Dark Energy and Dark Matter with SNAP

Eric V. Linder[a] *

[a]Physics Division, Berkeley Lab
1 Cyclotron Road, Berkeley, CA 94720, USA

The discovery that the expansion of the Universe is accelerating opens up new frontiers for our understanding of cosmology and particle physics. The nature of the dark energy responsible is intimately tied to the high energy theory and gravitation. Measuring the properties of the accelerating universe and studying both the dark energy and the dark matter of the Universe using supernovae and weak gravitational lensing is the primary aim of the Supernova/Acceleration Probe (SNAP). SNAP can discover and follow thousands of Type Ia supernovae at redshifts $z = 0.3 - 1.7$. The resulting magnitude-redshift relation can determine the cosmological and dark energy parameters with high precision: the dark energy equation of state w to ± 0.05 and its time variation $w' = dw/dz$ to ± 0.15. Wide area weak gravitational lensing studies will map the distribution of dark matter in the universe.

1. COSMOLOGY WITH SNAP

Mapping the expansion history of the Universe through the distance-redshift relation has proved quite successful. Using Type Ia supernovae as standardized candles (accurate to 7% in distance) led to the discovery of the acceleration of the global expansion – one of the highlights of the 1998 UCLA Dark Matter conference [1]. But the nature of the exotic, negative pressure energy density responsible for the acceleration and comprising some 2/3 of the total energy density of the universe remains a mystery. Besides the cosmological constant, candidates include dynamical scalar fields (quintessence) of many different properties (e.g. [2]), related to various forms of the fundamental physics explicit at high energies.

To investigate the dark energy and distinguish between classes of physics we need to probe the expansion back into the deceleration epoch, indeed over a redshift baseline reaching $z > 1.5$ (see Fig. 1; [3,4]). SNAP [5] is a simple, dedicated experiment specifically designed to map the distance-redshift relation out to $z = 1.7$ with high precision and tight control of systematic errors.

These data can determine the cosmological parameters with high precision: mass density Ω_M to ± 0.01, vacuum energy density Ω_Λ and curvature Ω_k to ± 0.03, and the dark energy equation of state w to ± 0.05 and its time variation $w' = dw/dz$ to ± 0.15. This time variation is a crucial distinguishing feature, not only for ruling out a cosmological constant explanation, but for guidance on the proper class of high energy physics theory to pursue. In addition, wide area weak gravitational lensing studies with SNAP will map the distribution of dark matter in the universe and teach us about the evolution of the nonlinear mass power spectrum.

The SNAP mission concept is a 2.0 meter space telescope with a nearly one square degree field of view (see Fig. 2). A half billion pixel, wide field imaging system comprises 36 large format new technology CCD's and 36 HgCdTe infrared detectors. Both the imager and a low resolution ($R \sim 100$) spectrograph cover the wavelength range 3500 - 17000 Å, allowing detailed characterization of Type Ia supernovae out to $z = 1.7$.

As a space experiment SNAP will be able to study supernovae over a much larger range of redshifts than has been possible with the current ground-based measurements – over a wide wavelength range unhindered by the Earth's atmosphere and with much higher precision and accuracy. Many of these systematics-bounding measurements are only achievable in a space environment with low sky noise and a very small and stable point spread function (critical for lensing as well). Unlike other cosmological probes, supernova studies have progressed to the point that

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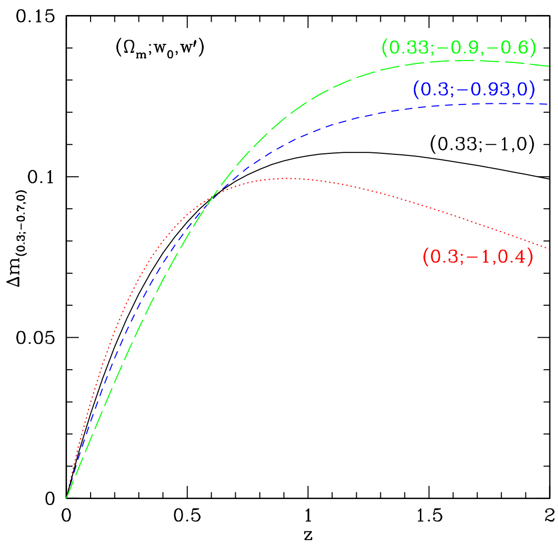

Figure 1. Degeneracies due to the dark energy model and the cosmological model cannot be resolved at low redshifts. In this differential magnitude-redshift diagram the three parameters to be determined are varied two at a time. Only at $z \approx 1.7$ do these very different physics models exceed 0.02 mag discrimination. From [4].

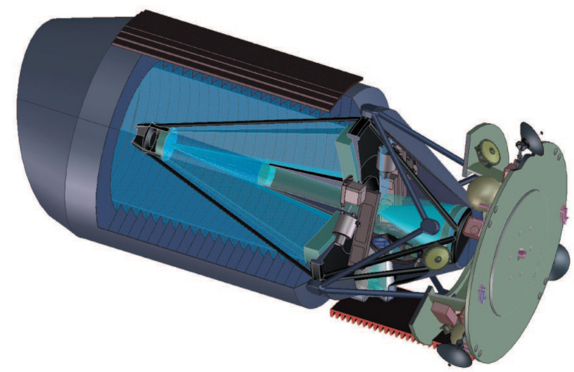

Figure 2. A cross-sectional view of the SNAP satellite. The principal assembly components are the telescope, optical bench, instruments, propulsion deck, bus, and thermal shielding.

a detailed catalog of known and possible systematic uncertainties has been compiled – and, more importantly, approaches have been developed to constrain each one.

For example, an approach to the problem of possible supernova evolution uses the rich stream of information that an expanding supernova atmosphere sends us in the form of its spectrum. A series of measurements will be constructed for each supernova that define systematics-bounding subsets of the Type Ia category. These data (e.g. supernova risetime, early detection to eliminate Malmquist bias, lightcurve peak-to-tail ratio, identification of the Type Ia-defining Si II spectral feature, separation of supernova light from host galaxy light, and identification of host galaxy morphology, etc.) make it possible to study each individual supernova and measure enough of its physical properties to recognize deviations from standard brightness subtypes. Only the change in brightness as a function of the parameters classifying a subtype is needed, not any intrinsic brightness. By matching like to like among the supernova subtypes, we can construct independent Hubble diagrams for each, which when compared test systematic uncertainties at the targeted level of 0.02 magnitudes.

With a prearranged photometric observing program one obtains a uniform, standardized, calibrated dataset for each supernova, allowing for the first time comprehensive comparisons across complete sets of supernovae. The observing requirements also yield data ideal as survey images, and one automatically obtains host galaxy luminosity, colors, morphology, and type. Full data downlink allows archiving and analysis for a variety of science without “biased” preprocessing.

2. ASTROPHYSICS WITH SNAP

While the thorough study of dark energy through Type Ia supernovae drives the design of SNAP, the resulting instrument will have broad capabilities that will be desirable for other astrophysical observations. For example, the exquisite image quality and stable point spread function from space, and the wide field, are highly advantageous for weak gravitational lensing studies. A wide area survey covering some 300 square degrees to AB magnitude 28 will allow creation of a large scale map of the distribution of the dark matter in the universe, while the main, deep survey covering 15 square degrees is excellent for lensing tomography, investigating the growth of structure in the universe and providing complementary constraints on cosmological parameters. Gravitational lensing magnification effects on the supernovae brightness can be used to determine the fraction of compact objects and substructure in galaxy halos, giving further insight into dark matter.

Additionally, SNAP's primary dataset will survey an area of sky almost 10000 times larger than the Hubble Deep Field and almost two magnitudes deeper. The rich range of science that can result from this and from SNAP Guest Survey programs includes: Weak/strong gravitational lensing; Galactic structure and evolution; AGNs and afterglows; Microlensing and planet surveys; Star formation and starbursts; Solar system studies.

SNAP's capabilities can be summed up succinctly: wide, deep, and colorful. Multicolor observation in 9 filters will provide an unprecedented wealth of data. SNAP's repeated sky scanning opens up the time domain to investigations of rare, transient, variable, and moving objects. Already supernova studies have revolutionized our picture of the universe and the new technology Berkeley Lab CCD's to be used for SNAP are producing valuable science at Kitt Peak telescopes [6].

SNAP offers great promise to uncover the nature of dark energy, and this is further enhanced by complementarity with other cosmological probes, particularly the cosmic microwave background radiation [7]. The goal is nothing less than a map of the recent expansion history of the universe (see Fig. 3, [8]) and new depths of understanding of fundamental physics.

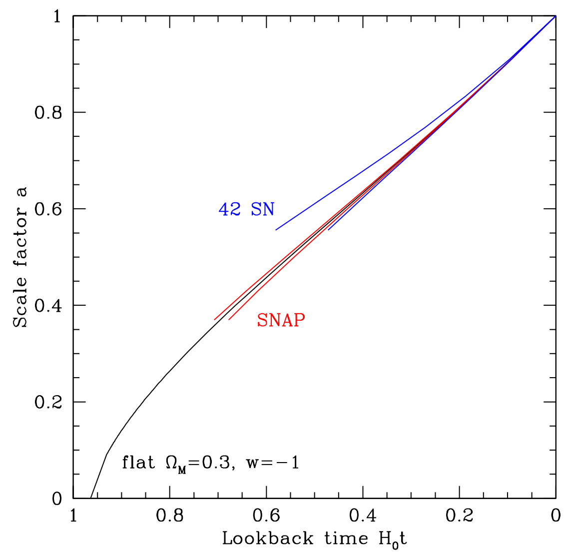

Figure 3. The distance-redshift relation derived from Type Ia supernovae is a direct translation of the expansion history of the Universe, $a(t)$. SNAP has the capability to map back from the current accelerating expansion into the deceleration epoch. Such a figure gives a model independent cosmological measure, valuable whether the acceleration is due to dark energy, higher dimensions, or modifications of gravitation. From [8].

REFERENCES

1. G. Goldhaber and S. Perlmutter, Phys. Rep. 307 (1998) 325.
2. J. Weller and A. Albrecht, Phys. Rev. D65 (2002) 103512.
3. E.V. Linder, astro-ph/0108255.
4. D. Huterer and E.V. Linder, in draft (2002).
5. http://snap.lbl.gov
6. NOAO Newsletter 67, Sept. 2001.
7. J.A. Frieman, D. Huterer, E.V. Linder, and M.S. Turner, in draft (2002).
8. E.V. Linder, in draft (2002).