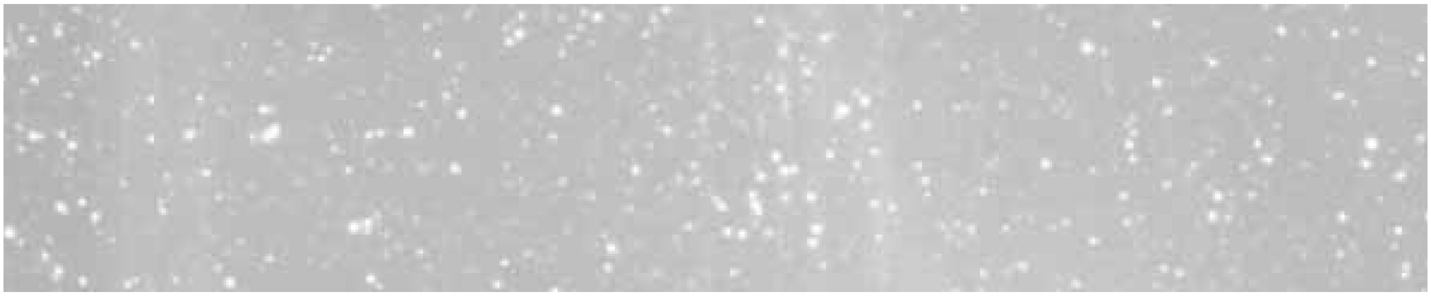
THE UNIVERSE AT LARGE

Astrophysics in 1994

by Virginia Trimble

The author takes typewriter, notebook, and eraser in hand to review, in brief and prejudiced fashion, a few of the highlights of the astronomical year.

BACK IN 1990, the then-new editor of *Publications of the Astronomical Society of the Pacific*, Howard Bond, asked me to undertake an overview of everything that had appeared in the astronomical literature over the past 12 months, with the intention that this should become an annual event, until either he or I was lynched by the uncited.



Papers called "Astrophysics in 1991," 1992, and 1993 in due course appeared, and Ap94 has just been handed over to the editor (or at least the US post office). It touches on something like 81 topics, a subset of which seemed like enough fun to be worth sharing with *Beam Line* readers. Incidentally, just in case you have been wondering about the author carrying three awkward things at once, it is clear that, since she has two left hands, the total must be at least three.

THE DEMISE OF THE JOVIAN DINOSAURS

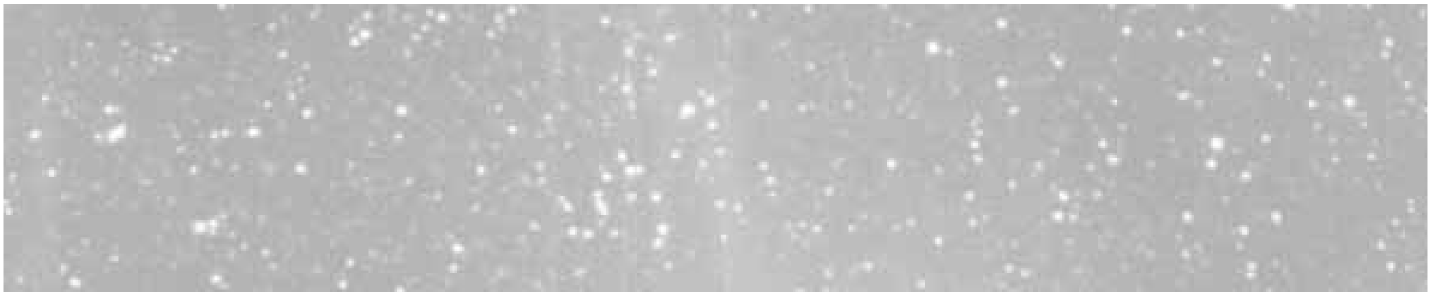
On 16 July, 1994 fragments of disrupted comet (or whatever) Shoemaker-Levy 9 began hitting Jupiter. Visitors to the planet after that date are guaranteed not to find any dinosaurs living there, by analogy with the damage done to the fauna of the terrestrial Mesozoic era by an asteroid/comet impact about 60 million years ago. Admittedly, I am pretty sure that Jovian visitors before July 16 would not have found any dinosaurs either.

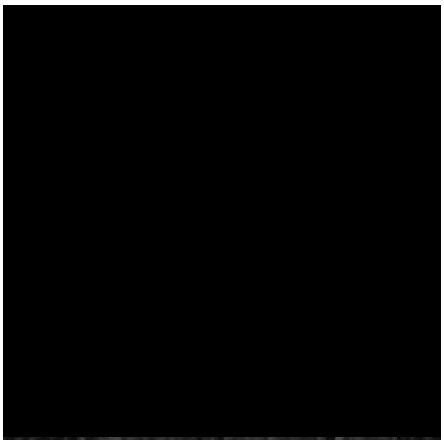
Some more controversial questions can also be addressed once the images and spectra of the impact events have been fully analyzed. These include the chemical composition of the layers of Jupiter that were kicked up (why so little water; how much of sulfur and its compounds?) and whether the impacting fragments belonged to a comet in the traditional sense of dirty snowball or something more like an asteroid, in the sense of ice-polluted rocky stuff. Even more interesting are the sociological questions. Why did comet experts so greatly underestimate (at least in public) how spectacular the collisions would be? The easy, and perhaps correct, answer is "once burned, twice shy," for overestimates of what casual observers might see of Comet Halley back in 1986 had done nobody any good.

Another issue where political considerations outweigh purely scientific ones is what, if anything, the event will mean for the progress of searches for asteroids that pass close to the earth and the development of technology to modify their orbits. Inevitably, many astronomers resent the thought that money that could be spent on useful topics like asymptotic giant branch stars and Seyfert galaxies might be diverted to comet and asteroid patrols. In fact, these latter are also capable of yielding information about the numbers of very small bodies in the outer solar system, their likelihood of collisional disruption, and the balance between rocks and ices in these objects that are the most nearly pristine samples left from when the solar system formed. This is interesting stuff in its own right, and I am prepared to give up a few of my white dwarf X-ray photons and half a HIPPARCOS (astronometric satellite) star in return for an

NASA

An image of Jupiter by NASA's Hubble Space Telescope, revealing the impact sites of fragments "D" and "G" from Comet Shoemaker-Levy 9. The large feature was created by the impact of fragment "G" on July 18, 1994 at 3:28 a.m. EDT. The smaller feature to the left of the fragment "G" impact site was created on July 17, 1994 at 7:45 a.m. EDT by the impact of fragment "D". The "G" impact has concentric rings around it, with a central dark spot 1550 miles in diameter. The dark thick outermost ring's inner edge has a diameter of 7460 miles—about the size of the Earth. The impact sites are located in Jupiter's southern hemisphere at a latitude of 44 degrees.





NASA

Wide Field Camera (Hubble Space Telescope) image of the core of nearby active galaxy M87. Spectroscopic data also exist. The signature of the central black hole is that both the surface brightness of the image and the velocity dispersion shown in the spectra increase rapidly toward a sharp, central cusp. The alternative explanation, in terms of a central very dense cluster of stars, is less likely because the cluster would rather quickly merge into a black hole. (Image courtesy of NASA.)

earth-crossing asteroid with surface composition like that of some of the commoner meteorites.

MY BLACK HOLE IS BIGGER THAN YOUR BLACK HOLE

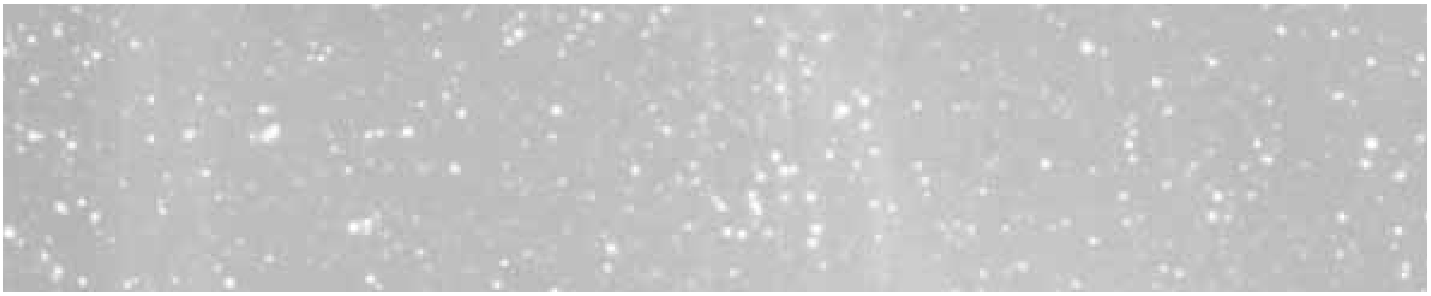
And M87's is bigger than just about everybody's. Most astronomers have accepted for at least a couple of decades that gravity can triumph over the other three forces and produce configurations inside their Schwarzschild horizons in at least two contexts. The first is at the death of very massive stars, whose cores collapse beyond neutron star densities. The other is at the centers of relatively massive galaxies, where stellar and gaseous debris, deprived of its fair share of angular momentum, will pile up, until, sometimes, $R < 2\ GM/c^2$, and even Houdini could not get out.

Such a black hole, with a mass of 10^6–10^{10} times that of a single star and accreting gas from its surroundings, is the standard model accounting for high luminosity, small size, and rapid variability in the active galaxies called quasars, radio galaxies, Seyferts and so forth. Statistical considerations indicate that the active phase should last 1 percent or less of the age of the universe, turning off when there is no longer much gas left in orbits where it can be accreted. Thus many seemingly normal galaxies ought to harbor massive black holes in their cores, left from their misspent youth.

Three interesting examples began giving up their secrets in 1994. First, M87, a nearby active, radio-emitting galaxy, was imaged with better-than-ever angular resolution by the Hubble Space Telescope. The light distribution, mass distribution, and stellar velocity dispersion all show sharp central peaks. These were known from earlier ground-based data, but the higher-resolution HST measurements make it much harder to imitate a black hole with a dense star cluster or other impostor. The implied mass is 2–3 billion solar masses, hefty but still small compared to a whole galaxy of 10^{11-12} solar masses.

Second comes NGC 4258, a totally boring galaxy that has not made the cover of *Science News*. But its center is studded with water maser sources, whose locations and velocities, determined with radio interferometers, look very much like a Keplerian disk around a central point mass of 10^7 solar masses, just what you would expect in a former, bright Seyfert galaxy. Other normal galaxies, like NGC 3115, seem to have billion solar mass, dead quasar, central masses.

Finally the presence or absence of a modest black hole in our own Milky Way has been under acrimonious discussion since at least the early 1970s. No final answer is in. But a gaggle of faint stars (seen as infrared sources) are grouped close enough to the center that, once their velocity dispersion has been measured, the issue will be settled. This has to be done by repeated imaging over several years, to follow their motions on the plane of the sky. Preliminary data say, yes, there is a million solar mass black hole. A firmer YES (or NO) should be possible by about 1997. Meanwhile, the absence of X-rays and other signatures of activity at the center of the Milky Way has to be blamed on lack of gas to accrete.



THE HELIUM GUNN-PETERSON EFFECT, PRIMORDIAL DEUTERIUM, AND BIG BANG NUCLEOSYNTHESIS

The big questions here are (a) how much stray gas is there between the galaxies, and is it a significant contributor to closing the universe? (b) how much deuterium (as well as He^3, He^4, and Li^7) was made in the early universe? and (c) do these fit together sensibly in terms of the nuclear reactions that turned the early proton-neutron-electron soup into simple elements?

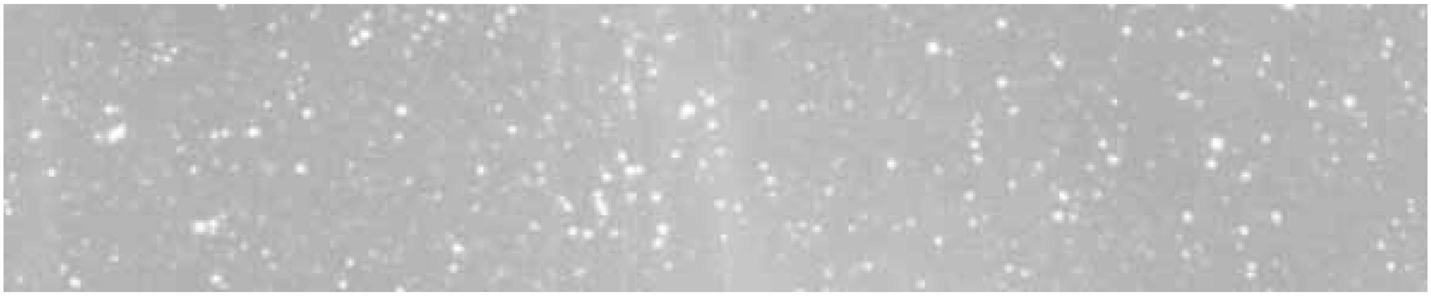
If you wish to add a fourth, minor question, "Who was Dr. Helium?", the answer is that he was a close relative of Mr. Metro (of Metro-Goldwyn-Mayer). Gunn and Peterson were the then-graduate students who, in 1965, pointed out that absence of trough-like Lyman-alpha absorption in the spectra of quasars with redshifts large enough to move 1216 Å into the visible spectrum set a very stringent limit on the amount of hydrogen gas between the galaxies. Gunn-Peterson absorption by neutral hydrogen has not been seen from that day to this (Friday), and the limit has become so stringent that highly ionized gas seems the only believable explanation. This has now been seen, in the form of trough-like absorption at the wavelength absorbed by ionized helium when its sole remaining electron is excited from ground to first excited level. The data come from the high resolution spectrograph on the 10-meter Keck telescope (currently the world's largest at optical wavelengths) and suggest an intergalactic medium whose density is 1 percent or less of that needed to close the universe, but which might be interesting in terms of the total amount of baryonic material around.

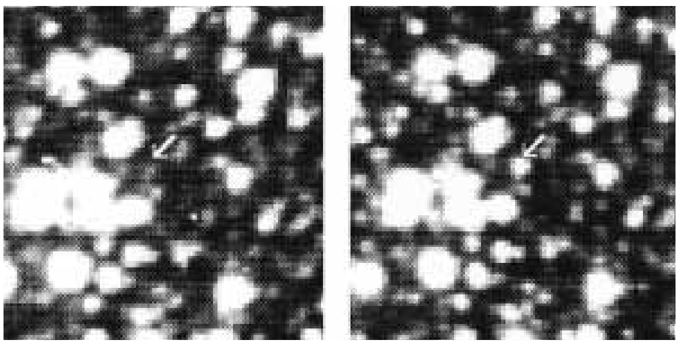
The deuterium-to-hydrogen ratio is the probe *par excellence* of baryon density in the early universe. Qualitatively, it's easy to see why. If there are lots of n's, p's, and d's floating around, everybody finds somebody and it all burns through to helium. If not, not. We have been living for a generation happily with a primordial $D/H = 1–4\times10^{-5}$, as implied by solar system measurements, nearby interstellar gas, and maybe a few other samples. Great, therefore, was the consternation when two separate groups this spring reported that they had seen $D/H = 2.5\times10^{-4}$ in the form of a greatly-redshifted pair of absorption lines in the light of a distant quasar. Preprints fluttered, because getting that much deuterium out requires a perilously low baryon density (you want, at least, to be able to make the stars and galaxies we see!). But the two groups were looking at the same lines in the same quasar (albeit with different telescopes), and suspicion has been rising that what they saw was not deuterium in a dense cloud at all, but rather ordinary hydrogen in a much less dense cloud that just happened to have the bad luck to be moving at a speed to put its Lyman-alpha line at the wavelength where the deuterium line would be in the dense cloud. Rumors abound of a different distant quasar with a line that is plausibly deuterium at the expected abundance. Wavelength coincidences cannot happen often, so detection of just a few more candidate lines will settle the issue.

Meanwhile, some pundits had hailed the mere detection of helium and/or deuterium at large redshifts as triumphal confirmation of the standard big bang picture of the early universe. Frankly, I had ceased to have any doubts about this about the time I gave up reading Winnie the Pooh for *Beam Line*.

TWINKLE, TWINKLE LITTLE MACHO

Another of the highlights of the year also has some bearing on the issue of how much baryonic material there is in the universe. Or at least it might have. At the moment, one feels more as if stars have been rediscovered by a very difficult method. The general idea (put forward by Bohdan Paczyński in 1986) is that, if the dark matter in the halo of the Milky Way consists of discrete objects with masses of anything from 10^{-10} to 10^{+6} solar masses, these will cause gravitational lensing amplification of background stars when they pass between us and the background. If you pick a very dense background region (a nearby companion galaxy or the center of the Milky Way), you need watch carefully only a few





Gravitational lensing event recorded by OGLE (Optical Gravitational Lensing Experiment) collaboration. The arrow in the left image points to a distant star at its normal brightness. In the right hand image, we see the star greatly brightened because a nearer star, too faint to see, has passed in front, magnifying the distant one. (Images courtesy of A. Udalski, M. Szymański, and Mario Mateo.)

million stars to have a good chance of catching one lensing event per year.

MACHO is an acronym for MAssive Compact Halo Object and also the name of one of the three collaborations that started to look for lensing events in 1991 and have now collectively reported many dozens (though only a few are in the archival literature). Several surprises have surfaced. First, the event rate toward a nearby galaxy, the Large Magellanic Cloud, is only about a third of what the searchers were expecting. The dark matter in the halo of our galaxy is not all in the form of MACHOs in the accessible mass range—and, therefore, at a much lower confidence level, probably not all baryonic.

Second, the event rate toward the galactic center is about three times the predicted rate. This means that there are more compact objects somewhere along the line of sight than we thought there were. The explanation apparently involves a non-spherical, bar-like component in the distribution of stars near the galactic center, with one end of the bar intruding into the search fields. Such bars are common in other spiral galaxies (and independent evidence for ours exists in the form of non-circular gas velocities in the region).

Third, the average properties of the events are not quite what was hoped for. One of the survey teams, called OGLE, started out looking toward the galactic center because that way they could be sure of seeing something eventually, if the technique and calculations were right. There are, after all, lots of massive compact objects in the galactic disk and bulge between us and the center. They are called stars. And this seems to be what the projects have discovered. The most probable masses (only statistical determinations are possible from the duration and amplification of lensing events) for most lenses are those of small stars, not substellar objects or brown dwarfs.

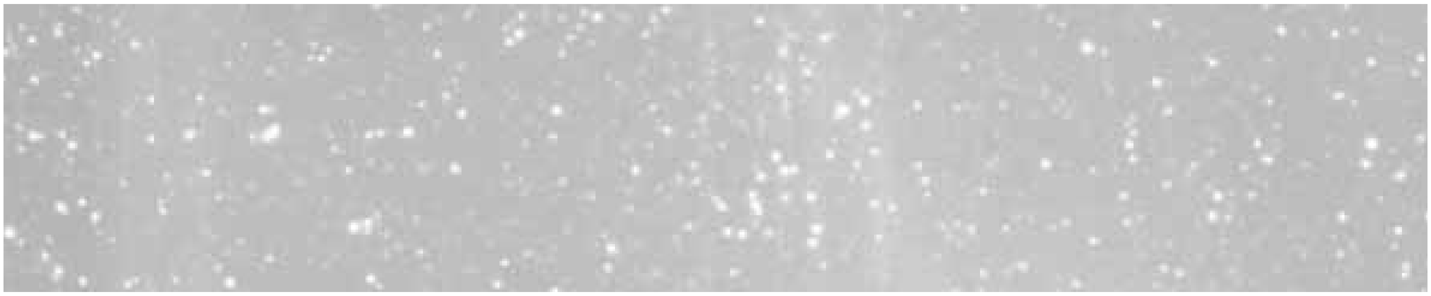
The three projects are producing enormous quantities of astronomical spin-off. I have already mentioned the demonstration that the Milky Way is a barred spiral. The MACHO group has seen a new class of variable stars that they call blue bumpers (given the PC level of the collaboration name, I wouldn't be surprised if these started out as "blue bump and grind stars!"). And OGLE is producing an enormous catalog of known and unknown variable stars, as well as having found independent evidence for the new galaxy mentioned in the next section.

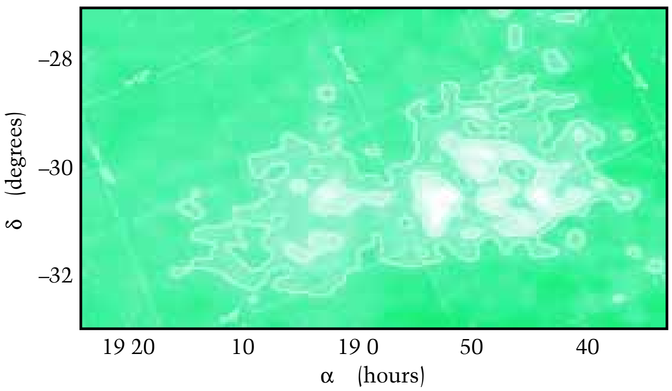
Despite the frivolous tone of most of these remarks, I would like to record here enormous admiration for the persistence, mechanical ingenuity, and prompt data release of the three survey groups.

Not quite incidentally, a number of other searches for brown dwarfs in the last few years, by a wide range of other methods, have yielded mighty slim pickin's.

IGI

The Milky Way belongs to a small, local group of galaxies, called (with that enormous creativity of nomenclature for which astronomers are world renowned) the Local Group. The other members are a second large spiral galaxy (the Andromeda nebula, or M31), a smaller spiral (M33) and more than two dozen dwarfs, some with gas, and some without. The inventory keeps growing, and the latest recruit is a dwarf spheroidal galaxy, meaning no gas and not many more than 10^{6-7} stars, that





An isodensity map of the newly discovered dwarf galaxy in the constellation of Sagittarius. (Courtesy of Rodrigo Ibata, Institute of Astronomy.)

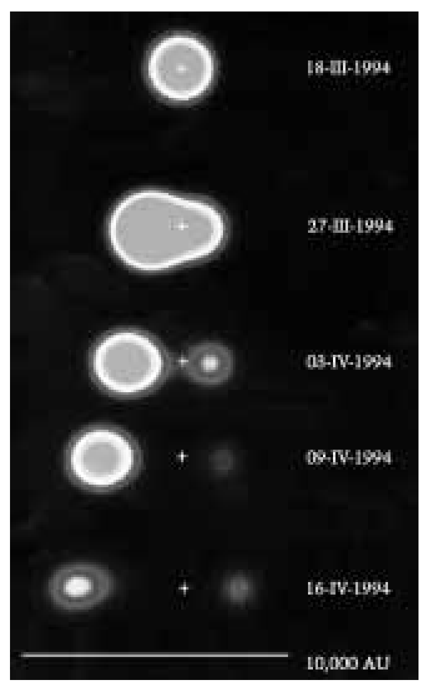
has the bad luck to be almost exactly on the far side of the galactic center from us, and close in at that. As a result, the new galaxy is quite difficult to see or photograph, and is in the process of being torn apart by tidal forces of the Milky Way itself.

The discoverers, Ibata, Gilmore, and Irwin (whose initials are NOT the official name of the galaxy) found our new neighbor accidentally, in a project intended to clarify the kinds of stars that make up the central regions of our own galaxy. It shows up independently in star counts by the OGLE group (above, and yes that is their official name). One can't help suspecting that such undiscovered dwarf galaxies may be fairly common. Even the ones found by Hubble early in the 20th century are hard to recognize until someone tells you what to look for. Slightly larger dwarf spheroidals are known to be the single commonest kind of galaxy in rich clusters like that seen past the constellation Virgo.

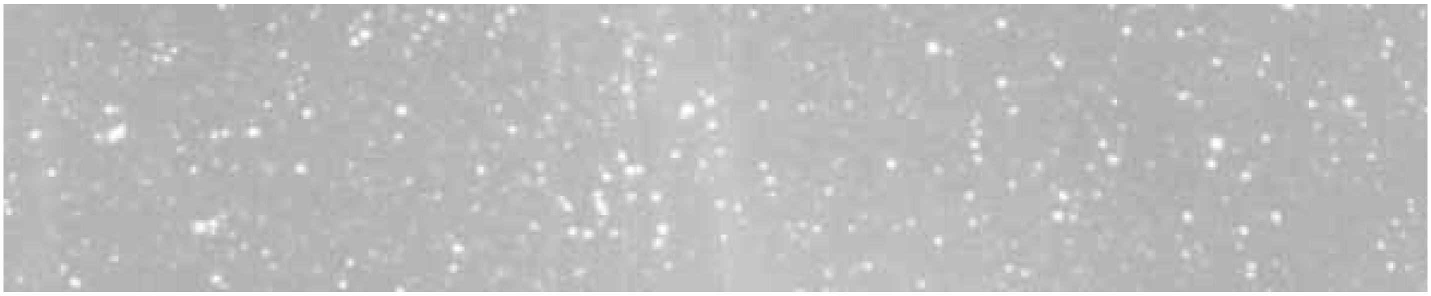
EINSTEIN IS DEAD

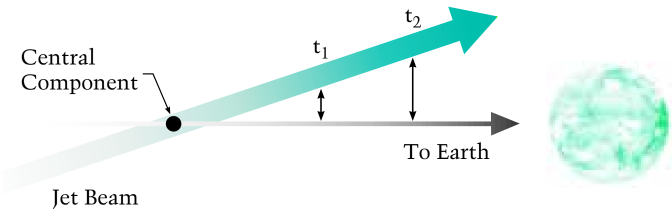
Not precisely news, you will say. But this was the headline in a nameless Pasadena newspaper (we have heard rumors of a morphological class called lawyers who take an interest in such matters) some 20 years ago, when radio astronomers reported that they had seen bits and pieces of compact, distant quasars and radio galaxies that seemed to be moving across the sky at 2–10 times the speed of light. No alarm was called for even then. The effect had been predicted (see top figure on next page) a few years before, and is a projection along the line of sight of relativistically beamed gas moving at 90 percent or so of the speed of light. From discovery in 1972 until this year, all were in distant galaxies.

The new development is that our own galaxy also harbors at least two superluminal sources. They are not associated with our rather feeble galactic center (with or without its black hole). Rather, the beamed jets are accelerated by neutron stars or black holes in binary systems that reveal themselves as flaring X-ray sources. The rapidly-moving jet tips (or whatever) are best studied as radio sources, and once again it is radio astronomers who have shown that what was first called "an X-ray nova in Scorpius" has a superluminal component. Press conferences on it were still being held when a second X-ray flare source started doing the same sort of thing in August. It is hard to escape the conclusion



Sequence of radio maps of X-ray nova GRS 1915+105 from March and April 1994. The source seems to be expanding rapidly, from a single blob to two widely separated ones, with components separating at 1.9 times the speed of light. This is a sort of optical illusion attributable to motion at about 0.92 c, at an angle of 70° to our line of sight. [Adapted from I. F. Mirabel and L. F. Rodriguez, Nature, 371, *46 (1994).]*



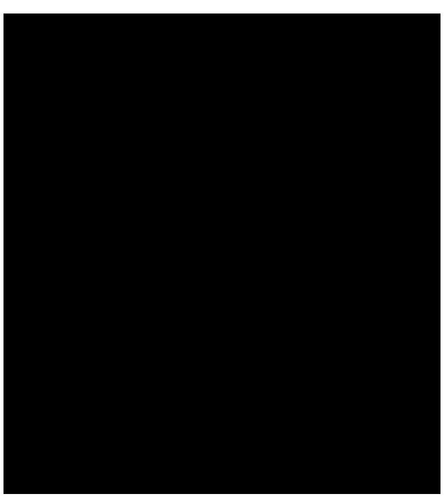


Because the jet is moving quickly and almost directly towards us, a photon emitted at t_2 doesn't have to travel as far as a photon emitted at t_1 and so arrives very soon after the first one. Thus it looks as if the emitting bit of gas had moved across the plane of the sky very quickly. The other jet, heading away from us, is Doppler-faintened and normally not seen, though its effects on its surroundings may be.

that these, like dwarf spheroidal galaxies, are very common, once you know how to look for them.

"A FAINT LUMINOUS HALO THAT MAY TRACE THE DARK MASS DISTRIBUTION OF SPIRAL GALAXY NGC 5907"

That's the title of the paper, published in *Nature* this fall, and it says it all. Penny Sackett and her colleagues have not necessarily seen dark matter. But they have seen a faint glow around this galaxy with a distribution that looks like the mass density distribution of a typical dark halo, that is, something that scales like R^{-2} rather than R^{-3} or steeper, the way the visible star distribution does. They had no color information about the light as they (and we) went to press. But if all the light and all the mass of the halo of this particular galaxy came from a single class of known astronomical object, then the objects would be faint, low-mass stars, very much like the ones that are turning up as lenses in the gravitational lensing (MACHO) searches described a page or two back.



Natonal Optical Astronomy Observatories

CCD image (taken with a 36" telescope) of the edge-on spiral galaxy NGC 5907. The data, in digitized form, show that, in addition to the obvious, very flat spiral disk, there is a power-law component, with luminosity density proportional to $r^{-2.2}$, extending at least 6000 parsecs (2×10^{22} cm) perpendicular to the disk. This is the sort of density law that dark halos must have in order to account for the dynamics of spiral galaxies. (Courtesy of Penny Sackett.)

AND ALL THE REST

"Astrophysics in 1994" cites about 400 papers, culled from nearly 20 times that many read by my co-author and me during the "reference year" 1 October 1993 to 30 September 1994. From the 81±x topics discussed there, I have picked about nine, and given even them fairly short shrift. Were it not for the impiety, one would be reminded of the time when Rabbi Hillel was asked to explain The Law while standing on one foot. He did so, saying "That which is hateful to you, do not do to another. All the rest is commentary. Now go read the commentary." In less lofty fashion, the archival literature of astronomy and physics repays reading!

Suggestions for Further Reading

"Astrophysics in 1994" by V. Trimble and P.J.T. Leonard is scheduled to appear in the January 1995 issue of *Publications of the Astronomical Society of the Pacific*. It contains the original references to the items mentioned here, and many others.