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Invited Review Paper

Astrophysics in 1996

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ABSTRACT. The loudest astronomical headlines of the year came from both very near (planets orbiting stars in the solar neighborhood) and very far (galaxies and parts of galaxies at redshifts of 1 to 3 and more). We explore these and other happenings in our Solar System (*Galileo* at Jupiter, Comet Hyakutake), Milky Way (the bursting pulsar, spotted stars), Local Group (masers, MACHOs, and more), and Universe (gravitational lensing, an assortment of extrema).

1. INTRODUCTION

The series Astrophysics in 199X begins its second half-decade by welcoming a new co-author. It is with greatly mixed feelings that we report the departure of Peter Leonard, who has taken a "real" job, which no longer allows him time for such frivolities. But you can still read his lucid prose occasionally in *Nature* (Leonard 1996a) and elsewhere. Astrophysics in 1991 to 1995 appeared in PASP on page 1 of volumes 104–107 and page 8 of volume 108. These are cited below as Ap91, Ap92, etc.

The journals scanned were *Nature, Physical Review Letters, Science, Astrophysical Journal* (plus *Letters* and *Supplements*), *Monthly Notices of the Royal Astronomical Society, Astronomy and Astrophysics* (plus *Supplements* and *Reviews*), *The Astronomical Journal, Astrophysics and Space Science, Acta Astronomica, Astronomy Reports, Astronomy Letters, Astronomische Nachrichten, Journal of Astrophysics and Astronomy, Bulletin of the Astronomical Society of India, Publications of the Astronomical Society of Japan, Astrophysical Letters and Communications, Icarus, Journal of Geophysical Research* (*Planets*), *Bulletin of the American Astronomical Society, IAU Circulars*, and (of course) *Publications of the Astronomical Society of the Pacific*.

A special selection effect needs to be confessed this year. The elder author prepared two extensive reviews during the summer, on distance scales and the Hubble constant (Trimble 1997a) and on a range of topics in the general area of galaxies and clusters for the triennial commission reports of the International Astronomical Union (Trimble 1997b). Some topics covered in these have been treated here less thoroughly than might otherwise have been the case.

We are still looking for a catchy word to mean critical moments in time (milestones, after all, and pace *Time* magazine, are located in three-space), but meanwhile wish to record the following Hail-and-Farewells. Losses during the year include: Kuiper Airborne Observatory (29 September 1995), *Pioneer 11* (30 September 1995), two respected telescope makers, Questar and Coulter Optical (bankruptcy filings in Fall 1995), the Tethered Satellite System (20 February 1996), the *Cluster* set of four magnetospheric satellites (4 June 1996), the entity we all fondly called Bell Labs (sometime in 1996), and the *International Ultraviolet Explorer* (30 September 1996), whose final archive is even now being prepared (Nichols and Linsky 1996). The dawn of 1997 will apparently see the end of Ohio State University's "Big Ear" radio telescope and one of our favorite journals, QJRAS. The starburst in M82 is expected to pass away on a slightly longer time scale (Lord et al. 1996). Finally, Nathan Rosen, the last of Einstein's close collaborators to be actively engaged in research, sent his final paper through two of our four hands (wearing their editorial mittens) very shortly before he died (Israelit and Rosen 1996).

The other, smiling, side of our Janus-like face meanwhile turns to welcome first light (or other photons) at a number of installations. Keck II (27 April 1996, from NGC 5850); the Mt. Wilson 100-inch with its adaptive optics in place; antennas 7–9 of the Berkeley-Illinois-Maryland Millimeter Array (Wedder et al. 1996); the second flight of the *Hopkins Ultraviolet Telescope* (a set of 17 papers beginning with Kruk et al. 1995); *Kosmos 2326* (20 December 1996, mostly gamma rays, and yes, the name apparently implies the existence of 2325 previous *Kosmos* launches); the *Rossi X-ray Timing Explorer* (30 December 1996, with a good deal of data already in print, and more credit due to Jean Swank than you might guess from the ordering of authors' names on the prints); and *BeppoSAX* (30 April 1996, the Italian X-ray satellite sharing a nickname with Occhielini and with most of its photons still trapped in IAU Circulars and web pages). In addition, greetings are extended to the first extensive data releases from *HIPPARCOS* (about 20 papers, roughly centered around Perryman et al. 1995), *COAST* (Baldwin et al.

1996), *ISO* (Kessler 1996 and 13 additional papers), *SOHO* (Poland 1996 and 8 additional papers), and GONG (Leibacher et al. 1996 and six additional papers). We hope you will join us in welcoming Lucent Technologies (at least a few old friends from Bell Labs seem to be there), and Julian Day 2,450,000, on the grounds that you don't get that many zeros in the date as often as you do in the mileage on your car.

2. IN AND AROUND THE SOLAR SYSTEM

By 19th century accounts we should know everything about the solar system by now. But it is clear that technology and human imagination drive knowledge. There is more to know and there is still a lot that we don't know or understand. Word clips from 1996's advances follow.

2.1 *Galileo* at Jupiter

Jupiter, still the largest planet in our solar system, took the limelight in 1996 with the arrival of the *Galileo* spacecraft at its destination. After a 6-year journey, the spacecraft and entry probe worked! Can you imagine your car starting after sitting in the cold for that long?

The probe operated for 61.4 min and reached a pressure of 24 bars, more than twice the targeted objective. Fifty-eight minutes of data were transmitted to and recorded on the orbiter (Young et al. 1996). Meanwhile, back on the mountain, Orton et al. (1996) carried out ground-based remote sensing measurements of Jupiter, placing the probe data in context with the rest of Jupiter's dynamic and heterogeneous atmosphere. As luck would have it, the entry site was at the southern edge of a relatively cloud-free and hence, water-free feature, with a meridional tropospheric and stratospheric temperature gradient of 0.17 and 0.10 K/°latitude. The Doppler wind speeds caused by zonal winds were measured below the clouds (Atkinson et al. 1996) to be prograde with $v>190\ \mathrm{m\,s^{-1}}$ between 3 and 20 bars. That the winds are strong to depths below that to which solar energy is deposited, supports the theory that convection powers Jupiter's atmospheric dynamics. Zhang and Schubert (1996) take these results and model the interior showing that rotation and spherical geometry permit penetration of deep convection, producing the observed zonal winds. Non-axisymmetric convective models are not necessary.

Seiff et al. (1996) measured the following state properties with the Atmospheric Structure Instrument: the probe penetrated ~160 km, or 0.22% of the planet's radius. Not quite stellar interiors, but providing important information, nevertheless. Velocities decreased from $\sim 400\ \mathrm{m\,s^{-1}}$ at parachute deployment and were $\sim 30\ \mathrm{m\,s^{-1}}$ at loss of signal. The temperature-pressure gradient is consistent with a dry adiabatic model. At pressure >10 bar, the temperatures diverge from adiabatic. With a lapse rate of $-1.8\pm-0.1\ \mathrm{K\,km^{-1}}$, between 5–16 bars, the atmosphere is stable against convection and heat flow is not by convection in this region. Atmospheric densities derived from the probe velocities and accelerations were 100 times higher than predicted at ~300 km above the 1-bar level. High temperatures in the upper atmosphere, reaching a maximum of 1350 K, suggest the presence of a superimposed wave structure, and Jupiter's exosphere is hotter than predicted by previous models (Yelle et al. 1996 and Orton 1981). Gravity waves and soft electron collisions with H_2 molecules are suspected to pump energy into the exosphere.

After decades of training graduate students, the schematic model of a layered atmosphere of Jupiter (consisting of upper level ammonia ice clouds, followed by a layer of NH_4SH and below that a water ice cloud) has not been observed. From scattered light measurements looking upward and downward Sromovksy et al. (1996) found evidence of the expected NH_3 cloud at ~0.6 bar from optical depths of 1.5 to 2. The nephelometer (Ragent et al. 1996) indicates a cloud of significant density only at 1.55 bar, and not at 0.6 bar. A number of instruments came up with results indicating low water abundance and hence no expected water cloud (Ragent et al. 1996; Seiff et al. 1996; Niemann et al. 1996; Sromovsky et al. 1996). One immediately asks the valid question whether this is true for all of Jupiter or represents the situation in just this clear hole? Jove maintains control of this question.

The entry probe included a quadrupole mass spectrometer capable of measuring m/z ratios up to 140 (Niemann et al. 1996). Compared to solar values, these measurements address the contribution of early, outer solar system planetesimals to Jupiter. Preliminary results show that the noble gases are fractionated. $^3\mathrm{He}/^4\mathrm{He}$ is lower than solar values derived from meteorites and $^{12}\mathrm{C}/^{13}\mathrm{C}$ is exactly solar. More deuterium was found than exists in the local interstellar hydrogen clouds. These results carry implications questioning a model of late-accreting, icy planetesimals, but also suggest that we don't know much about post-accretionary processing in Jupiter. Many formation scenarios will be constrained by these results.

Von Zahn and Hunten (1996), addressing the He mass fraction have conceded that their measurements will not reveal knowledge of the formation of the Universe at t_0, but rather, now believe their data are relevant to the formation of Jupiter, a more humble objective. Their results support the inference that He depletion is caused by a phase separation, so it is time to start designing the Jupiter Interior Probe mission testing this hypothesis.

On Jupiter, lightning lasts longer and is more powerful but of lower frequency than on Earth (Lanzerotti et al. 1996). A new region of energetic electrons and protons peaking at 2.2 R_J was observed (Fischer et al. 1996). These guys must feel like Nikŏla Tesla when he first started exploring electrical and radio phenomena on Earth.

Galileo and others meet the Galilean Satellites-At press time only a small part of the 2-year mission of satellite flybys has been completed. Initial magnetometer perturbations support a model whereby Io is magnetized by an active dynamo (Kivelson et al. 1996). *Hubble Space Telescope* (*HST*) measurements of Ganymede revealed the presence of O_3 (Noll et al. 1996). These findings combined with the detection of O_2 last year (Spencer et al. 1995) suggest the presence of human life using copy machines.

2.2 Saturn

Temporal changes in Saturn's atmosphere between 1991–1993 were reported (Ortiz et al. 1996; Achterberg and Flaser 1996). Storms are coming and going, and hazes are forming and subsiding. Take cover Dorothy.

The results from the ring-plane crossings deserve note because of their tri-decadal frequency. Saturn's rings passed through the Earth–Saturn and Sun–Saturn planes during 1995, prompting astrometric study of small, ring-embedded satellites (Nicholson et al. 1996; Bosh and Rivkin 1996), photometry of the faint, inclined E, F, & G rings (Nicholson et al. 1996) and of the ion environment associated with the rings (Hall et al. 1996). The longitude of Prometheus (S16) was found lagging its expected position by ~20° (Bosh and Rivkin 1996; Nicholson et al. 1996)! Murray and Giuliatti Winter (1996) discuss the transfer of momentum between Prometheus and the F ring and the possibility of collisions between the two. Calculated changes in Prometheus' orbit are an order of magnitude less than those actually observed, sending theorists back to their computers.

Hall et al. (1996) used *HST* to probe the vertical distribution of OH ions with respect to the rings. The calculated production rate varies between 10^{25} and 10^{29} molecules s^{-1} depending on whether the ions' lifetime is limited by collisional destruction with grains or with charged particles and solar protons. This is within the range of that found among comets, though spread over 340 000 km^2, explaining why Saturn doesn't look like a comet.

Modeling the gravitational interactions between dense rings, Salo (1996) showed formation of particle clusters. Gordon et al. (1996) searched *Voyager* data for the same in response to charged particle data from *Pioneer 11* and *Voyager 2*. They find four new satellites, possibly. Horn and Cuzzi (1995) analyzed the spatial structure of Saturn's A and B rings. Mosqueira (1996) invoked the role of viscosity on ring dynamics showing its significance in the nonaxisymmetric structure of Saturn's B ring. Other models, a by-product of ballistic transport (Dunsen et al. 1992), remain competitive in explaining the observations.

2.3 Other Rings

In the realm of other rings, Earth-based detection of Uranus' ring was made using ground-based telescopes (French et al. 1996), but skeptics will always think NASA scientists are making things up. Both Ishimoto (1996) and Hamilton (1996) addressed the hypothetical formation of dust rings around Mars derived from ejecta from Phobos and Deimos. Hamilton modeled the interplay between solar radiation pressure and Martian oblateness showing that the eccentricity and oblateness of Mars influence the structures. Is there a possibility of detecting these rings? Or of their being a hazard? With two spacecraft en route to Mars, there is still food for sleepless nights.

2.4 Comets

With each close passage of a comet through the solar system, there is new instrumentation available, inevitably providing new astrophysical discoveries. They are beautiful spectacles to boot. With the close passage of C/Hyakutake 1996 B2, in March 1996, Mumma et al. (1996) reported detection of C_2H_6, ethane, and CH_4, methane for the first time in a comet. Study of the chemical species near the comet nucleus tells us about either the interstellar cloud or the outer part of the solar system surrounding the protosun from which the comet formed. The detection of ethane was serendipitous. Methane was targeted and found, as were water and CO. Cometary origin can be inferred from abundance of homologous hydrocarbons indicating whether their kinetics was produced by gas-phase ion-molecule reactions or by icy mantle processes. The ratios of C_2H_6:CH_4, the low abundance of CH_3OH and moderate abundance of CO are consistent with H addition reactions modifying the icy core. But the presence of CO indicates the reactions are not complete. Radiation processes also could have played a role.

The close approach of Hyakutake and the bold thinking of a team of cometary and X-ray astronomers ushered in the era of X-ray astronomy of comets (Lisse et al. 1996). The observations are irrefutable; comets emit X rays. The explanations will occupy the minds of scientists for years to come. Interaction between the solar wind and the comet is the favored hypothesis at the moment.

Hale–Bopp predictions for its perihelion approach in April 1997 are for another cometary spectacle. Its comparison to Comet Halley makes it a superlative comet on almost all counts (Biver et al. 1996). The high levels of CO detected at 230 GHz with mm telescopes support the idea that sublimation of CO ice is the source of current cometary activity.

A'Hearn et al. (1996) published a large synthesis of comet photometry. First the similarities: about 75% of the population studied are compositionally similar; there is no differentiation with depth in comet nuclei; and dust-to-gas ratios don't vary with dynamical age. There is evidence of chemically different reservoirs, notably that Kuiper Belt comets are depleted in carbon-chain molecules C_2, C_3. Comets from this region also have smaller active regions.

On the dynamical front, Valsecchi et al. (1996) show that objects in Encke-like orbits can be derived from both Jupiter family comets and NEAs thereby reducing somewhat the probability that certain NEAs are cometary remnants. On the chemical and thermal modeling front, Prialnik and Podolak (1995) test for conditions in which liquid water might be stable in comets focusing, on the effects of porosity. Under conditions of low porosity and low conductivity, it is possible to have a liquid water core and an outer crust of pristine cometary material.

2.5 And Now for the Rest of the Solar System

Mercury

Sprague et al. (1995) propose that bright radar spots at Mercury's poles result from volume scattering from elemental sulfur. The observed brightness can be modeled with solar abundances of sulfur (Sprague et al. 1995, 1996). Furthermore, the high average index of refraction for surface materials and microwave transparency can be attributable to sulfides. A test of this hypothesis is a search for the SI multiplet at 1814 Å and sulfur emissivity features at 7.7 and 11.8 μm.

Venus

While most venusian research has moved into the realm of the geophysical (e.g., JGR special section: Second International Colloquium on Venus, 101, E2, 1996), EUV rocket spectra have revealed previously unknown chemical species. Stern et al. (1996) found emission features of N I, N II, and N_2 and CO. Furthermore, they cleared up an apparent mismatch between *in situ* and remote sensing measurements which previously had reported detection of Ar (Bertaux et al. 1981). Interpretation of *Venera 11/12* measurements implied 100 times the abundance of argon compared to predictions from the *Pioneer Venus* entry probe (Hoffman et al. 1980). As observed with a spectral resolution of 6.4 Å, the previously advertised Ar band is really O I at 1039 Å. A band at 867 Å remains unidentified but is not believed to be attributable to argon either.

Life on Mars and Elsewhere

The mass media frenzy (mmf) accompanying the possibility of biogenic material in a Martian meteorite aside, the study of secondary minerals associated with ALH84001 (McKay et al. 1996) is a truly exemplary piece of scientific research. No one of their findings alone is unambiguous evidence of life, but the combination of 5 lines of evidence makes even skeptical scientists a bit giddy. Additionally, they are bringing their high precision instrumentation into the field of terrestrial paleobiology. Read it.

Klein (1996) discusses a well-reasoned strategy for locating extant biology on Mars consisting of three stages, remote sensing, landed instrument analysis, followed by sampling any areas testing positive in the first two phases. Wetherill (1996) finds that between 5%–15% of stars between 0.5 and 1.5 solar masses have habitable planets. With these results, the phone company might want to start planning for interstellar connections.

And while we are dealing with our ordinary status as earthlings, we shouldn't forget that other bodies in the solar system might harbor life (translate to biogenic material or hot water). Wilson and Sagan (1996) show that the organic species on the dark side of Iapetus are endogenous. There are rumblings of liquid water oceans under the crust of Europa. Check next year.

Asteroids

With more power in radar telescopes, it is now possible to map large-scale topographic relief of more asteroids (Mitchell et al. 1995; Ostro et al. 1996). The discovery and nature of the first satellite of an asteroid (Belton et al. 1996b; Veverka et al. 1996a, b) are reported in the special issue on *Galileo's* Solid-State Imager results on Ida (Belton et al. 1996a). Analysis of weak absorption bands in some S-asteroids and their interpretation as evidence of oxidized Fe-Ni metal and spinel group minerals support the stony-iron interpretation of S-type asteroids (Hiroi et al. 1996). Go asteroids.

You've Come a Long Way Baby-Pluto

Roush et al. (1996) report spectral geometric albedos of Pluto and Charon between 1.4–2.5 μm, constraining the widespread occurrence of pure CH_4 ice on Charon. The presence of CO_2 patches covering ~20% of Charon's surface is plausible, and mixtures of the two are possible provided the CH_4 grains are ~5 mm. Radiative transfer models are being applied to Pluto thanks to the stellar-occultation data of 1988, 1989 (Strobel et al. 1996). Seasonal nitrogen cycles are modeled (Hansen and Paige 1996). Predictions are that barometric pressure will rise on Pluto until the year 2000 and will drop after 2020, persisting through aphelion...when?

3. HOW NOW BROWN DWARF, HOT JUPITER, ETC.?

At this time last year, there was firm evidence for 12 substellar objects in orbits around stars, the three planets of PSR 1957+12 (Wolszczan 1994) and the nine planets orbiting Old Sol (with credits to Clyde Tombaugh, Adams and Leverrier, William Herschel, and either Nicholas Copernicus or a Zinjanthropan named Og, depending on your point of view). Today (Thursday), this number has roughly doubled. Just as striking, however, is that the new inventory has contributions from six of the (at least) seven techniques that have been proposed for planet and brown dwarf searches. In addition, it is worth remembering that the solar system remains unique, not just in having lots of planets. So far (and this is largely a matter of limits of technology and time), the planets with masses like that of the Earth orbit pulsars, not G2 V stars; the planets with masses like that of Jupiter are (with one possible exception) much closer to their parent stars; and brown dwarfs are like nothing in this solar system (luckily for us).

3.1 The New Planets, etc.

First of the techniques to succeed was careful monitoring of pulsar periods. These act like clocks, whose Doppler shifts reveal small displacements of the pulsar. In addition to the Wolszczan trio, Shavanova (1995) has reported timing residuals in the 0.714 s pulsar B0329+54 indicative of an Earth-mass (or larger) planet in a fairly eccentric, 16.9 year orbit, with some hint of an additional three-year residual. Although the pulsar has been observed since 1968, orbit coverage is not quite complete enough to give the result a very high confidence level. And, of course, this is the sort of young, strongly magnetized pulsar for which planetary companions require somewhat contorted modeling (Ap92, Sec. 3).

The second technique is direct imaging at optical or infrared wavelengths. This led to the candidacy of Gl 229B for the title of "first companionate brown dwarf" (Nakajima et al. 1995), with a probable mass of 20–60 M_J and a projected semi-major axis of 44 AU. GD 165B remains the next strongest candidate for resolved, companion brown dwarf (Jones et al. 1995), while Gl 105C has been definitely promoted (or demoted?) to hydrogen-burning status (Rudy et al. 1996).

Third comes optical or infrared spectroscopy, which, by demonstrating the presence of both methane and water-vapor ("steam") lines in the atmosphere of Gl 229B, put it definitely at a temperature of less than 1000 K, where no hydrogen-burning stars live (Oppenheimer et al. 1995; Geballe et al. 1996).

Further details of brown dwarfs in the Pleiades (though they are single stars) belong here on the basis of detection techniques. For more about lithium in PPl 15, see Basri et al. (1996). Rebolo et al. (1996) present two more Pleiads (Teide 1 and Calar 3), each about 1 mag fainter than PPl 15, which pass the "lithium test" for never having had any significant amount of hydrogen fusion in their cores. Important recent sets of models for the evolution and atmospheric appearance of brown dwarfs and faint M dwarfs are those of Allard et al. (1996), Marley et al. (1996), Tsuji et al. (1996), and Tinney et al. (1995).

The fourth technique, looking for velocity residuals in optical spectra of likely parent stars, has been the most spectacularly successful. Most astronomers can probably remember exactly where they were when they first heard the name 51 Peg in October 1995. The star had been on two monitoring programs, so that the 4.23 day period, lower mass limit of 0.47 M_J, and so forth (Mayor and Queloz 1995) were quickly confirmed, but also quickly overtaken by the discoveries of 70 Vir B (P=116.6 d, minimum mass 6.6 M_J, Marcy and Butler 1996) and 47 UMa B (P=3.0 yr, minimum mass -2.4 M_J, Butler and Marcy 1996).

Of these, only 47 UMa B is anywhere near far enough from its parent star to feel like Jupiter (chilly). Neither of the others is at any particular risk of evaporation or Roche lobe overflow (Guillot et al. 1996), but formation *in situ* seems a bit improbable. Inward migration while the central star still had some residual dust disk has been suggested as an alternative (Lin et al. 1996).

We do not, of course, know the orientation of the orbits. Thus, for any one system, one might invoke a nearly face-on orbit (small sin i) and claim the companion mass to be large. The projected rotation speed of 51 Peg A (Francois et al. 1996) and the absence of wiggles of *HIPPARCOS* images of the three primaries (Perryman et al. 1996) argue against this interpretation, which in any case becomes less and less likely as examples proliferate.

Proliferation is rife, including unpublished companions to Tau Bootis, Upsilon Andromedae, and Rho^1 Cancri, all of which fall more or less into the "hot Jupiter" category, and probably some others that we, with our ears so far from the ground, have not yet heard about. The official rumor sources are two web pages, maintained by the Pic du Midi and Lick groups responsible for the discoveries so far: http://www/obspm.fr/planets and http://cannon.sfsu.edu/~williams/planetsearch/planetsearch.html

Other groups using technique four have found some additional brown-dwarf companion candidates. Mazeh et al. (1996) report three (two previously published) from a program monitoring 20 stars. A lower-precision search using Coravel has nine candidates, of which at least four are probably false alarms arising from small values of sin i. The three best candidates have M sin i=9, 46, and 55 M_J and orbit periods of 3 months to 3 years. That is, objects like them would easily have been seen in the planet-search programs. Yet more planets than brown dwarfs have been found. None of the samples is statistically complete or even easily describable. (All three of the Mazeh et al. primaries were IAU velocity standards!) But we are privately of the opinion that there really are more planets out there than brown dwarfs.

Method five is the oldest of all, the search for astrometric companions or proper-motion residuals. The demise some years ago of two putative companions to Barnard's star left the technique in mild disrepute, but a whole new generation of people, telescopes, detectors, and data-processing algorithms have brought it back to the forefront, happily accompanied by one or two planets with Jupiter-like masses, orbiting Lalande 21185 (Gatewood 1996).

The sixth possibility is to see transient fading when a planet in a nearly edge-on orbit passes across the face of its star. Guinan et al. (1996) have reported one such event, in the form of a 0.08 mag fading of CM Draconis. The amplitude of the event requires a planet with a size close to that of Jupiter, and the duration implies an orbit period of at least a few months.

3.2 Implications and Relationships

What is the difference between a planet and a brown dwarf? Past reviewers have made cuts by mass (around 10 M_J quite often), by formation mechanism (planets form in disks after a central star acquires its identity), by coplanarity (planets must lie near the equatorial plane of the most massive object in the system), by internal structure (planets are layered around rocky cores; brown dwarfs are homogeneous), and probably other considerations. Boss (1996), in a truly outstanding and up-to-the-minute (July anyhow) discussion, suggests that orbital eccentricity is a defining characteristic. On this basis, he puts 70 Vir B and one of the Mazeh et al. (1996) companions in the brown dwarf camp, and sets the mass cut at about 6 M_J.

Two closely related issues require at least passing notice. First, are brown dwarfs (and planets) dynamically important in the great scheme of things? Luminosity or mass functions of stars are still rising at the bottom end in various contexts (Cool et al. 1996; Itoh et al. 1996; Mera et al. 1996). But, despite this, brown dwarfs do not make up very much of the dark matter of the galactic halo (Flynn et al. 1996, a Hubble Deep Field result; Santiago et al. 1996, based on the Hubble Medium Deep Survey). According to the same papers, ordinary M dwarfs and white dwarfs are not the answer either.

The other related issue is the relevance and prevalence around young stars of dusty disks that are supposed to resemble the one from which our solar system formed. According to a review that appeared near the end of the reference year (Beckwith and Sargent 1996), such disks are both prevalent and relevant, and the formation of planetary systems should, therefore, be common.

Detailed analyses of DM Tau (Saito et al. 1995) and of DG Tau (Kitamura et al. 1996) indicate dust masses of 0.01–0.02 $M_\odot$, appropriate for producing 0.001 $M_\odot$ of planets with moderate efficiency. There is evidence that the size and composition of dust grains changes with evolution of the central protostar in the right direction (Grady et al. 1995; Koerner et al. 1966 on DO Tau; Miroshnichenko et al. 1996 on the K7 V star HD 233511).

Enthusiasts for widespread extraterrestrial life are most interested in forming planets around solar-type stars, but rather similar disks are to be found around a variety of stellar types, starting with the prototypes Beta Pic and Vega and their ilk (Sylvester et al. 1996), and including A0 (Stauffer et al. 1995 on HR 4796A), proto-B (Nagita et al. 1996), and Herbig Ae/Be stars (Sorelli et al. 1996; Grinin et al. 1996). The most spectacular images are the silhouetted disks around six proto-F-G-K stars in Orion, observed with *HST* by McCaughrean and O'Dell (1996), who believe that there is sufficient mass to make planets.

The quantity of gas, or at least of CO, associated with these disks by the time they turn up as infrared sources is very small (Dent et al. 1995). This is negative if you still need to make Jupiters, as is the conclusion from one group that the dust is often in a spherical shell rather than a disk (Miroshnichenko et al. 1996a). A third barrier to formation of planetary systems around a star is the presence of a close stellar companion. This has long been suspected, but observations now indicate that a companion at 10–100 AU will eat out just that central part of a protostellar/protoplanetary disk that is needed (Jensen et al. 1996; Roddier et al. 1996 on DG Tau; Dutrey et al. 1996 and Jensen et al. 1996a on UZ Tau, a triple whose third star, at 530 AU, is still happily ensconced in its disk).

3.3 The Seventh Way

Oh. Are you still expecting to hear about the seventh method for discovering planets? That's when something lands in your fish pond and somebody gets out and tells you that he is from the planet Alpha Venega, which orbits the third star on the left (and straight on until morning, or the booby hatch, whichever you get to first).

4. FINE STRUCTURE

The motivation for this section is a number of *HST* images of supernova remnants, planetary nebulae, star-formation regions, and so forth, about which one can only say Wow! Images of high angular resolution from other telescopes and wavelength bands are also mentioned, along with some cases where the features had already been seen and studied from ground. We begin, contrary to custom, however, by noting a unified model that attributes bullet-like structures in the Crab Nebula, star-formation regions, and planetary nebulae to *in situ* condensation in high-velocity gas due to Rayleigh–Taylor instabilities in the encounter with swept-up denser stuff from the surroundings (Stone et al. 1995). The remnant of Nova Persei 1901 has very similar bullet- or comet-like structures which will not be mentioned further because (a) it is not clear whether the model can explain them and (b) it is not clear whether we are supposed to have seen the picture.

4.1 Interstellar Stuff

Herbig (1951)–Haro (1952) objects (whose name was assigned by Ambartsumian 1954, who also began the numbering system) spent their first 25 years or so as emission-line regions with no central exciting star, since the apparent compact cores showed no evidence of being hot enough or bright enough to provide photoionization. The guns of infrared and radio astronomy were needed to show that they are by-products—shock-ionized bits of gas at the edges and tips of molecular outflows (often bipolar and jet-like) from young stellar objects that can be a long way from the visible ionized gas. Recent examples are described by Moneti and Reipurth (1995), Corcoran and Ray (1995), Bally et al. (1995), Moreira and Yun (1995), and Bence et al. (1996). That one can occasionally still not locate the underlying, driving young star (Reipurth et al. 1996) no longer undermines our confidence in the basic model.

Several Herbig–Haro objects have been imaged with *HST* during the reference year (Ray et al. 1996; Heathcote et al. 1996). The pictures resolve the narrow jets perpendicular to their axes even quite close to the parent stars. One learns, for instance, that the initial opening angle of some of the jets must be at least as wide as 60° and that acceleration of ambient gas by entrainment begins very close in.

Other interesting fine structure connected with ionized interstellar material includes the separation of infrared thermal emission and scattered light in Rudolph Minkowski's Red Rectangle (Cruzalege et al. 1996) and the detection of infrared bow shocks on the advancing sides of runaway stars, where the stellar wind meets the general interstellar medium (Van Buren et al. 1995). High angular resolution in radio lines (Lekoch and Lazareff 1995 on CO in cometary globules) or continuum emission (Garay et al. 1996 on the Ceph A region with the VLA) can reveal structures where gas is being pushed around by radiation or winds. The combination of infrared and radio (21 cm) data shows correlations of the emission from gas and dust down to a scale of about 12′ in the general ISM (Jones et al. 1995a). The interstellar magnetic field also exhibits structure on very small scales (Minter and Spangler 1996, and many earlier papers).

The picture, or at least the poster, of the year was, of course, the nearly fullcolor (except that the stars are pink) *HST* image of M16 (Hester 1996a). Similar images exist for M42 in Orion, but blurred a bit by the larger distance (O'Dell and Wang 1996). Morphological details suggest analogs from the animal kingdom—elephant trunks, Partially Ionized Globules, Evaporating Gaseous Globules, and so forth. It doesn't take a theorist to figure out that there must be a lot of interaction among the nearly naked OB stars, still-buried YSOs, and the diffuse material between them (though Henney et al. 1996 certainly have the proper credentials). Hester and others have suggested that the final masses of the emerging YSOs (and hence the shape of the lower end of the initial mass function) will be determined mostly by how much the YSO cores are allowed to accrete from their molecular shrouds before the shrouds are photodissociated away by ultraviolet light from the massive stars.

It is actually a radio image of an H II region (IC 1396 seen from DRAO by Moriarty-Schieven et al. 1996) that best shows the bullet+tail structures modeled by Stone et al. (1995).

4.2 Planetary Nebulae

The planetary nebula NGC 7293, variously called the Helix, the sunflower, and "planetary nebula in Aquarius" (under which title and looking rather red and undistinguished you will find it in most standard collections of slides for reluctant astronomy teachers), is, at about 200 pc, the closest one to us and also one of the oddest looking. Its bright outer shell and empty interior host between them countless (meaning probably more than 100 but less than 1000; we are slow counters) comet-like features with relatively bright compact heads and tails that point radially outward. These features show conspicuously in a 200-inch telescope plate reproduced by Vorontsov-Velyaminov (1968), in Malinized images (Malin 1982), and in a pre-war 100-inch plate taken by Walter Baade and mentioned by Verontsov-Velyaminov. The comets were clear enough in these early images for Liller (1968) to have measured the proper motions of three of them at 1.0±0.4 ″/century. This corresponds to an outward velocity of about 10 $\mathrm{km\ s^{-1}}$ consistent with the value found recently from radial-velocity data for a much larger sample of "heads" (Meaburn et al. 1996). Meaburn et al. find a larger speed, 25 $\mathrm{km\ s^{-1}}$, for the bright outer shell, implying that the knots are left over bits of AGB wind, not primary ejecta.

NGC 7293 appears here because of the glorious *HST* images record by O'Dell and Hadron (1996) and reproduced in many secondary sources. These latter generally give the impression that the knots and tails were *HST* discoveries. O'Dell and Hadron in fact mention the earlier images, but not the proper-motion measurement. Absorption by the knots of light from the part of the nebula behind them permits estimates of their masses in the vicinity of $10^{-5}\ M_\odot$ (O'Dell and Hadron). Thus the masses are more like those of terrestrial planets than of comets, and the lifetimes are likely to exceed that of the main nebula. The Helix is also on the program to determine distances and ages of planetary nebulae from radio proper motions, whose most recent increment appeared during the index year (Kawamura and Masson 1996).

NGC 7293 is not unique in having different parts of its anatomy moving outward at different speeds. NGC 40 has a couple of stationary worms outside its main, expanding, barrel-shaped body (Meaburn et al. 1996a), while Fleming 1 has two outlying, spiral-shaped, bipolar bits moving much faster (85 $\mathrm{km\ s^{-1}}$) than the rest of the nebula (Palmer et al. 1996).

A resolved image of the planetary nebula in M15 (Bianchi et al. 1995) leads to a smallish derived mass, 0.007 $M_\odot$, consistent with its faintness, but not outside the range found for disk planetaries. The central star, at 35 000 K, is still on its way up, not down, so the nebula might be a bit brighter in a millennium or two. (Notice by phrasing the remark this way we deprive the copy editor of the pleasure of distorting millennia into millenniums.) In contrast to the compact M15 object, the uneuphoniously named KjPn 8 (Lopez et al. 1995) is the biggest bipolar planetary around, 4.1×1.2 pc, but we fear this means it is not long for this world (on the millennial time scale again).

4.3 Supernova Remnants and Galactic Nuclei

The official supernova remnant of the year is the Crab Nebula (this last happened in 1970 when it got its own IAU Symposium) because of the *HST* resolution, first, of the dense, thermal gas filaments (Hester et al. 1996a) and then of the wandering, synchrotron-emitting wisps and jet near the center (Hester 1996). It is again probably the fault of the secondary sources that the work of Scargle (1969) on motions of the wisps has so far gone uncited, and the official, archival version of the *HST* results will surely credit him (and Walter Baade, who took most of the relevant plates). The line-emitting filaments are, depending on their angular size, stratified or unresolved as you compare one emission line with another, and reconsideration of magnetic field strength, total thermal gas mass, turbulent motions, etc., can be expected. The much-sought outer shell remains elusive (Frail et al. 1995).

Less official SNRs include the set of old ones described by Fesen et al. (1995), whose images in optical emission lines and 21-cm radio show many filaments and other features in common. The authors suggest this as the signature of old remnants. Since the Vela remnant, in which optical and radio are poorly correlated (Milne 1995) is a young one, this makes a certain amount of sense. The new Vela optical image also records the jet extending out from the pulsar, whose X-ray discovery we meant to include in Ap95 but seem to have dropped off the end of Sec. 6.8 (with due apologies to Markwardt and Ögelman 1995). In fact the Vela SNR was treated very badly all around last year, discovery of X-ray "bullets" outside the main X-ray shell (Aschenbach et al. 1995) also having been omitted. Corresponding structure shows up in a Parkes radio map that belongs to the present year (Duncan et al. 1996). For both the Vela and the Crab pulsars, it is natural to assume that the jets play a major role in carrying energy that is not seen in pulsar radiation per se outward into the nebula where it is needed.

Separate clouds on a scale of 1000–1500 AU have been resolved within Vela by making use of a pair of B stars behind it (Wallerstein et al. 1995). The relative velocities of the absorption lines from these clouds are such that the authors expect some collisions within about the next 50 years, saying that "at least one of us should still be around." We very much hope they all are!

X-ray data on supernova remnants now have enough angular resolution to reveal interesting substructure. *ASCA*-resolved spectra of Cas A (Vink et al. 1996 and of W 49A (Fujimoto et al. 1995 PASJ) show that chemical composition varies with location and velocity within the remnants in the way you would expect for material ejected from a layered star. For SNR 1006, it is the continuous spectral index that varies with location. Fairly circular at soft X-ray energies, the remnant turns into a pair of parentheses at the high end of the *ROSAT* bandpass (Willingale et al. 1996)

SN 1987A continues to fade from the literature as well as from the skies, being the focus of only about 15 papers during the reference year. About half of these dealt with some form of fine structure, and we note only the FOS spectra (Panagia et al. 1996) of the three-ring-circus whose *HST* image (Burrows et al. 1995) is now so familiar, because they indicate somewhat similar compositional stratification to that found in older remnants. The predicted date of X-ray return continues to retreat, most recently to 2005±3 (Chevalier and Dwarkadas 1995, and again we trust that all parties concerned will be around to celebrate). The radio has been back for some time (Ball et al. 1995) and appears to be rising toward its previous peak level.

One LMC supernova remnant, N 132D, has been the beneficiary of the Hubble machine (Morse et al. 1995). It looks quite Crab-like, including the stratification of resolved filaments, but is said to be shock dominated rather than photoionization dominated.

The *HST* image of the nucleus of the dwarf elliptical galaxy NGC 205 (Jones et al. 1995b) provides a logical nonbridge to active galaxies, since the presence of a black hole larger than 10^5 $M_\odot$ can be ruled out. The center actually looks a lot like a globular cluster. And, just to confuse the issue, globular cluster M15 looks through *HST* as if it might have a 10^3 $M_\odot$ black hole (Guhathakurta et al. 1996) or, admittedly, merely a post-collapse core.

Optical images of active galaxies with very high angular resolution derive a good deal of their interest from comparison with radio structure at comparable resolution. The only trouble is, as pointed out by Muxlow et al. (1996) in connection with the nucleus of NGC 1068, you have to be able to align the images to within their $0\farcs1$ resolution to know what you are seeing. As this is not yet possible, they can say with great confidence that the emission-line gas is either correlated or anticorrelated with the radio-bright core and jet. Jackson et al. (1996) believe that they have seen correlation in the central regions of Cygnus A, in the sense that optical filaments lie parallel to the radio jet. The radio galaxy Her A (3C 34) shows, in contrast, rings of optical obscuration associated with the radio jet (Baum et al. 1996).

5. THE BURSTING PULSAR AND RELATED OBJECTS

Until the other day (it was a Saturday in fact), a pulsar was a pulsar and a burster was a burster, and never the twain had met. Although both are neutron stars, pulsars are regular variables at the rotation period of a star with a magnetic field sufficiently strong to channel accreting gas ("accretion powered pulsars" or high-mass X-ray binaries) or outflowing relativistic fluids ("rotation powered pulsars") into the vicinity of their magnetic poles, leading to a corresponding modulation of the outgoing radiation. Such strong fields ($\sim10^{12}$ G) are associated with neutron stars early in their lives (or at least in their lives as accretors). Bursters are non-periodic, though with characteristic time scales, and are the result of sporadic accretion or (more often) sporadic explosive burning of helium accumulated on NS surfaces. The observed examples were all "low-mass" X-ray binaries, meaning that the gas donors were solar-type stars or smaller and that the neutron star dipole magnetic fields were (for whatever reason) less than about 10^{10} G, leaving the stars with fairly uniform surfaces.

On 2 December 1995, the *Compton Gamma Ray Observatory* spotted the first source that does both. Now called GRO J1744−28, it showed periodic modulation at 2.1 Hz, but also 200 irregularly timed bursts of 8 to $\geq$30 s in the first nine days, and an orbit period of 11.8 days. Early *GRO* data, reported by Kouveliotou et al. (1996), Lewin et al. (1996), Finger et al. (1996), and Strickman et al. (1996) indicate a featureless spectrum, burst characteristics like those of the previously known rapid burster (the one with variable accretion), and evidence for spin-up between bursts.

The first stretch of *RXTE* data just made it under the 30 September wire (Zhang et al. 1996a; Giles et al. 1996), revealing quasi-periodic behavior centered at 20, 40, and 60 Hz. This may just possibly be the first appearance of neutron star g-mode oscillations anywhere in nature. The peak luminosity is about 100 times the Eddington luminosity of a neutron star, if you suppose that the source is about 8 kpc away and radiates isotropically.

Beyond this, you must currently go to the IAU Circulars, preprint bulletin boards, and so forth. *ROSAT*, *ASCA*, and Granat/WATCH observations have been important in establishing the total luminosity and spectrum over a wide range of energies and in locating the source accurately enough to rule out several erroneous early radio and optical counterparts. The latest candidate (IAUC 6369) has already had doubts cast on it.

On the whole, the source has faded from its initial fireworks, with bursts becoming less common, and the rotation period being sometimes lost in the noise. There have also been at least partial recoveries in the first six months, and additional quasi-periodic oscillations at sub-Hz frequencies (IAUC 6415).

Models quickly followed, or, in some cases, led the observations (Sturmer and Dermer 1996; Cannizzo 1996; Daumerie et al. 1996; Miller 1996). All agree that the bursts are of the variable-accretion variety, though they disagree somewhat on whether it is the accretion rate, the magnetic field strength, or some other combination of properties that must be very finely tuned to allow both kinds of variability to occur in a single source.

By "related objects" we mean other binaries where one component is a neutron star or black hole. Most striking has been the expansion of the inventory of quasi-periodic oscillations (QPOs) from the narrow class of systems and behaviors discussed by van der Klis (1989). The range now includes (a) $\approx$0.04 Hz power in the rapid burster (Abramowicz et al. 1995), which acts like neither previously known atoll nor *Z*-type sources (Rutledge et al. 1995), (b) 26 Hz oscillations in Cygnus X-2 (Kuulkers and van der Klis 1995), (c) 27–72 mHz power associated with rapid spin-up of the neutron-star rotation in A 0535+262 (Finger et al. 1995b), whose donor is a fairly massive Be star, not one of the low-mass donors normally associated with QPOs, and (d) most spectacularly, QPOs at frequencies in the kilohertz range in four X-ray binaries studied with the *Rossi X-ray Timing Explorer* (van der Klis et al. 1996; Wijnands et al. 1996; Zhang et al. 1996b; Burger et al. 1996; Shirey et al. 1996), of which the most famous are Sco X-1 and Cir X-1. There are probably additional such sources skulking in the IAU Circulars and undoubtedly many more in the sky.

The *Rossi XTE* is, of course, the first satellite able to record enough photons with accurate enough arrival times to see these frequencies. No model yet does a very good job of accounting for these new classes of quasi-periodicities, but an interpretation in terms of beat frequencies would provide evidence that the neutron stars must be rapid rotators (e.g., 1.91 ms for KS 1731−260, IAUC 6437), as is generally advertized for low-mass X-ray binaries.

At the high-mass end of the X-ray binary kingdom *Beppo-SAX* reported its first detection, of Cygnus X-1 (IAUC 6431). No surprises there, yet, at least. More of a surprise are the very large mass and possible optical identification reported by Clark et al. (1996) for a new X-ray nova of the type often associated with black holes (but of 5–10 $M_\odot$, not 30 $M_\odot$).

Work continues on the two galactic "superluminal" sources, GRS 1915+105 and GRO J1655−40. The latter is clearly a black-hole accretor (Bailyn et al. 1995), and the former has what may be the largest reasonably steady X-ray luminosity of any Milky Way source at 3×10^{38} erg s^{-1} (Chaty et al. 1996). Infrared data confirm the radio in indicating that the present extended structure was expelled at the time of the outburst that led to discovery (Sami et al. 1996; Foster et al. 1996). The mass of the donor in 1655−40 is currently under discussion (Castro-Tirado et al. 1996), and one can make a case for these two sources having some underlying physics in common with superluminal motion in active galaxies and, perhaps, other kinds of rapidly varying, compact sources (Falcke and Biermann 1996).

SS 433 remains unique in showing optical emission lines of very large velocity (Brinkmann et al. 1996) and in some other less striking properties (Shakhovskoi and Sazaonov 1996). Finally, it must be confessed that the prediction (Ap94, Sec. 5.4) that such superluminals would turn out to be common, once one knew how to look for them, seems to have been wrong. The inventory in print remains at two.

6. NEW SOLUTIONS TO OLD PROBLEMS, AND CONVERSELY

Each of these was presumably meant quite seriously by its author(s), but we are not sure we want to add quite all of them to our permanent data base. Your choice of "keepers" may be different from ours.

6.1 The Solar System

The Earth goes around the Sun. This has been discovered by a number of independent methods over the years, but the most impressively complex is surely the distortion of the light curve of a gravitational microlensing event (MACHO) in the Milky Way that records the changing position of the Earth during the event (Alcock 1995b).

Meteor detectors on spacecraft to Mars. It is a little hard to explain why we think that putting gamma-ray burst detectors on anything that is heading an AU or more away from us is a good idea but are not so sure about this one (Adolfsson et al. 1996).

Bright features on the otherwise dark landscape of Titan may result from methane rain washing the highlands (Smith et al. 1996).

Anomalous metallicity. That the local interstellar medium and many nearby B stars are "metal deficient" relative to the Sun is an old result that we have tried to argue out of before (Ap94, Sec. 4). But Snow and Witt (1996) have decided to bite the bullet and declare the solar system to be abnormally enriched. This has implications for the composition of interstellar dust and the phenomenon normally called "depletion" (Greenberg 1974).

Solutions of the solar neutrino problem (and if the right one were known, the *s* wouldn't be needed). The reported correlation of neutrino flux with 19 years of solar wind variations measured by IMP-8 (McNutt 1995) is another hint that electron neutrinos may somehow be rotating to a different flavor in the solar magnetic field. Solar cycle variations in that field are now fairly well established (Lydon et al. 1996; Balmforth et al. 1996). An alternative solution, requiring the Sun to have a metallic core, is presented by Rouse (1996), not for the first time, and, we suspect, not for the last.

Solar oscillations, from which the evidence for magnetic-field variations comes, can be monitored in a number of ways. Looking at scattered light in large areas of the daytime sky sounds harder than most (Komonovich 1996).

Prediction of solar activity on time scales both shorter and longer than the 11 year cycles remains difficult. Acton and Hudson (1996) suggest that the corona dims just before large flares, which might permit prediction of the latter. That there were very few sunspots between 1645 and 1715 was first noted by Spörer, and the episode is therefore called the Maunder minimum. But that's OK: Spörer gets the previous one (1540–1540) named for him. It was discovered by H. DeVries in 1958 (Phillips 1992, p. 268). At least four papers by three groups during the reference year provided models/explanations of the Maunder minimum as a real cessation of solar activity (Knobloch and Landsberg 1996; Tobias 1996a,b; Schmitt 1996). All mention dynamo magnetic fields; several invoke Parker (1955); and none says just when the activity should turn off again. The present stretch of regular cycling has, after all, lasted a good deal longer than the time between the Spörer and Maunder minima.

6.2 Nearly Normal Stars

RV Tauri stars, pulsating variables with alternating faint and bright minima, were laid to rest in Ap92, Sec. 10.10. The problem of accounting for the alternation has been solved at least three more times this year, twice in terms of interacting, unstable modes (Pollard et al. 1996; Buchler et al. 1996), and once in terms of "intermittent bursts" (Takeuti and Tanaka 1995).

Conservation of stars in the Milky Way. The rate of formation of asymptotic giant branch stars is equal to the formation rate of planetary nebulae (Ortiz and Maciel 1996). This is a good thing, because AGBs are supposed to turn into PNe (Shklovskii 1956). The next stage downstream is a white dwarf, but some low-mass stars (by birth or by choice) can get there by skirting AGB and PN nucleus loci in the HR diagram, so the birth rates need not match.

R CMa stars were among our early favorite classes of binaries, because their combinations of masses and luminosities (radii) seemed to require them to be hollow. This would now be an exaggeration, but they remain unexpectedly big, hot, and luminous for their masses (Sharma et al. 1996).

Binary and triple systems can be non-coplanar without distressing anyone excessively (Glebocki and Stawikowski 1995 on non-synchronized systems; Horn et al. 1996 on 55

UMa, and we record with sorrow the last paper Jiri was involved in before his untimely death in December 1994; Corporon et al. 1996 on TY CrA), though nobody objects if three stars are all in the same plane (Skopal et al. 1996 on CH Cyg). One would, however, rather like to draw the line at non-coeval systems (Liu et al. 1996), though their example, AS 205, admittedly consists of two classical T Tauri stars, whose age difference would surely not be detectable by the time they were as old as the senior author. That stellar rotation periods ought to be shorter than binary orbit periods is a mere prejudice, not shared by RX J1940−1025 (Friedrich et al. 1996). And anyhow the dominant period we see is the beat between them.

Dwarf-nova outbursts are now generally attributed to instabilities in their accretion disks that result in a sudden increase of viscosity and mass transport. Armitage et al. (1996) have, however, addressed how DNe turn off, when rapid cooling inhibits a Balbus–Hawley instability, which quenches a dynamo, which reduces a disk viscosity (that lives in the house that Jack built). Ap94 Sec. 6 discussed the B–H instability and DN outbursts.

6.3 Dead and Active Stars

Is this a weird combination? Possibly, but most stellar fireworks are associated with old ones becoming compact, accreting from companions, and so forth.

Faint X-ray sources in globular clusters. These could be like field RS CVn systems but brighter, like field cataclysmic variables but brighter, like low-mass X-rays binaries but fainter, or something else, and we have changed several horses simultaneously in midstream in the past on the subject (Ap93, Sec. 6). *HST* images of NGC 6397 struck a blow for CVs this year (Grindlay et al. 1995).

Thorne–Zytkow objects are red giants or supergiants whose cores are supported by degenerate neutron pressure rather than by degenerate electron pressure (Thorne and Zytkow 1975). There are no confirmed examples, but White et al. (1996) suggest the X-ray pulsar 4U 0142+61 as a candidate.

Pulsar glitches (sudden decreases in period, changes in period derivative, etc.) were blamed on star quakes soon after their discovery in 1969. Fashion, and perhaps even fact, swung to mechanisms involving superconductivity, magnetic vortices, and such (Ap95, Sec. 12.4) some time ago, and it is nice to see a slight revival of starquakes (Link and Epstein 1996; Alpar et al. 1996), though their role is now the reduced one of heating and interacting with crustal vortices.

Pulsar second derivatives are conveniently parametrized as $n=\nu\ddot{\nu}/(\dot{\nu})^2$, where ν is the rotation frequency. Different ways by which a pulsar might get rid of its rotational kinetic energy "predict" different values of n: $n=5$ for pure gravitational radiation; $n=3$ for pure magnetic dipole radiation. None of the four measured values are just what you would have expected. Lyne et al. (1996) report $n=1.4$ for the Vela pulsar and summarize earlier results, $n=2.5$ (Crab Nebula pulsar), 2.24 (psr 0540), and 2.84 (psr 1509). Two implications are (a) that either magnetic moments or mass quadrupole moments of the neutron stars must be changing as the pulsar age and (b) that pulsar ages could, in principle, be longer than $P/\dot{P}$. The longer possible ages, in turn, mean that the space velocities of neutron stars derived from their apparent associations with rather distant supernova remnants need not be as large as sometimes advertised (up to 1400 km s^{-1} or thereabouts). Which leads us directly to the subject of

Neutron-star kick velocities. At least some pulsars are faster than a speeding bullet. Explaining this purely in terms of the unbinding of a close binary system by the first supernova explosion in it was advocated (Gott et al. 1970) and de-advocated (Trimble and Rees 1971) a quarter of a century ago. Iben and Tutukov (1996) continue to be of the opinion that binary processes are sufficient, especially the second supernova in a close binary, which can expel more than half the total mass of the system. Some support for their view comes from the fact that millisecond pulsars (still in binaries or liberated by nonviolence) tend not to be very high velocity objects (Camilo et al. 1996). Other modellers of binary populations prefer, however, an additional kick to the neutron star at its formation amounting to at least 100–200 km s^{-1} (Zwart and Verbunt 1996; Lipunov et al. 1996; Terman et al. 1996). Specific examples of possible kick victims are Lambda Orionis, on the assumption that it is associated with a 300 000-year old supernova, now represented by a gas ring (Cunha and Smith 1996) and the pulsar J0045−7319, whose precession suggests that its orbit is not in the plane of the equator of its B star companion (Kaspi et al. 1996). If neutron stars and their former companions are the kickees, what are the kickers? Asymmetric supernova explosions have been the obvious answer for a long time, but it is only within the last couple of years that models of Type II supernovae have been able to eject any material at all (Ap95, Sec. 5). Because the successful models are explicitly two or three dimensional, the asymmetries can be seen and their magnitude estimated. Vilenkin (1995) finds a kick velocity of about 30 km s^{-1} from neutrino effects alone. Burrows and Hayes (1996) raise the ante to 530 km s^{-1}, enough for all but the most tenuous pulsar-SNR associations.

OB runaway stars must be the parents of some supernovae [though there is no good way to tell whether their velocities are a result of ejection from a cluster or of a kick from a deceased companion (Leonard 1995)]. The remnant neutron stars will inevitably be high-velocity objects. Finally, Brandt et al. (1995) propose that low-mass X-ray binaries can be separated into those with neutron-star accretors (large space velocities) and those with black-hole accretors (small space velocities), giving Nova Sco, with $V\gtrsim 100$ km s^{-1} as an example of the former.

6.4 The Milky Way and Diffuse Matter (Wherever it may be)

Word of the year. Picking advection as the word of the year in Ap95 turned out to be more trouble than it was worth (see Sec. 13). Nevertheless, the sudden prominance of "dichroic" invites a second tempting of providence. The meaning of the Greek root is "two-colored," and probably the deepest association in most of our minds is with calcite in high school physics labs. In the current astronomical literature, however, dichroic extinction by aligned dust grains is credited for the production of visible and infrared polarization in a wide variety of objects (Casali 1995 on the dark cloud L 1641 in *HJK*; Draper et al. 1995 on NGC 2146 in *BVRI*, where uniformity of the magnetic field on kiloparsec scales in this slightly active galaxy is one of the implications; Chrysostomou et al. 1996a on the young stellar object GSS 30 in *JHK*, including references to earlier theoretical work on dichroism in astrophysics; Schreier et al. 1996 on Cen A seen with *HST*; Young et al. 1996 on Seyfert 2 and *IRAS* galaxies; and Scarott et al. 1996 on the dust lane of Cen A with analogies to NGC 2146, M104, and IC 4329 A).

Gas in spirals was associated with two neat ideas during the year. First, Honma et al. (1995) propose that the transition from mostly H_2 inside about 5 kpc to mostly H I further out is quite sharp in many spirals because it is a sort of phase transition driven by metallicity gradient.

The second idea is that enthusiastic star formation cuts in rather sharply when gas density in disks exceeds a critical value. A nice example is Sextans A, whose peak gas density is on the ragged edge of the critical one and whose star formation is patchy and mobile (Hunter and Plummer 1996). The idea has been around just long enough (Kennicut 1988, 1990) for counterexamples and excuses to have begun to show up (Downes et al. 1996 on the very low level of star formation in gas-rich NGC 1530 and Hunter and Thronson 1996 on similar behavior in NGC 4449). Elmegreen et al. (1996) suggest a slightly different criterion, in terms of gas density as a fraction of the local total, but we guess that it will also have some exceptions. Still puzzling, though not new, is the fact that some indicators of star formation are best correlated with the H_2 (or CO) content of spirals, and others with the H I content (Cassiolit et al. 1996). Smith and Harvey (1996) provide what sounds like a partial explanation, involving how IR-emitting dust is heated in different contexts (though this was probably not what they had in mind).

Depletion of metals in the interstellar medium is correlated with (and presumably caused by) how well they bond to polycyclic aromatic hydrocarbons (PAHs, the molecule of the year according to Ap92, Sec. 9.2), as determined from laboratory data compiled by Klotz et al. (1995). If the solar system is not actually a good sample of local abundances, this may have to be reconsidered (Sec. 6.1).

The dark matter in the Milky Way is not gas, at least out to 20 kpc, where we know there are cosmic rays, or there would be more secondary gamma rays than we see. The dark matter in the Milky Way is unresolved binary stars according to Malkov (1995). Well, you were warned that you would not want to add every item in this section to your permanent data base. The problem is that there is no range of separation at which companions of roughly equal mass can remain hidden from spectroscopic, astrometric, and imaging studies.

The black hole at the center of the Milky Way comes ever closer to having an infrared (Simons and Becklin 1996) and X-ray identification (Koyama 1996, who suggests that advection may be a sometime thing). The real news, however, is the completion and publication of a pair of projects to measure radial velocities (Haller et al. 1996) and proper motions (Eckart and Genzel 1996) of infrared stars near Sgr A*. No cluster of normal stars could be compact enough to live inside the region of large velocity dispersion. The remaining alternatives are, therefore, a tight cluster of small black holes or one big one, with a total mass of $2–2.5\times10^6\ M_\odot$ in either case, assuming we are 8 kpc from the galactic center. We suppose that if you dislike the whole idea of black holes and don't want any in the real world, you should vote for the single big one, while enthusiasts should favor the cluster of little ones; but an actual opinion poll would probably turn out the other way round.

Unidentified gamma-ray sources were the single most numerous product of the Cos B satellite. EGRET has increased the inventory considerably, with 129 cataloged sources (vs. a couple of dozen), including active galaxies, a handful of young pulsars and SNRs, etc., but more than half (71) still unidentified (Thompson et al. 1995). The ones at high latitude must be mostly AGNs and nearby faint neutron stars (Ozel and Thompson 1996; Sreekumar et al. 1996), but suggestions for the low-latitude ones include (a) open clusters in which shocks from stellar winds accelerate particles that hit ambient gas (Manchandra et al. 1996), (b) young pulsars in OB associations (Kaaret and Cottam 1996), (c) Gamma Cygni (Esposito et al. 1996), and (d) young cosmic-ray sources interacting with giant molecular clouds (Aharonian and Atoyan 1996). Most of these ideas go back to Cos B or before.

6.5 Normal Galaxies

These must present very few problems, since we found only two new solutions or anti-solutions. First, a nice definition of star bursts in terms of the ratio of stars just produced to the total over the life of the galaxy so far (Krüger et al. 1995). In some blue compact dwarf galaxies, the ratio is as small as 0.001, while it extends up to 0.1 for some of the brightest *IRAS* galaxies.

Second, we have always wondered what Adriaan van Maanen did wrong to find rotational proper motions in spiral galaxies (which made it "impossible" for them to be separate galaxies). This probably isn't the answer, and the authors don't suggest that it is, but Evans and Irwin (1995) report whorl-like systematic errors on Palomar Observatory Sky Survey plates that had to be removed before they could extract accurate proper motions for 170 000 stars and use them to study the rotation of our galaxy.

6.6 Active Galaxies

Ships that Pass in the Night? According to Fukugita and Turner (1996), quasi-stellar objects happen when wandering, naked black holes, of which there are many, collide with galaxies or gas clouds. This will sound faintly familiar if you have a very long memory. Back when the existence of other galaxies was in doubt, what we now call extragalactic novae were attributed to stars wandering into galactic gas clouds.

Radio source evolution. Compact, double, steep-spectrum sources that map out a lot like Cygnus A seen through the wrong end of the telescope probably really do eventually grow into large double sources (Fanti et al. 1995; Readhead et al. 1996). And these in turn eventually fade away (Klein et al. 1995, presenting 0828+32 as an example).

Stellar collisions as the energy source for active galaxies have been brought forward again by Courvoisier et al. (1996), though the current proposal differs from earlier ones (e.g., Woltjer 1964) in that a central black hole is part of the picture and serves to confine a dense cluster of stars in which the collisions occur.

A(nother) shrinking superluminal? The VLBI core of Q 0646+600 is reported to have contracted by 0.25 marcsec in two years (Akujor et al. 1996). An earlier candidate for contraction, 4C 39.25, eventually turned out to have two stationary components and a third one moving between them (Shaffer and Marscher 1987).

Periodically variable active galaxies are another class that has moved in and out of the inventories over the years, beginning with 3C 273 (Smith and Hoffleit 1963). The current one is the blazar OJ 287, whose 1994 December outburst fit onto a twelve-year cycle that can be traced back to 1910 (Sillanpaa et al. 1996). And there was at least one additional candidate in the intervening 33 years that was described at a conference on searches for extraterrestrial life as ''Someone was obviously trying to signal to one of the participants.''

The Baldwin effect is an anticorrelation of the equivalent widths of some quasar (etc.) emission lines with total luminosity of the source. That it is seen in some but not all lines is most simply explained as the shape of the continuum spectrum from blue to soft X-ray wavelengths being a systematic function of luminosity (Green 1996).

The maximum brightness temperature of (incoherent) synchrotron radiation is set by the photons all committing self-absorption suicide at about 10^{12} K (Slysh 1963). Despite this, 15% or so of sources resolved with VLBI have components hotter than this (Moellenbrock et al. 1996). Beaming of the radiation can push the limit up to 10^{13-14} K in the favored directions (Wang and Zhou 1995, not a new result). But the 10^{18} K reported for radio flares from EV Lac (Abdul-Aziz et al. 1995) remains beyond reach. Not too much sleep should be lost over this, however, since the authors point out that the bursts may not actually exist.

Supernovae from star bursts? In another notable non-discovery, Li and Li (1995) conclude that ''superproductive'' galaxies, spirals with exceedingly high supernova rates (pointed out by Richter and Rosa 1988) are nothing of the sort. They are merely chance combinations of late Hubble types, high luminosity, face-on presentation, and normal variations in SN statistics. Multiple SNe in single galaxies are, in general, found at larger radii than the average for single events, again indicating the significance of selection effects.

6.7 Clusters to Cosmology

In which the percentage of things you will want to add to your permanent data base probably drops.

Abell did a darned good job. According to a redshift survey being performed as one of the Key Projects of the European Southern Observatory, only 10% of the clusters of galaxies identified as richness class 1 or more in Abell's (1958) catalog and whose redshifts are less than 0.1 turn out to be artifacts (mostly superpositions of two less rich clusters at different distances—Katgert et al. 1996).

The Great Attractor found? According to Kraan-Korteweg et al. (1996), the cluster Abell 3627 (cz=4882 km s^{-1}, mass about 5×10^{15} $M_\odot$ from both X-ray temperature and galaxy redshifts) accounts for about 10% of the mass needed to produce the large-scale deviations from smooth Hubble flow that seem to occur in its general direction (Lynden-Bell 1988).

Helium shortage at the galactic center? From time immemorial, portions of the ionized gas around Sgr B2 have persisted in displaying a ratio of ionized helium to ionized hydrogen (measured from recombination lines) considerably less than the 0.1 by number that we all call ''primordial'' (Mezger et al. 1970). Years of improving angular resolution have shrunk the deviant bit of sky, leaving $He^+/H^+\approx0.1$ in most of the region. But there is still a stubborn core with He/H$\leq$0.05 in H66 alpha and He66 alpha maps (de Pree et al. 1996)

The Arp Effect is the observation that, in many small groups of galaxies (including the Local Group) the smaller members seem to have larger redshifts than the bigger members. The knee-jerk reaction, ''well, of course: they have smaller angular diameters and larger redshifts because they are further away'' is disallowed. It turns out, however, that some oddities in how you define the average velocity of a disk galaxy from angularly resolved data are part of the problem (Keel 1996), and much or all of the rest disappears if you look at red and blueshifts relative to the centers of masses of the groups concerned instead of relative to the single biggest galaxy (Karachentsev 1996, on groups associated with M31 and M81). We are, of course, aware that papers discussing non-cosmological redshifts continue to appear, but find it difficult to reconcile the text statement (Burbidge 1996) that the non-cosmological contribution is typically only 0.1–0.5 with the tables of specific examples given in the same paper, which seem to associate quasi-stellars having redshifts of one or more with very nearby galaxies. Non-cosmological redshifts of apparently arbitrary size are a natural consequence of the quasi-steady-state model of the Universe if younger matter has more massive particles (Hoyle and Burbidge 1996). This seems to be the opposite of what Narlikar and Arp (1993) proposed.

Primordial magnetic fields sufficiently strong to be twisted into modern galactic ones are a possible consequence of string cosmology (Gasperi et al. 1995). The mechanism requires some fine tuning of the pre-big-bang Universe in order to work, but try saying ''dynamic dilaton background'' quickly three or four times and see if it doesn't make you feel better. If this fails, have a go at ''rubber baby buggy bumpers'' or ''the big black bug bled bad blood.'' And the more massive author is a good deal puzzled to discover that this latter is even somewhat difficult to type!

Tired light (Zwicky 1929) is an explanation of Hubble's law alternative to an expanding universe. Photons simply lose energy on long trips (think of it as cosmic jet lag). The two explanations make several different predictions that are observationally testable. One pertains to counts of galaxies as a function of apparent magnitude (a can of K-corrections, evolutionary effects, and other worms we prefer not to open). The second concerns how surface brightnesses scale with redshift, $(1+z)^{-1}$ for tired light vs. $(1+z)^{-4}$ for true expansion [see Sandage 1988 for an account of where the other powers of $(1+z)$ come from]. Sandage and Perelmuter (1991) reported seeing the "approved" correlation some time ago, and another group who were originally skeptical of the associated error bars now concur (Pahre et al. 1996).

The third distinguishing feature is time dilation—yes, if the Universe expands, no, if it does not. Wilson (1939) suggested that the light curves of distant supernovae would be suitable clocks to have their slowing measured. Nǿrgaard-Neilsen et al. (1989) reported the first probable slowing of a Type Ia supernova at $z=0.31$. The data base has increased enormously (Perlmutter et al. 1995 and more than 20 additional events spotted by the same group and currently on paper only in IAU Circulars, with a record redshift of 0.65 for 1996at). The light curve of 1988U (though it was caught somewhat past maximum light) was nearly definitive on the issue of tired light, and we raise the matter again here because, as Leibundgut et al. (1996) point out, the supernovae with redshifts of order 0.5 also rule out redshifts that are proportional to age (Narlikar and Arp 1993). The searchers for distant supernovae want, of course, primarily to use them to measure the conventional cosmological parameters, H, Λ, Ω (density), and q (deceleration). All right-thinking astronomers wish them well, but there seems to be more cosmological model dependence in the analysis than has been generally recognized (Steinhardt 1996).

7. PLOT IT YOURSELF

Since 7 is a particularly lucky number, this section is left for the reader to use to summarize the most important topics that we left out. Some of our candidates were "the urge to merge," "something about supernovae," "galaxies in voids," and "variable stars that only a member of AAVSO could love." Is the astronomical literature growing exponentially? "No," said a distinguished editor, "It's only about 5% a year" (evidently mistaking "exponential" for a pejorative rather than a technical term). The same thing can be said about these reviews (count the pages and see). Thus, though the fraction of papers ignored is roughly constant, the number grows ever larger.

Ap96 probably also hits a new low point in not-very-subtle allusions to non-astronomical literature and other low forms of culture (starting with the title of this section). The more massive author will be happy to pay for and share a bottle of some suitably low-culture fluid with the reader who identifies the largest number of these correctly.

8. TOOLS OF THE ASTRONOMER

This is not a section about telescopes, or spectrographs, or computers. Rather it deals with processes and phenomena that were regarded, not so long ago, as a great triumph to have found at all, but which are today routine ways of investigating other things. The examples considered are astrophysical masers, gravitational lensing, and star spots.

8.1 A-masing

The first mased lines, those of OH, turned up in 1965 (Weaver et al. 1965; Gunderman 1965, and if you want to find the journal version of this latter, you must look under her later surname, Hardebeck). We haven't tried to check how many different molecules are known to mase under astronomical conditions, but papers during the year mentioned OH, H_2O, SiO, CH_3OH, H_2CO, and H27-α (not a new discovery, but not very familiar either, Seaquist et al. 1996a). Normally, masing gas is associated with regions of star formation or with winds shed by evolved stars, but Frail et al. (1996) report a new category of OH maser in the vicinity of supernova remnants, attributable to shocking of surrounding molecular material.

Water masers as tracers of mass distribution very close to the centers of (active) galaxies have progressed nicely since the work on NGC 4258 reported in Ap95, Sec. 2.3. Monitoring of the prototype galaxy has revealed acceleration of the maser velocities, as expected for a Keplerian disk around a $\approx 10^7\ M_\odot$ black hole (Greenhill et al. 1995). A central H_2O maser disk in the Liner NGC 2639 shows similar acceleration at 6.6 km s^{-1} yr (Wilson et al. 1995). A handful of additional candidate maser disks have been reported by Braatz et al. (1996) and by Nakai et al. (1995). The latter set includes NGC 1068, for which they report a central mass of $1.3\times10^8\ M_\odot$, a good deal larger than the $4.4\times10^7\ M_\odot$ found for the same galaxy, also using H_2O and OH maser lines, by Gallimore et al. (1966).

In these sources, measurements of velocity and acceleration, combined with faith in Kepler, tell you the linear size of the disk, while the maser positions tell you the angular size. The result is a "distance indicator," suitable for measuring Hubble's constant, if the disks are far enough away. TXFS 2226−1821, at $z=0.025$, is a promising water-maser host in this connection (Koekemoer et al. 1995).

Retreating cautiously back toward the Milky Way, we encounter the first extragalactic SiO maser. It is associated with a red supergiant in the LMC (van Loon et al. 1996).

The 20-some papers that dealt with galactic masers during the reference year can be categorized in two ways—those focusing on regions of star formation versus those focusing on evolved objects (about half and half), or, those primarily interested in understanding the masers themselves versus those primarily interested in using the masers for something else (also about half and half). We have picked out a biased set of the applications.

First, the OH associated with the water masers near the galactic center acts like that normally found around evolved, oxygen-rich OH/IR stars, and the water masers are, therefore, not evidence for recent star formation in this context (Sjouwerman and van Langevelde 1996). In general, though, one can say that mased H_2O is a signature of the star-formation process caught very early, before diffuse H II appears (Codella and Felli 1995; Codella et al. 1996). And, in this corner where no one is likely to notice it, we would like to call attention to the excellent, though non-native, English in which the latter paper is written. The combination of OH and methanol masing, on the other hand, is good at picking out compact H II regions (Casell et al. 1995). Actually, this whole topic may belong in our tomato/tomato section (10.4), because Yousef-Zadeh and Mehringer (1995) say that the H_2O masers at the galactic center are an indicator of star formation where the supernova remnant Sgr A East is hitting molecular clouds, quite the opposite of the conclusion of Sjouwerman and van Langeweldt (1996).

Second, skipping to the endpoint of stellar lives, the winds of single Mira variables are quite often maser sites, but binary (symbiotic) Miras are deficient in both OH and H_2O masers (Seaquist et al. 1995) and in SiO ones (Schwarz et al. 1995), revealing another example of how having a close companion can disturb your surroundings (cf. protostellar disks in Sec. 3.2).

Third, mased lines are useful kinematic tools, because their velocities can be measured so precisely. Riera et al. (1995) report the complex outflow patterns in an *IRAS* source that is in the process of converting from an asymptotic giant-branch star to a planetary nebula. Richards et al. (1996) probe NML Cygni, a somewhat similar object, in a somewhat similar way. On a slightly larger scale, Torrelles et al. (1996) have used water masers in the Ceph A region of star formation to trace out the mass distribution of the cloud. There is a central concentration of $70\pm40\ M_\odot$, which should not be interpreted as a black hole! Finally, Izumiura et al. (1995) have used SiO masers associated with evolved stars in the galactic bulge to find evidence for non-circular streaming motions caused by the galactic bar (Ap94, Sec. 3.1).

Fourth, it is generally agreed that certain combinations of maser parameters are good tracers and diagnostics for star-formation regions (Anglada et al. 1996; MacLeod and Gaylor 1996; Pavlakis and Kylafis 1996; Claussen et al. 1996). But it is not always 100% clear what they are tracing and diagnosing. Cassell (1996), for instance, associated a high ratio of H_2CO flux to OH flux with young stellar objects of low mass, while Ellingsen et al. (1996) associated strong H_2CO with high-mass YSOs. Admittedly they are not looking at the same part of the sky. And we freely confess that the semi-contradiction was noticed only because the two papers appeared so close together, separated only by a scenario for the production of binary white dwarfs (Sarna et al. 1996). This latter makes no pairs that can yield Type Ia supernovae upon merger. Since that is the number we see, the answer may well be right.

Fifth, and this closes the loop with NGC 4258, etc., Bloemhof et al. (1996) have (a) resolved the shapes of the maser blobs in the compact H II region W3 and (b) shown that those shapes don't change when the blobs move. This means that real cloud motion is involved and not just some sort of wandering excitation front and thereby justifies the use of extragalactic H_2O masers for dynamical studies.

8.2 Lensliness is Next to Godliness

When Fritz Zwicky first wrote about gravitational lenses (Zwicky 1936), he said (a) that galaxy-galaxy lensing was more likely than star-star, (b) that you could use lensing as a telescope to tell you about distant sources otherwise too faint to study, and (c) that lensing would provide a good way to measure masses of galaxies (etc.) independent of their velocity dispersions. We tackled some recent work on topic (c) in Sec. 11 of Ap95. Topics (a) and (b) are featured this year, along with an assortment of other products and by-products of gravitational lensing.

Active and Passive Galaxies

A bit of ray tracing will persuade you that one galaxy behind another is unlikely to be split into several discrete images the way compact quasars are. But weak lensing, in which shapes are distorted, is a possibility. It has now been seen (Brainerd et al. 1996). A typical lens has a mass of $10^{12}h^{-1}\ M_\odot$ within a radius of $100h^{-1}$ kpc (but, of course, the most massive galaxies are most likely to be caught in the act of lensing). New multiply-imaged, quasi-stellars with large galaxies as lenses continue to turn up (Ratnatunga et al. 1995, with two "Einstein crosses" from the Hubble Medium Deep Survey), as well as additional data on familiar objects (Falco et al. 1996 with a VLA radio map and Østense et al. 1996 with evidence for both optical microlensing and intrinsic variability in Q 2237+0305).

Einstein rings, where the background image surrounds or nearly surrounds the center of its lens in the sky, are a sort of transition case, previously found only in radio maps. Warren et al. (1996) show what seems to be the first optically selected one, in which a $z=0.485$ galaxy lenses a slightly resolved background source at $z=3.6$.

The first Zwicky telescope to be announced as such revealed a $z=1.5\pm0.3$ galaxy in the form of four arcs around position 0024+1654 (Colley et al. 1996). Each of the four images can be deconvolved to approximate the real shape of the background galaxy. The four agree, and the galaxy, rather improbably, resembles a slightly wobbly, lower-case θ, like a peculiar galaxy described by Morgan (1958) some time ago. A second case, not advertised as a Zwicky telescope, appears in Ebbels et al. (1996). The magnified and amplified galaxy is at $z=2.5$ and shows Lyman-alpha only in absorption, not emission, though the galaxy is very blue. Presumably the unenhanced galaxy would not be very bright. Neither would be the one convicted of lens amplification by Williams and Lewis (1996), which almost made it into Sec. 12 as "primordial galaxy of the year" on the basis of an apparent star-formation rate of $4700\ M_\odot\ \mathrm{yr}^{-1}$. The imposter is at $z=2.72$, and the lens is probably a foreground X-ray cluster at $z=0.37$.

Not surprisingly, images in the Hubble Deep Field include a number of candidates for assorted kinds of gravitational lensing (Hogg et al. 1996). Spectra are needed.

Like tongues to sore teeth (this has to be a section title next year!) we keep returning to the excess of associations in the plane of the sky between QSOs and bright galaxies. And, like the tooth fighting back, all the papers published during the reference year say "yes, this is part of the answer, but not all of it" (Seitz and Schneider 1995; Wu and Fang 1996; and Fort et al. 1996 on the implications of lensing for such associations). Quasars that are lensed by the galaxies (or whatever) responsible for absorption lines in their spectra obviously belong in here somewhere. Bartelmann and Loeb (1996) mention Lyman-alpha ones and Vanden Berk et al. (1996) C IV absorbers. Both agree that the phenomenon greatly complicates the interpretation of statistics of quasars, absorbers, and dust. We suspect the official shopkeeper includes these in the inventory just to make the bean counting more difficult.

MACHOS

Yes, we know that there are 7±1 events in the direction of the Large Magellanic Cloud in the first two years of reprocessed data from the MACHO collaboration. But no, we are not going to talk about what they mean for two reasons. First, only the first year's data (three events) appeared in print during the reference year (Alcock et al. 1996). And, second, we have not made up our minds whether to be complacent, puzzled, or panic-stricken by the set of seven durations and amplitudes and their possible decoding into lens masses, velocities, and locations (or dwarf novae? Della Valle and Livio 1996). You won't have found much praise for science writers in these pages over the years, but we vote with K. C. Cole of the Los Angeles Times, who looked hard at a January press release on the topic and concluded "this is not a story."

The OGLE, MACHO, and EROS projects continue, however, to be cornucopiae, spilling forth valuable byproducts in the form of variable stars and such.

EROS: A catalog of 97 Cepheids in the Large Magellanic Cloud (Beaulieu et al. 1995). The first overtone ones are a tad brighter and bluer than expected from models.

MACHO: A total of 9700 RR Lyraes in the LMC, 500 with light curves (Alcock et al. 1996a). They display properties somewhat intermediate between those in Oosterhof 1 and Oosterhof 2 globular clusters, and the stars belong to a population somewhat younger than most clusters in the Milky Way and LMC.

OGLE: A catalog of stars in Baade's window (Szymanski et al. 1996), a map of the region from it (Stanek et al. 1996), and the color-magnitude diagram (Ng et al. 1996). The assigned ages and metallicities for the three stellar populations seen in that direction are 10–16 Gyr and $Z=0.004-0.06$ for the bulge, 8–9 Gyr and $Z=0.005-0.03$ for the bar, and 2–7 Gyr and $Z=0.008-0.02$ for the disk.

OGLE's third (Udalski et al. 1995) and fourth (Udalski et al. 1996) catalogs of variable stars toward the bulge. The types include RR Lyraes, Delta Scuti stars, eclipsing binaries (with light curves in the shapes of W UMa, Algol, and Beta Lyrae types, though not necessarily those evolutionary stages), some Miras, and a large number of red giants and subgiants, mostly with chromospheric activity, that display periodic variability the team had not expected in advance. They describe it as ellipsoidal variation, and one is reminded of RS CVn stars.

8.3 Spots before Our Eyes

Sunspots were discovered by whichever of the ancients first looked hard enough (we hope, at least, it was sunrise or sunset on a smoggy day, but rumor has it that she was thereafter known as Blind Bi-yun). Other stars, even the biggest of them, and even with the best current adaptive optics or optical interferometers, have only a few resolution elements across their faces. As a result, most star spots are inferred rather than imaged. One exception is a single, bright spot on Betelgeuse, imaged in the ultraviolet with *HST* (Gilliland and Dupree 1996) and presaged in theory (Schwarzschild 1975) and Stratoscope II images (though an earnest search has failed to locate the reference).

Hot spots turn up in a few other contexts, including dwarf novae (Bruch et al. 1996), Algol-type binaries (Olson and Etzel 1995), and X-ray binaries (Psaltis et al. 1995), where they are the result of streams of material from a companion hitting a disk or the accreting star.

The spots on the prototypical spotted star are, course, cooler than the surrounding photosphere (apparently first enunciated by Warren de la Rue about 1865, with contributions from Secchi and Lockyer, according to Phillips 1992, p. 42; additional information very welcome). The surrounding regions are, however, hotter than average, and the question of whether active regions make a net, instantaneous positive or negative contribution to solar luminosity has remained open. The answer, apparently, is some of each, depending on the size of the active area (Steinegger et al. 1996).

The amount by which spot temperature deviates from that of the surrounding photosphere is positively correlated with the surface gravities of the stars, at least among slightly evolved ones (O'Neal et al. 1996). If asked to guess, the senior author would have predicted the opposite correlation. The RS CVn star IM Peg, in which the mean spot temperature changes over its 15 year activity cycle (Dempsey et al. 1996) must be responding to something other than changes in surface gravity.

The influence of sunspots propagates outward into the corona in the form of chemical inhomogeneities (Sheeley 1996). Similar propagation, at least in density structure, occurs in the winds of very hot (OB, WR) stars (Massa et al. 1995; Kaper et al. 1996) as well as in the winds of asymptotic giant branch stars (Frank 1995).

Returning again to the Sun, we find that most spots occur at latitudes of 5°–40°, varying systematically through the solar cycle (Galileo and Christoph Scheiner, according to Phillips 1992, pp. 6, 7). This is not a universal trait. Some cool spots live near stellar poles, whether magnetic (Catalano and Leone 1996, on helium-weak stars) or rotational (Hilditch and Collier Cameron 1995). There was some early concern that finding such cool, polar spots might be an artifact of the ways data on line profiles were processed. This concern can probably be laid to rest. The same Doppler-imaging algorithm that finds polar spots on some RS CVn stars (slightly evolved G-K binaries) finds only low-latitude spots when applied to V410 Tau (Hatzes 1995).

Another characteristic of sunspots noted by Galileo is that they come and go with lifetimes not very different from the one-month rotation period. The same can be said for RS CVn itself (Eaton et al. 1996), whose 10–40 spots at any given time also resemble the solar condition. In contrast, the spots on UX Ari (another RS CVn system) live at least 20 years (Raveendran and Mohan 1995), while on HD 12545, long-lived spot groups apparently rearrange themselves from time to time (Hampton et al. 1996).

Applied spotology comes into its own in measuring stellar rotation periods and correlating them with levels of activity (emission lines, X-rays, radio emission, etc., Ap93, Sec. 3). We note a few recent applications here. The aging open cluster IC 4665 has no detectable rotation periods longer than four days (Allain et al. 1996), though eight periods in the range 0.6–3.7 days were seen. Even differential rotation can be identified in the variability of emission-line fluxes associated with active regions. Among G-K V stars, the longer rotation periods have a wider percentage range across the stars (Donahue et al. 1996). This is more or less what you would expect from dynamo-driven fields in stars. AB Doradus, in contrast, shows no signs of differential rotation, though active latitudes change through the years as in the Sun (Unruh et al. 1995). The mean rotation period of the Sun and its (nonseparable) dependences on time, radius, and latitude are too complex to explain here (Kosovichev 1996 is one of many discussions of solar p-mode frequencies and their rotational implications). Whatever pattern you prefer, however, there are stellar analogs. The rotation periods of G-K V Hyads vary from year to year (Radick et al. 1995), while those of an assortment of weak-lined T Tauri stars do not (Grankin et al. 1995). The periods are days in both cases.

Star spots that come and go and rotate with their hosts are responsible for a good deal of the low-level brightness variability seen in young, solar-type stars (Henry et al. 1995), but not all of it (Fernandez and Eiroa 1996).

Binaries are over-represented among the spotted, presumably because synchronized rotation keeps their dynamos turning over longer than would be the case if they were isolated. In BY Dra, both stars have spots (Kovar and Olah 1996), while in UV Leo, only the more evolved, less massive star is so afflicted (Frederik and Etzel 1996). Strangest of all is the W UMa system BL Eri, which, despite its common envelope, apparently manages to support spots on both stars (Liu et al. 1996a). And, as the Ethiopian said to the leopard, "No, I don't mean spots in South Africa. I mean spots on your skin."

We close this section by noting a few other kinds of stars that have spots of one sort or another. Ap stars, of course, since this is where the p-ness mostly resides (Adelman and Boyce 1995). But also Be stars (Balona 1995), where the alternative would be non-radial pulsation, and Alpha Persei, an F5 supergiant (Hatzes and Cochran 1995), where the alternative would be radial, Cepheid-type pulsation occurring in a star somewhat outside the expected instability strip. And, finally, lunar occultation observations of the carbon star TX Psc have revealed either spots or dust clouds (Richichi et al. 1995). "Out, damned Spot," as Dick and Jane said to their dog.

9. ALL ABOUT AGING

The motivation for this section is a genuinely new handle on the age of the Universe, but, as in an airport-newstand book, you must turn to the end to find out "whodunnit." Meanwhile, we plow through a large number of incremental advances along traditional lines, the upshot of which is going to be (as if you didn't already know) that the globular clusters and many other stellar populations are older than you would like them to be if you are proposing to live in a universe with a Hubble constant of 65–80 km s^{-1} Mpc^{-1} (reciprocal time=12.2–15.0 Gyr), critical density, and zero cosmological constant, so that the age of the Universe is two-thirds of the reciprocal time or 8–10 Gyr.

9.1 Some Preliminaries

How firm are the other proposed numbers? The values of H reported during the index year include (and more are excluded than included): (a) $H=80\pm17$ or 73 ± 15 (from the *HST* Key Project Team's study of Cepheids in the Virgo Cluster, Kennicutt et al. 1995; Mould et al. 1997), (b) some small values, like $H=44$–57 (Sandage 1996) or $H=46$–50 (Gudehus 1995), (c) some large values, $H=84\pm4$ (Ford et al. 1996), and (d) some average values derived from unusual combinations of parameters, like Schmidt and Karachentsev's (1996) $H=73\pm10$. There are values from gravitational lensing, $H<70$ (Pelt et al. 1996 wrong) and $H=82.5$ (Grogin and Narayan 1996, right, but with considerable model dependence), and values from the Sunyaev-Zeldovich effect, $H=42$–100 (one sigma!, Markevitch et al. 1996). And occasionally there are even values that come from new methods or sets of assumptions, like $H=62$ (with large error bars) if other Sbc galaxies have the same supernova rate as the Milky Way (Mihara and Takahara 1996) and $H=76\pm8$, to keep gas disks from experiencing various instabilities (Zasov and Bizyaev 1996).

The density of the Universe had better be at least the 0.1–0.3 of the closure density that we see in clusters of galaxies (Carlberg 1996; Jing and Boerner 1996; Shaya et al. 1995). Coming at the problem from the high-density end, there has been some dissension in the theoretical ranks in favor of versions of inflation that do not insist on a universe with precisely the critical or closure density (Cornish et al. 1996; Kamionkowski and Toumbas 1996).

As for the notorious comsological constant, Λ, one can put limits on it either from models of structure formation in the early Universe (Liddle et al. 1996) or from the numbers of gravitationally lensed quasars at large redshift (Wu and Mao 1996; Matsubara and Yokohama 1996; Tomita 1996; Kochanek 1996), because the negative curvature of space associated with positive Λ puts a lot of volume at large redshift. All cited authors say that you can live with some finite Λ in the range 0.3–0.7 (in suitably normalized united to be added to Ω in matter to add up to unity), and whether the authors feel this is, on the whole, good or bad seems to precede the data analysis, not follow it.

9.2 Ages of the Globular Clusters

You can do this calculation for yourself. Population II stars begin their lives with about 76% hydrogen by mass; fusion releases 6.85×10^{18} erg/g in useful form (plus a bit wasted in neutrinos); a star becomes a red giant when its inert helium core grows to about 10% of its mass (the Schoenberg-Chandrasekhar limit); and luminosity in solar units scales with mass in solar units as M^4 or thereabouts. All finished? Now, just look up a color-magnitude diagram for a well-observed globular cluster and compare. Oh yes. Now worry about the effects of opacities, equation of state, non-solar metal ratios, atmospheric structure, convection, diffusion, rotation, magnetic fields... some of which affect the calculations per se, and some of which affect the comparison process. Not surprisingly, the accumulated uncertainties are fairly large (Catelan and de Freitas Pacheco 1995; Jimenez et al. 1996)

As a result, all honest "best values" and "lower limits" have uncertainties of a couple of gigayears. Even then, recent determinations do not completely agree. Herewith a representative sample for clusters identified by the authors as among the oldest. 15.8±2.1 Gyr (Bolte and Hogan 1995 on M92); 14.6 Gyr with a lower limit of 12.1 for a large group (Chaboyer et al. 1996a); 12–14 Gyr (Mazzitelli et al. 1996, with a treatment of convection that differs from standard mixing length theory); 16.4±1.6 Gyr (Jimenez and Padovani 1996, for M68); 13.5±2 Gyr, lower limit 9.6 (Jimenez et al. 1996 for eight clusters); 15 Gyr (Samus et al. 1995, M30); 13.4 Gyr (Chamcham and Hendrey 1996); 20±2 Gyr (Chaboyer et al. 1996b)

Even the smallest ones of these are problematic for many combinations of H and other parameters. In addition, it is worth remembering that many of the theorists working on the problem have spent a good deal of time over the past decade or two trying hard to make the clusters younger. One wonders what would happen to the "best fits" if suddenly there were all the time in the universe available. The simplest way to make globular clusters younger is to re-expand the galaxy back to a size somewhere between the classic Oort determination (which put us 10 kpc from the center) and the original Shapley calibration (which put us 20 kpc from the center) instead of the current best value of 8.5 kpc or less. More distant clusters means brighter, more massive main-sequence stars with shorter lifetimes!

9.3 Other Stellar Populations

One cannot help wondering occasionally whether it is possible that we are all making some terrible mistake about the ages of globular clusters as determined from their main-sequence turn-offs. Thus numbers for other stars, groups of stars, etc., are of interest even though (a) they will generally have even larger uncertainties and (b) they are not, for the most part, entirely independent, having many of the same assumptions and calculations of stellar evolution folded in.

An independent number would come from cooling of the white dwarfs in globular clusters if we could see the bottom of the sequence, made of stars that ceased fusion soon after the clusters formed. This is not possible with *HST* or other existing telescopes. The part of the WD sequence recorded in *HST* images of NGC 6752 (Renzini et al. 1996) includes only stars that ceased fusion recently. These stars are, anyhow, consistent with an age of 15.5 Gyr (or 14.5 Gyr with allowance for diffusion of helium to the centers of the stars while they are burning).

White dwarfs among the local old disk stars extend down to a luminosity of $10^{-4.44}\ L_\odot$, implying a cooling time of at least 9.5 Gyr (Oswalt et al. 1996), a number which has oscillated with declining amplitude since Winget et al. (1987) first suggested a somewhat smaller value.

An age of about 14 Gyr for the oldest bulge stars is frequently suggested (Idiate et al. 1996), but much of that population would be as young as or younger than the inner disk in some merger models for the formation of the Milky Way. Field halo stars present all the same problems as those in globular clusters and, besides, you don't know their distances as well. Not surprisingly, everybody finds about the same age for the field stars as they do for the clusters (e.g., at least 18 Gyr on the "Uppsala" scale, Schuster et al. 1996).

Stepping gently outside the Milky Way, we find that the oldest globular clusters in the Large Magellanic Cloud are "about as old as" the oldest galactic ones, whatever age that is (Mighell et al. 1996a; Brocato et al. 1996). Other places in the Local Group, we find 14±1 Gyr for the oldest stars in the dwarf spheroidal Leo II (Mighell and Rich 1996), 10–14 Gyr for the Sagittarius dwarf that we propose to continue calling IGI for its discoverers (Fahlman et al. 1996), and about 10 Gyr for the halo stars of the dwarf galaxy WLM (Minniti and Zijlstra 1996), which is indeed named for its discoverers. These are the most distant populations for which individual stars can be resolved down to the main sequence.

Ages for other galaxies necessarily come from giants or, more often, integrated spectra and colors matched to some sort of model of chemical and luminosity evolution. There is, notoriously, a considerable amount of age-metallicity degeneracy in these models, in the sense that a more metal-rich galaxy is very hard to distinguish from an older one, or, in the worst case, a dusty one (Wise and Silva 1996).

Rashly neglecting these degeneracies, model dependencies, and other metaphorical torpedos, many authors (and we) have steamed full speed ahead into the realm of Sa and Sab disks (17±2 Gyr when normalized to the Milky Way disk at 10 Gyr, Sommer-Larsen 1996, who also suggests that the Hubble sequence is largely one of disk age), the full range of spiral and irregular galaxies (all 10 Gyr old according to Gavazzi and Scodeggio 1996), and giant ellipticals (13–15 Gyr according to Bressan et al. 1996, but at most 9 Gyr according to Driver et al. 1996).

Galaxies at moderate-to-large redshift present a slightly different set of problems. The light you see (modulo all the above cautions) tells you the time since star formation began in the galaxy, and you must then add on the light travel time from it to us to decide what the age is and whether you like the answer. A quick summary is that, no you (or we) don't much like the answer, whether it is a cluster of galaxies that are already 8–13 Gyr old at $z=0.5$ (Oke et al. 1996), a 3.5-Gyr old radio galaxy at $z=1.55$ (Dunlop et al. 1996), or a large cloud of CO around a $z=4.69$ quasar (Ohta et al. 1996; Omont et al. 1996) at any age sufficient to allow synthesis of the carbon. The margin for error is, however, even larger here, because the radio galaxies at large redshift all seem to be very dusty (Mazzei and De Zotti 1996) and often to have their colors perturbed by emission lines (Eales and Rawlings 1996), increasing the degeneracy between age and other properties and expanding the error bars.

The message to be carried away from this subsection is that yes, we might still all be making some horrible mistake about how stars age, but it is a more complicated mistake than the one implied if you look only at globular clusters.

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9.4 Radioactive Decay and Death

The decay of radioactive nuclides is completely independent of our models of stellar and galactic evolution and of most other environmental conditions. Thus the amounts of residual uranium and thorium and of their daughter lead nuclides in meteorites tell us that solidification happened 4.55 Gyr ago. And the reported number has neither drifted nor oscillated in other than its last digit for a couple of decades.

It is possible to look back further because we have a fair idea of how U-235, U-238, and Th-232 are made (by r or rapid capture of neutrons on less massive nuclides) and, therefore, know what their abundances ratios must have been when they were synthesized and cast out into interstellar space, orphaned by the supernova explosions of their parent stars. The difference between that synthesis ratio and what got incorporated into the meteorites is, therefore, a clock measuring the time between synthesis and solidification. If synthesis had happened in a single burst of star formation, we would be home clear. But the disks of spirals don't work that way and the ''time back to first synthesis'' implied by U/Th ratios depends a good deal on what you assume about the history of star formation. According to Truran (1997), 10 or 20 Gyr BP (before present) is a reasonable estimate for the initial epoch of galactic star formation.

Residual uranium and/or thorium would be a better cosmic chronometer if the solar system were older (though of course we would probably not be around to worry about the problem). The detection of thorium in one halo (Population II) star, CS 22892−052, is therefore a major advance (Sneden et al. 1996). The authors cannot, of course, say anything about the amounts of lead isotope (Pb^{208}) that much of the thorium has decayed into. But they can measure the thorium/europium ratio and (reasonably) assume that it is smaller than the production ratio because some of the thorium has decayed, and the europium has not. The implied stellar age is 15.2 ± 3.7 Gyr. The galaxy must be a bit older to allow for the first generation of massive stars to die and cast out their r-process products. We very much hope that the discoverers are busily writing observing proposals to look for thorium in a few additional very old stars!

10. THEY ALSO RAN

10.1 Countdown

In which we work backwards from objects, classes, etc., of which there are a great many examples to those of which there are very few, leading up (or down) to the extrema of the next section. The list is, inevitably, very arbitrary.

To start with a nice, round number, there are 13 000 Einstein X-ray sources in the two-sigma catalog (Moran et al. 1996) of which, presumably, 95 and 44/100% are real. Extreme ultraviolet sources are less numerous, so far, with 2244 in the catalog from the *Ultraviolet Imaging Telescope* (Smith et al. 1996), 734 in the second *EUVE* catalog (Bowyer et al. 1996), and 328 in the *ROSAT* EUV catalog (Kreysing et al. 1995). At least 20 of these are, unexpectedly, extragalactic (Fruscione 1996).

The most recent list of gamma-ray bursts seen by BATSE (Meegan 1996) reports 1122 of them in four years. There are 233 cataloged BL Lac objects (that is, roughly, active galaxies with no strong emission lines, Padovani and Giommi 1995). Nearly all have redshifts less than one, a very different distribution from that of normal quasi-stellars. And we guess you are no longer allowed to count BL Lac itself, which had conspicuous emission lines for a while not long back (Corbett et al. 1996).

A search of the *IRAS* data base found 178 Wolf–Rayet stars in the Milky Way (Cohen 1995). There were only two candidates in the blue compact dwarf galaxy I Zw 18 as resolved by *HST* (Hunter and Thronson 1995), which is a bit of a surprise. And the first SMC Wolf–Rayet has just been subjected to a detailed atmospheric study (Smith et al. 1995).

Eighty damped Lyman-alpha absorption-line systems appear in Wolfe et al.'s (1995) catalog. A smaller subset constitutes a complete sample for statistical analysis and most are accompanied by metallic lines at the same redshift. The year 1995 saw roughly 56 supernovae, ending with 1995bc, according to the IAU Circulars.

Magnetic white dwarfs with surface fields in excess of a Megagauss number 42 (Putney et al. 1995) in a close race with the 38 pulsars in globular clusters (Lyne et al. 1996a; Biggs and Lyne 1996). The Milky Way has only two planetary nebulae belonging to globular clusters (one is M15, Sec. 4.2, and the other isn't), but of 48 candidates in the LMC, about 24 are likely to be real associations (Kontizas et al. 1996).

The extent to which pulsars live in supernova remnants and SNRs host pulsars remains in some dispute. According to one inventory, there are 17 pairings (Foster 1995), of which 11 are likely to be real (Gorham et al. 1996), plus or minus one or two new candidates and old claims removed, typically on the basis of discordant proper motions, ages, or distances (Gaeniler and Johnston 1995; Hailey and Craig 1995; Vasisht et al. 1996; Nicastro et al. 1996; Campbell et al. 1996; Kaspi et al. 1996a; Mereghetti et al. 1996; Anderson et al. 1996). The majority opinion appears to be that existing inventories are consistent with every Type II (core collapse) supernova leaving a pulsar behind, if only we could look deeper (against the annoying and nonthermal backgrounds of supernova remnants) and perhaps from the other side, if beaming is important.

X-ray binaries in the LMC include 12 high-mass systems, one low-mass system, and six supersoft sources (where the accreting star is probably a white dwarf rather than a neutron star (Haberl et al. 1995). The eighth pulsating DB (white dwarf with a helium atmosphere) just happens to have eight modes (Koen et al. 1995).

There are seven honest gamma-ray emitting pulsars, meaning the kind powered by rotational kinetic energy (Ramanamurthy et al. 1996), or maybe only six (Nel et al. 1996). Other sixes include X-ray binaries in which the primary is a black hole on the basis of its mass determined from a radial-velocity curve (Remillard et al. 1996) and binary pulsars in which the second star is probably also a neutron star (Nice et al. 1996 on PSR 1518+4904, at least one of whose components, at 1.3 $M_\odot$ is likely to be less massive than the most massive white dwarf at 1.43 ± 0.06 $M_\odot$, Vennes et al. 1996;

and the taller author owes Ken Brecher a bottle of wine on this one, but hopes he hasn't read this far).

Six also are the radio jets of quasars and other active galaxies whose optical counterparts have been seen. The sixth is 3C 120 (Hjorth et al. 1995) and the best studied is 3C 273, whose *HST* image shows features roughly corresponding to the radio fine structure, though the optical jet is narrower and its head not so bright (Bahcall et al. 1995).

Counting breathlessly downward, we reach the five components needed to fit even a fairly simple X-ray spectrum of an active galaxy (Leighly et al. 1996 on Mkn 766) and the fifth journal (Astronomy Reports, formerly Soviet Astronomy—AJ, or Astron. Zh. in translation) shown to over-cite itself (Minin et al., Astron. Rep. 1996). The first four were ApJ, AJ, MNRAS, and A&A. The idea is that citations contained in papers published in a given journal have an excess of citations to papers published in the same journal, compared to the frequency with which that journal is cited elsewhere. This is also, as far as we know, the first scientometrics paper to appear in A. Zh. and we welcome them to the mini-fray.

Four brings us to binary, millisecond pulsars with itty-bitty companions that seem to be boiling away (Stapper et al. 1996 on J2051−0827). The prototype is 1957+20, which should not be read as 1977. There are also at least four fake plerions, meaning supernova remnants that look as if they had compact, neutron-star cores, but are really just boiling away dense clumps of swept-up material (Rho and Petre 1996).

A fourth BL Lac source whose optical variability probably has a large contribution from microlensing is presented by Stocke et al. (1995). We do not, however, believe that assorted lensing is the only cause of QSO variability, nor that the dominant lenses are primordial black holes (Hawkins 1996, and judging from the delay between submission and acceptance of this paper, the first referee was not entirely persuaded either). If this were the right answer, then the Universe would be more or less closed by the lenses, whatever they are, since this is what it takes to affect every sight line (Press and Gunn 1973).

Our collection of threes (like Sherlock Holmes' collection of *M*'s) is a fine one, including the third cataclysmic variable with a strong magnetic field and an orbit period in the gap between 2 and 3 hours set by other types of CVs (Craig et al. 1996), eclipsing binaries that resemble Beta Lyrae in that the star responsible for the deeper minimum contributes nothing to the spectrum at any phase (Ivanova and Shkihagosheva 1995 on HD 187399 and Zola 1996 on W Cru, a near-tie), non-eclipsing Algols (Simon 1996 on CX Dra. Three is a guess here; the class used to be empty), and the best case so far for a third integral of motion in the context of the dymanics of planetary nebulae in the Milky Way (Durand et al. 1996).

10.2 Twins, Mostly not Identical

The second case of third dredge up is HD 187885 (HD 56126 was first), meaning that these stars show surface chemical anomalies indicative of mixing upward of processed material during the third possible opportunity, while they were AGB stars burning both hydrogen and helium in thin shells (van Winckel et al. 1996). The seeming rarity is, however, an artifact of sample definition. A large number of planetary nebulae in the Large and Small Magellanic Clouds had progenitors that probably experienced third dredge up (Leisy et al. 1996). Calculations of nucleosynthesis during this phase are necessarily complex, since material can be mixed between the two burning shells. Many details require further attention (Molawi et al. 1996).

Of our two's, many are slightly frivolous—the second planetary nebula in a dwarf spheroidal galaxy (Zijlstra and Walsh, 1996, assuming IGI is indeed a dSph, the first is in Fornax); the second shortest orbit period for a binary barium star (Jorissen 1995); a multitude of candiates for the second double star cluster in the Milky Way (Subramanian et al. 1995; the first is h and χ Persei=NGC 869+884, and the Magellanic Clouds have lots).

A couple are useful reassurances that the first one was not a freak, for instance the second TeV pulsar, B1706-44 (Nicastro et al. 1996, not the discovery paper) and the second TeV active galaxy (Quinn et al. 1996, which is the discovery paper, but which annoyingly does not give the redshift of the new source in abstract or conclusions). Mkn 501 has a TeV flux about 1/5th that of the first source found, Mkn 421. The latter experienced a month-long flare during the reference year (Schubnell et al. 1996) and even more spectacular hour and half hour ones (Gaidos et al. 1996). It was also seen by a second detector, HEGRA (Petry et al. 1996). The Whipple Observatory was first. Ten other AGN were not seen at TeV energies by 35 authors (Kerrich et al. 1995), amounting in total to 350 non-sightings.

And, finally, a couple of items in this category are probably important. The second sighting of the Sackett halo (Ap94, Sec. 5.8) by Lequeux et al. (1996) means that NGC 5907 really does have an extended halo with a radial density profile like that of standard halo dark matter. It is fairly red in $V-I$ and so low-mass red and brown dwarf stars could actually make up the mass of the halo, or only just trace it. We confess also to having heard rumors that other groups could not confirm the detection, but this review remains resolutely paper oriented.

Dark matter is the focus of another important second. The X-ray profile of the Fornax cluster of galaxies, as mapped by *ASCA* (Ikebe et al. 1996), is best modeled with two scales of concentration, one associated with the central galaxy NGC 1399 and one with the cluster as a whole. A possible interpretation is that the cluster harbors two kinds of dark matter (hot+cold or baryonic+nonbaryonic). Hierarchical clustering in models with a single kind of dark matter can, however, produce rather similar structures.

Two is also roughly the factor by which the present inventory of stars closer to us than 20 pc is incomplete (Cutispoto et al. 1996; Eggen 1996, not to be confused with any other O.J.'s). Presumably the ones we haven't identified are a lot like the ones we have, only fainter, further, and perhaps slower moving.

10.3 Second (and Third and...) Mechanisms

This is another incomplete set, defined by a few important papers plus a good deal of randomness, somewhat along the lines of Ap93, Sec 9, "Both Please."

Normally one thinks that shocks will cause collisional ionization, but because the heated layer can radiate ultraviolet photons, they can also be responsible for photoionization, with its different pattern of level populations (Morse et al. 1996). Alignment of interstellar grains (so that they can produce the observed polarization of partly scattered starlight) is another task assigned to the interstellar medium. The mechanism that caught on (Davis and Greenstein 1951), soon after the polarization was discovered (Hall 1949; Hiltner 1949), requires assistance from magnetic fields (as a result of which, the Hall–Hiltner papers are quite often cited as the discovery of the galactic field). There were, however, early alternatives using gas flows (Gold 1952) or cosmic rays (Purcell and Spitzer 1970). We initially had the impression that there had been a major resurgence of interest in these mechanical methods, until we noticed that, with the exception of one relevant observation (Chrysostomou et al. 1996), almost all the papers were by the same person, and so we cite only the most recent (Lazarian and Efroimsky 1996; Roberge et al. 1995).

We can remember when inverse Compton scattering (in competition with synchrotron radiation) was a nonthermal solution looking for a problem. It may have found its home in the Crab Nebula (De Jager et al. 1996), among the X-rays of the Fornax cluster (Kaneda et al. 1996), and especially among the now two dozen or more active galaxies that are variable sources of gamma rays (Marcowith et al. 1995; Böttcher and Schlickeiser 1996; Inouse and Takahara 1996; Ghisellini and Madau 1996).

Star formation, an important subject on which this is a fairly trivial comment, must start with things being somehow torn up in giant molecular clouds, but, because characteristic fragments can be small, numerous, and sticky, the mirror processes of cohesion and coagulation should also be important (Allen and Bastien 1996; Murray and Lin 1996). We mention the topic partly for the pleasure of noting just how long the idea has been around (Layzer 1963; Arny and Weissman 1973).

The second parameter in globular clusters is whatever it is beside metallicity that makes their color-magnitude diagrams look different from each other, especially the color and extent of the horizontal branch. Just after the nick of time last year, we got around to mentioning that age (with a spread of 3–4 Gyr) was *a* second parameter but not *the* (only) second parameter (Ap95, Sec 12.8). A review in these pages earlier this year concludes that age cannot be even *a* second parameter (Stetson et al. 1996), because there is no evidence for any real age spread at fixed values of cluster metallicity. Their alternative candidate is stellar rotation, correlated with the degree of central concentration of clusters (because dense cluster cores will result in spin-up or stripping or both of red giants). The same view is expounded more gently elsewhere by Fusi Pecci et al. (1995) and Peterson et al. (1995), who, however, find no values of $v \sin i$ greater than 40 km s^{-1} among the blue horizontal-branch stars in any of four clusters. Davidge and Harris (1996), Richer et al. (1995), and Bergbosch (1996) present related data. De Boer et al. (1995) note that spectroscopic surface gravities for the blue HB stars in NGC 6397 are too small by about 0.3 dex, which could conceivably be a result of rapid rotation.

Convergence on the topic of second parameters has not, however, occurred. Chaboyer et al. (1996b) say that age is an important item. The first extragalactic pair of globular clusters showing a second-parameter effect (Fornax 1 and 5 with the same Fe/H but red and intermediate HBs, respectively) are of very uncertain ages and do not help to resolve the debate (Smith et al. 1996b).

Neutron stars have the right to radiate for at least four reasons. The first is accretion from a close companion star, as predicted by Novikov and Zeldovich (1966; the paper was submitted in late 1965, when they could have known very little about Sco X-1, first observed in 1962, but with no optical identification until summer 1966). The second is the "pulsar mechanism," which we have had nearly 30 years to get used to not understanding. Three and four are accretion of material from the general interstellar medium by single neutron stars and radiation of residual heat by young ones. The last two have proven singularly elusive, and we have announced "firsts" on at least a couple of previous occasions.

A review of the topic during the reference year identifies seven candidates for non-pulsar, isolated neutron stars (Bignami 1996), with 1E 1207−5209 as a typical example. Part of the problem is that it is quite difficult to rule out either pulsar-type but unpulsed (at least with the number of photons available) radiation or a compact synchrotron nebula fed by an aging pulsar, as Slane and Lloyd (1995) explain in connection with the three sources they found with *ROSAT*. Other *ROSAT* candidates are presented by Walker et al. (1996, 1E 1853−379, with optical counterpart fainter than $V=+23.1$), by Rajagopal and Romani (1996, J0437−4715, which is old enough that reheating would be required if it is a non-accreting thermal source) and by Possenti et al. (1996, on PSR 0656+14, which they conclude is shining primarily at the expense of its residual heat). *ASCA* data on this last object are interpreted by Greiveldinger et al. (1996) as implying that the main radiators are hot polar caps and a magnetosphere. Because there are not vast numbers of isolated neutron stars to be found among soft X-ray sources (Manning et al. 1996; Blaes et al. 1995), the ensemble of more distant similar ones cannot be a major contributor to the galactic X-ray background (an interesting idea that, we confess, we had not thought about much since Ostriker et al. 1970 proposed it, though Zane et al. 1995 did).

10.4 You Say Tomato: I Say Tomato

This will be incomprehensible to non-native speakers of English, the young, and probably other groups. Suffice it to say that the word has two possible pronunciations in American English, rhyming the second syllable with either bay or bah, and the difference historically had class significance, which was (almost) immortalized in a Rogers and Hart song "Let's Call the Whole Thing Off." In any case, this section consists of a few items where different papers pretty firmly said pairs of things that cannot both be true. We exclude obviously profound and profoundly obvious cases like hot versus cold dark matter.

Mira variables virtually all pulsate in the fundamental mode (Bessell 1996), OR in the first overtone (Feast 1996).

Geminga has no known optical counterpart (Esposito et al. 1996) OR is so securely identified that its parallax has been measured with the Fine Guidance Sensors on *HST* (Caraveo et al. 1996). The parallax is about 0.″0063, and we are reasonably sure whom to believe on this item!

Quite massive stars live long enough (and their surrounding gas and dust disperse soon enough) that you see about half of all OB stars without any conspicuous H II regions (Patel and Wilson 1995, 1996; Wilson and Matthews 1996). Notice that if this is right, it means that star-formation rates determined from Hα fluxes are very much lower limits. OR, conversely, OB stars live such a short time and their garments so long that counting visible ones leads to a significant underestimate of formation rates for $M \gtrsim 40\ M_\odot$, and stars in the 85–150 $M_\odot$ range never get seen at all, creating an artificial cap to the masses of known main-sequence stars (Bernasconi and Maeder 1996).

The fraction of distant ($z \gtrsim 4$) quasars lost to obscuration by dust in themselves or in intervening galaxies is quite small (Boyle and di Matteo 1995, based on near-complete optical identification of an X-ray sample) OR quite large (Pei and Fall 1995, from considerations of chemical evolution). The latter idea has been around a long time (we vaguely blame J. P. Ostriker), but it is called the Webster effect, since she was the latest to suggest it (Webster et al. 1995). Half a dozen or so papers published during the index year called attention to specific example of reddened or dusty quasars and should probably also be counted in support.

The primordial deuterium abundance, based on Lyman-alpha absorption lines in the spectra of distant quasars is D/H=something$\times 10^{-4}$ (Carswell et al. 1996; Rugers and Hogan 1996), OR, D/H=something$\times 10^{-5}$ (Tytler et al. 1996). The latter is roughly the interstellar value (Larson et al. 1996; Hata et al. 1996; Linsky and Wood 1996; Lemoine et al. 1996), though one discussion starts "by assuming D/H=0.01" in interstellar gas (Womack et al. 1996).

This is arguably too important a topic to be treated in this casual way, but we claim two mitigating factors. First, it has been suggested that the determinations may have very large error bars, even if the deuterium lines have been correctly identified and are not being mimicked by weak H-1 lines. The two papers (Wampler 1996; Levshakov and Takahara 1996) discuss different effects. Second, a number of pundits have made the decision to treat the thing as a problem in helium-3 destruction, rather than in deuterium production, since turning H-2 into He-3 is fairly easy (Steigman and Tose 1995; Fields 1996; Scully et al. 1996; Prantzos 1996; Dearborn 1996; Weiss 1996). This has become more attractive since the local ISM component of He-3 has been measured from its leakage into the solar system (He-3/He-4=2×10^{-4}, Gloeckler and Geiss 1996). The value found says that the sum of deuterium and helium-3 hasn't changed much since the solar system formed (Turner et al. 1996). The higher deuterium abundance has, at any rate, the advantage of freeing us from having to claim that the observers don't know what they are doing when they estimate prestellar helium abundances (Hata et al. 1995; Copi et al. 1995; and it is perhaps significant that these papers did not appear in astronomical journals).

Thus one comes to the end of the day with the important result, the limit on the fraction of the cosmic closure density that can be present in baryons, pretty much unscathed. It is not more than about 10% even for small values of the Hubble constant (Jedamzik and Fuller 1995; Mathew et al. 1996; Leonard and Scherrer 1996; Dearborn 1996).

11. EXTREMA

Another attempt at the sort of listing of firsts, lasts, mosts, alwayses, and nevers that is responsible for the largest quantity of negative feedback each year.

11.1 Solar System

The shortest day of the year. Tidal interaction between the Earth and Moon has been lengthening the months and days for as long as both have existed. This was known to Darwin (George, not Charles) and evidence for it is found in the need for leap seconds nearly every year, the records of solar eclipses over the past few thousand years, and in layered fossils of creatures that respond to cycles of light, temperature, or tide. Sonnett et al. (1996) have pushed back still further in time to the late proterozoic, about 900 Myr ago, when days were only 18 hours long (with a correspondingly larger number of them per year). The data come from sedimentary rocks laminated by the tides.

The first (and we hope last) minor planet to appear in the variable star catalog is (8) Flora, which, by sitting atop TU Leo in 1917, converted it into a U Gem star (Schmadel 1996). Halley is among the slowest-moving comets known definitely to be periodic, but Hasegawa and Nakano (1995) report additional candidates at 65, 400, and 133 years, with next expected returns in 2022, 2260, and 1986 (we seem to have missed that one).

11.2 Living Stars

Arcturus (or at least models of Arcturus) gradually warmed from 3900 K in the 1930's to 4450 K in about 1980 (Trimble and Bell 1981). It appears to have passed maximum temperature and be cooling off, according to Quirrenbach (1996) who reports an angular diameter measured with the USNO interferometer though Dyck et al. (1996) report continued heating to 4628 K. Its oscillations remain unique, at least among field stars (Horner 1996).

Binary FUORs. Z CMa has a companion at about 0.″1 (Thiebaut et al. 1995), which may or may not make it the first such.

The most massive Wolf–Rayet star is a WN7 in a binary system with $M = 72\ M_\odot$ (Rauw et al. 1996). It is also quite rich in hydrogen and helium, indicating that it is still near the main sequence and burning hydrogen in its core rather than helium. It should evolve into a luminous blue variable (LBV), which class includes 5–10 of the brightest stars in the Milky Way and other galaxies (Massey et al. 1995; Stothers and Chin 1996; Koenigsberger et al. 1995). Some of them are pretty weird (Melikan and Jakubov 1996; de Koter et al. 1996).

The brightest stars shine in at $M_{\rm bol}=-10-11$, implying main-sequence masses of at least 60 $M_\odot$ (Van Genderen and Sterken 1996). The absorption lines of MWC 560, blueshifted to -6000 km s^{-1} in 1990, must also have set some sort of record (Tomov et al. 1996). They have since slowed down a bit.

The most inaccurate lithium abundances can be found all over the place, according to Kurucz (1995) messing royally up any efforts to use Li/H as an indicator of big bang nucleosynthesis. Somewhat more modest problems are suggested by Houdebine and Doyle (1995), Pavlenko et al. (1995), and Russell (1996). Contrariwise, Ryan et al. (1996) and Spite et al. (1996) believe that all is well and the derived abundances are meaningful.

Non-visible wavelengths have some stellar firsts as well, including the first V471 Tauri star identified from its X-ray emission (Hutchings 1996), the largest stellar X-ray flare, which came from a source in the Orion star-forming region (Preibisch et al. 1995), and a nice bright radio flare from a young stellar object in the CrA cloud (not guaranteed as "brightest" by Suters et al. 1996). Infrared observations (with KAO) are, of course, the reason that a star with $A_v=48$ mag can be seen at all (Harvey et al. 1995, and also probably not a record). Lim and White (1995) report the first single radio stars identified in an open cluster, three rapidly rotating Pleiads; binary ones are brighter (Stevens 1995 provides models).

A couple of new classes of variable or active stars have been reported, including eight K giants in 47 Tuc that behave a bit like Arcturus (Edmonds and Gilliland 1996), varying periodically at the 0.01 mag level, and K main-sequence stars with very rapid rotation that is apparently attributable neither to youth nor to synchronization with orbit periods, since their white dwarf companions are distant (Jeffries and Stevens 1996).

The faintest carbon stars in the SMC are fainter than the extremes in dwarf spheroidal galaxies, though the reporters (Westerlund et al. 1995) cannot entirely exclude observational selection effects as the underlying cause.

Eta Carinae, though it was only the second-brightest naked-eye star in 1843, is clearly several est's within the Milky Way (biggest, brightest, most spectacular non-supernova outburst...). The surrounding "homunculus" structure (probably fed by bipolar outflow, Falcke et al. 1996), is expanding at just the rate to indicate that it was expelled shortly before light maximum, in 1841 (Currie et al. 1996, who present *HST* images with the sorts of unexpected details we have come to expect). The central star displays an assortment of periodicities (Van Genderen et al. 1995; Sterken et al. 1996; Daminelli 1996) "consistent with" (as they say) its being the first *LBV* with a stable pulsation period. Something exciting is supposed to happen in December 1997. Two other non-supernova explosions during the reference year were 1961V (Zwicky's prototypical Type V, Filippenko et al. 1995) and SN 185 (Schaefer 1995) which may have had contributions from both a nova and comet P/Swift-Tuttle.

11.3 Dead and Dying Stars

The first (or second) last helium flash was among the press release items of the year (Duerbeck and Benetti 1996, plus notices in the ESO Messenger, Sky and Telescope, and many IAU Circulars). The object concerned was first reported as a nova or nova-like outburst called "Sakurai's object" for the discoverer. The physical event is supposed to mark the end of a long series of explosive ignitions of the helium-burning shell in an asymptotic giant-branch star at the time when the remaining hydrogen-rich envelope is so thin that the consequences of the flash appear conspicuously at the surface of the star. Duerbeck and Benetti mention Nova Aql 1919 (V605 Aql) as a probable previous case. The galloping giant FG Sge (Ap91, Sec. 11.1) has been interpreted in the same way, and continues to appear in the literature every year as its spectrum and continuum colors continue to change (Arkhipova and Esipov 1996). Various changes and structures in planetary nebulae have also been credited to last or late helium flashes (Rauch et al. 1996 on LoTr 4; Vassiliadis 1996 on SMP 83 in the LMC).

The extremes inhabited by white dwarfs continue to expand as more and more degenerate dwarfs are studied carefully. We note (a) the hottest magnetic one, RE J0317−853 at 50,000 K (Barstow et al. 1995), (b) the faintest, because it is both compact and cool, ESO 439−26, with $T=4560$ K, $\log g=9.04$, and $M_v=17.4$ (Ruiz et al. 1995), (c) the lowest and highest surface gravities, $\log g=6.76$ (van Kerkwijk, on a star that is the 0.16 $M_\odot$ companion to the millisecond pulsar J1012+5307), and $\log g=9.5$ (Barstow et al. 1995), (d) the longest rotation period, about 80 years for GD 229 (Beryogin 1995), and (e) the discovery of yet more metals, sulphur and phosphorus, in two hot DA (hydrogen atmosphere) white dwarfs (Vennes et al. 1996a). This brings the inventory of heavy elements in white dwarf atmospheres and winds up close to a dozen (including CNO, Ne, Si, Fe...). The detections are quite often in UV spectra from *IUE* of late, lamented memory.

Moving on to neutron stars, we find (a) the strongest magnetic field at 10^{18} G (Bocquet et al. 1995, a calculation, not an observation!), (b) the smallest pulsar period change (1.9×10^{-21} s s^{-1}, Camilo et al. 1996), (c) the highest frequency data on radio pulsars, at 34.8 GHz (Kramer et al. 1996; a couple of the spectra flatten or turn up, as must that of the Crab pulsar to meet its infrared flux), and (d) the lowest frequency data on a millisecond pulsar, at 76 MHz (McConnell et al. 1996). The most distant millisecond pulsar so far found outside a globular cluster is J0218+4232 at more than 5.7 kpc (Navarro et al. 1995). Much of its flux is unpulsed. Yet another odd period, 60 s, has been reported for the pulsar in the Crab Nebula by Cadez and Galicic (1996), who blame it on free precession of the neutron star.

Among the neutron star binaries we encounter the longest continuous spin-up of a neutron star rotation period (at least six years in GX 301−2, Pravdo et al. 1995) and what may be the brightest X-ray binary, a source in NGC 4945 with a luminosity of 10^{39} erg s^{-1} (Brandt et al. 1996). Several other source types are also possible.

11.4 Star Clusters

The densest open cluster? HD 97950 (in our only giant H II region, NGC 3603) may not really be the densest, but with something like a dozen stars within a "cubic light year" (Drissen et al. 1995), it has to be in the running.

The most massive globular cluster in the Milky Way is pretty clearly ω Cen (Meylan et al. 1995). Its chemical history is a good deal more complicated than that of most globulars (Norris et al. 1996; Suntzeff and Kraft 1996). It contains only one Mira variable (Origlia et al. 1995).

The most metal-rich globular clusters in the Milky Way continue to hover very close to [Fe/H]=0 (Minniti 1995 on Pal 6).

The most intense starbursts shed some light on why globular clusters are all rather similar, according to Meurer et al. (1995). Bursts apparently saturate at 0.7 $M_\odot$ yr^{-1} kpc^{-2} (including only the 5–100 $M_\odot$ stars that we can detect from the effects of their ionizing photons), and the cores of these events look like they should evolve into globulars. The alternative explanation of cluster uniformity is, of course, a selection effect on survival (Capriotti and Hawley 1996, not a new idea and perhaps also to be blamed on J. P. Ostriker).

11.5 Diffuse Material

Starting, as usual, nearby and working outward, we find a couple of new molecules, C_8H (Cernicharo and Guelin 1996) and CH_3COOH, otherwise, known as acetic acid or vinegar (and not attributed to interstellar pickles by its discoverer, Mehringen 1996), but not yet glycine, very probably because its lines remain confused with a large number of other unidentified ones at similar wavelengths (Combes et al. 1996).

Within the galactic halo comes the first O VI emission by galactic coronal gas (Dixon et al. 1996), seen with the *Hopkins Ultraviolet Telescope*, and the most distant coronal gas at 50 kpc (Weiner and Williams 1996).

Not far outside the Milky Way is the first extragalactic detection of extended red emission (a broad bump at 6500–7500 A), found in the light of M82 that has been scattered by dust in its halo (Perrin et al. 1995). The cause of this emission is not agreed upon, but we are betting against chloroplasts and bacterial pigments (Hoyle and Wickramasinghe 1996).

As we approach cosmological distances, 21 cm absorption at the highest redshift so far (z=3.38) appears, and, by sharing the redshift of the optical lines in the same system enables the discoverers (de Bruyn et al. 1996) to put limits on the amount by which the ratio of the fine structure constant to the nuclear g factor has changed over the life of the Universe.

The largest rotation measures ever seen, even for very distant radio galaxies and quasars, are never larger than about 5000 rad/m^2 (Inoue et al. 1996). This sets limits of the product of density of ionized gas and magnetic-field strength both in the host galaxies and in intergalactic space along the line of sight. Calculating these is left as an exercise for the reader and his tame lion.

Cosmic rays, even of the very highest energies, are fairly diffuse, though not apparently isotropic (Stanev et al. 1995; Hayashida et al. 1996). At energies in excess of 10^{20} eV per particle, it becomes something of a miracle that they can get to us at all through the 3 K photon sea (Greisen 1966; Zatsepin and Kuzmin 1966). The result is some fairly desperate models, like decay of an otherwise unknown particle (Sigl et al. 1996), acceleration in shocks in the Virgo Cluster (Kang et al. 1996), and co-production with gamma-ray bursts in the halo of the Milky Way (Vietri 1996; Cheng and Chi 1996).

11.6 Fairly Normal Galaxies

The nearest grand-design spiral is probably the recently discovered Dwingeloo 1, though you will need your radio telescope to study it the way Burton et al. (1996) did, owing to galactic obscuration in its direction.

The first ultraviolet flare in a normal galaxy, NGC 4552, has been spotted in a pair of *HST* images separated by a couple of years (Renzini 1995). This sort of report always makes us think of Ramanujan's "smallest uninteresting number," and whether it becomes interesting as a result.

The first examples of dwarf spiral galaxies, meaning $M_B > -17$, R less than 5 kpc to the 26 mag(sq sec)$^{-1}$ isophote, central surface brightness fainter than 24 mag(sq sec)$^{-1}$, and H I masses less than 10^9 $M_\odot$, have been reported by Schombert et al. (1995). Dwarf spirals are generally advertised as not existing, so we are not quite sure whether these can claim to be normal either. Schombert et al. found six of them among field galaxies and are in complete agreement that there is nothing like them to be found in Coma, Virgo, or other nearby rich clusters, even if you put Virgo as close as 11.8 Mpc (de Vaucouleurs 1982) let alone at 27.7 Mpc (Sandage 1993). These numbers constitute the widest range of distances published in recent years.

E+A galaxies (meaning that their spectra are like those of giant elliptical galaxies, but with Balmer lines in absorption, as you would expect from A-type stars) are in some sense transition objects from star bursts to quiescence. They are common in clusters at redshifts of z=0.3–0.5 (Belloni and Röser 1996), contributing to the excess of blue galaxies there compared to nearby clusters (Butcher and Oemler 1978). E+A galaxies go back at least to z=1.39 for 1608+656, which happens to be lensed so that you can see it decently (Fassnacht et al. 1996). The first nearby E+A galaxies have now been located (Zabludoff et al. 1996). They are associated with merger events in small groups and field galaxies with companions, rather than with the rich clusters in which E+A's happened in the past.

The brightest galaxy? FSC 10214+4724 may or may not still be a likely candidate (it is lensed and all), but it is a pretty good bet for "most papers in the year bearing on the issue"—roughly a dozen, indicating a luminosity near 10^{13} $L_\odot$ for some combination of its redshift (2.23), H, and q. Kroker et al. (1996) simply happens to be the last caught in the sieve.

11.7 Active Galaxies

The best-studied active galaxy is NGC 5548, according to Mathur et al. (1995). We admit to having seen about four other papers on this AGN during the index year, once we were made NGC 5548 conscious, but nevertheless suspect that a hostile committee containing representatives from NGC 1068, 3C 273, 3C 120, and so forth will shortly be calling on the authors (compare 7th method for discovering extra-solar-system planets in Sec. 3).

The latest candidates for most rapid AGN variability are 10-min spikes in the optical flux from a few quasi-stellars (Sugar et al. 1996) and a 30-min TeV flare seen in Mkn 421 with the Whipple Telescope (Gaidos et al. 1996).

Candidates for the most heavily obscured AGN include the radio galaxy PKS 0634−204 at $A_v \gtrsim 30$ mag (Simpson et al. 1995) and the starburst core of NGC 253 at $\gtrsim 35$ mag (Prada et al. 1996).

The most distant giant double radio source is currently 4C 39.24 at $z=1.887$ (Law-Green 1995), and the most distant radio-loud quasar sits at $z=4.46$ (Shaver et al. 1996), but we forgot to record its telephone number. Contrary to popular superstition, active galaxies with large double radio lobes are not enormously less common at redshifts above unity than they are closer (more recently) according to a 7C sample studied by Cotter et al. (1996). One implication is that the relativistic material of the radio lobes cannot be confined by intergalactic gas with density scaling like $(1+z)^3$.

The last 3C source. It seems fitting to end this section by reporting that there is, finally, a redshift for the optical counterpart of the very last 3CR radio source (Rawlings et al. 1996). It actually has a 4C number (13.66), but would have been in 3C if the sample had been perfectly defined and compiled. This is not the same source that the former Astronomer Royal for Scotland told us was the last 3CR optical identification more than 20 years ago. The problem is that as your radio resolution improves and your optical images go deeper, something that used to be obviously associated with something else becomes equally obviously not associated. Anyhow the newest addition is $z=1.45$ and is not a record for 3C.

11.8 Clusters, Large-Scale Structure, and Cosmology

The most distant X-ray cluster to date has been found around 3C 356, which has $z=1.079$ (Crawford and Fabian 1996). The X-ray gas itself does not tell you its redshift. The extent to which clusters and larger-scale structures have been established by any particular past epoch is still very much under debate. We note, however, what seem to be the first reports of clusters of (optically selected) quasi-stellars at redshifts exceeding one (Schade et al. 1996) and of clustered *ROSAT* sources at what seem to be similar distances and angular scales (Vikhlinin and Forman 1996).

The first Doppler peak. Eventually we come to size scales that can be probed only via fluctuations in the 3-K microwave background radiation. The COBE group reported a nearly final version of the analysis of the full four years of DMR data in a set of eight letters (Bennett et al. 1996). These measurements extend from whole-sky down to angular scales near 7° ($l=30$ in the usual, peculiar wave-number units beloved of physical cosmologists), almost meeting up with the largest scales explored from ground- and balloon-based detectors (Melchiorri et al. 1996). There is a regime between a few degrees of arc and a few tenths of a degree where one expects bumps and wiggles in a plot of fluctuation power versus angular scale (known as acoustic or Doppler peaks). Their amplitude, shape, and location in l-space could provide values of the standard cosmological parameters, H, q, Λ, Ω, and Ω (baryon) that are largely independent of traditional indicators (Jungman et al. 1996). Just possibly the first of these has been seen in the combination of *COBE* and ground-based data (Kogut and Hinshaw 1996). Taken at face value, it implies a baryon density between 0.5 and 7.8% of closure (for $H=50$ km s^{-1}/Mpc). Considerations of big bang nucleosynthesis say almost exactly the same.

The Higgsino (a weakly interacting, WIMP particle) has been reconsidered as the dominant form of dark matter on the basis of one possible accelerator event and the excess of $Z^0 \rightarrow b\bar{b}$ events seen at LEP (Kane and Wells 1996).

The tightest limit yet on changes in the gravitational constant comes from the masses of neutron stars in young and old binary systems (Thorsett 1996). The point is that a bigger G leads to a smaller Chandrasekhar limiting mass. The data say $\dot{G}/G < 4\times10^{-12}$/yr.

Finally, in this section we note the most distant active galaxy seen at gamma-ray energies by EGRET. It has $z\approx 2$. You might think this belongs in the active galaxies section, but the really interesting point is that the gamma rays get to us without wiping themselves out in pair production with intergalactic optical, infrared, and ultraviolet photons. The photon sea allowed is not much larger than what is expected from the sum of known galaxies (Madau and Phinney 1996). The part of this sea at 400–1000 μm has possibly been seen at a somewhat higher level than what galaxies would add up to (Puget et al. 1996)

11.9 People and Places

The most accurate radial velocities, good to 3 m s^{-1} are currently coming from Lick and Keck observatories, where an iodine cell serves as the wavelength standard (Butler et al. 1996).

The least persuasive excuse for republishing largely duplicate material belongs to a paper by Efremov (1995). It is said (not by the author) that most of the references are to items not readily available to American astronomers. We counted (to within ±1 or so in all cases) 32 to ApJ, 11 to AJ, 16 to A&A, 9 to MNRAS, 18 to Sov. AJ+Letters, 19 to conference proceedings published by IAU, ASP, and other western organizations, 6 to PASP, and so forth, with only 8 to journals (etc.) that would not be found in typical American astronomy libraries (two preprints, three observatory publication series, two to BAC, and one each to Vistas and Sov. Sci. Rev. E).

The astronomical longevity award goes to Joel Stebbins, if you count only papers published in *Astrophysical Journal,* where he appeared from 1902 to 1964 (Abt 1995). But among those who published over a longer time, if you count a wider range of journals, are Willem Luyten (1918–1989), Jan Oort (1922–1992), and William H. McCrea (1928–1995 and holding). We would appreciate hearing about other possible contenders.

12. STAR-FORMING GALAXIES AT HIGH REDSHIFT

A year or two ago, this section would have been called (in fact was called) "primordial galaxies," and there weren't any (Ap95, Sec. 8). Now that the title has changed, there are an enormous number. This really is, in part, a result of looking at the problem in a slightly different way. But it comes mostly from a sudden flood of new images and spectra, a large fraction the product of *Hubble Space Telescope* and the Keck I telescope.

Enough is now known about galaxies and parts of galaxies at $z=1$–4 that one can say something about the total, comoving rate of star formation in the past. The density of rest-frame ultraviolet radiation long ago and far away (redshifted into the visible band for us) is an indicator of star-formation rate, provided you are prepared to assume some specific initial mass function, $N(M)$, for the stars, typically the Salpeter one, M^{-x}, with $x=2$ or thereabouts. Derived rates can then be compared with the average required over the age of the Universe to produce all the stars we see now. The current rate is lower than the necessary average by a factor 10 or so; the rate around $z=1$–2 was a good deal higher than average; and at $z=3$–4 it is lower again, but not zero. At least one percent of the heavy elements we now see were in place before $z=3$. Notice that the $z=1-2$ peak in star formation is close to, or a bit later than the peak in numbers of quasi-stellars as a function of redshift (on which see Hawkins and Veron 1996, Hall et al. 1996, and Kennefick et al. 1995).

With somewhat less confidence, one can say that the earlier star-formation episodes were largely responsible for making spheroids (giant ellipticals and the round parts of spirals), while the later episodes made disk stars. Closely connected is the observation that, since $z=1$, reddish, round, big, bright galaxies haven't changed very much, while bluish, disky/messy, less bright ones have faded, reddened, and become less numerous by sizable factors.

And now that the punchline is in place, it will do no harm to start at the beginning and slog through lots of supporting data.

12.1 The Search that Failed and More Successful Approaches

The prototypical primordial galaxy was an elliptical or spiral spheroid, experiencing its first and primary burst of star formation at a rate much larger than the average rate over its subsequent history. Such objects should be copious sources of Lyman-alpha emission, and their gas density should be high enough that any Lyman-alpha absorption lines will have damping wings. Thus the prototypical and largely unsuccessful search strategy has been to look for redshifted Lyman-alpha emission from known damped Lyman-alpha absorbers at $z=2$–4. Some additional programs of this sort reported negative results during the index year (Lowenthal et al. 1995, who concluded that star formation is proceeding more slowly than 10 $M_\odot$ yr^{-1} in the gas of a number of damped clouds; Martinez-Gonzalez et al. 1995, who found nothing corresponding to a $z=3.4$ absorber; and Aragon-Salamanca et al. 1996, with, again, only upper limits for a number of clouds between $z=1.7$ and 2.8.

Even where emission is seen, the entities do not correspond to the original image of primordial galaxies. Warren and Møller (1996), for instance, report results from the vicinity of a $z=2.8$ damped Lyman-alpha system. But the emission is in the form of several blobs that can be expected to merge in a Gyr or so to make a galaxy fainter than L^*, and the current total star-formation rate is only a few solar masses a year.

Giavalisco et al. (1996) conclude that the non-detections are meaningful, because known starbursts in nearby galaxies would still show up if they were moved out to $z=2$–3. Many or most damped Ly-alpha absorption features have associated absorption lines of metals, and so the excuse that the clouds have not yet begun star formation is not permitted. Admittedly, known ellipticals of large redshift (most of which are radio sources) are very dusty (Mazzei and De Zotti 1996; Klein et al. 1996), but dust is not the entire explanation for the non-detections (Lowenthal et al. 1995).

Of course there are galaxies, or something very much like them, and star formation at $z=2$–4 and beyond which turn up in association with radio sources. A dozen or so papers during the reference year discussed morphology of radio galaxies and their evolution between $z=1$ and 4, and some of the details are very interesting (van Ojik et al. 1996; Eales and Rawlings 1996), but these also are not by any stretch of the imagination primordial galaxies within the meaning of the act.

In contrast, looking for galaxies as sources of Lyman-alpha and continuum emission in the vicinity of, and at the same redshift as, known quasars and radio galaxies has led to a number of detections of high redshift star formers. More remarkably, suitable examination of random patches of sky seems to work as well as anything else. The secret is that, for $z\gtrsim3$, anything that shines will have nearly all of its Lyman photons absorbed by neutral hydrogen in the source itself or in intervening clouds (a sort of *de facto* Gunn-Peterson effect). Thus one gets "ultraviolet dropout," where multicolor images of a region of sky will show galaxies with $z\gtrsim3$ in (for instance) I, R, and V bands, perhaps even looking quite blue in those colors, but nothing in the B band. For still larger redshifts, the dropout extends to V (and eventually R and I: see Lanzetta et al. 1996 for some candidate $z\gtrsim5$ galaxies picked out of the Hubble Deep Field images this way).

The properties of the not-very-primordial galaxies found in successful searches also sheds some illumination on the failures. Strong Ly-alpha emission is, for instance, rather rare. For moderate redshifts of 1–2 ("high" just a few years ago), conventional color criteria are useful for typing galaxies and picking out good candidates for follow-up spectroscopy.

12.2 Inventory of Things Found, by Redshift

$z=1$–2. In this regime, normal (meaning like nearby ones) elliptical galaxies turn up in both ground-based (Gardner 1995) and *HST* (Medium Deep) surveys (Im et al. 1996). Colors say that the galaxies were, for the most part, already old when the light we see left them (that is, they were not then primordial), though they were somewhat brighter than the modern average. Gardner (1995) notes that his sample, with $I-K$ and $B-K$ colors, ought to have some primeval galaxies, but that there is no way of indentifying them, short of getting spectra for all.

Blue galaxies in this redshift range are, in contrast, quite different from our neighbors. Spectroscopically confirmed ones are often blobby or chain shaped. Typical star-formation rates are near 10 $M_\odot\ \mathrm{yr}^{-1}$, but the galaxies in one *HST* plus Keck sample (Cowie et al. 1995) are not strong Ly-alpha emitters. At least some proper disk galaxies are in place by $z=1$, and spatially resolved spectra from Keck show rotation curves that are not very different from $z=0$ ones (Vogt et al. 1996). The galaxies are somewhat more compact, but not enormously brighter at a given emission-line width (Tully–Fisher correlation) than we are used to.

$z=2$–3. In this redshift range, searches for companions of quasars and radio galaxies have recently proven very productive. Pascarelle et al. (1996) found a couple of Ly-alpha-emitting galaxies near a $z=2.4$ radio galaxy. Both are fairly compact and fainter than L^*. The authors conclude (Pascarelle et al. 1996b) that the entities are likely to merge to make a spheroidal bulge or elliptical galaxy. Malkan et al. (1996), examining the neighborhood of a $z=2.5$ quasar, have found what seems to be an honest protogalaxy, experiencing its first major episode of star formation at a rate of 10–100 $M_\odot\ \mathrm{yr}^{-1}$. It has two fainter companions at the same redshift that are also busy making stars.

Chance (according to Pasteur) favors the prepared mind. And we feel that Yee et al. (1996), who have been thinking about the evolution of distant galaxies for a long time, deserve their serendipitous discovery of a $z=2.7$, bright ($M_v=-26$), compact young galaxy in a redshift survey whose nominal goals were quite different. The galaxy is generously endowed with OB stars and is perhaps being caught only 10^7 years after its first major starburst.

$z\geqslant 3$, The most distant galaxies and protogalaxies in the current inventory include quasar companions (sometimes spotted and studied by several groups at more or less the same time) and sources in "empty fields" imaged by the Keck telescope and by *HST*. These should not be called serendipitous discoveries, since the observers knew exactly what they were doing and had gone to a lot of trouble to do it. There is even one damped Ly-alpha absorber-turned-emitter in this redshift bin. At $z=3.15$, it has a star-formation rate of 6–7 $M_\odot\ \mathrm{yr}^{-1}$ for $H=75$ and $q=1/2$ (Djorgovski et al. 1996).

The companions to the $z=3.2$ quasar PKS 1614+051B are quite highly ionized and may have their own, separate active nuclei (Bremer and Johnstone 1995). Steidel et al. (1996b) imaged the environs of a number of $z=3$–3.5 quasars with damped Ly-alpha absorbers partly as a test of the "UV dropout" method of finding high redshift galaxies. It was a rip-roaring success, with a sizable yield of galaxies that look fairly normal and had already completed about 10% of their star formation by then.

Two companions of a $z=4.5$ quasar imaged in Ly-alpha by Hu and McMahon (1996) seem to be experiencing their first star bursts, but at rates of only about $3h^{-1}\ M_\odot\ \mathrm{yr}^{-1}$ (for $q=1/2$; smaller values of q would put the galaxies farther away, so that the implied star-formation rate would be larger).

The neighborhood of quasar BR 1202−0725 has been so crowded with astronomers lately (Hu et al. 1996; Petitjean et al. 1996; Fontana et al. 1996; Ohta et al. 1996; Omont et al. 1996) that it is a miracle there is any space left for the nearby object they all report on. Agreement is general that there is something smeary there that is a source of both Ly-alpha emission and some (stellar or dust-scattered?) continuum. It includes a good deal of CO and dust, but whether the primary energy source is the nearby quasar or indigenous star formation is less clear.

The ultraviolet dropout technique having proven itself worthy on tests around known quasars, Steidel et al. (1996) went on to apply it to seemingly empty parts of the sky. A number of galaxies (or galaxy parts) with Keck redshifts of 3–3.5 have been found. They tend to be compact (1.5–3 kpc across), to have linewidths of 200–300 km s^{-1}, and to be forming stars at a few solar masses per year. The co-moving number density is about the same as that of $L\geqslant L^*$ galaxies now, and they are expected to evolve into spheroids by $z=0$. Although the spectra show Wolf–Rayet and P Cygni type lines, there is little or no Ly-alpha emission.

Images from the Hubble Deep Field are clearly going to be a major source of high redshift galaxies in the near future. Early results (Steidel et al. 1996a; Clements and Couch 1996; Lanzetta et al. 1996) already show that galaxies with $z=2.5$–3.9 and beyond are well represented, compact, roughly as numerous as L^* galaxies now, and frequently quite untidily shaped. The UV dropout method from *HST* and from the ground picks out slightly different ranges of redshift because the color filters have slightly different wavelength edges.

12.3 Faint Blue Galaxies

Oh, I just put those in to make it more difficult, as the wag said when his victim failed to identify what is "tall and skinny and green and has wheels and grows around houses" as grass. Ap92 Sec. 11.4 already intimated that faint blue galaxies probably include several different types of objects with a wide range of redshifts and descendents. More recent work concurs that FBGs have mostly gone away, though whether specific examples now are like dwarf irregulars (Driver et al. 1995), low-surface-brightness galaxies (Babul and Ferguson 1996), gas-free galaxies (Gardner 1996), dwarf spheroidals (Guzman et al. 1996), or empty fields (Driver et al. 1996a) is still under discussion. Hubble Deep Field images include a good many FBGs (Metcalfe et al. 1996), which may or may not serve to clarify the issues, but will certainly expand the literature.

12.4 The Evolution of Heavy-Element Abundances

The chemical compositions of the gas clouds or (proto)-galaxies that produce damped Ly-alpha lines in the spectra of distant quasars are probably the best indicator we have of how the heavy-element content of most of the Universe has evolved from $z=3-4$ down to the present (Malaney and Chaboyer 1996). It is, therefore, a remarkable and happy circumstance that a dozen or so papers published during the index year seem to be telling roughly the same story. It is a simple one. Average metallicity was already about 1% of solar by $z=2-3$ and increased gradually thereafter to [M/H] ≈ 0 by $z=0.6-0.0$ (Petitjean 1996; Srianand 1996; Lauroesch et al. 1996). Absorption clouds associated with the QSOs themselves, otherwise known as BALs (broad absorption lines) are a special kettle of fish and often have solar metallicity or more, even at very large redshift (Tripp et al. 1996; Turnshek et al. 1996).

Where several heavies can be measured in a single cloud or group of clouds, the relative abundances are sometimes non-solar and resemble those of Population II stars in our own galaxy, for instance [O/Fe]>0 (Lu et al. 1996). Similar average metallicities and element ratios also appear in the clouds responsible for the stronger members of the Lyman-alpha forest of lines, if you look hard enough (Songaila and Cowie 1996).

An independent, though shakier, indication that star formation and metal production started early comes from the absence of Gunn-Peterson (diffuse Ly-alpha) absorption. If this means that the general intergalactic medium was reionized by about $z=5$, then many massive stars must have formed, nucleosynthesized, and died at that epoch (Giroux and Shapiro 1996).

12.5 Clusters and Clustering

It is widely advertised that galaxies were less clustered in the past than they are now, and supporting evidence continues to appear (LeFevre et al. 1996). An interesting counterexample appears in the pencil-beam survey of redshifts of galaxies selected at K (Cohen et al. 1996). About half the measured galaxies are in sharp peaks (walls?) at $z=0.39$, 0.42, 0.58, 0.675, and 0.77). This represents stronger clustering than has been found nearby in other surveys, but may be a reflection of how the sample was selected.

The clusters that do exist at moderate redshift are less likely to be strong X-ray sources than are nearby ones (Sokoloski et al. 1996), though the probability is not zero (Donahue 1996). An independent line of argument, based on the undistorted shapes of radio sources in $z\approx 0.5$ clusters suggests that no X rays may equal no intracluster gas (Rector et al. 1995).

12.6. Evolution of Field and Cluster Galaxies at Moderate Redshift

''Evolution'' in this context has tended to have the rather specific meaning of ''do you'' (or don't you) ''need to assume that the luminosity distribution of galaxies was different in the past in order to account for the numbers found in some survey or other?'' Notice that this is really a very odd way of looking at things, since we are asking what happens when time goes backwards, not forwards.

Selecting the answer ''yes'' for the moment, one then asks whether it is density evolution (more galaxies at each luminosity in the past) or luminosity evolution (each galaxy brighter in the past). Note that for $N(L)\propto L^{-n}$ (any value of n) you cannot tell the difference, and sometimes not even for fancier $N(L)$'s. Then you ask ''is passive evolution enough, or do we need active evolution?'' where ''passive'' means a single star burst long ago and galaxies fading monotonically (we are horribly tempted to say ''monotonously'' and earn a place in our own Sec. 13 next year), ever since and ''active'' means a succession of star bursts, commoner in the past, and presumably triggered by mergers and interactions. Not content to quit while he is ahead, the theorist then wants to know whether galaxies in rich clusters ''evolve'' differently from those in small groups (field galaxies).

By this time, almost nobody is speaking to anybody else politely, surveys with little or no redshift information (that is, number counts) having historically been responsible for more than their fair share of impoliteness. It is, therefore, no surprise that we found at least 18 papers dealing with some aspect of ''evolution'' during the index year. Redshifts from 0 to nearly 1.0 are represented, with a peak in number of papers vs. z near 0.5.

The real surprise is that the primary conclusions of all 18 can be summarized together, provided you are prepared to ignore some of the fine structure. Thus we can now say (a) at least some galaxies ''evolve'' in the particular sense intended, (b) nice people do not currently attempt to distinguish ''density'' from ''luminosity'' evolution (the distinction being not very meaningful for scenarios with lots of mergers), (c) evolution is strongest for blue, not-too-bright, star-forming, disk-like, not-too-strongly clustered galaxies (for which the ''passive'' picture is totally inadequate), (d) bright, red, spheroidal, strongly clustered galaxies also evolve, but less enthusiastically, and ''passive'' evolution is enough if the initial star burst occurred at the right time, and (e) as a result of (c) and (d), what is found will depend very heavily on the wavelength at which a sample is chosen and also on whether it is a cluster or field sample.

This is a case where the cumulative weight of many projects seems more persuasive than particular, well-conceived, or well-presented ones, and all the ones we found are cited, in roughly the order they appeared on the library shelves. Please skip to the next paragraph unless you are looking for your name among the following: McLeod and Rieke (1995), Lilly et al. (1995 and six following papers), Barrientos et al. (1996), Barger et al. (1996), Forbes et al. (1996), Bender et al. (1996), Schade et al. (1996b), Ellis et al. (1996), Roche et al. (1996), Lin et al. (1996a), Schade et al. (1996a), Lubin (1996), Giraud et al. (1996a), Belloni and Röser (1996), van Dokkum and Franx (1996), Garilli et al. (1996), Vilchez-Gomez et al. (1996), and Gardner et al. (1996).

12.7 Classification of Galaxies

The Hubble classification scheme (so-called, curiously, because it was invented by Edwin Hubble 1926) has stood up remarkably well, whether in its original form or as expanded and modified by Holmberg (1958), de Vaucouleurs (1959), van den Bergh (1960), and others. Even now, new ways of categorizing local spirals (Magri 1995) and ellipticals (Kormendy and Bender 1996) tend to be modifications in the direction of more focus on the underlying physics and evolution of galaxies that Hubble thought should dominate classification schemes. (There are other ways of approaching the problem, and Hubble's classifications were originally rejected by the International Astronomical Union in favor of an approach based only on morphology.)

But the Hubble types break down utterly as we look to high redshift, unless you are willing to classify virtually everything as "irregular." Whether "chain galaxies" (Cowie et al. 1995a) at $z=0.5-3.0$ are locally unprecedented or related to low-surface-brightness galaxies (but seen edge-on, Dalcanton and Shectman 1996), Hubble would not have called them E's or S0's or SB's or anything else printable.

High-redshift galaxies can be gassy (Petitjean et al. 1996) and messy (Francis et al. 1996) to the point that experts do not entirely agree about whether we are seeing a good deal of star light (Fontana et al. 1996) or mostly gas ionized by a neighboring quasar (Petitjean et al. 1996) in the case of one at $z=4.69$.

Whether images come from ground-based telescopes or from the Hubble Deep Field (Williams et al. 1996), many of the galaxies (or sub-galaxies) are blue, compact, engaged in vigorous star formation, and not reducible to any recognizable Hubble type (Abraham et al. 1996; Steidel et al. 1996, 1996a; Mobasher et al. 1996). Among those that can be assigned to recognizable types are some ellipticals and some flocculent spirals, but very few grand-design spirals and no barred spirals (van den Bergh et al. 1996). Among those that can be typed, the luminosity distribution is steeper for S's than for E's, and steepest of all for "weird" (Abraham et al. 1996).

Giavalisco et al. (1996a) have entered a caveat based on the fact that we see $z=2-3$ galaxies in what to them is ultraviolet light. They present images from the Ultraviolet Imaging Telescope of a number of nearby spirals. Indeed, the morphology is significantly different from that of the same galaxies seen in their (and our) rest-frame visible light, but they are still recognizably spirals and not necessarily very much like the HDF galaxies and galaxy parts.

It is worth mentioning that, because the entities seen around $z=3$ are typically only 2–3 kpc across, one cannot be sure whether each will eventually become the core of a normal-sized galaxy when star formation propagates outward, or if they will get together in groups of (say) 3–10 and merge to achieve the larger sizes we now associate with the luminous parts of L^* galaxies.

12.8 Star-Formation Rates as a Function of Redshift

An immediate caveat is in order. Nobody knows how to identify newly forming solar-type stars at $z\geqslant1$ (or even $z=0.01$). Most of the photons and all of the ionizing photons from young populations come from rare, massive stars. Thus numbers for star formation reported above and below assume some kind of $N(M)$, typically a Salpeter (truncated power law) or Scalo (log-normal) one. In addition, one sort of indicator of the presence of lots of young stars assumes that all their UV photons stay inside the parent galaxy (Ly-alpha or H-alpha emission), while another sort assumes that they all get out (diffuse ultraviolet flux revealed by its effect on QSO absorption clouds). These cannot both be true (really neither is), and there must be stray factors of two all over the place as a result.

The current, local star-formation rate is $0.013^{+0.007}_{-0.005}\ M_\odot\ \mathrm{yr}^{-1}\ \mathrm{Mpc}^{-3}$ (and when you look to larger redshifts you have to be careful to let your cubic megaparsecs shrink with the Universe, Gallego et al. 1995, based on H-alpha emission). At a redshift near one, the star-formation rate was larger by at least a factor of 10 (Lilly et al. 1996b). And at still larger redshifts, it drops back again, close to the present value (Steidel et al. 1996, 1996a; Lanzetta et al. 1996). But, while the highest z star formation was concentrated in large, eventually elliptical and spheroidal configurations, $z\approx1$ star formation is concentrated in smaller disk and dwarf galaxies (Gwyn and Hartwick 1996; Kauffman 1996; cf. Babul and Rees 1992).

In a very broad sense, the evidence from "the proximity effect" (deficiency of QSO absorbers at redshifts close to those of the QSOs themselves as a probe of diffuse UV background) concurs that there was a good deal more star formation in the past than there is now, but that the rate does not continue to rise when you look further back than $z=2$ (Impey et al. 1996; Giallongo et al. 1996).

Lest this seem too sudden an ending to a long section, we will reiterate that there was early ($z=3-5$) star formation, which contributed largely to spheroids and put at least the first 1% of heavy elements in place, but that the rate of star formation was largest at $z=1-1.5$, when disks and smaller galaxies came into being.

13. HOW GREEN WAS MY COPY EDITOR

We begin, as always, with a litany of our own failings, then move on to some particularly fine examples from other authors and journals. The good news this year is that the person who has complained about roughly the same item each of the past three years has promised not to read Ap96!

First, sincere apologies to D. A. Varshalovich, whose name was misspelled in both Ap94 and Ap95, and thanks to his colleague Alexander Potekhim for noticing (fingers are being kept crossed against an invasion by Potemkin). Apologies also to Stefano Andreon, whose surname appeared as Andrew in Ap95.

Second, concensus should have been consensus. Thanks to J. Michael Shull for catching it, and puzzlement over why the copy editor didn't.

Third, the second largest eccentricity in a binary orbit is still 0.96 for HD 165590 (Batten et al. 1979), and, no, Batten was not the only person who mentioned it, though he generously volunteered to appear among "most eccentric examples" this year.

Fourth, we took a good deal of flack over the discussion of advection (Ap95 Sec. 2.3), first from those not cited and, later, from those cited when commenting on their subsequent papers. Suffice it to say that the idea of accretion onto a black hole carrying a large fraction of the available energy down the tubes with it has been around for some time and in a great many minds, for instance, Begelman (1979), Paczynski and Bisnovatyi-Kogan (1981), Rees et al. (1982), Paczynski and Muchotrzeb (1982), Begelman and Meier (1982), Abramowicz et al. (1988), who seem to have been the first to use the phrase "advection dominated solution," Abramowicz and Lasota (1995, a conference report), Fabian and Rees (1995), and Chakrabarti (1996).

And now for the rest of the world. In many cases, it is impossible to decide whether a particular item should be credited(?) to author, referee, editor, or gremlin, and so only enough of the reference is given for you to be able to check that the item really did appear as described.

The "I wish I'd said that" award to ApJ, 461, 154 for "RP, TS, and CH made pertinent comments on the manuscript. TL made impertinent comments." And the "there but for the grace..." award to all parties concerned in the report of the 1995 September 9 nova that turned out to be Barnard's star a long ways away from its (old) chart position (with thanks to Michael Richmond for the story). The distant chuckle you hear is probably the ghost of Peter van de Kamp.

Department of unlikely colleagues: "Michelle Mayor" (AJ, 110, 1588, acknowledgements); "S. Heatcote (AJ, 110, 1823, acknowledgements), "S. A. Babus (ApJ, 464, 372, references; correctly spelled, he is one of the authors of the paper); "M.D.I. would like to thank..." (ApJ, 462, 671, acknowledgements; but the author is M.D.L.); "Oppenheimer and Volkoff 1989" (in text and references of MNRAS 277, L17, a ghost-written paper, we presume); "V. I. Trimble" (PASP, 108, 39, references); "Victor Hugo" (AJ, 111, 2367, references; correctly spelled, just unlikely); "the Burdige and Hewitt's classification" (ASS, 235, 195, abstract); "Solomon process" (ApJ, 467, 522; in the absence of any suitable reference, one must suppose it pertains to baby-slicing); and "following the precedent set by van der Kruit and Searle (1982), the order of the author's names has been determined by spinning a Moody graphite tennis racket" (AJ, 111, 190; we are surprised not that the racket should have been feeling out of sorts but that the first and last names came out the right way around in both cases—look again at where the apostrophe is). References to the work of "Harlow Shapely" are too common to deserve individual recognition.

And the winner in this category is....."Westerbork is the site of the array of radio telescopes originally built by Jan van Snort" (Nature, 378, 11).

To be or not to be; that is the Gezornplatz. Carry-overs between lines seem to cause the largest number of these. For instance: "support from the Space Telescope Science Incxcvstitute" (AJ, 110, 1574, acknowledgements); "development of a coreen-ergy source (PASP, 108, 78, summary). But, curiously, "....the Crab flux above $E_1 \approx 5$ TeV. Novitgedacht..." (ApJ, 417, 746) means exactly what it says. The capitalized word is the site of the detector.

Creative arithmetic:. "...greater than $630h^{-1}$ Mpc ($z > 0.25$)..." (ApJ, 461, L69) is at least correct to one significant figure. "The six countries... Taiwan, Vietnam, Brunai, Malaysia, and the Philippines..." (Nature, 381, 10) cannot quite make even that claim. "We fix $m_\star / m_\star = 200$..." (and presumably choose a very small value of unity, ApJ, 456, 587). "Negative values of the ratio of contraction time to age of the galaxy" (A&A, 312, 797, abstract, appears to involve sign errors in an odd number of places).

We were also a bit surprised by "the first Strombo Symposium" (MNRAS, 278, L36, references), the three titleless papers that appeared in ApJ, 465 (pp. 73, 425, and 451), and "an irregular, foggy patch of stars which he thought resembled a crab. The name of the patch, the Crab Nebula, survives today" (Nature, 379, 383, news item....sadly, however, most of the stars seem to have vanished).

Careful copy editing, with attention to correct spelling, grammar, and so forth is supposed to be a significant part of the "value added" we pay for with our page charges. The reader is, in this spirit, invited to parse the following item from the summary of ApJ, 468, 531: "While we cannot rule out the possibility that fluctuation amplitude changes [verb] with radius in many of the galaxies studied, we find no compelling evidence for their existence either." "Their" is apparently intended to have as its antecedent "changes" interpreted as a noun. In fact, the only (marginally) possible antecedent is "galaxies." And if their existence is in doubt, why are we reading the paper? The problem could have been solved by changing "that" to "of", in which case "changes" would be a noun, and the sentence a tad awkward, but parsible. And a gem from the abstract of Icarus, 119, 130 "Spring and fall equinox Viking infrared thermal mapper 15-μm channel atmospheric brightness temperature observations are used..." The text then begins most sensibly by saying "Mars has weather." It is, not unexpectedly, a multi-author paper.

No, it just seems like that sometimes. "3C 345 is fainter during observing periods" (A&AS, 114, 337, abstract). "Most of these *IRAS* planetary nebulae are heavily extinct" (A&AS, 118, 243, abstract). "...role of scattering in dumping primary CMB anisotropies" (ApJ, 456, 1, abstract). "The possibilities of surviving the hypothesis..." (AJ, 111, 42 abstract). "Call our too-free phone number" (Bulletin of the American Physical Society 41, No. 2, p. viii). "The first contaminated hard X-ray spectrum of..." (ApJ, 463, 134; just possibly this means what it says, but we doubt it). "The lack of monotony in the present scenario... (A&A, 311, 509, abstract; not as much of a problem as they feared). "The photometric properties...denounce a clear partnership..." (A&A, 311, 484, abstract). "Dragged particle winds are hard to escape compared with the case of non-dragged winds" (PASJ, 48, 529, abstract). And, "We finish by provoking that..." (A&A, 311, 506, summary).

And the winner in this category: "Research Funds New Friends in Japan's Diet" (Nature, 378, 8, headline). Now that you have reminded yourself that this is not a statement about unusual cuisine (remember the Diet of Worms???), bribery seems to rear its ugly head. We think "research finds new friends in Japan's Diet" was intended.

As always, we are grateful to the libraries and librarians who manage to maintain reasonably complete collections of journals at the University of Maryland, the University of California (Irvine), California Institute of Technology, and Space Telescope Science Institute in these stringent times.

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