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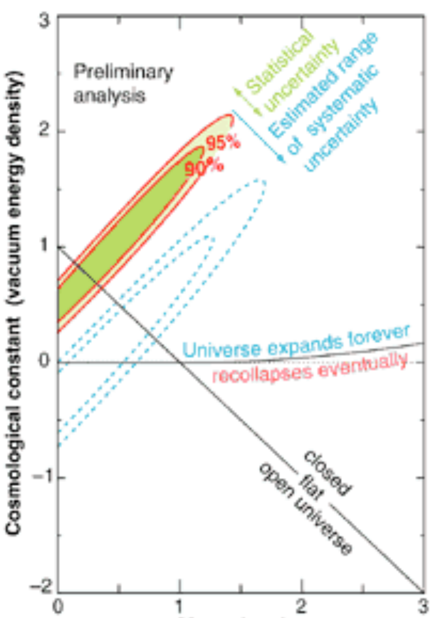
NEWS

ASTRONOMY:
Exploding Stars Point to a Universal Repulsive Force

James Glanz

By now, even newspaper readers with a casual interest in astronomy may have heard the unsettling message delivered by distant, exploding stars called supernovae: The universe will likely expand infinitely, growing ever more tenuous. Now a new batch of supernovae has lent support to a strange picture of just what the universe is made of. A preliminary analysis may provide the first strong evidence that the universe could be permeated by a large-scale repulsive force. The reservoir of energy fueling that force could be anything from a quantum-mechanical shimmer in empty space, called the cosmological constant, to even more exotic possibilities that go by names like X-matter and quintessence.



Mass density

What the stars show. A preliminary analysis of 40 distant supernovae, reported by the Supernova Cosmology Project, offers strong evidence for an energy density in empty space, if space is "flat." The green regions indicate statistical uncertainties; the dashed lines show the preliminary estimates (now being refined) if all the systematic uncertainties added up in one direction.

S. PERLMUTTER *ET AL.*, SUPERNOVA COSMOLOGY PROJECT

At the meeting of the American Astronomical Society in Washington, D.C., earlier this month, Saul Perlmutter of Lawrence Berkeley National Laboratory in Berkeley, California, announced that he and an international team of observers have now studied a total of 40 far-off supernovae, using them as beacons to judge how the cosmic expansion rate has changed over time. Not only did the results support the earlier evidence that the expansion rate has slowed too little for gravity ever to bring it to a stop; they also hinted that something is nudging the expansion along. If they hold up, says Perlmutter, "that would introduce important evidence that there is a cosmological constant."

"It would be a magical discovery," adds Michael Turner of the University of Chicago. "What it means is that there is some form of energy we don't understand." Other observers had already found signs that the universe contains far less mass than the mainstream theory of the big bang predicts, which left open the possibility that some form of energy in empty space could be making up the deficit. The cosmological constant--also called lambda--is a longtime candidate for serving as this energy reservoir. But the new observations are encouraging cosmologists to speculate about other ways to flesh out the universe with pure energy, ones that may fit more comfortably with recent observations.

Even before the latest supernova results, cosmologists were warming toward a high-lambda universe, as it's called, because their preferred picture of the big bang implies that the present universe should have a specific density of matter or its equivalent in energy. In this picture, called inflation, the big bang was sparked when a fleck of the primordial vacuum underwent a chance fluctuation that filled it with something much like a colossally intense cosmological constant. This "scalar," or directionless, field drove the patch into an exponential growth spurt. As the patch expanded and cooled, energy from the scalar field fed an explosion of material particles: The material universe was born--"creating everything from nothing," as the theory's creator, Alan Guth of the Massachusetts Institute of Technology, puts it.

During the exponential growth spurt, inflation would have ironed out any primordial curvature of space-time into a universe that is geometrically "flat." Because both mass and energy can curve space-time, according to Einstein's theory of relativity, a flat universe has to contain a specific density of mass-energy. Known as an omega of 1, that density--if it all takes the form of mass--would be just enough to halt cosmic expansion after an infinite time. But the mass just doesn't seem to be there.

Neta Bahcall and Xiaohui Fan of Princeton University, for example, have probed the cosmic mass density by searching for giant clusters of galaxies that had coalesced when the universe was less than half its present age. In a dense, mass-dominated universe, such cosmic "Mount Everests" should be vanishingly rare at that stage of cosmic history, says Bahcall--otherwise, powerful gravity would have continued to snowball them into a much lumpier galaxy distribution than we see in the sky today.

But Bahcall and Fan have already detected a few of these early clusters, "and there may be more," she says, implying that matter can account for an omega of only 0.1 to 0.3.

Those numbers mesh nicely with previous measurements from Perlmutter's group and another supernova search team. Each used the apparent brightnesses of a handful of remote supernovae, observed either from the ground or with the Hubble Space Telescope, to gauge their distances from Earth. They plotted those distances against the "redshifts" of the light--a measure of how fast cosmic expansion is sweeping the supernovae outward--to judge cosmic expansion at the time they exploded, billions of years ago. Then they compared that result with findings from nearby supernovae to see how much the expansion has changed over time. Both teams concluded that the expansion had slowed so little that it will probably go on forever--the hallmark of a low-density universe (*Science*, 31 October 1997, p. 799,).

To salvage inflation--at least the simplest version of the theory--something has to be making up for the mass deficit to flatten the universe again. Now the Perlmutter team has come up with positive evidence for that possibility. When they added 34 new supernovae, observed from the ground, to the six they had already studied, they were able to discern an extra boost to the expansion rate that could be caused by a cosmological constant. With the new supernovae added in, the data now favor a lambda larger than about 40% of the energy density for closure in a flat universe. The team has not yet finished correcting the new supernovae for several factors that could have skewed the brightness measurements. But so far, says Perlmutter, the remaining corrections appear to be small.

The most familiar of the strange possibilities raised by this finding is the cosmological constant itself. Einstein was the first to propose this universal repulsive force, although he later abandoned the idea. Lately, theorists have been dusting it off again and speculating about sources for the energy, such as the fleeting particles that wink in and out of existence in empty space, according to quantum mechanics. But calculations based on that idea lead to lambdas that are wildly out of line with reality--50 to 125 orders of magnitude too large.

Moreover, the plain-vanilla cosmological constant would have been stretching all of space throughout the lifetime of the cosmos. As a result, a large lambda should affect such observable features of the universe as the frequency with which distant galaxies happen to fall directly behind foreground galaxies, allowing the nearer galaxy to act as a gravitational lens and bend the distant light. A powerful lambda would also begin to overpower gravity as the universe expands, setting limits on the formation of large-scale structure. To some cosmologists, these features are setting uncomfortably tight limits on a cosmological constant.

So theorists are playing with alternatives. "People have started to realize that there are lots of good models that may even be more physically motivated," says Martin White of the University of Illinois, Urbana-Champaign, who updated earlier work on what he and Turner call X-matter. X-matter would permeate the universe with a uniform density of energy, fueled by sources that could range from exotic wrinkles in the fabric of space-time, called textures or light cosmic strings, to some mysterious scalar field. Unlike the cosmological constant, it could change as the universe expanded, ramping down the "pressure" through which it affects matter and evading the gravitational lensing constraints, for example.

Like ordinary matter, however, such an energy reservoir would form denser and more rarefied regions over time as gravity acted on it. Paul Steinhardt of the University of Pennsylvania and his collaborators have explored that behavior in a physically consistent candidate for a variable background energy, which they call quintessence. Quintessence, says Steinhardt, might not only flesh out the universe to an omega of 1 but, by evolving a structure of its own, might also have influenced the formation of giant gatherings of galaxies.

Any form of background energy would also have shaped how ripples grew in the primordial sea of matter soon after the big bang, says Steinhardt. And because those ripples left their mark on the cosmic microwave background--the afterglow of the big bang--the high-resolution maps of the cosmic background that are expected from spacecraft early in the next century could point to the true nature of the universe's hidden energy. Meanwhile, physicists and cosmologists have plenty to speculate about. Strange as every possibility may sound, it's a strangeness that cosmologists may have to live with.