Status Report: SuperNova / Acceleration Probe (SNAP)

Saul Perlmutter
SAGENAP
14 April 2004
Energy budget of Universe

Composition of the Cosmos

Neutrinos: 0.6%

Baryons (atoms): comprising stars, heavy elements, and helium and free hydrogen: 4.4%

Dark matter: 22%

Dark energy: 73%
Expansion History of the Universe

After inflation, the expansion...
Expansion History of the Universe

After inflation, the expansion either...
- first decelerates, then accelerates
- or always decelerates

relative brightness

past ← today → future

redshift
0.0 0.5 1.0 1.5 2.0 2.5 3.0

Average Distance Between Galaxies
Relative to Today's Average

Billions Years from Today
-20 -10 0 10
After inflation, the expansion either...

- first decelerates, then accelerates
- or always decelerates

Expands forever or collapses

KAIT, CfA, and others (100's)
Nearby SN Factory (300)

ESSENSE (200) and
CFHT/Legacy (600)

Subaru/SCP (10)
HST/GOODS (6) and upcoming HST (6)
Expansion History of the Universe

After inflation, the expansion either...

first decelerates, then accelerates
...or always decelerates

relative brightness

past → today → future

decelerates

expands forever

collapses

redshift

0

0.5

1

1.5

2

3

Billions Years from Today

Average Distance Between Galaxies Relative to Today's Average
Expansion History of the Universe

After inflation, the expansion either...

- First decelerates, then accelerates
- Or always decelerates

past ← today → future

Relative brightness

0.0001

0.001

0.01

0.1

Billions Years from Today

Average Distance Between Galaxies Relative to Today's Average

redshift

0

0.5

1

1.5

2

3

expands forever

collapses
From Science Objectives to Project Design

- Discover large numbers of supernovae
- Large 2 meter class telescope, large field of view (0.7 sq degree)
- Dedicated space-based mission
From Science Objectives to Project Design

- Discover large numbers of supernovae
- Look back 3 - 10 billion years (z=0.5 - 1.7, light is redshifted up to 1.7 um)
- Large 2 meter class telescope, large field of view (0.7 sq degree)
- Dedicated space-based mission
- Visible to near-infrared camera
- Space-based to avoid absorption in earth’s atmosphere
From Science Objectives to Project Design

• Discover large numbers of supernovae

• Look back 3 - 10 billion years (z=0.5 - 1.7, light is redshifted up to 1.7 um)

• Measure each supernova in detail (light curve, spectrum)

• Large 2 meter class telescope, large field of view (0.7 sq degree)

• Dedicated space-based mission

• Visible to near-infrared camera

• Space-based to avoid absorption in earth’s atmosphere

• Detailed spectrum at maximum light to characterize supernovae

• Observing program of repeated images in visible to near-infrared
SNAP Mission

- SNAP design meets these scientific objectives
  - **Telescope:** 2 meter aperture sensitive to light from distant SNe and galaxies.
SNAP Mission

- SNAP design meets these scientific objectives
  - **Photometry:** half-billion pixel mosaic camera, 0.7° instrumented FOV

Field of View Optical (36 Sensors) = 0.34 sq. deg.

Four filters on each 10.5 μm pixel CCD detector

Field of View IR (36 Sensors) = 0.34 sq. deg.

One filter on each 18 μm pixel HgCdTe detector
SNAP Level 1 Science Requirements
Two Methods: SNe & WL

Four Key Level 1 Science Requirements:
1. SNe Quantity
2. SNe Quality
3. SNe Spectroscopy
4. Weak Lensing Surveys

Tomographic density maps: Deep multi-band visible-NIR surveys with field sizes of up to 1000 square degrees (much larger surveys are possible)
Weak Lensing Level 1 Requirements

- Weak lensing provides a complementary means to measure $\Omega_m$ and greatly enhances the joint measurement of dark energy with SNe.
- Weak Lensing requires (using space to greatest advantage)
  - Superb point spread function (PSF) controlled to better than 0.1%
  - A statistically large sample of resolved galaxies $\sim > 100$ million resolved galaxies
  - Accurate photo-z determination
  - Depth in redshift to $z \sim 1.5-2$
Synergy of Supernovae + Weak Lensing

- Comprehensive: no external priors required!
- Independent test of flatness to 1-2%
- Complementary (SNe + WL only):
  - conservative:
    - $w_0$ to ±0.05, variation $w'$ to ±0.12 \textit{(with systematics)} $\Lambda$ model
    - $w_0$ to ±0.03 variation $w'$ to ±0.06 \textit{(with systematics)} SUGRA model
  - Adding panoramic survey and better systematics:
    - $w_0$ to ±0.03, variation $w'$ to ±0.06 \textit{(with systematics)} $\Lambda$ model
    - $w_0$ to ±0.015 variation $w'$ to ±0.03 \textit{(with systematics)} SUGRA model
- Flexible: Panoramic is available if improved systematics in space warrant greater than 1000 sq. deg.

### SNAP Surveys

<table>
<thead>
<tr>
<th>Survey</th>
<th>Area(sq.deg)</th>
<th>Depth(AB mag)</th>
<th>$n_{gal}$(arcmin$^{-2}$)</th>
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<td>15</td>
<td>30.3</td>
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<td>Panoramic</td>
<td>7000-10000</td>
<td>26.7</td>
<td>40-50</td>
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</table>
Combined Power of SNe and WL

\[ w' = \frac{w_0}{2} \]

With systematics

68% cl

- SN+CMB
- SN+WL
- SN+WL+CMB

WL=1000 deg², \( n_{gal} = 100 \), CCC₃%, PSBS(stat)
SNAP Surveys

SN+WL: Comprehensive+Independent+Complementary+Flexible

Unique capabilities of space:

• Peak SNe signal > background even at $z=1.7$ in broad-band filter

• Small, stable, isotropic PSF

• Wide range of survey capabilities
  very deep and/or very wide -- instrument able, just need time

• Control of systematics
  Our new method: Cross-correlation Cosmography divides out PSF, nonlinear mass model, but photo-z must be unbiased to 0.001 in log$(1+z)$, without “blow-ups” to 99.9% -- can’t control from ground or without NIR -- but no added complexity to SNAP
Weak lensing galaxy shear observed from space vs. ground

(Bacon, Ellis, Refregier, Nov. 2000)
A ground-based PSF varies greatly over time, so we need to measure and correct for it using only the finite number of stars within each exposure.

The stellar ellipticities can be corrected by an order of magnitude using current techniques.

Space offers stable PSF at small scales, while corrections from ground are limited below the star-star separation by thermal instability.

WL signal is ~2% and systematics need to be kept to ~0.1%
Galaxy Sizes

Many faint galaxies are too small to be resolved from the ground

0.5 arcsecond seeing (currently best consistent seeing is 0.7 arcseconds)

SNAP PSF

Photo-Z Accuracy Requires NIR

NIR Filters are crucial for photo-z accuracy and to reduce catastrophic failures (see Massey et al astro-ph/0304418).
Space vs. Ground Lightcurves

SNAP

Ground 8m Visible & NIR

SNAP

restframe B

restframe V

Band-5

Band-6

Band-7

Band-8

Ground 8m Visible & NIR

restframe B

restframe V

Band-5

Band-6

Band-7

Band-8
Simulated Hubble Diagrams

- Here, SNAP is computed for one year, and 8m-class ground-based telescope is computed for two years, with only *SNe with spectra plotted*. Ground based telescope assumed to have wide-field NIR capability in addition to visible and access to 8-10m spectroscopy.
- SNAP-quality spectra are assumed (not possible from the ground)
Collaboration
SNAP Collaboration

LBNL

UC Berkeley

Caltech
R. Ellis, R. Massey†, A. Refregier†, J. Rhodes, R. Smith, K. Taylor

Fermi National Laboratory

Indiana U.
C. Bower, N. Mostek, J. Musser, S. Mufson

IN2P3

LAM (France)
S. Basa, R. Malina, A. Mazure, E. Prieto

University of Michigan

University of Pennsylvania
G. Bernstein, L. Gladney, B. Jain, D. Rusin

University of Stockholm
R. Amanullah, L. Bergström, A. Goobar, E. Mörtsell

SLAC

STScI
R. Bohlin, A. Fruchter

Yale U.
C. Baltay, W. Emmet, J. Snyder, A. Szymkowiak, D. Rabinowitz, N. Morgan

SAGENAP Presentation 14 April, 2004
SNAP Collaboration
NASA Centers

JPL (pending)

GSFC (pending)
## Institutional Activities

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<th>Simulation</th>
<th>Data Acquisition</th>
<th>Detector Electronics</th>
<th>Storage/Telemetry</th>
<th>Telescope</th>
<th>Spectrograph</th>
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Does not show flight center mission management, and many other important activities.
SNAP Science Papers in the Last Year

SNAP Omnibus Paper (in prep)
Overview of the SuperNova/Acceleration Probe (SNAP) G. Aldering et al., SPIE 4835
Wide-Field surveys from the SNAP Mission, A. Kim et al., SPIE 4836
Importance of SNe at z>1.5, E. Linder, D. Huterer, Phys.Rev. D67
Frieman, Huterer, Linder, & Turner: Probing Dark Energy with Supernovae: Exploiting Complementarity with the CMB
Weak Lensing from Space II: Dark Matter Mapping, Massey et al.
Weak Lensing from Space III: Cosmological Parameters, Refregier et al.
Effects of Systematic Uncertainties on the Supernova Determination of Cosmological Parameters, A. Kim, et al.,
MNRAS
Baryon Oscillations as a Cosmological Probe, Linder, PRD 68, 083504 (2003)
Gravitational Lensing by Cosmic Strings in the Era of Wide-Field Surveys, Huterer & Vachaspati, PRD 68, 041301
(2003)
Joint Galaxy-Lensing Observables and the Dark Energy, Hu & Jain, submitted to PRD
Cosmological parameters from lensing power spectrum and bispectrum tomography, Takada & Jain, submitted to
MNRAS
Strong Gravitational Lensing and Dark Energy Complementarity, Linder, submitted to PRD
Testing the Cosmological Constant as a Candidate for Dark Energy, Kratochvil, Linde, Linder, & Shmakova, sub. to
JCAP
Mapping the Dark Energy Equation of State, Linder, in Maps of the Cosmos, IAU 216
Physics of SNeIa and Cosmology, Hoeflich, Gerardy, Linder, & Marion, in Stellar Candles, Lecture Notes in Physics
Instrumentation Papers in the Last Year


C. Bebek et al. Proc. SPIE 5167, Fully depleted back-illuminated p-channel CCD development

**IR:** G. Tarle et al, Proc SPIE 4850, SNAP Near Infrared Detectors

**Spectrograph:** A. Ealet, et al. Proc SPIE (2003), An integral field spectrograph for SNAP supernova studies

**Electronics:** J.P. Walder, IEEE Trans Nucl. Sci., submitted for publication

**Calibration:** S. Deustua et al, SPIE 2003, Calibrating SNAP

**Telescope:** M. Lampton et al, Proc. SPIE 5166, 2003, SNAP Telescope
Instrument Concept
Evolution of SNAP instruments

1999:
• Objective prism concept, all visible detector system

2000:
• Separated functions, but multiple focal planes to keep focused
• Filter wheel provides no constraint on observation scan, but a single point failure
• Small number of NIR imager: ~4 detectors

2002:
• Imager detectors and spectrograph on one focal plane.
• All detectors near radiator.
• Filter wheel allows flexible observation program, but a single point of failure.
• Most efficient if dual band filters used for visible and NIR observing simultaneously.
Current Focal Plane

2003:

• All instruments coalesced on one focal plane.
  – Common 140K operating temperature.
  – Single focal plane simplifies optics, pointing and focusing

• Photometer sensors in one focal plane, example.
  – 36 2k x 2k, 18 µm HgCdTe NIR sensors.
  – 36 3.5k x 3.5k, 10.5 µm CCD sensors

• Spectrograph mounted to focal plane.
  – Two channel spectrograph with light access port in the focal plane.
  – Objects dropped into spectrograph light port by steering the satellite.

• Fixed filter mosaic
  – 3 Fixed Filter array eliminates wheel risk
  – 3 NIR bandpass filter types organized in 3 x 3 arrays.
  – 6 visible bandpass filter types organized in 6 x 6 arrays.

• Guide off the focal plane during exposures.
  – 4 regions of star guider CCDs.

• Telescope I&T and on-orbit calibration hardware
Current Concept: Compact & Extremely Simple

- 90 deg Symmetric Focal Plane allows continuous year round science data taking
  - one side always sunward, allowing fixed solar panels hence a rigid spacecraft
  - other side always dark, allowing fixed passive thermal radiator serving sensor array
- Innovative telescope design does IR imaging with room temperature optics
  - three mirror anastigmat has accessible exit pupil and complete cold stop baffling
- Built in end-to-end optical test capability simplifies Integration and Testing
- The fixed telemetry antenna eliminates a major mission risk:
  - no gimbals
  - rigid spacecraft eases ACS task
- No onboard data analysis: all images are downlinked to Earth
  - lossless onboard compression via hardware
New Technologies for SNAP
Key Technologies

• Key enabling technologies that are being developed:
  — By developing smaller pixel sizes than previously possible in astronomical sensors we have been able to increase the field-of-view by a factor of 2.5.
  — Using our experience in radiation sensors we have greatly extended the current life of CCD sensors for use in high earth orbit.
  — By developing new infrared pixel sensors from InGaAs and HgCdTe substrates we are enabling the observation of the early universe before the time of cosmic acceleration.

• There are more IR detectors in SNAP than currently deployed on ground based telescopes.
• “the most ambitious detector focal plane ever proposed, for ground or space.”
• “With the recent re-direction to JDEM, it is very important to re-focus and heavily emphasize work on advancing key technologies. Detectors and electronics are likely the highest risk area in the mission concept. The visible arrays, and especially the near-IR arrays, are not in the bag.” (technical review)
High-Resistivity CCD’s

- New kind of Charged Coupled Device (CCD) developed at LBNL
- Better red response
- “radiation detector” silicon has better radiation tolerance for space applications
- Smaller pixel sizes enabling compact arrays

LBNL “Red Hots”: NOAO September 2001 newsletter
Visible detectors

Focus is on LBNL CCD technology:
- Extended red response – overlaps NIR detectors
- Control of charge diffusion – small pixels possible
- Radiation tolerance – high resistivity, n-type silicon

Challenges:
- Robust fabrication process still being developed
- Space qualification
- Packaging challenging

Alternatives:
- Dual source dual technology strategy
- Silicon PIN diode arrays
  — Same multiplexer, package, and readout at NIR
  — Only available in large pixels – expensive development to get to ~10 µm
  — Uncertain dark current and spatial response
  — Have acquired one to understand state of the art

Current wafer with four SNAP CCDs – 3.5kx3.5k, 10.5 µm pixels.

Rockwell 2k x 2k HyVisi
Visible Detector Roadmap
Dual Source Dual Technology Strategy

<table>
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<tr>
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<td>2k x 2k 10µm pixels</td>
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<td>3.5k x 3.5k 10µm pixels</td>
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<td>3.5k x 3.5k 10µm pixels</td>
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<tr>
<td>4k x 4k 9 µm pixels</td>
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</table>

Primary Source (CCD)
- DALSA Frontside
- LBNL Finish

Secondary Source (CCD)
- LBNL 4” Line

Technology Study (Si:PIN)
- Rockwell Science Center

Source Selection

Silicon Hybrid

LBNL Technology
CCD testing - radiation tolerance

- CCDs in space have proven to be very sensitive to CTE degradation and hot pixel formation due to radiation – mostly protons.

- Our proton radiation testing at room temperature shows >10 more radiation tolerance than previous space CCDs.

- Preliminary USAF/NRL/GSFC results: “…see about an order of magnitude improvement in the CTE degradation as compared to that observed in our WFC3 data.”

- Program starting at Yale van de Graaff to study heavy ion damage.

- FNAL using GEANT and MARS codes to design a radiation shield.

CTE degradation as a function of integrated particle fluence – 12 MeV for LBNL CCDs and 35 MeV for HST ACS CCDs. The data have been scaled to an equivalent NIEL dose.
**CCD electronics**  
**Photon-to-bits Focal Plane**

**CRIC-I**  
- Four channel dual integration correlated double sampler CRIC constructed.  
- 3-ranges, auto-ranging.  
- Tested w/ an LBNL CCD  
- Operates at 140 K so it can be co-located with CCD.  
- Achieves 2 e- noise @ 100 kpix/s  
- Meets specs, even after cold irradiation to >150 krad

**CRIC-II**  
- Added 13-b ADC to design  
- Submitted for fabrication 22 March

Image acquired with CRIC mounted next to an LBNL CCD operated at 140K.
IR Detector Development

• Major advances in Near IR Sensors:
  — Make use of short (1.7 µm) wavelength cutoff 1k x1k devices for HST/WFC3, but in 2k x 2k format.

• But,
  — Dual source dual technology strategy
  — Risk mitigation of new technologies
  — Achievement of adequate performance

• Expanding effort in:
  — HgCdTe: dual vendor: Rockwell, Raytheon
  — InGaAs: second technology: Sensors Unlimited/Raytheon
Infrared Detector Roadmap

FY04

- **Dual Source (HgCdTe)**
  - Rockwell Science Center
  - 2k x 2k Engineering Grade

- **Dual Source (HgCdTe)**
  - Raytheon Vision Systems
  - 1k x 1k Engineering Grade

- **Technology Study (InGaAs)**
  - Sensors Unlimited/Rockwell
  - 1k x 1k Engineering Grade

FY06

- 2k x 2k Engineering Grade
- 2k x 2k Science Grade
- 2k x 2k Science Grade
NIR detector status

Rockwell HgCdTe
- Lot 1 complete – reproduces WFC3 results in 2k x 2k format; SNAP testing beginning.
- Lot 2 nearing completion – addresses decoupling readnoise and QE

Raytheon HgCdTe
- 3 parts made, 2 delivered; SNAP testing beginning.
- Large dark current; improvement implemented. QE looks good

Rockwell/Sensors Unlimited InGaAs
- Photodiode array complete
- Assembly in progress
  (acquiring similar part from Raytheon)
NIR testing

Things to measure

- Dark current vs temperature
- Readnoise and readnoise scaling with multiple samples
- Quantum efficiency
- Spatial response

Four test sites

- U of Michigan – HgCdTe
  - General measurements – dark current, readnoise, …
  - Equipment to do absolute QE measurement
  - Pin hole projector for intra- and inter-pixel response
- Cal Tech – HgCdTe
  - General measurements – dark current, readnoise, …
  - Calibration lamps for QE
- JPL – InGaAs
  - General measurements – dark current, readnoise, …
  - Calibration lamps for QE
- GSFC/STScI – HgCdTe
  - DCL/IDTL starting this week
InGaAs IR Sensors

Used extensively in telecommunications fiber optic receivers.

Not used in any photon counting astronomy applications.

1k x 1k H1RG device with Sensors Unlimited photodiode material being assembled by Rockwell.
Focal plane - spectrograph

Integral field unit based on an imager slicer. Input aperture is 3” x 6” – reduces pointing accuracy req. Simultaneous SNe and host galaxy spectra. Internal beam split to visible and NIR.
How to rearrange 2D field to enter spectrograph slit:

1. Field divided by slicing mirrors in subfields (20 for SNAP)
2. Aligned pupil mirrors
3. Sub-Field imaged along an entrance slit
Mirror Slicer Stack Prototype (Nov. 2003) (L.A.M. – Marseille)

18 “Flat” Slices (Dummies)

10 “Curved” Slices (Actives)

2 “Flat” Slices (Dummies)
Spectrograph image slicer
All Sub-elements Prototyped
Full spectrograph model of a $z=1.7$, background-subtracted, Type 1a SNe includes detector, slicer, spectrograph optics, and telescope model with all inefficiencies.
Telescope Status

• **Why develop the SNAP telescope?**
  — show we have a feasible mission concept
  — demonstrate manufacturing/test heritage: no new technology
  — permit systems engineering approach to the complete science payload

• **R&D Phase to date:**
  — adopted three-mirror anastigmat optical configuration
  — Telescope Requirements & Specification Document
  — Wave Front Error Budget
  — mechanical alignment & tolerances
  — gravity-induced wave front errors
  — All four mirrors: dynamic FEMs, strength stress, gravity, mounts
  — Telescope metering structure: stability, strength, materials
  — Telescope Assembly: dynamic FEM
  — Observatory structure: strength, dynamic FEM
  — Stray Light Model
  — Integration and Test Plan
  — Built-In Test Equipment concept
Telescope

Integrated Observatory Modeling
— Optical Elements & Metering Structure

GFRP Composite Telescope Structure
Stray Light
Stray Light
SNAP Orbit

L2 lagrange point

~1,500,000 km

~374,000 km

~1,500,000 km
Why L2?

• **LEO is unacceptable due to low time on target, cooling**

• **Advantages of L2 over HEO include:**
  — More stable thermal environment gives stable science optics and eases ACS task
  — Stray light issues are minimized – lower risk of science loss
  — Radiation environment is more benign: no Van Allen belt passages
  — A smaller rocket will place a larger payload at L2 than into HEO
  — L2 has higher observing efficiency, typically >90%
  — HEO has stray light & eclipses, L2 mitigates stray light, can be designed w/ no eclipses

• **There is one disadvantage to be traded off:**
  — Requires high-bandwidth Ka-band 35m DSN ground sta. upgrade (in plan for JWST)
  — Ka band downlink requires a 35 watt TWTA instead of a 6 watt solid state amplifier (TWTA’s have a long history of use on TDRSS and JPL deep space missions)
Supernova Mission Simulator

With our Monte Carlo:
— Have simulated SNAP with detector characteristics and observing program
— Have simulated other potential experiments including ground-based instruments
— Use state-of-the-art SNe models that simulate SNe population drift with redshift
— Introducing pixel level simulation
— Included systematic effects and calibration errors
— Can generate error ellipses for cosmological parameters
— Can optimize SNAP
SN

Dust
host galaxy
intergalactic

Gravitational
Lensing

Atmosphere
absorption
emission
blurring

Telescope

Filters

Detector
response

Interpretation
Simulation code architecture

- Framework built on architected computer science foundation
- Object-oriented code (Java) for maintainability
- Data persistence in SQL database for complete history and traceability
- Facilitates development by multiple, geographically disperse collaborators
Static fundamental calibration:
- Fundamental spectrophotometric standard stars are calibrated using NIST sources
- Fainter primary standard stars in the SNAP fields are established from the fundamental standards
- The SNAP spectrograph is critical in tying the MKS and SNAP photometric systems; its design is specifically tailored to provide robust spectrophotometry

Dynamic calibration monitoring:
- An on-board program establishes the calibration of the SNAP broad-band filters
- On board flat-field capabilities (lamps, etc…)
- Calibration of flat-field is manageable because peak signal > background in filters
Status
SNAP Reviews/Studies/Milestones

Nov 1999  Preproposal ad hoc committee review
Mar 2000  SAGENAP-1 (recommends R&D)
Sep 2000  NASA Structure and Evolution of the Universe (SEU)
Dec 2000  NAS/NRC Committee on Astronomy and Astrophysics
Jan 2001  DOE-HEP Review R&D (SNAP is uniquely able)
Mar 2001  DOE High-Energy Physics Advisory Panel (HEPAP)
Jun 2001  NASA Integrated Mission Design Center (determines feasibility)
July 2001  Snowmass Workshop (Community analysis)
July 2001  NAS/NRC Committee on Physics of the Universe
Dec 2001  NASA/SEU Strategic Planning Panel
Dec 2001  NASA Instrument Synthesis & Analysis Lab
Jan 2002  HEPAP subpanel report: HEP Long Range Planning
Mar 2002  SAGENAP-2
Apr 2002  NRC/Committee on Physics of the Universe releases report
July 2002  DOE/SC-CMSD R&D (Lehman)
Dec 2002  JPL Team-X Study (studies potential NASA cost)
Jan 2003  NASA releases SEU roadmap: Beyond Einstein
Feb 2003  DOE HEP Facilities Prioritization Panel
Feb 2003  SNAP in the DOE budget
Mar 2003  DOE HEP releases Facilities 20 Year Roadmap
Nov 2003  JDEM Announcement
Nov 2003  Internal Review
Feb 2004  Directors SNAP Policy Board
“To fully characterize the expansion history and probe the dark energy will require a wide-field telescope in space (such as the Supernova/Acceleration Probe).”
NASA/SEU Roadmap: Beyond Einstein

What powered the Big Bang?
What happens at the edge of a black hole?
What is dark energy?
Facilities for the Future of Science
A Twenty-Year Outlook

November 2003
A Multi-Agency Approach to the Dark Energy Probe

“The U.S. Department of Energy (DOE) has made the mystery of dark energy a high science priority and, under the leadership of its Lawrence Berkeley National Laboratory, is funding a study of a possible space mission entitled the Supernova Acceleration Probe (SNAP) to address this topic. Therefore, in order to encourage consideration of all possible approaches, as well as the potential of interagency collaborations, mission concept proposals for the Dark Energy Probe in response to this NASA solicitation may be of two types, both of which are encouraged with equal priority:

**Type 1:** Proposals for a full mission investigation concept that uses any technique to meet the science goals of the Dark Energy Probe; and

**Type 2:** Proposals involving a significant NASA contribution (> 25% of the total mission cost) to the existing DOE SNAP concept mission. Note that prior endorsement from the SNAP team or DOE is not required, but the proposal must clearly state how the proposal team envisions working with the SNAP team to develop a joint concept.”
SNAP Mission Concept Studies

- NASA funding four SNAP Mission Concept Studies
  - One LBNL led (Type I)
  - One LBNL led with JPL (Type II)
  - One GSFC led
  - One industry technology study

- These studies should be proceeding shortly
US launches joint effort to probe dark secrets of the Universe

Tony Reichhardt, Washington

Physicists are shooting for the stars in a bid to understand the mysteries of dark energy — the enigmatic force behind the Universe’s accelerating expansion.

In a ground-breaking collaboration, the US Department of Energy (DOE) has teamed up with NASA to plan a series of launches that will explore this exotic area of astrophysics.

The proposed Joint Dark Energy Mission could reach the launch pad around 2014 and, although it is not yet funded, has strong political backing. The White House Office of Science and Technology Policy initially asked the DOE and NASA to find a way to cooperate on a space-based mission to investigate dark energy, a topic that figures prominently in both agencies’ scientific ‘road-maps’.

A National Academy of Sciences report released last year also identified dark-energy investigations as an area where astronomers and high-energy physicists could join forces.

NASA envisions the mission as the first in a series of ‘Einstein Probes’, costing around $500 million each, which would address specific problems in astrophysics (see Nature 420, 593–594; 2002). Meanwhile, scientists at the DOE’s Lawrence Berkeley National Laboratory in California have been leading conceptual studies of a Supernova/Acceleration Probe (SNAP), which would be geared mainly towards characterizing dark energy. Saul Perlmutter, an astrophysicist at the laboratory and primary investigator on the SNAP project, says that studies of dark energy unite the interests of cosmologists and particle physicists. “The fields have become so intermixed that you really can’t do one without the other,” he says.

SNAP would consist of a two-metre telescope, roughly the same diameter as the Hubble Space Telescope. But its detector would have a billion picture elements, more than 100 times the number on Hubble’s best camera. From its vantage point in space, SNAP would be optimized to survey supernovae, which serve as yardsticks to calibrate the distance and speed of objects receding from us — key evidence of dark energy’s mysterious pull.

Although an instrument such as SNAP would not automatically be selected for the Joint Dark Energy Mission, it would be a strong contender, says Paul Hertz, NASA’s lead scientist for research on the structure and evolution of the Universe. He says that NASA and the DOE will soon form a panel to set the scientific requirements for the dark-energy mission.

The two agencies have worked together on smaller projects before, and are collaborating on the Gamma-ray Large Area Space Telescope (GLAST), which is planned for launch in 2006. The dark-energy probe would be an even closer partnership. But it would not be equal in terms of funding: Hertz reckons that NASA would pay as much as three-quarters of the cost, and the project would be based at the agency’s Goddard Space Flight Center in Greenbelt, Maryland.
NASA-DOE
Joint Dark Energy Mission

Paul Hertz / NASA
Robin Staffin / DOE

Endorsed by
Raymond L. Orbach
Director of the Office of Science
Department of Energy
September 24, 2003

Edward J. Weiler
Associate Administrator for Space Science
NASA
September 25, 2003
JDEM Strawman Schedule

(assumes new funding in Year 0)

Year -1  Pre-phase A / Pre-conceptual planning (CD0)
        Conduct mission concept studies in anticipation of an AO
        Establish study office

Year 0  Phase A / Conceptual design
        GSFC in-house mission concept definition study
        Write AO

Year 1  Issue AO; select investigations (CD1)
        Industry participation in spacecraft Phase A studies

Yr 2-3  Phase B / Preliminary design (CD2)
        Issue RFP or use RSDO; select prime contractor

Yr 4-8  Confirmation; Phase C/D / Final design (CD3) / Construction (CD4)
        Develop the mission, on time and on budget

Yr 9-11  Launch; Phase E / Operations
        Dark energy phase

Yr 12-14  General astronomical observing phase

Year 15  End of 6 year prime mission
• **Detectors:** “There is a good detector technology development strategy and R & D plan as long as adequate funding is available to execute the plan. …Critical R & D phase budget is marginally adequate to assure proper mitigation of key technology risks.

• **JDEM:** “With an anticipated date in 2006 for an AO for a Joint Dark Energy Mission (JDEM) as a DOE and NASA partnership, the SNAP team will have to focus on the key activities required for a strong response to the AO. This will require significant funding for the next two years. To not lose momentum the SNAP team will also require continued funding during the year that AO responses are made and evaluated as well as the time the agencies negotiate an implementation plan.

• **Team:** “The team … provides an excellent group to mount a successful dark energy mission and extract the science.

• **Management:** “The SNAP management and systems engineering team is a particularly strong amalgamation of two nationally recognized organizations…. has extensive experience in delivering large-scale, complex, scientific instrumentation.

• **DOE in Space:** “It became apparent to those members of the committee with limited prior exposure to DOE that the influx of expertise into space research and engineering will be very beneficial to the spaceflight community.
SNAP Policy Board Review – Feb. 2004

• SNAP concept for a comprehensive mission devoted to Dark Energy including methods other than SNe is the right way.

• “Keep up the SNAP team’s excellent program of scientific research and mission development. This is not the time to stop because of perceived funding uncertainties in NASA. Note that Congress has approved the Beyond Einstein initiative.”

• “It is imperative that the SNAP team urge NASA to get the science definition process underway as soon as possible”

• “Encourage NASA to select a lead center as soon as it is feasible”

• The scientists must be an integral part of the telescope design and construction – this is why the Chandra mission was successful.

[Members of the Directors Policy Board: Warren Moos - chair (JHU/FUSE-PI), Jonathan Ormes (Dir. GFSC Space Sci.), Larry Simmons (JPL/SIRTF), Martin Weisskopf (MSFC), Charles Baltay (Yale), Peter Michelson (Stanford/GLAST-PI), Burton Richter (former SLAC Director), Harvey Tananbaum (Harvard/Chandra-PI),]
SNAP R&D Geared toward a Successful Mission

- Program has come a long way since our 1999 SAGENAP proposal.
- Built strong collaboration, including experts in space and experts in large detector systems.
- JDEM is a major step.
- Science: Multi-faceted approach to dark energy science has been developed. Comprehensive yet simple mission concept.
- R&D: Vibrant program in developing major technologies. Strong team making great advances.