THE UNIVERSE AT LARGE

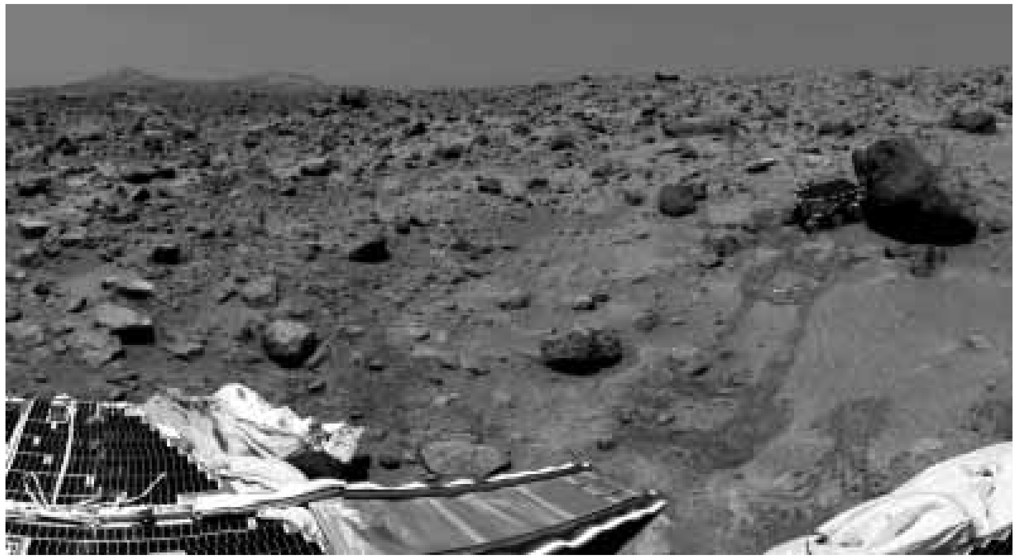
by VIRGINIA TRIMBLE

This Was the Year That Was (Astrophysics in 1997)

THE PROGRESS of science is not generally much like that of a kangaroo. Rather, we tend to advance amoeba-like, cautiously extending pseudopods in some directions and retracting them in others. 1997 witnessed at least its share of advances and retreats, with perhaps a leap or two. The following sections are meant to be logically independent and readable (or at least no less readable) in any order.

MICRO- AND MACRO-MARS: WATER, WATER, EVERYWHERE

Readers my age may remember when "I don't think so" was an expression of genuine doubt. Last year's announcement of possible microfossils in a meteorite that had come to us (or anyhow to Antarctica) from Mars provided an opportunity to try out the X-generation meaning of the phrase. Our curmudgeonly pessimism has been justified. After several months of rat-like gnawings on the edges of the evidence by other experts, the original proponents have essentially with-drawn the suggestion. Tactfully, they switched from *Science* to *Nature* for the recantation.



Meanwhile, a number of Martians have acquired personal names. But it's no use calling them, because, like cats and Victor Borge's children, they don't come anyhow. In fact, they all seem to be rocks. And while reports from the Sagan Memorial Station indicate that the said rocks have carefully washed their hands for dinner, there doesn't seem to be anything to eat. Continued analysis of Pathfinder data will probably yield additional information on Martian geology,* but more advanced probes will be needed to dig below the surface and look for possible relics of early pre-biological or biological evolution. If you happen to have some old slides of the Viking lander site lying around, you can check my impression that the topography of Mars has changed less in the last twenty years than that of our faces.

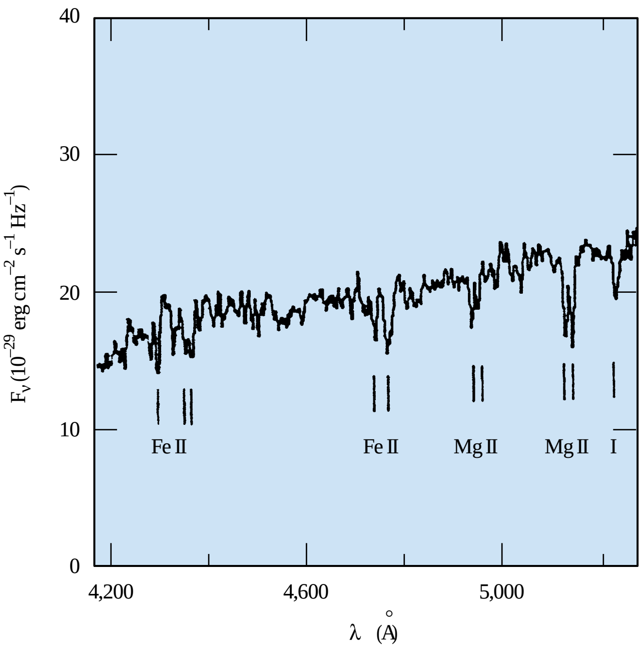
Liquid water continues its role as the probable limiting factor for the development of chemically based life. It may, however, not be so very rare. Besides the Earth and Mars, wet places in the solar system appear to include subsurface regions of two moons of Jupiter, Europa and Ganymede. Lots of images are already in from the Galileo mission, which, after staring at Jupiter for a while, has begun contemplating the moons, and will continue to do so into 1998.

Gaseous and solid water are all over the place. We have always suspected this from their prominence in comets and other reservoirs of local volatile material, but the inventorying has not been very easy. The problem is terrestrial water—a very good thing in its way, but given to smearing its absorption features across any spectrogram you take from Earth's surface. ISO, the Infrared Space Observatory, a mostly-European effort with good resolution in both wavelength and position on the sky, has finally climbed above even the very highest terrestrial ice crystals and water vapor molecules. It sees H_2O emission and absorption features in star formation regions, in shells around evolved stars, in external galaxies, in the planets, and just about anyplace where it is cool enough for molecules to remain bound and perhaps clump together. The water features are often so strong and numerous that they in effect constitute the noise in investigations of other species that emit and absorb primarily at infrared wavelengths. Just what you would have expected in retrospect.

Nevertheless, not all water is created equal, at least not in its ratio of deuterium to hydrogen. That ratio has now been measured in three bright comets, Halley, Hyakutake, and Hale Bopp. In all three cases, D/H is about twice the ratio in terrestrial ocean water. This means that water supplies from comet impacts cannot be the primary source of terrestrial water, unless there is a comet reservoir not yet probed by the observations. The old-fashioned source of volatiles was outgassing of material trapped when the Earth formed.

Mars Pathfinder. The view is not so very different from that recorded by the Viking lander a couple of decades ago, but the device itself, including the rover, is clearly much more elaborate. Additional data on additional particular rocks makes clear that Mars, like Earth, has experienced a variety of processes, leading to a variety of minerologies and petrologies. (Courtesy Jet Propulsion Laboratory, California Institute of Technology, and NASA)

**Areology would seem to be the obvious word, but it just hasn't caught on.*



Spectrum of the GRB 970508 in blue light. The features marked are absorption lines due to singly ionized iron and magnesium in intervening gas clouds. The fact that the lines are doublets makes them fairly easy to recognize, and similar lines are common in the spectra of quasars with redshifts of one or more. The more redshifted of the two systems in the GRB is at z = 0.83, telling us that the event itself must have occurred at still larger distance. The visible source has faded enormously since May 1997, and the spectrogram could not now be duplicated. (Reprinted with permission from Nature *© 1997 Macmillan Magazines Ltd. and the GRB team, Palomar Observatory.)*

This is perhaps as good a place as any to tell you that the animal pictures come from a Dover volume called Animals, *whose cover specifically declares the images to be free of copyright restrictions.*

THE FAT LADY BURSTS

I have been told on equal authority (that is, none) that the pulchritudinous person in question was either Kate Smith rendering "God Bless America" to end a baseball game or a Sutherland-like soprano expressing the desire to leave Paris shortly before the end of *La Traviata* (not at all a bad thing to do, particularly if the performance happens to be in Paris). I would not presume to choose between them. But we were told with equal authority about three years ago* that the gamma-ray bursters were located either in the halo of our own galaxy or in other galaxies at distances comparable with the size of the observable Universe. This choice is now easy. They are at cosmological distances.

GRBs are, tautologically, bursts of gamma rays (meaning anything above 50 keV or so) that come to us at completely unpredictable times from completely random directions in the sky, at a rate of about one per day (given the sensitivity of the detectors now orbiting on the Compton Gamma Ray Observatory). Most last from a tenth of a second to a few hundred seconds, show substructure and complex spectra, and dump from 10^{-8} to 10^{-4} erg/cm^2 at the top of the Earth's atmosphere, with the faintest ones being commonest. Oh yes. And until February 1997, none of them had ever been caught doing anything detectable at any other wavelength.

CGRO data had additionally confounded expectations by showing that we see the edge of the GRB distribution in space, despite seeming to be at the center of it (see box on the next page). Thus the edge was supposed to be either the edge of an enormous halo of our own galaxy (not host to any other known sort of object) or an optical illusion, introduced by the redshifting of the energy of sources far enough away that cosmic expansion is important.

In the last year, a suitable satellite, the mostly-European BeppoSAX, began picking up X-ray tails to the

**At a 75th anniversary restaging of the Curtis-Shapley debate, whose proceedings appear in the December 1995 issue of* Publications of the Astronomical Society of the Pacific.

COUNTING SOURCES OF RADIATION

I HAVEN'T SUBJECTED YOU to a calculation for a long time, and this one is just too much fun to miss out. Suppose static space is littered uniformly with candles of a fixed, standard intrinsic luminosity. Count all the ones you can see down to apparent brightness S. You will get $N(S) \sim S^{-3/2}$, where the 3 is the dimensionality of space, and the 2 is the inverse square law. Add a second population with a different intrinsic luminosity. It, too, will contribute a power-law $N(S)$, and, no matter how many classes you add together, $N(S)$ is always proportional to $S^{-3/2}$. Counts of GRBs rise toward faint S, but not as steeply as $S^{-3/2}$. Thus either distant events are rare (we are in the center of a finite distribution, and Copernicus is unhappy), or the bursts are being redshifted so that the S we see is the Newtonian one cut down by a factor $(1+z)^2$, and distant events are lost from the sample equally in all directions.

bursts fast enough and with good enough angular precision to swing other telescopes toward their locations before all the fireworks were over. Three events, in February, May, and December, have been recorded—briefly!—in visible light, and the May one as a radio source. They are not all the same. The February location has an underlying steady, fuzzy visible object that is probably a distant faint galaxy. Most important, the May event (see figure on page 24) had sharp absorption lines in its spectrum that could be identified as being produced by Mg II and Fe II in clouds of gas between it and us. The lines had a redshift of 0.83, meaning that the source had to be further away than that (but not beyond a redshift of about 2). And no, I am not going to tell you how much that is in light years because it depends VERY much on your favorite values of the Hubble constant and other cosmological fudge factors.

Theorists had, of course, modeled most of the possibilities long before February. But knowing where the events are and roughly how much energy each must put into gamma rays (10^{51} ergs or more, unless the photons are strongly beamed) has triggered a new round of simulating . Most of the simulees involve at least one neutron star or black hole, or sometimes two in a binary system. Given the sub-second time scales of many bursts, there aren't really a lot of other possibilities.

PEOPLE AND PLACES

This can only be a "good news/bad news" section. The astronomical community lost more members than ever before (not surprising; we are, like most of the sciences, an aging community), but Alan Cousins, a South African stellar observer (see cover photo), set what appears to be a new world record for longevity in publication, with papers in 1924 and 1998.

The SAGE detector for solar neutrinos managed to resist for another year having its gallium resold for commercial purposes, but the HEGRA detector for extensive air showers partially burned soon after it had confirmed the second extragalactic source of TeV gamma rays, a quasar previously seen from the Whipple Observatory. SAGE also survived a calibration run with a radioactive source, showing that, if neutrinos get to it in their electron-flavored garments, it sees them, while SuperKamiokande came on line in Japan and confirmed that, for the highest energy neutrinos expected from the sun, only about half the predicted flux is arriving in due order and technically correct.

Some important satellite launches failed, including what was to have been the High Energy Transient Explorer (HETE) , left looking up the rear end of its launch partner after they failed to separate. Others did just what they should, including the Japanese X-ray mission that carries both the acronym HALCA and the name Haruka (a type of bird).*

**Yes, they really are nearly identical in pronunciation. The unvoiced vowel "u" may be familiar from "sukiyaki." As for the seemingly-double-valued consonant, about all I can suggest is that you try saying "rocket flights" and "locket frights" quickly, in alternation, until they start to sound the same.*

The literature contemplated itself, with conclusions that Einstein (a) really did write down “his” equations before David Hilbert and (b) had tackled calculations of gravitational lensing as early as 1912, but thought the results hardly worth publishing. A couple of colleagues introduced into the literature the words “isopedic” and “enstrophy.” Yes, of course you could look them up, but isn’t it more fun to guess “having the same feet” and “a nourishing thermodynamic quantity?” And the gremlins of typography and copy editing brought us many treats, of which my favorite is the acknowledgment “to the TIRGO tune allocation committee for the award of telescope time. At most observatories, TAC is an acronym for “time allocation committee,” but having once shared nights at Mt. Palomar with a colleague who kept awake by singing music of the old Polish church, I can see that the other might sometimes also be needed. If only they had allocated me “99 bottles of beer on the wall” (those were long winter nights), or even *La Traviata*.

DON’T GIVE UP YOUR DAY JOB

Non-Hollywoodites may need reminding that, along with “don’t call us, we’ll call you,” these are words spoken to an aspiring actor or musician who may not be quite ready for the big time. Here I have in mind cases where somebody went out on a limb (often a very sturdy-looking, oak one) only to have some portion of it sawed off from under him. Additional examples include the Martian micro-fossils and Type I supernovae as distance indicators mentioned in other sections.

Our own Local Group of galaxies consists of two big ones (us and the Andromeda Nebula) and a whole bunch of little ones, whose number has seemed to increase at about one per year of late. But the 1992 and 1996 “discoveries,” small, faint galaxies a million or two light years away in the directions of the constellations Tucana and Antlia were actually catalogued back in 1977. New at least as confirmed LG members? Perhaps not even that. Antlia is probably further away than the million-parsec limit of gravitational binding to the Local Group.

Accretion disks around proto-stars, white dwarfs, neutron stars, black holes, and prominent theorists appear in every year’s highlights of astrophysics because they are part of the standard models of quasars, X-ray sources, nova explosions, bipolar molecular outflows, and all sorts of other (real, observed) phenomena. The first, persuasive data-based proposal came in 1956 from John Crawford and Robert Kraft, who concluded that AE Aqr (a nova-like variable) must be a binary system with an accretion disk of material from its normal star swirling around the white dwarf. The latest word is that AE Aqr is actually a net excretor. Accretion of course persists for most of the other advertised objects, preferentially this past year in the form of “advection dominated accretion,” meaning that it carries a good deal of heat and kinetic energy with it down the tubes. The concept, then unnamed, can be traced in the literature at least back to 1977.

One of the dwarf spheroidal galaxies that just barely belongs gravitationally to our Local Group (or just misses). Perhaps the most remarkable point is that anybody can succeed in finding and recognizing little smears like Antlia as galaxies in the first place. (Courtesy Mike Irwin, Royal Greenwich Observatory, UK)

Planetary companions to nearby stars, mostly with masses like Jupiter but shorter orbit periods, glimmered out of press releases from the October 1995 announcement of 51 Peg onward. Perversely, much of the community embraced with enthusiasm a late 1996 suggestion that no such planets were orbiting. Instead, said David Gray of Western Ontario, we were merely seeing winds and waves in the atmospheres of (unaccompanied) stars. These would perturb profiles of stellar absorption lines and mimic the effects of small, orbiting companions. A pair of January 1998 papers, from him and from an

independent group at University of Texas, will have given us back our planets by the time you read this.

Yes, we live in a screwy Universe, but is it also chiral? Theorists have predicted and observers not seen for decades any indication that space-time is rotating or skewed on cosmic scales. This spring, a *Physical Review Letter*, from theorists in Kansas, announced net rotation, based on details of polarization of radio emission from sources at redshifts exceeding 0.3. The announcers had, however, relied on data that they had not collected themselves (always risky) and that were mostly well over a decade old, non-uniformly collected around the sky, and of sufficiently poor angular resolution that bits of the sources with different intrinsic polarization were smeared together. Owners and operators of more recent, more suitable data sets rapidly fired back upper limits to the twisting of space considerably below the positive value claimed in the *Letter*.

In fact (pause for the modest cough of a minor poet) the previous year had seen a published upper limit slightly below the PRL number, which, naturally, went uncited. Probably only two people in the world noticed this, Maurice Goldhaber and yours truly, the authors of the limit paper!

Some things really do have net chirality, including, unexpectedly, some of the amino acids in the Murchison meteorite. Contamination by the sticky fingers of meteoriticists, you will say? Apparently not, for the 5–10 percent excess of L-enantiomers occurs both in some amino acids that terrestrial creatures don't use and in association with non-terrestrial values of nitrogen isotope ratios.

HIP, HIP, HIPPARCOS SAVES THE UNIVERSE, OR, TWO AND A HALF CHEERS FOR OUR SIDE

Hipparcos is an acronym (origins lost in the mists of time), a slight misspelling of the name of a Greek compiler of star catalogues, Hipparchus, and a (mostly European) satellite that scanned the skies for several years, establishing a coordinate system made up of precise positions for more than 100,000 stars. In the process, it also determined for each star its annual parallactic shift (that is, its distance) and its angular motion across the plane of the sky (that is, two-dimensional velocity, if you know the distance). The community had been counting on Hipparcos for quite some time to improve our knowledge of the brightnesses and kinematics of a number of kinds of stars that are either interesting for their own sake or important in climbing up the "distance ladder" to far away galaxies and the Universe.

The Hipparcos satellite. Its launch was almost a failure (owing to maloperation of nearly the only part on it of U.S. manufacture), leading to an elliptical rather than circular orbit; but close to 100 percent of the expected data were obtained over several years. Hipparcos established its own coordinate system on the sky by swinging back and forth from star to star to (more than 10^5 stars), and this needs to be tied to other systems of earth-centered coordinates. (Courtesy European Space Agency)

The splashiest press release belonged to a problem that has been around for half a century, "the age of the Universe." The time scale of the Universe implied by its measured expansion rate (the Hubble constant) has sporadically seemed to be rather less than the ages of the oldest stars we see. And this particular example of "old wine in less old bottles" has never been one we were happy with. Fifty years ago, it led to the invention of the Steady State model of the Universe. More recently, the faint at heart had been driven to invoking Einstein's notorious cosmological constant or even to doubting the

correctness of the basic picture of a universe expanding out of a hot dense state (a.k.a. Big Bang).

Two solutions are possible—make the Universe older (that is the Hubble constant smaller, by deciding that the galaxies you used to calibrate it are further away than you had thought) or make the stars younger (also achieved by shoving them away from you, so that they are brighter and use up their fuel faster). One way of looking at stars measured by Hipparcos seemed to do exactly these two things. Parallaxes of a set of stars called Cepheid variables (a traditional distance calibrator) were a bit smaller than expected, nominally both increasing the time 1/H and decreasing stellar ages. Unfortunately, equally valid ways of looking at the data, using young clusters of stars to calibrate the Cepheids and statistics of stellar motions to get brightnesses of the old ones, have precisely the opposite effect. 1/H gets smaller, and the stars get older. Some assembly is apparently still required.

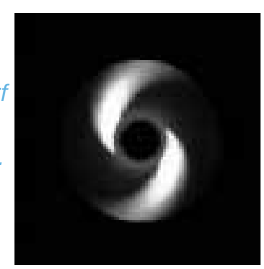
Any astronomer who had planned ahead by asking in 1982 was entitled to some slice of Hipparcos data. My proposal (with George Herbig, then of Lick Observatory) was inspiringly titled "parallaxes and proper motions of prototypes of astrophysically interesting classes of stars," but you must read the archival literature to find out what we learned (other than that fifteen years is a long time even to the middle aged). The hundreds of astronomers who were also 1982 proposers have thus far probably produced an average of one paper each, and many more are expected, clarifying the evolutionary status of Barium II stars and other problems you never even knew you had.

WE KNEW YOU HAD IT IN YOU

Some discoveries were bound to be made eventually and fall largely by luck to the first person who happens to turn the right sort of telescope or equation in the right direction, much like the case in *Moby Dick*, where Captain Ahab nails a gold doubloon to the mast for the first person to spot the whale, or, said Richard Armour, the first person up on deck after dark with a claw-headed hammer. Finding the optical counterpart of the May 8th gamma-ray burster was one of these. Some other 1997 examples follow:

• Radio pulsations from Geminga. This gamma-ray source in Gemini was long a mystery because it seemed (like the bursters) to have no counterpart at any other wavelength. Sensitive X-ray and optical detectors remedied this several years ago and also showed that it was a rotation-powered neutron star ("true" pulsar), with a period of 0.237 seconds. But all proper pulsars should beep radio signals at us (that is, after all, how they were discovered in 1967), and Geminga seemed to be a failure. Three groups, all centered in Russia, have finally found the radio pulses, more or less simultaneously (and each has published the discovery at least twice, once in the Russian literature and once elsewhere). The problem was that the source is simply very faint and steep-spectrumed, so that the best bet for catching it was at lower radio frequencies than are usually used for the purpose.

• A spiral wave in the accretion disk of a cataclysmic variable. Theorists have been predicting these for some time, because a spiral or $m = 2$ perturbation is the natural consequence of having a large point mass off to the side of a disk (hence the particularly spectacular arms in spiral galaxies with close companions like M51). IP Peg is the first cataclysmic where the wave has been spotted, via a clever mapping technique that uses changes in shapes of spectral lines through the orbit period of the system to locate bits of gas with different densities and velocities.



Reconstructed distribution of density in the disk surrounding the white dwarf in IP Peg. The central star is blacked out and contrast somewhat enhanced. (Courtesy D. Steeghs, E. Harlaftis, K. Horne, Astronomy Group, Univ. St. Andrews, UK)

• Central black holes in galaxies. These have become so common they no longer make the *New York Times*. Whoever happens to get the first HST images and spectra of the center of a nearby galaxy is just about guaranteed to find a black hole somewhere in the range

10^6–10^9 solar masses. In a few cases, where more than one technique has been brought to bear on a particular galaxy, the results for BH mass are in clear disagreement. You can argue about whether this constitutes progress, but it does at least guarantee employment for future generations of astronomers. Our Milky Way is part of the great majority with a central black hole of $2–3\times10^6$ solar masses as the only possible explanation of the details of the motions of stars and gas near its center.

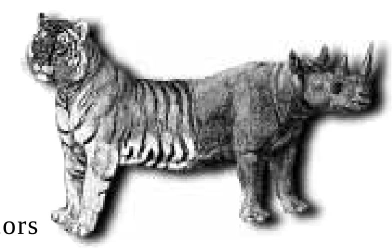
• Broad absorption lines in a radio quasar. Proper quasars are strong sources of radio emission (the others are QSOs or quasi-stellar-objects, unless you are feeling lazy). BALs or broad absorption lines are saturated ones with redshifts just a smidge less than the redshift of the emission lines. They are attributed to gas being blown out of or around the QSO nucleus. Until 1997, the radio-loud and BAL sets were disjoint. And it took a survey of something like 10^5 radio sources to find the first, faint overlap (this is a pun; the survey is called FIRST). The source's telephone number is 1551+3517 (actually its location in the sky) in case you want to call.

• The most distant galaxy. There is a new one of these practically every year, and quite often it is really a QSO. The 1997 queen for a day, at a redshift of 4.92, is an ordinary galaxy. It is visible at that distance partly because it is forming stars like mad (and new, massive stars are the brightest kind) and partly because it is gravitationally lensed and amplified by a foreground cluster at $z = 0.23$.

• The most distant supernova. Here too records are falling constantly, and the current one at $z = 0.9$ or thereabouts is not very important for its own sake. Distant galaxies contain heavy elements, so we know they must already have had supernova explosions. But the members of one class of supernova (called Type Ia) all seem to have the same intrinsic luminosity and so can be used to measure very large distances and get global values for the cosmic expansion rate (H) and its change with time, the deceleration parameter, q_0. These, in turn, are algebraically related to the mean density of the Universe. Through most of 1997, the supernova method seemed to be the one hold-out in finding a q_0 or density value large enough to stop the expansion of the Universe in the (very remote) future, while a number of other methods that looked at masses of clusters of galaxies or their distribution in space were finding perhaps 30 percent of that critical density. But the result came from a very small number of distant Ia's. With a larger sample of about fifteen events, the best fit is a smaller deceleration parameter, or a density of 30–40 percent of the critical value, agreeing with the other methods.

• A new class of pulsating variable star. This is a beautiful case of theory and observation rising to meet each other. Even as a group of French Canadian modelers of stars were predicting that a particular kind should be unstable to pulsations with periods near one hour, a group of South African observers of stars were serendipitously discovering a handful of stars whose brightnesses vary with several modes near one hour, in just the part of luminosity-temperature space where they were predicted. So far, they are merely called pulsating sdB stars (where "sd" says they are faint, compact, and evolved, and "B" says they have surface temperatures of 15–20,000 K), and my efforts to coin the term SubDued Bumpers has met with resounding failure.

EVERY DOG IS ENTITLED TO ONE BITE



The fact that the parts of a picture can be made to fit together does not guarantee this is the way Nature actually does things.

This is my attitude, as one of the adjectival editors of a fairly prestigious journal, toward authors bearing papers about which one is tempted to quote Pauli, "It isn't even wrong." Because there are lots of journals, many of these ideas turn up as "new" year after year. Still, isn't it a sort of relief from the seriousness of transverse optical phonons to contemplate.

a. A model of star formation that produces cylindrical stars.

b. A universe whose metric oscillates with a period of 160 minutes, and so accounts both for that period

in the sun and for the peak mode of the variable star Delta Scuti (actually 162 minutes).

c. A scenario for making gamma-ray bursters in the heliosphere.

d. Dark matter candidates in the form of a vector-based theory of gravity or solid hydrogen.

e. Redshifts quantized by "giving up the arbitrary hypothesis of the differentiability of space-time."

ACKNOWLEDGMENTS

I asked the editor to perch the amoeba atop the kangaroo in the first picture so as to have an excuse for mentioning Robert K. Merton, author of *On the Shoulders of Giants* (no, Newton was not the first to say it), who has been an occasional, generous reader of these maunderings for some time. Reviewers, even more than other scientists, are indeed supported by their colleagues.

The series, *Astrophysics in 199x*, arose from a suggestion by Howard E. Bond, the immediate past editor of *Publications of the Astronomical Society of the Pacific*, who must often have felt like the parent of Rosemary's baby, and who also just happens to have been the chap who first spotted the optical counterpart of the May 8th, 1997, gamma-ray burst—that was the one that had a measurable redshift, but he couldn't measure it, because he was using a 0.9 meter telescope (it took the Keck 10-meter). I am grateful both to him and to my some-time co-authors, Peter Leonard and Lucy-Ann McFadden, for their contributions to the series (and also to the IRS for the schedule C deduction that has enabled me to pay the page charges for its publication most years).

READ ON

The complete text of "Astrophysics in 1997" by V. Trimble and L. A. McFadden appears in the March 1998 issue of *Publications of the Astronomical Society of the Pacific.*

The proceedings of the 75th anniversary restaging of the Curtis-Shapley debate, with contributions from R. J. Nemiroff (organizer), V. Trimble (on the original C-S event), G. J. Fishman (on observations of gamma-ray bursters), D. Q. Lamb (arguing for events in the halo of our own galaxy), and B. Paczyński (arguing for events in very distant galaxies) appear in PASP **107**, 1131-1176, with a summary by M. J. Rees, the moderator.

The announcement of cosmic chirality is found in B. Nodland and J. P. Ralston, Phys. Rev. Lett. **78**, 3143 (1997). One of the refutations is J. F. C. Wardle et al. Phys. Rev. Lett. **79**, 1801 (1997); and the premature upper limit appears in M. Goldhaber and V. Trimble, J. Astrophys. Astron. **17**, 17 (1996) . . . and next time we're going to publish in a prestigious journal too!