

The Curious Energy of the Void

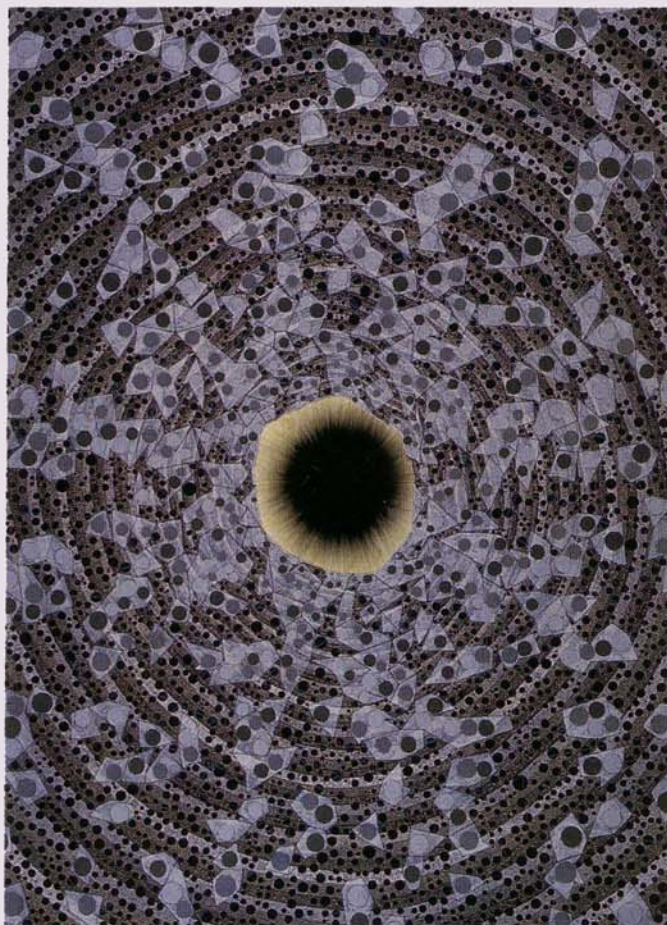
Dark energy is making the universe bigger and bigger, faster and faster.

By Donald Goldsmith

In February 1998 new observations of exploding stars in distant galaxies stood the world of cosmology on its ear. The expansion of the universe, far from slowing down, as earlier theories had implied it should, turned out to be speeding up. Objects in the universe are moving apart from one another at progressively greater speeds. The new findings foretell a future in which the cosmos becomes an unimaginably vast, cold, dead, and barren expanse of near-nothingness.

How did astronomers reach such a startling conclusion?

In 1916 Einstein, shortly after completing the formulation of his theory of general relativity, discovered that the solutions to a key equation within the theory implied that the universe must always be either expanding or contracting. Einstein's pencil-and-paper discovery took him by surprise, because astronomers of the era had no evidence to suggest that the universe either expands or contracts. To fix what he then took to be an error, he restated his key equation with an additional, constant term—which quickly became known as the cosmological constant. If the constant had precisely the right value, Einstein wrote in



Andrea Way, *The Holy Tree*, 1997

***The Extravagant Universe:
Exploding Stars, Dark Energy,
and the Accelerating Cosmos***
by Robert P. Kirshner
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1917, the universe could exist in a state of perfect, static balance.

But the Russian mathematician

Alexander Friedmann soon demonstrated that such a static universe must be balanced, as it were, on a knife edge: the slightest tremor would topple it over in one direction or the other, into a state of either expansion or contraction. Another, even more serious objection to Einstein's solution appeared in 1929, when Edwin Hubble discovered that the cosmos is indeed expanding. On distance scales as large as the ones between clusters of galaxies, all objects are moving away from all other objects at speeds that increase in proportion to the distances between them. (Cosmologists imagine the expanding universe most simply as the three-dimensional analogue of the skin of a balloon. As the balloon expands, every point on the skin of the balloon moves away from all others, yet no one point is motionless.)

Einstein soon pronounced the cosmological constant a dead letter, calling it his "greatest blunder."

The results announced in 1998 effectively resurrected Einstein's "blunder." Those observations included two kinds of measurements: first, the distances to certain kinds of supernovas, or exploding stars, that astronomers discovered in distant galaxies; and second, the speeds with

which those galaxies are receding from us. But when astronomers tried to describe the relation between those distances and speeds, they found they had to restore Einstein's full equation from 1917, including a nonzero cosmological constant.

The value that the 1998 observations imply for the cosmological constant is not equal to the value Einstein adopted to keep the universe static—after all, the two kinds of universe could hardly be more different. But the fact that the recent observations require a nonzero value for the constant carries a tremendous implication: Every cubic centimeter of what seems to be empty space instead teems with hidden energy, which astronomers now call dark energy. As the universe expands from its origins in the big bang, more space continuously comes into being, and so the total amount of dark energy also increases proportionately. The ever-growing amount of dark energy progressively accelerates the universal expansion. Although gravity acts in the opposite sense, tending to slow the expansion because all matter in the universe attracts all other matter, the expansionist tendency of the dark energy has now become dominant. The cosmos has entered a phase of accelerating expansion.

Such a striking result should be accepted with caution. Astronomers have spent years determining the distances and velocities of remote galaxies. Although the galaxies' velocities can be found relatively easily by measuring the shift in the colors of their light, finding their distances has proved much more difficult. In fact, astronomers could make only fairly crude estimates of the distance to any faraway galaxy—until they identified a marvelous type of exploding star called a type Ia supernova (or SN Ia for short).

Like the light from other exploding stars, the apparent brightness of a type Ia supernova grows for a few days, reaches a peak, and then fades away

over several months' time. But unlike other supernovas, all type Ia supernovas at their brightest generate nearly the same amount of energy per second. Thus they furnish astronomers with "standard candles," objects that are almost identical in their intrinsic luminosities. If observers can identify two such supernovas in different galaxies, measuring how bright they appear at their peak outputs is enough to calculate their relative distances. For example, if one SN Ia appears four times as bright as another, the fainter supernova must be twice as distant as the brighter one (by simple geometry, the brightness decreases with the square of the distance).

This method works only if astronomers can identify exploding stars as members of the SN Ia class and can control for the fact that, even within that class, some variation does exist. Beginning in 1995, two competing groups of astronomers have been obtaining brightness measurements of type Ia supernovas to analyze the expansion of the universe.

At first the findings of the two groups contradicted each other, leading to suspicions within each group that the data from the other group were flawed. The cause of science could hardly ask for more favorable circumstances. There is probably no better way to check the accuracy of one group's results than to pit that group against another, particularly if the second group suspects the first of promulgating grievous errors. In this case, happily, the results converged. As improved techniques began to eliminate the differences in the observational data, both groups concluded that their measurements could be explained only if the universe has a nonzero cosmological constant.

Robert Kirshner, a supernova expert at Harvard, has written an excellent insider's account of the race to discover the fate of the cosmos. In *The Extravagant Universe* Kirshner skillfully weaves the details of his career—which brought him to the

leadership of one of the SN Ia observer groups—into the larger cosmic story. Along the way he pauses to describe a host of astronomical phenomena, from the life cycles of stars to the effect of the cosmological constant on the universe's expansion.

Kirshner shows an impressively deft touch with complex explanations, and he doesn't hesitate to bridge gaps in the reader's knowledge with an apt metaphor. For example, one of the constraints on the synthesis of every element heavier than helium is that no atomic nucleus only slightly heavier than helium is stable in nature. As a result, no natural process can make the heavier elements by adding protons or neutrons one by one to a helium nucleus. How then do stars succeed in doing so? As Kirshner puts it, they "skip across that gap, as improbably as crossing a stream by stepping on a salmon, to fuse three helium nuclei into a single carbon nucleus." The image may not exactly explain the phenomenon,

but it remains satisfyingly in mind.

The Extravagant Universe presents an intriguing history of how supernova observers discovered the accelerating universe. But the full story of the acceleration has another crucial aspect. In 1999 and 2000, radio astronomers announced that entirely independent observations—made by radio telescopes studying the faint glow from the early universe known as the cosmic microwave background (CMB)—likewise imply a nonzero cosmological constant. Hence they, too, imply an accelerating universe.

The new data are arguably even more fundamental than the observations of distant supernovas. Not only do they reveal an accelerating universe; they also record how the amount of radiation generated by the universe in the earliest years of its expansion varies in different directions in space. By measuring those variations astronomers can determine how strongly space is curved. The amount of curvature depends on the sum of

the dark energy and the energy locked up in all the matter in the universe—the second of which, at least in theory, is equivalent to the energy given by Einstein's famous formula $E = mc^2$. Hence measuring the variations in the cosmic microwave background can help determine the amount of dark energy in the universe.

The supernova observations, in contrast, give the difference between the amount of dark energy, which accelerates the expansion of the universe, and the amount of matter, whose mutual gravitational attraction slows it down. In the best of all worlds, combining the results from the radio and the supernova observations will give an accurate measurement not only of the amount of dark energy but also of the amount of matter—most of which, as it happens, is made up of a completely unknown form called dark matter.

Kirshner deals only in passing with the CMB observations, yet those data are highly relevant to the story because they have sharply increased astronomers' confidence that the cosmic expansion is accelerating. A further exploration of that story, however, would require another book. *The Extravagant Universe* delivers the promise of its subtitle extremely well, and should serve as the definitive insider's story of how Kirshner led his motley group of astronomers to glory in their search to find the fate of the universe. Nothing now remains for cosmology—except to explain why the universe has turned out the way it has. That's a big challenge for our new century, but, given the remarkable successes so far, it may prove to be well within our grasp.

Donald Goldsmith, an astronomer and science writer, won the 1995 Annenberg prize, given by the American Astronomical Society for outstanding contributions in popularizing astronomy. His most recent books on cosmology are Einstein's Greatest Blunder? (Harvard University Press) and The Runaway Universe (Perseus Books).