. G. Scheuer, that the only way to radiate electromagnetic waves is to wiggle charges. These are usually electrons, which are easier to wiggle, but proton synchrotron continues to hang in there, or at least advocates of it do. Kardashev (2001) makes the case for FR II radio galaxies and for supernova remnants with pulsars but with no synchrotron nebula or plerion, and Aharonian (2002) for the extended X-ray jets in AGNs mapped by *Chandra*.

Such jets are normally attributed to electron synchrotron and/or inverse Compton scattering. "Some of each" was clearly the call for 2002. Don't try this on the toss—30% heads and 70% tails will win you no first downs. Harris & Krawczynski (2002) provide a convenient table of 18 *Chandra* active galaxies and tell you which is which. Mei et al. (2002) do the same for BL Lacs (with the 70% belonging to synchrotron emission). Similar thoughts come from Sambruna et al. (2002) on specific knots in jets, except more of theirs are C^{-1}, with one synchrotron example. M87 is a synchrotron case, say Marshall et al. (2002), while the first inverse Compton X-rays from a gamma-ray burst were reported by Harrison et al. (2001a) for 000926.

At sufficiently large redshift, inverse Compton ought always to win, because the flux we see should be redshift invariant, while all other processes are discouraged by some power of $(1+z)$. This happens for C^{-1} on the microwave background radiation because its energy density is raising as $(1+z)^4$, which just balances the $(1+z)^{-4}$ by which observed surface brightnesses decline in a relativistically expanding universe.

Our most-bemoaned foggy window for astrophysics remains X-ray polarization. Sazonov et al. (2002) predict that it might be as large as 10% in relaxed X-ray emitting clusters of galaxies like Coma, because of resonant scattering. That's a calculation we think we know how to do ourselves, but the index year yielded three other sorts of EM radiation where we might have to go back to Maxwell or at least Shu to know which equations to solve.

First is the description of radio galaxy Her A given by Sadun & Morrison (2002), in which small clouds of dense gas from the optical double core reach the edge of the halo and radiate picoHz spherical acoustic trains of waves. The second is Faraday conversion in radio jets. It requires that the jet be carrying magnetic flux and permits both (*a*) circular polarization larger than linear and (*b*) considerable Faraday rotation with little depolarization (Ruszkowski & Begelman 2002).

The third is laser emission without a population inversion. Sorokin & Glownia (2002) apply this to narrow UV lines of O VI in RR Tel and invoke a laboratory mechanism that makes a two-level atom non-absorbing at the transition frequency (stimulated hyper-Raman scattering and fourwave mixing). The authors are at IBM, so we suppose the thing must work. Liu et al.'s (2002a) non-inverting pumping mechanism for methanol masers does not come with that guarantee.

6.6. Things of Science

Long, long ago, Things of Science was a commercial organization that, for a consideration, would mail your child a monthly packet of, for instances, magnets, diffraction gratings, vacuum tubes, crystals, or prisms, with suggestions on what to do with them (all polite). Perhaps it still is. If so, the authors of the 34 papers we collected under this heading might be able to provide particularly interesting packets. It is conceivable that, by the time this is published, the subset cited will have self-organized by wavelength.

The same gamma-ray instrument package, called THEMIS, has been used to record the solar high energy spectrum (Bommier & Rayrole 2002, and the next seven papers) and the Crab Nebula (from the ground) down to 60 GeV via Cerenkov radiation (de Naurois et al. 2002). Because the EGRET detector flown on the *Compton Gamma Ray Observatory* recorded the Crab up to 10 GeV, the opaque window now spans only a factor of six in energy. Mind you, the Crab Nebula is the brightest source in the sky at these wave-lengths, and the entire optical spectrum is only a factor of two wide in energy.

A given X-ray flux collected by the *Chandra* and *XMM-Newton* satellites will look different by 10%–20%, but Lumb et al. (2001) will tell you how to reduce each to the other system, and we wouldn't dare vote on who is right. The USA "experiment" on the *Argos* satellite saw about 2000 outbursts of the black hole X-ray binary XTE J1550−569 and can perhaps be declared to have advanced beyond the experimental stage (Reilly et al. 2001).

Absolutely our favorite optical telescopes of the year are those designed by Lynden-Bell (2002), of which the author says, first, that "some may be appropriate for solar furnaces or light houses," and, second that "we have not required that the light can get to the primary … nor that [it] can reach the focus." We are reminded of an earlier telescope design by a senior colleague who desires to remain anonymous, which provided the collecting area, angular resolution, and mimization of aberrations that had been part of the spec, but which unfortunately required that the observer put his eye inside the telescope.

An observer would be ill advised to put his eye inside the tube of a liquid mirror telescope since the liquid is generally mercury, but these have become good enough that the dominant aberration is Coriolis force arising from the rotation of the Earth (Hickson 2001).

No examples of "world's largest telescope" saw first light during the fiscal year, but some curious focal plane devices did (or made progress toward it) as well as some smaller telescopes. Kandpal et al. (2002) carried out the first double slit observation of a star and used the spectral degree of coherence to get angular diameters of 2–20 milliarcsec across 3250–6600 Å for four. All, you will not be surprised to hear, were very bright stars, called Alpha something.

The observation by Debes et al. (2002) of a star with a Gaussian aperture pupil mask was also a first. It provides dynamic range comparable with that of a coronagraph (at greatly reduced expense). The mountain (Mt. Wilson in this case) labored and brought forth a mouse (a very faint companion to μ Her A). If the beginning of this paragraph led you for a moment to envision a star clutching a mask in its hot little chromosphere, then feel free to rearrange the sentence.

We wouldn't have thought of either of these, or of the adoption of integrated optics components from telecommunications for astronomy. Berger et al. (2001) provide lots of details on how you combine beams and such when looking at 4 Ori (not an Alpha, you notice), and there are more details from Laurent et al. (2002) looking at ι Aur.

Where is all this going? Well, fairly soon to time-resolved imaging spectral polarimetry, with a transition edge sensor (Romani et al. 2001). The authors looked at the Crab pulsar, guaranteeing that there would be interesting things to see in the time, wavelength, and polarization domains all at once. Tunable Fabry-Perot filters (of which the elder of our two thesis advisors was inordinately fond) can do some of the same things (Jones et al. 2002a). Photon arrival direction and approximate energy are also recorded simultaneously by superconducting tunnel junctions, and the STJ camera on the William Herschel Telescope can now measure QSO redshifts to about 1%, even when the previously "known" spectroscopic one was wrong (de Bruijne et al. 2002).

MOA is the fourth installation to look for gravitational lensing of one star by another toward the galactic bulge, after OGLE, EROS, and MACHO (Bond et al. 2001). The acronym is Microlensing Observations in Astrophysics, but is also supposed to suggest that the installation is in New Zealand. It also records other optical variables like eclipsing binaries in the SMC (Bayne et al. 2002).

There were a whole flock of image-improvement papers, including adaptive optices with multiple laser guide stars (Le Louarn 2002), a competition between AO and *HST* on the structure of the accretion disk of the cataclysmic variable GG Tau (Krist et al. 2002, who say that *HST* won, and the disk does not have spokes) and an astronomical eyechart for image reconstruction (Fruchter & Hook 2002).

A large optical number is 192, from the Sloan Digital Sky Survey. This is not the number of sources, which is umpzillion, but the number of authors on the paper, coming from 23 institutions, and reporting as Stoughton et al. (2002). The next large data set is being released even as we write this, in January 2003.

The non-coplanar radio T array on Mauritius is carrying on with the 151 MHz survey that was its original purpose (Golap & Udaya Shankar 2001). Given its operating wavelength, it would need its second antenna 10 times as far away as the Moon to equal the angular resolution of the $1.5 \times 10^9\ \lambda$ observation described by Greve et al. (2002). This is the longest baseline, in wavelengths, over which fringes have been seen. They saw 3C 273 and 3C 279.

Radio astronomers using Earth-rotation aperture synthesis have always had to be patient folk, but Macquart & Jauncey (2002) have carried out the first high resolution radio mapping with an Earth orbit synthesis array. We think it takes all year and that the baseline will be difficult to vary.

Do you think detectors at various wavelengths have gotten to be just about as good as they can be? Dravins (2002) points out that a *really* good detector would record (*a*) energy of the photon (so no spectrometer or spectrograph is needed), (*b*) amplitude and phase of the arriving EM wave (so that no separate telescope is needed, and pointing is done with software—SOFAR may work that way), (*c*) individual photon times of arrival (so that no readout is necessary). In other words, there are still something like 20 orders of magnitude of improvements possible beyond today's CCDs!

7. NINETY-NINE BOTTLES OF BEER ON THE WALL

Probably no one living has ever sung this all the way down to zero, because those who tried in childhood, on long family drives, were murdered by their parents at about 43. This section, however, attempts a count down from very large astronomical numbers to unique examples.

7.1. Countdown

10^7 per square degree, was the largest number we spotted in the index year. It is the number of (extragalactic!) globular clusters that ought to be visible down to $m_{\rm AB} = 31.4$ (or 10π). They will be confused at the diffraction limit of a 6-meter telescope (Carlberg 2002). The underlying model for evolution of the clusters came from Fall & Zhang (2001), which was on our list of "must visits" for slightly different reasons.

$1.2 \pm 0.5 \times 10^6$ asteroids of diameter larger than 1 km in the main belt (Tedesco & Desert 2002). The number comes from ISOCAM data, but we suspect it may be based on actual counting of some smaller numbers, plus adjustments for undercounts, POSSLQ's, etc.

765,787 pulses observed from six pulsars, without seeing any giant ones (Johnston & Romani 2002).

200,000 variable stars recorded by OGLE II (Wozniak et al. 2002), and also 200,000 redshifts measured in the first two-degree fields of the two-degree field (2dF) survey in its first 2 × 2 (sorry, four) years of operation (Lewis et al. 2002a).

147,900 galaxies so far with colors measured in the Sloan Digital Sky Survey (Strateva et al. 2001).

100,000 as the value for N that counts as "enough" for an *N*-body simulation of the formation of a galactic halo (Boily et al. 2002). "Enough" apparently means enough for violent relaxation to develop fully under the Lin, Mestel, & Shu (1965) instability.

84,486 (later increased to 98,084) stars in the 2001 edition of the US Naval Observatory *Washington Double Star Catalogue* (Mason et al. 2001). Of these, only 1430 have orbits (Hartkopf et al. 2001) and 10,475 estimated magnitude differences (Worley et al. 2001).

68,000 OGLE II variable stars in the Large and Small Magellanic Clouds (Zebrun et al. 2001).

62,219 components of 32,631 double and multiple stars (most $0''.3$–$1''.0$ apart) in the Tycho catalog from the *Hipparcos* satellite (Fabricius et al. 2002). We suspect that the near agreement in numbers with the Washington Double Star Catalog is a coincidence and does not mean that they are mostly the same systems.

29,300 in the first set of SDSS galaxies whose clustering properties have been examined by Zehavi et al. (2002). The power law index is -1.75 for separations between 0.1 and 16 h^{-1} Mpc, very much like that in other samples.

5004 galactic dust clouds in the catalog compiled by Dutra & Bica (2002).

3000 variable stars in globular clusters (Clement et al. 2001; Helen Sawyer Hogg is one of the co-authors, but is not in the running for longest-deceased, mentioned in the next subsection). Of these, 1800 are RR Lyrae stars, 100 are eclipsing binaries, 120 SX Phe stars, 60 assorted Cepheids (Pop II, anomalous, RV Tauri), and 120 are semi-regular variables.

2641 previously-known asteroids (90% of the total) recovered in SDSS fields (Juric et al. 2002).

2432 high resolution optical and infrared observations of 1625 sources, from interferometry and lunar occultation (Richichi & Percheron 2002).

2249 catalogued white dwarfs (Holberg et al. 2002), of which 109 have good parallaxes and distances less than 20 pc (including 28 binaries). The set is said to be complete to 13 pc, yielding a number density of $5.0 \pm 0.7 \times 10^{-3}/\mathrm{pc}^3$, with a DA/nonDA ratio of 1.2 (DA's are the ones that show strong hydrogen lines and not much else).

2068 BATSE trigger gamma-ray bursts and 1838 slightly below threshold, implying that there are several thousand per year in the observable universe, and that $N(S)$ flattens at the faint end but does not turn down the way the radio source one does (Stern et al. 2001).

1956 high velocity (H I) clouds surveyed from the Southern Hemisphere (Putnam et al. 2002).

1537 open (galactic) star clusters catalogued so far (Dias et al. 2002).

1510 planetary nebulae catalogued up to 1999 (Kohoutek 2001). The name was coined in 1779 by Messier and Darquier to describe NGC 6720, and William Herschel added about a dozen to the inventory.

1331 of 1912 cold *IRAS* sources are also CO sources (Yang et al. 2002). The CO survey was done with a 45-foot dish at Purple Mountain Observatory.

483 very low frequency (10–25 MHz) radio sources found with the Ukraine UTR-2 telescope. 90 of them are not in 4C (Braude et al. 2002).

459 of 460 of Luyten Half Second (i.e.. proper motions in excess of 0″.5/yr) stars are recovered in a digitized sky survey (Lepine et al. 2002) which also found a number of additional stars of large proper motion, especially at small galactic latitudes.

387 dwarf irregular galaxies (compared to 179 in 1979). The sample added by Huchtmeier et al. (2001) has a median redshift of 1127 km/sec, and there could still be 350–400 uncataloged dwarfs in that distance range.

124 radio sources in the Shapley concentration of galaxies (Venturi et al. 2002). This sounds more interesting if you are old enough to remember when the catalogues (like Parkes and 3C) contained only sources so bright, at the low, survey, frequencies, that there was at most one per supercluster, and they were randomly distributed on the sky.

120 the combined ages of the two honorees at the conference whose proceedings appear as Henney et al. (2002). The topic was ionized gaseous nebulae. In general, we think that a 60th birthday is much too early to celebrate, but are willing to make an exception when the sum is 120 (the age to which Moses lived). The proceedings include lots of neat papers, the core content of which, we hope, can be found elsewhere.

39 carbon stars from SDSS (Margon et al. 2002). About half are dwarfs and have, we hope, been polluted by now-vanished or faint companions.

The 21 amino acids that have been known since 1986 to be essential for some form of terrestrial life are now 22 (Srinivasan et al. 2002). The new one is pyrrolysine and appears in a stop codon in archaeobacteria and such (Hao 2002).

Before counting down below 10, we pause to note that the set of nearby stars, meaning closer than 10–20 pc, must remain very incomplete, since "more" are being recorded every few months: McCaughrean et al. (2002, two late M dwarfs closer than 10 pc), Reyle et al. (2002, a DENIS star at less than 10 pc), Koen et al. (2002a, 6 *Hipparcos* stars at 10–20 pc and one at 8.5 pc), Cruz & Reid (2002, 19 stars within 20 pc that Luyten might reasonably have caught but didn't), Scholz et al. (2002, some more proper motion stars from an APM seach out to 25 pc), and Phan-Bao et al. (2001, 30 additional late M DENIS dwarfs at 15–30 pc).

Eight (out of 23) is the order of the author of Alcock et al. (2001) who apparently wrote the paper. At least he is the one who thanks the referee. The authors are alphabetized.

Six are the radio emitting comets (Altenhoff et al. 2002), the radio-emitting black hole X-ray binaries (Clark et al. 2001), the number of images in the most complex lensed QSO (Rusin 2001), and the WZ Sge stars (Kato et al. 2001b). These are dwarf novae with long recurrence times and superhumps. The new one is HV Vir.

Five are the planetary nebulae with expansion parallaxes from optical data (Palen et al. 2002; Li et al. 2002b). Credit is rightly given to the person who developed the technique for radio PNe but, perhaps wrongly, not to the person who first did it optically for one nebula, NGC 6397.

Four are the X-ray emitting planetary nebulae (Guerrero et al. 2002, all are young), the dwarf novae with spiral structure in their disks (Morales-Rueda & Marsh 2002), and the foregrounds that can confuse attempted measurements of detailed structure in the cosmic microwave background radiation (McCullough & Chen 2002).

Three are the accretion-powered millisecond pulsars (Galloway et al. 2002), the resolved R CrB stars (Clayton & Ayres 2001), the bodies in the dynamics problem involving Hill stability (Lukyanov & Shirmin 2002, who are gracious enough to cite Hill 1905), and the integrals of motion in a Stäckel potential (Famaey et al. 2002; Stäckel 1890). Galaxies living in such a potential (or anyhow in the model of one) can have unequal velocity dispersions of their stars in the radial and vertical directions, as does the Milky Way.

Two are the black hole X-ray binaries that display superhumps (Zurita et al. 2002), the types of quasi-periodic oscillations (flickering) in dwarf novae (Warner & Woudt 2002), and the kinds of objects that display unidentified infrared features, the corona of Nova Cas 1995 having joined the cooler interstellar medium (Rudy et al. 2002).

7.2. The World's Greatest Living Jewish Organist

This brings us to a collection of more than 40 extrema, some of which are indeed rather like the heading: the gentleman in question was just about the only living Jewish organist. He is no longer living, which perhaps casts doubts on the whole things, but his son, who was trained as a mathematician and is now something of a gadfly in the scientific community, goes shining on. Here, then, are some of the onlies and mosts with potential astrophysical significance, and a few others just for fun. Some effort has been made to order them from far to near.

The largest redshifts: Published QSO, $z = 6.28$ (Fan et al. 2001); BAL QSO, $z = 5.74$ (Goodrich et al. 2001); Type II QSO, $z = 3.7$ (Norman et al. 2002); Binary QSO, $z = 2.45$ (Impey et al. 2002; it is, or they are LBQ 0015+0239 and the objects are separated by 660 km/sec, most of which is likely to be orbit speed, and a projected distance on the sky of 12.5 h^{-1} Mpc); protocluster, $z = 4.1$ (Venemans et al. 2002; it includes a radio galaxy); dust emission, $z = 5.5$ (Bertoldi & Cox 2002; it is in a QSO but the dust seems to have been heated by stars, which is characteristic of distant QSOs say the authors). The largest "small" redshift is $z = 1.47$, according to Turnshek & Rao (2002). And the largest redshift at which a survey has been carried out is $z = 90.7$ for lithium hydride in protoclusters, using the RATAN 600 radio telescope (Gosachinski et al. 2002). They didn't find any.

Largest polarization of an integrated extragalactic radio source, 54% (Liang et al. 2001).

Brightest globular cluster, at least in M31 (and trumping all the aces in the Milky Way), $M_V = -11.75$ for 037-B321, after removal of considerable reddening (Barmby et al. 2002).

The most distant nova is in NGC 1316 in the Fornax cluster (Della Valle & Gilmozzi 2002). The authors suggest that novae can be used as distance indicators via the "Buscombe–de Vaucouleurs relation," neither of whom is cited. The oldest nova? Well, we're not quite sure. The novae stellae of 1572 and 1604 were supernovae. The 1670 event (CK Vul) has been moved to the "last helium shell flash" category (Evans et al. 2002a). 1677 in Orion was probably the periodic variable U Ori, which leaves 1783 (Payne-Gaposchkin 1964).

The first extragalactic T Tauri star is, surprise, in the LMC and associated with a dark cloud called Hodge II 139 (Wichmann et al. 2001, who report spectroscopic confirmation of its nature).

The shortest-period binary is a X-ray emitting pair consisting of two white dwarfs, each of small mass (an AM CVn star) with a period of 321 sec (Israel et al. 2002). It is called RX J0806+15 (Ramsay et al. 2002). You may, if you wish, measure the length of time it takes you to read this tome in RX J0806+15 orbit periods (and we would hope that the answer would be, to astrophysical accuracy, more than 10 but less than 100).

The shortest dwarf nova recurrence time, 2.65 days for V425 Cas (Kato et al. 2001a). 10–100 days is more typical.

The W UMa star with smallest mass ratio, SX Cru with $M_2/M_1 = 0.066$ (Rucinski et al. 2001). The interest lies in maintaining thermal contact between stars with such intrinsically different desires for their effective temperatures by standard mechanisms.

The coolest Am star is perhaps the giant member of the pair omicron Leo at 6100 K (Griffin 2002).

The first oblate star? Altair at 2.2 μm appears to be $3''.46 \times 3''.04$ with the Palomar test bed interferometer (van Belle et al. 2001). The distortion is just what you would expect from its spectroscopic rotation speed of 210 km/sec. It is advertized as the first oblate main-sequence photosphere, but we wonder about the Sun.

The closest star. Oh. That's the Sun; we can't fool you on that again. No, not the Sun. Well, Proxima Centauri. Nope, we mean G1710, which will come within 0.337 pc about 1.36 Myr into the future (Garcia-Sanchez et al. 2001). The *Hipparcos* sample from which it was taken is missing about 80% of nearby stars (mostly M dwarfs), so that the actual rate of stars coming within 1 pc must be about a dozen per million years.

The longest period comet, Ikeya-Zhang at 341 years. It was seen by Hevelius in 1661 and also perhaps in 1320 and 979 (not by Helvelius) according to Marsden (2002). Of course, most comets really have periods much longer than this; they just haven't been measured (yet).

The rarest isotope in the solar system, Ta^{180}, is only metastable, and laboratory data indicate that it is an *s*-process product, co-produced in shell flashes with Ta^{179} and W^{180} (Wisshak et al. 2001).

The youngest and the oldest moons. Just when a new crescent becomes visible is significant for Islamic and Jewish calendars, and has a considerable lore. But wondering whether a friend in a time zone further west would still be able to see the tiny crescent next to Venus that had greeted us at dawn led the more sentimental author to ask the world's expert on such things, Brad Schaefer, what was the oldest moon ever seen, when, and by whom. His response was 16.7 hours before conjunction, by Danjon, on 13 August 1931 (Schaefer 1996 and personnal communication). But it turned out to be of purely calendric interest. Our friend doesn't get up that early. The youngest moon, by the way, is only 15 hours after conjunction, seen by John Pierce, in Collins Gap, Tennesse, on 25 February 1990, consistent with more people having looked harder for these.

The smallest ocean is the Arctic (Jakobsson et al. 2002), not because its surface area has shrunk but because half of it is underlain by continental shelf and the mean depth therefore only 1.2 km vs. 3 km for the others.

On the astronomical front, the newest spectral type is O2, assigned to stars whose evolutionary state probably just precedes the Wolf-Rayet phase (Walborn et al. 2002b), and the newest broad-band color is Y at 1.035 μm (Hillenbrand et al. 2002). One fears that it may soon be necessary to resort to Greek letters for naming these. The strangest spectral type is surely kA3hA4mA9, assigned to the secondary of α Equ (Griffin & Griffin 2002). The primary is G7 III.

The oldest astrophysical society was founded in 1871 by Angelo Secchi, Pietro Tacchini, and others, as Società deglie Spettoscopisti Italiani. It is now the Italian Astronomical Society and may have scored another first by starting in 1997 an Arabic-language edition of its non-technical magazine, *Al-Magella al-Falakyya*.

Several authors clearly also scored extremum points. The longest deceased is the first author of Serkowski & Shawl (2001) who died in October 1981. This is not an all-time record. The most under-appreciated requires you to read an entire paper. Gonzalez-Perez et al. (2001) go on for 44 pages about photometry on the Landolt system, thanking 11 people at the end, not including Arlo Landolt (whose long service as secretary of the American Astronomical Society is perhaps also not adequately appreciated by some of the membership). The author most clueless about the Heisenberg uncertainty principle has had competition. There was a candidate for this some years ago in the realm of "solving the solar neutrino problems" (just put an electron between two protons that are about to interact to form a deuteron). The current candidate (Jones 2002) was, curiously, also trying to put an electron where no electron should have to go, boldly or otherwise.

There were five contenders for "most difficult method of the year:" (*a*) the discovery of the rotation period of the Sun from the time dependence of the flux of anomalous cosmic rays (Reames & Ng 2001), (*b*) simulations of jet structure from two-dimensional MHD codes, some of which may not actually converge (Krause & Camenzind 2001), (*c*) discovery of the rotation of the Earth from aberrations of a liquid mirror telescope (Hickson 2001), (*d*) the smallest antenna used for timing of millisecond pulsars (gleefully recorded as such in the abstract of Hanado et al. (2002 so it must be deliberate), and (*e*) the attempt to reunite the Soviet Union with observations carried out simultaneously using telescopes located in the Crimea (Kiev), Abastumani (Georgia), Maidenek (Uzbekistan), and Tien Shan (Kazakhstan). The authors (Karitskaya et al. 2001) hale from all of these places except Kazakhstan, and they were looking for time variability in the optical counterpart of Cyg X-1 (whose 147 ± 2 day period they recovered).

There was also unusually strong competition this year for the "oops" award (followed by the sound of crashing dishes).

a. The statement that V605 Aql is the only other star like Sakurai's object (Kerber & Asplund 2001). The prototype of these these stars experiencing last helium flashes is FG Sge. But then elsewhere in the paper, they tell us that main-sequence stars live 10^8–10^9 years and red giants 10^7–10^8 years (followed immediately by the asymptotic giant branch stage). This is bound to be true for stars in some mass range, but not the Sun, and probably not those that become FG Sge stars.

b. Some early work on X-ray sources was done by "one S. N. Milford" according to Helfand (2001), from which one might deduce that there was nothing more to be said about the presumably deceased Milford. Sidney is, however, to be found living both in the current APS membership directory and in Brisbane, Australia.

c. Worst choice of nomenclature is a century award, to the originators of *American Men of Science*, who (according to Heilbron 2002) thought that "Scientist" sounded too much like "Dentist" (§ 9.4). Inevitably, linguistic change has led to its being *American Men and Women of Science* in recent editions (though even the first had a few women).

d. A paper published in the 1 April issue of *Astrophysical Journal*, which had been accepted on 28 January 2000. Perhaps the proofs were just very difficult to correct. You should see how much help we need with ApXX each year!

e. The red halo around NGC 3115 apparently belongs to the wings of the point spread function of the CCD rather than to the galaxy (Michard 2002).

8. SUPERNOVAE: GROUND ZERO AND THE AFTERMATH

8.1. The Events

Supernovae have appeared in every ApXX since the first, which remarked upon the absence of suitable (binary white dwarf) progenitors for the Type Ia (nuclear explosion) events. We hasten to tell you that there are still none. What you need for the best fits to observed light curves (Piersanti 2002) is a pair with total mass exceeding the Chandrasekhar limit and an orbit period short enough that loss of angular momentum in gravitational radiation, or some other drain, will bring them together in a Hubble time. The most massive known, short-period pair, with a total mass of 1.26 $M_\odot$ and a merger time of $2t_\mathrm{H}$, still doesn't make it (Napiwotzki et al. 2002a). The authors have looked quite hard for other candidates, in a project called SPY (Napiwotzki et al. 2001). The recurrent novae are an alternative possibility for the progenitors. U Sco, for instance, has a white dwarf very close to the Chandrasekhar mass (Thoroughgood et al. 2001), and, while it blows off some material in each outburst, the 1999 explosion removed less gas than had been accreted to cause it (Evans et al. 2001).

The other classic SN problem is how the Type II, core-collapse events transfer about 1% of the available 10^{53} ergs ($= GM^2/R$ for a product neutron star) to the stellar envelope and blow it off as seen. The shock that starts out when the collapsing core hits nuclear density and bounces always seemed to stall, letting material drain down and the energy drain out in neutrinos and gravitons. The idea has been floating around (e.g., Herant et al. 1994, cited in Ap95) that fully three-dimensional calculations, in which energy is carried by neutrino-driven convection on a variety of length scales, might provide the solution. This now seems to be the case (Fryer & Warren 2002; Janka 2002). A better understanding of how neutrinos behave in dense matter has also been relevant (Horowitz 2002). Our first draft began this paragraph with a chorus of drums and trumpets in celebration, which may still be appropriate. Participants at a recent meeting, however, kept emphasizing that to fit a whole, three-dimensional supernova into even the largest computers at Los Alamos, you have to be rather approximate about some of the physics. Bruenn et al. (2001) emphasize in particular the effects of general relativity on core collapse and its outcome.

In the interests of symmetry, we ought to say something about (*a*) the mechanism for nuclear (Ia) events and (*b*) the progenitors of core collapses.

Nuclear explosions can propagate either supersonically (detonation) or subsonically (deflagration). We caught one vote for delayed detonation in SN 2000cx (Li et al. 2001), which was an unusually energetic event, and one for deflagration in the general case (Reinecke et al. 2002a). Here, too, one-dimensional calculations are being replaced by two- and three-dimensional ones, which are less sensitive to the initial conditions and tend to "predict" more energetic events (Reinecke et al. 2002a, 2002b). One implication is that the pre-explosion rotation and convection will matter to the calculated light curves, spectra, and nucleosynthesis (Höflich et al. 2002). Given such asymmetries, it is perhaps a bit surprising that ejecta are as spherically symmetric as they are (Thomas et al. 2002).

Why does all this matter? Well, most people, we think, will be more comfortable using SNe Ia as distance indicators for cosmology when it is understood what underlying physics contributes to the different amount of Ni^{56} made in each one. But, lest you might have supposed that there were only a few choices, here is Capetti (2002) calling attention to the sixth SN Ia (of 14 found so far in radio galaxies) that happened right on top the radio jet, as if triggering were in operation. Presumably this would favor a progenitor or mechanism in which diffuse gas or gas transfer was important and enhanced by the passage of the radio jet.

The progenitors of Type II events, and Types Ib and Ic (which are a continuum of core collapses in stars that have lost their hydrogen-rich envelopes; Hamuy et al. 2002), are massive stars. Clearly the mass range is large. SN 1986J ejected more material in hydrogen alone (at least 12 $M_\odot$; Perez-Torres et al. 2002) than the entire progenitor mass of 2002ep (based on preneed photos of the galaxy, M79, in which it occurred; Smartt et al. 2002a) and of 1999em (Pooley et al. 2002b). In each case, nothing was seen at the right place in *HST* images. Perhaps all Type IIP (plateaus in the declining light curves) come from 8–12 $M_\odot$ stars, say the authors.

Progenitor type of the year is, however, the sort that leads to a small class of events of which 1993J is the prototype (Immler et al. 2001). The fourth example turned up this year (1997eg; Salamanca et al. 2002). The defining characteristic of these Type IIn events is spectroscopic evidence for an enormous amount of nearby red supergiant wind material, indicating that the star has been caught in a superwind phase. The number of papers saying more or less the same thing slightly outnumbered the events (Gruendl et al. 2002 on SNR 0540−69.3 in the LMC; Fransson et al. 2002 on 1995N; Pooley et al. 2002b on 1998em; Di Carlo et al. 2002; Gerardy et al. 2002).

The progenitor of SN 1987A was special. Special to the point, say Smartt et al. (2002b), that nowhere in the Milky Way have they found evidence of a blue supergiant that looks like it might have been a red supergiant in the past. They have data (surface composition etc) for only 25 stars however.

What are supernovae good for? Well, they make supernova remnants (next subsection) and, we think, all of the following.

1. Pulsars and other neutron stars. You may have to wait a long time to see these, 150 years for 1993J, according to Mioduszewski et al. (2001), and 16 years and counting for SN 1987A. But the long years of having to describe the association between pulsars and SNRs as, "well, there is the Crab Nebula … and Vela … and, oh yeah, 0540−69.3 in the LMC" are over. Up to July 2002, 27 pulsars had recognizable radio remnants around them, including all those with slowing-down ages less than 5000 years (Manchester 2003). Neither the young pulsars nor the remnants are necessarily very bright.
2. Black holes (Lee et al. 2002b; Podsiadlowski et al. 2002). The argument is the presence of supernova ejecta on the surface of a companion or in the interstellar stuff around a black hole X-ray binary.
3. Quark stars rather than neutron stars? Not required, say Kaplan et al. (2002d) on RX J1856.5−3754. It was all a false alarm, and a corrected *HST* parallax plus the X-ray temperature leads to a radius of 15 ± 6 km, just right for an ordinary neutron star.
4. Skyrmion stars? Well, perhaps (Ouyed 2002), but it is not clear what they are good for or how you would distinguish them, since the radii are the same sizes as for neutron stars. They could, however, have masses extending up to 3.45 $M_\odot$.
5. Cosmic rays (Bykov & Toptygin 2001 among very many papers over the years), out of material that is 25% fresh ejecta and 75% swept-up ISM (Alibes et al. 2002).
6. New stars, by triggering star formation when the expanding shell hits and compresses the gas around it (Ojeda-May et al. 2002).
7. All sorts of heavy elements. Well, we certainly all believe this, but there are measured numbers for amounts of ejected iron, oxygen, magnesium, and such for only five Type II events (Argast et al. 2002), and the error bars are so large that it is hard to see even the expected correlation of yield with progenitor mass. This is a territory where, truly, "more work is needed." The *r*-process elements are specifically advertized as coming from supernovae, or, rather, the *r* processes, say Qian & Wasserberg (2001). There are three. Two may come from supernovae that leave neutron stars and black holes, respectively, and the third from massive Population III stars.

Of the things you had always thought you knew about supernovae, it remains true (*a*) that Ia's happen in all kinds of galaxies, while Ib/Ic and II's are concentrated in late types (though SN 2000I, an SN IIn, happened in the E2 galaxy UGC 2836; van den Bergh et al. 2002), and (*b*), that SNe Ia are the brightest at maximum light at $M = -19.46$ (for some value of H and all) and SN II-L's the faintest at −17, but with sizable numbers of subluminous and superluminous events that make the ranges overlap a good deal (Richardson et al. 2002). S And (SN 1885) apparently did not belong to any of the recognized types (van den Bergh 2002b). And the Co^{56} in Ia's really does decay to Fe^{56} on the laboratory half life, because you can see the colors change as the dominant absorber changes (Milne et al. 2001).

8.2. The Remnants

We start with gaseous remnants (young to old, roughly) and eventually move on to compact ones. The lament about how little is known observationally about the composition of supernova ejecta continues with the fact that most of the X-ray (Michael et al. 2002) and optical emission from SNR 1987A is coming from unprocessed material. The composition is essentially solar, apart from enhanced N/O. This is, however, surely just a matter of time, until heavy elements from the inner parts of the star, which glowed briefly in 1987, get lit up again. There is currently no energy input from a pulsar to be seen, down to 5.5×10^{33} erg/sec (Park et al. 2002). Meanwhile, however, there are all sorts of bright spots and rings in visible light, X-rays, and infrared to be seen (Sugarman et al. 2002; Gaensler, Sugarman, & McCray 2002) and modeled (Fischer et al. 2002 on the blast wave seen by *ISO* in 1998; Tanaka & Washimi 2002).

Cas A is one of the few remnants for which a truly enriched composition has been established, with lots of oxygen (shared by MSH 11-54, at an age of 1600 yr; Hughes et al. 2001; Camilo et al. 2002a), Pup A, and a couple of remnants in the LMC, especially 0540−69, which is also about 1600 yr old. *Chandra* has also recorded for Cas A significant amounts of Ne, Mg, Si, S, Ca, Fe, and Ni (Willingale et al. 2002) "not inconsistent" with current best models. Is Cas A one of those 27 young pulsars with supernova remnants around them? Well, not yet, anyhow. Murray et al. (2002a) very tentatively reported a 12 msec period in *Chandra* flux from the compact core, but not with the flurry that generally comes with such announcements. Mereghetti et al. (2002) have seen no period in the *XMM-Newton* data. They suggest the core might be a member of the anomalous X-ray pulsar family, having a strong magnetic field and long (undetected) rotation period. The author who remembers 1680 more clearly has refrained from mentioning it in connection with Cas A as a result of reviewing an out-of-period book that concludes fairly firmly that Flamsteed did not see the supernova leading to SNR Cas A.

The Union[1] requires us to mention the Crab Nebula every year, though most of the things to be said for 2002 are negative. The optical emission line knots that are bright in [Ar III] are not moving any faster than you would expect for their location (Schaller & Fesen 2002). The pulsar is not sending most of its energy out as Poynting flux, but only 10^{-5} or so, for which we spotted a couple of explanations (Contopoulos & Kazanas 2002; Okamoto 2002). The nebula we see is not noticeably colliding with a surrounding shell of interstellar, circumstellar, or extrastellar stuff. Nine other SNRs can also make that claim (Safi-Harb et al. 2001). On the positive side, you can see where the beams from the pulsar are hitting nebular material in their vicinity, at optical, radio (Bietenholz et al. 2001), and X-ray (Bogovalov & Khangoulyan 2002) wavelengths. The older pulsar PSR B1509−58 ($P = 0.15$ sec, $P/2\dot{P} = 1700$ yr) is doing the same sort of thing, and Gaensler et al. (2002) associate the details with the large ratio of particle to Poynting flux in the jets. Hester et al. (2002) explain how you can see it for yourself in "Crab Nebula: The Movie." And as if the thing weren't complicated enough already, Bandiera et al. (2002) have found an additional 1.3 mm emission region about the size and shape of the X-ray nebula. They describe it as a pulsar wind nebula.

How stands the SNR inventory? Unchanged, you might suppose, if Vela X, previously advertized as having a spare, little young one in its corner (Aschenbach 1998) really all came from a single event (Wang & Chevalier 2002), but the Cygnus Loop, formerly supposed to be a single SNR, is really two interacting ones, with a compact bit (neutron star?) in one of them (Uyanikar et al. 2002). Vela may also be closer (300 vs. 500 pc; Caraveo et al. 2001) and less jet-powered (Radhakrishnan & Deshpande 2001) than we are used to thinking.

The second closest supernova remnant is perhaps B0950+08 (McCullough et al. 2002). And the closest one is the Sun? Ooops. No. Wrong cliche. But we are inside it, and it's called the Local Bubble. What may be the oldest remnant, GSH 138−01−94, has just asked for its 4.3 millionth birthday candle (Stil & Irwin 2001). It is at galacto-centric distance 24 kpc, which is apparently a good place to look for such things, along with other low density, metal-poor locations. But the gold medal for weight lifting goes to S147, which has swept up 2×10^4 $M_\odot$ of H I in only 650,000 years. This would be enough to make a sizable star cluster if it is in the mood for supernova-triggered star formation (Elmegreen et al. 2002).

We have not yet seen the edge of the galaxy in either SNRs or pulsars, since deeper searching continues to yield new, fainter sources. Kothes et al. (2001) report two remnants of very low surface brightness, of which, say the authors, there could be many. And there are young pulsars as faint as 10^{25} erg/sec (Camilo et al. 2002b). A specific example is J0205+6449 in the remnant 3C 58 (probably from SN 1181), previously known as a pulsed X-ray source, and faint despite having a $P/2\dot{P}$ age of only 5300 years (Murray et al. 2002b). Since 2003 minus 1181 is smaller than 5300, the initial period must have been fairly close to the current one.

8.3. Pulsars and Other Neutron Stars

A paragraph or two back, we wandered across the border from SNR to PSR territory, only to find some 49 papers recorded as highlights at first reading (not to mention those that got indexed under radiation mechanisms, magnetic fields, or some other category). Most of these will not even be allowed off the bus to meet you.

Masses in line first, please $1.29 \pm 0.02 M_\odot$ for the binary pulsar J1141−6547 (Ord et al. 2002, who pinned down the angle of inclination for the orbit with a scintillation velocity) and 1.78 ± 0.15 $M_\odot$ for the Vela X-1 X-ray binary (not to be confused with the supernova remnant or the pulsar; it is, you will recall, a big constellation; Barziu et al. 2001). The ordering, at least for these two objects, is just what we want. The neutron stars in accretion-powered binaries have been accreting and so

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[1] No, not the International Astronomical Union. The Union of Aging Scientists Who Don't Want Their Theses Forgotten.

should be more massive than the rotation-powered binaries, which have only been rotating lately. If you say you can think of a different pair that line up the opposite direction, we won't dispute you.

As for some other measured properties:

a. Magnetic fields. These are small, 10^7–10^8 G, for XRBs with quasi-periodic oscillations and bursts, including Sco X-1 (Titarchuk et al. 2001), and big, up to 10^{16} G in calculations (Miralles et al. 2002 for a toroidal field).

b. Glitches. Only the biggest are likely to be recorded. There were two candidates, $\Delta\nu/\nu = 16 \times 10^{-6}$ for J1806−2125 (Hobbs et al. 2002) and $\Delta P/P = -3 \times 10^{-6}$ in the Vela pulsar (Dodson et al. 2002). This is a record only for Vela, but they were watching it at the time (from Hobart, Tasmania) and say the change happened in less than 40 seconds followed by recovery over several different time scales. Some poor pulsars never recover at all, in the sense of dP/dt trending back to a smooth curve (Urama 2002), including, he says, NP0532 in the Crab Nebula. Glitches occur because some interaction among crust, superfluid, and the array of magnetic vortices decreases the moment of intertia. Larson & Link (2002) consider two sorts of interaction, and conclude that both may well occur, though events in both the Crab and Vela pulsars are dominated by quake-heating of the crust.

c. Slowing-down indices and initial periods. Only if pulsars both lose energy in pure magnetic dipole radiation and start with very short periods is it true that $n = \omega\ddot{\omega}/\dot{\omega}^2 = 3$ and that age $= P/2\dot{P}$, and it seems to be pure good luck that these are both roughly true for the Crab pulsar, having allowed us to have initial faith in the essential correctness of the scheme. Urama (2002) reported $n = -4$ for B1737−30 (but only briefly, and yes, the sign is right, or rather wrong). The $n = 2.1$ for B0540−69 in the LMC (Hirayama et al. 2002) is more typical. Whatever slowing-down index you find, Malov (2001) has a model for it, though $P/2\dot{P}$ will have very little to do with age and dP/dt can be negative.

As for initial periods, we saw two votes for nearly 8 sec for RX J0720.4−3125 (Kaplan et al. 2002c; Pavlov et al. 2002), and one for less than a millisecond (Burderi et al. 2001). Suppose you want to measure a pulsar period and its change for yourself. We recommend Geminga, discovered at 59 sec some years ago, and now up to 61.94 (Neshpor & Stepanyan 2001). The difference is within human clock accuracy, at least for Galileo (said to have used his pulse), old fashioned photographers who time developer and hypo by counting "and-aone-anda-two", and anthropologists, who are said to count "one chimpanzee, two chimpanzee …".

d. Kick velocities. These are the speeds at which neutron stars are sent on their way from asymmetric SNe or binary systems. The distribution is bimodal say Arzoumanian et al. (2002), with peaks at 90 and 500 km/sec, and Pfahl et al. (2002), with peaks at less than 50 and 200 km/sec. The latter paper suggests that rapidly rotating cores give rise to slowly moving neutron stars.

e. The most featureless spectrum. Well, B0656+14 is definitely in the running. It cannot have on its surface any element that is partially ionized at 10^6 K. Marshall & Schulz (2002) seem to have found this something of a frustration, but it counts as a triumph for Gansicke et al. (2002), who succeeded in producing a featureless model spectrum without having to invoke quark stars.

f. Pulsar radiation mechanisms. Every few years, we feel the need to quote Sandra Faber's aphorism, "We understand why they pulse; what we don't understand is why they radiate," especially in the radio. Most innovative, though not quite new the year is the Compton upscattering of photons that start out at 1–10 MHz (that is, speed of light divided by gap height; Qiao et al. 2001), and most mainstream, indeed arising from particle streams in the polar caps, is the suggestion from Gedalin et al. (2002) that these streams generate up-going waves that break loose when their frequency equals the local resonant frequency.

8.4. Neutron Star X-Ray Binaries and Related Sources

The reference year saw the discovery of a new class of NSXRB and some confusion within or among several old ones.

8.4.1. Accreting Millisecond Pulsars

The new class is that of accretion-powered sources with millisecond rotation periods. These should be regarded as distinct from X-ray emitting, millisecond, binary, but rotation-powered pulsars like PSR J0437−4715, a *ROSAT* class known since about 1994. The accretion-powered sort provide direct evidence for spin-up of old neutron stars by mass transfer and can be regarded as the progenitors of the rotation-powered ones (Bildsten 2002). In order of discovery, or at least publication, the first member of the new class was SAX J1808.4−3658 (Wijnands et al. 2001; additional data in Wang et al. 2001d; Campana et al. 2002).

Next came J1640−5340 in the globular cluster NGC 6397, whose optical counterpart also shows a 1.35 day orbit(?) period. We thought it might be a second example, and so perhaps did D'Amico et al. (2001) and Ferraro et al. (2001), until Burderi et al. (2002) assured us that it is rotation-powered at the moment (though with accretion in its past and conceivably in its future).

Example number two is therefore XTE J1751−305 (Markwardt et al. 2002), sharing with the first an orbit period less than an hour, a rotation period less than 5 msec, and a donor with remaining mass less than 0.05 $M_\odot$. Number three is XTE J0929−314 (Galloway et al. 2002) with an orbit period of 44 minutes and a rotation period of 5.4 msec. The rotation period can be used a clock to measure the radial velocity of the neutron star. The resulting mass function, $M_2^3 \sin^3 i/(M_1 + M_2)^2$, is 2.7×10^{-7}, the smallest ever measured, and implies that the donor star has been whittled down to about 0.01 $M_\odot$.

A possible fourth case is the previously-known 4U 1636−53, which showed a 582 Hz period (1.7 msec) during 800 sec of superoutburst (Strohmeyer & Markwardt 2002), but it could also be an example of quasi-periodic oscillation, in which the frequency we see is probably related to the neutron star rotation, but is not directly a measure of it. The orbit period is longer (several hours) and the donor mass larger (≈0.4 $M_\odot$) than in the previous three cases.

8.4.2. Supersoft Gamma Repeaters, Anomalous X-Ray Pulsars, and Who Ordered Thats

The soft gamma repeaters, anomalous X-ray pulsars, and a possible third related class probably do not belong in this section, because they are (mostly) almost certainly not binaries, at least not with any detectable companions or orbital motion. What they have in common is evidence for rotation periods in the range 5–10 seconds, fairly rapid spin-down (though not rapid enough for the energy seen in X-rays to be powered by the standard pulsar magnetic dipole radiation mechanism), and calculated, measured, or implied magnetic fields in excess of about $10^{13.5}$ G, from which comes the name "magnetar."

In earlier years, there have been significant numbers of papers doubting the strong fields, but we caught none this year and will assume that the issue can be regarded as settled, at least until next year. Enough of them also glitch that a statistical analysis can show a pattern not so very different from that of normal pulsars; the more glitchy ones have the larger period derivatives (Gavriil & Kaspi 2002). The key issue obviously is where does the energy come from if not from the spin of the star. A subsidiary one is whether they all do it the same way.

The soft gamma repeaters are, as the name implies, softer in spectral index than ordinary gamma-ray bursters and have been caught in one or more episodes of multiple bursts, though the time histories over the past 20-plus years for the five known ones are very different, both in numbers and in durations of active episodes (Aptekar et al. 2001).

The anomalous X-ray pulsars are "on" as X-ray sources all the time. The first extragalactic one, in the LMC, with $P = 5.44$ sec, $P/\dot{P} = 11{,}000$ yr, and an implied field of 3×10^{14} G fits right into the characteristics of the Milky Way population (Lamb et al. 2002). Kern & Martin (2002) conclude that the detection of optical pulsations from 4U 0142+61 definitely rules out the competing AXP mechanisms of a rotating, magnetized white dwarf (for which the larger moment of intertia would mean that magnetic spin-down at the observed rate could power the luminosity) and accretion on an isolated, slowly spinning neutron star.

Finally, the who-ordered-thats (a quote from I. I. Rabi about the muon, before the tau came along to diversify the menu still further) inhabit yet a third, newer, small class of soft X-ray pulsars, the three members having rotation $P = 22.7$, 8.37, and 5.2 sec and much lower X-ray luminosities than the SGRs and AXPs, suggesting that they might be old magnetars (Thompson et al. 2002a), though one has $P/2\dot{P} = 10^4$ yr (Hambaryan et al. 2002). Finally, RX J0720.4−3125 ($P = 8.39$ sec, $dP/dt = 4–8 \times 10^{-14}$ sec/sec) lives here because of the conclusion that neither we nor the authors (Zane et al. 2002) understand it very well. This may be the reason that the paper is not a very easy one to read and construe.

That no one seems to be doubting the strong fields at the moment does not quite absolve us from mentioning the data in favor. The gold standard is spin-down rate. For a neutron star with a moment of inertia I, angular frequency Ω, spin-down rate $\dot{\Omega}$, radius R, and magnetic dipole field B (perpendicular to the rotation axis)

$$\frac{dE}{dt} = I\Omega\dot{\Omega} = \frac{B^2R^6\Omega^4}{6c^3}$$

in, of course, the units (cgs) in which the world was created. Some sources, for which spin-down has been steady over many years meet this standard, including 1E 1841−045 (Gotthelf et al. 2002). In other cases, it is more a matter of ruling out alternatives, e.g., SGR 1900+14 is simply too faint at K for a residual accretion disk, left from when it was a supernova or something, to be the X-ray energy source (Kaplan et al. 2002b). Additional support comes from the success of "strong magnetic field" models in accounting for detailed behavior, bursts, glitches, and all, of various sources (Thompson et al. 2002a; Ozel 2002; Ioka 2001; Kondratyev 2002). It is probably also a good thing that convection in the first 10 seconds of the life of a neutron star allows fields of 10^{13} G or more to reach the surface (Thompson & Murray 2001).

The largest reported field of the year is 10^{15} G from both period change and cyclotron resonances at 11.2 and 17.5 keV for SGR 1806−20 (Ibrahim et al. 2002), though you will discover in the fine print that this is then proton cyclotron, not the electron cyclotron that used to be blamed for spectral features at similar energies (but in much weaker fields) in GRBs when we were all much younger. And, straying still further from evidence to applications, comes the calculation by Lai & Ho (2002) showing that in very strong fields the atmosphere will have very different opacities for modes of different polarization, opening the window to X-ray emission by photon mode conversion analogous to MSW oscillation of neutrinos in the presence of nuclei.

Finally, are the AXPs, SGRs, and WOTs all the same sort of beast? We thought that this had been settled on the side of "not entirely" by the report that three of the five or six known AXPs are to be found in supernova remnants, while none of the SGRs are persuasively so (Gaensler et al. 2001; Kaplan et al. 2002a, who also note that the period derivative of SGR 1806 is not constant). And then Gavriil et al. (2002) announced that the AXP 1E 1048.1−5937 had been caught in two SGR-like outbursts. This and the implied field of 2×10^{15} G (again a proton-cyclotron value) have been endorsed by Kulkarni

(2002), whom we are always reluctant to doubt. The development of SGR behavior in an AXP is at least consistent with the suggestion from Gaensler et al. (2001) that soft-gamma-repeating is something that overtakes an anomalous X-ray pulsar in its old age, so we guess everybody can go home happy.

8.4.3. The Supersoft X-Ray Binaries

These are generally advertized as being systems in which the accretor is a white dwarf (Kitabatake et al. 2002; Torrejon & Orr 2001) or pre-white dwarf (Smak et al. 2001; King et al. 2002). Smak et al. are constructing a system like V Sge, and King et al. look at a short-period supersoft in M31, in which future decline of the mass transfer rate will leave it simply a plain old X-ray emitting cataclysmic variables. Indeed the class is not really distinct from the X-ray CVs, expect that the sources were initially catalogued by X-ray rather than optical astronomers.

Because a soft spectrum is all too easily absorbed by interstellar gas, the initial inventory appeared mostly in the LMC and SMC, though CAL 86, which was almost the prototype, is actually a foreground object toward the LMC (Schmidtke et al. 2002). This is a round-about way of saying it is in our Galaxy! Interstellar processes, while they redden (soften) visible light, bluen (harden) X-ray light because what the gas and dust both do is grab UV protons.

Finally, the Michellin experience that led to the subject of accreting white dwarfs as X-ray sources being flagged down was the description of CH Cyg and MWC 560 as "nanoquasars" by Zamanov & Marziani (2002). Both binaries show emission lines rather like those of Seyfert 1 galaxies and have radio jets. The supersoft XRB AG Dra has its radio jets along the axis of the binary orbit (Ogley et al. 2002; Mikolajewska 2002), and if the latter authors had published first and coined the "nanoquasar" name, the topic would all fit much better into this section. Perhaps there is a suitably relativistic frame with that ordering of events, but we think it is our task only to record what happened during the year, not to try to change it.

9. DOWN THE TUBES: THE CARE AND FEEDING OF BLACK HOLES

We claim that astrophysical black holes are entities compact enough that they cannot be much larger than their Schwarzschild radii (independent of what happens inside), and that, therefore, their existence is fully established. The subsections start with small ones and end with large ones, radiation processes being tucked in the middle.

9.1. Single, Stellar-Mass Black Holes

A few years ago, there were none of these in catalogs of anything. They now appear as the most likely interpretation of long-duration microlensing events recorded by the MACHO and OGLE projects. Mao et al. (2002) provide a detailed discussion for the longest, 640 day, OGLE event. Agol et al. (2002) note that larger distance plus smaller mass can yield the same duration (and optical luminosity below whatever limits can be set), but conclude that the sum of the probabilities of each of several events being black holes exceeds unity, so one probably is, but there is no way of being sure which one. The same sorts of black holes wandering through interstellar gas should also accrete more than neutron stars, because they are more massive and slower moving, and so appear as compact X-ray sources. The best estimate of the number of these catalogued is still zero (Agol & Kamionkowski 2002).

9.2. Black Hole X-Ray Binaries

We have no truck with "candidates" here. These are black holes, except for poor old GX 339$-$4, in the "candidate" inventory since about 1974 and still with no firm orbit period to yield a definitive mass (Cowley et al. 2002; and what are you doing over there in that Other Journal, Anne? Come back here where you belong!). It has, however, added another name over the years and is also V821 Arae.

The key characteristic signifying a black hole is mass too big for anything else. Here, therefore, is a list (probably incomplete) of BHXRB mass determinations from the index year. They are not all completely self-consistent, and while Finoguenov & Jones (2002) said that there is a real range in M_1, we don't think they mean for a single source. The real point, however is that all are big, well above the maximum possible for a neutron star, whether you think this is 1.8 or 3.2 $M_\odot$. Where there is a real spectroscopic orbit, Newton (or perhaps Kepler) is the gold standard, and other numbers must be made to fit around that answer. Where there is not, the others are "mass indicators" (like the "distance indicators" of cosmology). Significant, but not maximal, rotation also seems to be the norm (more about this in Greiner et al. 2001 and Bailyn 2001). Can lots more be said about BHXRBs? Yes, of course, and several dozen papers did. Are we going to? Not this year.

A0621$-$00 = V616 Mon. $M_1 = 11.0 \pm 1.9\ M_\odot$, from radial velocity data and $i = 41°$ from optical and infrared light curves (Gelino et al. 2001).

V4641 Sgr. $M_1 = 5.84\ M_\odot$ (Uemura et al. 2002).

XTE J1550$-$569 attracted three kinds of analyses, leading to $M_1 > 4\ M_\odot$ (Reilly et al. 2001, using the patriotically named USA experiment on the *ARGOS* satellite, which we missed last year, but which you can find described by Wood et al. 2000); $M_1 = 7.5$–$13.2\ M_\odot$ from quasi-periodic oscillations at 249 and 276 Hz during a second outburst (Miller et al. 2001). Zero angular momentum is possible only for a mass near the bottom of the range. Martocchia et al. (2002) also decide that the Kerr solution is the best bet but do not discuss the mass. And Titarchuk & Schrader (2002) derive $M_1 = 12$–$15\ M_\odot$ from another QPO analysis.

GRS 1915+105 and XTE 1655$-$40. The issue for these is that two, more or less equally probable sounding approaches lead to different values. If the quasi-periodic oscillation frequency is the period of the last stable orbit, then one gets a mass of 5.5–7.9 $M_\odot$ and angular momentum of 15%–50% of the maximum possible (Strohmayer 2001) for GRS 1915, while attributing the 67 Hz QPO to a particular disk mode yields $5.9 \pm 1.0\ M_\odot$, but angular momentum of 92% of the maximum value. In the case of XTE 1655, the angular momenta are more or less consistent (70% ± 4% from last stable orbit and 93% from the specific mode; Wagoner et al. 2001), but the masses are not, at $18 \pm 3M_\odot$ from last stable orbit and $42 \pm 7\ M_\odot$ for the particular mode. The GRS 1915 source has an honest radial velocity curve, measured on the CO band heads in near-infrared (Greiner et al. 2001; Bailyn 2001), and the answer, folding in a spectroscopic mass of about 1.2 $M_\odot$ for the K–M III secondary, is $14 \pm 4\ M_\odot$, which we guess is a vote for "last stable orbit," but it is not self-evident that the mechanism has to be the same for both sources.

9.3. Intermediate Mass Black Holes

IMBHs are the ones whose masses fall between those in BHXRB (5-15 $M_\odot$ just above) and those in galactic centers (which, at 10^6-10^{10} $M_\odot$ have fallen a good ways down from here). The primary evidence for them during the academic year continues to be X-ray sources with luminosities large enough that the Eddington limit implies 30–1000 $M_\odot$ or thereabouts. We voted for them last year, continue to do so this year, and probably will again next, in light of some dynamical evidence in the pre-pipeline.

But the alternatives should not yet be counted down and out. Goad et al. (2002) call attention to a very bright X-ray source in NGC 5204 which resolves into three sources on closer examination. This reduces the average luminosity by a factor three, according to difficult numerical calculations carried out for us by Ms. Canna Helpit. The second possibility is that the X-rays are beamed, and we happen to be in the beam, the right interpretation for many of these sources, according to Georganopoulos et al. (2002). Beaming leads one to expect rapid variability, as is indeed the case for some, perhaps most, of them (Sugiho et al. 2001; Strickland et al. 2001).

And third, if most of the X-rays are coming out in one or two directions, then most of the accretion can be coming in along all the other directions, and the Eddington limit no longer applies. Such are the ultraluminous X-ray sources in both spiral and elliptical galaxies, according to King (2002), who gives as examples the galactic sources SS 433 and GRS 1915+105, high mass and low mass XRBs respectively, that would mislead us if seen from afar. Begelman (2002) concurs, putting the accretion in a thick disk. Indeed flaring above the Eddington luminosity is "not uncommon" in binaries where the black hole mass is more or less known, say Uemura et al. (2002) about V4641 Sgr.

Beware, however, the blunted classification scheme. One of the nine supersoft (generally taken to mean white dwarf accretors) X-ray sources in M81 is, at 1.5×10^{39} erg/sec, either "super Eddington," blowing off stuff, or actually an IMBH (Schwartz et al. 2002). The authors could, of course, have suggested some new physics that would permit white dwarfs of 30 $M_\odot$, but not in that journal.

Theorists-voting-in-favor have weighed in with several possible ways of making IMBHs, (*a*) directly from collapse of supermassive, probably Population III, stars (Shibata & Shapiro 2002), (*b*) in a hypernova (Wang 2002 on a source in the M81 group), and (*c*) in dense star clusters, where one largish seed BH left by a very massive star can sweep up other remnants, raising the BH mass to 0.1%–1.0% of the mass in stars (Miller & Hamilton 2002; Ebisuzaki et al. 2001). The latter group envisages them then sinking to galactic centers and merging to make still more massive black holes. Mouri & Taniguchi (2002) and Portegies Zwart & McMillan (2002) also make IMBHs in star clusters. It is encouraging that at least some ultraluminous X-ray sources actually occur in globular clusters (Wu et al. 2002a on the one in NGC 4565).

9.4. The Keen Amateur Dentist

This section is actually going to be about energy extraction from black holes, but we had to find someplace to tell you the following story, and, after all, extraction is one of the things that dentists do best. A famous astronomer was concluding a public lecture to thunderous applause, when a member of the audience came up to ask a question and introduced himself by saying that he was a professional dentist but a keen amateur astronomer. The speaker replied that the questioner had clearly made the better career choice, since he himself, a professional astronomer, would make very few friends as a keen amateur dentist.

If you own a black hole, there are (at least) three ways you can use it as an energy source. First, you can think of it primarily as a garbage disposal and if the cantaloupe peels and all collide as they spiral in, they will heat up as they go, and you will have accretion energy to use in whatever way the law (the second law) allows. If your black hole has non-zero angular momentum, method two applies. Transport the garbage in a truck into the region where dragging of inertial frames precludes standing still (the ergosphere), toss in the garbage in a direction to counteract the BH spin, and your truck will come out with more total energy than you went in with. This is called the Penrose (1969) process, for Roger Penrose, who envisioned some more elegant material than garbage trucks and their contents. Electromagnetic radiation is another possibility.

Third, if your rotating black hole also has a magnetic field coupled to it somehow (the somehow is perhaps the problem), you can hang on tight to the field from well outside the horizon and let it spin you up to high velocity, at which point how to radiate the energy away is more or less up to you. The only people who have any difficulty in knowing what to call this[2] are Blandford & Znajek (1977), since they are modest fellows both (being, after all, the student and grand-student of the keen amateur dentist).

Can more than one happen at a time? Indeed yes, in effect all three, according to a numerical simulation by Koide et al. (2002). They start with an inflowing, magnetized plasma. Dragging of space-time causes torsional Alfvén waves in the plasma that transport energy outward until all the plasma close to the horizon has negative energy. Accretion of that fraction of the material then slows down the black hole rotation, extracting part of its rotational kinetic energy. Thus the BH has accreted, Penrosed the plasma, and hung on with magnetic field. The authors call this an MHD Penrose process.

If the plasma initially has uniform density ρ_0 and magnetic field $B_0 = 10\rho_0 c^2$, the black hole has a Schwarzschild radius r_S and angular momentum to mass ratio $a = 0.9995$ of the maximum possible (before you would have a naked singularity), then the initial luminosity is $0.4B_0^2 r_s^2 c/\mu_0$,which is very close to the luminosity available from the process advocated by Punsley & Coroniti (1990) and to that of the Blandford-Znajek process. Blandford (2002) provides additional commentary. Observations to which the calculation may be relevant are provided by Wilms et al. (2001), Miller et al. (2002), and MacFadyen et al. (2001). Li (2002b) looks at a similar situation and concludes that accretion flux and magnetically extracted flux can be radiated at the same time. Miller et al. (2002) draw interesting analogies between the BHXRB XTE J1650−500 (a microquasar) and MCG −6-30-15 (an AGN) and come out in favor of a magnetically mediated extraction process, perhaps in the plunge region.

What more could you possibly want—in this context, of course. We still want a chocolate icecream cone and a previously owned Mercedes Benz. Two things. First a guarantee of the required inward gas transport, and, second, an answer to why some large black holes are so faint.

The first, inward gas transport, requires outward transport of angular momentum, which generally means some kind of disk instability that will churn things up a bit. Turner et al. (2002) and Hawley & Krolik (2002) show a disk with a lovely swirley pattern due to radiation-damping turbulence. The disk of Font & Daigne (2002) has a tendency to run away and take things with it, and you should not let it near your gamma-ray burst (or anyhow your gamma-ray burst model). As for the disk presented by Li & Zhang (2002), all we can do is quote the authors, who aver that "a transverse plasmon field is modulationally unstable in the Lyapunov sense" and that this leads to collapse of a self-generated magnetic field and so to anomalous magnetic viscosity (which transports angular momentum).

Second, with all this richness of ways to extract energy, why are some largish black holes with seemingly adequate food supply, including the one at the center of the Milky Way, in fact rather faint? The various suggestions (Ap01, § 10.1) have been acronymed ADAF (advection dominated accretion flow, meaning that most of the energy goes down with the gas), CDAF (convection dominated accretion flow, meaning that the energy gets carried back out unradiated), and ADIOS (meaning that not even most of the gas gets sucked in). See, for instance, Nagar et al. (2001), Merloni & Fabian (2002), Narayan et al. (2002, a former ADAF supporter voting for CDAF), and Igumenshchev (2002, who also discuss CDBF where the B stands for Bondi). There were three votes for traditional ADAF from Awaki et al. (2001), Ulvestad & Ho (2001), and Kong et al. (2002), making the point that the process requires a black hole horizon.

There is also a statistical converse to these dimming processes. Sometimes the combination of observed masses and luminosities requires radiation to be at least as efficient as is relativistically possible for some individual sources (Melia et al. 2002 on the nucleus of NGC 6252), whole classes (Collin et al. 2002 on active galaxies with BH masses measured from reverberation mapping), or even the entire set of active galaxies that contribute 7%–15% of the local luminosity density, since they add up to only 4–5 × $10^5\ M_\odot$ Mpc^3, and so must have had at least 15% efficiency at converting accreted material into photons (Elvis et al. 2002). These papers could, if you wish, be filed under "anti-ADAF," or, if the point to be taken away is that QSOs and such are bright, under "Queen Anne is dead."

9.5. Bang On: Gamma-Ray Bursters

The index year both began (Woosley 2001) and ended (Meszaros 2002) with informative reviews of the topic. The former focused on total energies implied by beaming of the gamma rays and wider emission cones as you look at later times and longer wavelengths. This total is, obviously, smaller than one deduces for isotropic events, but is nevertheless larger by as much as a factor of 10 than the FOE (fifty one ergs) that Hans Bethe always said we should associate with a typical core collapse supernova. The latter review concentrated on the fireball scenario for the prompt (gamma) emission and the longer wavelength afterglows, and we will note here, so as to get it over with, that there are still holdouts against this model, which its opponents charmingly describe as consuetudinary (Dado et al. 2002). One alternative is cannonballs (Plaga 2002). And there were also a couple of votes for processes connected with quark stars (Ouyed et al. 2002; Ouyed & Sannino 2002) and one vote against the collapse of supermassive objects (Linke et al. 2001).

Since you probably associate GRBs with gamma rays, we will begin with X-rays. *HETE-II* has not yet localized very

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[2] We do not know a generic solution to the question of what to call some effect or phenomenon named for oneself (and are most unlikely ever to experience it as a personal problem). Feynman assured us many years ago that the diagrams were called "the diagrams," and Martin Schwarzschild once spoke of "my father's criterion."

many bursters (Price et al. 2002a; Ricker et al. 2002; and Park et al. 2002a on the very first), but these have included several examples, still locked in pre-topia, of what are awkwardly described as gamma-poor GRBs or X-ray flashers. Yes, X-ray burster would be the obvious name, but it is already taken, for events powered by nuclear explosions on the surfaces of neutron stars. They key issue is whether the flashers are one side of the GRB family (the distaff perhaps) or yet another new class of events ripe for runaway theory. The probable existence of an event of intermediate type (990704; Feroci et al. 2001) suggests the former, but we aren't voting yet. Most of the rest of the GRB scenary for the year is part of a landscape we have all been surveying for some time, defined approximately by the following questions.

What are the short duration ones? A lot like the long-duration ones, say Liang et al. (2002). And if the underlying process is the merger of two neutron stars, then out-flow is either driven by neutrinos (Salmonson & Wilson 2001) or not driven by neutrinos (Ruffert & Janka 2001).

Are there really spectral features due to iron in some? Perhaps (Ghisellini et al. 2002) and, if so, the total event energy must be quite large or the surrounding density very large, or both, but the iron abundances in the radiating gas need not be anomalously large according to Ballantyne et al. (2002a) and Wang et al. (2002d), invoking a Cerenkov process described by You & Cheng (1980). Indeed the iron abundance could be nearly zero if what we are really seeing is freshly synthesized nickel and cobalt (McLaughlin et al. 2002).

Are there optical and/or radio orphans, that is, afterglows of GRBs beamed away from us? Not many (VandenBerk et al. 2002 on one SDSS candidate; Levinson et al. 2002a with nine radio candidates from FIRST), but the radio Search for Extraterrestrial Intelligence with the Allen Telescope should find, and we supposed be briefly confused by, about 400 (Totani & Panaitescu 2002). If anyone has suggested that GRBs are really hollers from ETI, we missed it, and would prefer to continue to do so. There is a certain temptation to try to make the case that, if you don't see an optical afterglow, it doesn't matter whether the GRB you didn't see in the first place was of long or short duration. But everybody in practice means the long-duration ones in these contexts.

Conversely, as it were, where we don't see an optical tail following a burst, is it because the location is dusty, because the event is at very large redshift, or for some other reason? Djorgovski et al. (2001b) vote for dust. Fruchter et al. (2001) are against, because, they say, the gammas will charge up dust grains which then break apart under stress before they have a chance to absorb or scatter visible light. Simon et al. (2001) reject dust for other reasons. Large redshift is surely the most interesting answer for cosmology. Lazzati et al. (2002) point out that the question can perhaps be answered by very prompt searches for infrared counterparts.

Does the light you see come mostly from the surface of a cone or along its axis? Yes, say Gaudi et al. (2001) and Rossi et al. (2002). That is, there is at least one additional variable after the cone angle has been decided upon by whoever decides these things.

Are the correlations seen among duration, maximum flux, spectral hardness, and such intrinsic to the sources, the result of cosmological effects, or the product of selection effects? Probably, say Amati et al. (2002), though their sample, with measured redshifts, permits removing the cosmological corrections.

Do GRBs happen mostly in star formation regions (well, again, the long-duration ones with counterparts and so only about a sample of 17 in anybody's database as these papers went to press). Yes (Jimenez et al. 2001; Berger et al. 2001a on the first host that is a bright millimeter source; Stern et al. 2002a); yes, but not so much as you thought (Reichart & Price 2002; Vreeswijk et al. 2001; Smith et al. 2001c); and no (Filho et al. 2002; Tsvetkov et al. 2002).

What about the supernova connection? Well, there was SN 1998bw, which was very probably also GRB 980425 (Sollerman et al. 2002; Weiler et al. 2001). The latter is based on the radio tail looking supernova-ish (the converse is a supernova whose GRB was not beamed at us, but which you might also identify from radio data; Paczyński 2001). GRB 970508 perhaps had ongoing optical input from a young pulsar with strong magnetic field (Chang et al. 2002). This is what people who make up multiple choice tests call a distractor, at least if you think that GRBs with afterglows leave rapidly rotating black holes rather than pulsars.

Shining out over the distractor, however, are two confusers, both early in the index year for maximum exposure and both displaying assorted chemical and photometric evidence for an associated supernova. They are GRB 011211 with an absorption redshift of 2.14 (Reeves et al. 2002; Marshall 2002) and GRB 011121 at a redshift of 0.36 (Bloom et al. 2002; Prince et al. 2002b). Yes, really, 011211 and 011121. Worse, it is said that for 011211 the SN happened 10–100 years before the gamma-ray burst, while for 011121 it was at essentially the same time.

Is there anything else you might conceivably want to know about these events? Well, probably not, but we are going to tell you anyway (*a*) that there are six different possible compact binary progenitors involving various combinations of black holes, neutron stars, white dwarfs, and helium stars (Belczynski et al. 2002b), (*b*) that if you add up BATSE data for enough events, the gamma rays last more than 100 seconds (Connaughton 2002) and the other wavebands turn on sequentially from short to long (Giblin et al. 2002), and (*c*) that GRBs that are also supernovae may be responsible for accelerating the ultra-high energy cosmic rays (Dermer 2002). A prediction of this last modeloid is that one supernova remnant in 20–100 should be hadron rich. This does not seem to include any of the ones we know well (§ 8.2).

9.6. A Poor Thing, but Mine Own (Sagittarius A*)

The center of the Milky Way is notoriously faint, at most 1% of the Eddington maximum luminosity. A number of people continue to know why, but they seem to know different things. Energy going down the tubes (ADAF) continues to have supporters, including Yuan et al. (2002) and, we think, Cramphorn & Sunyaev (2002), who conclude that Sgr A* cannot have been much brighter than it is now for most of the past 80,000 yr, given the amount of radiation now being scattered by nearby giant molecular clouds.

Hawley & Balbus (2002) and Balbus & Hawley (2002) have put forward a more complex, non-radiative accretion process, involving a hot Keplerian disk that persists down to the last stable orbit, a coronal envelope, and an outgoing jet. In the end, not much of the mass that seems to be accreting far out actually gets in, both mass and energy being carried back out. Contradicting part of the above, but nevertheless fun to contemplate, is the thought that we might have had many more galactic center photons to study if only we had started doing radio and X-ray astronomy a while back, perhaps as recently as the great epoch of exploration in the 17th century, before a nearby supernova remnant had blown away the gas that should be accreting in this century (Maeda et al. 2002). Vollmer & Duschl (2002) have something similar in mind. The evidence for more vigorous activity is the ionized gas near the galactic center (Maeda et al.).

More information about the orbits of stars around Sgr A* continued to appear during the year (Eckart et al. 2002), though the press release item was slightly out of period (Schoedel et al. 2002). Suffice it to say that we have stopped indexing papers that claim a mass very different from $3 \times 10^6 M_\odot$ for the black hole per se or significantly more diffuse composition than a single BH (neutrinos, confusons, dense star clusters and all).

Have we been blessed with a rapidly rotating black hole that might also be amenable to some of the other extraction processes of § 9.5? Yes, say Liu & Melia (2002), at least if the 106-day period previously reported is spin-induced precession of a disk. This favors, they say, a Blandford-Znajek energy source, but also implies a/m less than 0.1 of the maximum possible angular momentum, so that the emission is faint. We are thinking about whether it is worth doing the calculation to report how much longer all this can keep up if rotational kinetic energy is the reservoir being drawn on.

9.7. The Pickle in the Middle: Black Hole-Bulge Connections

The notion that the mass of a galaxy's central black hole is closely correlated with its stellar bulge population is now several years old. The relationship was first spotted using bulge luminosities. Later it was realized that plotting bulge masses gave a tighter correlation, when these could be determined from velocity dispersions. This year, Graham et al. (2001) have suggested that the true underlying controlling factor is degree of central concentration, yielding a Spearman[3] rank correlation of 0.91, vs. 0.86 for bulge mass. Tremaine et al. (2002) stick by central velocity dispersion as the real independent variable, but put forward a slightly different expression

$$\log (M_{\rm BH}/M_\odot) = 8.1 + 4.0 \log [\sigma_v({\rm km/sec})/(200\ {\rm km/sec})]$$

as well as some criticisms of earlier compilations of data. If you plot your numbers in linear coordinates, you may include M33, but should not try to do this in a log-log plot, since the best number is zero for both bulge and black hole (Gebhardt et al. 2001; Long et al. 2002, who note that the bright, persistent X-ray source is actually an off-center 10 $M_\odot$ black hole X-ray binary).

Are special galaxies also special in this respect? No for Seyferts and BL Lacs say McLure & Dunlop (2002), Falomo et al. (2002), and Wandel (2002), and yes for radio galaxies, which have black holes of thrice the mass of radio quiets with the same bulges (McLure & Dunlop 2001). Our index item on radio loud vs. radio quiet AGNs has 22 other papers in it (a few mentioned in the next section), but, lest it be elsewhere forgotten, special mention here of De Breuck et al. (2002), who come right out and say that powerful radio galaxies are the most massive ones to be found at any redshift, with radio power proportional to galaxy mass, and both proportional to black hole mass. The radio louds are also optically brighter at all redshifts, by 2 magnitudes for $z \geq 1$.

How did galaxies get this way? Black hole first, stars first, or co-formation? We caught several "black hole first" ideas, from Hennawi & Ostriker (2002), whose black holes collapsed very early and are made of self-interacting dark matter, Dokuchaev & Eroshenko (2001), who start with primordial black holes of $10^5 M_\odot$, and Mangalam (2001), for whom a gas cloud of $10^{10} M_\odot$ has already made a black hole of $10^8 M_\odot$ and turned the rest into stars by $z = 5$. This last could also be seen as co-formation, but very early.

Some stars first, says Wang (2001), at least one very dense cluster, which makes the BH and accounts for the observed correlation of black hole masses in QSOs with the metallicity of their inner regions. The author credits the idea to Rees (1984).

Wang (2001) got indexed as "stars first" and Romano et al. (2002) as "co-formation," but the distinction is not this sharp. What Romano et al. are actually saying is that, if QSO turn-on stops the growth of the bulge, then star formation is quickly truncated in giant ellipticals, leaving the galaxy to look like it has been formed from monolithic collapse (including the right Mg/Fe ratio as a function of mass), while in smaller galaxies star formation lasts longer and the chemical history will be more like that of a hierarchical process.

In the true camp of co-formation reside one vote for accretion

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[3] This is the same guy as the Spearman g (for general) factor in intelligence testing but not to be confused with Spearmint gum.

feeding both the bulge and the black hole at $z = 2.8$ to 1.8 (Page et al. 2001) and three for radiation drag as the dominant physics (Umemura 2001; Fabian et al. 2002a; Kawakatu & Umemura 2002). The idea is that radiation drag by bulge stars takes angular momentum from gas and lets it accrete. This predicts BH/bulge $= 0.3–0.5\varepsilon$, where ε is the fraction of mc^2 liberated by hydrogen burning in stars. As is often the case, when we have indexed two or three papers together as having put forward closely related ideas or data, they turn out to have authors in common. This undoubtedly means that the authors are more persuaded but we are perhaps less so of basic correctness. And, speaking of data, Carilli et al. (2001) have collected a bunch for $z = 4.5–5.0$ quasars whose long-wavelength radio emission comes from the nucleus, but whose millimeter flux is stars and dust, in ratios favoring co-formation.

9.8. Big Brother Is Watching (or at Least Radiating at) You: Active Galactic Nuclei

Some of the galactic centers that harbor $10^7–10^{10}\ M_\odot$ black holes are, as you well know, to be seen as quasars (with radio), QSOs (without), and all the lesser breeds of AGNs. Since § 9.6 ended with a reported periodicity in the emission by Sgr A*, we start here with periodic AGNs, of which the longest known is OJ 287, with a period a bit more than 12 years. This is said to be the orbit period of a black hole pair, and another possible 73-day period is surely something else (Efimov et al. 2002). A 336 day period in PKS 1510−089 (a gamma-ray emitter) is perhaps also due to a binary BH (Xie et al. 2002), but if nine out of 10 sources are periodic, in the range 1.4 to 17.85 years (Fan et al. 2002a), this begins to cast doubts on the binary scenario.

If you would like to check for yourself how long such systems can keep going (since they lose angular momentum and energy in gravitational radiation) a useful expression is

$$\frac{dE}{dt} = \frac{32G^4m_1^2m_2^2(m_1 + m_2)}{5c^5a^5}$$

for a circular orbit of semi-major axis a. The available kinetic energy is of order $(m_1v_1^2 + m_2v_2^2)/2$, and you can use Kepler's third law to get from semi-major axis to period to velocity. Don't want to do it? Then, if black holes have to be at least $10^7\ M_\odot$ each and you want the system to last at least 10^7 years, then the orbit period must not be less than about a year.

Is the typical duration really 10^7 yr? We seem to remember agonizing over this before, in connection with luminosity vs. density evolution. This year, Beckert & Duschl (2002) say "only" 10^7 yr for AGNs in general. Kauffmann & Haehnelt (2002) report $10^6–10^7$ yr for bright QSOs, if a numerical simulation is going to agree with the relative numbers of AGNs and normal galaxies seen in the 2dF survey. McNamara et al. (2001) conclude that bright radio galaxies in rich clusters can turn back on again after 10^8 yr of quiescence, leaving ghost cavities in *Chandra* images. The integrated "on" time is the sum of several episodes, and, for galaxies brighter than L^*, amounts to a few percent of the age of the universe (Barger et al. 2001).

What else might one say about active galactic nuclei? A great many things, of which we have picked nine (one for each muse), about which factoids range in number from one or less to as many as Stenonychosaurus could count on his fingers.

1. They have hosts. That is, they really are at the centers of galaxies which could exist without them. You, of course, are too young to remember when this was an issue, but some of us are not. Most of these hosts are very bright, especially for the brightest QSOs (yes, we can see how this might be partly selection effect) and radio loudest (Kukula et al. 2001; Jarvis et al. 2001; Hamilton et al. 2002; Teerikorpi 2001). Most are giant ellipticals, again especially for the optically brightest and radio loudest (Bettoni et al. 2001; Pursimo et al. 2002), though some of the less spectacular radio galaxies are really S0s (Veron-Cetty & Veron 2001). As you look back into the past, the radio galaxies at $z = 1.1–3.8$ might be described as giant ellipticals under construction (Steinbring et al. 2002).

And here is a sort of anomaly which we are not sure how seriously to take. While the really bright QSOs are mostly giant ellipticals, most gEs are not really bright QSOs at any one time. And when you start digging down into the faint *Chandra* sources, most are Seyferts, that is spiral hosts. This seems to mean that the rest of the E and S0 galaxies have X-ray core luminosities much less than 10^{-3} of their Eddington limits (Page 2001). Perhaps they belong to a union (not the International Astronomical Union, more like an Inertional Union).

2. Some of them are gravitationally lensed, with the first example of a six-image system reported during the year (Rusin 2001). It is called B1359+154, and calculations for six- and eight-image systems appeared just a bit earlier (Evans & Witt 2001). Whether such lensing is common or rare depends on exactly what you are asking. Significant amplification of flux received from sources at large redshift is common (Wyithe & Loeb 2002), while actually seeing two or more images at any redshift is rare (Phillips et al. 2001), indeed rare to the point where it butts its head against values of the cosmological constant as large as the ones favored in § 12. Similarly, some rapid variability is caused by microlensing (stars in an intervening galaxy passing through the line of sight), but most is not (Chartas et al. 2002; Trevese & Vagnetti 2002). And for anything else you might want to know about the subject, please see the fine review by Claeskens & Surdej (2002).

3. Some QSOs emit MeV and GeV gamma rays by the inverse Compton and synchrotron self-Compton processes (Pian et al. 2002; Sikora et al. 2002). Indeed some carry right on up to the TeV range. Probably many do, but TeV photons do not find it easy to travel through the sea of intergalactic optical and infrared photons. The evidence that this is the dominant process in cutting off most AGNs that might otherwise be seen as TeV sources is that, for those we do see, the cut-

off energy does not vary when the luminosity and spectral slopes of the sources do (Krennrich et al. 2002). The record redshift at the moment is probably $z = 0.129$ for H1426+428 (Aharonian et al. 2002; Horan et al. 2002; Djannati-Atai et al. 2002). These represent detections from three different facilities, Whipple, HEGRA, and CAT in the French Pyrenees. It was the sixth or eighth TeV source reported and the third to receive third site confirmation.

Custom distrusts single-site detections until confirmed elsewhere, such as those of BL Lac (Neshpor et al. 2001) and 3C 66 (Stepanian et al. 2002) both from an installation in the Crimean peninsula.

4. As long as they are producing really high energy photons anyhow, might QSOs also be sources of the very high energy particles (cosmic rays) we observe? Yes, on both theoretical (Uryson 2001b) and observational (Uryson 2001a) grounds, though there are competitors, including supernova remnants in OB associations (Bykov & Toptygin 2001), the plane of the Milky Way and the local supercluster (Glushkov & Pravdin 2001), and other clusters of galaxies (Glushkov & Pravdin 2002a). It is not clear that any of these reach the largest observed energies, which exceed 10^{21} eV. We are also disconcerted to realize the extent to which this has become (at least within the astronomical literature) a purely Russian enterprise. Perhaps physicists from other countries are beavering away and publishing elsewhere. The arrival directions of the events about $10^{19.5}$ eV are a good deal clustered on the sky but not correlated with any particular sort of object say Ide et al. (2001).

5. Broad absorption lines at redshifts close to the emission line redshift are found in about 5% of the QSOs in the FIRST sample and in early release SDSS data (Menou et al. 2001). Such lines must come from fairly dense gas, and it is the custom to attribute them to material blown out of the QSO itself. No QSO has more than one or two BAL systems (and most have none), but large assemblages of narrower lines close to the emission redshift occur, and they too are generally blamed on associated gas clouds, in the host galaxy or its cluster (for instance Richards et al. 2002b; Savaglio et al. 2002).

An important issue still not fully resolved is whether (*a*) all QSOs have BAL clouds but with covering factor near 5%, (*b*) a few QSOs have BALS all the time, in all directions, or (*c*) most QSOs are fully enveloped, but only occasionally (e.g., Gregg et al. 2002). We don't know the answer, but think that the enormous SDSS sample may well provide relevant statistical information. It is already picking up some very strange examples, with rapid variability in the absorption and gradients in velocity across the continuum source (Hall et al. 2002).

Given that BAL gas must have started out very close to the business center of the QSO, one might be surprised that the chemical composition is not stranger than it is. Arav et al. (2001) note excess phosphorus (though not at the extreme, 50 times solar, level found for the dwarf nova VW Hydri; Sion et al. 2001), and Hasinger et al. (2002) report one example with Fe/O = 2–5 times solar, derived from an *XMM-Newton* spectrum. The giant surveys will not help much with this. Someone has to do the hard work of obtaining and analyzing high-resolution spectra for each.

Someday, of course, the composition of QSO and other active galaxy gas will all be understood within the context of over-arching models of galactic chemical evolution (§ 10). Meanwhile, you may or may not want to be surprised that, even for the largest redshifts, the gas responsible for the broad emission lines has achieved solar metallicity or even twice it (Warner et al. 2002, $z = 4.16$; Aoki et al. 2002, $z = 5.74$; Pentericci et al. 2002, $z = 6.28$). And the brighter ones are probably more metal rich (Shemmer & Netzer 2002). Having an active nucleus does not, however, enrich a whole galaxy, and the X-ray gas in M87 is, on average, subsolar, and indeed less enriched than the stars of the same galaxy (Sakelliou et al. 2002).

6. Unification is the idea that the direction from which we happen to see a beamed AGN is a, perhaps the, factor controlling what we see. Yes, orientation is important. It is, for instance, the primary difference between some BL Lac sources (jet end on to us) and radio galaxies (jet in the plane of the sky, Birkinshaw et al. 2002) and probably the primary difference between Seyfert galaxies of Type I (end on) and Type II (in-the-plane, so the nucleus is obscured by the accretion torus) says Tovmassian (2001). Equally clearly it is not the whole story. Among the most luminous AGNs, the BL Lacs and quasars are intrinsically different (Lister 2001), and the latter may evolve into the former (Boettcher & Dermer 2002). The relationships among the fainter Seyfert galaxies are also more complicated (Smith et al. 2002b).

A closely related question is whether there are any true Type II QSOs, that is, with the optical emission from the nucleus completely obscured in our direction, but recognized from an X-ray luminosity in excess of 3×10^{44} erg/sec, polarized light, and such. There are lots, say Stern et al. (2002b), having emission line profiles like Seyfert 2's, modest radio luminosities, and strong X-rays, which add up to a significant contribution to the X-ray background. Richards et al. (2002a) provide a vote in favor of broad absorption lines and associated absorption systems in AGNs also having an orientation aspect, which you can tuck back into the previous section if you prefer.

7. Jets are a common property among AGNs, and collimation is required, sometimes very close to the central black hole engine, less than 0.02 pc away in the case of Cen A (Tingay et al. 2001). The jets carry lots of energy, at least 10^{47} erg/sec for the longer X-ray ones (Ghisellini & Celotti 2001). Despite this, they can realign by 90° in less than a few million years, leaving ghostly X-patterns (meaning the shape, not the wavelength) on the sky (Dennett-Thorpe et al. 2002). Some jets are precisely perpendicular to the dust lanes that, one supposes, show the orientation of the inner, collimating disk (Karovska et al. 2002 on M87). Others are not perpendicular, but they are never exactly parallel either (Schmitt et al. 2002).

The acceleration of jet electrons is distributed in both time

(Wilson & Yang 2002) and space (Neronov et al. 2002), the latter implying that energy transport along the jet must be at least partly in the form of photons or Poynting flux. Beckert & Falcke (2002) note that polarization patterns require that magnetic flux also be transported along some jets. In other words, if you have a model, we are pretty sure that somewhere there are AGN jets like it.

8. We won't argue this year about whether the distribution of radio luminosities of active galaxies is bimodal, but if you are interested in faint ones, see Fomalont et al. (2002), who have counted the faintest yet with the VLA. The counts are flatter than Euclidean, so, like the BATSE detectors on the *Compton Gamma Ray Observatory*, Ed and his colleagues have seen the edge of the universe. For heaven sake don't quote us to an introductory class or science journalists. We are confident that you will know that what is really meant is that redshift effects are wiping out the distant ones. They may not.

If, on the other hand, you want enormous radio luminosity, you need a big, optically bright, massive galaxy, in a massive halo, with lots of accretion onto the central black hole. De Breuck et al. (2002) say this perhaps most clearly, but the point is made also by Ballantyne et al. (2002b) on accretion rates, Enya et al. (2002) on radio correlations with optical and infrared variability, Boroson (2002) on radio loudness and black hole mass, and Ubachukwu (2002) on Doppler boosting effects. Even better, there is a model, which looks back to an idea (from a few years ago), that a black hole with large angular momentum is more likely to power a large radio luminosity. And, says Cattaneo (2002), a black hole assembled, with its galaxy, from several mergers in a group or poor cluster, will probably have more angular momentum than a BH assembled in the field from a single accretion event (or, we think, than a BH assembled in a very rich cluster from a whole bunch of mergers). Thus should arise the environmental dependence of the incidence of active galaxies of various types.

If you want to vote against all this, you will have on your side Ho (2002), who finds a considerably more complex relationship among black hole mass, L(radio)/L(optical), L(total)/L(Eddington), and so forth, which extends from the faint Milky Way to quasars. Wu et al. (2002) find no real correlation at all between accretion rate and radio loudness.

9.9. Not Martin's Father's Black Hole

If you are contemplating a visit to higher-dimension space, you may find it useful to know that asymptotically flat, static, charged, dilaton black holes are unique, though Kerr-type rotating ones are not (Gibbons et al. 2002). Having met relativists before, you will know that uniqueness does not guarantee existence, but, since the authors say the solutions are relevant to the sort of TeV black holes one might make at accelerators or from colliding cosmic rays, as well as to string theory and p-branes, existence is probably implied.

The entropy of a black hole can be calculated from tachyon condensation (Dabholkar 2002). The answer is the same as that obtained by Hawking (1976) and Beckenstein (1973) from very different considerations.

And, strange to tell, Antoci & Liebscher (2001) say that the "Schwarzschild" (1916) solution we use is not actually the 1916 original, which has two parameters (rather than just one, the mass). We use the solution due to Hilbert (1917). He made a different choice of radial coordinate which also affects the nature of the singularity.

10. GALAXIES AND CLUSTERS OF GALAXIES

Every year, some topic is written about last (though it usually doesn't appear in the last section) and so gets very cursory treatment. It has been the custom of the broader based author (this is meant to refer to the distance between College Park and Irvine, not the distance between …) simply to go back to the "important questions" in the field as defined so far through the series, explain the issues, and cite one paper on each side. This will happen for a subset of topics here. But, in the spirit of experimentation, for every topic on which more than 10 papers were indexed as potential highlights, even if no well-defined question can be asked, a genuinely random one is selected in an effort to pick out other important questions of which we were not in the past properly aware. The "random reference" is simply the middle one in the order the papers were read. Thus the subsections here are "Classic Questions," "Middle References," and two longer disquisitions on cooling flows and evolutionary scenarios.

10.1. Classic Questions

1. When you see something really bright at large redshift, is it a starburst or a black-hole powered active galaxy? Yes, that is, a very large fraction are both (Allen et al. 2002, on the ultraviolet from radio galaxies at large redshift). This was the middle of 27 references indexed as "both, please." The middle one of 13 that found only one or the other was Mundell et al. (2001), who report that both the nuclei of Arp 220 are starbursts, but of course Arp 220 is not at large redshift.

2. What is the source of the excess emission at UV and soft X-ray wavelengths that seems to be coming from some large clusters of galaxies, if indeed the excess is real? Yes it is, but much is merely warm gas in individual galaxies (Cheng 2002). Maybe it's real and produced by inverse Compton scattering of CMB photons by relativistic electrons that have leaded out of active galaxies (Tsay et al. 2002).

3. What is at the center of our Galaxy and gets called Sgr A*? It is just as well you already know the answer to this question from § 9, because the middle of 11 Sgr A* papers is radio polarization data (Bower et al. 2002). The circular polarization exceeds the linear by a factor three or more, and the direction has been stable for 20 years, though the percentage goes up during flare events. This implies that the field polarity has been stable for that length of time, which bears on the

mechanism by which gas either flows in or doesn't and energy is either extracted or not (§ 9.4).

4. What causes S0 galaxies? Well the star formation stopped rather suddenly a few Gyr ($z \approx 0.5$) ago, say both of the middle references (Mathieu et al. 2002; Bicker et al. 2002), but they do not say why.

5. Now that we all believe in the bottom up or hierarchical picture of galaxy formation, can it account for everything we see? No, of course not, because the really hard part is the feedback of star formation, supernovae, galactic winds and fountains, and all the rest of gaseous astrophysics.[4] Thus one is not particularly surprised to hear, for instance, that counts of galaxies at moderate redshift (based, of course, on light generated entirely by their baryonic content) compared to $z = 0$ counts act more like pure luminosity evolution than like hierarchical merging, with or without triggered bursts of star formation (Cimatti et al. 2002). Other cases where a monolithic collapse model fits the data as well or better than bottom-up (but most of the dirt is hidden in the baryons) are the correlation of Mg/Fe with galaxy mass (Romano et al. 2002), galactic chemical evolution in general (Tantalo & Chiosi 2002), amount of clustering vs. redshift (Daddi et al. 2002), and the evolution of colors of galaxies in the Hubble Deep Field since $z = 4$ (Westera et al. 2002). If, however, you look at something that is largely a signature of gravitational potential, like substructure and alignments in clusters and superclusters, then the hierarchical picture works just fine (Plionis & Basilakos 2002a).

Another way to say this is that, if you want to see a particular phenomenon in your model, then you had better resolve down to the scale of that phenomenon (Kay et al. 2002). And if you have been down this path with us before, you will know that at the far end is to be found weather forecasting, mud wrestling, or both.

6. Are dark matter halos triaxial? Yes, based on how H I behaves far from the center (Bekki & Freeman 2002).

7. Why do the Faber-Jackson and Tully-Fisher relations work even as well as they do? Beats us, but Seljak (2002) says it must mean that the baryons in galaxies make a significant contribution to the velocities. And ditto for the success of the fundamental plane in describing the relationships of the properties of elliptical galaxies (Dantas et al. 2002). What are the relations, you ask? Tully-Fisher is a correlation between the maximum rotation speed in a spiral galaxy and its total luminosity, allowing the measured rotation (which does not depend on distance) to be used to get "standard candle" distances. Faber-Jackson is a similar relation for ellipticals, using the velocity dispersion measured in a standard way rather than rotation (of which they tend to have rather little).

8. Do galaxies evolve from one morphological class to another? Before we can tackle this mountain, we must get several molehills out of the way. The standard Hubble sequence doesn't really come into being until a redshift of 1–2 (Kajisawa & Yamada 2001), so the dominant long-term evolution cannot be from Scd to E3 or any other such combination. Fear not, however, friends are waiting with more empirically based schemes that should apply any time things you would recognize as galaxies exist. That of Conselice (2002) is triaxial, with dissipation, star formation, and interaction as the three axes, while that of van den Bergh (2002a) has the sound of a result from cluster analysis, in which classes are described as (1) stellar, (2) fuzzy, (3) comma, (4) tadpole, and (5) chain, with for each qualifiers s = single, b = binary, and m = multiple. It is intended specifically for z in excess of about 2.

But even if you have defined your terms carefully, the question of what class evolves into what else may not have a simple answer. Murali et al. (2002) and Weinberg et al. (2002) contemplate the Lyman break galaxies and ask, "where are they now?" These are the galaxies recognized in broad color surveys because absorption at the Lyman limit moves across color bands with increasing redshifts. And the answer is that they are now diffused over ellipticals, bulges, haloes, and rich clusters. Most big galaxies now include some stuff that was already in galaxies at $z = 3$, but you cannot pick out any one class as the answer to where are the Lyman breaks of yore? And the answer to the original question is that a particular galaxy is unlikely to change from one Hubble type to another very different one, but just about all galaxies have changed from "then" types to "now" types.

10.2. The Middle of Our Tether

Here, with some italics and such to indicate roughly the subject under discussion, are topics that had lots of indexed papers, but for which we were not quite sure how to express the important issue(s) as question(s).

The Local Group (which immediately defies our algorithm by having 12 highlight papers) has very little diffuse gas at the temperature of its central gravitational potential, n_e less than 1.3×10^{-4} from absence of keV X-rays (Osone et al. 2002). On the other hand, there is a good deal of diffuse light around both the large and small members, probably coming from tidally displaced stars (Choi et al. 2002, with new data, and Johnston et al. 2002 with new calculations).

Within the *Virgo Cluster*, the dwarf ellipticals fell in after the giant ellipticals formed and were dwarf irregulars before they did it. Notice that this is also part of the answer to one of the "classic questions" about changes of morphological types among galaxies (Conselice et al. 2001).

Preheating of gas in X-ray clusters? The issue, which has not much appeared in previous editions of ApXX, is whether the emitting gas has to have been heated by something that adds energy beyond what you would expect if it was simply blown out of the galaxies and sloshed around in the cluster

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[4] The participants at a recent conference were calling this gastrophysics, though we feel the term might equally well apply to the literature exemplified by Kurti & Kurti (1988) and indeed was first used in that context by a keen amateur mycologist.

potential. The middle reference says (*a*) yes, (*b*) it is done by active galaxies in the clusters between $z = 4$ and $z = 1$, and (*c*) the process is on-going and now contributes to control of cooling flows (§ 10.3 below; Nath & Roychowdhury 2002).

Compact clusters of galaxies. A small but select class this, and two old friends in the middle, both carrying the message that all is well. First, the Shakhabazian groups have outlying bound members and, like the Hickson groups, last long enough for us to see the number we do (Tovmassian & Tiersch 2001). And in Stefan's quintet, the communal gas shows a shock, Rayleigh-Taylor instability, and such where the high velocity member is coming through, as opposed, for instance, to its being at rest with a non-velocity, non-cosmological component to its wavelength shift (Sulentic et al. 2001).

cD galaxies. The second most important issue of which we are aware is how to put them at the beginning of a paragraph without turning them into certificates of deposit or compact disks. The former comes closer, since you must add in some large galaxies if you want to make a cD, and the streams of stuff disrupted in the process could cover 10% or more of the sky (Zhang et al. 2002a). How to make them and what it does to the rest of the cluster are the most important issue, and the middle references on this sound a bit mutually contradictory. Koranyi & Geller (2002) conclude that the rest of a smallish cluster doesn't seem to know or care whether there is a cD at its center, while Matsushita et al. (2002) conclude that M87 is fully integrated with the inner part of Virgo, at least in X-ray properties.

Dwarf spheroidal galaxies dominate all or most volume-limited samples, at least near $z = 0$, including the Local Group. The notebooks contain 21 papers, just about the same number as there are dSph's in the LG, and the middle one says (a bit to our surprise) that at least some will still be around after many billions of years, because the Draco dSph shows no evidence for tidal damage by the Milky Way (Piatek et al. 2002). The implied mass to light ratio in solar units is 92 ± 28 (Odenkirchen et al. 2001). The dSph's formed from tidal tails, in contrast, have no dark matter of their own, and their dynamical masses are just the sum of the H_2, H I, and stars (Braine et al. 2001). This is not much of a surprise; but we still don't quite know what to think about the conclusion that the dwarf ellipticals and dwarf S0s in Virgo have shapes that are largely rotationally supported (Simien & Prugniel 2002).

Low surface brightness galaxies are another category for which the inventory is surely incomplete. According to Zwaan et al. (2001), they make up about 10% of the local mass and luminosity density. Neeser et al. (2002) have just reported the first one with a thick disk component among its stellar populations. On the other hand, most do not have bulge stars and so ought not to have central black holes (de Blok & Bosma 2002).

Extremely red objects do not deserve to be a class of galaxy, since, at least in the Hubble Deep Field South, about half are old ellipticals and half are dusty star bursts (Vanzella et al. 2001). Anyhow, the moment you have more than one, they are EROS, and that acronym is already taken for one of the microlens search projects.

Barred spirals are a small or large fraction of total spirals depending largely on how hard you look. The bar of the Milky Way was gradually recognized over the past few decades, but it would have been a mistake to look too soon, since it has been there for less than 3 Gyr, say Cold & Weinberg (2002). Look too hard, though, and you begin to find that some SBs have additional smaller bars (Petitpas & Wilson 2002, on NGC 2273 and 5728; Schinnerer et al. 2002, on NGC 4303). Why would they want to do that? is not, perhaps, a philosophically correct question to ask of an astronomical object, but the extra bars are apparently useful for moving gas inward at a few $M_\odot$/yr, the rate required to fuel a modest active nucleus of the sort found by Laurikainen et al. (2002) in about half of a sample of 40-some SBs. There is a temptation to say correlation = causality, but even to decide whether half is a real over-representation requires working equally hard on samples of galaxies not known to be barred and not known to have active nuclei.

Irregular galaxies used to include both little scruffy things like the Small Magellanic Cloud and big messy things like Arp 220 (or indeed most of the other Arp galaxies, on whose merger origins Chitre & Jog 2002 have interesting things to say). Typically one now means only the dwarf irregulars, but Mihara (2001) finds that there are still at least two kinds, with large and small rates of star formation, and that you still cannot make them add up to known numbers of faint blue galaxies of unknown distance. This sounds like the sort of issue that should be revisited with a large sample of SDSS and 2dF redshifts.

SCUBA galaxies are not a physical type in quite the same way as some of these others. (And to our collection of corn oil, sewing machine oil, neats foot oil, and midnight oil, we have recently added Standard Oil.) What is meant is entities that are so extremely red that the submillimeter regime is the best bet for finding them. Some do have optical counterparts, and, in the range $z = 2.7$–3.0 (where there is the best hope of optical IDs; Chapman et al. 2002), the SCUBA galaxies tend to have very large velocity dispersions (≈350 km/sec) and large star formation rates. They are presumably the contents of very massive halos en route to becoming giant elliptical galaxies (Shu et al. 2001).

Blue compact dwarf galaxies. We only wish some of our friends had such accurately descriptive names; they would be easier to recognize. All BCDGs have, besides the obvious hot stars, an underlying old stellar population (Vanzi et al. 2002). Long ago, when the same thing was said about blue spirals and irregulars, it was taken to mean that galaxy formation was all over long ago. No one would, we hope, claim this now.

About *giant elliptical galaxies*, one can say, if not an infinite number of things, at least 26 interesting things, yielding again two middle papers. One reminds us that, although they do not have the giant clouds of dusty molecular and atomic gas found in spirals, they are not completely lacking in diffuse material either. The amount of dust is very much what you would expect from the accumulated mass loss of evolving old stars (Athey et al. 2002). This amount is a bit less than 1 $M_\odot$ per year, mostly of course, gas, in a typical gE, and not so very different from the death and destruction rate in the Milky Way. The other points out that merging pairs of massive black holes (expected in a merger scenario for gE formation) will tend to make the galactic centers less cuspy in their density profiles and so more like real galaxies (Milosavljevic et al. 2002).

Polar ring galaxies have been widely advertized, even by us, as the product of a small, gas-rich unit hitting a previously staid, respectable S0 more or less right in the kisser. Iodice et al. (2002) agree about the "pow" part, but conclude that a better fit to the photometry is produced by two comparable disk galaxies coming together and making both of the components we now see at the same time.

Lyman break and damped Lyman alpha galaxies (in contrast to the BCDGs) have names that require a bit of explanation. Lyman break means that the flux reaching us as a function of wavelength drops precipitously blueward of 912 Å in the rest frame of the galaxy, while damped Lyman alpha galaxies are the ones that introduce into the spectra of background QSOs Lyman alpha absorption features of sufficient strength that natural damping (quantum mechanical broadening) dominates the widths of the features. The Lyman break galaxies are significantly brighter than the DLA ones at the same redshift (Colbert & Malkan 2002) or even at different redshifts (Warren et al. 2001). They are also, we think rather less metal poor at a given (largish) redshift (Pettini et al. 2002b on a Lyman break galaxy and Petitjean et al. 2002 on a DLA, both near $z = 2$). But the most discouraging paper of the year on this topic has to be Aguirre et al. (2002), who say that none of the determinations (including theirs) of chemical compositions of these objects is really to be trusted, and, therefore, the real trends (if any) with redshift and density of the environment are largely unknown. The point is that the physical conditions are very different from those in galactic H II regions, for which a certain amount of ancient lore of spectral analysis exists.

Void galaxies are a lot like galaxies elsewhere. There just aren't so many of them (Cruzen et al. 2002), unlike beetles, common persons, and binary stars.

Episodic vs. continuous star formation, in three or four dimensions. The "middle reference" method picked out (*a*) the LMC, for which the answer is continuous in the bar but episodic elsewhere (Smecker-Hane et al. 2002) and (*b*) the dwarf irregular in Sagittarius, whose star formation has been patchy in both time and space (Momany et al. 2002). Yes, there are also smallish galaxies for which the answer was "continuous" (e.g., Ma et al. 2001 on the surviving star clusters in M33 with ages between 3 Myr and 10 Gyr). We started worrying, however, about whether their resolution was as good as that of the patchy people. Triggering of star formation by spiral arms, cloud-cloud collisions, stellar winds, or supernova ejecta is one way to make peaks and valleys in the star formation rate. The central of 27 papers on triggered star formation happened to concern the possibility of triggering by hypernovae, events 10–100 times more powerful than ordinary supernovae (Efremov 2001). Frequent multiple supernovae in a single large star cluster would have many of the same effects, patchiness in triggered later star formation among them.

10.3. Cooling Flows Reheated?

A cooling flow or cooling flow X-ray cluster denotes the idea that, in many rich clusters of galaxies, the central temperature, density, and luminosity of the X-ray emitting gas seem to be such that the time to radiate away half (say) of the energy content is a good deal less than the Hubble time. Under such circumstances, you would naturally expect that gas to be demonstrably cooling, flowing inward as the support of thermal pressure is lost, and gradually turning into the same quantities of much cooler (non-X-ray emitting) gas, stars, purple chalk, or something. Not really, for a good many years. Most such clusters have at most small amounts of H II (10^4 K), atomic (21 cm), or molecular (CO tracer) gas near their centers and little evidence for star formation. This has worried us a good deal over the years (Ap94, § 10, "cooling flows to where?", and most years since), perhaps more than it had worried the X-ray astronomers compiling the data.

Their worry quotient seemed to rise in the last couple years as the *Chandra* and *XMM-Newton* satellites confirmed first that central temperatures are lower than outer ones in many clusters (Ettori et al. 2002 on Abell 1795, standing proxy also for a dozen or so other papers; Smith et al. 2002a on Cyg A), and, second, that this stops rather abruptly near 1 keV, with nothing cooler to be seen (Lewis et al. 2002; Matsushita et al. 2002). But, perhaps as a result of the increased attention, several speakers at an IAU Symposium (214 in Suzhou, China) during the index year announced that everything was OK and the amount of material that must be flowing in is not larger than the observed sinks can hold. Thus the author with the longer cooling time decided to attempt a complete head count of the relevant literature, to see whether this might be a reasonable summary. Each of the 44 recorded papers counted as one head, in most cases apparently attached to one or more authors, and, yes, there was a sort of tie, so we'll have to look at some details.

The first change comes from improved data that show, for instance, that X-ray temperature actually peaks at the center of some clusters (Krawchynski 2002 on 3C 129), while for others, a closer look at density distributions and cooling times reduced the estimated inflows from hundreds of $M_\odot$/yr to tens of $M_\odot$/yr (Molendi & Pizzolato 2001; Boehringer et al. 2002), comparable, for instance, with the gas flow rate through the regime for emitting far-UV (Oegerle et al. 2001 on Abell 2597 and 1795), the small observed star formation rates of central galaxies (Schmidt et al. 2001), and the 10^9–$10^{11.5}$ $M_\odot$ of molecular gas that appears in about half the cooling flow clusters (but was previously seen only in that around NGC 1275) and must come between the *FUSE* gas and stars (Edge 2001).

The second change has arisen from reconsideration of various heat sources that might actually keep the gas structures we see in equilibrium for a Hubble time, particularly input from radio bubbles, jets, lobes, and other AGN products. First comes mergers of small clusters to make big ones. These will certainly reheat the gas, interrupting a cooling flow. But it will also make a nasty mess of both the chemical and the temperature gradients that are actually seen in some "cooling flow" clusters. This disruption might persist for the age of the universe (Ritchie & Thomas 2002), in which case mergers are probably not even part of the answer, or perhaps only briefly (Gomez et al. 2002; Sodre et al. 2001), in which case one might reduce the total amount of cool stuff dumped at the center over a Hubble time, though not, one would suppose, the current throughout in O VI gas, H-alpha emitting gas, and so forth.

Another potential savior of the center is conduction of heat from the outer to the inner regions of clusters. During the index year, it was declared to be a significant part of the solution by three papers (Narayan & Medvedev 2001; Voigt et al. 2002; and Fabian et al. 2002c, who also note that conduction, by stopping the inflow of baryons, limits galaxy masses to a few $\times\ 10^{12}\ M_{\odot}$) and denied by one (Loeb 2002a), on the grounds that the outer parts of the clusters would then also be cooled by conduction to the intergalactic medium. We wonder though whether density gradients might somehow make outward conduction much less efficient than inward conduction.

The heater of the year, without doubt, was energy input from assorted AGN products, radio jets, bubbles, lobes, cavities, and all, which you might not even be able to see at the time they are doing their job most effectively (Brüggen et al. 2002). Of the 15 or so papers supporting the idea, the more persuasive were ones about clusters where you do see some evidence for the input, for instance McNamara et al. (2001, a *Chandra* image of Abell 259), Saxton et al. (2001 on Cen A), Markevitch et al. (2002, a bow shock near a radio halo in 1E 0657−56), Mazzota et al. (2002, a hot gas bubble inside the cooling flow region of MKW 3, due perhaps to a brief AGN episode), and Fujita et al. (2002, a rising bubble from a cD galaxy whose motion through the cluster is probably another heat input). These are supported by a number of theoretical discussion of reheating (Quilis et al. 2001 and Brüggen & Kaiser 2002 being the first and last read during the index year). There was also at least one firm vote against reheating from the center, on the grounds that it would result in instabilities and cycles in $T(t, r)$ which are not seen (Brighenti & Mathews 2002).

Some closely related issues are (*a*) Might there be non-thermal X-ray emission from clusters, in which case the estimated mass and flow rate go way down? Could be say McCarthy et al. (2002a), (*b*) Is there non-thermal pressure at the center, which would prevent inflow? Yes, say Machacek et al. (2002b), and (*c*) Do the current gas temperatures in clusters of various masses imply additional heating on beyond what you get by converting potential energy and the shocks of mergers into gas kinetic energy? Yes, say McCarthy et al. (2002b), Holden et al. (2002), and several others. Our favorite preheater is gas turbulence pumped by dark matter sloshing around in its own gravitational potential well (Ricker & Sarazin 2001). One of the speakers at the IAU Symposium that got us started on all this also included such sloshing around among the central heaters that keep giant cooling flows from cooling and flowing gigantically.

We would like to give the last word to Andy Fabian, since over the years he has been a key player in batting the cooling flow ball back and forth. You therefore have your choice of (*a*) yes, the problem has been solved (Fabian et al. 2002c), (*b*) no, it has not, and there must be star formation by some mechanism that favors small mass stars that are not easily detected (Fabian et al. 2002b), or (*c*) please stay tuned (Fabian 2002).

10.4. The Big Picture

One kind of scientific progress is to be able to go from collecting details to putting them together into models or scenarios and then into great evolutionary schemes, just before you fall over the edge of the cliff into philosophy of science. We think the topics treated here are still (perhaps only just) on the safe side.

10.4.1. The Redshift History of Star Formation

What is the total star formation rate as a function of redshift? In particular, can we identify the time when most of the small stars that are still around were made? After having written on this for a number of years, we find ourselves tempted to ask why would anyone want to? A possible answer is that the numbers are, in effect, the integral over a large (three-dimensional) volume of the galactic evolution that gastrophysicists are now struggling with.

Oh, all right. But what is the current star formation rate? Sadler et al. (2002) say $0.022 \pm 0.004\ M_{\odot}/\mathrm{yr}/\mathrm{Mpc}^3$ (for $H = 50$ km/sec/Mpc and counting 2dF galaxies surveyed by the VLA). Condon et al. (2002) say $0.018\ M_{\odot}/\mathrm{yr}/\mathrm{Mpc}^3$ (for $H = 70$ and galaxies from the Uppsala Catalogue for which there are radio data). The difference is not in values of H chosen (which would go the other way), but in astrophysical uncertainties like the initial mass function adopted, since only the brightest, heaviest stars contribute much to any of the star formation indicators, whether X-rays (Read & Ponman 2001), submillimeter (Le Flosch et al. 2002), far-UV (Leitherer et al. 2002), Lyman alpha (Lanzetta et al. 2002), or mid-infrared and H-alpha (Balogh et al. 2002) and undoubtedly we have missed some. One indicator can easily yield a rate 10 times that from another indicator for the same population of galaxies (Duc et al. 2002), usually because the former is less obscured than the latter; but it is possible to overcorrect and have things come out the other way (Rosa-Gonzalez et al. 2002).

So what is the answer already? Much larger rates as you look to $z = 1$–2 (Cohen 2002). To be specific, say Rosa-Gonzalez et al., SFR proportional to $(1 + z)^{4.5}$ back to $z = 1$ ($2^{4.5} = 22.6$ if you left your sliderule at the counting house), flat from $z = 1$ to 2, and declining again as $(1 + z)^{-2.5}$ before that, taking us back down to eight times the present rate at $z = 5$, and three times the present rate at $z = 10$ (about which, of course, we have absolutely no direct evidence). BUT, say Lloyd-Ronning et al. (2002), if the rate of gamma-ray bursts tracks star formation, then star formation is flat or even still rising back to $z = 10$. There is also no direct evidence of GRBs at $z = 10$, the current record being about 4.5. Once again, this means the massive stars that seem to be responsible for long-duration GRBs, as well as radio, X-ray, FIR, and all the other sorts of photons, but also for most of nucleosynthesis, so that SFRs in the sense discussed here are directly useful for models of chemical evolution.

The age distribution in stars now is an independent check on SFR(z), if, that is, the initial mass function, $N(M)$, has been constant. Nelson et al. (2001) conclude that the galaxies or galaxy pieces now to be found in giant ellipticals and S0's made most of their stars before $z = 5$. This is not obviously inconsistent with any of the previous remarks. Apparently if what you want is an input star formation rate vs. time for your models of galactic evolution, you still have lots of freedom.

10.4.2. The Construction of Galaxies

The overarching question in this field of gaseous astrophysics is, of course, can one put it all together into consistent scenarios of galaxy formation and evolution, both dynamical and chemical, whose products at $t = 14.7$ Gyr (or whatever) look like the modern range of galaxy types in the proper proportions. In the style pioneered by presidential pardons, the answer will depend on your definition of "it" and "like."

We found six "grand scenario" papers and more than 200 with specific data on chemical composition of particular objects or classes, gradients, distinct nuclear processes, composition of supernova ejecta of Populations II and III, contributions from active galaxies, gamma-ray busters, and hypernovae as well as better known sites of nuclear reactions. Some of these, were, of course, mutually contradictory.

The most forthcoming was probably the discussion by Molla & Hardy (2002) of a bunch of spirals in the Virgo cluster vs. 500 possible models. They noted that "uniqueness is an issue." Hernandez et al. (2001) also found that a range of scenarios works for the Milky Way, and the dynamical and chemical issues cannot really be decoupled when gas flows in, out, and around galaxies (Churches et al. 2001). Qian & Wasserburg (2002) put forward a very specific scheme for assembling the heavy element component of the Milky Way, starting with very massive objects (products as described by Heger & Woosley 2002), then a couple of kinds of core collapse supernovae, and adding in nuclear explosion supernovae and intermediate mass stars still later.

Rather than abandoning you in the slough of despond and variable parameters, let us lead you back out with a thread of little questions and answers, because if we are going the right direction and keep at it, the goal will get closer, as it has for understanding structure and changes of individual stars.

Do you guys have a G dwarf problem? Meaning, are there fewer metal-poor, old stars still lying around than would be expected if a population has enriched itself over time? Yes for our own halo subdwarfs as well as the disk (Caimmi 2001, and cf. Hartwick 1976). Yes also for the disk of M31 (Williams 2002). But no for low surface brightness galaxies (Galaz et al. 2002).

What do you mean, primary nitrogen? Well, nitrogen that could be synthesized other than via the CNO cycle in stars that already had a good deal of C and O at birth from earlier generations. Evidence for it there certainly is (Pettini et al. 2002a) in contexts indicating that the source should be stars of 4–8 $M_\odot$. which kick in after Type II supernovae have been doing their thing for a while (Prochaska et al. 2002). And it can be produced in, as it were Pop II$\frac{1}{2}$ stars (Meynet & Maeder 2002) with initial metallicity of 10^{-3} solar, when carbon from the triple alpha process diffuses into the hydrogen burning zone above.

11. PLANETS

11.1. Orbiting Other Stars

Now that there are something like 100 planets known to orbit stars that are not the Sun, it becomes more difficult to get excited about any one. We will start then with undiscoveries. The events described last year as microlensing by orphan planets in the globular cluster M22 were actually cosmic-ray hits on the *HST* detectors (Sahu et al. 2002). We therefore deleted from the itinerary all papers explaining how the cluster could retain such planets for more than 10 Gyr. Such papers can now, however, claim the status of predictions. The clearest case for a rotating, spotted star with variable activity that might easily have been mistaken for the effects of a planet is HD 166435 (Queloz et al. 2001). The period is 3.7987 days, but not coherent for as long as that many digits make it sound. The importance of this result is the increased confidence that other reported planets are not artefacts of the effects of stellar activity on absorption line profiles.

Also not actually orbiting anything (now) are the orphan planets seen in the σ Ori cluster, where $N(M)$ is still rising into the planetary regime (Barrado y Navascues et al. 2001). Three pairs of these may be equal-mass binaries, leaving us a little uncertain about who is not orbiting whom. Such objects, though of planetary mass, form like stars, with core contraction, gravitational collapse, and disk accretion, say Testi et al. (2002), who have looked in the ρ Oph cloud.

The proper way for planets to form is in a disk around a protostar, either by the accumulation of planetesimals (Rafikov 2001) or via a gravitational instability (Boss 2002a), each a somewhat random paper chosen from a largish group. The gravitational instability process should yield more planets, because typical protostellar disks hardly last long enough for accretion to make big things (Oliveira et al. 2002; Bary et al. 2002). Massive stars sometimes have rather similar disks (Grady et al. 2001 on the Herbig AeBe star closest to us), but we haven't a clue whether they should be called protoplanetary or not.

While planets are forming, you might quite reasonably expect to see their effects on the distribution of matter in the remaining disk. This has been claimed in several cases (Wilner et al. 2002; Ogilvie & Lubow 2002), but stellar or protostellar magnetic fields can produce rather similar structure (Ultchin et al. 2002). You should probably not acquire an advance-purchase necessary, no refunds or exchanges ticket to visit one of these in the hopes that the planet will exist by the time you get there.

Once planets acquire their identities, they can migrate in or out if there is still some disk around (Papaloizou 2002; Kuchner & Lecar 2002; Masset 2002). Papers on this topic increasingly mention things like Lindblad resonances and co-rotation, familiar from the dynamics of galactic disks. Probably this helps in understanding the planet case only if you already understood the galactic case.

Apparently all the planet systems whose properties have been deduced from radial velocity data are stable for at least gigayears (Malhotra 2002 on υ And; Lee & Peale 2002 and Kinoshita & Nakai 2001 on Gl 876; and Wu & Goldreich 2002 on HD 83443). Extrastable, we suppose, are members of a new class with semi-major axes of an AU or more and very small eccentricities (Vogt et al. 2002).

Arguably of greater interest, if you are looking for a place to live after we spoil the Earth, is the potential stability of some kinds of orbits not yet seen, including an Earth at 1 AU where there is a "hot Jupiter" close to the star or a cold Jupiter farther out (OK for 51 Peg, an example of the first class, and 47 UMa, an example of the second, say Noble et al. 2002). Another, less familiar, habitat might be a Europa-size moon of a Jupiter-size at about 1 AU. This configuration too should last for gigayears, say Barnes & O'Brien (2002). The inhabitants may not last quite so long.

The only thing so far observed in an exoplanet atmosphere is sodium (Charbonneau et al. 2002), which will surely be bad for the inhabitants' blood pressure. The atmosphere in question is not in local thermodynamic equilibrium (Barman et al. 2002). This should not be taken as a signature of life there (heavy breathing, for instance), though lack of chemical equilibrium might be. Selsis et al. (2002) mention a mix of O_3, CO_2, and H_2O as found on Earth as a combination that could not be established by photo chemistry. Chlorophyll, whose absorption "red edge" at 7300 Å was finally seen in the reflection spectrum of Earth (that is, earthshine; Woolf et al. 2002) would be even more persuasive, but, we gather, not easy to detect.

Where else might you look for planets? In the Hyades, perhaps, since none has yet been found (Paulson et al. 2002; Cochran et al. 2002). In the OGLE III and other MACHO (microlensing) databases, either as transits (Udalski 2001) or as blips in a microlensing event (Bond et al. 2002, putting forward MACHO 98-BLG-35 as a strong candidate for an Earth-mass planet about 1 AU from the star), or (and this is our hands-down favorite) in an optical search for extraterrestrial intelligence, which found no laser signals perturbing a bunch of spectra of FGK stars that were being examined in a conventional radial velocity search (Reines & Marcy 2002).

What about the hosts? They have normal kinematics for their location (Barbieri & Gratton 2002) and a normal distribution of rotation periods for their spectral types (Barnes 2001). This latter would have been revolutionary a generation or two ago, when it was widely supposed that the Sun is a slow rotator compared to many other stars because the planets got most of the angular momentum. Even now it seems a bit odd, given that both rotationally-broadened lines and energetic stellar activity (favored by rapid rotation) make planetary effects harder to see.

Oh, all right. Something has to be said about the metal-richness of host stars, though it has become less extreme as the sample has grown. Your choices are accretion of residual dust material by the stars (not of Jupiters, which are mostly hydrogen and helium), primordial richness which made planets easier to form, and selection effects in favor of stars with stronger lines. All of the above, said Murray & Chaboyer (2002), though we counted double handfuls of papers favoring each of the choices, accretion to make DAZ white dwarfs, for instance (Debes & Sigurdsson 2002). The details of how the various types of WD atmospheric compositions arise remain obscure, and if we had thought of it, we would have claimed terrestrial planet accretion for the metal-contaminated helium atmospheres in preference to general ISM infall, which would seem to bring hydrogen along.

Only for the sun can much more be said. Once upon a time, accretion of "meteoric material" was suggested as a cure for the solar neutrino problem (e.g., Bahcall & Ulrich 1971), because coating only the convective surface with metals reduces interior opacity enough to allow the core to be a bit cooler and the flux of B^8 neutrinos smaller by a factor three. Now we can go the other way, and use helioseisimic data to say that the interior metallicity is very similar to the surface 1.7%, and the Sun has not added more than 2 $M_\oplus$ of iron or 30 $M_\oplus$ of heavies in general to its convective envelop, compared to the average composition (Winnick et al. 2002).

11.2. Orbiting the Sun

Let's start at the very beginning (a very good place to start). A supernova trigger for the formation of the solar system is back in the literature this year, with fossil radioactivities injected by a Rayleigh-Taylor instability and total injection amounting to 0.1% of the inner solar system, say Vanhala & Boss (2002). It happened 4.57 ± 0.11 Gyr ago, which is the age of the Sun (Bonanno et al. 2002) derived from helioseismological data and a new, improved equation of state. This is in good accord with the age from meteorites (Bahcall et al. 1995). And it was all over in a considerable hurry, with Vesta, Mars, Earth, and Moon all formed within less than 30 Myr of one another (Yin et al. 2002; Cameron 2002). The number comes from measured ratios of Hf^{182} to W^{182}, the unstable one having a half life of only 9 Myr.

And how long will it all last? Well, the planet orbits are probably good for a few more Gyr (Mardling & Lin 2002 on evection and eviction resonances). But asteroid and comet orbits can easily go wild after only 10^3 yr among the inner Apollo, Aten, and Amor objects (Wlodarczyk 2001) and 10^4–10^5 yr even for the main asteroid belt, Trojans, and KBOs. We have noticed before, however, that nature sometimes does a better job of the physics than even the most mathematically skilled of our colleagues (consider galaxy formation, ejection by Type II supernovae, and such). Thus the orbits may last longer than the forecasts.

What was made 4.57 Gyr ago was, of course, one Sun (§ 2), about nine planets, and some very large assortment of comets, asteroids, and smaller fragments. The numbers of papers about each that we tagged as potential highlights seems to have been more nearly proportional to the numbers of the objects than to their masses, and we will according proceed from the planets down to the scruff.

11.2.1. The Major Planets

Cassini and *Galileo* looked at Jupiter at the same time (Gurnett et al. 2002 and five following papers). They saw the magnetosphere, aurorae, volcanic gases from Io, and lots of other tenuous stuff, including the magnetic footprints of two more moons, Ganymede and Europa (Io's tread having been known since 1969).

Venus became the latest solar system X-ray source recorded by *Chandra* (Dennerl et al. 2002). The mechanism is fluorescent scattering of solar X-rays, of which the Moon was proven guilty by *ROSAT* some years ago.

Mars has climate cycles, driven by changes in orbital eccentricity and inclination of the rotation axis and shown by layering in the north polar cap (Laskar et al. 2002). There is also Martian weather (Nakakushi et al. 2002 on the Martian equivalent of Hadley cells in atmospheric convection). What's the difference? Well, Southern California has climate (that is, for month-long stretches you can guess that tomorrow will be a lot like today and not go far wrong), while Cambridge, England, has weather. This is why, at a recent meeting there, the organizers passed out umbrellas with the conference logo on them rather than tote bags (which can be worn over the head in emergencies but look a bit silly). In the Martian case, CO_2 snow depth traces both the climate cycles and the shorter-term weather (Richardson & Wilson 2002; Smith et al. 2001b; Malin et al. 2001).

But if we have to argue the case for Martian rain, or anyhow water, again this year, it will drive us to drink (something stronger). Please, therefore, consider Wyatt & McSween (2002) to have done it for us all.

Genuinely new this year, however, is the evidence for ice, or at least something with lots of protons not too far under the surface (Feldman et al. 2002; Mitrofanov et al. 2002). The evidence is the energies of the neutrons and gamma rays scattered up when solar gamma rays and energetic particles hit and slightly penetrate the surface. This works only because the Martian atmosphere is too thin to stop these things, going either direction, and the idea can be traced back to Lingenfelter et al. (1961).

Do protons really equal ice? Well, no, but it's the most horselike (as opposed to the zebras of, say, carbohydrates) choice for making this particular set of hoofbeats, just as all is not gold that glisters, but at least you know it has free electrons.

11.2.2. Moons

Among the moons of Jupiter are some more new X-ray sources, Io, Europa, and maybe Ganymede (Elsner et al. 2002, reporting soft *Chandra* data). The mechanism is not the charge exchange that leads to comets being sources but, perhaps, bremsstrahlung by non-thermal electrons. And while the tour bus is parked near Jupiter, you might want to notice that the ice layer on Europa is disturbingly thick (Turtle & Pierazzo 2001) if you want to imagine energy and material from the surface getting down to the brine layer through cracks. Also parked around Jupiter is Io, but only temporarily. Its eccentric orbit means that there is both an outward force of tidal torqueing by Jupiter and an inward drag due to internal dissipation. But the dissipation is winning and Io gradually spiralling inward (Aksnes & Franklin 2001).

Our Moon is, of course, moving out, currently at 3.8 cm/yr, the latest result from the lunar laser ranging project, which has been underway since January 1972 (Chapront et al. 2002), and yes, this seems like a long time even to the longer-timed author. The corresponding secular acceleration is 2.5858 $\mathrm{arcsec\ (century)^{-2}}$ and leads also to a small correction to the constant of precession.

The moons of Saturn appear unable to keep their dirty hands to themselves. The dark side of Iapetus is perhaps coated with stuff knocked off Hyperion (Marchi et al. 2002). By whom was not clear.

11.2.3. Rings

The big planets all have rings, though at present the biggest planet does not have the biggest rings. The only dispute we caught was whether the confinement of the Neptune arc is due to a particular resonance with the moon Galatea (Namouni & Porco 2002) or not (Dumas et al. 2002). In either case we like her overture. Galatea, not Neptune or the female author, who once committed an overture, but you wouldn't want to hear it.

11.2.4. Asteroids

The landing of *NEAR* on Eros happened during the previous reference year, but many of the details of what it found were reported in fiscal 2002 (Veverka et al. 2001 and the next two papers). Though Eros would cause a crater if it hit a planetary surface, it is itself cratered, like Ogden Nash's fleas. The *LINEAR* mission also reported in with a package of results on near-Earth asteroids (Stuart 2001 and several following papers). They found fewer and more highly inclined orbits than expected, reducing the average risk of impacts.

Asteroids also hit each other, but fragmentation is typically followed by reaccumulation (Michel et al. 2001; Nesvorny et al. 2002), so that all the large ones have had structural repairs and satellites should be common.

Bottke et al. (2001) note the importance of the Yarkovsky effect on orbit evolution (Ap01, § 4.2.4) and conclude that Eros, which is now a near-Eearth object, could have taken several gigayears to leave the main belt. Yarkovsky surfaces (or perhaps resurfaces) again for 1950DA which could hit Earth in 2880 (Giorgini et al. 2002; Spitale 2002). The main uncertainty in integrating its orbit forward in time is the acceleration due to thermal reradiation of absorbed sunlight. But one could make this work in our favor by changing the albedo or thermal conductivity over part of the surface. A single one-ton TNT blast should remove 1 cm of loose material from the impact site and suffice.

Most asteroids rotate (including the Kuiper Belt Objects a few paragraphs down). The period of 20010E$_{84}$ is 29.2 minutes (Pravek & Kusnirak 2002). This is faster than breakup, and so we conclude that the object is held together by non-gravitational forces (which is more striking when applied to a horse working so hard that he generates more than the Eddington luminosity for his mass).

The set of asteroids waiting for names is large, though probably not so large as the set of people who would like to have asteroids named for them. Well, wouldn't you, honestly now?? But the puzzle of the year is the set 8990 Compassion, 8991 Solidarity, and 8992 Magnanimity, specifically commemorating 11 September 2001, though the policy of the International Astronomical Union is that names "cannot honor … events of the past 100 years."

Our favorite asteroid topics of the year are, however, some dynamical items. Venus, Earth, and Mars could have Trojans, leading and following in their orbits by 120° (Brasser & Lehto 2002). Mars actually has a few and Earth one or two. Stability of an orbit is, however, no guarantee of occupancy. There are places for stable asteroid belts between Earth and Mars at 1.08–1.28 AU (Evans & Tabachnik 2002), but no one seems to live there. Conversely as it were, even smallish changes in the relative locations of Jupiter and Saturn would destabilize the Jovian Trojans (Michtchenko et al. 2001).

More and more asteroids are turning out to be orbiting pairs, as predicted a couple of paragraphs back. The 16.5 hour light curve of 90 Antipole (Michalowski et al. 2001) is a result of the components being funny shapes, not of occultations. Indeed the shapes are sometimes so distorted that the light curves look like those of contact binary stars (W UMa's). Kaasalainen et al. (2002) discuss three cases none of whom are close friends. About 16% of a particular sample of near-Earth objects are binaries (Margot et al. 2002). The authors blame disruption in planetary encounters rather than actual collusions.

The asteroid 1998ww31 was the first binary in the Kuiper Belt when it was reported (Veilleti et al. 2002). These are apparently also common, though you will have to wait till next year for the official theory paper on formation mechanisms, which appeared after 30 September. A large number of papers dealt with the range and distribution of asteroid colors and their interpretation in terms of surface composition and tatteredness. Jewitt & Lu (2001) mention ices and olivines as typical surfaces, and Hainaut & Delsanti (2002) conclude that there is no systematic difference among KBOs, Plutinos, and Centaurs. But the most outré facts about these scraps of ice and rock from the year are (*a*) that Cubewanos are so called from the first KBO, 1992QB$_1$ and (*b*) that an observer looking from outside the solar system would find that our most conspicuous extended feature is the KBO dust disk, as seen by *Pioneers 10* and *11* as they went by (Landgraf et al. 2002).

11.2.5. Comets: Now You See It, Now You Don't

Maria Mitchell saw a comet in 1847, and Hoffleit (2001) thinks that the upcoming *James Webb Space Telescope* might be able to recover it. We feel that GTO time should definitely be reserved for Dorrit to carry out this search! The sungrazing comets seen in recent years by *SOHO* all came from a single breakup event (Sekanina 2002). The little *SOHO* ones all vanish at perihelion, while some of the large sungrazers found earlier from the ground survive (e.g., C/1882R1). They can be traced back into pre-telescopic times in Chinese records (Strom 2002), and were typically seen during the season, June to October, when the Kreutz (1891) orbit family to which they belong was above the horizon in daylight. There was, perhaps even one sungrazer in the year 4 B.C.E. according to Hasegawa & Nakano (2001) who inevitably put it forward as a candidate for the Laser of Bethlehem (Signmondi 2001 on Mira).

Apparently we (and Edmond) are lucky to have seen Comet Halley, since it comes from the Oort cloud (Nurmi et al. 2002), and most comets that set out to do this are disrupted en route (Levinson et al. 2002b). If they were not, we would see about 1000 dormant ones rather than the 11 known.

11.2.6. Meteorites

Meteorites currently offer the clearest window on two important solar system issues (and you will be able to deduce that all the other windows must have been smeared with lampblack). First of these is the question of how far organic chemistry advanced toward complex, pre-biotic molecules in non-terrestrial contexts (for which Mars may some day also provide some answers). One of the most faithful sources of new molecules, Murchison, this year yielded up an assortment of sugars and related compounds (Cooper et al. 2001). The only one whose name we could spell is dihydroxyacetone, but there are also some sugar alcohols and three types of sugar acids (Sephton 2001) responsible, presumably, for the three types of cavities on cometary teeth.

Second is the question of how much solid material ("pre solar grains") survived intact from interstellar grains to meteoritic grains without melting or vaporization and mixing into the gaseous protoplanetary nebula. At least some, with, say Hoppe & Besmehn (2002), V^{49} (half life 330 days), so that its daughter Ti^{49} is correlated with V^{51}, in silicon carbide grains from, again, Murchison. We finally gave up counting new extinct radioactivities like this, but you should plan to take off your shoes. The nanodiamonds, on the other hand, were probably made inside the solar system (Dai et al. 2002). The isotopes of Mo are even more complicated, but their over and under-representations in various meteorite types sound more like separation of the *r*, *s*, and *p* process components (that is, pre-solar grains) than like mass segregation in the nascent solar system (Dauphas et al. 2002).

11.2.7. Meteors

Apart from the atoms of the solar wind (§ 2.8) the smallest solar system particles we interact with are the meteors, most of which vaporize in the air. Where do they come from? As a rule, comets and asteroids, for instance the 1998 Bootids from the 1925 perihelion passage of comet 7P/Pons-Winnecke, since which they have been moving at 10–20 m/sec (Asher & Emel'yanenko 2002). The larger departure velocities of the Lyrid particles, 25–150 m/sec, correspond to the escape velocity from a small asteroid (Arter & Williams 2002). But, lest you should think the issue is closed, Meisel et al. (2002) have revisited the case for interstellar origins for meteors seen as reflectors of Arecibo radar waves. They suggest a source in the supernova that made Geminga.

Looking inward rather than outward, we are inclined to suspect that the place of origin of the Leonids with a spectral feature due to bacteria (Wickramasinghe & Hoyle 2001) was cloud cuckoo land. Hoping in turn to be able to tell you where that is, we consulted our *Oxford Companion to English Literature*, and were told "see Nephelococcygia." But the English-speaking tour doesn't stop there.

11.3. Janet from Earth, or, Stationary at the Center of the Universe

"Are you tanned from the Sun?" a friend of ours used to ask, and, receiving the expected answer, "Yes," would respond, "Hi! I'm Janet from Earth." Almost this Ptolemaic we must be, because the notebooks this year picked out more than 80 Earth-related items, very few of which can really be described as of astronomical importance or "Earth as a planet." But we love every hair on their fuzzy little heads, and so will start with the ones that conceivably belong here and keep going until the phone rings.

One genuinely important thing Earth can do is act as a prototype for the appearance from a distance of a planet with chemically based life. The light we reflect (sent back again to us by the Moon) shows features due to O_3, O_2, H_2O) and, found at last after many efforts, enhanced reflectivity at wavelengths longer than an edge at 7300 Å, due to chlorophyll (Wolf et al. 2002).

Just how the Earth has managed to remain habitable as the Sun has brightened about 30% remains something of a puzzle. Kasting & Siefert (2002) suggest methane, a more powerful greenhouse gas than CO_2, produced by early anaerobic bacteria as partial compensation for the faint early Sun.

The climate has changed on many time scales and for many reasons, some of them driven by the Sun (Bond et al. 2001a on a possible 1500 year period that includes the Maunder minimum; Shindell et al. 2001). But, it seems that the terrestrial response on all time scales from Gyr down to the 11 year activity cycle, in the form of feedback and other sources of variability, is always as large or larger than the solar forcing (Rind 2002). There were more than a dozen other papers on global change and such, every one of which could get us in trouble with somebody, but here are two that are worth it. (*a*) If things keep going the way they are, there will be an ice-free Northwest Passage, for which the navigators of the heroic age searched heroically, in another 50 years (Brass 2002), and (*b*) "When lilacs last in the dooryard bloomed" it was indeed a smidge less than a year ago. Fitter & Fitter (2002) report an average of 4.5 days earlier flowering over 20 years, averaged over 385 "plant species" (now why did they leave out the flowering turtles and other animals?). But this also has a component from the Vernal equinox coming a bit earlier through each century because of our leap year rules (Sagarin 2001).

What else has been changing? Well, the Earth's moment of intertia had been dropping for (at least) the past 25 years, due to post-glacial rebound raising land levels at high latitude. But it started increasing again in 1998 for reasons that are not understood (Cox & Chao 2002). Light pollution has also been increasing, for reasons that are only too well understood. Two-thirds of the world's population can no longer see the Milky Way from home (even after going outdoors; Cinzano et al. 2001). The darkest remaining places are Liberia, the Seychelles, and the Central African Republic, though the Norfolk Islands, Mayotte, and the Malvinas aren't bad. The Czech Republic has been the first to try to do something about this on a national scale, and beginning in June 2002, will supposedly impose a fine of 3000 Euros for unshielded lights (Anonymous 2002).

The Earth was a gamma-ray source. Between 1991 and 2000, BATSE reported 78 bursts coming from below rather than above. Fargion (2002) suggests that the radiation was due to showers of tauons, secondary to the impact of ultrahigh energy

(PeV) neutrinos and antineutrinos on the upper atmosphere. Some feel for the weakness of these events can be gleaned by realizing that, at a distance of a few hundred miles from the satellite, they crossed the same thresholds as real GRBs at cosmological distances.

Humans are still evolving. Diamond (2002) concludes that the dominance of agriculture has gradually made West Asians and Europeans less prone to carbohydrate-induced diabetes than are Native Americans, Africans, etc. Has there been enough time? Yes: 4500 years = 150 generations, and a 15% disadvantage can lower the incidence of a dominant allele from 93% to 18% in that number of steps. The classic example is the blackening and whitening with the coming and going of coal fire dust of peppered moths in England, And yes, this really did happen (Grant 2002).

Birthday stars? Neither the International Astronomical Union or the Astronomical Society of the Pacific (which used to sell craters on Mercury) will sell you a star, but they have no objection to your developing a fondness for a star for which the light we now see left the year you were born. Farinalli (2001) provides a starter list, but with three caveats: (*a*) the error bars are less than 10% only for those within 20 pc, (*b*) you had better not be over 70 (we are currently thinking about it), and (*c*) it takes a moment (even using all the areas of our brain; Park et al. 2002b) to figure out in what sense the list will become obsolete. Never, if like Jack Benny, you intend to remain 39 forever. But within the year otherwise, though you can move from star to star till you reach 70 (after all, certain statistics of public health consider that "years of potential life lost" to various causes pertain only to years before 65).

The place of scientists in the human family. We apparently come from fairly high up the food chain. In a Danish sample, more than 40% of scientists had Class 1 fathers, compared to 5% of the total population (Andersen 2002). Only the lawyers score higher. The main effect cuts in at the level of access to high quality university education. Women come from somewhat higher classes, in the sense of having a larger fraction of fathers who are themselves university graduates in each age group, in a Croatian sample (Prpic 2002). The obvious explanation is that a family doesn't systematically choose to educate its daughters unless it is doing rather well. One result is that "there are more women percentage wise in the Loya Jirga than in the US National Academy of Sciences." (Geller 2002). The ones who make it, however, seem to be extraordinarily well behaved (Gould 2002 on Carolyn Herschel and Mary Fairfax Greig Somerville) and for a long time as well. Herschel's dates were 1750–1848 and Somerville's 1780–1872. Compare, say, Werner Heisenberg on both axes.

Some other of our favorite animals, besides scientists, include (*a*) Armadillos, who sleep 17 hours a day and dream for three of them (Siegel 2001). The only thing that keeps us from applying for one of their jobs is that they also get leprosy. (*b*) Crocodiles can sense their prey in the dark with pressure receptors on their faces that are sensitive to wiggles in the water/air surface when the face is halfway out (Soares 2002). The more water-adapted author can remember finding the feel of the water/air surface on her face exceedingly unpleasant during childhood swimming lessons. But she also eventually got used to the fact that marzipan does not taste nearly as good as it looks. (*c*) Ancestral turtles had horns (Gaffney et al. 2001). And you will surely have seen enough cartoons about tortoise/hare races to understand why they needed them.

Here is a collection of terrestrial extrema, mostly firsts and lasts.

- Ziggurats were not necessarily the first observatories (Krupp 2001).
- The first fossils in the form of 3.5 Gyr old cyanobacteria have been supported by Schopf (2002) and attacked by Brasier (2002) as non-biological. We naturally vote with the California team.
- The first eukaryotes were a more complex advance over precursor prokaryotes than multicellular creatures were over single celled ones according to their genome differences (Wood et al. 2002).
- The first land animals have been pushed back to 505 Myr B.P. (MacNaughton et al. 2002). They were amphibious arthropods a few centimeters long.
- The first eutherians (placental mammals) have been pushed back to the lower Cretaceous, 125 Myr ago (Ji et al. 2002).
- First cousins? Humans and Strepsirrhine, a primate of some sort and the closest human relative in early placental radiation. It differs from us by as much as the long-eared elephant shrew differs from the short-eared elephant shrew (Murphy et al. 2001).
- First cousins, part II. The closest relatives of the land plants (=embryophytes) fall within the charophytes, with five orders of fresh water algae (Karol et al. 2001). The only familiar units are Arabidopsis (because it was recently sequenced) and Sphagnum, because an old friend, attempting to order both address labels and a device for holding flowers in place in a vase from the same company, ended up with 1000 labels saying "Sphagnum Moss Frog."
- First life arose, perhaps, around hydrothermal vents, with a chemical energy source (Wachtershauser 2002).
- The first trichromatics (primates) became so to recognize and eat red leaves on tips of branches rather than red fruit (Lucas et al. 2002). And some species lack the third receptor in one gender much more often than the other, including, of course, humans. Humans also have more aneuploidy than any other species examined for it so far (Hunt & Hassold 2002a, 2002b). Oh. Having a triple chromosome rather than a pair. Down's syndrome is the commonest manifestation, but possibly only because triples of most other, longer chromosomes are always lethal.
- The latest oldest hominid fossil is *Sahelanthropus tchadensis* (Brunet et al. 2002). It was last alive 6–7 Myr B.P. The

name means a hominid found in the part of the Sahel now called Chad, but found by a Frenchman, to whom it is Tchad.

- The first mummies were dried and protected with conifer resins. Bitumin appears only from 700 B.C.E., though it is common in 18th dynasty historical fiction (Buckely & Evershed 2001).
- The oldest art may be engraved ochres from about 77,000 B.P. found in Blombos Cave in South Africa (Henshilwood et al. 2002).
- Evidence for the first boat takes the form of a piece of wood, with bitumen, barnacles, and rope marks, found in Kuwait near the Persian Gulf (Carter 2002). It dates from the Ubaid period (5511–5324 B.C.E.), and the age is not in question, only the boatness. What else might have those four things together? A pier, perhaps? (implying boats anyhow). The old oaken bucket that hung in the well?
- The first chocoholics were perhaps the folk who left a residue of theobromine in Mayan pottery cooking vessels from 600 B.C.E. (Hurst et al. 2002).
- The first real Americans anywhere, contrary to the poem, were probably not Peregrine White and Virginia Dare. Probably not Kennewick man either, but he was a good deal firster, and can now be studied before reburial (Bonnichsen 2002).
- The first cat clone (Shin et al. 2002) came from an egg donor named Rainbow (a calico) and a womb named Alie (a tortoiseshell, and, come to think of it, Alie is probably the name of the whole cat, like the Jack Smith classic, "a little girl with a broken leg named Euphronia."). The clone is a calico, but of a different pattern (this is known to be environmentally determined) named cc. The trouble with a kitten is that, eventually it becomes a cat. One of the on-going worries about clones is that they may become old cats before their time.
- First advantage to being old? Us 50+'s with childhood smallpox vaccinations still probably have a good deal of protection against mortality (though not morbidity) based on what happened during a 1902–03 outbreak in Liverpool (Fenner 2001). The less said about our brains the better, though Park et al. (2002b) say we (have to) use more parts of them for a given task than do younger folk. Does this include cracking boiled eggs on one's head?
- The last Norseman in Greenland consumed food that was 50%–80% of marine derivation for the last hundred years. That is, they approached an Inuit diet (Arneborg et al. 2002, well the article said "Eskimo," but we know which side our schmeur brot is schmeured on) and the cause of their failure to thrive as the climate turned colder was not their unwillingness to try seal, fish, and so forth but, apparently, lack of skill at gathering enough. This contradicts something many of us have been told since early childhood.

Puzzles enough, but there is hope of eventually understanding all these things, for human life expectancy has been increasing at a steady 2.5 yr/decade since 1840, with the forecasters always lagging behind (Oeppen & Vaupel 2002). Oh, and Janet from Earth turned up at our 40th high school class reunion a couple of years ago and illustrated another well-known demographic trend that must surely be warring with the previous one. Her body-mass-index is now about 30. Perhaps she is training for the astronaut program. Swain et al. (2002) note that NASA now has only large size space suits available.

"Hello?" "Oh, Janet, hi! How are you?"

12. THE UNIVERSE IN A NUT CASE

The four star locales on this second to last part of the tour are undoubtedly the ones in baryonland (§ 12.6), but we will first visit an assortment of quaint old villages, where you will have the opportunity to purchase typical examples of the local folk arts.

12.1. *H* and *t* and All

The median of 18 values of the Hubble constant published during the index year settled at 58 km/ sec/Mpc and the mean at 62.0, almost as steep a decline as the stock market from last year's median of 70. The high was 84 (Grainge et al. 2002, looking at the Sunyaev-Zeldovich effect in one X-ray cluster), and the low 44 (Winn et al. 2002, from the time delay in one lensed quasar). The median was hit smack on by Cardone et al. (2002, time delays in two lensed QSOs) and by Sandage (2002, Cepheid and supernova yard-sticks recalibrated on both Hubble and van den Bergh types of the host galaxies). Worth the extra fee for a stop-over is $H = 55$ km/sec/Mpc, offered by Arp (2002b) as the value found by the *HST* Key Project team, after correction of a component due to non-cosmological redshifts in their data.

How much time we have left to contemplate these things remains uncertain (not forever if the dark energy responsible for current acceleration should decay away), but there has been a good deal of convergence on the time elapsed so far. A couple of "oldest globular clusters" have celebrated their 12–13 Gyr and 13.5 Gyr birthdays (Yi et al. 2001 with Yale isochrones; VandenBerg et al. 2002 with Victoria isochrones). Two elderly halo stars agree perhaps a bit better than they should, given the large error bars, at 13.8 and 14.0 Gyr (Cowan et al. 2002; Hill et al. 2002). Both were dated from the very small amounts of uranium and thorium lingering in their atmospheres. These are, or should be, lower limits to the actual age of the universe, which did not start forming 0.85 $M_{\odot}$ stars during the first 3 minutes.

We cannot allow much time for lingering by the wayside, however, because the most recent round of analyses of acoustic peaks in the cosmic microwave background (plus the assumption of flatness, limits on H, and a glance at distant supernovae) has produced total cosmic ages of 14.0 ± 0.5 (Knox et al. 2001) and 13.2 ± 1.0 Gyr (Ferreras et al. 2001).

12.2. Global Numbers

The universe is slightly flatter than Kansas, enabling us to cover this territory at high speed, the more so as it has now been flat in more or less the same way, with one-third positive pressure stuff (mostly dark) and two-thirds negative pressure stuff (even darker) for at least 5 years. The selection of data from CMB measurements, large scale structure, and distant supernovae carried by Bridle and Sons, sorry, Bridle et al. (2001) should be wide enough to please even the most discerning customer. The remaining paragraphs of this subsection address disagreements, discrepancies, and doubts.

Numbers for the density of matter (in all forms) found from clusters of galaxies are often somewhat smaller than those from more global considerations, like cosmic shear and the CMB, and this may (or may not) constitute a problem (Bahcall & Comerford 2002).

The masses of some clusters can be measured by three different methods, velocity dispersions (one-dimensional), weak gravitational lensing of background galaxies, and X-ray emission. There is not complete agreement. For RX J1347−1145 Cohen & Kneib (2002) conclude that the virial mass is the smallest, the X-ray mass is the largest, and lensing comes in the middle. They suggest that the cause might be a merger in progress, which has shocked the gas (making it hotter than it ought to be), while the two separate velocity dispersions have not yet had a chance to discover that they now belong to a single more massive cluster. This sort of thing probably does not deserve to be called “a problem.” It may, however, mean that one cannot use agreement of lensing masses with others as a confirmation of General Relativity in comparison to some other theory of gravity with the same weak-field limit. Remember that Newtonian gravity also bends light, by half the GR angle.

Not every analysis of every conceivable data set yields the common numbers. Gray et al. (2002) reported an upper limit of 0.1 to the total matter density Ω_m, based on X-ray and weak lensing data for three clusters. The opposite divergence, to $\Omega_m \approx 1$, is a bit more wide spread. Often the suggestion is only that a closed universe is just as good as dark matter plus a cosmological constant, not that it is better, e.g., Inskip et al. (2002, the K-magnitude, redshift relation for strong radio galaxies), and Hoyle et al. (2002, the clustering along and perpendicular to the line of sight of QSOs in the 2dF survey).

An upper limit to Ω_λ of 0.74 is not actually discordant, but getting there. It comes from the absence of an integrated Sachs-Wolfe (1967) effect in the correlation of CMB intensity with large scale structure (Boughn & Crittenden 2002). And no, we won’t be such negligent guides as to insist that you make the side trip on your own. Sachs and Wolfe pointed out that, in a lumpy universe, a photon gains energy sliding down into a potential well and loses it climbing out again. The loss exceeds the gain if the well is getting deeper (non-linear structure growth), but the gain exceeds the loss if the well is getting shallower because the universe is expanding and growth of the perturbations hasn’t yet started on that scale. Boughn and Crittenden point out that the latter of these should yield a correlation between observed large scale CMB fluctuations and the distribution of distant radio galaxies, which is not seen.

Uncited here are something like 35 papers dealing with how you actually measure mass to light ratio for galaxies, clusters, and all, apart, that is, from assuming fixed M/L and using the cosmic luminosity density of $2.18 \times 10^8\ h\ L_\odot/\mathrm{Mpc}^3$ (Cross & Driver 2002). This is another number of remarkable stability, even at the level of the 15% error bars invariably assigned to such quantities, and the index 2002 value would not be disowned by Felten (1985) or even Oort (1958).

Finally, the implications of $q < 0$ are going to take a while to sink into our conscious and subconscious minds. The equations relating time, apparent magnitude, and angular diameter to redshifts are, of course, more complex (Gudmundsson & Bjornsson 2002). But, in addition, no message that we send now to a galaxy with a redshift larger than 1.7–1.8 will ever arrive, unless the dark energy decays away (Loeb 2002b). We will never see a galaxy with $z = 5$ at any age larger than 6 Gyr. And, a few more Hubble times into the future, we will be surrounded by a stationary event horizon at 5.1 Gpc with only our own supercluster inside. The obvious implication is that you should do cosmology now, while it is still possible.

12.3. Very Large Scale Structure and Streaming

Something about this topic always reminds us of Great Aunt Mary (1878–1974), perhaps because she knew how to get lumps out of gravy—add a bit of very cold water and stir like mad. She also knew how to say “no thank you” in the right tone of voice to get a second piece of cake anyhow. The arrangement of the subsection is, roughly, from the very largest scales downward and from the present back to times predating even Great Aunt Mary.

The cosmic dipole is not really a feature of the universe at all, but a reflection of our motion at several hundred km/sec relative to the ensemble of electrons that last scattered it. This same motion should show up as a dipole in any other distant background, for instance the distribution of radio galaxies. The expected asymmetry has now been seen (Blake & Wall 2002) as a 1% enhancement in the number of sources from the VLA survey in the direction in the sky where we are headed (data from Condon et al. 1998). The 1% sounds larger than the 10^{-3} dipole in the 3 K radiation. The difference arises because the intrinsic number of radio sources is a steeply rising function of flux density, so that a small Doppler boost in received power brings lots more sources into your survey (Ellis & Baldwin 1984).

This is not a good year to report on whether our peculiar motion is caused by the tug of the Great Attractor but only to note that more stuff continues to be found in the GA volume when one works harder (Woudt & Kraan-Korteweg 2001) or at longer wavelength (Vauglin et al. 2002) and so penetrates better through the obscuration of the galactic plane. The radio sources are not themselves randomly distributed on the sky if, again, you look deep enough. There are 134 in the Shapley concentration, more or less the same part of the sky as the Great Attractor (Venturi et al. 2002). Should we expect to see additional images of it in other directions in the sky? Only if the topology of the universe is complicated. No positive claims this year, but limits are less good in flat space than in other cases (Sokolov 2002).

What is the largest scale on which statistically significant clustering occurs? At least 400 h^{-1} Mpc for $z = 1.4$ QSOs, say Hoyle et al. (2002). This is not unexpected in a standard Λ-CDM simulation (Petry et al. 2002). The QSOs from 2dF behave the same way (Roukema et al. 2002).

The lumpiness of the present universe around the average conditions of the previous subsection can be described by a couple of numbers (on sale at Wild and Woolley in Market Square). One is called σ_8 and is the RMS value of density fluctuations (though often measured in light) on a scale of 8 h^{-1} Mpc. It made its debut in the shops about a decade ago with a value of unity and has crept down a bit since. The smallest numbers we saw were 0.65 (Atrio-Barandela et al. 2001) and 0.7 from the *IRAS* Point Source Catalog (Plionis & Basilakos 2001), and the largest 0.94 from cosmic shear in *HST* images (Refregier et al. 2002). The error bars of largest and smallest overlap, though the latter pertains to mass and the former to light. Cosmic shear is another name for weak gravitational lensing by structures larger than superclusters of galaxies.

The second descriptor is called bias, the extent to which $\Delta L/L$ fluctuations exceed $\Delta\rho/\rho$ fluctuations. In the days before non-baryonic dark matter (this means before 1985, not before 15,000,000,000 B.C.E.), it needed to be fairly large to account for visible galaxies being as clustered as they are. No longer much needed at the present time (i.e., $b \approx 1$), bias hangs around from the days ($z = 2$–3) when it was larger ($b = 2$–3) and more useful (Lahav et al. 2002; Arnouts et al. 2002). Jing et al. (2002) have asked it to take on the job of accounting for the very small value of the local pair-wise velocity dispersion, and Kopylov & Kopylova (2002) would like to enlist bias for the task of preventing excess expansion in voids by making them not very underdense in matter, despite the dearth of visible galaxies. An adjustable parameter seems a poor tool for making cosmic repairs, but who knows.

How does clustering change with redshift? Well, in a hierarchical universe, the general idea is that any given sort of entity capable of clustering gets to be more so as time goes on, but, when you look back, you see the most massive, most clustered halos preferentially, and these two effects tend to cancel, so that, for instance, normal galaxies now look like quasars then (Hoyle et al. 2002). The increase with time for a given sort of object shows up for SDSS galaxies (Dodelson et al. 2002) and even the puny clouds of the Lyman alpha forest (Scott et al. 2002).

"Now" is both $z = 0$ and 2002, and results published in the latter to describe the former often confirmed what we all already thought. The slope of the power density spectrum $\xi(r)$ is -1.75 (Zehavi et al. 2002, SDSS again). Contrary to what you might expect, there are no breaks in the power law either at the length scale where structure has begun to grow (linear to non-linear) or on the length scale that has completed equilibration (non-linear to viralized) according to Hamilton & Tegmark (2002, using *IRAS* galaxies). If you look at subsamples, the more strongly clustered galaxies are redder, brighter, and have older stars (Zehavi et al.; Daddi et al. 2002; Firth et al. 2002; Norberg et al. 2002).

If you would like to compare observations with theory, the good news is that, not only do different optical surveys agree on the clustering amplitude (Gaztañaga 2002), but so do optical and X-ray samples, on scales from clusters to superclusters (Tago et al. 2002; Einasto et al. 2002; Cruddace et al. 2002 on the Local Supercluster). The bad news is that, for a given set of cosmological numbers and initial conditions, *N*-body simulations make clean, unique predictions only for the distribution of dark matter halos, but not for the visible galaxies, with their tiresome habit of depending upon dissipation, feedback from stars and supernovae, and so forth (Zheng et al. 2002 and several talks at the barely out-of-period October Workshop; Holt & Reynolds 2003).

The dominant topology of the large scale structure remains bubble or sponge-like, made of sheets and filaments with dense clusters at their intersections and voids in between. The average void size is about 30 h^{-1} Mpc (Hoyle & Vogeley 2002) or perhaps 20 h^{-1} Mpc, but the latter was published in a somewhat smaller journal (Plionis & Basilakos 2002b). The voids with density deficits (measured as usual in light) of at least $\Delta L/L = -0.94 \pm 0.02$ fill about 40% of the universe, and prolate ones are about as common as oblate ones.

Not everything avoids voids, perhaps. We were at least as surprised as the author by a study of Lyman alpha forest clouds at modest redshift that found they were just as common in voids as anyplace else (Manning 2002), unless perhaps some overwhelming selection effect has made the previous cosmic number density for these pertain only to voids?! More plausible are deductions that there are some Lyman alpha clouds in voids, but not most of them (McLin et al. 2002), and they occupy the same filamentary structures that everybody else does (Penton et al. 2002). As the default option, we will vote for the clouds not only being distributed like other stuff, but for that distribution being nicely fit by Λ-CDM considerations (Phillips et al. 2001a). But if you don't like that, you can vote for intermittency (Pando et al. 2002). Meaning? Well, roughly that that forest clouds are indeed clustered, but the distribution of power in them (that is, in the fraction of light transmitted) is spiky, concentrated in only a few modes, not a smooth power law. This is not "predicted" by any model.

Velocity deviations from uniform Hubble expansion also show large scale structure. Time was when the database would have tolerated anything from 300 to 1000 km/sec as the characteristic deviation. Improvement has come mostly in distance indicators and has squeezed this down to 325–375 km/sec for the pairwise velocity distribution (Landy 2002). Some numbers are smaller (at most 35 km/sec for the M81 group, Karachentsev et al. 2002; and 72 km/sec for Coma, Bernardi et al. 2002), and some of the non-local ones are bigger (Zehavi et al. 2002), but we think that is how power laws are supposed to work. Somehow the process of galaxy formation knew how to do it this way, perhaps with some help from our old friend bias (Jing et al. 2002) and/or from dark energy (Baryshev et al. 2001).

Is the large scale structure periodic or quantized? Clyde Cowan (1969), better known for the discovery of the neutrino, though he did not live to win a Nobel Prize for it, thought so. Broadhurst et al. (1992) reported a pencil-beam survey with apparent periodic structure and a cell size of 120 h^{-1} Mpc. A similar sort of cell size continues to turn up in much less restrictive sorts of surveys (Tago et al. 2002; Einasto et al. 2002), and we suppose there must be something in it (besides voids inside the cell wells). It is much harder to develop enthusiasm for redshifts quantized in intervals of $\ln(1+z) = 0.089$ (Ryabinkov et al. 2001; Roberts 2002), and we are inclined to wish that Basu (2001) had chosen to publish in some more widely read journal. He concludes that the “0.089” effect in three recent samples arises from the numbers and strengths of the emission lines available for measurement and how they move through the V and B color bands, changing $B-V$ as they go. The conclusion is the more notable because the author has, in the past, been a supporter of some non-cosmological redshift effects.

12.4. The Photon Haze: Background Radiations

The background of the year for 2002 is the one in visible light. Just a century after Simon Newcomb recognized that the sky from Earth is never dark, Bernstein et al. (2002b) have succeeded in subtracting off the contributions from atmosphere, zodiacal light, and galactic emission and looking between other galaxies to see the diffuse part, which, they say, is larger than the flux in resolved galaxies by a factor of 2–3. Their data were collected at 2000, 5550, and 8140 Å, but they report a number, 100 ± 10 nW/m^2 sr, for the full range from 0.1 to 100 μm. You will recall that the light from resolved galaxies amounts to $2.0\text{–}2.5 \times 10^8 L_\odot h^{-1}/\text{Mpc}^3$. Step one is to convert one set of units to the other and verify that factor of 2–3. Yes, the more diffuse author did it, and all is well, but by such an inept method (via local energy density if both things had been happening over a Hubble time and a Hubble volume) that she is ashamed to reproduce the calculation.

Bernstein et al. (2002b) conclude that if all of the photons have come from nuclear reactions in stars, then something like one-third of all the baryons have been in stars at some time, and that black hole accretion has not been sufficient to make much difference. One-third is a good bit larger than the 5%–10% of the baryons being in stars that we suggest to you elsewhere, but it is actually reassuring when you consider that the number could have come out 10^{-3} (odd) or 10^{+3} (much odder). The luminosity density is obviously a function of time or redshift, but there is some compensation between numbers of galaxies and their star formation rates, so that L^* (the typical galaxy brightness in a Schechter luminosity function) doesn’t change much between $z = 2$ and 5 (Nagamine et al. 2001).

The ultraviolet background is the only one we can measure directly at $z \neq 0$, because of its effect on the ionization level of intergalactic gas clouds near QSOs compared to the effect of the ionizing radiation from the QSO itself. The larger the intergalactic background, the closer you have to be to a particular QSO for it to dominate what you see. The phenomenon is called the proximity effect (meaning fewer absorption clouds at z close to the QSO emission z), and it can all be made to sound yet more befuddling by telling you that the main current issue is whether the sum of all the other QSOs at a given z adds up to the UV background seen by each one, or do you need input from very hot stars as well? The answer is maybe (Pascarelle et al. 2001; Telfer et al. 2002; Giallongo et al. 2002). The most distant known QSO ($z = 6.28$) shows a proximity effect and has ionized its surrounding to 23 h^{-1} Mpc (Pentericci et al. 2002). Since reionization (below) was soaking up nearly all of everybody’s photons just then, there can’t have been much competition. Our very own local UV background is nearly all due to scattering of galactic star light by dust, and the extragalactic part is only about 5% of the total (Schiminovich et al. 2001), mostly to be seen at high galactic latitude (Henry 2002).

For X-ray and gamma-ray backgrounds, you can reasonably also ask “is it mostly AGNs or something else?” Among the soft and hard X-rays, the answers “mostly QSOs and other AGNs” and “mostly resolved or will be by the next mission” are about as old as this series and remain in place in 2002. So do the caveats (*a*) that the largest uncertainty is in the absolute value of the background flux (Campana et al. 2001) and (*b*) that the source population is not the same mix of types that we can easily find nearby but has harder average spectra (Nandra et al. 2002, picking out, by the way, the first and last of a dozen papers on this topic during the year). But nothing is ever quite so simple as you hope. Of the non-AGN, soft part (0.02-1.0 keV) of the background, a very large fraction is actually in emission lines of O VII, O VIII, and other ionized species seen by a rocket-borne spectrograph (McCammon et al. 2002). The implication is that less than 34% of the 0.75 keV flux is diffuse, extragalactic bremsstrahlung from the intermediate temperature intergalactic material of the next subsection. A certain class of self-interacting dark matter is also ruled out, because the particles would have scattered off the 25 and 60 eV detectors on the rocket and looked like X-ray counts.

QSOs vs. stars is also the competition for the mid-infrared (e.g., 15 μm) background observed and partly resolved by *ISO*. Eighty percent or more from star bursts is the majority view (Elbaz et al. 2002; Franceschini et al. 2002), but the obscured QSOs needed for X-rays cannot help but have some of the obscured flux come out as IR. Since we never quite know where to draw the line between far-IR and submillimeter, it is lucky that the latter also comes mostly from starlight reprocessed in dusty, luminous galaxies at moderate redshift (Smail et al. 2002).

This leaves only the radio regime, to which local galaxies contribute $1.53 \pm 0.07 \times 10^{19}$ W/Hz-Mpc^3 at 1.4 GHz (Condon et al. 2002), and the star forming galaxies and AGNs (in roughly equal measure) can be made to add up to the antenna temperature of 37 ± 8 K at 178 MHz (Dwek & Barker 2002). If your dominant reaction is, “Oh, for heaven sake. How much is either of those in Euros?”, we sympathize, but were even more struck by the fact that the latter data point has apparently not been improved since Bridle (1967). If you want to tackle the units, remember νF_ν is a good first guess at converting W/Hz to W, and that antenna temperature means that the receiver is taking in as many W/Hz/m^2/sr as it would be emitting at the same frequency if kept in equilibrium with a heat bath at that temperature. Or ask a radio astronomer, possibly one who was already collecting data in 1967.

Stars between the galaxies might be supposed to be another source of diffuse photons in various wavebands. There are such stars, but only within clusters. If your tour travels at a typical galaxy escape speed, 300 km/sec, you cannot get out of a cluster in a Hubble time. Thus one is not surprised that the classes of stars found between galaxies in clusters are long-lived ones like planetary nebulae (Ciardullo et al. 2002) and red and asymptotic giants (Durrell et al. 2002). The integrated light from these could be comparable with that from (old) stars still inside their galaxies (Arnaboldi et al. 2002).

12.5. Galactic and Cosmic Magnetic Fields

Where do large scale magnetic fields (galaxies to clusters and beyond) come from? Along with “flat lux” during the epoch of creation was Fritz Zwicky’s (not entirely unserious) answer. We caught a few votes for various sorts of primordial or primeval magnetic fields this year (Dolag et al. 2001; Vachaspati 2002), with two mechanisms suggested for making them—inhomogenous lepton number in the early universe (Dolgov & Grasso 2002) and non-zero photon mass during the inflationary epoch (Prokopec et al. 2002).

The alternative for getting started is dynamo fields in a few powerful, compact sources which blow out magnetic flux along with gas. Gamma-ray bursters might be a good choice, says Gruzinov (2001). Zweibel (2002) prefers old radio galaxies. Notice that such things don’t have to provide much field, though whether 10^{-13} G is needed or 10^{-19} enough has not perhaps been sorted out. The seed gets amplified by rotation in disk galaxies, turbulence in clusters, and so forth. Hanasz et al. (2002) discuss one example of the sorts of processes that can do this. And no, we don’t know where the currents go.

On the cluster and supercluster scale, there is general agreement on the existence of some pervasive field of microgauss amplitude, but whether it is 2 μG (Vallee et al. 2002; Gruber & Rephaeli 2002) or larger by an order of magnitude (Eilek & Owen 2002) remains under discussion. Taylor et al. (2002) say 10–40 μG in cooling flow clusters and 2–10 μG in others.

On smaller scales, a few papers carried surprising results, and if you know more about these topics than does the more dipolar author, please feel free to change the advice offered on whether the information should go on your hard disk. (*a*) First detection of a magnetic field in an O-type stars, about 1100 G for θ^1 Ori C, it is said to be a fossil field, the youngest one known, and the star to be a high mass analog of Ap stars (Donati et al. 2002), (*b*) magnetic field as the key organizational element in the gas arms of spirals (Lou et al. 2002), and (*c*) the solar magnetic field as a fossil with interior strength 2 MG and the 22 year cycle as its nutation frequency (Isaak & Isaak 2002). One of the implications is that flux tubes bring up and eject nuclearly processed material from the core. The same should happen in other more evolved stars and affect nucleosynthesis scenarios. Our votes were (*a*) yes, (*b*) maybe (it is anyhow not a new idea, though the person most often associated with it is not cited, Woltjer 1962), and (*c*) perhaps not, though again the idea has old roots (Dicke 1978).

12.6. The Baryons Did It

Did what? Well, just about everything in §§ 1–11 and 13, but also, in the cosmological context, they (1) polarized the microwave background, (2) illuminated the first gravitationally bound objects in the universe, and (3) gradually came out from hiding at $z = 0$. All three are at least partial answers to questions that have been around a long time.

12.6.1. Polarization of the 3 K *Radiation*

Anisotropies of many sorts in the early universe will polarize the cosmic background radiation because of non-uniform scattering. That this would be an important cosmological probe on beyond the temperature fluctuations and spectrum of the radiation seems to have been pointed out first by Rees (1968). We entered the year with an upper limit (Keating et al. 2001) and the authors’ promise that the next iteration would reach the level expected to accompany the known intensity fluctuations. And we left the year with this having been accomplished by the south polar installation called DASI (Carlstrom 2002) though not quite out in the archival literature. DASI is pronounced like “daisy” in case you weren’t sure.

As expected, the polarization (meaning, for instance, the RMS difference of the *U* and *V* Stokes parameters from place to place) is about 10% of the RMS differences in absolute flux on the same angular scales. The *Microwave Anisotropy Probe* (*MAP*) may or may not have added much to this result by the time these words see light of print. Truly new information, for instance the ratio of vector to scalar components of the polarization (a test of inflation), will probably have to wait for the *Planck* satellite 5–10 years downstream.

Measurers of the CMB have been so productive of late that the previous round of results, saying that all is well with the flux anisotropies on various scales, are nearly contemporaneous with the polarization result: De Bernardis et al. (2002) on agreement between DASI and BOOMERANG, Leitch et al. (2002), Pryke et al. (2002), Halverson et al. (2002), Santos et al. (2002), an independent look at some of the MAXIMA data.

12.6.2. Reionization, the First Objects, and the End of the Dark Ages

The early universe was hot and fully ionized, but cooled below 3000 K near a redshift of 1200, so that protons and electrons combined to make hydrogen atoms. Everybody calls this "recombination" though there is no evidence that the atoms had ever been neutral before. Some time between then and $z = 1.95$, nearly all the hydrogen atoms got out of the way of our sight line to 3C 9, so that its continuum flux at rest wavelengths shorter than 1216 Å could reach Earth in 1965 (Schmidt 1966; Gunn & Peterson 1965; Scheuer 1965; Shklovski 1964, not quite a prediction, because he was making the point in connection with other lines at longer wavelengths). At the time, this was widely perceived as evidence for a very efficient process of galaxy formation, though Gunn and Peterson noted that, if everybody had a 3C 273 as close as ours, a critical density in gas could probably be kept ionized. As calculations of galaxy formation became more elaborate (and less efficient), getting the atoms out of the way came to be described as reionization (with the "re" deserved this time), and, ever since, a few people at first, and then many have been looking for the epoch at which it happened.

The He II got out of the way in Ap94 (§ 5.9), or at $z = 3$–4, depending on your point of view (Sokasian et al. 2002; Theuns et al. 2002, and, we regret to note, two other rather similar papers by the same group in the same year).

And in 2002, or at $z \approx 6$, the hydrogen finally got out of the way. Djorgovski et al. (2001a) described the spectrum of a $z = 5.73$ QSO in which there are still some windows of transparency shortward of Lyman alpha. Fan et al. (2001) and Becker et al. (2001) present a set of three QSOs from the Sloan Digital Sky Survey at $z = 5.82$, 5.99, and 6.28. The most distant has well and truly faced an opaque intergalactic medium in its immediate vicinity. The authors remark that they are eager to explore additional sight lines, since reionization could have been quite non-uniform, with contributions from both QSOs and star-forming galaxies. If the redshift $z = 6.56$ is correct for the galaxy discussed by Hu et al. (2002) then, they point out, that bit of space was already transparent.

Immediately post-reionization, hydrogen is about 1% neutral and the Lyman alpha mean free path is about 8 Mpc (comoving; Fan et al. 2002b). One feels vaguely that this ought to bear some relation to that length scale being the one on which the RMS density fluctuations are now about unity. It probably doesn't.

The ionized gas will be a good deal hotter than the neutral gas was and therefore much less inclined to fall into relatively shallow potential wells of dark matter. This cuts off the formation of dwarf galaxies near $z = 6$ (Cen & McDonald 2002) so that they are much less numerous than their potential halos. Unless otherwise instructed, we are happy to take this as the definitive answer to "where are the missing satellites," the more so as it is advocated in half a dozen other papers from the year (e.g., Somerville 2002). If reionization is the right answer, then the poor empty halos ought still to be floating around inside the halos of bigger galaxies and clusters. This seems to be true within the Milky Way (Newberg et al. 2002), M31 (Ferguson et al. 2002), and some galaxies that lens their backgrounds (Dalal & Kochanek 2002). In case you have forgotten the question to which "no baryons" is the answer, standard Λ-CDM simulations predict that the ratio of little galaxies to big ones should be 100:1 or more. The numbers found, e.g., Trentham & Tully (2002, reporting $N(L)$ in five groups) are about 10% of this.

What reionized the baryons? Photons shortward of 912 Å, of course. What makes UV photons? Well, various baryon processes. That is, a small fraction of the material (10^{-3} or so) made stars, mostly of large mass but in smallish halos. There may also have been an early generation of gamma-ray bursters and QSOs within 10^8 years of the big bang, which would also contribute. Still under intense discussion is whether a "massive" star in this context means 10, 30, 100, 200, 1000, or $10^4\ M_\odot$ (Bromm et al. 2002) and whether a small halo is 10^6 or $10^9\ M_\odot$ (that is, a globular cluster or a dwarf galaxy; Hutchings et al. 2002). We are waiting for the single, transferrable vote before casting our ballot, but Abel et al. (2002) and Rees (2002) have a superb summary of the campaign statements if you need them.

Given the "they did it to themselves" scenario, star (etc.) formation must have started before reionization. When? Well 10 seems like a good number (Dietrich et al. 2002), especially in redshift units. Thus this slightly earlier time can be described as "the end of the dark ages," with visible photons being added to the submillimeter of the CMB then. And the radiating big stars, small galaxies, and intermediate size black holes are presumably "the first objects in the universe."

12.6.3. Baryons Lost and Found

The lower lights of Ap01 included some preliminary CMB measurements that seemed to require a higher baryon density than easily made consistent with the products of nuclear reactions in the early universe (lithium-7 and the isotopes of helium and hydrogen). The astronomical literature has a good deal of hysteresis, so that fiscal 2002 included several papers whose primary purpose was to explain (away) the gap. These were automatically deleted from our database. If you want to catch up on the ideas, lest the problem should arise again, Pettini & Bowen (2001) is a good place to start.

The present year saw only fluctuations on "how much you expect," caused by small downward revision in the best value of the primordial helium abundances to $Y_p = 0.238$ (Sauer & Jedamzik 2001; Gruenwald et al. 2002). It arose from corrections due to temperature and density fluctuations in the metal-poor H II regions from which the estimates are made and another data point in the on-going quest for a useful primordial abundance of He^3, $He^3/H = 1.1 \pm 0.2 \times 10^{-5}$ for one metal-poor H II region in the outer Milky Way (Bania et al. 2002). The number is probably an upper limit to the BBN contribution, since there would be some input from planetary nebulae. It leaves all well with the early universe (Charbonnel 2001).

So, where are all the baryons, all 4% of the closure density of them? Back at a redshifts of 3 ± 1, a plurality were in various gas clouds detectable because they introduce absorption lines in the spectra of QSOs behind them (Schaye 2001 and many papers in earlier years). And where are they now? Theorists through the year continued to assert that only a minority (25% perhaps) had condensed into stars, galaxies, and clusters, including the hot X-ray gas in rich clusters, and that most (75% perhaps) should still be in some warm-to-hot diffuse medium (Cen et al. 2001; Nath & Silk 2001; Balogh et al. 2001).

Very dilute, unprocessed gas at 10^5–10^7 K is not, however, so very easy to look for unless (*a*) its contribution to the X-ray soft background can be separated off from other sources. Bregman & Irwin (2002) say that it can, because you see a shadow in the X-ray background caused by cool gas in the edge-on spiral NGC 891, (*b*) it imposes intergalactic scintillation upon distant radio sources (Ferrara & Perna 2001, not a detection), or (*c*) the gas has acquired an admixture of heavy elements whose atoms retain some bound electrons at these temperatures. And there, waiting patiently from $z = 3$ until 2002, are a good many of the missing baryons, seen in absorption by O VIII (Fang et al. 2002) and in Kα emission from O VII and Ne IX (Nicastro et al. 2002). Some less direct lines of argument concur. Wakker et al. (2002) described confinement of the Magellanic Stream by hot gas in the Local Group, previously unknown. Savage et al. (2002) and Fang & Bryan (2001) present other aspects of the O VI gas.

Can we now say that our baryon shelf is fully stocked and no further salesmen need to bother to visit? Observationally, it might seem so, and we plan to go back to travelling in sprocket wickets and sump pumps. Valageas et al. (2002) aver, however, that yeah, a bit less than 10% each is in stars and X-ray cluster gas, as much as 38% in intergalactic gas cooler than 10^4 K (Lyman alpha absorbers and all), 38% in the warm/hot intergalactic medium (WHIM, as if the universe had only just thought of it; well, perhaps it did), but that 22% is to be found in collapsed structures that have not yet been observed, for instance cool gas in galactic halos and groups, where it would make up some part of the dark matter.

And if you would like to look for baryons much before the epoch of reionization, greatly redshifted 21 cm emission seems still to be the only game not in town. A future large ground-based installation called LOFAR has this as one of its goals.

12.7. Three for $5 with Your Amateur Cosmologist's Frequent Reader Card

Here live the ragtag, bobtail bits and pieces that always turn up somewhere in the cosmology section.

"*Distance indicators*" are used to indicate distances and should, according to a serious colleague, be distinguished from methods that actually measure distances, like parallax and non-interacting spectroscopic, eclipsing binaries. Even the binaries, however, yielded a couple of warnings during the year, one specific (that two in the LMC gave distances of 50.7 and 45.0 kpc; Fitzpatrick et al. 2002) and one generic (remember the Maine, the Alamo, and the Lutz-Kelker correction; Jerzykiewicz 2001). As for the LMC (a calibrator of Cepheids en route to many values of the Hubble constant), if you chose to read only one of about 80 discussions over the past few years, you might suppose it to be anywhere from 38.9 to 61.7 kpc away (Benedict et al. 2002). If, however, the old Maryland custom of "vote early and vote often" is suspended, we'll save our endorsement for Feast et al. (2002) who say 52.5 kpc, after having looked, for many years, at both Cepheids and Miras there. Lingering around the Local Group just a bit longer, the red giant and clump stars in M33 are 914 kpc away, while the Cepheids are closer at 797 kpc (Kim et al. 2002).

The news, however, is not all bad. The first nova further away than Virgo has been spotted (Della Valle & Gilmozzi 2002), presaging their use as independent indicators. Mind you, the actual location is NGC 1316 in Fornax, which we are not so sure really is further away than Virgo, and the authors point out that one must apply the Buscombe–de Vaucouleurs relation to nova brightnesses, without citing either of them. Since you were thinking of Virgo anyhow, Fouqué et al. (2001) say that it is at 18.0 ± 1.2 Mpc, based on the Tolman-Bondi model, which is also not cited. The Cepheid distance is 15.4 ± 0.5 Mpc. A couple of relative newcomers to the inventory of potential standard candles are the plateaus in the light curves of Type IIP supernovae (Leonard et al. 2002) and white dwarfs (Percival et al. 2002). Well, no. Not at cosmological distances yet, just in globular clusters for the moment, and they say that 47 Tuc is at distance modulus $m - M = 13.27$, vs. 13.57 from main-sequence fitting. The discrepancy, in other words, is no worse than realistic estimates of the residual uncertainty in Cepheid distances (Paturel et al. 2002). Some of the causes are composition dependence and Malmquist bias, and part of the evidence for a large uncertainty is a correlation between the value you find for H from a particular galaxy and the maximum luminosity of the Cepheids in that galaxy (Teerikorpi & Paturel 2002).

The Tully-Fisher distance indicator is an old friend (especially to us Maryland Terrapins). That it works at all must mean that the baryons (responsible for the luminosity) and the dark matter (responsible for the rotation speed) are in close communication. The same applies to elliptical galaxies and their Faber-Jackson relation (Verheijen 2001; Seljak 2002).

Neither relation was so much of a surprise when they were put forward, since baryons were then alone in the universe.

"*Dark matter candidates*" presumably means the ones about whose existence you remain in some doubt. Neutrinos therefore do not belong, because the non-zeroness of their rest masses has been pretty firmly established (Nakamura 2001) and confirmed by yet another experiment, called K2K. What are those masses and, therefore, the contribution to cosmic matter density? Perhaps all small (less than 0.1 eV) in which case you won't often need to include them in your calculations. But, alternatively, perhaps all very close to 0.39 eV (Klapdor-Kleingrothaus et al. 2001), in which case the hot dark matter somewhat outweighs the baryons. That latter mass comes from a tentative detection of neutrinoless double beta decay of Ge^{76} to Se^{76}, and Witten (2002) has a clear commentary on how it works. A Ge^{76} experiment was already running at UC Irvine under the custodianship of young faculty member Michael Moe when the more decayed author arrived in 1971. Visitor Maurice Goldhaber asked Mike how many counts he had seen, and, getting the answer "none," responded, "Well, that's a lot for that experiment." It may still be.

As for the things that remain "candidates," a few are apparently brand new this year, including stars made of WIMPs (Apparao 2002, for which one of us was a referee), point-like particles of stellar mass with gas halos around them, so that the gravitational lensing events they produce are not colorless and so are missing from the database (Bozza et al. 2002), and Planck mass relics of the evaporation of primordial black holes (Alexeyev et al. 2002). What about primordial black holes themselves, which have the virtue of being non-baryonic during nucleosynthesis? Well, either they are not the dominant dark matter, or Hawking radiation does not occur in the advertized fashion, or, of course, both (Barrau et al. 2002; He & Fang 2002).

Other things that are probably not the answer, if your question was "what is the dominant dark matter component?" are (1) halo white dwarfs (Goldman et al. 2002; Majewski & Siegel 2002), (2) brown dwarfs (Chabrier 2002), (3) topological solitons, but Hill (2002) will introduce you to instantons, Skyrmions, and 't Hooft-Polyakov monopoles if you haven't met them on an earlier tour, and (4) warm dark matter, whether sterile neutrinos or something else, unless the particle masses fall in a fairly narrow range (Dalcanton & Hogan 2001; Hansen et al. 2002; Abazajian et al. 2001) and you don't mind their not really solving the cusp problem (Knebe et al. 2002). What is the cusp problem? Well, in simulated Λ-CDM universes, the centers of galaxies and clusters tend to have density profiles that rise to sharp points very close to $r = 0$. Real galaxies and clusters more often have flat-topped cores (Keeton 2001; Bolatto et al. 2002). These predicted cusps, along with the "missing satellites" (discussed with reionization above), are the second observational objection to cold dark matter as the answer. But baryons make a difference to what you see and so do central black holes during the merger assemblage of big galaxies, and we are inclined to wait a year or two before panicking.

A number of other dark matter candidates still lurk on the à la carte menu. There is annihilating dark matter (Craig & Davis 2001) and several sorts of self-interacting dark matter (McDonald 2002), one of which is also a non-topological soliton called Q and B balls (Kusenko & Steinhardt 2001; don't ask us—it's your language, we're just trying to use it). We caught one vote this year on each side of "Does self interacting dark matter solve the cusp problem?" Balberg et al. (2002) vs. Gnedin & Ostriker (2001). We won't tell you which is which, because the theorists involved are of the high-creativity sort, who might easily find a scenario that goes the other way next year. Indeed from some of the tents in the same camp comes the charming thought that large lumps of SIDM could collapse very early into the seed black holes for active galaxies and for the onset of the black hole–bulge mass relationship (Hennawi & Ostriker 2002). You are then spared the photons and nucleosynthesis that would be associated with early black hole formation from baryons (Balberg & Shapiro 2002).

Candidates for *dark energy*, *quintessence*, or other physical interpretations of stuff that acts like a cosmological constant and exerts negative pressure are a recent addition. Erickson et al. (2002) and Heyl & Loeb (2002) discuss how you might tell some of them apart by difficult measurements of the CMB or by noticing that you have not yet been enveloped by a bubble of negative potential expanding at the speed of light. This observation may well come within the capabilities even of typical theorists. Yokoyama (2002) reminds us that there are model universes in which we live in an unstable, excited state. Some of us do that anyhow, with no help from cosmology.

Cosmological models differing from standard hot big bang are next in our hearts and notebooks to the more innovative dark matter candidates. Indeed the line between is faint and narrow, and it was arbitrary indexing that put decaying dark matter above and a universe with decaying dark energy or lambda (the "deflationary universe"; Cunha et al. 2002) here. The latter yields remarkably complex relationships among age, lookback time, luminosity distance, angular diameter distance and redshift, even in series approximations. We also seem to remember that this is the sort of universe that, if the Λ all decays away, could change its mind and start contracting (not quite before the end of the semester, but almost). This is not, however, the paper that says so.

The less steady author has often said and written that Steady State made cosmology a science by providing observational predictions different enough from those of hot big bang to be testable. In that spirit, "inflation" has now become scientific too. Hogan (2002) describes some of its newer predictions. But there is competition for its traditional tasks called horizon, flatness, causality, and monopoles. Start with the cyclic universe of Steinhardt & Turok (2002). It has an infinite (three-dimensional) volume of flat space, the usual radiation and mass eras (but with past temperature and density merely very large, not infinite), a fifth force that is too small to see in our greatly expanded state, and much else. An important difference from other earlier cyclic ideas is that all observers with whom we can communicate will belong to the present cycle. One expects no relics per se, but there should be signatures in cosmic gravitational waves and in the details of the behavior of the dark energy. Some brane universe scenarios (Avelino & Martins 2002) also are said to preserve the good aspects of hot big bang but to provide alternatives to the less satisfactory ones, as are some of the extra-dimension theories (Starkman et al. 2001; Randall 2002; Tegmark 2002; Liu & Wesson 2001; Khoury & Zhang 2002).

Extra dimensions can, however, also do some very strange things and, next time we see one, we are going to look for the Kaluza-Klein gravitons around neutron stars threatened by Hannestad & Raffelt (2002). The need for advanced as well as retarded potentials to describe radiation by accelerated charges is another of the possible oddities (Bicak & Krtous 2002), and, as best we can understand the situation, next time we encounter one of these, we will already have seen the results.

The year's diverse cosmologies extend still further. There are also (1) axion-photon oscillations to dim distant supernovae (Csaki et al. 2002), (2) fractality on a scale of 0.7 $M_\odot$ (Oldershaw 2001), (3) a universe with negative pressure at the Planck time (Berman & De Melo Marinho 2001), (4) reheating by evaporation of surface charge on fragmented inflation condensate (Enqvist et al. 2002), (5) universes based on Barber gravity (Mohanty & Mishra 2002) and bimetric gravity (Yeranyan 2001); Barber is cited, Bimetric is not, (6) detectability in ultrahigh energy cosmic rays of quantization of space-time on the Planck scale (Lieu 2002), (7) break down of Lorentz invariance (Kostelecky & Mewes 2001), and (8) another modification of special relativity with a second, new invariant, perhaps the Planck energy (Magueijo & Smolin 2002).

In comparison, the following are practically old friends: (1) conformal gravity (Mannheim 2001), (2) non-cosmological redshifts (Arp 2002a for; Sembach et al. 2001 against), (3) quantized redshifts (Roscoe 2002), and (4) modified Newtonian dynamics (MOND) as an alternative to dark matter (Milgrom 2002).

13. IS THIS THE ENGLISH-SPEAKING TOUR?

Ap01 set a new record by antagonizing an entire IAU Working Group. After some consultation, they decided they probably did not want an apology, having, perhaps, read some of our previous apologies ("All right; I *would* vote for him for dog catcher."), but we have done our best to make amends by referring to the topic on which the Working Group works in the main body of the text without attaching extraneous frivolous remarks.

Indeed a Frequent Contributor of Advice this year contributed the advice that there should be no frivolous remarks at all and the entire piece written, he suggested, "in the style of an IAU triennial report." The latter half of this advice has been taken, but no one will ever know except the author and the editor of the Division VIII triennial report, because no one else reads them. Sorry George.

And so onward to specific errors, inoperative statements, and other items that someone might reasonably regret having published, beginning, as usual with our own, ordered by the ApXX sections in which they occur.

Ap00, § 5.7. Sophie Brahe's dates were 1559–1643, so she did not live to be 107. But Live Larsdatter, who worked for Tycho as a young woman, supposedly died in 1698, at the age of 123. If any then-young astronomers met her near the end of her life, this could easily take two steps out of the Tycho chain in the game "Shaking hands with Shakespeare." (Christianson 2000).

Ap01, § 3.2.2. The reference quoted for extinction at various observatory sites reports numbers only for the Czech and Slovak Republic ones, but we are still betting that the Himalayan site is better.

§ 5.4. Some of the differences between classical R CrB stars and the fainter DY Per class remarked upon within the LMC were noted by Payne-Gaposchkin (1963) and others in between. This somehow implies that there must also be such stars in the Milky Way. We suppose that DY Per is an example, though you never know.

§ 6.3. The scale length of the disk of the Milky Way is not, in fact, very abnormal. The author quoted there as the authority for scale lengths in other galaxies informed us that 2.8 kpc is not particularly anomalous (See Fig. 6*b* in the paper cited). The typical numbers we had quoted, 5–25, were perfectly correct too, coming from her Table 5. But the units were arcseconds, rather than kiloparsecs. The (ir)responsible author awaits momentarily a job offer from the NASA Mars program, probably as a Lander.

Ap02, § 8. Yes, some mistakes are so egregious that they get caught before they are made. A correspondent reminds us that massive stars do build (most of) their iron-peak cores as Fe^{56}, which gets photodisintegrated in the core-collapse supernova and never comes out. The Ni^{56} you do see is made a few seconds later by explosive nucleosynthesis in the silicon layer.

And so onward to items from other authors, editors, and gremlins. As usual, these are referenced only by journal page number, so you can look them up if you wish to.

"Talks will be given indifferently in Castillian or in English" says a conference announcement inside the back cover of *Astronomy and Astrophysics* 391, no. 3. Well, our talk was given indifferently in English, but some of the Spanish presentations were actually quite good.

"Star Formation in the *Infrared Space Observatory* Atlas …" is part of the title of *AJ* 124, 1380. It is, after all, a big Atlas, and fairly gassy.

Europhysics News 33, 95 included "a list of those who had held Marie Curie Fellows." We have no opinion on their probable gender.

How much is that in Euros? The temperature in part of a coronal loop described in *ApJ* 556, 896 was 1 mK, which is surely a record. A research summary in *Science* 296, 9 extends "almost 6 years into the Sun's interior." According to the abstract of *ApJ* 567, 515, "normal galactic evolution should begin in matter with $[Fe/H] \approx 3$." And the introduction to *Astron. Lett.* 27, 581 explains that the paper will discuss "one of the four brightest stars in the Orion Trapezium," but admittedly we would have been much more worried by the five stars of the Summer Triangle or other (im)possible combinations.

Element 110 is shown as H in *Nature* 418, 815. They printed a correction later, but we wasted a lot of time trying to make VERY heavy water out of it.

"Running head" does not mean quite what you might suppose if you have met the noun only as part of your course in plumbing, but the attempt to compress the entire meaning of a paper into fewer than 80 characters, occasionally yields items like "educational spectrograph" (*PASP* 114, 579, and we had always hoped they all were), and "life in H ii regions" (*Rev. Mexicana Conf. Ser.* 12, 11), which, we believe, is confined largely to Saturday night.

WHERE did you say you were?? "HH 111 jet from the Space Telescope Imaging Spectrograph" according to *ApJS* 138, 19. "There isn't a space mission on the planet that hasn't at some stage of its gestation had to overcome problems," according to *New Scientist*, issue of 28 September 2002, quoting an HNO, speaking about *Beagle 2*. This is surely true, in the sense that the missions without serious problems are found in space rather than on the surface of the planet. Oh, a HNO is a High NASA Official. And, in a paper read on 17 July, but with volume and page not recorded, "Thank are due … to A. B. for his hindsight on dark matter halos."

WHO did you say you were? Ira Shapiro is the long-time director of SAO in Cambridge MA according to a May issue of *Science* (most of us call him Irwin). "Justin Oelgoetz[1]ty" is given as the name of an author in *MNRAS* 327, 442. The superscript 1 refers to a footnote with his address. "O.G. Badalyan et al. Caaspas" appears as an article title on the contents page of *Contr. Ast. Obs. Skalnate Plesa* 31, no. 2. But PINOCCHIO is merely PINpointing Orbit-Crossing Collapsed Hierarchical Objects according to *ApJ* 564, 8, throughout. This takes us inevitably to acronyms.

NICE is the Near Infrared Color Excess method (*A&A* 377, 1023) and NICER the Near Infrared Color Excess method Revisited. FREGATE is the FREnch GAmma ray TElescope, in many papers and public talks, and we are gradually learning not to blush. An English teacher of our acquaintance once noted that it is simply no use trying to teach the Emily Dickinson poem that begins "There is no frigate like a book, To take us lands away." AIRY is Astronomical Image Restoration in interferometrY (*A&A* 387, 733, subtitle). Well, he always was at the back of the pack. IMF is the interplanetary magnetic field throughout *A&A* 389, 1039, and we suppose they have just as much right to it as the Initial Mass Function, but are inclined to wish that there were a master list of such things to be found somewhere.

There were many competitors for the "well, that's approximately what I meant" award for 2002, including "Heavy absorption due to Galactic H i and related observational effects" (*ApJ* 574, L17, abstract); a "preliminary conclusion for the first time" (*Chinese Journal of Astronomy and Astrophysics* 2, 103); the "method of fuzzy comprehensive evaluation" (*Acta Astron. Sinica* 42, No. 4, 375); "The population of M31 GCs did turn out to be include clusters that appear …" (*ApJ* 570, 635, conclusions); "emission lines from either highly ionized atoms or low-ionized irons" (of which the authors of*ApJS* 138, 19 evidently had many in the fire); "… release of gravitational energy due to the approximation of a stellar companion …" (*A&A* 317, 895, mid-text). But the winner comes from a footnote (*ApJ* 566, 911) which explains that "source names consisting of two numbers separated by a minus sign should be understood to have an acronym of [OW94]."

Competitors for the "who did what to whom?" prize generally arise from trying to assemble a few too many nouns adjectively modifying more nouns, for instance: "the fatal long-wave mode kink magnetohydrodynamic instability" (*ApJ* 564, 102, abstract), "metal rich, highly flattened, and rapidly rotating disk globular cluster systems (*ApJ* 566, 245, abstract). But the winner defies such simple explanation. It comes from the abstract of *ApJ* 562, L23 "and another [of field E galaxies] much older, formed ≥4 Gyr since the redshift of the observation." Now the redshift of the observation would seem to be $z = 0$, since when very little has happened. We think "before the redshift at which the light was emitted" might have been the intended meaning.

Secretly, we quite like "the diocotron instability" (*A&A* 387, 520), but wish it had been defined; "Deep Groth Strip Survey" (*ApJ* 571, 137, title), but think he looks at least as good fully clothed; "loss of apatite" (*Nature* 417, no. 6890, p. xi, heading) which was surely a deliberate punlette; the "EIS Deep Public Survey" (*A&A* 384, 81, abstract), which presumably found entrails; and "the Born and Ray Approximation" (*ApJ* 561, L229, title), which should not be confused with Bob and Ray of radio's golden days. Born was surely Max, but we think Ray did not have a first name.

The disappointment of the year came from *Science News* (161, 180) which began a short item with "FOSSILS OF A CREATURE THE SIZE OF A LARGE HOUSE (second line) cat."

And one correspondent never disappoints. Some complimentary ASP conference volumes arrived, which he generously acknowledged as "The bureaucratic maschinas work. Your one send books, and our one make puctiliously the mark of the censor (!) on all of books."

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Colleagues who provided feedfront include Heinz Andernach, Barbara Cunow, George Herbig, Kevin Krisciunas, Zdzislaw Musielak, Nikos Prantzos, Alexander Rosenbush, Bradley E. Schaefer, John Sidles, Stanislaw Stefl, and George Wallerstein (who regretfully informed us that there were really no items in Ap01 that he could claim to have published 20 or more years ago in Ze Basel Bullsheet or Ze Zuricher Zeitung). Feedback on Ap02 and advice for Ap03 are, as always, welcome.

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