ASTRONOMY

Supernovae Offer a First Glimpse of the Universe's Fate

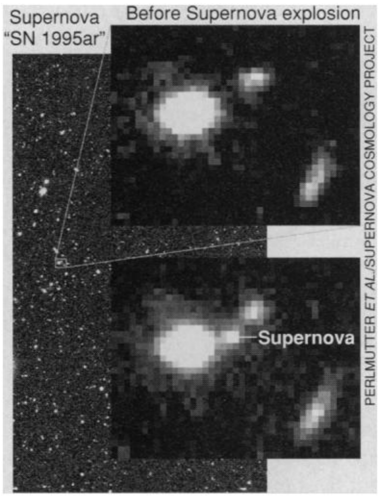
Of all cosmological questions, perhaps the most resonant is the universe's ultimate fate, billions of years in the future. Is the cosmos destined to expand forever, becoming ever more tenuous? Or will it eventually slow to a halt, or even recollapse into a state of near-infinite density? It all depends on the density of matter in the universe, because gravity is what slows the cosmic expansion, and also on whether space itself has an innate "springiness," as described by a term called the cosmological constant. But cosmologists don't know the value of either one well enough to predict the fate of the universe.

Now, by studying Type Ia supernovae—exploding stars visible at distances so vast that they represent earlier epochs of cosmic history—astronomers are getting a direct look at which way the universe is headed. By comparing the brightness of these beacons—an indicator of their distance—with the rate at which cosmic expansion is carrying them away, two groups of observers are now closing in on the rate at which cosmic expansion has changed over time. Both groups, one led by Saul Perlmutter of Lawrence Berkeley National Laboratory in California and the other by Brian Schmidt at the Australian National Observatory, have found and studied dozens of supernovae far out in the visible universe.

So far, only the Perlmutter group has announced results, at a Texas Symposium held in Chicago last December and in a paper soon to be published in *The Astrophysical Journal*. And these results are based on just seven of the distant supernovae. But they are enough to suggest that the density of matter in the universe may slow it to a halt, although perhaps only after an infinite amount of time has passed. "This is the first [systematic] attempt to use distant supernovae to constrain the deceleration and geometry of the universe," Schmidt notes.

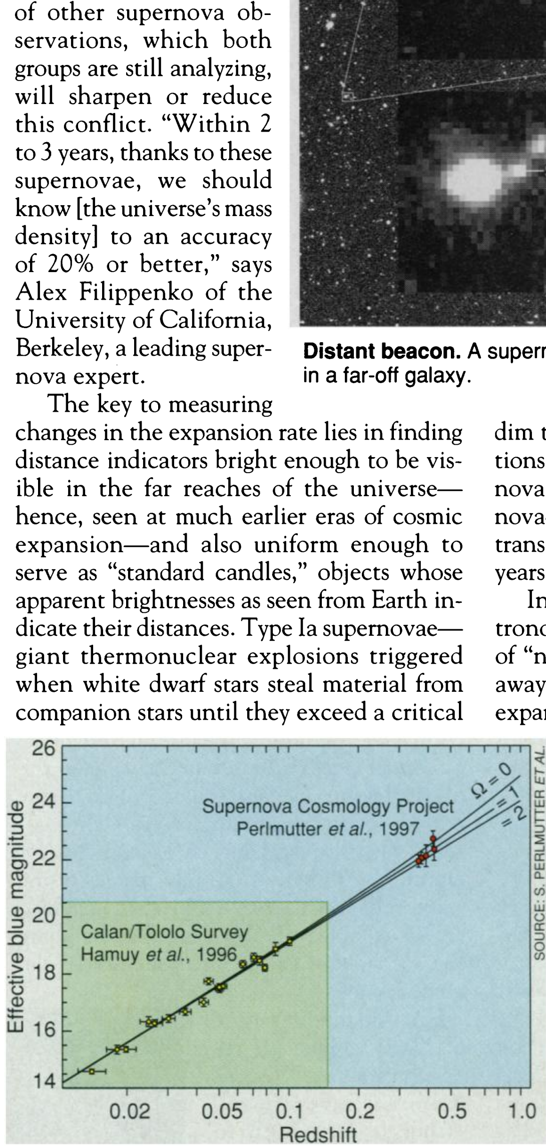
Although these first results come with large error bars—Schmidt judges them to be "uncertain, although not necessarily incorrect"—their implications are startling. If they prove to be correct, the cosmos contains hundreds of times more mass than can be seen as stars and galaxies, and several times more than can be traced indirectly. In addition, the tentative results leave little room for a cosmological constant—the hypothetical attractive or repulsive force exerted by empty space. That would please cosmologists, who have never been fond of the constant, but the results may conflict with other clues suggesting a low-density universe (see previous page).

Now, astronomers must wait to see whether scores of other supernova observations, which both groups are still analyzing, will sharpen or reduce this conflict. "Within 2 to 3 years, thanks to these supernovae, we should know [the universe's mass density] to an accuracy of 20% or better," says Alex Filippenko of the University of California, Berkeley, a leading supernova expert.



Distant beacon. A supernova flares in a far-off galaxy.

The key to measuring changes in the expansion rate lies in finding distance indicators bright enough to be visible in the far reaches of the universe—hence, seen at much earlier eras of cosmic expansion—and also uniform enough to serve as "standard candles," objects whose apparent brightnesses as seen from Earth indicate their distances. Type Ia supernovae—giant thermonuclear explosions triggered when white dwarf stars steal material from companion stars until they exceed a critical mass—have the needed brightness. Flaring to a maximum in 2 or 3 weeks, then fading over the following months, they are the most violent stellar events known. And, in principle, because the critical mass should be the same for each explosion, they should furnish good standard candles.



Hints of a slowdown. A handful of distant supernovae (red) suggests that high matter density—an omega close to 1.0—is slowing the cosmic expansion. Magnitudes are linked to distance and redshifts to velocity.

In practice, though, the peak brightness of these supernovae varies, threatening their usefulness as standard candles. But during the past 2 years, astronomers have learned how to recognize and compensate for these variations. Mark Phillips, Mario Hamuy, and Nicholas Suntzeff of the Cerro Tololo Inter-American Observatory in Chile have found that the brighter a supernova is at its peak, the more slowly it fades afterward. Hence, the shape of the supernova's "light curve"—its brightness over time—reveals its intrinsic luminosity at maximum light.

In addition, Adam Riess of the University of California, Berkeley (a member of the group led by Schmidt), has found a way to correct for the varying amounts of dust in the galaxies containing supernovae—variations that can dim their light. Together, these two corrections allow astronomers to turn each supernova into a standard candle. "Type Ia supernovae as distance indicators have made the transition from childhood to their teenage years," says Schmidt.

In one demonstration of their value, astronomers have used corrected observations of "nearby" Ia's, up to a billion light-years away, to track how fast the universe is now expanding—the so-called Hubble Constant. To measure it, observers need to know the speeds at which objects at different distances are flying away from the Milky Way. The velocity is the easy part, because the motion displaces the light of an object toward the long-wavelength end of the spectrum, creating a "redshift" that is simple to measure. But finding standard candles reliable enough to measure absolute distances has been much more difficult.

Astronomers have tried using objects ranging from pulsating stars to giant gas clouds as standard candles, and they have derived many different values for the Hubble constant. But when the corrected supernova observations entered the fray (*Science*, 24 November 1995, p. 1295), they yielded a result that could eventually help end the debate. Late last year, for example, Riess, along with Robert Kirshner and William Press of the Harvard-Smithsonian Center for Astrophysics in Cambridge, Massachusetts, reported a Hubble constant of 64 kilometers per second per megaparsec (1 megaparsec equals 3.26 million light-years), a figure many astronomers find plausible.

Cosmic slowdown. Now, by finding, correcting, and analyzing supernovae at much greater distances (as much as 7 billion light-years), the Perlmutter and Schmidt groups are learning how this expansion rate has changed over cosmic history. In the nearby universe, where the expansion hasn't changed much, the corrected brightnesses of the supernovae should fall along a straight line when plotted against redshift. For supernovae in the far-distant, long-vanished universe, however, the line should begin to bend, indicating that the expansion rate was different at earlier times.

The amount of bending holds clues to the "geometry" of the cosmos—whether we live in an "open" universe, doomed to expand forever, a "closed" universe that will eventually recollapse, or the state just in between, which theoretical cosmologists prefer because it is predicted by a favorite scenario for the early universe called inflation. Two factors can change the expansion rate, thus bending the line: the mass density of the cosmos—expressed as omega, the ratio of the actual density to the density predicted by inflation—and the cosmological constant.

Most theorists would prefer the cosmological constant to be zero, because they have no good way to justify any other value. But there is strong motivation to accept a positive value: This property of empty space could increase omega, reconciling the density predicted by inflation with the apparent lack of mass in the universe. All the visible stars and galaxies provide an omega less than 0.01, and even tallying all the invisible "dark matter" suggested by indirect measurements brings omega up to only 0.2 or 0.3. A cosmological constant could push omega up to the long-sought 1.0.

Fortunately, mass and a cosmological constant have different effects on the way the expansion rate varies over time. With enough distant supernovae at a range of different redshifts, astronomers should be able to disentangle these effects. The Perlmutter and Schmidt groups have used automated techniques to spot scores of distant supernovae, but analyzing and correcting these observations require months of effort. They also require waiting a year or so to make follow-up observations of the supernova host galaxies, so that the galaxies' own light can be subtracted from the supernova measurements.

With only seven distant supernovae analyzed so far, covering just a modest range in redshift, the Perlmutter group can only hint at the answer. But their preliminary results suggest that mass accounts for an omega of about 0.9, implying the existence of vastly more dark matter than has been traced so far, and the cosmological constant for an effective omega of only 0.1. The uncertainties are broad, however, leaving open the possibility that matter accounts for an omega as small as 0.3 and that the cosmological constant has a substantial value.

The Perlmutter group's competitors say even this level of accuracy may be overly optimistic. "The actual [uncertainties] may be larger than those that are quoted," says Kirshner, who notes that those in the Perlmutter group followed different procedures in observing their distant supernovae from the ones that Hamuy, Phillips, and Suntzeff used when they learned how to correct nearby supernovae to a standard brightness. What's more, says Schmidt, the Perlmutter group observed their first seven supernovae in one color, even though two or more colors give a better indication of reddening and dimming from dust.

Richard Ellis of Cambridge University in the U.K., a member of Perlmutter's group, responds that "even with the best will in the world, it is not possible to treat low- and high-redshift data identically" because of differences in the intensity and colors of light from near and distant supernovae. Ellis adds that the Perlmutter group has done a better job at finding the farthest of these beacons, having cataloged some that lie twice as far away as their first seven.

More detailed analysis of these and the dozens of other distant supernovae that the Perlmutter and Schmidt groups have observed will narrow the uncertainties. Both groups have been assigned large amounts of time on the Hubble Space Telescope during its next observing cycle, which begins this July, for follow-up observations of the supernova host galaxies. And by the end of 1998, both should have completed their work and had a chance to compare it. "I won't believe 'the answer' unless we both get the same answer," says Riess. Perlmutter concurs: "It's great that there are two projects—there are so many things you can do wrong. Of course, we started first, and we would like to have our results out first."

Either, way, thanks to Type Ia supernovae, cosmologists now stand on the threshold of knowing the shape of the universe—and the shape of things to come.

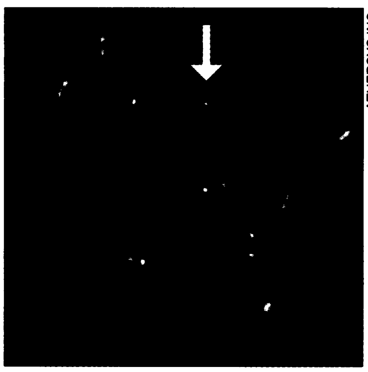
–Donald Goldsmith

Donald Goldsmith's most recent book on astronomy, Worlds Unnumbered: The Search for Extrasolar Planets, *has just been published by University Science Books of Sausalito, California.*

MOLECULAR BIOLOGY

Counterfeit Chromosomes for Humans

The name is not very elegant—YACs, standing for yeast artificial chromosomes. But for about a dozen years, these artificial constructs, containing the minimal elements of a functional chromosome, have been the basis of some elegant science. They have both aided understanding of yeast chromosome function and served as vehicles for cloning large genes from any species, using yeast cells' own DNA-replication machinery. Now, however, YACs may have to share the spotlight with HACs: human artificial chromosomes.



ATHERSYS INC.

HAC for hire. Humanmade microchromosomes (arrow) could shelter supplementary human genes.

In this month's issue of *Nature Genetics*, researchers at Case Western Reserve University and Athersys Inc., both in Cleveland, report constructing the first wholly synthetic, self-replicating, human "microchromosomes," one-fifth to one-tenth the size of normal human chromosomes. While the team still hasn't found an efficient way of transplanting microchromosomes' self-assembling components into new cells—a crucial step before researchers can exploit them fully—future refinements could give HACs even broader research applications than YACs.

"They have created a system where they can now do a great deal to analyze [human chromosome] function," says David Schlessinger, a genome researcher at Washington University in St. Louis. Custom-made HACs could, for example, help reveal how each gene's chromosomal packaging affects its activity. And there may also be medical payoffs: These chromosomes-in-miniature could be loaded with genes that are missing or impaired in patients with genetic disorders such as muscular dystrophy, then introduced into the patients' cells to compensate for the defect.

Biologists have wanted to mimic human chromosomes ever since they performed the feat for yeast. To make YACs, researchers combine telomeres, the protective DNA seg-