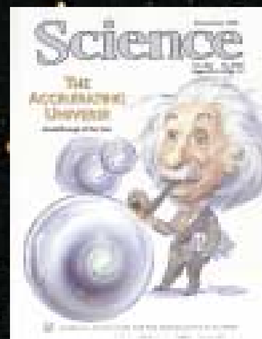
The accelerating universe, breakthrough of the year

— the cover of *Science*,
18 December 1998



What is dark energy?

"Maybe the most fundamentally mysterious thing in basic science."
— Prof. Frank Wilczek

"This is the biggest embarrassment in theoretical physics."
— Prof. Michael Turner

"Would be number one on my list of things to figure out."
— Prof. Edward Witten

"Right now, not only for cosmology but for elementary particle theory, this is the bone in our throat."
— Prof. Steven Weinberg

SNAP

The SNAP project, now being formulated, is headquartered at the Department of Energy's Lawrence Berkeley National Laboratory in Berkeley, California. Visit the SNAP web page at http://snap.lbl.gov/.

SNAP SUMMARY

telescope aperture	2 meters
field of view	optical, 1° x 1°
optics configuration	3-mirror anastigmat
effective focal length	20 meters
diffraction limit	1 µm
wavelength coverage	0.35 µm to 1.7 µm
pointing stability	within .03 arcsec, focal plane feedback
orbit	high inclination polar orbit, 7 or 14 day period
telemetry	50 Mbit/s

OPTICAL PHOTOMETRY REQUIREMENTS

field of view	1° x 1°
plate scale	1 pixel ~ 0.1 arcsec
mosaic	128 3k x 3k mosaic
wavelength coverage	.035 µm to 1 µm
detector type	high-resistivity p-channel CCDs
detector temperature	150 K
quantum efficiency	>85% at 0.4 µm - 0.8 µm
read noise	4 e- at 100 kHz
exposure time	up to 600 seconds
dark current	0.08 e- /min/pixel
filter wheel	15 bands (U, V, R, I, Z, and 10 special filters)

INFRARED PHOTOMETRY REQUIREMENTS

field of view	up to 10' x 10'
plate scale	1 pixel ~ 0.1 arcsec
mosaic	4 2k x 2k mosaic
wavelength coverage	1 µm to 1.7 µm
detector type	HgCdTe (1.7 µm cutoff)
detector temperature	130 K
read noise	5 e- (multiple samples)
dark current	3 e- /min/pixel
filters	J and H, plus 5 special filters

3-ARM SPECTROGRAPH REQUIREMENTS

OPTICAL	
spectrograph architecture	integral field spectrograph
wavelength coverage	0.35 µm to 0.6 µm, .55 µm to 1 µm
spatial resolution of slicer	0.07 arcsec
field of view	2" x 2"
resolution	15Å, 30Å, 100Å selectable
detector type	CCD
detector array temperature	150 K
quantum efficiency	>85% at 0.4 µm - 0.8 µm
read noise	2 to 4 e-
dark current	<0.08 e- /min/pixel
INFRARED	
spectrograph architecture	integral field spectrograph
wavelength coverage	0.9 µm to 1.7 µm
spatial resolution of slicer	0.12 arcsec
field of view	2" x 2"
resolution	30Å, 50Å, 200Å selectable
detector type	HgCdTe
detector temperature	120 K
read noise	<5 e- (multiple samples)
dark current	1 e- /min/pixel

SNAP

SuperNova/Acceleration Probe

Dark Energy in the Accelerating Universe

PRELUDE TO DISCOVERY

For over ten years the Supernova Cosmology Project, an international collaboration centered at Lawrence Berkeley National Laboratory and the University of California at Berkeley, and supported by the Department of Energy, the National Science Foundation, and NASA, has been studying the expansion of the universe by measuring the redshift and brightness of distant type Ia supernovae.

Type Ia supernovae — stars that explode in thermonuclear cataclysms brighter than entire galaxies — make ideal “standard candles” with which to survey the universe. Their light curves and spectra are all nearly alike and they are bright enough to be seen across billions of light years.

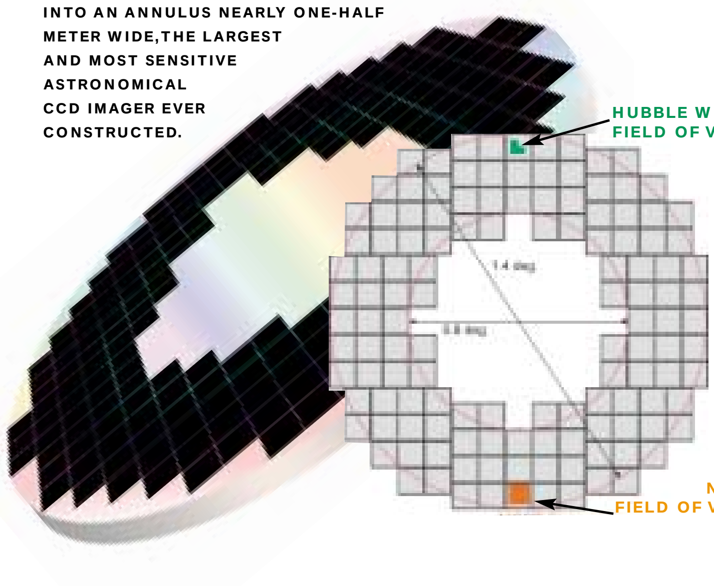
By 1998 a few score type Ia supernovae had been analyzed in detail, enough to lead the Supernova Cosmology Project and their colleagues in the High-Z Supernova Search Team to a startling discovery: the expansion of the universe is not slowing, as had been expected, but accelerating.

Redshift in an accelerating universe

As light travels through space, space itself is expanding. The effect is to stretch light waves and shift their color toward the red end of the spectrum.

Light from the most distant galaxies has traveled billions of years, giving a snapshot of the universe at a fraction of its present age. If expansion were slowing under the influence of gravity, supernovae in distant galaxies should appear brighter and closer than their high redshifts suggest.

AN ARRAY OF CCD CHIPS WILL BE ASSEMBLED INTO AN ANNULUS NEARLY ONE-HALF METER WIDE, THE LARGEST AND MOST SENSITIVE ASTRONOMICAL CCD IMAGER EVER CONSTRUCTED.



The distant supernovae found so far tell a different story. At high redshifts, the most distant are dimmer than they would be if expansion were slowing; they must be located farther away than would be expected for a given redshift — powerful evidence that the expansion rate of the universe is accelerating.

WHILE LIGHT FROM A DISTANT GALAXY TRAVELS ACROSS SPACE, SPACE ITSELF, LIKE THIS BALLOON, IS EXPANDING. THE WAVELENGTH OF THE LIGHT INCREASES, AND ITS SPECTRUM SHIFTS TOWARD THE RED.

The cosmological constant

In the very dense early universe, when matter was close together, gravitational attraction was strong and expansion was slowing. Today, because of continued expansion, matter is farther apart and the density of the universe is low — so low that it has apparently dropped below the density of some unidentified “dark” energy now causing it to expand ever faster.

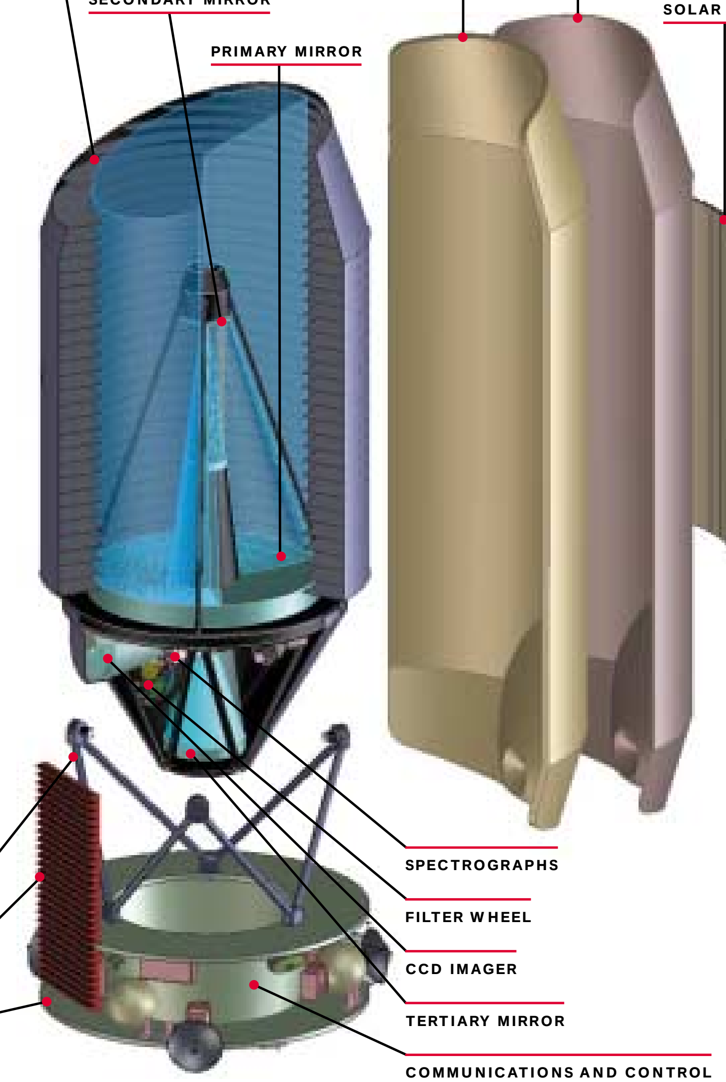
The dark energy may be what Albert Einstein called the “cosmological constant,” an arbitrary term he added to the general theory of relativity to make sure it described a static universe. Although Einstein later abandoned the idea, evidence for an accelerating universe has forced cosmologists to consider the existence of a cosmological constant once again.

In a typical galaxy, type Ia supernovae occur only a few times in a millennium, and so far only several dozen have been measured with enough precision to answer key cosmological questions. Before the nature of the dark energy can be determined with confidence, observations of many more supernovae over a wider range of redshifts are needed — observations with much better control on systematic uncertainties.

THE PROPOSAL: A SATELLITE TO UNVEIL THE DARK ENERGY

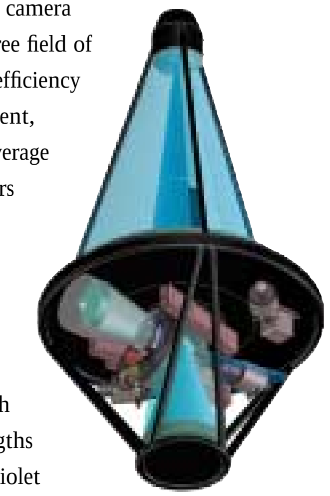
The proposed SNAP satellite — the SuperNova/Acceleration Probe — will orbit a three-mirror, 2-meter reflecting telescope. By repeatedly imaging 20 square degrees of the sky, SNAP will discover and accurately measure 2,000 type Ia supernovae a year, 20 times the number from a decade of ground-based search.

New supernovae will be discovered at redshifts greater than any yet found. Because of SNAP’s ability to measure light curves and spectra to high precision, any uncertainties concerning the brightness and redshift of very distant supernovae can be minimized.



SNAP’s optics will serve a set of precision instruments:

- a billion-pixel CCD camera with a 1 square degree field of view and quantum efficiency greater than 80 percent, with wavelength coverage from 350 nanometers to 1 micrometer
- an infrared imager with up to 10 x10 arcminutes field of view
- a 3-arm spectrograph sensitive to wavelengths from the near ultraviolet to the near infrared



Unlike most astronomical CCDs currently in use, which have relatively poor response to red and infrared light and are difficult to combine in large arrays, SNAP will use radiation-tolerant, high-resistivity CCDs based on Berkeley Lab’s experience with detectors developed for high-energy physics. These can be combined in large-format mosaics and will extend sensitivity into the infrared, creating an ideal tool for finding distant, high-redshift supernovae.

SNAP will also shed new light on galaxy clusters, gamma-ray bursters, cold dark matter, weak lensing, asteroids, astronomical transients, and many other phenomena. But its primary mission is to discover the nature of the dark energy that accelerates the expansion of the universe.

In the ancient light from thousands of exploding stars, the mysterious energy that fills the universe will be unveiled.