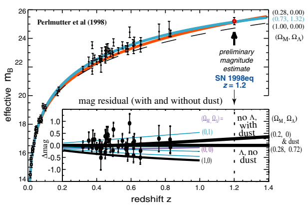
Fundamental Questions

Will the Universe last forever?
Is the Universe infinite
What is the Universe made of?

Einstein developed the conceptual tools to address these questions with his discovery of special and general relativity early in the 20th century. It is only in the last decade or so, almost a century later, that the technology is available to make the measurements that can begin to answer these fundamental questions.

Progress is now being made with large scientific programs, including the Supernova Cosmology Project, the High-Z Team, COBE, Boomerang, MAXIMA.

Current Results



Hubble diagram for 42 high-z SNe (Perlmutter et al. 1999). The best-fit world model with (Ω_M, Ω_Λ) = (0.73,1.32) is drawn through the data (solid line). The Einstein-de Sitter case (1.0, 0.0) is strongly excluded by the current data (dashed line). The case (Ω_M,Ω_Λ)=(0.28,0.00) indicates that some contribution from the cosmological constant is required for values of Ω_M favored by dynamical measurements. The magnitude difference between the best-fit world model and suitable ones with Ω_Λ=0 show redshift dependencies which would be very hard to mimic within the context of SNe evolution or gray dust hypotheses (see inset panel). By extending our survey beyond z=1, the form of the Hubble diagram alone would become sufficient evidence to support a cosmological constant.

The implications of an accelerating universe:

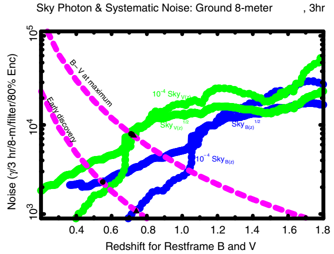
The expansion is not slowing to a halt and then collapsing (the universe is not "coming to an end"). In the simplest models, it will expand forever.

There is a previously unseen energy pervading all of space that accelerates the universe's expansion.

This new accelerating energy ("dark energy") dominates the current dynamical behavior of the universe.

Why From Space?

Sky Photon & Systematic Noise: Ground 8-meter , 3hr



The sky background will introduce two forms of photometric uncertainty. The solid lines plot the redshifted B and V-band Poisson sky noise as a function of redshift. In addition to Poisson noise, the bright foreground can produce additional errors if it is not perfectly uniform; plotted as dots are 10^{-4} non-uniformity errors. The photometric search and peak color signal-to-noise requirements for the SNAP mission are given by the dashed lines. Ground-based searching and precise color measurements are impossible from the ground beyond z=0.7, independent of exposure time and mirror aperture.

Science Case

SNAP Science Objectives:

1. **Precision measurement of the mass density and dark energy density. Provide a pillar for observational cosmology.**
These measurements also determine the "curvature" of the universe, and can tell us about the extent of the universe: **finite** or **infinite**
2. **Characterization of "dark energy". Particle physics theory proposes a number of alternatives, each with different properties that we can measure. Each of the alternative theories raises some important questions/problems of fundamental physics.**

What's wrong with a non-zero vacuum energy / cosmological constant?

- ***Why so small?***

Might expect $\frac{\Lambda}{8\pi G} \sim m^4_{Planck}$

This is off by ~120 orders of magnitude!

- ***"Why now?"***

$$\frac{\ddot{R}}{R} = \frac{-4\pi G}{3}(\rho + 3p)$$

MATTER: $p = 0 \rightarrow \rho \propto R^{-3}$

VACUUM ENERGY: $p = -\rho \rightarrow \rho \propto constant$

What are the alternatives?

New Physics:
"Dark energy": Dynamical scalar fields, "quintessence",...

COSMIC STRINGS: $p = -1/3\,\rho \rightarrow \rho \propto R^{-2}$

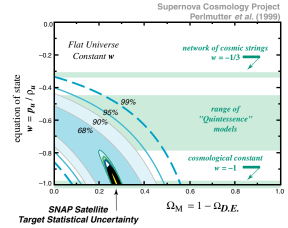
General Equation of State: $p = w\rho \rightarrow \rho \propto R^{-3(1+w)}$

and w can vary with time

Dark Energy

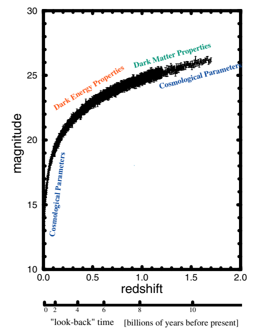
Unknown Component, $\Omega_{D.E.}$, of Energy Density

Supernova Cosmology Project
Perlmutter et al. (1999)



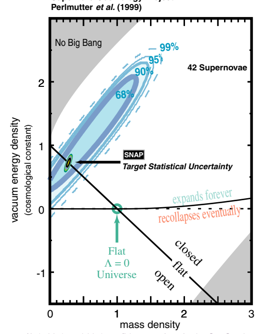
Best-fit 68%, 90%, 95%, and 99% confidence regions in the Ω_M - w plane for an additional energy density component, Ω_w, characterized by an equation-of-state w=p/ρ. (If this energy density component is Einstein's cosmological constant, Λ, then the equation of state is w = p_Λ/ρ_Λ=−1). Also shown is the expected confidence region that can be measured by SNAP.

One Year Baseline : 2000 SNe

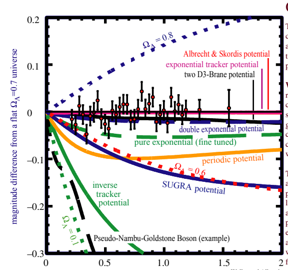


One year baseline SNAP Hubble Diagram shows the expected distribution of 2000 Type Ia supernovae out to a redshift of z =1.7 (with ~70 SNe at z < 0.1, ~200 SNe at redshifts between 1.2 < z < 1.7). Properties of the dark energy and dark matter are best determined using supernova observations between 0.3 and 1.2. Precision measurement of cosmological parameters are best determined by maximizing the range of redshifts.

Supernova Cosmology Project
Perlmutter et al. (1999)



68%, 90%, and 99% confidence regions in the Ω_M-Ω_Λ plane from the 42 distant SNe Ia in Perlmutter et al. (1999). These results rule out a simple flat, [Ω_M=1, Ω_Λ=0] cosmology. They further show strong evidence (probability >99%) for Ω_Λ>0. Also shown is the expected confidence region from the SNAP satellite for an Ω_M=0.28 flat universe.



SNAP constraints on dark energy models, viewed in the magnitude-redshift plane. Shown is a set of simulated SNAP supernovae (each SNAP point represents 50 supernovae). Theoretical curves correspond to a variety of dark energy models currently found in the literature.

Other Science

The dataset of images and spectra obtained with this wide-field imager and three channel spectrograph can address other important science goals with very little additional effort in data collection or in the instrument specifications. It is important to note that we can obtain complementary measurements of the cosmological parameters with completely independent measurement methods.

Weak lensing. Because the observation strategy observes the same patches of sky repeatedly over a year of supernova observations, a very deep, high-resolution image can be added together from thousands of images taken at every orientation of the spacecraft. This is an ideal way to look for weak-lensing elongations of distant galaxies, since the optical distortions of the image will be small and well characterized. Such images of several dozen square-degree fields can constrain the cosmological parameters in a manner complementary to the SN Ia measurements, with different systematics.

Type II supernovae. As we discover and follow the SNe Ia, we will also discover and have the option of following SNe II. While these supernovae are not of predictable luminosity, they are close enough matches to a black body that their luminosities can be determined from the size and temperature of their photospheres, along with a fit to any spectral deviations from black body. (Since our experiment provides a very tight constraint on the date of explosion and the velocity of the expanding gas, the size of the photosphere will be easy to determine.) Most SNe II are about six times fainter than the prototypical SNe Ia, so most will not be studied with early detections beyond redshifts z ~ 0.5. However since SNe II are much more frequent than SNe Ia, we can afford to study the brightest few percent and this will extend the SN II study beyond z = 1. The sources of systematic uncertainty for these SNe II measurements would generally be different from the SNe Ia systematic uncertainties.

There is also important science to be gained from this project that is not aimed specifically at the cosmological models. It is clear, for example, that the final set of very deep, wide field images would become a resource for all of astrophysics, as the Hubble Deep Fields have been but with 7000 times larger solid angle. Our images can be used in a wide array of cutting-edge astronomical research such as discovery of the first galaxies and quasars formed in the universe, galaxy evolution and clustering, searches for gamma ray burst counterparts, planets, black holes, and red dwarfs, etc. SNAP will uniquely provide valuable targets for NGST to follow-up.

A percentage of SNAP time will be allocated to non-supernova activities. Proposals for key survey projects will be solicited and heritage or key-project-class guest programs will be considered so that the scientific community will have the opportunity to benefit from the unique capabilities of SNAP. We plan to make archival data available to the community.

Data Requirements

SCIENCE
- Measure Ω_M and Λ
- Measure w and w(z)

STATISTICAL REQUIREMENTS
- Sufficient (~2000) numbers of SNe Ia
- ...distributed in redshift
- ...out to z ≈ 1.7

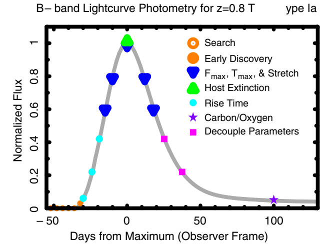
SYSTEMATICS REQUIREMENTS
Identified & proposed systematics:
- Measurements to eliminate / bound each one to <0.02mag

DATA SET REQUIREMENTS
- Discoveries 3.8 mag before max.
- Spectroscopy with S/N=10 at 15 Å bins.
- Near-IR spectroscopy to 1.7 µm.

SATELLITE / INSTRUMENTATION REQUIREMENTS
- ~2-meter mirror
- 1-square degree imager
- 3-channel spectrograph (0.3 µm to 1.7 µm)

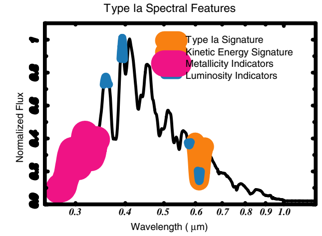
Derived requirements:
- High Earth orbit
- ~50 Mb/sec bandwidth

B– band Lightcurve Photometry for z=0.8 Type Ia

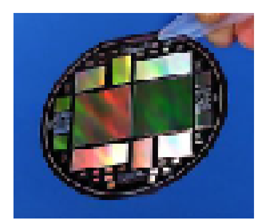


B-Band light-curve sampling for a Type Ia supernova at z = 0.8, and the supernova physics addressed at different times from peak brightness.

Type Ia Spectral Features



SN Ia spectroscopic regions relevant for identification and systematic studies.



Instrumentation Suite

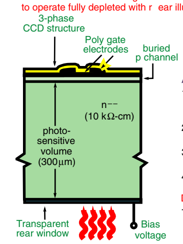
Instrumentation Suite

The optical imager and spectrographs use the LBNL high resistivity, p-channel CCDs. These have high quantum efficiency in the optical, operate at 150 K detector temperature, 4 e- read noise at 100kHz, and low dark current of 0.08 e-/pixel/min, and fast, 20 second, readout time.

The near IR imager and spectrograph channel use HgCdTe detectors, run at between 77 K and 130K detector temperature, quantum efficiency of 56% at 1000 nm, less than 5 e- read noise, a low dark current of 1 e-/pixel/min, and 20 second read out.

All the detectors have mechanical shutters.

The New Approach:
Make a thick CCD on a high-resistivity n-type substrate, to operate fully depleted with rear illumination.

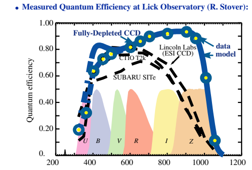


Advantages:
1) Conventional MOS processes with no thinning => "inexpensive"
2) Full quantum efficiency to > 1 µm => no fringing
3) Good blue response with suitably designed rear contact
4) Radiation tolerant

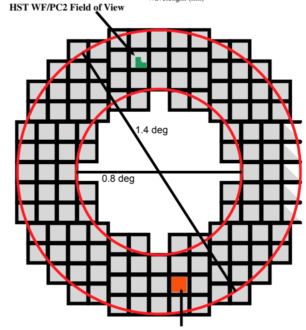
Disadvantages:
1) Enhanced sensitivity to radiation (x-rays, cosmic rays, radioactive decay)

Quantum Efficiency

- **Better overall response than more costly "thinned" devices in use**
- **High-purity silicon has better radiation tolerance for space application**
- **Measured Quantum Efficiency at Lick Observatory (R. Stover):**



HST WF/PC2 Field of View



NGST Field of View

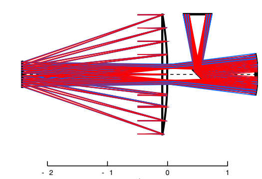
SNAP Optical Imager Footprint.

The annulus covers one square degree on the sky. The supernova survey will cover 20 such fields selected to minimize Galactic extinction. Co-added images will achieve a depth of ~32 mag. Shown for comparison are the WFPC2 and the planned NGST fields of view.

SNAP Observatory Requirements.

2.0 meter aperture, f/10, three mirror anastigmat
1 square degree FOV
Diffraction-limited at 1µm
Wavelength coverage 350 nm – 1700 nm
Solar avoidance angle 70 degrees
Operating temperature < 200 K
(well below thermal background for 1.7 micron)
Image stability of 0.03 arcsec over each exposure
Plate scale of 0.1 arcsec / 10 µm
Enhanced Silver Mirror Coatings
Guider: fast, unobscured CCDs
15 bandpasses +"open"

Side View of TMA Optics



Optical Imager Requirements.
1° × 1° field of view
10 µm/0.1 arcsec spatial resolution
128 3k × 3k, 10.5 µm pixel CCD mosaic
30th AB mag. limiting magnitude in I
15 bands (U, B, V,R, I, Z, & 9 special filters)

NIR Imager
1′ × 1′ field of view
256 × 256, 18.5 µm pixel HgCdTe detector
1µm – 1.7µm wavelength coverage
30th AB mag. limiting magnitude
J & H plus 5 special filters

Optical Spectrograph
Two channel, integral field unit spectrograph
350nm – 600nm & 600nm – 1 µm
0.07 arcsec spatial resolution
2″ × 2″ field of view
15, 30 and 100 angstrom selectable spectral resolution
2k × 2k pixel High resistivity, P-channel CCD

NIR Spectrograph
One channel, integral field unit spectrograph
1 µm – 1.7µm wavelength range
0.12 arcsec spatial resolution
2″ × 2″ field of view
30, 50, 200 angstrom selectable spectral resolution
2k × 2k HgCdTe detector