COSMOLOGY

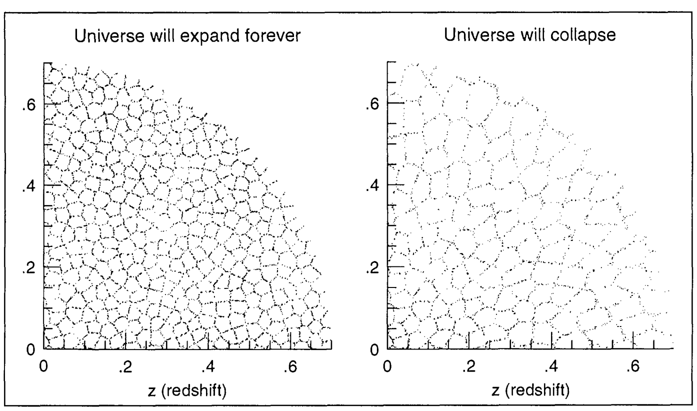
To Learn the Universe's Fate, Observers Clock its Slowdown

Cosmologists have a reputation as dreamers—scientists who base their ideas as much on philosophy and aesthetics as on hard facts. Hard facts about the origins and fate of the universe have been scarce, after all. But cosmology is changing as telescopes on Earth and in space open a view on the farthest reaches of the cosmos and its earliest days. Perhaps nowhere is the shift better illustrated than in the dash to determine the cosmological "deceleration parameter," called q_0. Once open only to speculation, this number—which indicates how fast the pull of gravity is slowing the expansion of the universe—is now coming under the hard-nosed scrutiny of astronomers like Barbara Ryden of Ohio State University, who says, "I have no strong views [on the value of q_0]. I'm one of those astronomers who like to go out and measure things."

It would be hard to find a more basic number to measure than q_0, a clue to whether cosmic expansion will continue forever or whether the universe will ultimately recollapse. Says Andrew Lange, an astronomer at the California Institute of Technology (Caltech), "I can't imagine something more fundamental about living in an expanding universe." In the simplest cosmological picture, the value of q_0 not only foretells the universe's ultimate fate; it can also reveal how much mass is scattered throughout the cosmos, braking the expansion through the pull of gravity. And it can hint at whether the underlying nature of the universe is more complex—whether a force inherent in space itself is counteracting gravitational forces and keeping the expansion rate high.

In pursuit of q_0, astronomers like Ryden and Lange are using as benchmarks everything from distant supernovas to the powerful radio beacons called radio galaxies to the shapes of the great voids in the cosmos, which would be distorted by a change in expansion rate from the early universe to the present. So far, the answers are preliminary—and contradictory, with some measurements favoring endless expansion and others suggesting that the braking force of gravity could be large enough to reverse the expansion. As radio astronomer Chris Carilli of the Harvard-Smithsonian Center for Astrophysics (CfA) puts it, "If it was so easy then we wouldn't still be searching." But in the next couple of years, as he and other researchers refine their techniques for forecasting the fate of the universe, they hope to reach a cosmic consensus.

Like so many of cosmology's key numbers, q_0 is entangled with omega—a measure of how much mass the universe contains. Omega isn't an absolute value; instead it is the ratio between the actual density and a value called the "critical density." At an omega of 1—a universe with just the critical density—the pull of gravity would be just high enough to ultimately bring the expansion to a standstill. If omega were less than 1, the universe would expand forever; above 1, the expansion would eventually reverse, turning the big bang into a "big crunch." Cosmologists have made slow progress in measuring omega directly, and so far no definitive answer has emerged. Now, by checking the rate at which the expansion of the universe is slowing—q_0—they may be able to get an indirect fix on omega.



SOURCE: BARBARA RYDEN

Fateful tapestry. In a model of the universe, the shape of the voids between galaxies reveals the geometry of space—and whether the universe will expand forever or collapse. Redshift is a measure of distance.

A joker in the deck is the so-called cosmological constant—a nongravitational, repulsive force first postulated by Albert Einstein. The idea of such a force had little support until recently, when it was revived by cosmologists who think it might resolve a possible contradiction between measurements suggesting a high expansion rate (which could imply a young universe) and the extreme age calculated for some star clusters. A large enough cosmological constant could counteract the effect of gravity, allowing an old universe to expand fast, like a youngster, no matter how high omega is. As techniques for sizing up the amount of mass in the nearby universe improve, cosmologists could search for the constant's fingerprint by seeing whether q_0 is as large as the measured mass density would predict. "That will enable us to say conclusively whether or not [the cosmological constant] is zero, rather than waving our hands about," says Ohio State's Ryden.

Distant beacons. All that is enough to motivate q_0-searchers like Saul Perlmutter of the Lawrence Berkeley National Laboratory, whose group will publish an analysis based on its first batch of observations in a month or two. Perlmutter's approach is perhaps the most direct of the competing strategies: look far out into the universe for beacons in the cosmic expansion and see whether they are rushing away from Earth at a rate that increases linearly with distance. That is the situation expected in a universe whose expansion rate has not changed. If it has slowed, for example, distant landmarks—observed earlier in the history of the universe—will seem to be moving disproportionately fast.

As beacons, Perlmutter and his colleagues use type Ia supernovas, brilliant exploding stars all thought to reach roughly the same actual brightness. That allows the supernovas to serve as "standard candles," whose apparent brightness can be taken as a measure of their distance. Perlmutter and his colleagues compare the estimated distances of remote supernovas with their redshifts—the extent to which their light is reddened by their velocity away from Earth. By seeing how much the distance-redshift relation is distorted, Perlmutter and company can search for any signs of cosmic deceleration—or acceleration.

Their preliminary analysis of one supernova already casts doubt on a strongly accelerating expansion—the mark of a cosmological constant in a low-density universe. Perlmutter and his colleagues are now at work on an analysis of seven supernovas, which could definitively rule out strong cosmic acceleration. It may not distinguish between a low-density universe without acceleration and a denser universe with, say, an omega of 1. But as the group expands its supernova search, the exact rate of deceleration—and hence the fate of the universe—should come into sharper focus. In a couple of years, says Perlmutter, "we will pin this down once and for all."

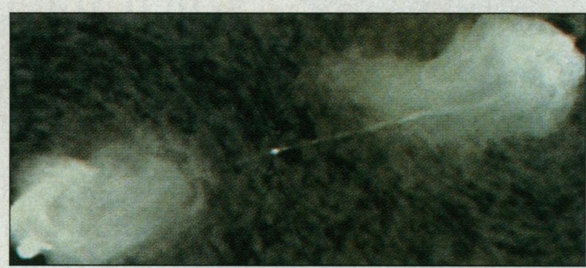
Close behind the Berkeley group are other supernova watchers, including Robert Kirshner at the CfA and researchers at the University of Washington and observatories in Chile and Australia. Already, though, these groups have some competition from a Princeton University effort led by Ruth Daly. Instead of looking for "standard candles" in the distant universe, Daly and others are applying "standard yardsticks" to gauge what she calls "the global geometry of the universe." According to Einstein's theory of general relativity, gravity is actually a curvature of space-time, so the shape of the cosmos indicates how strongly gravity is acting on it and slowing its expansion.

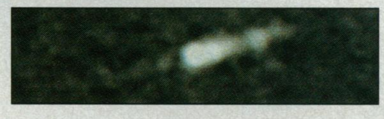
Sketching out the shape of the universe requires a standard object whose apparent size at various distances can reveal space-time curvature. As the distance increases, the object's apparent angular size should shrink at first, just as a figure on Earth shrinks with distance. But in a space-time geometry that is curved by gravity, the apparent size should eventually reach a minimum at distances of billions of light years, after which "the angular size actually increases," says Ken Kellermann of the National Radio Astronomy Observatory in Charlottesville, Virginia.

Princeton cosmologist Jim Peebles offers one way to think about this magnification in his textbook *Principles of Physical Cosmology*: It arises "because the light we detect was emitted when the object was looming over us." The more rapidly the universe is decelerating, the less it will have expanded since that time, and the nearer the point at which the magnification sets in. If omega equals 1, for example, that point lies at a distance of roughly 10 billion light-years. In universes that have a lower density—and hence a lower q_0—it recedes to greater distances and becomes difficult if not impossible to observe.

A cosmic standard. Searching for that minimum point requires a yardstick that is visible at great distances and has intrinsic characteristics that don't change with time—or change only in ways that are well understood. Large radio galaxies, distant objects that jet out spectacular plumes of plasma, fit the first criterion, because they can be seen out to the farthest reaches of the universe. But the CfA's Carilli and others point to a serious drawback: Theorists believe that the average density of the gases enveloping radio galaxies was higher earlier in cosmic history. Denser surroundings would have cramped a radio galaxy's plumes, reducing its actual size by an amount that varies with distance and making it an unreliable yardstick.

Daly, however, thinks she has found a way around the problem. Such radio sources, she says, are thought to "go on and off like lightning bugs" on cosmological time scales, burning for only 10 million to 100 million years. The radio waves they generate carry clues to how fast the plasma in the plumes is streaming outward and how long they will last. By multiplying the relatively constant velocity times the lifetime, Daly can calculate a source's average size over its lifetime. As a result, in spite of differences in the radio galaxies' environments, she can convert each one into a standard yardstick, able to serve as a measure of the bending of space between Earth and the point where the source is observed in cosmic history.

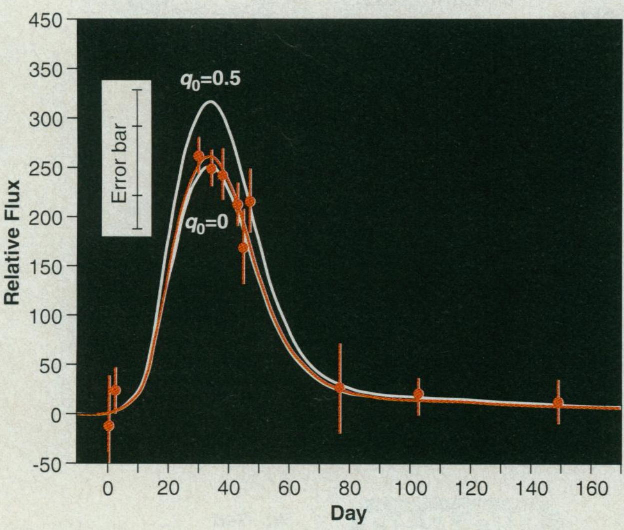

CHRIS CARILLI



Cosmic benchmark. Radio images show Cygnus A, a galaxy spurting twin plumes of radio-emitting plasma *(above)* from a compact nucleus *(right)*.

Her results for about 12 sources, to be published in the *Astrophysical Journal*, imply a q_0 too low for a universe with an omega of 1, but they are consistent with a low-mass universe—with an omega of, say, .1—either with or without a substantial cosmological constant. On the evidence of the radio galaxies, the cosmos will be spared a big crunch.

Still waiting to be applied is a potentially more sensitive test of the shape of space-time: examining the shapes of the million-light-year voids in the distribution of galaxies. As early as 1979, Charles Alcock of Lawrence Livermore National Laboratory and Bohdan Paczyński of Princeton pointed out that apparent changes in the shapes of such structures at great distances could, like tattoos on a growing body, reveal the stretching of space.



Brake light. The graph compares a supernova's measured brightness to the brightness expected if cosmic expansion is not slowing (q_0=0) or is slowing to a standstill (q_0=0.5).

The voids appear on redshift maps of galaxies, in which each galaxy's redshift is taken as a measure of its distance. Like the radio galaxies, the voids would reveal cosmic curvature by seeming to widen. But they would also provide an additional clue to q_0. If the universe is decelerating, they would appear stretched out along the line of sight, because the increasing ratio of redshift (apparent distance) to actual distance would seem to push their far edges outward.

The search for these distortions languished for about 15 years, says Ohio State's Ryden, because redshift mapping had been carried out only for limited chunks of sky. Now, however, astronomers from half a dozen institutions are collaborating in a vast mapping project, the Sloan Digital Sky Survey, which is expected to chart about a million galaxies at distances of up to two billion light-years. On an idealized "toy universe" that she created on a computer screen, Ryden has shown that distortions in the voids seen at that distance could be enough to distinguish between, say, a decelerating, omega=1 universe and a universe that is accelerating because of a cosmological constant. (See figure, p. 756.)

But Ryden cautions that the work, which is in press at the *Astrophysical Journal*, is an exercise in "highly modified optimism." Local or "peculiar" velocities in the real universe, she thinks, might confuse the redshift maps enough to blot out any hints of the universe's underlying shape.

All of which means that no single technique will be able to deliver a convincing verdict on the fate of the universe. Approaches "with different strengths and weaknesses" will be needed, says Perlmutter. And that's why astronomers are developing still other techniques. Caltech's Lange, for example, hopes to use x-ray emitting plasma clouds as standard candles, just as Perlmutter and his colleagues are using type Ia supernovas. And when the LIGO gravity-wave detector comes online in 1999, cosmologists may be able to take advantage of still another yardstick for measuring the geometry of the universe: pairs of neutron stars, powerful sources of gravity waves expected to be common enough for astronomers to use their distribution as a gauge of spatial stretching.

Even with all these tools for estimating q_0, the universe isn't likely to surrender the secret of its future easily. The necessary measurements still test astronomy to its limit, says David Schramm, an astrophysicist at the University of Chicago. "It's just so hard. I think it's going to remain hard." For cosmologists, like the rest of us, there's no easy road from dreams to reality.

–James Glanz