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Astrophysics in 1997

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ABSTRACT. Martian marvels, a gamma-ray burster with a redshift, *Galileo* converses with Ganymede, a record galactic redshift of 4.92, and much else. Fiscal 1997 was definitely an exciting year for astronomers. We have tried hard to hit all the obvious highlights, but also to report more gradual progress on traditional problems of understanding planets, stars, galaxies, and the universe. Though the year was saddened by the loss of many valued colleagues, we nevertheless indulge in occasional soupçons of frivolity.

1. INTRODUCTION

It is with considerable regret that we record Ap97 as the last review we will prepare for retiring editor Howard E. Bond. The series was originally his idea (though he must have felt occasionally like the parent of Rosemary's Baby), and he has generously allowed us to call spades bloody shovels, even when perhaps they were merely muddy. It is unclear at the moment what the future will bring, but we can say with some confidence that the past has held six previous Ap9x's, which are cited herein as Ap91 to Ap96, and which appeared near the beginnings of volumes 104–109 of PASP. And yes, this year, as Don Wilson used to say about The Jack Benny Show, "We're a little late, folks."

The journals scanned were the issues that reached library shelves between 1996 October 1 and 1997 September 30 of *Nature*, *Physical Review Letters*, *Science*, *The Astrophysical Journal* (plus *Letters* and the *Supplement Series*), *Monthly Notices of the Royal Astronomical Society*, *Astronomy and Astrophysics* (plus *Supplements* and *Reviews*), *The Astronomical Journal*, *Icarus*, *Journal of Geophysical Research* (*Planets*), *Acta Astronomica*, *Astrophysics and Space Science*, *Astronomy Reports*, *Astronomy Letters*, *Astrofizica*, *Astronomische Nachrichten*, *Journal of Astrophysics and Astronomy*, *Publications of the Astronomical Society of Japan*, *Bulletin of the Astronomical Society of India*, *Baltic Astronomy*, *Astrophysical Letters and Communications*, *New Astronomy*, *IAU Circulars*, and (of course) *Publications of the Astronomical Society of the Pacific*.

The American and worldwide astronomical communities are still growing at about 3% a year, at least as measured by memberships in the American Astronomical Society and the International Astronomical Union, but we are also aging communities and have lost record numbers of members in the past year. The necrology at the 1997 General Assembly of the International Astronomical Union numbered 112. Members of the American astronomical community (meaning current or former members and prizewinners of AAS and ASP Bruce Medalists) who died during the reference year, or whose deaths were belatedly announced, include Viktor A. Ambartsumian, Jeno Barnothy, Louis Berman, Robert Dicke, Isadore Epstein, Thornton Carl Fry, Robert L. Golden, Robert Herman, Richard Herr, John B. Irwin, Allan (Bud) Jacobson, Igor Jerkevich, James Klavetter, Jerome Kristian, Robert B. Leighton, Thomas Markert, Leonard Martin, Andrew Mitchalitsianos, Walter Mitchell, Jacobus (Koos) Petterson, Edward M. Purcell, Jurgen Rahe, Barry Rappaport, Carl Sagan, Leon W. Schroeder, Martin Schwarzschild, Eugene Shoemaker, Jack William Slowey, Roman Smoluchowski, Lyman Spitzer, Jr., Ralph E. Sturm, Victor Szebehely, Roger Tayler, Lois Keener Thome, W. Reid Thompson, Clyde Tombaugh, Richard Tousey, Vladimir Vanysek, Beat Wackernagel, Fletcher Watson, Samuel Crane Wheeler, and Henry Lincoln Yeagley.

2. IN AND AROUND THE SOLAR SYSTEM

The solar system remains in the same old circle game, the planets, they go round and round and we earthlings are the wiser for it. Last year's discoveries lead to this year's theories, and last year's acquisition of spacecraft data lead to this year's analysis and interpretation. Active imaginations, more sensitive and new instrumentation, combined with the human tendency to seek holes in scientific theories, advance knowledge of the solar system.

2.1. By Jove

The big satellite that can (*Galileo*) and the big scientists that can (still analyze data from decades'-old instruments) came forward with more scientific results on the Jupiter system, that mini–solar system in the sky.

The inside scoop.—Close passes of the *Galileo* spacecraft past its namesake satellites provide the opportunity to measure Doppler-shifted radio signals and derive their external gravitational field. The magnetometer and plasma wave instruments

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provide data that can nicely constrain interior models of mass and electromagnetic states. Discovery of Io's metallic core was reported last year (Anderson et al. 1996a), as was Ganymede's three-layer structure (Anderson et al. 1996b).

Europa's internal structure is the most complex of the four, having a deep interior of a mixed core of metal and rock, or a metal core with a rocky mantle. Its outer shell is water ice and liquid about 100–200 km thick. Regions of Europa's interior are probably not in hydrostatic equilibrium, a condition inferred from inconsistent results from two close passes of the spacecraft. The available data cannot discriminate between a solid and a liquid water mantle (Anderson et al. 1997b). Perturbations in Jupiter's magnetospheric field during one of *Galileo*'s close approaches to Europa was modeled with a Europa-centered dipole moment with maximum surface strength of 240 nT (Kivelson et al. 1997). The existence of an internal magnetic field can be modeled to the data, but its existence cannot be proved with currently available data. The orientation of the dipole is oblique to Europa's spin axis.

Evidence for a magnetosphere at Ganymede is derived from intense plasma waves in the form of whistler-mode emissions, upper hybrid waves, electrostatic electron cyclotron waves, and escaping radio emission (Gurnett et al. 1996). Hats off to those who analyzed the signal of one mode from the noise of another. Then, of course, the magnetometer measured a field strength of 750 nT consistent with a dipole tilted 10° relative to the spin axis (Kivelson et al. 1996). The questions about the magnetic fields of Ganymede (and Io for that matter) have now evolved to whether or not they are remnant fields, dynamo-induced or magnetoconvective in nature. Schubert et al. (1997) conclude that dynamo action is the likely cause of Ganymede's magnetic field because it is 6 times larger than the ambient Jovian field. For Io, with large tidal forces and a dipole moment as large as Ganymede's, the existence of a dynamo is easily invoked, though its core could be in a magnetoconvective state, too.

Poor Callisto; life seems rather forlorn there. Not only is its interior uniform and undifferentiated, but the plasma wave experiments showed no evidence of a magnetosphere or an internal magnetic field (Gurnett et al. 1997). The movement on the magnetometers represented a paltry ~7 nT field strength, which could be explained by Callisto's interaction with the Jovian plasma environment (Khurana et al. 1997). Callisto seems like the ugly ducking of the Galilean satellites.

The big guy.—Analysis of Jupiter's exospheric temperature by Seiff et al. (1997), using *Galileo* probe data, showed a temperature variation from 109 K at 175 mbar to 900 ± 40 K at 1 nanobar with wavelike oscillations throughout observed altitudes. Young et al. (1997), using *Galileo*'s atmospheric structure instrument, detected wavelike temperature fluctuations that they attribute to evidence of gravity waves in a viscously damped thermosphere. With the availability of thermal measurements, it is now possible to constrain models producing the observed high temperatures in the exospheres of the outer planets, where solar radiation alone could not provide the necessary energy. The energy transferred in the gravity waves can provide the energy required to produce the observed temperatures. It's all a matter of physics, you know.

2.2. Comets

Thank God there are no new bright comets this year! This means there is time to think. What produces soft X-rays in comets? Last year, they were discovered in comet Hyakutake (Lisse et al. 1996); this year, explanations abound. Krasnopolsky (1997) claims that only scattering by small particles and charge transfer of solar wind heavy ions can do the job. Northrop et al. (1997) and Northrop (1997) posit electron-neutral and electron-dust collisions producing bremsstrahlung radiation. These are the same thing using different words. Häberli et al. (1997) come to the rescue with their MHD model whereby charge exchange excitations of high charge state solar wind ions with neutrals produce X-rays. This happens in Jupiter's upper atmosphere, too (Waite et al. 1997). The results of their model agree with observations including the observed time variability of Hyakutake. Bingham et al. (1997) see it as follows: cometary plasma and the solar wind are accelerated by the solar wind's electric field to high energies. An instability is created, generating low hybrid frequency waves. Subsequent absorption of the wave energy by electrons results in suprathermal electrons of sufficient energy to produce bremsstrahlung and cometary gas K-shell radiation of X-rays. This wave-particle interaction theory produces keV photons of the energy interval at which *ROSAT*'s high-resolution imager is most sensitive. Therefore this model should be testable.

Denerl et al. (1997) went to press in time to be included here with their survey of archival X-ray data obtained during *ROSAT*'s all-sky survey. The great advantage of this analysis is that multiple comets were observed under different geometric conditions, thus constraining some theories (more to the point, shooting them down) and providing some systematics of cometary X-ray production. It appears that X-rays are emitted only on the sunward side of a comet, and there is no evidence that X-ray emission is associated with any plasma or dust tails. These authors propose a relationship between the gas-to-dust ratio in the comet and its X-ray production, with X-ray production correlating positively with gas production. Only Cravens's (1997) model and subsequent treatments expanding it (Häberli et al. 1997) predict this circumstance and stand up to the results of these data. It works by charge exchange between highly charged heavy ions (i.e., the likes of O^{7+}) in the solar wind and cometary neutrals. Thus cometary X-ray emission can be a probe of solar wind conditions, a poor space physicist's mission.

All hail Hale-Bopp.—Discovered at 7 AU in 1995, this comet, assuming a 4% albedo, is likely to be 30–40 km in diameter, 3–4 times that of Halley (Weaver et al. 1997). Its dust production rate was more than 2 orders of magnitude greater than that of Halley at the same heliocentric distance, and its gas production rate was 20 times greater (Schleicher et al. 1997). Its NH_2 and H_2O^+ production cannot be explained by fluorescence excitation models at large heliocentric distances (Rauer et al. 1997), but its CN production is compatible with fluorescence production (Wagner & Schleicher 1997). Water production began, as expected, at 3.5 AU, with water taking over CO-driven production of the coma at 3 AU (Biver et al. 1997). We look at all these parameters, you recall, to determine whether all comets are alike or whether or not there are significant differences that provide us with a peek into the solar system's early beginnings.

The reports of crystalline olivine in Hale-Bopp's coma (peridot for those with a gemstone bent) (Hayward & Hanner 1997; Crovisier et al. 1997) are telling us something. Olivine and ice are as immiscible as oil and water. There's something else going on here: either mixing from two different temperature regimes at different times, or a misunderstanding of the physical interpretation of the data and/or more mineral species that remain to be identified, such as hydrated by-products of olivine and ice. While we are on the subject of things that don't fit, Crovisier et al.'s (1997) assumption that materials found in two places, Hale-Bopp and the interstellar medium, have a consanguineous origin seems oversimplified when talking about mineral species that have a large range of thermodynamic stability. Their coexistence, in this case olivine in Hale-Bopp and in circumstellar dust clouds, implies that both have passed through a similar temperature gradient; similar processes but not necessarily the same material.

Soft X-rays were observed in Hale-Bopp (Krasnopolsky et al. 1997) offset from the nucleus (as expected) and not correlated with dust jets (see the paragraph above; they're not supposed to be). Continuing in Krasnopolsky et al. (1997) are reports of Ne abundances that are depleted relative to solar abundances, implying formation at or subsequent exposure to temperatures greater than 25 K. It can be said that temperatures above 25 K support the idea that Oort cloud comets were formed in the Jupiter–Neptune region of the solar nebula and then sent to the Oort Cloud. What can be said and the truth remain to fall from the scientific process. Helium line emission and ionized oxygen were also reported with the *Extreme Ultraviolet Explorer* (*EUVE*) satellite. All in all, Hale-Bopp was a prolific comet. All Hail Hale-Bopp.

2.3. A Child's Garden of Asteroids

While those who used to consider asteroids as "vermin in the sky" may soon have the opportunity to be put to rest on one or at least buy stock in a company selling space on private planetary probes (OTC Bulletin Board: PSDM), diligent scientists continue to learn more about them. We'll start close to home.

It's always good to know.—The meteoroid flux dominates the dust population of particles greater than 30 μm in low Earth orbit (LEO) in the 240 km altitude region. Man-made space debris dominates at higher altitude and smaller particle sizes (less than 5 μm) (McDonnell et al. 1997). Projections of orbits of Earth-approaching objects into the next millennium reassures us that there is no known threat of being hit by a short-period comet (Carusi & Dotto 1996). The only better place to avoid impact hazards is Mercury. We'll take our chances here, thank you very much.

An asteroidal companion to Earth? It's all a matter of how you look at it. Wiegert et al. (1997) note that asteroid 3753 (1986 TO), when viewed in a Sun-centered reference frame but orbiting with Earth, has a horseshoe-shaped orbit. It doesn't orbit Earth, but Earth's gravitational force keeps it in tow by increasing the asteroid period from slightly below to slightly above 1 year. This oscillation prevents the object from colliding with Earth. When looked at in this rotating reference frame, the path of the asteroid draws a kidney-shaped orbit. Ever wonder how many kidneys Earth has?

Does the term "stable chaos" make you feel fuzzy and warm? To reconcile the apparent contradiction between the stability of the main belt asteroids through orbital integrations with their large and positive Lyapounov characteristic exponents, a parameter of chaos, the term "stable chaos" is invoked. Trust your asteroid dynamicists (Milani et al. 1997). They can explain it in terms of high-order mean motion resonances with Jupiter in combination with secular perturbations on the perihelia of asteroids. It appears that non-linear, unpredictable motion actually transports asteroids from one high resonance to another protecting Earth from catastrophic collisions. Now if we can only get a handle on the comets.

Mix together, shake, then separate.—Reach et al. (1997) combine IR data sets from *COBE*, *DIRBE*, and *IRAS* to create brightness maps in three dimensions of the zodiacal dust bands. The recipe calls for Fourier transforms to filter the smallest structure and the large-scale background. Dust bands are found associated with the Themis, Koronis, Eos, and Maria families, after taking into account the effects of Poynting-Robertson drag (sunward force) and vertical spreading due to transfer of energy or dispersion from mutual collisions.

Moving on out.—Whereas Holman (1997), through numerical calculations, finds a dynamically stable region at 24–27 AU with low eccentricity and low inclination that would survive the age of the solar system, no objects have been found there to date. The Edgeworth-Kuiper Belt, located at about 39 AU, contains 1000 times the number of objects in the main asteroid belt (MAB); this population occupies a factor of 1000 times the volume containing objects that are moving 10 times slower than the main belt. Therefore, collisions are less frequent, which results in their longer lifetime. In the inner edge of the Edgeworth-Kuiper Belt, objects between 50 and 100 km are not depleted by disruptive collisions and therefore represent the original population (Davis & Farinella 1997).

Luu et al. (1997) and Helin et al. (1997) found objects at greater distances, 84 and 47 AU, but with high eccentricity and inclination ($e = 0.58$, 0.3 and $i = 24°$, 32°). Luu et al. (1997) posit that the discovery of their object demonstrates that the Kuiper Belt is extended more so than represented by the inventory of this population until now. With good timing, Duncan & Levison (1997) presented numerical simulations that suggest that there are two components to the Kuiper Belt (or Edgeworth-Kuiper Belt): one with almost circular, stable orbits, and another with the characteristics of 1996 TL_{66} and 1996 RQ_{20}. This more distant region has survived the age of the solar system after having been scattered once by Neptune, and it is feasible that they supply Jupiter-family comets.

Oh, one last thing I shouldn't say (one author is involved, and the first results aren't published): the *NEAR* spacecraft flew past the main belt, slowly rotating (217 hr) asteroid 253 Mathilde in 1997 June. The imaging camera collected over 500 images. As many people don't hear about this mission (it is operated out of APL with a strong military tradition and small public relations budget), recall that it is on its way to asteroid 433 Eros for a year's rendezvous beginning in 1999.

2.4. Moving On In or Poynting-Robertson Drag

On matters of Little Green Men.—Following McKay et al.'s (1996) report of possible evidence for fossil life on Mars, numerous alternative arguments both supporting and refuting aspects of their arguments have been presented. Recall that five independent findings from studies of one Martian meteorite, ALH84001, led this group of scientists to conclude that they were staring at evidence of fossil life on Mars! The final interpretation of this complex meteorite, also to be considered the truth, will take some time. Also required is a better understanding of the biological organisms on Earth that are being compared with those cast in stone from Mars. Studies in the past year have focused on three aspects of the evidence, so let's take them one at a time.

1. *Temperature of carbonate formation*.—The question boils down to the temperatures at which carbonate globules formed. These mineral aggregates possibly formed as a by-product of bacteria-like organisms. Last year, Harvey & McSween (1997) proposed a high-temperature origin for these carbonates that they argue precludes the possibility of a biological contribution to their formation and supports a totally inorganic formation mechanism.

Approaching the question of formation temperature from a different angle, Kirschvink et al. (1997) bring paleomagnetism to bear upon the question. They suggest that the carbonates formed at low temperatures as there is no evidence of reheating after the initial magnetic field was locked into rock during crystallization 4.5×10^9 yr ago. Different orientations of the nuclear remnant magnetic field are a result of shock and subsequent reorientation of fragments that occurred at temperatures below the rocks' melting point. Had the rock been at high temperature when the carbonates formed, a new and uniform magnetic field would have been recorded in the rocks, which was not. Their vote is for low-temperature formation which still keeps the biogenic interpretation in the game.

Valley et al. (1997) find concurring evidence of the extraterrestrial nature of carbonate globules in ALH84001 in their high $\delta^{13}C$ values that are higher than anything terrestrial in nature. They also find evidence of a low-temperature formation for the carbonate globules based on oxygen isotope measurements and the inhomogeneity in observed isotope ratios of both carbon and oxygen. The theory behind this is that high temperatures would diffuse inhomogeneities. The presence of inhomogeneities supports lower temperature, metamorphic formation. A biogenic origin is still possible.

2. *Magnetite grain morphology*.—Surrounding the carbonate globules are dark, magnetite bands of nanometer dimensions comparable to similar features created by terrestrial bacteria by McKay et al. (1996). Temperature is a factor here as well. Bradley et al. (1996) claim that whisker-shaped magnetite grains are evidence of vapor deposition and hence a high-temperature (>650 K) formation of the carbonate globules and aggregate minerals, of which magnetite is one.

3. *Shape of carbonates revisited*.—Treiman (1997) alludes to publications to come. McKay and colleagues are imaging the carbonate globules with different techniques to investigate whether their morphology might be an artifact of sample preparation methods. One is always pleased to hear that the initial investigators continue to investigate their original findings with different techniques. This shows scholarly skepticism and an open mind.

Can't remember the fourth and fifth lines of evidence? Let's see; there were little tiny segmented, wormlike shapes and PAHs. Most of us don't know the likes of worms in space, but we are all pretty familiar with PAHs (polycyclicaromatic hydrocarbons). You be the judge, but don't vote early. One is still left to wonder what it will take for us mere mortals to be convinced that life exists on Mars, if it does? For starters we can cultivate an appreciation of the life forms on Earth. Will that lead us to believe in little green men, Mom?

Lost on the Moon.—Something in us longs for the protective blanket of an atmosphere around any large, solid body, or at least the residual evidence of one. The search for metallic neutral and ion emissions in the lunar atmosphere still only provides upper limits using *Hubble Space Telescope* (*HST*). The $5\ \sigma$ upper limit for neutral magnesium is depleted by a factor of 9 relative to lunar soil abundances, which leads Stern et al. (1997) to conclude that stoichiometric sputtering is not operational on the Moon. Furthermore, the process producing Na and K ions on the Moon preferentially favors these species over other atomic neutrals. The suspected culprits are meteoritic bombardment or that the Na and K ions are being added to the Moon and not taken away from it. Now there's an interesting thought.

There are wise men who strongly suspect that the poles of the Moon harbor trapped water ice. Many a younger man, and a few women, have sought evidence of this. One year, we think it's been found; the next year, it's gone. This is an off year. Stacy et al. (1997) used Arecibo Observatory's 2.38 GHz radar system to map regions of the lunar poles at high spatial resolution in an effort to confirm high backscattered signals from the *Clementine* mission's bistatic radar observations of the south pole. These data show no enhancement in circularly polarized ratios (CPRs) at the south pole relative to the north pole, as did *Clementine* (Nozette et al. 1996). The experiment reported this year, carried out at higher spatial resolution than that of *Clementine*, offers the explanation that smaller areas with high CPR values are associated with craters, some of which are sunlit. This group interprets their high backscatter values as rough-surface scattering. In fact, they believe the ice interpretation offered last year is not valid.

Found elsewhere.—Venus has a thick crust (thermal lithosphere 200–400 km) that is thinned beneath volcanic highlands by 80% according to models using Magellan Global Topography Data Records (MGTDR) (Moore & Schubert 1997). Haldemann et al. (1997) demonstrate the effects of distinct geologies having different tectonic origins on radar scattering properties of the surface of Venus. Is this getting too geological? We include it as radar technology fostered more than one astronomer out there. Just one more thing: be aware that there are two different ages now proposed for the surface of Venus: one in the 300–500 million year range (old value), and another a factor of 2 older, 750–800 million years (McKinnon et al. 1997). Without any ground truth, this strikes the blondy author as quite an extrapolated argument.

3. *PATHFINDER* FINDS A PATH

This section almost didn't get written, because neither of us wanted to be third on a two-author paper. But never mind—you knew it all before. The Martian rocks all have names, but it is no use remembering them, because, like cats and Victor Borge's children, they don't come when you call them anyway. Many of the rocks seem to have washed their hands and faces for dinner, but it is not at all clear that there is anything to eat. And if you can unearth your collection of *Viking* lander pictures, you can test our conclusion that the surface of Mars has changed remarkably little in the last 20 years.

It nevertheless remains true that Mars is our best bet for finding chemical evolution that has progressed beyond the point represented by organic molecules in meteorites (§ 7.1) but not as far as vice presidents. Thus further exploration by probes, sample return, and so forth is very much worthwhile, whether the processes have reached the biological (slime mold?) stage or only bigger and better polymers. The former case is obviously easier to sell, but the latter, by preserving traces of what must have happened on Earth but has long been devoured by its successors, might be more interesting.

Meanwhile, it is a pretty safe bet that the 1998 literature will include a number of interesting results from the non-imaging parts of the Carl Sagan Station in the area that is not (yet) called Aresology and Aresphysics.

4. SOME FAVORITE PEOPLE

4.1. Long-lived (or At Least Long-published) Astronomers

Even the record for publication in *The Astrophysical Journal* (Ap96, § 11.9) has fallen. Philip C. Keenan (Keenan 1931 to Barnbaum, Stone, & Keenan 1996) has exceeded the 1902–1964 span of Joel Stebbins and shows no significant signs of tapering off. A still earlier paper appeared in PASP (Keenan 1929). And the new world record holder, by virtue of a 1996 publication, and probably some in the pipeline for 1997 and later, is Alan Cousins (Cousins 1924; Cousins & Caldwell 1996).

Some other notable contenders are Ernst Öpik (Öpik 1914 to Öpik 1979) and Charles Greeley Abbott, for whom we can set only a lower limit, because (dying in 1973 at the age of 101) he very probably started publishing before the first volume of *Astronomische Jahresbericht* (1899), but also appears in the 1967 volume. Öpik also holds the record for most prolific astronomer, with 1094 scientific publications and 16 piano compositions (Krisciunas 1988, p. 300). Younger colleagues who aspire eventually to challenge these records should note that one arguably has somewhat more control over the year of one's first publication than of one's last. Luyten and Cousins have in common a considerable degree of precocity as well as stick-to-it-iveness. Where does Hans Bethe fit in this golden (or rather platinum and beyond) ensemble? We're not quite sure because his early work was not in astrophysics, but certainly much preceded his arrival at Cornell in 1932; and two papers in the reference year (Bethe 1996a, 1996b) on the behavior of shocks in Type II supernovae are clearly part of a series meant to continue well into the millennium.

4.2. Those Who Did Things by Very Difficult Methods

These include the following:

1. Dravins et al. (1997), who showed that summer is nicer than winter from scintillation monitoring.
2. Schwab (1997), who showed that Earth rotates with a superfluid ^{3}He gyroscope; actually this may not be any harder than using any other sort of gyroscope for the purpose (à la Foucault), but it sure must be a lot more expensive.
3. Aglietta et al. (1996), who used cosmic rays to show that Earth goes around the Sun (and if we tell you that this is dignified by the name Compton-Getting effect, you will probably just ask what he got). Incidentally, they saw no other significant anisotropies in the arrival direction of cosmic rays.
4. Grandpierre (1997), who blamed the solar cycle on non-tidal effects of the planets.
5. Gayley et al. (1997), who managed to stop a stellar wind with photons.
6. Sills et al. (1997) and Sandquist et al. (1997), who man-

aged to keep mergers or at least models of mergers of binary stars from mixing, so that the products retain helium-rich cores; on second thought, using a full-scale model probably would have been harder.

7. Preibosch & Smith (1997), who have gone ahead and carried out a suggested "difficult method" from a few years ago by measuring distances to stars from the combination of their rotation period (from spot-induced variability) and $v \sin i$ (from line profiles), with the assumption that i is randomly distributed (though given some of the items mentioned in § 5, they may be on to something).

8. Jaroszyński & Paczyński (1996), who showed that energy is conserved by considering gravitational lensing (but this probably means that somebody got it wrong before).

9 Airapetyan & Matveenko (1997), who investigated the structure of radio sources in a data base originally intended for geodesy.

4.3. The Ones Who Said...

Where these appear without author's names, it is because we suspect that they may have meant to say something slightly different.

1. "[We have provided] convincing evidence both for and against the presence of hidden Seyfert nuclei" (Kotilainen et al. 1996).

2. "Simple general inversion formulae to construct distribution functions for flat systems the surface density and the Toomre Q number profiles of which were given and illustrated" (a complete sentence in MNRAS, 282, 1158, conclusions); probably a comma would help, if only we knew where to put it, and possibly a verb.

3. The abstract of ApJ, 470, L81, which rhymes but definitely doesn't scan.

4. "Three millimeter molecular line observations of..." (ApJ, 470, 981)—is it the millimeters, the lines, or the observations of which there are three?

5. "Isopedic" (Li & Shu 1997; Shu & Li 1997) and "enstrophy" (Medina Tanco et al. 1997); you could, as it were, look them up, but isn't it more fun to contemplate "having the same feet" and "a nourishing thermodynamic quantity"?

6. "Post starburst nuclei are not necessarily the result of preceding starbursts, but could be the result of drastic truncation of star formation activity" (ApJ, 481, 132); is the contrast between starbursts and star formation activity or something more subtle to do with "post hoc ergo proper hoc"?

7. "Recombination lines, Miss Trimble, are called recombination lines because they form when atoms recombine" (meaning you cannot get gas temperatures from them, but we've been noticing for some years that respectable astronomers seem to, e.g., Afflerbach et al. 1996).

8. "An agreable surprise" and "the review beeing more complete" (both A&A Rev., 7, 284), illustrating conservation of e's).

9. "The best-studied carbon star in the universe (by humans)"; Groenewegen (1997).

10. "It might be clarified by future spectroscopic observations of the progenitor" (A&A, 318, 185, conclusions), to be made, apparently, using a time machine.

11. "[We express our gratitude] to the TIRGO tune allocation committee for the award of telescope time" (A&A, 318, 337, acknowledgments). In fact, the lower voiced author once shared nights on the 48 inch Palomar Schmidt telescope with a colleague who kept awake by singing music of the early Polish church, so perhaps there really is a "tune allocation committee" at some observatories. (I just wish they had given me Rodgers and Hart, or even Gershwin and Gershwin.)

12. "The most outstanding characteristics of Be stars include errors in spectral type determination" (A&A, 318, 443, abstract).

13. "In summary, nothing simple works" (concerning the second-parameter problem in globular clusters; Ap95, § 12.8; Ferraro et al. 1997a).

14. "Our readers will no longer be getting 60,000 word articles about zinc." This was actually the current editor of *The New Yorker* at the onset of her tenure, and since we always rather liked 60,000 word articles about zinc, we note with enthusiasm a 20,000 word article about mercury (Smith 1997), the element, not the planet.

4.4. Both Citers and Citees of Some Classic References

The oldest we happened to notice was the work by W. W. Campbell in 1894, mentioned by Savage et al. (1997). Unfortunately the Campbell (1894) reference was given incorrectly. The turn-of-the-century journal *Astronomy and Astro-Physics* is not the same as the "European Journal" *Astronomy and Astrophysics*, born in 1969. Any bets whether we can make it come out right here?!

A close second is work by Solon Bailey in 1896, mentioned by Gies et al. (1997). The paper is roughly the discovery of what is now called the Struve-Sahade effect.

Einstein's 1936 paper on gravitational lensing is widely cited, but Renn et al. (1997) make clear that the calculation was done in 1912 and went unpublished because Einstein thought it "wenig wert." Zwicky's judgment on this was perhaps better. A "pre–post-discovery" of the possibility of gravitational lensing of one star by another, meaning after Chwolson's 1924 paper but before Paczyński's 1986 one, is contained in the unpublished Ph.D. dissertation of Maria Petrou (Petrou 1981). The more Cantabridgian author remembers well asking her how her thesis was coming along and not understanding the answer very well.

Luminous blue variables are sometimes eponymously called Hubble-Sandage variables, but Szeifert et al. (1996) note that Willem Luyten found the first two in 1927 and 1928, when Hubble was busy with other things and Sandage was *very* young.

A-masing: We should have noted in Ap96 (§ 8.1) that the possibility of population inversions in astrophysical molecules and "negative absorption" as a result had been suggested by Cillie (1936) and by Baker & Menzel (1938), but we had momentarily forgotten it, until reminded by Strelnitski et al. (1996).

Masing is, of course, a counterexample to the principle that you can't fool Mother Nature. Another is using collisions to give homopolar molecules a transient dipole moment, thus strengthening their lines. Borysow et al. (1997) credit the idea to Herzberg (1952), which goes some way to make up for his having declared that the 3 K temperature of excited interstellar molecules was of limited significance. *The Bell System Technical Journal* has been one of the leaders in reporting attempts to fool nature (often successful ones), and it is thus cited by Lyon (1997) as the first home of a paper on something like the methods of maximum entropy and maximum likelihood.

This item could have gone at least two other places because Griffiths et al. (1996) used weak gravitational lensing by galaxies in an *HST* survey field to show that the giant ellipticals there cannot be shaped like a de Vaucouleurs (1948) or $r^{1/4}$ profile. Gravity also showed itself to be a weak force in the limits to gravitational radiation set by Kravchuk et al. (1997). Their result might alternatively have come under "difficult methods," since they were using a seismograph to monitor triggering of Earth's normal modes in the absence of earthquakes, a method they credit to a 1967 paper by Joseph Weber (a close friend of the more relativistic author).

Volume 17, Nos. 3 and 4, of the *Journal of Astrophysics and Astronomy* was a memorial to S. Chandrasekhar. Two of the many items worth noting are (1) that he was among the first to endorse the idea that the energy source for supernovae is the formation of neutron stars (Chandrasekhar 1939) and (2) that some of his work on general relativistic instabilities in white dwarfs (Chandrasekhar & Tooper 1964) had been anticipated by Kaplan (1949).

You too were undoubtedly taught not never to use double negatives but may still be interested to hear that the Cowling anti-dynamo theorem (Cowling 1939) does not apply in the spacetime around a black hole (Nunez 1997).

A very positive positive, on the other hand, is the achievement of the diffraction limit to full width at half-maximum of images obtained with the Lick 120 inch telescope, using a sodium-laser "guide star" reported by Max et al. (1997), who note that the suggestion can be traced back to Babcock (1953). And we are grateful to the authors for explaining what a Strehl ratio is, since we had forgotten an equal number of times to having been told. It is the ratio of peak intensity to what you would get if diffraction were the only thing against you. One is not a likely value. Who was Strehl? Ah; that you must find out for yourself. Ignale et al. (1997), who have used the Hanle effect to measure magnetic fields in stellar winds, however, generously both explained it and credited Hanle (1927).

4.5. That Happy Company ...

Who expect to live a long, long time, including the schedulers of the longest astronomical conference, "Brown Dwarfs and Extrasolar System Planets Workshop, 17–120 March 1997" (*AAS Newsletter*, No. 83, p. 8), and the writers on what the universe will be like when Earth's last picture is painted and the oldest M star has died (Adams & Laughlin 1997; Laughlin 1997).

Which includes George Gatewood, who has frankly withdrawn Lalande 21185 (Ap96, § 3.1) from the ranks of the contenders for extra–solar system planets on the grounds that he is seeing "an acceleration" not "an orbit" (and Paul Butler who passed on the information).

Of colleague Muhamed Muminovic of Sarajevo and his friends who have completed clearing field mines from the railroad between Sarajevo and Tuzla (and Korado Korlevich of Visnjan Observatory for passing on the news that conditions are slowly improving there). If you want to check out how the astronomy is coming, their home page is http://astro.visnjan.hr and is the only one we will mention in this review. We are warned that connection time can be long and that portions of it are maintained only in Croatian (which, at least, is not written in squiggly letters).

Comprising the possibly Daltonian authors or editors of MNRAS, 284, 27 (Fig. 2), the caption of which explains that "the color table has been chosen to delineate...", but the figure is in glorious black and white. And at least one of the pairs of authors of Luu & Jewitt (1996), who say that asteroid 1993 SC is gray and Tegler & Romanishin (1997), who say that it is red.

Both of the authors of "On the Revision of Radiometric Albedos and Diameters of Asteroids" by Alan W. Harris and Allan W. Harris (Harris & Harris 1997). And yes, both the middle names are William. Only one of them is listed in the current AAS directory; we are not quite sure which one.

5. HIP, HIP, *HIPPARCOS*; OR, TWO AND A HALF CHEERS FOR OUR SIDE

Ap96 (§ 1) welcomed the first descriptions of data and their implications from the European astronometry satellite, *Hipparcos*. Several things have happened in the intervening year. Item zero, as it were, was a press release giving the impression that one or more important problems in cosmology had been solved by making the universe a bit older and its contents a bit younger. Naturally, things are not that simple.

5.1. Progress

First, the teams associated with the project have continued to examine the total data base and to provide additional information about it (Perryman et al. 1997, summarizing the *Hipparcos* Catalogue; Lindgren et al. 1997, on the double star annex; Høg et al. 1997, on the Tycho Catalogue; van Leeuwen et al. 1997a, on the photometric system; Geffert et al. 1997 and Odonkirchen et al. 1997 on the comparison of the proper-motion system with an absolute one). For those who were not waiting with bated breath for these papers, we remind you that the main *Hipparcos* Catalogue (ESA 1997) contains accurate positions plus parallaxes and proper motions (of widely varying accuracy) and ancillary photometric and other data for about 10^5 stars, including all down to about 8th magnitude and a subset of fainter ones. The double star annex presents about 30,000 systems of the sort we would normally call visual and astrometric binaries. And the Tycho Catalogue includes less precise information on another, mostly fainter, 10^6 stars. The accurate positions can eventually be used to register optical and radio coordinate systems tightly enough to look for correlations in jet structures and the like (Capetti et al. 1997). The parallaxes and proper motions can be used both to investigate individual stars or astrophysically interesting groups and statistically to improve the calibration of our distance scales that rest on Cepheid and RR Lyrae variables and on fitting of open cluster main sequences to the Hyades and Pleiades.

Second, the data requested by "the 1982 proposers" (including the grayer haired author) in their 1982 proposals were released to them in January. Third, the entire data base became publicly available in print, on CDs, and electronically in June. Fourth, scientific results have begun to appear in press releases, conference abstracts (including a session at the 1997 General Assembly of the International Astronomical Union), and even the archival literature. Some of the results are distinctly puzzling, and the cheering, therefore, has not been quite universal. The results should not be taken as final, however, if only because the process of defining just how the catalogs should be used is not complete. For instance, tying the coordinate system to an extragalactic one requires several intermediate steps, involving "radio stars," quasars, and several radio interferometric arrays (Kovalevsky et al. 1997), as well as stars observed in common with *HST* (Tucholke et al. 1997).

5.2. Individual Stars and Classes

Let's start with them, because they seem to be less distressing. β Pictoris (Crifo et al. 1997) lands quite close to the main sequence at a distance of 19.3 pc, with no need for circumstellar extinction. A group of 54 barium stars (Bergeat & Knapik 1997) turns out to include dwarfs, giants, and supergiants from G0 to K4. All are at least consistent with the standard scenario of pollution by a more evolved binary companion, though most looked single to *Hipparcos* (presumably because the white dwarf companions are very faint). The putative Mira variables included in the catalog are apparently all honest giants, and the 16 examined by van Leeuwen et al. (1997b) have parallaxes of 1.5–9.8 mas.

Van der Hucht et al. (1997) report that γ^2 Vel is 258 ± 40 pc away, in front of the cluster Cr 173, where it contributes to ionization of the Gum Nebula. Schaerer et al. (1997) have also looked at γ^2 Vel and find masses of 5 and 29 $M_\odot$ for the Wolf-Rayet and O-star components, respectively. This appears to be one of a number of cases in which more than one group received the same early-release data. Høg & Petersen (1997) looked at seven high-amplitude δ Scuti stars, including AI Vel and SX Phe, and described them as being fitted by normal main-sequence and post–main-sequence evolution. Since SX Phe, at least, is some sort of blue straggler, probably resulting from mass transfer or merger in a close binary, the result is not as comforting as you might suppose. Presumably, they mean that the stars show no evidence of merger-induced mixing and look normal apart from the straggle factor. A group of Herbig Ae/Be stars (the traditional high-mass equivalent of T Tauri, pre–main-sequence objects) indeed all came out brighter than main-sequence stars of the same temperature, and the stars that have physically moved away from star formation regions look older than the others, in the sense of being closer to the main sequence, as you would expect (van den Ancker et al. 1997).

And, finally, if we are allowed to regard the Large and Small Magellanic Clouds as individual, interesting objects, their proper motions (Kroupa & Bastian 1997) agree with the ground-based values and put the two galaxies on parallel paths, with the Magellanic Stream trailing behind. The measured values differ from zero by only about one standard error, as turns out to be the case for *Hipparcos* numbers pertaining to all kinds of things you might want to study.

5.3. Statistical Studies

V471 Tau provides a natural transition. It is indeed in the Hyades (Provencal et al. 1997; Werner & Rauch 1997). Ah, but where are the Hyades, not to mention the Pleiades, globular clusters, and Cepheid variables that we were counting on *Hipparcos* to locate for us? A number of values for the distance to the Hyades determined from the ground appeared during the reference year. Torres et al. (1997a) reported 48 ± 2 pc from astrometry and a new radial velocity orbit for the binary 51 Tau. The same group (Torres et al. 1997b) found 47.4 pc from 70 Tau, also studied as both a spectroscopic and visual binary, and a best value of 47.6 ± 1.8 pc (Torres & Latham 1997). The moving cluster method led to 45.8 ± 1.2 pc (Cooke & Eichhorn 1997), while van Altena et al. (1997a) concluded that the ensemble of direct measurements of parallax implied 44.7–46.8 pc. These numbers do at least all overlap within their errors.

Hipparcos and *HST* Fine Guidance Sensor data appeared at almost the same time, and they, in contrast, do not overlap. Van Altena et al. (1997b) provide a comparative analysis of proper-motion (moving cluster) and direct parallax determinations from the two data bases, leading to best values of 48.3 pc (*HST*) and 46.3 pc (*Hipparcos*). But the most important conclusion is that there are real, systematic differences between the two data sets. Turning to the Pleiades, we find that *Hipparcos* has placed it a good deal closer than it used to be (116 pc vs. 125 pc), a location that S. van den Bergh (1997, private communication) describes as "impossible."

The situation does not improve as we look to larger distances. The first and most widely quoted press release came from 1982 proposers Feast & Catchpole (1997). They had requested parallaxes for a large number of field Cepheid variables and used those that are at least 3 times their standard errors to recalibrate the period-luminosity relation. They put the Large Magellanic Cloud at 55 kpc, compared to 50 kpc adopted by the *HST* Key Project Team. Loud was the rejoicing, on the assumption that everything would carry smoothly across, so that the Hubble constant went down 10%, its reciprocal (and so the age of the universe) up 10%, and the globular clusters would move out, too, making the stars that are just leaving their main sequences brighter, more massive, and shorter lived. This would reduce the lower limit they set on the age of the universe.

Inevitably, it's not that simple. If, instead, you tie your Cepheids to the ones in open clusters and those to the Pleiades at 116 pc, everything then moves in rather than out, putting the LMC at about 46 pc, raising H_0, lowering its reciprocal, and making the globular clusters older than ever.

Okay. Let's try looking directly at the globular clusters, or at least at field horizontal-branch and RR Lyrae stars close enough to us to have meaningful individual or statistical parallaxes. These can, in turn, be used to calibrate the clusters. Since the LMC also contains RR Lyrae variables, you also get another crack at it. De Boer et al. (1997) tackled field horizontal-branch stars and found them faint, so that cluster RR Lyraes would have $M_v = +1$ or larger, and the clusters move in closer to us. A group led by Fernley (1997) went after field RR Lyraes directly and also came up with a shortened distance scale, putting the LMC at 44.9 kpc and rendering the globular clusters correspondingly more geriatric. On the other (and by now roughly fifth) hand, Reid (1997), who was also a 1982 proposer and apparently asked for essentially all the Lowell proper-motion stars, has used 15 local subdwarfs to tell him the distance to M3 (or at least its main sequence). The result is RR Lyraes at $M_v = +0.15$, the LMC at 53.7 kpc, a somewhat longer expansion time for the universe, and somewhat shorter lifetimes for the globular clusters. He suggests 12–13 Gyr using standard isochrones. Harris et al. (1997) are willing to go as low as 10 Gyr for the cluster ages, though with those distances and luminosities, none of the isochrones really fits.

Several ground-based determinations of the distance to the LMC also appeared during the year. Multi-mode RR Lyraes (whose brightnesses you can, in principle, calculate, if not from first principles, at least from second or third) in the MACHO data base lead to a distance of 49.7 kpc (Alcock et al. 1997b), and another analysis of single-mode RR Lyraes (not easily understood from the presentation) pulls it all the way back to 44.7 kpc. Hopes that you could get an unambiguous distance from the geometry of the surroundings of SN 1987A were excessively sanguine; after all, the analogous method doesn't really work even for the much simpler Crab Nebula.

How might this all get sorted out?

1. Proper application of Lutz-Kelcker corrections, according to Ivan King (1997, private communication).
2. Better allowance for the effects of unresolved binary companions of the Cepheids and others (Wielen 1997).
3. Perhaps comparison of interesting and uninteresting stars in the same fields, according to George Herbig (1997, private communication, in which he declined to be associated with the publication of the results of our 1982 proposal; the papers have appeared).
4. In addition, you will need to allow for some large stars seeming to move because their surfaces are not uniformly or symmetrically bright (Lattanzi et al. 1997 on the Mira variables R Leo and W Hya as tracked by the *HST* Fine Guidance Sensor).
5. Or perhaps there is something fundamentally wrong that cannot be sorted out post facto. We hope this isn't the answer, since a repeat of the *Hipparcos* mission in the lifetimes of any of the 1982 proposers is fairly unlikely.

Meanwhile, there is a little bit of good news from the ground. First, subdwarfs in the field and in globular clusters have the same average and extreme metallicities (Gizis 1997), a good thing if you want to use one to figure out the brightnesses of the other. Second, extra ultraviolet opacity is still needed to make model atmospheres and isochrones fit the light we see coming from Arcturus (Short & Lester 1996). This may not sound like good news, but a very large sample of field Population I stars with *Hipparcos* parallaxes also requires extra ultraviolet opacity to make reasonable isochrones go through the observations (Baglin 1998). And a corresponding phenomenon has been known in globular clusters for some time.

6. SOME FAVORITE WIDGETS

The author who has never been able to figure out which end of the screwdriver you are supposed to look through remains enormously impressed by people who can build things and make them work. Their names all too often go unrecorded, including here, but we hope they find some satisfaction in the exciting science that has been achieved with their widgets.

6.1. X-Rays

The year congratulated one newcomer and mourned another. *IXAE* (the *Indian X-Ray Astronomy Experiment* went up on 1996 March 21 and sees quasi-periodic oscillations in X-ray binaries and other good things (Paul et al. 1997), while *HETE* (the *High Energy Transient Explorer*) and the rest of its launch package went into the sky on 1996 November 4 but did not deploy properly and so were unable to look at anything except each other.

Meanwhile, *BeppoSAX* and *Rossi XTE* go on from triumph to triumph. The standard package of papers on the former mission and its instruments appeared (Boella et al. 1997 and several following papers), and its role in forcing the surrender of gamma-ray bursters is addressed in § 11. All kinds of science, from comets to quasars, is coming forth from both missions.

We focus, however, on what seems to be the final word in a long paragraph, concerning the rotation periods of the neutron stars in low-mass X-ray binaries. These ought to be pretty close to the millisecond minimum allowed, because incoming material from the companion arrives with considerable excess angular momentum and should spin up the stars. But, because the neutron stars have (for whatever reason, and this is still under debate) relatively weak magnetic fields, the rotation periods do not modulate the X-rays or other fluxes in obvious, conspicuous ways.

This remains true, but *RXTE* has opened the era of the unobvious and inconspicuous, in the form of kilohertz QPOs in a number of these systems. First reports appeared just in time to be mentioned in Ap96 (§ 5). The number of published kilohertz sources has now reached and surpassed the "you've had five, but who's counting?" point beyond which no one can remember all the individual numbers. Particularly noteworthy are 4U 1636−53, with QPOs at about 900 and 1163 Hz (the current record high: Wijnands et al. 1997); KS 1731−260, whose rotation period now seems more likely to be 3.8 ms than 1.9 (Wijnands & van der Klis 1997); MXB 1743−29 at 589 Hz, which may be showing straightforward rotational modulation (Strohmayer et al. 1997a); 4U 0614+091, where it seems most likely that the rotation frequency is the different between the two shifting QPO frequencies (Ford et al. 1997) also somewhere around 3 ms; 4U 1728−34, with a hot spot in the accretion column (Strohmayer et al. 1997b); and the first such source in a globular cluster, 4U 1608−52 (Smale et al. 1997).

On the theoretical side, there were papers considering the importance of the angle at which you view the sources (Kuulker & van der Klis 1996); on rotational splitting of frequencies (Titarchuk & Muslimov 1997); and on the period of the last stable orbit around a star as a function of its mass, which (after you have made the proper relativistic corrections) can be used in combination with gravitational redshift to solve for both mass and radius of the neutron star. Kaaret et al. (1997) obtain $2 \pm 0.1\ M_\odot$ and $R = 9.6$ km for 4U 1636−536, on the assumption that a 4.2 keV spectral feature is redshifted Fe XXV. Which rotation periods and orbit periods are possible naturally depend on your choice of the equation of state for dense nuclear matter, and Goussard et al. (1997) show that a few very extreme versions are already impossible.

6.2. The Ultraviolet

The shuttle-borne ultraviolet trio, HUT, WUPPE, and UIT, flew again some time ago. One slightly arbitrary result each. Large and small interstellar grains are not distributed in the same way, based on incomplete correlation of optical and UV polarization (WUPPE; Anderson et al. 1996). Metal abundances in E and S0 galaxies derived from continuum colors come out higher than those based on detailed line profiles (HUT; Brown et al. 1997b). One's knee-jerk reaction to assume that the lines are right and the colors wrong should be tempered, at least among us old folk, by the memory of a similar discrepancy in globular clusters, where the colors turned out to be right. UIT has been used to try to get some "ground truth" on what nearby galaxies look like in the rest-frame UV. Seyfert galaxies, for instance, can have ratios of AGN to starlight contributions at their centers that range from nearly zero to nearly infinity (Fanelli et al. 1997).

Contrary to popular superstition, *HST* is not the only ultraviolet game in town. FAUST has imaged a bunch of elliptical galaxies in Virgo and has found a range of ratios of UV-to-optical flux (Brosche et al. 1997), while ORFEUS has provided detections of H_2 in unexpected places (Jenkins & Peimbert 1997).

Further into the ultraviolet, the imaginative continue to make use of data left behind by *Skylab* (Widing 1997 on the solar abundance of neon) and *Voyager* (Li & Leahy 1997 on colliding winds in symbiotic novae like RR Tel). But, by now, the extreme UV belongs largely to *ROSAT* and the *Extreme Ultraviolet Explorer*. The fainter sources now being catalogued are virtually all stellar coronae, with a distribution on the sky driven largely by transparency of interstellar material in different directions (Lampton et al. 1997), but there remains a significant residue of unidentified sources whose spectra don't persist into the X-ray region the way most coronae and white dwarfs do. Maoz et al. (1997a) suggest that they might be old, isolated neutron stars.

6.3. Visible Light

We welcome the Hobby-Eberly Telescope (HET), which collected its first official photons on 1996 December 10. A new radial velocity spectrometer (which we still think should be called a Griffinometer) uses an echelle to achieve 15 m s^{-1} resolution. It is actually called ELODIE (Baranne et al. 1996). A three-element optical interferometer (of six planned) is using closure phase (Jennison 1958) to improve its sensitivity (Benson 1997). Not surprisingly, they looked at a star. Other newish technologies have led to adaptive optics spectroscopy (Rouan et al. 1997) and interferometric polarimetry (Rousselet-Perrault et al. 1997).

The AAVSO (American Association of Variable Star Observers) is the first and still most successful biomechanical neural network of which we are aware, and it continues to reveal complex, long-term stellar behavior that isn't necessarily very well understood but that couldn't even have been found any other way, for instance, decadal outbursts and minima in the symbiotic star YY Her (Munari et al. 1997).

6.4. The Infrared

A whole journal issue could easily be filled with early results from the *Infrared Space Observatory*. In fact it was: Vol. 315, No. 2 of *Astronomy and Astrophysics* (Kessler et al. 1996 with some mechanical details and several dozen following letters). Targets have included galaxies, active and normal, clusters of galaxies, star formation regions and stellar populations in the Milky Way, individual stars, planets, comets, and, of course, theories. What stands out is the large fraction of results that are more or less wet. That is, after decades of hiding behind terrestrial water vapor, astronomical water, both gaseous and solid, is turning up all over the place. There are even contexts where the long-sought spectral features of water now count as noise when you are trying to see something else.

Another successful satellite, the *InfraRed Telescope in Space* (*IRTS*), was launched on 1995 March 18 and completed its survey of the sky on April 25 (when the helium ran out). A number of its results, focused largely on gas and dust in the Milky Way, appeared in a group during the reference year (Murakami et al. 1996, describing the spacecraft and instrument, and about 10 following papers).

Two infrared surveys of the sky or half-sky have begun yielding results. DENIS early data appear in Ruphy et al. (1997). The disk of our Galaxy (at least the cool stellar disk) stops at about 15 ± 2 kpc in the direction of the Galactic anticenter. Cambresy et al. (1997) report on more crowded and obscured regions and conclude that, if you want to measure interstellar extinction by counting stars, you will do better in the J band than in V whenever A_v exceeds 4 mag—otherwise, there aren't enough stars to count.

2MASS began official operation in September, but the earlier verification data seem to have turned up some very cool stars, including one later than M10 (Kirkpatrick et al. 1997). Proper application of the MKK process would seem to require another letter of the alphabet, and, with due regard to the customary mnemonic for OBAFGKM, we would like to suggest that the next cooler type after M9 should be PO ("Oh be a fine geek; kiss me passionately.").

Some 0.5 mm (500 μm) polarimetry (which concluded that cold dust is a lot like warm dust; Schlenning et al. 1997) goes right here, because whether it is IR or radio obviously depends on which way you choose to write the wavelength.

6.5. The Radio Regime

The first satellite dedicated to doing very long baseline interferometry from space was promoted from the preliminary designation *VSOP* to *HALCA* following its successful launch in February and has seen its first useful fringes (we are tempted to say photons but suspect that radio astronomers don't think that way). They came from a quasar 1156+295 when both *HALCA* and the VLBA were pointed at it (Romney 1987).It is useful to remember that the acronym *HALCA* and the Japanese word Haruka have nearly identical pronunciations. We have mastered the nearly silent "U" after years of ordering sukiyaki and are working on the R/L by saying "locket frights" over and over.

Back on the ground, a new VLBI network, involving stations in the former USSR, Tasmania, and mainland Australia has begun operation (Slysh et al. 1996). And Sault et al. (1996) have described a way to recover antenna spacings from $D + d$ to $D - d$ (the sum and difference of antenna size and minimum separation) so as to fill in the u-v plane and produce better images. They call them radio mosaics.

6.6. Particles and Fields

Ulysses passed over the solar pole a while back and filled a whole issue of *Astronomy and Astrophysics* (Marsden et al. 1996 and following papers) with results on magnetic fields, solar and extra-solar cosmic-ray compositions, and many other things. Some of the results actually improve on laboratory physics (Du Vernois 1997). ALICE is a balloon-borne cosmic-ray isotope spectrometer, which showed, for instance, that silicon and iron in the cosmic-ray source composition are a good deal like the solar system mixes (Hesse et al. 1996). Given how much balloon astronomy has been done from Alice Springs, Australia, we regard it as confusing that this flight occurred in Canada.

On the solar neutrino front, SAGE (the Soviet-American Gallium Experiment) underwent testing of its capture rate by exposure to a ^{51}Cr source. The count rate is 0.95 ± 0.11 of what theory predicts when the neutrino source is close enough that no rotations or decays can occur. Thus we should believe that, when the neutrinos come from an astronomical unit away, only half as many low-energy ones reach us as you had expected. At the high-energy end of the neutrino spectrum, the upgraded Superkamiokande in Japan reported its first results—also about half of the theoretical flux (Totsuka 1997). Results are most effectively interpreted in combination with solar oscillation data (Bahcall 1997) and can be modeled by a plausible modification of our theory of the weak interaction (giving neutrinos a small rest mass) but not by any plausible modification of the structure of the solar interior.

6.7. MACHOs and Their Relatives (Surveys and Results)

The original goal of these projects was to pick out that part of the galactic dark matter that was attributable to MAssive Compact Halo Objects and so would gravitationally lens background stars. There is no denying that the official result of the first 2 years of the campaign has been published (Alcock et al. 1997c). They found eight microlensing events in the direction of the Large Magellanic Cloud, which indicates about 6 times the optical depth in lensing you would expect from known, low-mass stars, and about half of the total needed to account for all the dark matter, though these numbers still have large error bars.

The distressing part is that the lens mass that bets fits the ensemble of events is $0.5^{+0.3}_{-0.2}\,M_\odot$. No sort of known or imagined object in this mass range is a very happy solution. Real stars would be seen. Primordial black holes at the low end of the mass range have been revived by Yokoyama (1997), but we think the X-rays from accreted gas when they pass through the Galactic disk would outshine the known Galactic background.

Neutron stars are really too massive (and have other problems; Möller & Rouley 1997). Planets are too small (Alcock et al. 1996b). One begins to think, with Dorothy Parker, that you might as well live.

What is left are old white dwarfs, and the observers themselves are the first to emphasize that the number required is on, or beyond, the ragged edge of getting you into trouble with galactic chemical evolution, numbers of associated M dwarfs you would expect from a reasonable initial mass function, the luminosities of galaxies at moderate redshift, and big bang nucleosynthesis. Gibson & Mould (1997) concur. There are a couple of possible escape hatches. First, the error bars on masses and everything else remain large, since each event can be fitted by a wide range of parameters. Even the location of the lenses in the halo of the Milky Way is not absolutely established (Mao & Paczyński 1996). Second, if light from the star being lensed is blended with light from the lens or from an unrelated fore/background star, the observer will underestimate the duration of the event and the mass of the lens causing it (Woźniak & Paczyński 1997).

Meanwhile, preliminary results are in from the effort to find lensing of stars in the Andromeda galaxy. No events so far, which is already a bit of a limit on brown dwarfs as the dominant dark matter (Crotts & Tomaney 1996). And, of course, all of the surveys continue to perform magnificently as locators of variable stars. Beaulieu et al. (1997; EROS) report on Cepheids in the Small Magellanic Cloud that display beat periods with period ratios different from those characteristic of the LMC and Milky Way. Alcock et al. (1997d) report 611 eclipsing binaries in the LMC from the MACHO project, nearly 10 times the number found by the most complete previous survey (due to Sergei Gaposhkin). And the OGLE project has surveyed for W UMa contact binaries in the direction of Baade's window, finding large numbers (one star in about 200) except among the M dwarfs, where there are none (Rucinski 1997). The OGLE project has completed its last year of data collection with a borrowed telescope and will begin using a dedicated instrument shortly (Udalski et al. 1997).

7. ASSORTED COSMIC CHIRALITIES; OR, AT LEAST TWO LEFT FEET

This section was inspired by one big step forward and one backward during the year. The former involves complex molecules in meteorites, and the latter, the polarization of distant radio sources, after which, we curl up with some spirals, before spinning off into an assortment of other objects and events with curious-sounding asymmetries.

7.1. Molecules in Murchison

The detection and analysis of organic molecules in meteorites has a sadly checkered history. Early reports, based on museum specimens, were of a mix of amino acids so like that found in human tissues that one could only suppose nearly human entities had been in close contact with the meteorites. They were in fact museum directors.

The case for truly extraterrestrial organic molecules could be made only with the availability of less handled, newer falls (particularly Murray and Murchison), and the case rested on two points. First, there were amino acids (and, later, other similarly complex molecules) that don't happen to be among those that terrestrial life has "chosen" to use. Second, even molecules of the chosen types were represented by equal amounts of their right- and left-handed forms, where life uses only one or the other. This is called a racemic mixture. "Left" and "right" are defined by the direction that a solution of the molecules rotates the plane of polarization of a passing light beam. And you will never believe the etymology of "racemic" unless you look it up for yourself, so please do. Reading *The Documents in the Case* by Dorothy Sayers and Robert Eustace is also recommended, and if you never come back to Ap97, it is our own fault.

The last decade has seen sporadic reports of slightly nonracemic mixes of molecules, but the specter of the museum director, with his sweaty, contaminating fingers, continued to loom. Two recent papers seem to have resolved the issue in favor of extraterrestrial chiral asymmetries. First, Cronin & Pizzavello (1997) reported 7% and 9% excesses of the L-enantiomer in two amino acids that are not among the "chosen" of terrestrial life. Second, Engel & Macko (1997) have found similar modest L-excesses (yes, that's the one we use) in "chosen" molecules, but with associated anomalies in nitrogen isotopes that indicate terrestrial contamination was not responsible.

Two questions immediately arise. How did the excesses form; and why should it matter? The reporting papers (and editorial discussions in the same issues of *Science* and *Nature*) suggest that either circularly polarized light or beta decays in the regions where the molecules formed could have established the L-excesses. As for the utility, if Earth acquired a significant fraction of its volatile materials from comet and asteroid impacts, then it could have started with excesses of the "correct" handedness in its initial supply of organic material (Chyba & Sagan 1997). An additional implication is that dominant handedness in chemistry we might find elsewhere is not necessarily a signature of extraterrestrial life (Lederberg 1965).

Meanwhile, however, it has become clear that large, long-period comets of the sort that have dominated recent skies cannot have been the main source of Earth's water. Both Hale-Bopp and Hyakutake had ratios of deuterium to hydrogen roughly twice that in our oceans (Owen et al. 1997).

7.2. The Untwisted Universe

A large fraction of science popularizers picked up on a report (Nodlund & Ralston 1997) of non-uniformity over the sky of the polarization of radio galaxies and quasars at redshifts greater than 0.3 (after correction for Faraday rotation). The authors attributed the asymmetry to an intrinsic chirality of the universe, citing a subset of theoretical discussions and predictions, though not some of the more physically motivated ones (Carroll et al. 1990; Carroll & Field 1997).

The main flaw in Nodlund & Ralston's approach was the use of data collected before 1985 (and before the VLA came into routine operation) that necessarily had quite poor angular resolution. The polarization vector of radio source cores and jets is often parallel to the jet over part of its length and perpendicular elsewhere; thus, the average angle of polarization you find depends largely on your beam size. Additional problems arise from trying to combine northern and southern hemisphere data, collected with different instruments at different angular resolutions and wavelengths.

Observers with access to better data were immediately quoted as doubting the result or, in one case, misquoted as supporting it (Kronberg 1997). And one data set of radio and optical polarizations obtained at high angular resolution has now been published by Wardle et al. (1997). Not surprisingly, their universe is not birefringent. A very small subset of those data had already been looked at and used in 1995 to set an upper limit to the chirality of the universe slightly below the positive result reported by Nodlund & Ralston (1997). That paper (Goldhaber & Trimble 1996) was published too early to count as a highlight of 1997, and it was clearly not a highlight of 1996 either, since Nodlund & Ralston didn't cite it. Hence we violate no principles by mentioning it here!

7.3. Spiraling In

The inspiration for this section was the report of the first clear case of long-expected spiral ($m = 2$) arm structure in the accretion disk of a dwarf nova, IP Peg (Steeghs et al. 1997). The disk structure was probed with Doppler tomography; the probable cause is tidal forces from the companion (Sawada et al. 1986; Dgani et al. 1994); and the arms should increase the efficiency of angular momentum transport through the disk, changing the rate and nature of outbursts (see § 9.3 on why dwarf novae nova).

Theory says that accretion disks in general should have lots of spiral structure, with $m = 1, 2$, or 3 appearing under different circumstances (Drimmel 1996). Thus one should not be surprised that it has been seen in at least one X-ray binary (Reig et al. 1997 on LSI $+61°$) and a number of Be stars (Okazaki 1997; Hammel & Hanuschik 1997). These are all single-arm ($m = 1$) modes. Presumably Cassen & Woolum (1996) have in mind $m = 2$ modes for their protostellar disk models, but we haven't checked on whether such have actually been seen.

All the rest of our spirals are galaxies, beginning with the strangest. NGC 4650A has H I spiral arms in a disk of gas perpendicular to the main plane of the galaxy, in what one would normally call a polar ring or disk (Arnaboldi et al. 1997). Next come hosts of active galaxies. Spirals are perfectly respectable homes for radio-quiet QSOs, etc. (Boyce et al. 1996). But radio sources are supposed to live in non-gassy ellipticals (so the jets can get out). Nevertheless, Carilli et al. (1997a) have logged in the second radio-loud AGN in a disk galaxy, at $z = 0.67$. It (telephone number beginning with 1504) and its predecessor (at R.A. $14^{\rm h}13^{\rm m}$ and $z = 0.25$) differ in having one- versus two-sided jets and in a variety of other ways.

Spiral galaxies are supposedly divisible into two types—grand design (where you can trace the arms all the way around) and flocculent (where you cannot). But NGC 5055, a prototypical flocculent spiral, has a grand-design, two-armed underlying density wave of high pattern speed (Thornley & Mundy 1997), which you can trace in CO (Kuno et al. 1997). Sleath & Alexander (1996) have a model that also has both sorts of arms, which they fitted to M81.

It also came as a bit of a surprise to read that 70% of spirals, both Seyfert and normal, have bars if you look hard enough (Mulchaey & Regan 1997). That the Milky Way is one of them is yesteryear's news, though the bar has now also been seen in data from DIRBE (Binney et al. 1997), but not with sufficient luminosity to account for the large number of star lenses it contributes to events seen by the MACHO and OGLE projects (Bissantz et al. 1997). Our home Galaxy also apparently has a modest four-arm component (Amaral & Lepine 1997), though nowhere near so much as NGC 5204 (Sicotte & Carignan 1997), whose multi-arm condition is probably due to an unusually massive halo stabilizing the $m = 2$ mode which would otherwise dominate. The Sun is once again in a somewhat special place, not quite the center of the universe, but at least near the co-rotation radius of the Milky Way, where pattern speed and matter speed are the same (Mishurov et al. 1997).

Single-armed ($m = 1$) spirals are apparently associated with counter-rotating rings of gas and/or stars, which enhance that instability (Lovelace et al. 1997; Comins et al. 1997). We say "apparently" because neither paper actually mentions any real, one-armed galaxies. In contrast, Pherari & Dottori (1997) have proposed NGC 7479 as an authentic example of a spiral whose arms lead rather than trail its rotation. Masolini et al. (1997) have suggested that the large star formation rates in type II Seyfert galaxies are to be attributed to their large asymmetries.

The terrain of just what you expected is rapidly approaching. For instance, rings of gas and stars or star formation, the beginnings and ends of spiral arms, discontinuities in abundance gradients, and the like often occur at the inner or outer Lindblad resonances (places where pattern frequency and matter frequency differ by plus or minus the epicyclic frequency), at co-rotation, or at other resonances (Regan et al. 1996; Storchi-Bergmann et al. 1996; Verdes-Montenegro et al. 1997; Beauchamp & Hardy 1997; Roy & Walsh 1997a, 1997b; Patsis et al. 1997; Sempere & Rozas 1997; Canzian & Allen 1997). One fit along these general lines of a model to 21 cm and $H\alpha$ velocity fields of two galaxies implies that even grand-design arms are transient, damping out and re-forming many times in the life of a galaxy (Mulder & Combes 1996). Flocculent arms are, of course, supposed to do that (Perdang & Lejeune 1996).

And, returning to the realm of the fairly strange, a model that is just too good to be entirely true. Yuan & Kuo (1997) report that, when arms are excited by a bar, excitation at the outer Lindblad resonance makes tightly wound arms that transport gas outward; excitation at the inner Lindblad resonance makes loosely wound arms that transport gas inward; and excitation at the inner-inner Lindblad resonance gives rise to leading arms.

7.4. Other Strange Asymmetries

Several of these are vaguely cosmological in nature. Four years of *COBE* data have been used to put limits on the shear (σ/H) and vorticity (ω/H) of the universe that are 10–100 times tighter than the pre-*COBE* ones (Bunn et al. 1996). The limits say that the shear and vorticity were not in Planck equilibrium with other cosmic parameters in the early universe (Barrow 1995). Another sort of cosmic asymmetry is a region of nonuniform expansion, not centered on us, as an alternative to solar motion as a cause of the dipole part of the pattern of the microwave background on the sky. Humphreys et al. (1997) say that this is not absolutely ruled out, but it creates a quadrupole term in the Hubble and deceleration parameters, H and q, that should be detectable in due course (see Paczyński & Piran 1990).

On a much smaller scale, the Local Group does appear to have introduced a modest asymmetry into the expansion around it (Karachentsev & Musella 1996; Karachentsev & Sharina 1997; Governaty et al. 1997). The warps of the Milky Way, M31, and M33 are all aligned to within about 30°. The probability of this being a chance pattern is not terribly small (Zurita & Battaner 1997), but one is alternatively tempted to say, “well, they did it to each other.”

Magnetic fields are always good for tipping and tilting things. Massetti & Storini (1996) have looked yet again at an apparent correlation of solar neutrino flux reaching Earth with solar cycle and blame a north-south asymmetry in the field (which also shows in coronal emission lines). Even more unexpected is the conclusion that pulsars will rapidly turn off if embedded in an external, anti-parallel field of even 10 G (Tsygan 1996). A close, magnetized white dwarf companion could provide such a field. Magnetic fields with significant deviations from axisymmetry are to be found in RS CVn and other close binaries (Mus & Touminen 1997) and in X-ray binaries like GX 17+2 (Kuulkers et al. 1997).

Still more magnetically induced off-centerednesses occur in the disks and winds of binary systems (Arnal & Roger 1997), in bubbles blown in H I by Wolf-Rayet stars (Larwood & Papaloizou 1997), in the strange orientations of the rotation and composition axes of σ Ori E (Groote & Hunger 1997), and in the precessing jets of SS 433 (Panfer et al. 1997).

And, finally, we are especially fond of gauche ethyl alcohol (Pearson et al. 1997c). Contrary to expectation, this is not the sort that makes you misbehave at parties but is merely a state excited 57 K above the ground or trans state.

7.5. A Few Things That Go Backward

Retrograde disks, meaning some portion of the stars and/or gas near the center of a spiral galaxy that don’t seem to know which way the rest is going, appeared in Ap93 (§ 10.8) and proliferated in Ap94 (§ 13), along with some preliminary explanations. These in turn have now proliferated, and it seems likely that both of the main contenders, sudden acquisition of a small galaxy coming out of left field or gradual infall of contrary-minded gas, will work (Thakar et al. 1997). Both can also trigger starbursts (Coziol et al. 1997). Once you have counter-rotation, it becomes possible for a galaxy to develop two bars, one going each way (Davies & Hunter 1997). And you can expect to encounter W. C. Fields having a drink in both of them simultaneously.

Another thing that goes backward is the Sachs-Wolfe effect. That is, if you start making structure in the universe out of adiabatic fluctuations, then the regions of space with more photons than average look cool, because climbing out of the associated gravitational potential costs them more than they had gained from the intrinsic positive temperature perturbation (White & Witten 1997).

You expect globular clusters to lose stars from their outskirts and, sometimes, to get torn apart completely. At least 11 papers during the reference year addressed aspects of this process. We note just one, a review pointing out that a good many of the clusters actually seen in the Milky Way have no business still being around (Meylan & Heggie 1997), though wasn’t there somewhere a late correction pointing out that bumble bees can fly after all? In contrast, only one paper suggested that some clusters near the Galactic center that have double red giant branches might have captured stars from the bulge (Bica et al. 1997).

We are pretty sure there is some place you can perch close to a maximally rotating black hole from which everything will seem to go backward. This is likely to be a hot topic next year, when a few more of the virtual papers have become real. Phrases to look for are dragging of inertial frames and Lense-Thirring effect (no, they are never cited). Meanwhile, Hadrava et al. (1997) have looked at the XRB case, though much of what they predict seems to be comprehensible as mere special relativity, and Bromley et al. (1997) at the AGN case, with an acknowledgement to John A. Wheeler.

8. SOME FAVORITE STARS

Each of these sections had a precipitating event: doubt being cast on the very existence of extra–solar system planets, increasing recognition of the existence of sub-luminous supernovae, discovery of the existence of a new sort of pulsating star, and some objects that still exist but are not quite what we thought they were, but before we were through, each had mushroomed into a whole section. And here you thought existence wasn't a predicate!

8.1. The Primaries of Extra–Solar System Planets

There is no getting around the need to address this issue, for, even as new examples of planets identified by variations in the radial velocities of their primaries continued to appear (along, of course, with a megatude of models) doubt has been cast on the entire enterprise.

Additional data during the reference year included the definitive orbits for the companions of 51 Peg (Marcy et al. 1997) and 16 Cyg B (Cochran et al. 1997), the first proper appearances of ρ^1 Cnc, ν And, and τ Boo (Butler et al. 1997), and, from a new group entering the fray, a companion for ρ CrB (Noyes et al. 1997), which has $M \sin i = 1.1 M_J$, $a \sin i = 0.23$ AU, and eccentricity less than 0.07. The suggestion that the warp of the disk of β Pic is best explained by a Jupiter-mass planet (Brunin & Benvenuto 1996) is not quite the same sort of thing.

Theorists looked both at the reported systems and at other possibilities. Can binaries have planets? Only in a rather restricted range of locations according to Weigert & Holman (1997, on α Cen), though perhaps not quite so restricted as previously thought (Benesh 1966, on η CrB). Could the stars that host "hot" (short-period) Jupiters also have additional, perhaps Earth-like, planets? Yes, according to Gehman et al. (1996). There is no objection to more massive stars having planets, though they will be difficult to detect, and the known lumps in shells of Herbig Ae/Be stars could be the loci of planet formation (Kholtygin et al. 1997). And some of the hot Jupiters might even have habitable moons, provided that said moons are massive enough to retain atmospheres and are adequately protected by magnetic fields (Williams et al. 1997).

Three other theoretical issues attracted attention. First was the possibility that some stars might have started with two planets of Jupiter-like mass, whose encounters kicked one out completely and knocked the other inward to an eccentric, short-period orbit (Rasio & Ford 1996; Weidenschilling & Marzari 1996), though the highest eccentricities seen apparently require more than a single encounter between the planets (Katz 1997b). Second, alternative ways of achieving high eccentricity came from Lin & Ida (1997), who considered interaction with the residual disk, and from Holman et al. (1997) and Mazeh et al. (1997a), who blamed the companion star for the specific case of 16 Cyg B. Mazeh et al.'s (1997b) model to explain a correlation between companion mass and orbital eccentricity (encompassing both planets and brown dwarfs) was overtaken by events, in the form of systems not displaying the proposed correlation.

Third came issues of rotation, synchronization, and associated abundance anomalies, with some regard to solar system analogies. The planet orbiting 51 Peg will survive its parent's main-sequence phase, but not the asymptotic giant branch (Rasio et al. 1996), which is probably true also for the Earth. The standard rates of circularization and spindown of the planets can be calculated, though we currently have no way of testing the answers (Lubow et al. 1997). One non-standard model would already have slowed the rotation period of 51 Peg down to the orbit period of its planet, which is not the case (Rieutord & Zahn 1997). King et al. (1997) have noted that 16 Cyg A and B nicely bracket the solar lithium abundance and suggest that rotationally induced mixing in the presence of planets may be relevant to the lithium depletion rate, Gonzalez (1997) has remarked that ν And, τ Boo, ρ^1 Cnc, and 51 Peg all have metallicities in excess of the solar value. We have already conceded (Ap95, § 7.1) that the Sun has a larger share of heavy elements than either the local interstellar medium or most of its contemporaneous neighbors. At least another 10 papers said more or less the same thing this year, though we note only the case of krypton (Cardelli & Meyer 1997) and are pleased that Superman would not have too difficult a time in the interstellar medium. Gonzalez (1997) suggested that the stars have become polluted during planet formation, though we find at least equally attractive the idea that having lots of refractory material around makes it easier for planets to form, even Jupiters and Saturns, since they have rocky cores (Boss 1997).

Now for the bad news. Gray (1997) has very carefully examined changes in the profile of the 6253 Å line of Fe I in the spectrum of 51 Peg and concludes that he has found non-radial pulsation or running surface waves that are also responsible for the apparent periodic shifts of radial velocity that constitute the evidence for a planetary companion. He is not the only person to have worried about the issue. Hatzes et al. (1997) used a similar, line-bisector method to look for non-radial pulsations of 51 Peg, in a paper submitted before the Gray one but published later, and set quite tight limits. Two papers, Henry et al. (1997a) on 51 Peg, 47 UMa, 70 Vir, and HD 114762 and Baliunas et al. (1997) on ρ^1 Cnc and τ Boo find no evidence for light variability or cyclic chromospheric activity that one would expect to find associated with surface waves or pulsation. It remains true, of course, that effects of star spots and convection can easily mimic or conceal the velocity variations due to a companion, if the period is close to those of stellar rotation or an activity cycle (Saar & Donahue 1997). G–K giants habitually show velocity jitters around 1.5 km s^{-1}, correlated with variability at levels of about 0.01 mag, and so presumably are oscillators rather than planet hosts (Jorissen et al. 1997).

Honesty probably requires allowing the jury to remain out a little longer on this one (though we have already voted), but the real surprise was the glee with which a large fraction of both the popular press and our colleagues greeted this possibility that there might not be planets after all.

Planets orbiting pulsars are well established (Ap94, § 9.5). But they are rare. One new candidate, belonging to PSR B1620−26, has surfaced (Joshi & Rasio 1997), but two other searches (Bell et al. 1997; Bailes et al. 1997) have come up empty-handed (we think we mean CLEANED out or some other more graphic and appropriate cliche).

8.2. Progenitors of Type Ia Supernovae

Circumstances require that these be able to explode about one solar mass of carbon and oxygen to heavier elements, including lots of iron peak elements, without polluting the spectrum of the ejecta with hydrogen lines. This sort of explosion requires the fuel to be degenerate, and models have thus long focused on white dwarfs with other white dwarf or less extreme companions. A particularly popular choice has been a pair of WDs with total mass in excess of the Chandrasekhar limit of 1.4 $M_\odot$ and orbit period short enough that loss of angular momentum in gravitational radiation would spiral them together in less than the age of the universe. And the ongoing problem has been that there are no such binary white dwarfs observed. None. The short-period ones have small total mass, and the more massive pairs have orbit periods of a couple of days or more. The shortest period known, 1.46 hr, belongs to 0957−666 (Moran et al. 1997), and, like the others, the stars add up to only 0.6–0.8 $M_\odot$ total and have a mass ratio close to 1.

None of this has changed. What has happened is a gradually increasing recognition that Type Ia supernovae have some variety in their light curves, peak brightnesses, and spectra and that these are likely to be associated with a range in the mass of ^{56}Ni (etc.) produced and, therefore, a range in the mass of degenerate material involved in the explosion. This has prompted theorists to search for mechanisms that might lead to explosions of sub-Chandrasekhar masses.

On the observational front, the subluminous Type Ia supernova SN 1991bg (Turatto et al. 1996), with its also subnormal kinetic energy, needed only about 0.07 $M_\odot$ of ^{56}Ni to power it (Mazzali et al. 1997), while the more vigorous and slowly rising SN 1994D needed 10 times as much, 0.7 ± 0.3 $M_\odot$ (Vacca & Leibundgut 1996). Some spectra as well as light curves are best fitted by sub-Chandrasekhar explosions (Nugent et al. 1997; Liu et al. 1997).

Several papers have drawn attention to a large range in real peak brightness among the sorts of Type Ia supernovae often included in calibrations of the distance scale, in tones of voice that range from triumphant to grudging (Riess et al. 1997; Höfflich et al. 1996; van den Bergh 1996b, who notes also that events in spiral galaxies are brighter than those in ellipticals). The range in peak brightness is perhaps as large as a factor 20 and is at least 0.4–0.8 mag even for a given rate of decline from peak, the normal abscissa in attempts to correct peak brightnesses to a standard value. This range does not include the events of 1181 and 1680, candidates for historical supernovae in the Milky Way, whose peak absolute magnitudes were only about $M_V = -13$ (Hatano et al. 1997) and which we have no reason to think were Type Ia, or any other recognizable type.

The issue of just how the explosion occurs remains in some (fairly subtle) dispute, which seems to have a component of "my idea is better than your idea" even when the ideas are indistinguishable to outsiders. Contenders include deflagration (explosions travelling slower than the local sound speed), detonation (explosions travelling faster), deflagration turning into detonation, one or both with pulsations, and one or the other igniting away from the center of the degenerate star (Niemeyer et al. 1997; Khokhlov 1997; Wiggins & Falle 1997; Niemeyer & Kerstein 1997). The more verbose author has been involved in the advance to publication of enough of these to feel something akin to "a deflagration on all your houses." But the important point is that a good many of the combinations will work with less than 1.4 $M_\odot$ of degenerate material to play with.

In light of this, what can be said about specific candidate progenitors? Iben et al. (1997) continue to favor inspiraling white dwarf pairs. They conclude that the real number of pairs available is 20 times the observed number, and that this is enough, even if you insist on a Chandrasekhar mass (though 20 × 0 is still 0 as a rule). Potentially promising systems in which a white dwarf seems to be increasing in mass include the 1944 nova RR Tel (Nussbaumer & Damm 1997), because mass loss turned off in 1960, before the star had expelled as much stuff as it must have accreted to trigger the explosions; the supersoft X-ray sources (Li & van den Heuvel 1997), which seem to come in low- and high-mass flavors, suitable for elliptical and spiral galaxies respectively; and symbiotic stars (Hachisu et al. 1996), which can burn accreted hydrogen steadily and grow in mass provided that fresh hydrogen is provided at a high enough rate, perhaps through Roche lobe overflow. The problem here is that not seeing sharp hydrogen lines in spectra of the events rules out symbiotics with very large rates of mass transfer (see, e.g., Cumming et al. 1996 on SN 1994D). Recurrent novae are not the dominant progenitors, if only on statistical grounds (Della Valle & Livio 1996), but could make some contribution.

Where does this leave the use of Type Ia supernovae as distance indicators? Up the creek without a paddle is perhaps too strong a statement (Nomoto et al. 1997). Things can, however, only be made worse by the asymmetry of light emission remarked upon for SN 1996X on the basis of its polarization (Wang et al. 1996) and predicted by the models of Wiggins & Falle (1997). Von Hippel et al. (1997), pessimists after our own hearts, point out that, once you admit to a range of white dwarf masses making Type Ia supernovae, then the actual range and the distribution within the range is bound to vary with the type of the host galaxy and as a function of redshift. What is more, you can't actually figure out what the range should be and correct for it until you are sure of what the real progenitors and explosion mechanisms are!

8.3. Pulsators: Predictable and Otherwise

A new class of subdwarf B (*sdB*) *stars* with *p*-mode oscillations. Here is science as we think it ought to operate! Even as the theoretical prediction of a new class was being refereed and published (Charpinet et al. 1996), a completely independent group was discovering the first nine examples (Kilkenny et al. 1997 and three following papers). The prototype is EC 14026−2647. All have multiple periods in the 100–200 s range, amplitudes of less than 0.01 mag, F–G main-sequence companions, and surface temperatures of 29,000–37,000 K. The driving mechanism is the temperature-sensitive opacity of iron (which is enhanced in their envelopes) and is analogous to the opacity of hydrogen close to its ionization as the driver for ordinary Cepheids (Charpinet et al. 1997). One late-arriving member of the class is single, but otherwise similar (Billeres et al. 1997). The group seemingly has, so far, no name, though SubDued BumPers comes to mind. Actually, it is amazing that Kilkenny et al. (1997) did not suggest something of the sort, given the originality of their section titles (beginning with Comedy of Errors).

Cepheids, long a part of the pulsating inventory, have also had a new mode predicted, the second overtone or pure $n = 3$ mode (Antonello & Kanbur 1997). The predictors believe that Cepheids in the LMC might display it. A couple of Cepheids have received detailed chemical analyses (surely not the first, but we had forgotten the answer). V553 Cen, one of at least seven Cepheid carbon stars (Lloyd Evans 1983), has enhanced C, N, and Na, with C^{12}/C^{13} very close to the value 4 that represents the equilibrium of the CNO cycle, but it is not enriched in *s*-process elements (Wallerstein & Gonzalez 1996). On the other hand, α UMi, a representative s-type Cepheid (meaning small amplitude, short period, and sinusoidal light curve) has high N but low C (Kovtyukh et al. 1996). In both cases, one is led to conclude that a good deal of mixing has already taken place, and the stars are not crossing the instability strip for the first time.

Cepheids occur in binary systems. The shortest period found so far is 1 year for Z Lac (Sugars & Evans 1996). It is also the only one with a circular orbit, resulting from interactions during the red giant phase. δ Cephei itself has the honor of being the first member of the class to achieve angular resolution (Mourard et al. 1997, who used a two-telescope optical interferometer). The angular diameter plus a linear diameter from the Baade-Wesselink method put the star at 240 ± 24 pc, which somehow did not lead to press releases revising the cosmic distance scale.

Anomalous Cepheids or SX Phe stars are relatively short period and small-amplitude beasts. In addition, at least some are clearly related to the blue stragglers, in the sense of being too massive (hot, bright) for the globular clusters and dwarf galaxies in which they find themselves. They are probably commoner than you thought, because some of the amplitudes, at least in NGC 6397 are small and easy to miss (Kałużny 1997). Detailed analysis of one with $P = 0\overset{\mathrm{d}}{.}8$ in the globular cluster NGC 5466 leads to a minimum mass of 1.1 $M_\odot$ (clearly above the turnoff) and a best value of 1.6 $M_\odot$ (McCarthy & Nemec 1997). Bono et al. (1997a) have provided a new set of evolutionary tracks and pulsation models and describe the stars as horizontal-branch members of more than 1.5 $M_\odot$ occurring both in relatively young populations (like the Carina dwarf irregular galaxy), where the stars can be single, and in old populations (like the globular clusters and Leo II galaxy), where they must be the products of binary mass transfer or merger. None of this is really new, but it all fits together nicely.

RR Lyrae stars, as long as we are so close, display the Oosterhoff dichotomy in the field as well as in globular clusters (Bono et al. 1997c). The who? Oosterhoff (1944) showed that the average period of common types of RR Lyraes had two different mean values in two different sets of clusters. It is blamed on there being two different average masses for the horizontal-branch stars and has been understood by a number of theorists, not all of whom have understood the same thing. Another characteristic of RR Lyraes first seen in globular clusters and later in the field is the occasional presence of two simultaneously excited modes. The fourth field example, NSV 09295, has periods of $0\overset{\mathrm{d}}{.}463$ and $0\overset{\mathrm{d}}{.}344$ and is otherwise quite unremarkable (Garcia-Malendo & Clement 1997).

Multi-mode variables are many and varied, not always given the same names by everybody who looks at them, and sometimes seem like more trouble than they are worth. RV Tau stars, with minima of alternating depth, appeared in Ap92 (§ 10.12) for that reason. This year their very complex chemistry has begun to make sense. Gonzalez et al. (1997a, 1997b) report that, for nine of them, what you see can be interpreted as, first, some mixing in a post-AGB single star, followed by fractionation when dust forms and a wind blows it off. Thus the most refractory elements are the most depleted. Curiously, one RV Tau star in a globular cluster, though having the same intrinsic metallicity as the field examples, shows no such dust-gas separation (Gonzalez & Lambert 1997).

β Cephei stars belong to the main sequence of Population I and can have four or more interfering unstable modes with periods of hours (Jerzykiewicz & Pigulski 1996; Telting et al. 1997). The frequencies are so sensitive to average stellar density that they may be the best available age indicators for the open clusters that happen to harbor them (Balona et al. 1997).

δ Scuti stars, also Population I and near the main sequence, are the second most common class of pulsating variable (Soland & Fernley 1997). They are not easily distinguished from the previous class, except for having shorter periods (e.g., 20–40 cycles per day). At least one has 13 recognizable modes (mostly *p*-type, meaning that pressure is the restoring force) but does not show the high-frequency oscillations characteristic of rapidly oscillating Ap stars (Handler et al. 1997). There is also no evidence in a representative sample of them for the longer period γ Doradus type of variability (Breger & Beichbuchner 1996). Bono et al. (1997b) have provided recent models for

the overtones and mixing in δ Scuti stars, as have Buchler et al. (1997) as part of a wider investigation of resonances. And, in a particularly fine bit of confusion, 4 CVn is merely an ordinary δ Scuti star and not a γ Doradus "variable without a cause." The nearby comparison star used in its initial evaluation, HD 10800, is the γ Dor star! (Breger et al. 1997). And other new examples continue to turn up (Baade & Kjeldsen 1997).

What is the most common sort of pulsating variable? You probably won't guess; it's the white dwarfs of ZZ Ceti, PG 1159, and such varieties.

Mira variables (low-mass, highly evolved, semiregular variables) appeared in Ap96 (§ 10.4) throwing tomatoes at each other over whether their primary pulsation mode is the fundamental or first overtone. The ketchup continues. BS Lyrae has both modes, at 305 and 232 days (Mantegazza 1996). Stars in the Magellanic Clouds also include both types, but only the large-amplitude, longer period (fundamentally pulsating) ones are real Miras in the eyes of Wood & Sebo (1996). Mira itself has the longest data train and seems to be dominantly a first-overtone pulsator but with non-linear coupling to at least two more radial modes (Barthes & Mattei 1997). In spite of all this, Miras do display a recognizable period-luminosity (or period-color-luminosity) relation (Kanbur et al. 1997) and so could plausibly be used as distance indicators (Alard et al. 1996). That Galactic Miras apparently belong to more than one kinematic population (Luri et al. 1996) makes the mystery-modality situation less worrisome but the use as distance indicators more problematic.

But a Mira rated a press release during the year for quite another reason. Their winds are often the sites of Si0 masers (Humphreys et al. 1996; Jiang 1996). For one of these, TX Cam, a mapping of the polarized Si0 emission permitted the mappers to trace out its magnetic field and show that it has a strength of 5–10 G and is quite ordered, not so very different from the field of the Sun, though whether toroidal or poloidal structure predominates was not clear (Kemball & Diamond 1997). The wind of Mira itself has been optically resolved with *HST*. Predictably, it is lumpy and somewhat extended toward the white dwarf companion (Karovska et al. 1997). The elliptical shapes of the stars themselves, when resolved by speckle interferometry, are probably due to hot spots (Weigelt et al. 1996).

Finally, carbon-rich Miras are subject to occasional, unpredictable fading, on timescales of a few years. The cause appears to be the formation and gradual expulsion of dust, somewhat along the lines of the fadings of the (also-pulsating) R Coronae Borealis variables, which brings us to the last topic in this section (Lloyd Evans 1997).

R Coronae Borealis variables were distinguished first for their rapid, unpredictable disappearances (Pigott 1797) and later for their carbon-rich and nearly hydrogen-free atmospheres (Berman 1935). Regular, Cepheid-like, but low-amplitude pulsation was first seen in RY Sgr (Jacchia 1933), later in R CrB itself, and can now be said to be nearly ubiquitous, at least in radial velocity data (Lawson & Cottrell 1997). Several curiosities turned up during the reference year. First, those with the most residual hydrogen fade most often (Jurcsik 1996). This feels backward! Second, on the basis of ultraviolet data, Drilling et al. (1997) have concluded that the dust actually covers the whole surface of the star, as it does for the fading Miras just mentioned, rather than being, as previously advertised, patchy. Infrared data indicate that the dust also varies in complicated ways on timescales of 100, 1000, and 10,000 days (Feast et al. 1997; Menzies & Feast 1997). The class remains an exclusive one, with about 40 members, though new examples surface from time to time (Goswami et al. 1997 on Z UMa).

Third and most exciting, the MACHO project has begun to find additional R CrB's in the LMC, and they are 1–2 mag fainter than the existing sample of three (Alcock et al. 1996a). Rozenbush (1996) has long been a (fairly lonely) advocate for a wide range of absolute magnitudes for R CrB's outside of fading episodes.

The dust-induced explanation for fading is of respectable antiquity (Loreta 1934) and apparently also applies to some pre–main-sequence, Herbig Ae stars (Krivova 1997) and to other carbon-rich AGB stars (Whitelock et al. 1997). Since the three AGB examples have semiregular variability at 380–450 days, perhaps they are really Miras and belong in the previous subsection.

Very massive stars probably all pulsate, and this is relevant to their not being any more massive than they are. Glatzel & Mehren (1996) have calculated new models for the 20–80 $M_\odot$ range and Papaloizou et al. (1997) for masses larger than 100 $M_\odot$. Both emphasize the importance of interaction with convection for destabilizing particular modes.

8.4. Starry, Starry Night

In which we collect some extrema, confusaria, and other items that might well have belonged with van Gogh's ear, and reluctantly admit that others must be abandoned.

The coolest star apparently detected by *ROSAT* is really a galaxy (Huensch et al. 1996), and CC Boo, previously advertised as a halo red giant (Jura & Kleinmann 1992), is actually a QSO with $z = 0.172$ (Margon & Deutsch 1997). The names of BL Lac, X Com, AP Lib, V396 Her, and a few others record earlier examples of the same phenomenon. Only the Reasonbly Mature will recall that the optical counterpart of 3C 273 had a similar adventure very early in its life, with its emission lines being attributed to transitions in highly ionized neon and such, at their rest wavelengths.

Star streams containing stars of different ages and chemical compositions (Eggen 1996) were refugees from our "terminally weird" section, as are old novae CK Vul (1670) and V605 Aql (1919), which are also nuclei of planetary nebulae (Harrison 1996), and the suggestion that not all PNe leave white dwarfs behind (Vennes et al. 1997). The opposite arrangement, white dwarfs that were never nuclei of PNe, is more familiar.

The Sun is obviously too important to be treated in this casual way, but we note (1) a somewhat indirect discovery of the first non-solar spicules, on ER Vul (Gunn & Doyle 1997); (2) a non-confirmation of the previously advertised first non-solar *p*-mode oscillations in a similar star, η Bootis (Brown et al. 1997a; the paper has no authors in common with last year's discovery paper, but the two sets did at least talk to each other); (3) the second biggest star after the Sun, R Dor with angular diameter 58 mas (Bedding et al. 1997); (4) a review of stars that are like the Sun in various ways (Cayrel de Strobel 1996) and a new candidate for "best match yet," HR 6060 (Porto de Mello & da Silva 1997); and (5) from our "that settles that" section, at least 10 papers addressing how changes in the luminosity of the Sun on various timescales are reflected in the average temperature of Earth; the abbreviated answer is that the Sun is probably getting a bit brighter at the moment and that this accounts for about half of global warming over the last century (Soon et al. 1996; Willson 1997). If you are reading this by artificial light, you are contributing to the rest (though not as much as we did in the writing).

The inventory of nearby stars is still very incomplete. The 20th nearest has just logged in (LHS 1565; Henry et al. 1997b), and if all those within 5 pc are known, we are missing 130 out to 10 pc.

Some stellar extrema include the following:

1. Two A7 V candidates for "earliest chromosphere" (Marilli et al. 1997; Simon & Landsman 1997); X-ray coronae cut in at the same spectral type (Schmitt 1997).
2. The first EUV detections of the nucleus of a planetary nebula (Hoare et al. 1996) and of a T Tauri star (Polomski et al. 1997).
3. The first firm cases for detection of lithium in a brown dwarf candidate in the field (Thackray et al. 1997) and also in a field M dwarf (Zboril et al. 1997), and we think this casts some doubts on the use of lithium to distinguish the two.
4. Yet another "most massive star" that is really a compact cluster (Massey et al. 1996) and an 03 If that probably is not (Taresch et al. 1997).

Another two dozen or so stellar extrema, many of them involving binary systems, lie on the cutting room floor.

Ap and Bp stars are strongly magnetized ones whose surfaces are spotted with regions ridiculously rich in mercury, europium, and such. We caught something like 16 papers on their botany (e.g., Savanov et al. 1997; Malanuschenko 1997) and related laboratory work (e.g., Wahlgren et al. 1997 on rhenium). But, in addition, they have been joined by Fp stars (Savanov 1996) and Op stars (Babel & Montmerle 1997). Having just invented the spectral class P (§ 6.4) we hope soon to welcome Pp stars.

A proper treatment of convection is important for all sorts of things, including making the members of binary systems look the same age (Asiain et al. 1997; Pols et al. 1997), the location of sunspots (Weiss 1996; De Luca et al. 1997) and dynamos (MacGregor & Charbonneau 1997; Charbonneau & MacGregor 1997), and the extent of composition gradients in stars (Grossman & Taam 1996). Unfortunately, a proper model for convection continues to elude theorists (Castelli et al. 1997 and MANY others). But the phenomenon has been turning up in some strange places, like neutron stars with weak magnetic fields (Miralles et al. 1997), white dwarfs (Benvenuto & Althaus 1997), and star formation regions (Vazquez-Semadeni et al. 1996). We had just finished telling you that the spot on Betelgeuse was a manifestation of convection there (Ap96, § 8.3), when the spot disappeared (Burns et al. l997).

AE Aqr was the first astronomical entity to have a published accretion disk (Crawford & Kraft 1956, who made their proposal in defiance of the conventional wisdom [meaning what Joy and Merrill said] of outflow). The star has taken its revenge and now seems to be excreting, ejecting, or whatever the polite antonym is (Hollis et al. 1997; Kuipers et al. 1997). Perhaps it is alternating between accretion and excretion, like an X-ray binary subject to propeller episodes (Wynn et al. 1997). Among the XRBs, the first, second, and third examples of systems caught propellering appeared so close together that we were unable to sort out which was which (Campana 1997; Jablonski et al. 1997; Cui 1997).

Stars that are changing faster than you might have expected constitute yet another large class that have been left behind in our notebooks (but an entire joint discussion at the 1997 IAU was devoted to them, so watch for the proceedings!). Here peek out only Sakurai's object, the third candidate for a "last helium flash" star that is about to become an R CrB variable (Asplund et al. 1997; Kipper & Klochkova 1997). The first, of course, was FG Sge, models for which continue to appear (Bloecker & Schoenberner 1997). And, like many other "of course's," this one isn't quite true; V605 Aql, noted by Lundmark (1921), came first, though we were probably not the only ones who had missed that paper the first time around. A worrisome point persists: given the very modest inventory of R CrB stars, three progenitors in one century is rather a lot.

9. PUT THAT IN THERE WITH THE OTHERS

The title of this section derives from a masculine parody of one woman telling another where a freshly washed dish goes. The male equivalent is supposed to be, roughly, "the middle size yellow platter goes on the left side of the bottom shelf of the top cupboard between the large and small yellow platters." We consider a number of topics where there used to be just a few things lying around and are now a whole bunch, ending with a few gems that didn't seem to fit anywhere else. These, as any woman our age will tell you, go in the kitchen drawer.

9.1. Contributors to the X-Ray Background

This background is now more than 35 years old (Giacconi et al. 1962; well, okay, it is probably more like 10^{10} yr old, but you know what we mean), and for the first 20-some years, the main question was whether it came primarily from hot, diffuse intergalactic gas (which would then nearly close the universe) or from a large number of discrete sources. As time went on, more sources were counted individually, but the issue was not finally resolved until the FIRAS instrument on *COBE* (Mather et al. 1990) put a firm upper limit on the distortion of the spectrum of the microwave background radiation that a hypothetical 40 keV plasma would produce. This left a very large number of extragalactic sources as the only remaining alternative (given the high degree of isotropy), and we have previously declared the issue closed in favor of active galaxies as the primary contributor (Ap93, § 5.6).

The problem remains, however, that nearby active galaxies do not share the spectrum of the background, which can be described as either optically thin thermal bremsstrahlung from a 40 keV plasma or as a broken power law with slope much flatter than that shown by 3C 273 and the like. Nor is it entirely clear that the AGNs will add up to enough, if you assume their number to change with redshift the way radio and optically selected AGNs do.

Candidate contributors put forward during the reference year include (1) normal galaxies (because the background fluctuations are correlated with galaxies in catalogs—Refregier et al. 1997; Soltan et al. 1997); (2) galaxies with vigorous star formation (Roche et al. 1996); (3) the post-QSO phase of evolution, in which hot, advective gas is still radiating thermal bremsstrahlung (Di Matteo & Fabian 1997a); (4) a single population of flat spectrum sources that are, anyhow, not like local QSOs (Chen et al. 1997); (5) optically obscured active galaxies (Moran et al. 1996; Granato et al. 1997); (6) what seem to be normal galaxies but are really subtle AGNs with very narrow permitted lines (Blair et al. 1997; Wisotzky & Bade 1997); and (7) active nuclei with X-ray spectra more complex than you had thought (Schartel et al. 1997a).

On the whole, we are inclined to vote with Pearson et al. (1997a) who say that you need to add up all the kinds of galaxies you can think of (normal emission-line ones, starbursters, Seyferts, and quasi-stellars) to account even for the 0.5–2.0 keV background.

Meanwhile, a small amount of hot gas has been spotted outside individual clusters of galaxies (Wang et al. 1997), but it seems to be part of hierarchical structure around several ordinary clusters and is at only 10^7 K, not hot enough to produce much background at 2–10 keV.

The Milky Way has its own diffuse (or many-sources) X-ray emission, at least some of which must come from isolated old neutron stars that accrete interstellar gas (Zane et al. 1996), an idea that is itself nearly 30 years old. There is, of course, also emission from hot interstellar gas (Snowden et al. 1997). NGC 891 can make the same claim, as indeed can most other spirals appropriately observed (Read et al. 1997), though not all have radio halos (Elmouttie et al. 1997).

9.2. Binaries in Open and Globular Clusters

When the more verbose of the authors was first asked to review this topic in 1979, the numbers were small enough that one could look at the systems and their implications one by one. In fact, globular clusters, as the prototype of Population II, were once advertised as having next to no binaries, an idea that goes back remotely to Oort. The topic remains a cherished one because Cecilia Payne-Gaposchkin provided some input for that review shortly before she died. Since then, binaries in both types of clusters have become routine, but astronomers still often begin discussing a topic by asking what Oort thought about it.

In the realm of open clusters, there have now been enough long-term surveys of radial velocities to provide a sizable catalog of accurate orbits (Mermilliod et al. 1997a) and also to say something about average numbers of spectroscopic binaries in clusters (e.g., Mermilliod et al. 1997b on Melott 71). In a very general sort of way, one confirms that one-third to one-half of the stars in a typical open cluster are part of close pairs from looking hard at the width of the main sequence (Bragaglia et al. 1997 on NGC 6253). Old clusters ought in any case to have more binaries because the lighter, single stars are more likely to boil or be torn away (de la Fuente Marcos 1996). Conversely, just what happens to a cluster as it ages will depend (inter alia) on its initial binary population (de la Fuente Marcos 1997).

Large samples also mean that you begin to find unusual sorts of objects. Thus we welcome to the inventory (without swearing that they are the first of their kind in open clusters) the following: (1) a cataclysmic variable and an RS CVn star in NGC 6791, which has an assortment of eclipsing binaries near its turnoff as well (Rucinski et al. 1996); (2) a double O star in NGC 7380 (Hilditch et al. 1996; Penny et al. 1997), though the groups differ about whether the masses are thirty-somethings or forty-somethings (the star is DH Cep); (3) a binary protostar with some remaining protostellar disk in IC 348 (Kales & Jewitt 1997); (4) a star in M67 rather like V471 Tauri in the Hyades, that is, a pre-CV with white dwarf and nondegenerate star not yet in contact (Landsman et al. 1997); (5) two possible binary brown dwarfs, of 19 new candidate BDs in Praesepe (Pinfield et el. 1997); and (6) one of 21 Be stars in NGC 663 whose variability is periodic at $0\overset{\mathrm{d}}{.}2$, and the authors didn't say it wasn't a binary (Pietrzynsky 1997). Finally, lots of planetary nebulae turn out to have binary nuclei (Bond 1995). We haven't a clue whether this is true for NGC 2438, but Pauls & Kohoutek (1997) conclude that it is a member of the open cluster NGC 2437 because they share a radial velocity near 60 km s^{-1}, relatively rare in that part of the sky.

Turning to globular clusters, we start with W UMa stars and others, mostly eclipsing, close to the main sequence. Inevitably, the various surveys are not sensitive to exactly the same ranges of periods, mass ratios, and so forth, so numbers are not really comparable. Nevertheless, it is by now clear that not all clusters are the same. Yan & Cohen (1996) report 21%–29% spectroscopic binaries in NGC 5053. The width of the main sequence in NGC 6753 tells Rubinstein & Bailyn (1997) that it has 15%–40% unresolved binaries. McVeon et al. (1997) confirm four of five candidates in M71 (but these were not stars selected at random). Kałużny et al. (1997a) report seven W UMa's in M4 (though it is not clear how many stars they looked at). Finally, Kałużny et al. (1997b) looked at 36,269 stars in 47 Tuc and found only one W UMa, which translates into at most 10% of the incidence in some of the other clusters.

Blue stragglers are perhaps too obvious to mention (Ap91, § 5). Ferraro et al. (1997c) have, however, suggested that two of the mechanisms pursued by theorists are actually at work—stellar collisions in cluster cores and binary mergers in the outskirts. The data include numbers as a function of radius in *HST* images of several clusters.

The one CH star in M14 and the several previously known ones in ω Cen are probably also the result of mass transfer in close binaries (Côté et al. 1997). Whether this is a lot or a little depends on how hard anybody has looked. We know we haven't!

Next come the cataclysmic variables. White dwarfs are common and neutron stars are rare in the great scheme of things. Thus the over-representation of X-ray binaries in the clusters naturally suggested (starting 20+ years ago) that CVs should be similarly over-represented. They clearly are not. A short summary of investigations of a number of clusters with *HST* images (to look for outbursts of dwarf novae and related systems) is that CVs are, contrarily, quite rare, perhaps 10% of what you might have expected (Shara et al. 1996a on 47 Tuc and M80). Typical yields are one or two candidates or events per cluster (Bailyn et al. 1996 on NGC 6752; Shara et al. 1996b on NGC 6624). The previously known CV in M5 was seen by *ROSAT*, but the X-ray source in M80 is apparently not T Sco (an old nova and one of the few confirmed cluster CVs; Hakala 1997). A variable white dwarf in M4 with a period of about an hour but no emission lines might or might not be a nearly silent CV (Kałużny et al. 1997b).

Not only are CVs rare, so are their precursors, close but noninteracting pairs of white dwarf + M dwarf (Richer et al. 1997, who have inventoried the WDs in M4). Nevertheless, Fox et al. (1996) continue to be of the opinion that CVs are the best explanation of low-luminosity X-ray sources in the globulars, and Davis (1997) has provided a model in which the CVs, like the blue stragglers just mentioned, will be of two types, descended from primordial binaries in the cluster outskirts but the result of interactions and collisions in the cores.

X-ray–emitting binaries and the binary pulsars sometimes, at least, descended from them are, in contrast, much more common in globular clusters than in the field, and the explanations again involve both primordial binaries and assorted interactions. We note a subset of ongoing projects here. The system in NGC 6624 (Anderson et al. 1997d) retains its record for shortest orbital period at 11.46 minutes, but the one in NGC 6712 has taken over second place with $P = 20.6$ minutes (Homer et al. 1996). The tiny orbits require late M dwarfs as the donor secondaries. Not surprisingly, the GC systems are fainter than low-mass X-ray binaries in the field, as shown by the optical counterpart of the XRB in NGC 1851 (Deutsch et al. 1996). The previously known optical counterpart, AC 211 in M15, seems to be enhanced in carbon, nitrogen, and oxygen, but this is an X-ray result and could have been achieved without the identification (Christian et al. 1997). And we leave some other good papers uncited to hurry on to the (not very surprising) conclusion that the brightest X-ray binaries in the globular clusters of M31 are a lot like the ones in the Milky Way (Supper et al. 1997).

No such claim can be made for recycled pulsars in the clusters of M31, since none has been detected (nor will they be in the near future!). But, within the Milky Way, a couple that seem to be speeding up their rotation rather than slowing down, the way any self-respecting rotationally powered pulsar should, are probably to be blamed on accelerations by third stars (Shearer et al. 1996 on PSR 1620−26 in M4) or on the gravitational potential of the cluster as a whole (Anderson et al. 1997c on B1516+02B in M5). That is, we are seeing negative changes in the Doppler shifts of the pulsar periods, not real speed-ups.

9.3. Causes of the Dwarf Nova (and Related) Outbursts

By way of introduction, dwarf novae are the subset of cataclysmic variables that flare up a few magnitudes on timescales of weeks to months (with a few, longer timescale exception) in a way that is most convincingly modeled by sudden increases in the rate at which material lands on the white dwarf, releasing its gravitational potential energy. Nuclear flashes of the classical nova type will happen much more rarely. The historic question has been whether the rapid increase comes about because of something the donor star does or something the disk does. "Related" outbursts are sudden flare-ups in low-mass X-ray binaries, active galaxies, young stellar objects, or anything else you think might have an accretion disk with variable throughput, perhaps for similar reasons. Ap94, § 6 and Ap95, § 6.6 touched on the subject.

WZ Sge used to count as a recurrent nova because of going off at intervals of more than a decade, until it was recognized as lacking the basic nova signature of blowing off material. (The reason for the signature is that nuclear reactions release more energy than accretion does when the recipient is a white dwarf). Viewed as a dwarf nova with unusually long intervals between outbursts, it became both something of a mystery and a prototype. An interesting solution to the long-interval and large outburst problems has come from Warner et al. (1996) and Hameury et al. (1997), who propose that the accretion disk has a central hole. The cause could be either the magnetic field of the white dwarf or evaporation because it is unusually hot (King 1997a, 1997c). In either case, material has trouble reaching the white dwarf, piles up in the disk, and, when it does fall in, lets go with an almighty splat. Curiously, a magnetic field attached to the other, donor, star has the opposite effect, encouraging transport of angular momentum and mass and shortening the intervals between outbursts (Pearson et al. 1997b).

Somehow nothing is ever totally clean cut. Nogami et al. (1996) point to CT Hya as intermediate in outburst intervals and amplitudes between WZ Sge and normal dwarf novae like SU UMa, while Osaki et al. (1997) note that, immediately after a major outburst, WZ Sge retains a high-viscosity disk for a while, which leads to a bunch of short outbursts after the main one. EG Cam does the same thing. As for WZ Sge being an eponymous prototype, nothing can be done about this unless you are prepared to live with TOADs (standing for Tremendous Outburst something or other).

Further details of the instabilities in both dwarf novae and low-mass X-ray binaries can be extracted from how they turn off at various wavelengths (Cannizzo 1996; Sheffer & Lyutyi 1997). The envelope-back summary is that both contributors to variable accretion rate seem to be at work. This is also the case for the X-ray transients modeled by Lasota et al. (1996) and for DQ Her, a well-known magnetic CV (Dimitrienko 1996). AM CVn, where both donor and donee are low-mass, helium white dwarfs, in contrast, has most of its variability coming from changes in disk viscosity rather than from anything the donor does (Tsugawa & Osaki 1997). The alternation between high (outburst) and low (quiescent) accretion rates, when caused by changes in the disk viscosity, has the character of limit cycling. But so, it seems, does alternation due to changes in the donor star, when both evolutionary expansion and irradiation affect its radius (King et al. 1997).

We conclude by seeing with the observers that, when some of these systems are off, they are really OFF, with M_v as faint as +14 among some CVs with short orbit periods (Sproats et al. 1996) and thinking with the theorists that this really is just what you would expect, once the donor is less massive than the recipient star, and that the very small luminosities at quiescence in either CVs or XRBs will wreak havoc with all sorts of statistical arguments (King 1997b).

9.4. Cause(s) of the Initial Mass Function

The (or an) initial mass function (hereafter IMF) is the numbers of stars of each mass that come out of a particular episode of star formation, or, quite often, an analytical fit to *N* (*M*) in the form of a broken power law or Gaussian. The gold standard is the Salpeter (1955) IMF, a power law rising from large to small masses as $M^{-2.35}$ in mass units or $M^{-1.35}$ in number units, and, of course, some sort of cutoff to prevent our being crushed to death by itty-bitty stars. A Gaussian, with its peak near where the cutoff sets in, is not as different as you might suppose (Miller & Scalo 1979).

The party line on star formation has been summarized by Shu, Adams, & Lizano (1987) as consisting of four stages. A giant molecular cloud develops dense cores (by different mechanisms in the cases of high mass and/or high efficiency vs. low mass/low efficiency). The cores collapse, inside out, leading to a protostar at the center with continuing infall. A wind breaks out at the rotation poles of the protostar. And infall terminates, leaving a young stellar object with an accretion disk and bipolar outflow. From a theoretical point of view, one can ask whether this is the only possible scenario and, from an observational one, whether there really is a unique IMF calling for a unique explanation.

Let's start with the observations (on the principle of either age before beauty or pearls before swine, depending on your tastes). Do we see a universal IMF? A Scots verdict of "not proven" is probably the only safe one. But, in any case, the answer depends a little on just what you mean by the question. Local fluctuations undoubtedly occur. Specific Bok globules with different infrared spectra are on their way to making different mixes of stars (Launhardt et al. 1997). Low-density regions will perhaps produce a larger fraction of close binaries (Bouvier et al. 1997). And there is a good deal of agreement that it takes a Really Big Giant Molecular Cloud to make a Really Big Star, meaning perhaps $10^5\ M_\odot$ and $10^2\ M_\odot$, respectively (Williams & McKee 1997; Yonekura et al. 1997; Khersonsky 1997), which will then put on a Really Big Show (but luminous blue variables are an exciting topic that will have to wait for another year).

What about the IMF on larger scales? At the low-mass end, efforts to extract a reliable *N* (*M*) from the data are bedeviled by persistent uncertainties in the mass-luminosity-composition relation (Malkov et al. 1997; Kroupa & Tout 1997). For older clusters one has, in addition, to worry about the loss of the 1ower mass stars. It is, nevertheless, quite widely found that assorted populations show a Salpeter-like rise in *N* (*M*) to a mass of 0.1–0.3 $M_\odot$, followed by a plateau or turnover (De Marchi & Paresce 1997 on globular clusters of low metallicity; Hillenbrand 1997 on the Orion region; Reid & Gizii 1997; Gould 1997). Favata et al. (1997) suggest a flatter slope for the local stars of low metallicity, but it sounds a bit as if they have simply rediscovered the G dwarf problem by a difficult method. An important exception to the pattern is the young cluster Praesepe, where the IMF is still rising at the cut between red and brown dwarfs (Pinfield et al. 1997).

At the high-mass end of the IMF, it is difficult to get enough stars to say anything except by looking at whole galaxies or large parts of them, then generally some distance away, so that you cannot study the low-mass *N* (*M*) at the same time. Voting for "same everywhere" we find Hunter et al. (1997a), who looked at young clusters in the LMC (but only for stars of 0.85–9 $M_\odot$); Bresolin & Kennicutt (1997), who considered OB associations and H II regions in Sa to Scd galaxies; and Calzetti (1997) and Satyapal et al. (1997), who looked at a passel of starburst galaxies. On the other side, we find Feinstein (1997) with an IMF that varies with galaxy type, Lancon & Rocca-

Volmerange (1996), who conclude that starbursts extend to higher masses than the local IMF, and Goldader et al. (1997), whose *IRAS* galaxies apparently make no stars smaller than 1 $M_{\odot}$.

Now, if you'll come over here where the observers can't hear us (roughly as KoKo said to Pooh Bah), we'll consult the theorists. In comparison with the party line standard model, several classes of things have happened. First are improved versions of more or less the same processes, like Norman et al. (1996) who use magnetic reconnection to get rid of flux in contexts roughly equivalent to Shu et al.'s (1987) high-mass/high-efficiency mode of star formation, and Safier et al. (1997), who use two-dimensional ambipolar diffusion to get rid of flux in the low-mass/low-efficiency mode. Bizyaev (1997a) has something like the two modes, described as global and local instabilities to the onset of star formation.

Second come calculations that say cloud collapse and accretion should go either a good deal faster (Tomisaka 1996a) or a good deal slower (McLaughlin & Pudritz 1997) than the received rate. The main reason seems to be choices of initial conditions different from, and arguably more appropriate than, the traditional isothermal sphere (Whitworth 1996; Clarke & Pringle 1997; Henriksen et al. 1997). Disagreement is, however, already setting in at this stage on, for instance, whether or not fragmentation (which means making two or more little bits out of one big bit during the collapse phase) can happen more than one. Sigalotti & Klapp (1997) say yes; Li & Shu (1997; Shu & Li 1997) say no. Opting for "none of the above," Inutsuka & Miyama (1997) point out that some real, cold giant molecular clouds are characterized by clusters of cores of about 0.04 $M_{\odot}$, so that hierarchical clustering rather than hierarchical fragmentation will be the dominant process.

Third is the inclusion of more or different physics of a kind that strikes us as being justified. For instance, several modelers, inspired, one guesses, by the spectacular *HST* image of M16, have explicitly included effects of strong external radiation (often ultraviolet) on a cloud that was thinking about making stars. Both radiation-driven implosion and evaporation are possible responses (Wiehe et al. 1996; Newsom & Langer 1997), with the cloud shown by Sugitani et al. (1997) as a possible example. Another case is the inclusion of enough rotation that the initial cloud is more nearly a disk than a sphere. Some real clouds are like this, e.g., NGC 6374A and its environs (Kraemer et al. 1997); and Basu (1997) and Matsumoto et al. (1997) have provided at least first steps toward relevant models.

Yet another example of additional, relevant physics is the recognition of the random (stochastic, fractal, or what have you) nature of the star formation process, which will almost inevitably put the biggest stars in the biggest clouds, as seen (Elmegreen 1997; Padoan et al. 1997).

Fourth, and mercifully last, come modelers who have added physics that we probably don't understand well enough to try to explain (in accordance with a theorem due to Ehrenfest). These include the cylindrical molecular clouds of Tomisaka (1996b), the epicycles of Sotnikova & Volkov (1996), a new instability that speeds up the accretion process, reported by Hunter et al. (1997b), and a new non-instability identified by Zweibel & Lovelace (1997) for cases in which magnetic fields are dynamically important in star formation.

9.5. QSOs with Broad Absorption Lines

A subset of optically selected quasi-stellar objects displays broad ($\gtrsim 100$ km s^{-1}) absorption lines at redshifts just slightly less than the redshift of their emission lines. These are the BAL QSO's. When we last looked at them (Ap93, § 8.1) there were certain things they were doing and others they were not. Many of the items were not terribly well understood, but they were at least well defined. In the interim, a good many borders have blurred.

To begin with, they were thought to be fairly rare, a few percent of optically selected quasi-stellars. In fact 30% may be a better estimate when you allow for their being more attenuated by dust than the general run of QSOs (Goodrich 1997). Next the absorption z was supposed to be pretty close to the emission z, since, after all, how vigorously can even a QSO kick out gas? One case where $z_e = 2.51$ and $z_a = 2.24$, nevertheless, has been claimed as an example of ejected gas producing lines 400 km s^{-1} wide (Hamann et al. 1997a).

In addition, there was supposed to be a fairly clean line between BAL QSO and other classes. The edges have been blurred by the detection of (1) rather similar absorption in the Seyfert galaxy NGC 4151, requiring *HST* data in the ultraviolet (Weymann et al. 1997), (2) ultraviolet absorption features in the blazars Mrk 421 and PKS 2155$-$304, that would look very like BALs if the galaxies were farther away from us (Karth et al. 1997), (3) strong Lyα troughs in the optical spectra of radio galaxies at redshifts $z \gtrsim 2$ (van Ojik et al. 1997a), just blueward of the Lyα emission, and (4) one case of narrow absorption lines at z_a a bit less than z_e, but nevertheless clearly associated with the host galaxy, probably the broad emission line clouds, in a radio-loud quasar PKS 0123+257 (Barlow & Sargent 1997).

These last two items are sneaking up on the biggie: BAL QSOs were not supposed to be radio-loud—not that the observation had been confirmed by theory, but it seemed to be of considerable statistical rigor. The first clear counterexample appeared this year in the FIRST survey (Becker et al. 1997, with further details given by Hall et al. 1997). Its telephone number is 1551+3517, in case you would like to call. Given the size of the FIRST survey, it remains safe to say that radio-loud BAL quasars are rare. BALs that are "weak" or "intermediate" but nevertheless detectable radio sources, typically not classic large doubles, are rather more common (Barbainis et al. 1997; Goodrich 1997) and have the same range of VLA morphologies that appear for non-BAL quasars with similar radio flux.

In partial compensation, the one BAL QSO with an anomalously large X-ray luminosity, PG 1416−129, has gone away (Green et al. 1997, whose senior author, incidentally, is not the G of PG). The X-rays are feeling fine, but the broad lines seem to have been a mistake. At least two BAL QSOs are gravitationally lensed, but this is about what you would expect multiplying the chances of one times the chances of the other (Chavushyan et al. 1997).

And now, of course, we can answer the fundamental theoretical question about BALs. Are they a subset (small or moderate) of all QSOs (a) because only some QSOs blow out such clouds, (b) because the absorbing clouds are little things that might or might not happen to cover the nucleus along our particular line of sight, or (c) because the obscuring gas is part of some large torus or disk whose plane we are in for some QSOs and not for others? The answer is yes (Turnshek et al. 1997; Hamann et al. 1997b). That is, one or more of these choices is probably correct, but we are not sure which, nor whether it is the same for all BAL versus non-BAL QSOs.

9.6. Shakespeare's Middle Period

Since you just met the "radio-intermediate" QSOs above (Falcke et al. 1996 have more to say about them), here are a few other categories that are reminiscent of a suggestion from Richard Armour that Romeo and Juliet was written neither at the end of Shakespeare's Early Period nor at the beginning of his Middle Period, but in between the two ("an idea that will surely revolutionize studies in the field"). Brinkmann et al. (1997) clearly agree, since they conclude that the distribution of radio luminosities of active galaxies is continuous, not bimodal.

Other examples include intermediate turbulence (Goldreich & Sridhar 1997), which comes between weak and strong in its cascade properties; intermediately peculiar galaxies (Naim & Lahav 1997, who note that only five of 827 galaxies looked peculiar to all of five classifiers, on whose normality they do not comment); an X-ray binary in the black hole category that spends much of its time stuck between high- and low-mass accretion rates (Mendez & van der Klis 1997; it is GX 339-4); a transition between two different sorts of supergiant winds (Achmad et al. 1997); and a class of cataclysmic variables that come between the AM Her and DQ Her stars (which are already called polars and intermediate polars), now including about a half-dozen examples (Howell et al. 1997a, 1997b; Mouchet et al. 1997; Silber et al. 1997; Ramsay 1997) and characterized by imperfect synchronization of rotation with orbit, intermediate magnetic fields, and so forth.

9.7. Some Really Big Numbers

How big is a big number? Well, that depends on what you are looking at. Consider the case of the 1970s experiment that was looking for double beta decay. When the graduate student in charge of day-to-day operation confessed that, so far, he had seen zero events, Maurice Goldhaber consoled him with the thought, "Well, that's a lot for that experiment." In that spirit we note the following:

Twelve million comets originally from the Oort cloud, now traveling in the ecliptic plane (Levison & Duncan 1997). The number came from current counts, an assumed lifetime of 12,000 yr, and numerical orbit integrations that span 10^9 yr (in solar system time, not computation time, we are relieved to report). Oh, and we should get hit once every 13,000 yr. Anyone for comet insurance?

6.3×10^5 faint blue galaxies per square degree to $R = 27$ and $z = 3$ (Hogg et al. 1997) and an interesting view of their formation (Dalcanton et al. 1997).

138,665 radio sources whose angular correlation on the sky was calculated by Cress et al. (1996). Their correlation with Abell clusters is stronger than their autocorrelation function, and the catalog is described by White et al. (1997).

A total of 40,000 pulsars in the Milky Way, being replenished at a rate of one per century (Pskovskii & Dorofeev 1997). Not all have been observed.

19,000 stars in the H-R diagram of M3 obtained from CCD images, which at this point are clearly competitive with photographs for the purpose (Ferraro et al. 1997b).

4495 near-infrared sources in the ρ Ophiuchi cloud (Barsony et al. 1997).

Tully-Fisher distances for 2945 galaxies obtained by Willick et al. (1997a). Admittedly they haven't printed them all, but they are ahead of Lee et al. (1996) who appear to have published the first paper with no content, none of the tables being presented in the paper.

1545 redshifts in Abell cluster 2319, collected by Fadda et al. (1996).

The 1020 cataclysmic variables catalogued by Downes et al. (1997). It is the complete sample known to date.

1000 knots in the shell of recurrent nova T Pyx (Shara et al. 1997).

Herbig-Haro objects 366 and 367 observed in CO by Bally et al. (1996).

The lunar gravity model that extends in multipoles to up to $l = 70$, corresponding to 80 km resolution on the surface (Lemoine et al. 1997).

Thirty-five millisecond pulsars excluding those in globular clusters (Lorimer et al. 1996, who present the most recent four).

Roughly the 15th V471 Tauri star (Burleigh et al. 1997). These are CV precursors, consisting of a white dwarf primary and non-interacting secondary.

Thirteen absorption-line systems in the spectrum of a single quasar (Tripp et al. 1997). Two pairs of C IV lines are apparently line locked, though well away from the emission redshift, which would seem to rule out radiation pressure as the mechanism.

Zero detections of CO in radio galaxies at $z = 2$–4.3 (van Ojik et al. 1997b). And three massive white dwarfs within 80 pc (Segretain et al. 1997), which requires a very large number of close pairs to merge, if that is how it is done.

Three is also rather a lot in the context of three *Physical Review* letters refuting a single paper (Baumgarte et al. 1997 and the two following); the issue is the extent to which a close companion affects the structure of a neutron star and its maximum possible mass. Wilson et al. (1996) are said to have greatly overestimated the effects, but their response was not presented. Three seems to us to be just the right number for brown dwarf candidates in the Pleiades (Martin et al. 1996), the number of plots of warm and cool spots in the microwave background radiation that agree (Inman et al. 1997), the number of independent sightings of the halo around NGC 5907 that seems to trace its dark matter distribution (Rudy et al. 1997), the number of pulsars whose optical colors look like synchrotron radiation (Nasuti et al. 1997), the number of spectroscopic binaries whose component spectra have been separated by tomography (Liu et al. 1997a), and the number of soft X-ray transients with neutron star components and optical identifications (Wachter 1997).

Three, on the other hand, seems rather few as the inventory of astronomical objects in which free precession has been identified (Cadez et al. 1997), especially given how much time we all spent studying the topic in classical mechanics! The three are Earth, the X-ray binary HZ Her (where the period is 35 days), and the pulsar in the Crab Nebula. Nearly everybody would agree about the first at least!

Finally, yet another set of large numbers describes the topics and papers that were left behind at one of three stages in compiling this review. Perhaps we never even read or took notes on your favorite paper. Perhaps it was read and recorded but was part of the 50% of those not identified as belonging to some interesting class when we read over our notes from the year. Or perhaps it was a preliminary highlight in extrema, or seconds, or supernovae, or galactic gas and dust, or globular clusters, or galactic chemical evolution, or oddities, or large-scale structure, or any of dozens of topics that there was not time or space to explore thoroughly. In all cases, our apologies to the uncited, though we hasten to note that it is not always exactly a compliment to appear in some of these sections. The two authors initially read and took notes on slightly more than 5000 papers in preparing for this review.

10. SOME FAVORITE GALAXIES

10.1. Galaxies with Central Black Holes

Ap94 (§ 8), Ap95 (§ 2.3), and Ap96 (§ 6.4) have all mentioned this topic, with gradually decreasing tones of awe and wonder. Evidently most of the community agrees, since a large number of papers during the reference year have simply incorporated the presence of black holes of 10^6–10^{10} $M_\odot$ into models intended primarily to deal with other problems.

In our own Milky Way, the central star cluster yielded one more *very* large velocity dispersion, squeezing its central (2–3) × 10^6 $M_\odot$ up to a density in excess of 10^9 $M_\odot$ pc^{-3} (Genzel et al. 1996; Eckart & Genzel 1997), and reviewers became complacent (Mezger et al. 1996). Meanwhile, the presence of a million solar mass black hole was more or less assumed in looking at (1) mid-infrared radiation (Stolovy et al. 1996); (2) the near-infrared, where Sgr A* is very faint (Menten et al. 1997); (3) the cloud of stars with He I lines (Najarro et al. 1997); (4) central star formation (Caswell 1996); (5) gamma-ray sources, one of which, 2EG J1746−2852, is probably Sgr A* (Mahadevan et al. 1997); and (6) the spectrum you should see from a fossil accretion disk (Falcke & Melia 1997). At least one set of authors had enough confidence in Sgr A* being pinned down by a large mass to use it as the center of coordinates for a study of galactic rotation (Frink et al. 1996).

M87, the biggest black hole of Ap94, similarly attracted one study with *HST* confirming the large central mass and mass-to-light ratio (Marconi et al. 1997), while others confirmed that you see just about what you would expect in anisotropies of the stellar velocity distribution (Merritt & Oh 1997) and total luminosity (Reynolds et al. 1996, who make the generic suggestion that radio sources of Fanaroff-Riley type I are advection dominated, while FR II's are radiation dominated). MCG −6-30-15, another of the early strong cases, has now had the angular momentum of its black hole measured, on the assumption that Kerr geometry is responsible for the asymmetry of its X-ray iron line (Dabrowski et al. 1997). The answer is a/m greater than 0.94, but not much greater; general relativity says that for angular momentum greater than one, you could look down into a naked singularity and violate causality and other cherished prejudices of physics.

Additional galaxies have been added to the list of those with ground-based evidence for central condensed masses and *HST* confirmations. The best fit for the radio galaxy NGC 4261 is about 5 × 10^8 $M_\odot$ (Farrarese et al. 1996); (2–5) × 10^6 $M_\odot$ for M32, which is, after all, a small galaxy (van der Marel et al. 1997a, 1997b); and 6 × 10^8 $M_\odot$ for NGC 4486B, which is not particularly active and so does not support any strong correlation between central black hole mass and fireworks (Kormendy 1997). It does, however, have a double nucleus, like that of M31, and Kormendy suggests that a central black hole may promote the survival of these. The two nuclei of M31 have very similar stellar populations (Davidge et al. 1997), which argues against them being the result of accretion or merger, and P_2 is probably the "real" nucleus with the black hole (Emsellem & Combes 1997).

Several papers estimated or limited central black hole masses using indirect methods, including the shape of the big blue bump in the continuous spectrum (Wang & Zhou 1996), timescale of variability (Pesce et al. 1997 and two following papers), rising central rotation curves (Keneko et al. 1997), total luminosities (Di Matteo & Fabian 1997), velocity profiles (van den Bosch & de Zeeuw 1996), line asymmetries (Nandra et al. 1997), and polarization (Lee & Blandford 1997). Possibly these tell us more about the opinion of the authors than about the galactic centers in question, but also that said opinion is overwhelmingly pro–black hole.

NGC 4258 was the hero of Ap94 for its central black hole traced out by orbiting water maser sources. The good news is that the results have held up robustly, so that most people now feel free to concentrate on models for the warped disk, though admittedly not always the same model (Maloney et al. 1996; Okazaki et al. 1996) and for the pumping of the maser emission (Cao & Jiang 1997). The bad news, or perhaps just bad luck, is that an alternative, non–black hole model for the gas velocities (Burbidge & Burbidge 1997) was preceded into print by a mapping-out of the jets (Herrnstein et al. 1997) that leaves little or no phase space for the alternative model. The sources's core has been seen in the infrared *H* and *K* bands, and the total luminosity at all wavelengths, which is not much more than a few × $10^7\ L_\odot$, makes sense as advection-dominated accretion (Chary & Becklin 1997).

NGC 4258 is no longer alone in the literature either as a water maser galaxy or as host of a Keplerian disk that may circle a black hole (Baan & Haschek 1996; Braatz et al. 1997). Analysis of NGC 5793 leads to a probable central mass in excess of $1.5 \times 10^8\ M_\odot$ (Hagiwara et al. 1997) and that of NGC 1068 also to something in the neighborhood of $10^8\ M_\odot$ (Greenhill et al. 1996). These are both close to the NGC 4258 number, but NGC 1068 is a much more active GN and must rejoice in a larger accretion rate (Murayama & Taniguchi 1997), or less efficient advection!

Bad news deserves its own paragraph. NGC 4954 was actually the first extragalactic water maser ever found. Its maser velocities imply a central black hole of about $10^6\ M_\odot$ (Greenhill et al. 1997), in which case the luminosity is about one-tenth of the Eddington value. But the *HST* results lead to $10^9\ M_\odot$ (Kormendy et al. 1996) and much less efficient radiation. Arp 102B shares the trait of seeming to have a very massive black holes according to one indicator (separation of velocity peaks) and a much smaller one according to variability and spectrum (Newman et al. 1997).

10.2. Getting Our E's in Shape

This section began its career as a single item in the category "terminally weird," prompted by the report early in the reference year that models indicate big ellipticals are triaxial (three axes of symmetry with $a \neq b \neq c$; Merritt & Valluri 1996), while small ones are oblate (two axes $a = b > c$), followed quickly by the realization that we always begin the year by setting our threshold of "terminally" far too low. There are, nevertheless, several interesting issues to be explored in connection with the three-dimensional shapes of ellipticals and their correlations with other properties, including radio brightness.

Cen A has been reported as both triaxial (at least kinematically; Mathieu & Dejonghe 1996) and as oblate (but with a nearly polar structure of gas and dust precessing around its axis of symmetry; Sparke 1996). One is tempted to say that the difference is bound to be small anyhow, because triaxial galaxies that try to be too triaxial (Merritt 1997) and oblate galaxies that try to be too oblate (Sellwood & Valluri 1997) both get into trouble. Despite this, a warped disk can apparently keep its warp in shape as it precesses through a triaxial potential (Colley & Sparke 1996).

For some purposes, it is tempting to treat giant ellipticals as spheres. At that level, it becomes clear that they do not all have the same run of mass-to-luminosity ratio with radius (Brighenti & Mathews 1997) or, alternatively, that the dark matter, X-ray gas, and galaxies do not all fall off with radius the same way (Davis & White 1996). One paper concerning the analysis of X-ray emission from E galaxies also lived for a while under "terminally weird" until we understood it. You derive a larger total mass when you first subtract out the contribution of X-ray binaries in the galaxy (Buote & Canizares 1997). It's because the X-rays look less centrally condensed after the correction.

An important duty of elliptical galaxies is to host radio sources and quasars. We were initially surprised that four papers more or less agreed that (1) host galaxies are bigger and brighter than the general run of ellipticals and (2) that the hosts of FR I and FR II radio sources differ systematically, the former being most often central cD galaxies, the latter interacting N-type galaxies. Surprise decreased considerably with the recognition that three of the papers had the same author (Zirbel 1996a, 1996b, 1997; Taylor et al. 1996). In contrast, Kaiser & Alexander (1997) attribute the FR I/FR II distinction primarily to jet power, though these might well come down to the same thing.

Another traditional distinction within the class of elliptical galaxies is that between those with boxy isophotes and those with disky isophotes. In reality, it is probably a continuum, associated with the rate of star formation, perhaps after mergers (Bekki & Shioya 1997). Star formation goes slower in the disky ones, so that they now have more young stars (de Jong & Davies 1997). Kissler-Patig (1997) points out that the boxy-shaped E galaxies also have higher metal abundances and a larger number of globular clusters per unit luminosity, and he concludes that they have been more affected by mergers than the disky ellipticals. We feel vaguely that the two sorts ought somehow to be found in underlying potentials of different shapes (triaxial, prolate, oblate, or whatever) but have no evidence to support or refute the suggestion.

In fact, the distinction between a disky E and a real disk is not a very clean one, according to Mizuno & Oikawa (1996) who cite NGC 4621 as an example. Ellipticals and bulges with peanut-shaped isophotes perhaps come in between (Quillen et al. 1997). And some post-merger ellipticals may actually regrow disks from infalling coronal gas (Baugh et al. 1996). Finally, and in order to blur probably legitimate distinctions as much as possible, we end by noting that neither Ss nor Es (or at least their models) are as much disturbed by adding companions as you might have expected (Huang & Carlberg 1997 and Cora et al. 1997 on spirals and Weinberg 1997b on ellipticals and their fundamental plane).

10.3. Dwarfs (More than Seven and Not All Snow White)

The Local Group stops growing.—Do not spend too much time looking for new dwarf members of the Local Group. The two most recent nominees, dwarf spheroidals in Tucana (Ap92, § 10.5, with additional data given by Saviane et al. 1996) and in Antlia (Whiting et al. 1997) were both catalogued a couple of decades ago (Skiff 1997) by Corwin, de Vaucouleurs, & de Vaucouleurs (1977, 1978). The less trusting author has checked that the Antlia dwarf indeed occurs on the page cited as object 1001.9−2705. What the new papers have done, of course, is to present accurate H-R diagrams that permitted both accurate distance determinations (so you know where they are) and studies of stellar populations (so you know what they are). While dwarfs at *cz* less than 500 km s^{-1} are still being found (Huchtmeier et al. 1997), any remaining, undiscovered members of the Local Group are probably fainter than one-eighth of the luminosity of the Sculptor dSph (Kleyna et al. 1997).

Many and varied.—There are, however, still lots of interesting things to be said about the existing dwarfs (even neglecting faint blue galaxies, blue compact dwarf galaxies, and a few other shifting classes, as we shall). A small number of additional dwarfs with spiral-shaped isophotes appeared (Patterson & Thuan 1996), and if you feel that this still does not quite make them dwarf spirals, we won't object. At least two dwarf Wolf-Rayet galaxies also claim existence as a predicate. One is I Zw 18, the well-known calibrator of primordial helium abundance (Izotov et al. 1997a), and the other is the more obscure Henize 2-10 (Beck et al. 1997).

Perhaps the most striking thing about dwarfs is that there are such a lot of them (like beetles and the common man, they must be loved by Higher Authority), though never quite enough that they dominate anything except number counts. Examples include the Coma Cluster, with a ratio of dwarfs to giants as large as in the smaller Virgo Cluster (Secker & Harris 1996); four clusters examined by Trentham (1997a), in which the luminosity function is very steep from $M = -14$ to -10; and, among more distant clusters, four Abells at $z = 0.02$–0.14, where the luminosity function is still rising at $M_v = -18$ to -13 (Sodre & Cuevas 1997), and two at $z = 0.1$ and 0.2, where the rise is seen at $M_v = -19$ to -16 (as faint, of course, as those counts go; Smith et al. 1997a).

The luminosity function is, nevertheless, apparently not a universal constant. Valotto et al. (1997) suggest that it is flatter in poor clusters (excluding, presumably, the Local Group), and Gaidos (1997) did not see the faint-end upturn in any of the 20 clusters he examined. Despite the widespread plethora of dwarfs in rich clusters, they are not the primary source of metal-rich intracluster gas there (Gibson & Matteucci 1997), though their disjecta membra may have contributed to central cD galaxies (López-Cruz et al. 1997).

Old versus young.—In a general sort of way, dwarf irregulars have considerable gas content and ongoing or recent star formation, while dwarf ellipticals (with recognizable nuclei) and dwarf spheroidals (without) do not. Nevertheless, the irregulars have an underlying population of old stars (Skillman et al. 1997; Gallart 1996a, 1996b on NGC 6822; Aparacio et al. 1997), as was pointed out by Baade (1963) some time ago.

Conversely, at least some of the "early-type" dwarfs have stars that do not go back to predeluvian times. Han et al. (1997) point to a 3 Gyr population in NGC 147; Johnson et al. (1997) found a handful of O stars in A0951+68; and Grebel (1996) reports a range of stellar ages in Sculptor and Fornax. The dSph's are, however, definitely shy on gas of any kind (Oosterloo et al. 1996; Bowen et al. 1997; Young & Lo 1997; Welch et al. 1996), though the sparsity of CO is partly an effect of low metallicity (Madden et al. 1997).

Are the elliptical and spheroidal types merely former dwarf irregulars that have had their gas used up or removed some time ago? This question has been asked and answered (both ways) many times before, and the 1997 answers remain of the form yes, no, maybe, and yes but (Mould 1997; Sodre & Cueves 1997; Spaans & Norman 1997).

One swallow does not a summer make.—And it takes more than one accreted dwarf galaxy to make a polar ring (Galletta et al. 1997). In fact, for NGC 2685, the high oxygen abundance of the ring gas says that it did not come from any number of accreted (low-metallicity) dwarfs (Eskridge & Pogge 1997). One galaxy should probably not make a primordial helium abundance either. Not only does I Zw 18 show Wolf-Rayet spectral features (above), it also has a companion (Dufour et al. 1996; Pustil'nik et al. 1997) and is all together not to be trusted (Garnett et al. 1997; Izotov et al. 1997b), though these last two papers disagree about whether the helium value found for I Zw 18 is likely to be larger or smaller than the right one. The second most metal-poor galaxy is perhaps SBS 0335−052 (Thuan et al. 1997).

Finally, we return to the one dwarf in the Local Group that really is a recent discovery (Ibata, Gilmore, & Irwin 1994) and note that IGI is so stretched out along its long axis that it probably contributes to the optical depth in gravitational lensing toward the bulge of the Milky Way (Alcock et al. 1997a; Ibata et al. 1997). Its survival up to the present time is somewhat remarkable (Edelsohn & Elmegreen 1997; Ibata et al. 1997). And we were just about to crow with triumph at having made two converts to this name for the dwarf spheroidal in Sagittarius, when we figured out that Layden & Sarajedini (1997) were talking about the discoverers, not the discovery.

10.4. The Ones in the Hubble Deep Field

The important result here is undoubtedly the derivation of star formation rates in the universe as a function of redshift.

Galaxies in the HDF permit filling in some of the gaps in SFR(z) as implied by galaxies and quasar absorption lines studied from the ground (Ap96, § 12). This has been addressed by at least two groups. Madau et al. (1996) report that, if you call the current SFR 1 unit, the numbers are 12 units at $z = 1$, 3 units at $z = 2.75$, and probably still in excess of one unit at $z = 4$. Connolly et al. (1997) essentially concur, though putting the peak perhaps a little later at $z = 1.5$. The closely related topic of the brightnesses of individual galaxies as a function of redshift was tackled by Sawicki et al. (1997), who put peak brightness at $z = 3$. And the $z = 3$ bits that are clustered on the sky are probably puzzle pieces that will later be put together to make galaxies like the ones here and now (Colley et al. 1996; Lowenthal et al. 1997), not protoclusters.

What else is there in the HDF? Some gravitational lensing—not much strong lensing according to Zepf et al. (1997, from which some sort of limit on the cosmological constant might be obtained), though quite a lot of galaxy-galaxy weak lensing according to Dell'Antonio & Tyson (1996). They looked at 2221 foreground/background pairs and derived an average mass of $(6 \pm 2.5) \times 10^{11}\ h^{-1}\ M_\odot$ out to a radius of 20 h^{-1} kpc.

There are 19 *Infrared Space Observatory* (*ISO*) sources, including 15 galaxies (vigorous star formers at high redshift) and one star (Sarjeant et al. 1997, and five following papers). This sounds like very few, given that *ISO* is 1000 times more sensitive than *IRAS* was, until you remember how narrow the HDF is in the other two dimensions and allow for source confusion as the limiting factor. There are also six VLA radio sources, all ellipticals and early spirals with $I < 24$ and $z = 0.2$–1.2, according to Fomalont et al. (1997). A longer observing run could lower their flux limit by a factor of nearly 6 and so presumably pick up many more radio sources. Next there are 12 candidates for polar ring galaxies (Reshitnikov 1996), which the author says is a lot, considering, and an indicator of vigorous merging activity at large z.

And there are nine stars (Mendez et al. 1996) and seven other blue compact things that are not quasars. Well, Hubble told us half a century ago that fainter than some fairly moderate magnitude limit, most of the things in the sky are galaxies. *Hubble* (*Space Telescope*) apparently agrees with Hubble (Edwin Powell).

10.5. The Milky Way

We guess this has to be a favorite, since we all live here (but consider College Park, MD, Urbana, IL, Pasadena, CA, and other places where astronomers live). Unfortunately, an exciting item that (perhaps) settles the issue of whether high-velocity clouds (HVCs) of neutral hydrogen include lots of virgin material being added to the galaxy is still in the press release and rumor stage. The idea was first put forward by Jan Oort in 1966, and Willy Fowler endorsed it regretfully a while later, in the form, "Here these stars are burning their hearts out trying to make heavies, and those bastards keep diluting it." We note, however, several relevant results. First Oort's very first cloud is at least 3 kpc above the Galactic plane and not of zero metallicity (Wakker et al. 1996). The authors note that this rules out some small number of 11 suggested models for HVCs. Second, at least a few have some star formation going on (Ivezić & Christodoulou 1997). Next, a case can be made for one hitting the LMC at the present time, so that they must pervade the Local Group (Braun 1997). Finally, a survey of other galaxies concludes that only those spirals with large current rates of star formation are blessed with their own supplies of high-velocity clouds, which implies a model of the recycling or galactic fountain variety (Schulman et al. 1997). Make of all that what you will!

On the more coherent side, the author whose father was a chemist, after years of shuddering at papers that mentioned more than one molecule at a time, finally sees how it may be possible to make sense out of sequences of relative abundances that trace out the evolution of clouds from formation to dissipation. It takes a while for the most complex molecules to form; they condense onto grains in a predictable order and finally are photodissociated and blown away (Bergin et al. 1997). Thus one can assign specific ages to specific clouds (Bergin & Langer 1997; Pratap et al. 1997). She continues to wish that somebody could manage to make the number of carbon atoms seen in different phases of the interstellar medium come out even (Greenberg 1974; Li & Greenberg 1997; Dwek 1997; Mathis 1996). It should be noted that, while Greenberg (1974) was inclined to feel that somebody had hidden a bunch of carbon atoms that we know must be there (on the basis of solar system abundances), Mathis (1996) is conversely worried that nature may not have supplied enough to go around and make the various grains and gases we see.

Other colleagues found new molecules, catalogued and characterized globular clusters, divided galactic stars into no fewer than six populations (Ng et al. 1997), and found what are apparently the second and third examples of expanding supernova remnants bashing into molecular clouds (Koo & Inoue 1997; Zanin & Weinberger 1997). The first was IC 443 (De Noyer 1979). Given that this is supposed to be a trigger for star formation, we are glad it has happened more than once. Once is perhaps enough for the peculiar extension of electron-positron annihilation radiation out of the Galactic plane seen in OSSE and other data (Cheng et al. 1997). An expanding bubble of stuff from a starburst of supernovae is one possible explanation (Dermer & Skibo 1997), though more exotic possibilities are easily imagined. Undoubtedly just the first among many are the polarized molecular emission reported by Glenn et al. (1997) and the first organic molecules in a protostellar disk (Dutrey et al. 1997).

10.6. Some Galactic Extrema

The most distant galaxy is, once again, an honest-to-goodness galaxy, not a quasar, at R.A. $= 14^{\rm h}$, decl. $= +62°$, and $z = 4.92$ (Franx et al. 1997), though it is admittedly lensed by a $z = 0.23$ cluster in the same direction. Its brightest knot has a star formation rate about as high as anything going, and both it and a companion galaxy at the same redshift show significant outflows. The most distant radio galaxy, GC 0140+326 is also lensed but has little or no star formation or optical continuum (Rawlings et al. 1997). Its redshift is 4.41.

The possibility of lensing casts doubts on yet another potential candidate for brightest galaxy, FSC 15307+3253 at $z = 0.97$ and $L \sim 10^{13}\ h^{-2}\ L_{\odot}$ (if it is not lensed; Liu et al. 1996). The galaxy with the largest luminosity in CO is apparently neither lensed nor bursting (Lo et al. 1997 on Arp 302). NGC 1143 and 1144, in contrast, have perhaps the most turbulent CO ever seen and are bursting all over the place (Gao et al. 1997). While we're on CO, the first unlensed, high-redshift galaxy to be detected is 53W002 at $z = 2.4$ (Scoville et al. 1997).

The first galaxy outside the Local Group for which a large sample of supernova remnants has been identified (in Sculptor; Blair & Long 1997) was inevitably followed by the second (M82; Greenhouse 1997), and then by many (Matonick & Fesen 1997). In general, all groups report that supernova remnants outside the Local Group are a good deal like supernova remnants inside the Local Group, only harder to identify cleanly. The relative paucity of supernovae in classic starburst galaxies is a long-standing puzzle. Trentham (1997b) reported the first supernova in a galaxy brighter than $10^{12}\ L_{\odot}$, and he notes that the less extreme starburster NGC 3690 has actually had two (reported in IAU Circulars 5718 and 5960).

The host galaxy of quasar 3C 48 is apparently the brightest one (Wink et al. 1997). Less spectacular homes for AGNs display a range of types, a propensity for optical and radio alignments, and a generous supply of close companions (Bahcall et al. 1997a; Hooper et al. 1997; Ridgway & Stockton 1997; Le Brun et al. 1997). PKS 1229−021 currently holds the redshift record ($z \approx 1$) for an optical counterpart of a radio jet (Le Brun et al.).

The most familiar example of an active galaxy that is supposed to display true periodicity is OJ 287, whose 1994–1995 December outbursts occurred as expected from the 12 yr period (Sillanpää et al. 1996). It has been modeled both as a binary black hole (Sundelius et al. 1997; Valtonen & Lehto 1997) and as a precessing disk (Katz 1997a). As for other candidates, Hagen-Thorn et al. (1997) suggest 15 yr for 3C 120, but on the basis of only 20 yr of data, while Lik et al. (1997) rely on nearly 90 yr of brightness measurements in proposing a 23.1 yr period for Mrk 421.

And last among the firsts, lasts, and nevers, we are happy to report (a) gravitational lensing by what seems to be a disk galaxy (Mathur & Nair 1997), (b) both limits on and detections of what would have been clusters of galaxies if only they had galaxies in them in addition to lensing material and diffuse gas that emits X-rays and scatters microwave background photons (Maoz et al. 1997b; Briggs 1997; Hattori et al. 1997; Barnes et al. 1997; Jones et al. 1997; and Saunders et al. 1997; a small subset of whom cite the first paper that considered the Sunyaev-Zeldovich effect in "empty clusters"—Cavalieri & Fusco-Femiano 1976), and (c) a quasar survey that makes use of proper motions (Scholz et al. 1997)—they are required to be small!

11. THE FAT LADY BURSTS

No decision has been reached on whether the portly person in question was really Kate Smith rendering "God Bless America" to terminate a baseball game or a Sutherland-like soprano declaring her desire to leave Paris toward the end of *La Traviata*,[3] but, beyond doubt, at least one gamma-ray burst occurred at a cosmological distance, meaning z between 0.851 and 2.31 (Metzger et al. 1997); and there are reasonable grounds on which to conclude that all or most of these long-mysterious events happen at redshifts of 1–3.

11.1. What They Saw

The already much-told story begins with the *BeppoSAX* satellite, launched last year, and not without problems of its own. It does, however, when all is well, have fast response time and good angular resolution, as a result of which it picked up and located an X-ray afterglow from the burst of 1997 February 28 (Costa et al. 1997a), in time for optical telescopes to swing there and, 21 hr postburst, see an optical counterpart (van Paradijs et al. 1997). The source included a fading point, off-center in a bit of fuzz. An *HST* observation, obtained just as the field was disappearing behind the Sun, concurred (Sahu et al. 1997). The energy in the tails, especially the X-ray part, was a significant fraction of the total seen in gamma rays (and snide remarks about tails wagging dogs are therefore inappropriate).

The next few months witnessed a good deal of reprocessing of images (best followed in IAU Circulars of the period), but, when the Sun finally got out of the way in early September, *HST* found the fuzz at the same place and brightness (not implausible as a $z \approx 1$ dwarf galaxy), while the point component had continued to fade in roughly exponential fashion (Fruchter 1997). All other observations of this event—radio counterparts, spectral features, and parallax—are currently upper limits. It was, for instance, at least 11,000 AU away (Hurley et al. 1997b).

Meanwhile, before boredom could set in, the burst of 1997 May 8 arrived, dragging its X-ray tail behind it (Costa et al. 1997b). Our own PASP Editor, working that night at the KPNO 0.9 m reflector, caught the optical counterpart on its way up (Bond 1997) and modestly suggested that "although the brightening (rather than fading) may make the identification with the GRB dubious, follow-up observations are desirable." Larger telescopes were on the job almost immediately (Djorgovski et al. 1997; Metzger et al. 1997). This time, spectral features were unambiguous—an absorption system of Fe II and Mg II lines at $z = 0.851$ (and also Mg II at a lower redshift), indicating

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[3] Actually we ourselves have occasionally felt the desire, before the end of *La Traviata*, to leave Paris or, indeed, whichever city happened to host the performance.

that the GRB photons must be coming to us from beyond that distance, but also from less than $z = 2.31$, or Lyα forest lines would have begun intruding at the 4000 Å blue edge of the spectrogram. As the source faded, an [O I] emission line at $z = 0.851$ also appeared. Through rise and fall, the event was fuzzless.

"May 8th" was also a radio source, brightening about a week later at 8.5 GHz and, to a lesser extent, at lower frequencies (Taylor et al. 1997; Frail et al. 1997). Received flux was initially quite erratic, settling to a steadier level after some weeks. Both this interstellar scintillation (if that is the right explanation of the variability) and the inverted spectrum (interpreted as synchrotron self-absorption) imply a size of about 3×10^{17} cm and expansion.

At this point, one was already forced to conclude that there are (at least) two kinds of GRBs, one (like 970228) living in galaxies, and one (like 970508) whose host galaxies, if any, are considerably fainter.

Subsequent events and revelations have, if anything, complicated the picture, having included another X-ray tail or two, some X-ray counterparts of very short lifetime, but no additional radio or optical identifications. *BeppoSAX*, sadly, spent most of the late spring and summer on the sick list (six initially functioning gyros having been reduced to two). *Rossi XTE* has come to a sort of rescue, spotting, so far, X-rays from three additional GRBs on varying time scales: 970616, 4 hr postburst and short-lived (Marshall et al. 1997); 970815, lasting only 130 s (Smith et al. 1997); and 970826, lasting at least 160 s (Remillard et al. 1997). And there were good *BeppoSAX* positions for a somewhat prolonged event identified with GRB 970111 (Galama et al. 1997) and for 970402 (Feroci et al. 1997). None of these has displayed optical, infrared, or radio counterparts, whether point-like or fuzzy. Thus bursters with comparable gamma-ray fluxes vary in optical brightness by a factor of 10^3 or more, and their hosts (if any) are comparably non-standard. And you can argue about which X-ray counterparts lasted long enough to be called tails.

11.2. What Are We Supposed to Think?

Where have the theorists been through all this? As usual, both ahead of and behind the observations. Discussions of gamma-ray bursters as extragalactic phenomena customarily begin with Paczyński (1986) who considered the merger of a pair of neutron stars driven together by the loss of angular momentum in gravitational radiation, though suggestions of various combinations of neutron stars and black holes followed hard upon the 1973 announcement by Klebesadel, Strong, & Olsen (1973). But the paper most often mentioned this year is the analysis of a fireball-type model by Mészáros & Rees (1997) that specifically predicted optical and radio afterglows with e-folding times of hours and days to weeks, respectively. This paper was part of an ongoing effort by them and several colleagues to understand both gamma-ray bursts and other possible manifestations of very energetic, relativistically expanding sources, like gamma-emitting active galaxies (see, e.g., Mészáros et al. 1994). The (very) general idea is that outgoing and probably beamed relativistic stuff radiates gamma rays from internal shocks, and, a good deal later, starts producing lower energy photons when it has plowed up a significant amount of surrounding material. This should happen when the burst source is somewhere close to the size implied by radio observations of 970805, but you see the X-rays, visible, and radio radiation very soon after the gamma rays because the source material has been moving toward you almost as fast as the photons.

Post facto models, aimed specifically at 970228, have come from Tavani (1997), Wijers & Mészáros (1997), and Reichart (1997, who wanted to allow the extended bits to fade, just in case), and Waxman (1997). All the specifically extragalactic models require at least 10^{51} ergs, and so are consistent with the event having been located near $z = 1$. Also deserving of mention is a post facto test for beaming. As the ejecta slow down, the cone they fill should expand in angle, leading to optical and radio afterglows with no preceding GRB (Rhoads 1997). Early experience in looking for GRB counterparts over large error boxes indicates that these will not be easy to find. Quite strong beaming is a prediction of at least some of the relativistic fireball models (Mészáros & Rees 1997b).

An important issue that remains under the rug in our rush to declare victory over the gamma-ray burster problem is the reality of spectral features in the 20–60 keV range. These were firmly reported by *Ginga* investigators and several other satellite groups and were, in their day, held to be (1) cyclotron resonance lines from Landau levels, (2) a measure of magnetic fields near 10^{12} G in the sources, and (3) strong evidence for origin of the bursts in neutron stars within the Milky Way.

No such features have been reported for any burst observed with the *Compton Gamma Ray Observatory*. The official party line appears to be that there is no real contradiction, owing to differences between the detectors on the two satellites (Band et al. 1997). But we note that OSSE sees the same 110 keV feature in A0535+26 that *Ginga* did (Maisack et al. 1997) and that HEXE has confirmed the 23 and 45 keV features reported from *Ginga* for Vela X-1 (Kretschmar et al. 1997). At present you are allowed to choose among three alternatives: (1) the *Ginga* (etc.) lines weren't real, (2) not all bursts are extragalactic, or (3) there is some way to make keV spectral features in sources at $z \approx 1$, but Martin Rees hasn't told us about it yet.

11.3. And All the Rest

Normal science, of course, grinds on even as the revolution is occurring, and we note here four classes of papers representing work not directly related to the X-ray and optical counterparts: (1) analyses of observed burst properties and their correlations that bear on their distances and associations with galaxies, (2) models published or underway before the February event which still seem relevant, (3) suggestions that should now probably be declared inoperative (though the authors might disagree), and (4) one interesting new idea.

First, an assortment of observational remarks that seem likely to continue to be of use. Spectral evolution from hard to soft through bursts is more or less ubiquitous (Band 1997). Events lasting more than 10 s differ from the shorter ones on average (Katz & Canel 1996), which suggests that two or more mechanisms may be responsible (neutron star mergers, failed supernovae, hypernovae, ...). One can define a wide variety of correlations among spectra, durations, fluences, substructure, and so forth (Horack & Hakkila 1997), though many of these are not very robust (Lee & Petrosian 1996). The use of Haar wavelets to analyze burst structure could make definitions of properties more quantitative (Kolaczyk 1997), but we suspect this is not the core of the problem.

More to the cosmological point, a number of authors have attempted to describe the correlations as the effect, primarily, of redshift. A fair summary of the results seems to be that time dilation and the rest are in there, but they do not wholly dominate intrinsic associations of luminosity, duration, and so forth (Che et al. 1997a; Lee & Petrosian 1997; Che et al. 1997b; Brainerd 1997; Reichart & Mészáros 1997). In particular, the range of redshifts that seems to be contributing to observed events is quite dependent on the spectral indices of the sources (Wei & Lu 1997; Mallozzi et al. 1996).

It doesn't matter to the theorists whether GRBs go off always, sometimes, or never inside galaxies (they have explanations for all three), but one might nevertheless want to know. One paper found that the event locations were correlated with the positions of Abell clusters (Marani et al. 1997), one that they were not (Hurley et al. 1997a), and one that they were anti-correlated (Gorosable & Castro-Tirado 1997). There was also a finding of correlation on the sky with radio-quiet quasi-stellar objects (Schartel et al. 1997b). The safest bet in such cases is usually with the people who originally collected the data. Unfortunately, some BATSE people are on each side this time.

Now that we "know" that the GRBs originate at large distances, can we use them to pin down any or all of the traditional cosmological parameters? (§ 12.3) The short answer is no (Piran & Singh 1997). So is the long answer, in the sense that the parameters you get are no better constrained than they were before you included the bursters (Horack et al. 1996).

Second, some pre-February models that come through the revolution with their uniforms in fairly good condition, at least in the sense of being able to yield 10^{51} ergs or more, and perhaps "predicting" something else roughly as seen, like time scale versus photon energy (Sari et al. 1996), an X-ray tail (Vietri 1997), an optical tail (Bisnovatyi-Kogan & Timokhin 1997), or how the spectra change with time (Liang et al. 1997). Three papers specifically predicted large neutrino fluxes from the bursts (Waxman & Bahcall 1997; Ruffert et al. 1997; Mathews & Wilson 1997), though not quite the same sorts of neutrinos in all cases, and don't hold your breath while waiting for them to be seen.

Models that simply focused on particular sorts of extragalactic compact objects probably belong to this class, including collisions of neutron stars and black holes in various combinations (Kokhchaev & Eroshenko 1996), black holes swallowing stars (Cadez & Gomboc 1996), mergers of binary stars (Vietri 1996), neutron stars with thick disks left from mergers (Daigne & Mochkovitch 1997), and cosmologically distant neutron stars with long-lived precessing jets (like SS 433 or GRS 1915−105, only more so; Blackman et al. 1996).

Third (and this part is always the most fun), the models that retrospectively seem to have misspoken themselves. Wrong by the largest factor in distance are gamma-ray bursts made in the heliosphere (Kuznetsov 1997). Next are galactic disk plus halo models (Belli 1997) or pure halo ones with beaming (Duncan & Li 1997, who say they didn't much like it in the first place). Whether associating GRBs with Sco X-1 and Cyg X-1 belongs in this category depends on what fraction of the total is involved (Mason et al. 1997). And then there are primordial black holes, whose decays have long been sought and not seen at gamma-ray or other wavelengths. Belyanin et al. (1996, modifying quantum chromodynamics as they go) and Cline et al. (1997, keeping to standard physics, but addressing only a subset of 11 GRBs with durations less than 0.1 s) have put these into the pool again. Moderate fluence ones would have to be less than 30 pc away, even with 100% efficiency for conversion to gamma rays, and how firmly you want to exclude them depends on how firmly you believe that the classic GRBs are all the same sort of beast.

Fourth, and last, an interesting new idea. Totani (1997) has noticed that, if you accept cosmological distances as definitely established and try to convert BATSE statistics into rate versus redshift for the events, you come up with something that, at least approximately, tracks the star formation rate as a function of redshift (Ap96, § 12.8; Sawacki et al. 1997 and many other papers this year). One implication is that GRBs should be closely associated with star-forming galaxies at their own redshifts, and not just be relics of star formation long before and possibly far away. A supporting point is apparent absorption in the X-ray spectrum of 970228, such as would be produced by the gas in a star formation region. If this is the right way to look at things, then the majority of events are happening at $z \approx 2$ where the star formation rate peaks, their average energy is more like 10^{53} ergs than 10^{51} ergs (for unbeamed sources), but we sample far more space and far more galaxies than at smaller mean redshift, so that the necessary event rate per galaxy goes down a factor of 20 or so.

Stay tuned for further developments!

11.4. A Few More Gamma-Ray Goodies

Geminga, whose name once meant "does not exist," owing to its elusiveness at all other wavelengths, has, over the years, gradually revealed pulsating X-rays and a rapidly moving optical counterpart. Now, at long last, the expected radio pulsation has been found, at the X-ray period of 0.237 s (Kuzmin & Losovskii 1997, and several other groups not quite in print by the end of the reference year). The emission is indeed faint, 0.1 Jy at 102 MHz and very steep of spectrum, with a slope less than −1.7, based on not seeing any flux at 1.5 GHz. The dispersion measure is only 3 ± 1 pc cm^{-3}, commensurate with its being very close to us.

Active gammatic nuclei.—Once the inventory of AGNs emitting gamma rays had grown from its historic total of three (3C 273, NGC 4151, and Cen A; Ap92, § 6.4), they proliferated rapidly. Mattox et al. (1997a), for instance, found a sample of 42 in which they had enough confidence to look for correlations of radio and gamma-ray fluxes; and new correspondences continue to be suggested, including eight new candidates from a cross-correlation of polarized radio sources with the EGRET catalog (Iler 1997) and a few more from Zook et al. (1997).

In sharp contrast, Punsly (1997) has claimed that a large fraction of the high-latitude EGRET sources merely seem to coincide with QSOs by chance and that the real inventory of gamma-ray AGNs is 10 or fewer BL Lac sources and 35 or fewer quasars.

Undeterred by such doubts, data analysis and modeling go forward (or at least sideways). For instance, Mattox et al. (1997) report strong correlations between radio and gamma-ray luminosities for their sample, while Mücke et al. (1997) conclude that the apparent correlation is merely an artefact from seeing only the brightest sources at high redshift. Xie et al. (1997) find that the gamma-ray luminosities are better correlated with infrared flux than with X-rays, which they interpret as meaning that the gammas come from inverse Compton interactions between beamed electrons and radiation from a hot disk. Piner & Kingham (1997) find something at least consistent for the well-studied blazar 1611+343, where gamma-ray enhancements seem to be associated with the ejection of new radio components along a jet.

No complete inventory of the year's models for gamma-ray emission from active galaxies was attempted, but nearly all the ones we happened to spot shared at least one feature—jets moving even faster than the ones invoked for AGNs in general (Piner & Kingham 1997; Mattox et al. 1997b; Bower et al. 1997; Zhou et al. 1997; Bednarek 1997; Lin et al. 1997, who also comment on the correlation issue; Bednarek & Protheroe 1997a, where the jet hits a passing star now and then; and McGlynn et al. 1997).

The gamma-ray background.—This takes over from the X-ray background anywhere from 10 keV to 1 MeV, depending on taste, and now has in common with the lower energy background sufficient information that it is possible for experts to disagree about whether it can be completely accounted for as the sum of known populations of active galaxies (Kinzer et al. 1997; Zhou et al. 1997) or reasonable extrapolations thereof (Impey 1996; Kazanas & Perlman 1997). For similar remarks at greater length concerning the X-ray background, see § 9.1.

The PeV/TeV *regime*.—The second active galaxy (Mrk 501) has been seen by the second detector (HEGRA, an air Cerenkov counter on La Palma that was badly damaged by fire even as we wrote; Bradbury et al. 1997). Both Mrk 501 and Mrk 421 were first found as TeV sources at the Whipple Observatory. The majority of active galaxies seen by EGRET cannot, however, be similar sources, or their sum would exceed the TeV background (Coppi & Aharonian 1997). It is significant in this regard that BL Lac itself, which has EGRET flux extending to at least 100 MeV (Catanese et al. 1997), is not a TeV source, since it is closer to us than the Markarian galaxies. That is, not seeing it says something about the source itself, not about loss of very high energy photons en route.

Such a loss is expected because high-enough energy photons meeting other photons from the 3 K or infrared backgrounds will produce $e^{\pm}$ pairs and be lost to the gamma-ray flux. The result should be a break in spectral index. Mrk 421 shows no such break out to the highest energies at which it has been seen, and the absence is beginning to be interesting (Stecker & de Jager 1997; Krennrich et al. 1997). Moderate numbers of models for the very high energy emission, invoking a variety of beamed protons and electrons, continue to be ejected each year (Dar & Laor 1997; Mastichiades & Kirk 1997; Bednarek & Protheroe 1997b).

And the Vela pulsar has (once again; Ap92, § 11.2) been reported as an unpulsed TeV source, this time from CANGAROO, a Japanese–Australian–New Zealand collaboration (Yoshikoshi et al. 1997).

12. SOME FAVORITE UNIVERSES

You probably noticed that many of our favorite stars and even galaxies were also among your favorites. In contrast, many of the universes mentioned here do not sound at all homelike. There must be some reason that cosmology inspires people to Flights of Rampant Originality in a way that barium stars and dwarf galaxies do not.

12.1. Not Your Father's Metric

Assuming, of course, that your father was Friedmann, Robertson, or Walker, we go on to explore, first, interesting variants on the standard model and then larger deviations.

Topological defects are glitches in spacetime left behind by major phase transitions such as are supposed to occur when the universe drops through the various temperatures at which the forces (gravity, strong, electroweak) cease to be unified. Defects can have dimensionality zero (monopoles), one (strings), two (domain walls), three (textures), or "decline to state" (non-topological). Such glitches are probably unavoidable, but the astrophysical question is whether they contribute significantly to the origin of large-scale structure, for which the main competing source is adiabatic density fluctuations left behind by an inflationary epoch.

Through most of the year, papers appeared that either regarded defects as a strong contender (Allen et al. 1996; Avelino

1997; Sicotte 1997) or concluded that judgment should be reserved until slightly more precise measurements of structure in the microwave background could uncover the relevant signatures (Turok 1996; Seljak & Zaldarriaga 1997). Bettancourt et al. (1997) pointed out that you cannot actually embed strings in a standard FRW cosmology. This is not so worrisome as it sounds; it's not very easy to embed an ordinary Kerr solution in FRW either, yet Earth rotates on, unconcerned by the problem. But, as the leaves began to fall, Pen et al. (1997) and Seljak et al. (1997) scored two triumphs. First, they made a strong case that any defect-based scenario to produce large-scale structure in the universe would have left behind less structure in the 3 K background than is actually seen (Netterfield et al. 1997). And, second, by carefully rearranging their authors, they succeeded in publishing what is in effect the first eight-page *Physical Review Letter* in history.

Another relatively benign, and also false, variant is topology more complex than the minimum necessary to hold the universe together. Roukema (1996) and Levin et al. (1997) point out that quasars at high redshift and the microwave background (respectively) might have shown evidence for periodicity or other complex topology and have not, in fact, done so.

Even a Friedmann-Robertson-Walker universe can look pretty strange if you give it an unexpected equation of state to chew on. Bonner (1996) has explored a model in which rulers expand with the universe. It requires that all the density be in dust with charge equal to mass in the units of general relativity (as proposed by McVittie 1933 for somewhat different reasons). Saslaw's (1996) static universe is perhaps the limit of an Einstein–de Sitter one as time goes to infinity. Its pressure is equal to gravity. We are not sure what the effect on the metric would be of the early-time sink of particles invoked by Brevik & Stokken (1996) to explain the present ratio of photons to baryons, but if you want your universe to have time machines in the form of wormholes, the effects is that of embedding a bunch of Reissner-Nordstrom black holes with closed timelike curves (Schneider & Arendberg 1996). The FRW model with creation described by Johri & Desikan (1996) probably goes about as far in the direction of non-standard equations of state as you can, and they related their work to the original form of steady state. A mirror universe "merely" has a whole additional set of particles chirally opposite to the ones we are used to. We wouldn't necessarily even know bout them (Mohapatra & Teplitz 1997), leaving the idea, for the moment, unfalsifiable.

General relativity describes gravity and geometry entirely in terms of tensors and is the simplest possible theory. Next come scalar-tensor theories, associated with the names of Brans & Dicke (1961). A generalized version allows you to have strings and/or dilatons without any singularities, in a homogeneous, isotropic universe (Rama 1997).

From here on out, it becomes difficult to decide which ideas deviate most sharply from the standard model and, sometimes, even whether two authors are talking about essentially the same model. The arbitrarily adopted order in the following paragraphs is quantized redshifts, MOND, Newtonian cosmologies, non-cosmological redshifts and quasi–steady state, Segal's quadratic universe, and "unclassifiable."

Quantized redshifts.—Apparently one way to end up with redshifts that cannot have a continuum of values is to "give up the arbitrary hypothesis of the differentiability of space time" (Nottale 1996). This may or may not be exactly what Cocke and Tifft have had in mind over the years and describe again (Tifft et al. 1996; Cocke & Tifft 1996) during the reference year. But their quantization scheme has, at any rate, grown more complex with time, now requiring intervals as fine as 5.76 km s^{-1} (Tifft 1997). It is a little difficult to get non-believers to look at effects like this (even as referees!), but when they do, they don't find the same periodicities (Nordgren et al. 1997).

MOND (*modified Newtonian dynamics*) has also been with us for some years, invoked most often to replace dark matter in accounting for large velocity dispersions in clusters of galaxies and for the flat rotation curves of spiral galaxies (Sanders 1996). Known gravitational lenses can also be accounted for (Sanders 1997) but at the price of giving up Lorentz invariance.

Newtonian pictures of the universe of course predate relativistic ones, and Wild (1996) seems to feel that the community made a major mistake in giving up one for the other in 1915 (his date). In fact, the main types of relativistic models have Newtonian analogs that can be very helpful in trying to figure out what things should look like (McCrea & Milne 1934; Zeldovich 1963). This is not, however, what Audit & Alimi (1996), with their "Newtonian counterpart of the magnetic part of the Weyl tensor" and Barrow (1996) with his changing, Newtonian, gravitational constant seem to have in mind. Ellis & Dunsby (1997) conclude that there are recent modifications of Newtonian cosmology (e.g., Bertschinger & Hamilton 1995) that are better than pure Isaac, but, in the end, east or west, GR is best.

Quasi–steady state and non-cosmological redshifts are the key phrases in the next set of ideas and are strongly associated with the names of Arp, G. R. Burbidge, Hoyle, and Narlikar (in alphabetical order). Quasi–steady state is an infinitely old universe that has, nevertheless, experienced hot, dense states. Non-cosmological redshifts are those that are not attributable to the Doppler effect, gravitation, or the expansion of the universe. And it is primarily the overlap of the sets of people focusing on the two that makes one think they must be associated (though indeed a traditional steady state universe is strictly inconsistent with the observed redshift distributions of quasars and such unless the redshifts have a mystery component). Sachs, Narlikar, & Hoyle (1996) have provided a set of field equations for quasi–steady state. Members of the group continue to find configurations of galaxies, quasars, X-ray sources, and so forth on the sky that they conclude can be explained only by non-cosmological redshifts (Arp 1996, 1997; and other papers during the year). They also conclude that one of their variant cosmologies (a static one with variable masses) is not ruled out by the observation of time dilation in the light curves of distant supernovae (Narlikar & Arp 1997). The group has gained a new recruit from the ranks of formerly conventional observational astronomers (Burbidge 1997).

Not surprisingly, other astronomers looking at the same patterns on the sky do not reach the same conclusions (Fried 1997; Bartsch 1997; Zaritsky et al. 1997a). Klose (1996) has devised a new test applicable to the X-ray configurations. If an X-ray–emitting quasar is just behind a much lower redshift gas-rich cluster of galaxies, you should see a halo of scattered X-rays (of the sort first discussed by Overbeck and later by Slysh) but not if at the quasar is at its redshift distance, $d = cz/H$. At this stage, no such test, whatever its outcome, is likely to convince people from either camp.

Segal's universe has a redshift that is quadratic in distance (which he calls a Lundmark law, somewhat unfairly to Lundmark 1925) rather than linear as in a Hubble law. It is not, he believes, ruled out by time dilation (Segal 1997). But others find that it disagrees with the observed distributions of galaxies in, for instance, surveys of *IRAS* sources (Koranyi & Strauss 1997).

A quartet of unclassifiable models ends this set of Baker Street Irregulars:

1. The static universe of the late Troitskij (1996), which attributes redshifts to something like tired light and so is probably ruled out by time-dilated supernovae at large redshifts.
2. The universe with time-variable constant of gravity, G (Massa 1997), which will run into problems with observations of the changes in orbits of binary pulsars (they are spiraling in, as predicted by gravitational radiation in general relativity rather than expanding as expected for a weakening G).
3. "The luminescence process for proto objects moving with a peculiar velocity at high redshift" (Dubrovich 1997), and
4. Our absolute favorite, the metric of Kotov & Kotov (1997), which oscillates at a period of about 160 minutes and so accounts both for that period in the Sun and for the peak mode of δ Scuti at 162 minutes.

For more about many of these, consult the conference proceedings edited by Tifft & Cocke (1996), which also include a number of other non-standard ideas that happen not to have been revisited during the reference year.

12.2. Through Darkest Matter

The conventional candidates are hot (almost certainly ordinary neutrinos but allowed to have masses of 5–25 eV), cold (supersymmetric partners, inos, or WIMPs with masses of GeV or more), and other (including topological defects and a few more). Their job is to hold together galaxies with rapid rotation or large stellar velocity dispersions; clusters of galaxies with large velocity distributions, hot X-ray gas, and the ability to produce lots of gravitational lensing; and perhaps the universe. The ones that follow, from the reference year, are ordered from most to least unusual and also show gradients in the proportion of single-author papers and in representation of various journals.

1. A vector-based theory of gravity (Jeffries 1996).
2. Short-lived particles, created continuously from vacuum quantum fluctuations in the gravitational fields of galaxies (Majernik 1996).
3. 10^{-34} eV (rest mass) spin zero, neutral bosons with a time-dependent scalar field (Israelit 1996).
4. Conformal gravity (Mannheim 1997).
5. Solid hydrogen (White 1996).
6. MACHOs in clusters of 4×10^4 $M_\odot$ (Kerins 1997).
7. A decaying neutrino that only slightly overproduces background ultraviolet photons (Overduin & Wesson 1997b).
8. Small, cold gas clouds, at least in the Milky Way (Gerhard & Silk 1996).
9. Neutrinos of more than 40 eV rest mass, the only ones that can be confined in galaxies according to Salucci & Sinobaldi (1997), but which will considerably overclose the universe, so that it can all be folded up and put in Pauli's pocket.
10. Any of the combinations that don't work according to Overduin & Wesson (1997a).
11. Particles with a velocity dispersion in the Milky Way of only 270 km s^{-1} versus an earlier, erroneous 600 km s^{-1} (Bienayme & Pichol 1997), which returns us essentially to the realm of the conventional.

12.3. The House We Live In

At this point, you may even feel that there is a lot to be said for the particular universe we observe around us. Topics addressed are Hubble's constant, the other cosmological parameters (density, age, cosmological constant, …), and clustering of galaxies at large redshift.

12.3.1. What the H.....?

During the index year, there appeared at least 38 papers reporting specific values of the Hubble parameter H_0 and 36 others discussing related issues like the period-luminosity-color relation of Cepheid variables, the amount of absorption at the poles of the Milky Way, problems with familiar distance indicators (like the peak brightness of Type Ia supernovae and the Tully-Fisher relation between the brightnesses of disk galaxies and the widths of their emission lines), and potential new distance indicators. In addition, the published version of a restaging of the Curtis-Shapley debate explored many of the issues that continue to divide not only reported values of H but also the people reporting them (Tammann 1996; van den Bergh 1996b). Having participated in both the 1995 and 1996 restagings, the more historic author is sorry to report that Robert Nemiroff's has landed a "real" job, and this probably means there will be no more such events.

The largest two published values were 82 ± 10 km s^{-1} Mpc^{-1} from a study of the Virgo Cluster (Yasuda et al. 1997) and 92 ± 10 km s^{-1} Mpc^{-1} from considerations of the stability against star formation of the disks of various types of spiral galaxies (Bizyaev 1997b). The smallest two were 51^{+14}_{-13} km s^{-1}

Mpc^{-1} from the time delay in gravitational lens PG 1115+080 (Keeton & Kochanek 1997) and 51 km s^{-1} Mpc^{-1} from a Tully-Fisher relation with the line width taken from CO rather than the customary H I (Sofue et al. 1996). The median value was 65, and several papers hit it right on, using the luminosities of globular clusters, lensing, and Cepheids in the Leo I group. The narrowest error bars, 52.5 ± 2.5 km s^{-1} Mpc^{-1}, came from Sciama (1997), based on identification of dark matter with a specific decaying neutrino and the assumption that the cosmological constant is zero.

A double handful of new distance indicators or new ways of applying them were suggested, including the Tully-Fisher relation using CO, just mentioned, and also line widths from Hα and other optical lines. An important one is the demonstration that images from *HST* can be used for the method that makes use of fluctuations in surface brightness across the image of an early-type galaxy, which will, therefore, reach out to some Abell clusters (Ajhar et al. 1997).

12.3.2. The Other Cosmological Parameters

These include q (the deceleration parameter), t (the real age), Ω (the density in units of what is needed to stop the expansion), Λ (the cosmological constant of checkered history), and R (the radius of curvature). They are not all independent. In fact, given H, you are allowed to choose only two others, and different observations are primarily sensitive to different parameters. For instance, if you really want to measure q, you should look at the redshift-distance relation at large redshift; things that give you masses and densities are best for Ω; various geometrical tests (number counts, angular diameters) for R; and ages for t.

Still other parameters often invoked and only partly independent of the main ones include bias (the extent to which the light of galaxies does or does not trace the underlying gravitational potential), σ_8 (the average density variance on a scale of 8 h^{-1} Mpc, k (the slope of the spectrum of initial perturbations that have grown into the structures we see), and Ω_b (the fraction of the closure density present in baryonic material, which may or may not be the only sort present).

We have our favorite set of numbers and came across a dozen papers that agree—but also a dozen papers that disagree. Four recent changes or contradictions are perhaps of more interest.

First, globular clusters continue to set most people's favorite lower limit to the age of the universe, and, in case you have been having a time out for the last few decades on this one, the main worry is that the GCs tend to come out older than the reciprocal of the Hubble constant, or 2/3 of it. Because shoving a globular cluster away from you automatically makes it younger, nothing sensible can be said until the implications of *Hipparcos* data for the galactic and extragalactic distances scales have been sorted out (§ 5). Meanwhile, D'Antona et al. (1997) are the bearers of the additional bad news that how you decide to treat convection adds another uncertainty to derived cluster ages. On the bright side, two other age indicators are slowly sneaking up on the 12–18 Gyr that has come out of looking at the main-sequence turnoffs of globular clusters. The coolest, faintest, oldest white dwarfs that are just barely seen by *HST* in M4 clock in at 9.6 Gyr (Richer et al. 1997). This is not the faint end of the sequence, only the limit of existing observations. One very old open cluster, Berkeley 17, has been dated to 12^{+1}_{-2} Gyr (Phelps 1997). If its distance has come from fitting its main sequence to the Hyades or Pleiades, it also is presumably in *Hipparcos* limbo. The thorium/europium clock we hailed last year (Ap96, § 9.4) has been both supported (Cowan et al. 1997) and doubted (Goriety & Arnould 1997).

Second, the average local density of the universe is, in principle, a measurable quantity, if one knew what to do about regions of space with no galaxies in them to act as tracers of the gravitational potential. The commonest approach is some sort of numerical simulation, compared with data on galaxies, clusters, quasars, quasar absorption lines, and so forth. Twenty-some papers reported numbers, often combined with values for Λ, the amount of cold dark matter, and so forth. Consensus is too strong a term, but several papers during the year came up with numbers in the range 0.2–0.4 (Peacock 1997; Smail et al. 1997; Shepherd et al. 1997; Kolatt & Dekel 1997; Bahcall et al. 1997b). Many of them (and other authors) also favor a cosmological constant to make the total add up to one and the universe flat ($R =$ infinity).

Violent disagreement arose from the analysis of the first few Type Ia supernovae identified at $z \gtrsim 0.5>\tilde{}$ (Perlmutter et al. 1997), and no amount of theoretical fiddling could budge the result that the best value of Ω was near 0.9, with or without cosmological constant (Wambsganss et al. 1997). A larger data base will, however, make a difference, and this result will be modified in the archival literature fairly soon (and already has been in the rumor mills).

Third, and without immediate resolution in sight, at least a bouquet of nasturtiums has been cast at the standard numerical simulations with which data are normally compared (Gnedin & Bertschinger 1996; Fabbri & Natale 1996; Weinberg 1997a; Melott et al. 1997; Steinmetz & White 1997; Bate & Burkert 1997). One problem is that most models do not have adequate mass resolution to deal with some of the phenomena in the observations. The other is that solutions are often not unique, different aspects of a given data set being best fitted by rather different models. Every once in a while, someone doubts the meaning of the observations being fitted as well. Fasenko (1996) has appeared in our pages before (for him, all apparent large-scale structure is a result of differential absorption in the Milky Way). Praton et al. (1997) are newcomers to the fray, concluding that the Great Wall, apparent periodicities in numbers of galaxies versus redshift, and so forth, are optical illusions.

Simultaneous with the doubts and caveats, observational and theoretical studies continued to address very large scale structure and streaming and model universes that might produce what we see. Even within the mainstream, it has been noted that velocity and gravity fields derived from different, seemingly equally good surveys and catalogs don't actually agree

(Davis et al. 1996; Shi 1997; though Willick et al. 1997b find consistency). No one has been seriously deterred from determining Λ, Ω, σ_8, and all the rest by this problem either. The largest scale structures advocated during the year were in the range 150–160 h^{-1} Mpc (Schuecker et al. 1996; Di Nella et al. 1996).

Fourth, we look at the fraction of the universe that is made of baryonic matter, both as determined directly from X-ray–emitting clusters of galaxies and as limited by observed values of the primordial deuterium and helium abundances. Ap95 (§ 11) opined that there was no "baryon catastrophe." That is, it was possible for X-ray clusters to be typical of the universe, with their fair share of luminous baryons, dark baryons, and dark other stuff, and to have $\Omega = 1$ without ending up with more baryons than are allowed by nucleosynthesis in the early universe. Ap95 was very probably wrong. The index year saw about three papers reporting on clusters with only a few percent of their mass in baryons or on ways of making clusters that look baryon-rich be less so (Mohr et al. 1996; Ensslin et al. 1997; Pederson et al. 1997). But about a dozen reached contradictory conclusions (typically not for the same clusters) with 10% or more of cluster masses in X-ray gas. Evrard et al. (1996) were first in the index year and Awaki et al. (1997) last.

Probably one should conclude, first, that not all clusters are alike (the Local Group, for instance, has very little stray, hot gas; Banday & Górski 1996), but also that the majority are too rich in baryons to make everything fit together with $\Omega = 1$. This is true even if the deuterium-to-hydrogen ratio is the traditional one near 10^{-5}, and still more so if deuterium is more like one part in 10^4, because the amount left by the big bang is a steeply decreasing function of the baryon density (Wampler et al. 1996; Songaila et al. 1997; Webb et al. 1997, who suggested that the D/H ratio is not uniform throughout the unprocessed universe). Fuller & Shi (1997) have come up with a lamp-odored trick for making occasional high spots in D/H, so 10^{-5} and 10^{-4} could both be right.

12.3.3. Clustering at Large Redshift

As Ap96 went to press, reports were just beginning to appear of clusters and superclusters of galaxies, plus quasars, QSO absorption lines, etc. at $z \gtrsim 1$ that were not very different from those here and now (§ 12.5). In contrast, index year 1997 included something like 50 papers relevant to the topic. The subject is important because many "preferred" models of the universe and of galaxy formation make little things first and big ones later, and so find it even harder to deal with clusters (etc.) at large redshift than with fully developed, metal-rich galaxies there. Universes with less than the critical density and long time scales are correspondingly favored (Bahcall et al. 1997b; Carlberg et al. 1997a; and many others).

Clusters can be identified in several ways: by surveying the galaxies themselves; by looking at redshift and angular distributions of quasars and radio galaxies; by looking hard at the fields around active galaxies (good signposts because they are brighter than the average galaxy); by counting absorption-line systems as a function of z in quasar spectra; by mapping X-ray emission; and perhaps even from the Sunyaev-Zeldovich effect, as in the case of a $z = 2.56$ cloud of 10^{13} $M_\odot$ of gas that apparently produces a decrement in the 3 K background, though it is otherwise seen only as a couple of quasars and a few faint galaxies (Richards et al. 1997).

A zeroth-order summary of results from all these approaches is that there is more clustering now ($z = 0$) than there used to be ($z \geq 0.5$), but not by nearly as much as had been widely believed a couple of years ago. Early searches for X-ray–emitting clusters of galaxies, for instance, seemed to find very few, at redshifts greater than 0.2–0.3. It isn't yet clear exactly what was wrong, but *ROSAT* and *ASCA* data have led to the identification of many at $z = 0.5$ and beyond (Collins et al. 1997; Nichol et al. 1997; Mushotzky & Scharf 1997). Some of the clusters at moderate redshift are very much like Coma and other nearby ones (Andreon et al. 1997).

Clusters near $z = 0.5$ found by traditional optical techniques have become so common that individual listing is impractical (but also so common that analysis of the galaxy populations and their evolution is proliferating as well). We note only that many of the clusters are rich enough that Abell would have catalogued them if he had lived there instead of here (Lidmant & Peterson 1996), that there are also superclusters spanning hundreds of Mpc and including more than one X-ray cluster (Connolly et al. 1996), and that examination of galaxies in the Hubble Deep Field has increased the inventory (Cohen et al. 1996). HDF entities at still larger redshift and smaller angular scale should probably be interpreted as "parts of galaxies" that are thinking about merging, rather than as protoclusters (Lowenthal et al. 1997; Colley et al. 1996).

Clusters near $z = 1$ have been found by both traditional and innovative methods. A combination of several *HST* surveys and Keck spectra showed structure at $z = 0.8$ and 1.0 (Koo et al. 1996). And, in the "I wish I'd thought of that" department, Zaritsky et al. (1997b) found a good many high-redshift clusters by looking for variations of surface brightness across the sky, while Deltorn et al. (1997) and Bower & Smail (1997) have each found structure at $z = 0.9$–1.0 by looking for—and finding—weak gravitational lensing in the vicinity of a known, distant radio source.

To probe still more distant and long-ago structure, we turn to quasars and the absorption lines in their spectra. No candidate for "most distant structure" will receive a prize here, but Lyα absorption clouds at $z = 3$–4 show clumping, pairing, and clustering at scales from 100 km s^{-1} (Lu et al. 1996; Khare et al. 1997) to 1000–1500 km s^{-1} (Christiani et al. 1997; Lespine & Petitjean 1997). These assorted structures are apparently more or less continuous in properties with those to be found in the clouds of higher column density that produce absorption lines of heavy elements.

Finally, the quasars and radio galaxies at $z \gtrsim 2$ indicate structuring in two ways. They are themselves not distributed at random on the sky (Chambers et al. 1996; Loan et al. 1997; Kundic 1997; Stephens et al. 1997; Gosset et al. 1997). But, in addition, a hard look around them often reveals a group or cluster of fainter non-active galaxies (Le Fèvre et al. 1996; Knopp & Chambers 1997; Francis et al. 1997). There are also seven cases of what seen to be very distant clusters with lots of ionized gas, signified by unusually large rotation measures in radio polarization data (Carilli et al. 1997b). Weak gravitational lensing is normally the fault of clusters at moderate redshift, but the more distant lensees are themselves also sometimes clumped in three-dimensional space (Bezecourt & Soucail 1997).

In contrast, we note two things that should not be blamed on clustering at large redshift. The first is the fluctuating infrared background recorded by DIRBE, which is mostly produced nearby (Kashlinsky et al. 1996). The other is variance in the X-ray background at 0.9–2 keV, which is best fitted by a purely Poisson distribution of sources on the sky (Carrera et al. 1997).

In summary, clustering has increased (1) since $z = 0.6$ (Hudon & Lilly 1996), (2) since $z = 1.41$ (Carlberg et al. 1997b), (3) between $z > 1.7$ and $z < 1.3$ (Ulmer 1996), and (4) between $z = 3.5$ and $z = 2.1$ (Kim et al. 1997), but not by an enormous amount. Undoubtedly it has increased most between 1994 and 1997.

13. LIKE TONGUES TO SORE TEETH

As usual, we commence with our own undoubted errors and pass on to those of others and to cases where the situation is not entirely clear.

13.1. The Face is Familiar...

But not even a mother could recognize some of these names as they appeared in Ap96. Apologies to (a) our BIMA colleague Jack Welch, who was transmogrified into Wedder et al.; (b) Bryan Gaensler, disguised as Gaeniler; (c) Dr. S. Inoue, expanded into Inouse (and we did it again just now in trying to apologize, indicating that the error is somehow hard-wired in the typing fingers); (d), X. P. Wu (not Xu); (e) D. Mehringen (not Mehriger); and (f) George and Ira Gershwin (not Rogers and Hart!). The location reported as Novitgedacht is actually Nooitgedacht, and the paper was in ApJ, 453, not 417, but at least it is still the site of a high-energy gamma-ray detector.

Even our flack attracted flak, on the grounds that it was originally an acronym for FLieger Abwehr Kanone. Our Webster says kanonen, but the provider of the information says that it was, in any case, intended as friendly fire. In case you had forgotten the provocation, it was the discussion of advection in Ap95 (§ 2.3). This correspondence is now closed, with a notation of the first paper generally recognized as having the key ideas (Ichimaru 1977) and what should be the last paper on the subject (Bisnovatyi-Kogan & Lovelace 1997 who conclude that the process will almost never happen) but undoubtedly will not be.

We are not alone in this particular penalty box. The editors of *Astronomy Reports* apologize in Vol. 41, No. 4 for having "improved" the name of author Rspaev by printing it as Ropaev (the original paper is in Astron. Rep., 41, 190).

13.2. "Ve hef known ziss for thirty years"

A quote from Fritz Zwicky, more or less echoed by several people responding to our remarks on non-coplanarity of triple star systems (Ap96,§ 6.2), third dredge-up (§ 10.2), and shocks in Herbig-Haro objects (§ 4.1).

The discussion of which is the second most eccentric binary is also declared closed, though we have accumulated several additional candidates for "second most eccentric astronomer." First place still clearly belonging to Zwicky himself.

The Sporer minimum in sunspot numbers probably lasted a little longer than 1540–1540 (§ 6.1), more like 1450–1540. The image of Betelgeuse we couldn't find (§ 8.3) was published by Lynds et al. (1978) and is the product of heroic ground-based effort, rather than Stratoscope II in the same era. Looking at it again, we are struck by how badly we must have wanted to see that spot.

Another dozen or so corrections to Ap96 arrived during the year, but they seem to be corrections to the papers cited rather than to our interpretation (except insofar as we may have been excessively trusting—but consider the opposite if one reads something like 5000 papers a year!).

The prize for identifying the largest number of references to Winnie the Pooh and other forms of low culture goes unambiguously to Eric Schulman, who reports that he was trapped at the VLA by a CLEAN with nothing to read but Ap96! He picked out something like 30 of the 60+ items we were aware of (and one or two we were not). Second prize belongs to Barbara Ryden who knew perfectly well that tomato/tomato (§ l0.4) came from George and Ira Gershwin (well, probably mostly Ira), not from Richard Rodgers and Lorentz Hart (who, however, died the year the less musical author was born and so remains a favorite).

Our thanks go, as always, to those who maintain the astronomy, astrophysics, and planetary science collections in the libraries we frequent. Maggie Berry again alphabetized the references; we sure couldn't have done it!

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