Dark energy

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| **Homing in on Dark Energy with Supernova Studies from Space *— What is Dark Energy?*** |
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**BERKELEY, CA** � When SCP researchers initially set out to measure the expansion rate of the universe, they expected to find that distant supernovae appeared brighter than their redshifts would suggest, indicating a slowing rate of expansion. Instead they found the opposite: at a given redshift, distant supernovae were dimmer than expected. Expansion was accelerating.Not only did this discovery mean that the universe would never come to an end, more fundamentally it implied that a large part of the universe is made of something we know nothing about — the mysterious whatever-it-is that goes by the name "dark energy."

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| **As this NASA chart indicates, 70 percent or more of the universe consists of dark energy, about which we know next to nothing.** |
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Later, new measurements of cosmic microwave background (CMB) radiation provided strong evidence that the universe is flat (having an overall geometry of space like Euclid's, in which parallel lines never meet or diverge) — and because there is not enough matter in the universe, whether visible or dark, to produce flatness, the difference can be attributed to dark energy, providing a strong confirmation of the supernova measurements.The first attempt to explain the nature of dark energy was by invoking Albert Einstein's notorious "cosmological constant," an extra term he introduced in the equations of the theory of general relativity early in the 20th century under the mistaken impression, shared by astronomers and cosmologists of the time, that the universe was static. The cosmological constant, which Einstein signified by the Greek letter lambda, made it so.Einstein happily abandoned the cosmological constant when, in 1929, Edwin Hubble found the universe was not static but expanding. However, lambda came back strong — albeit 70 years later! — when supernova studies led to the discovery that expansion was accelerating."For the cosmological constant, the vacuum — space itself — possesses a certain springiness," says Eric Linder, a cosmologist at Berkeley Lab and director of the Center for Cosmology and Spacetime Physics at Florida Atlantic University. "As you stretch it, you don't lose energy, you store extra energy in it just like a rubber band."Such springiness, whether of matter, energy, or space itself, is described mathematically by a term called the equation-of-state parameter (*w*). For lambda, the value of this parameter is minus one, corresponding to a component of the universe that has "negative pressure" — unlike matter or radiation, which have zero or positive pressure. True to its name, the cosmological constant doesn't change over time: the energy stored by lambda scales uniformly, increasing exactly as the volume of the universe increases.The problem is that the most obvious source for lambda's stored energy is what quantum theory calls the energy of the vacuum — so much more powerful (10 to the 120th power!) than what's been observed for lambda, Linder says, that if this were the dark energy "it would overwhelm the expansion of the universe. It would have brought the universe to a swift end a miniscule fraction of a second after it was created in the big bang."Other explanations of dark energy, called "quintessence," originate from theoretical high-energy physics. In addition to baryons, photons, neutrinos, and cold dark matter, quintessence posits a fifth kind of matter (hence the name), a sort of universe-filling fluid that acts like it has negative gravitational mass. The new constraints on cosmological parameters imposed by the HST supernova data, however, strongly discourage at least the simplest models of quintessence.Quite different "topological defect" models attribute dark energy to defects created as the early universe cooled, during the phase changes that precipitated different forces and particles from a highly symmetrical early state.Certain of these theoretical defects, known as domain walls, could have partitioned space into distinct cells whose boundaries would have repulsive gravity, thus filling the role of dark energy. But the new HST supernovae study rules out — with 99 percent certainty — domain walls as the source of dark energy.While the case for the cosmological constant looks strong by comparison to these alternatives, many other exciting possibilities remain. Some even propose a cosmos in which our universe, having three dimensions of space, is afloat in a higher-dimensional world, with gravity free to interact among the dimensions.Or there could be a time-varying form of dark energy that only temporarily mimics lambda. If it becomes less gravitationally repulsive in the future, it could bring acceleration to a halt, perhaps even causing expansion to reverse and triggering the collapse of the universe.The opposite is also possible: superaccelerating dark energy. These models have *w*, the equation-of-state parameter, less than minus one — unlike lambda, stored energy would not scale uniformly as the universe expands but increase faster than the increase in volume.

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|  | **The SuperNova/Acceleration Probe, SNAP, is a satellite designed to study dark energy through the discovery and precision measurement of thousands of distant supernovae.** |  |
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"One of the goals of the SuperNova/Acceleration Probe satellite is to determine whether *w* may be changing with time," says Saul Perlmutter, coprincipal investigator of the SNAP satellite now under development. "This will help us narrow the possibilities for the nature of dark energy. That's an exciting prospect for physicists, because understanding dark energy will be crucial to finding a final, unified picture of physics." |