

# FROM SLOWDOWN to SPEEDUP

By Adam G. Riess and Michael S. Turner

Distant supernovae are revealing the crucial time when the expansion of the universe changed from decelerating to accelerating

From the time of Isaac Newton to the late 1990s, the defining feature of gravity was its attractive nature. Gravity keeps us grounded. It slows the ascent of baseballs and holds the moon in orbit around the earth. Gravity prevents our solar system from flying apart and binds together enormous clusters of galaxies. Although Einstein's general theory of relativity allows for gravity to push as well as pull, most physicists regarded this as a purely theoretical possibility, irrelevant to the universe today. Until recently, astronomers fully expected to see gravity slowing down the expansion of the cosmos.

In 1998, however, researchers discovered the repulsive side of gravity. By carefully observing distant supernovae—stellar explosions that for a brief time shine as brightly as 10 billion suns—astronomers found that they were fainter than expected. The most plausible explanation for the discrepancy is that the light from the supernovae, which exploded billions of years ago, traveled a greater distance than theorists had predicted. And this explanation, in turn, led to the conclusion that the expansion of the universe is actually speeding up, not slowing down. This was such a radical finding that some cosmologists suggested that the falloff in supernova brightness was the result of other effects, such as intergalactic dust dimming the light. In the past few years, though, astronomers have solidified the case for cosmic acceleration by studying ever more remote supernovae.

But has the cosmic expansion been speeding up throughout the lifetime of the universe, or is it a relatively recent development—that is, occurring within the past five billion years or so? The answer has profound implications. If scientists find that the expansion of the universe has always been accelerating, they will have to completely revise their understanding of cosmic evolu-

tion. But if, as cosmologists expect, the acceleration turns out to be a recent phenomenon, researchers may be able to determine its cause—and perhaps answer the larger question of the destiny of the universe—by learning when and how the expansion began picking up speed.

## Battle of Titans

ALMOST 75 YEARS AGO astronomer Edwin Hubble discovered the expansion of the universe by observing that other galaxies are moving away from ours. He noted that the more distant galaxies were receding faster than nearby ones, in accordance with what is now known as Hubble's law (relative velocity equals distance multiplied by Hubble's constant). Viewed in the context of Einstein's general theory of relativity, Hubble's law arises because of the uniform expansion of space, which is merely a scaling up of the size of the universe [see top illustration in box on page 65].

In Einstein's theory, the notion of gravity as an attractive force still holds for all known forms of matter and energy, even on the cosmic scale. Therefore, general relativity predicts that the expansion of the universe should slow down at a rate determined by the density of matter and energy within it. But general relativity also allows for the possibility of forms of energy with strange properties that produce repulsive gravity [see box on page 66]. The discovery of accelerating rather than decelerating expansion has apparently revealed the presence of such an energy form, referred to as dark energy.

TO MEASURE DISTANCES across the universe, astronomers rely on type Ia supernovae, which are represented in this photograph by lightbulbs.

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