Dark Energy Observer

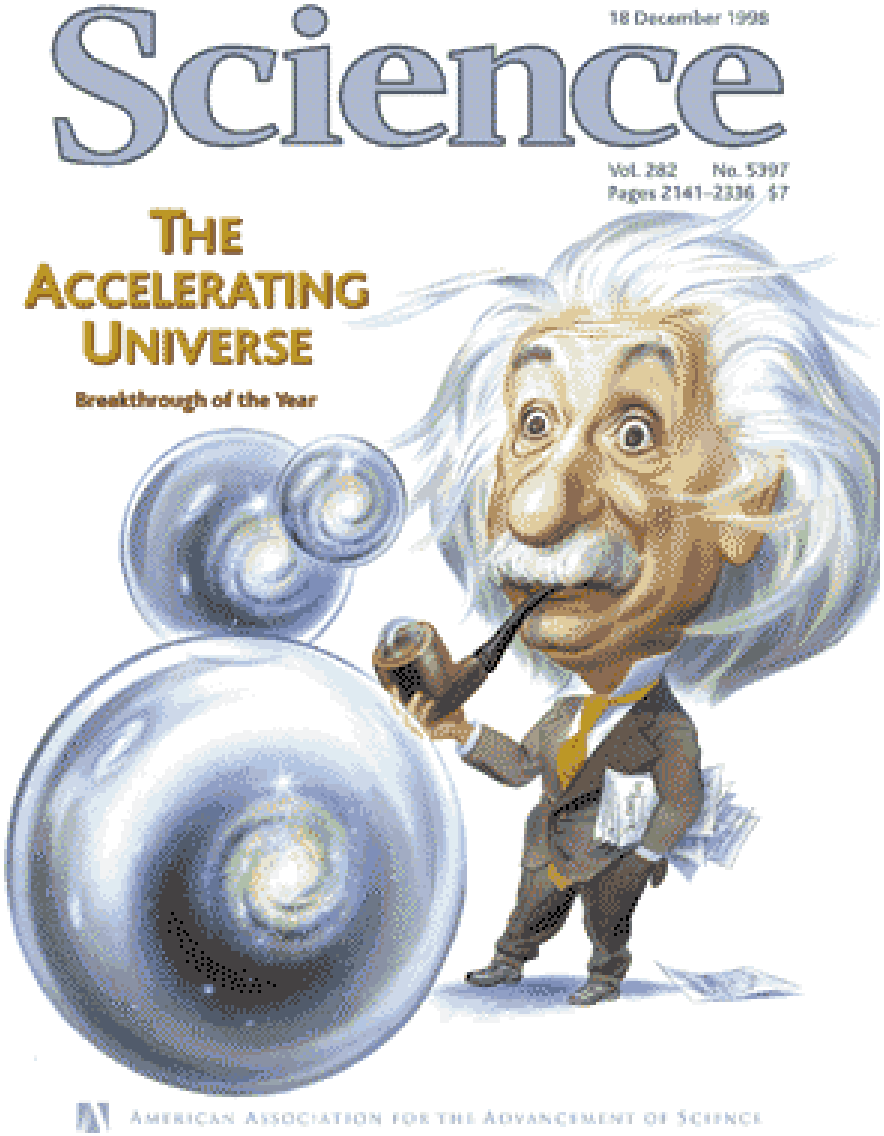
SNAP: Supernova / Acceleration Probe

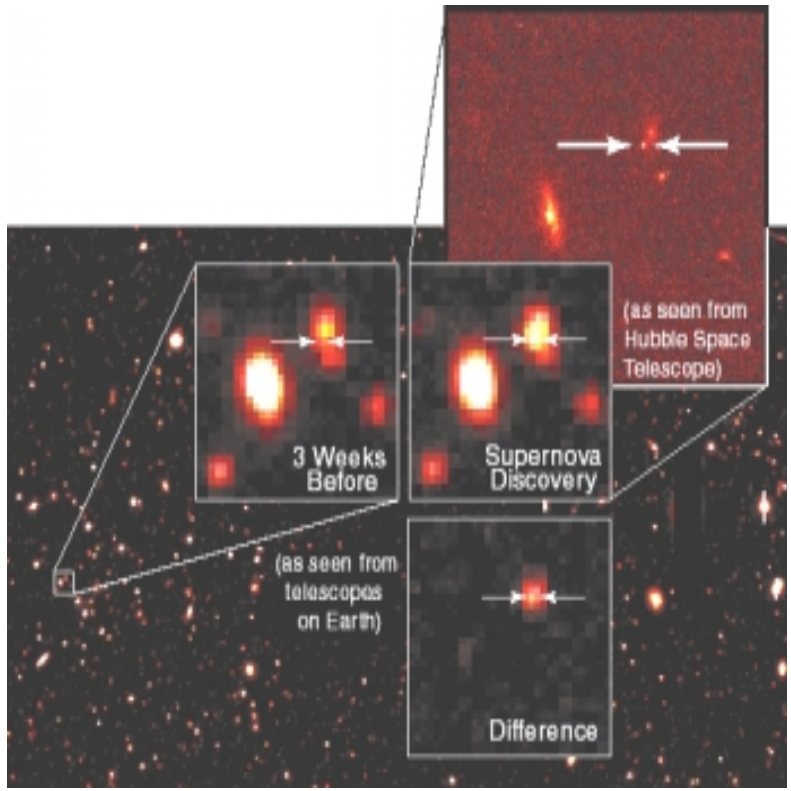
BERKELEY LAB

Using DOE-developed science and technology,
we have an unusual opportunity
to answer fundamental questions of physics
with a definitive, precision cosmology measurement.

Astrophysics to Understand the Universe

Mass Density, Vacuum Energy Density, and Curvature





Fundamental Questions:

- *Will the universe last forever?*
- *Is the universe infinite?*
- *What is the universe made of?*

An unusual moment in human history:

At the beginning of this century, Einstein developed the conceptual tools to address these questions empirically.

In the past decade or so, technology has advanced to the point that we can now make the measurements that begin to answer these fundamental questions.

Progress is now being made with large scientific programs, including the Supernova Cosmology Project* and the Cosmic Microwave Background satellites: COBE,* MAP, and PLANCK.*

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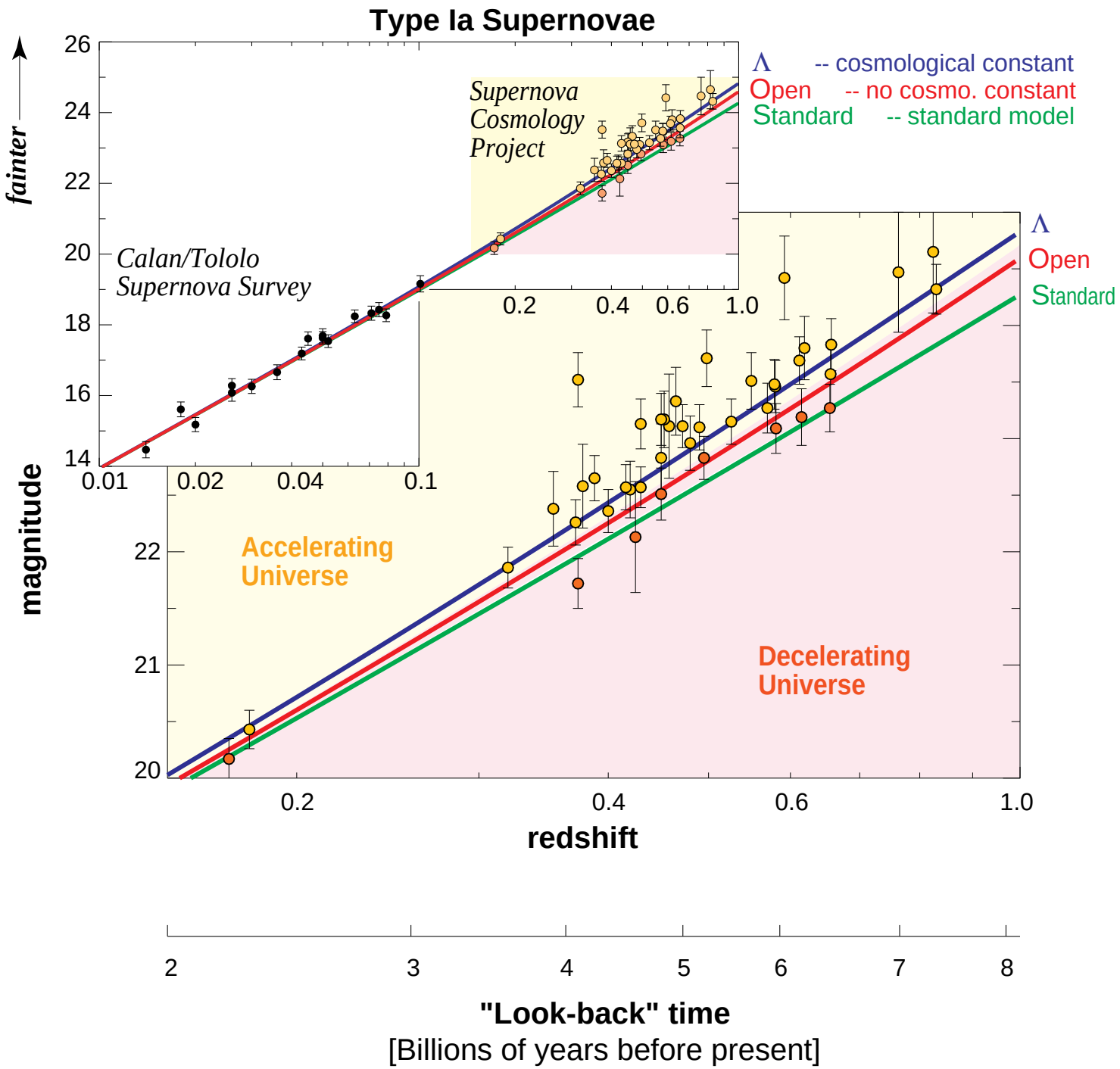
* Programs with DOE support.


Type Ia Supernovae
fainter
magnitude
Λ -- cosmological constant
Open -- no cosmo. constant
Standard -- standard model
Supernova Cosmology Project
Calan/Tololo Supernova Survey
Accelerating Universe
Decelerating Universe
redshift
"Look-back" time
[Billions of years before present]

The implications of an accelerating universe:

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

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

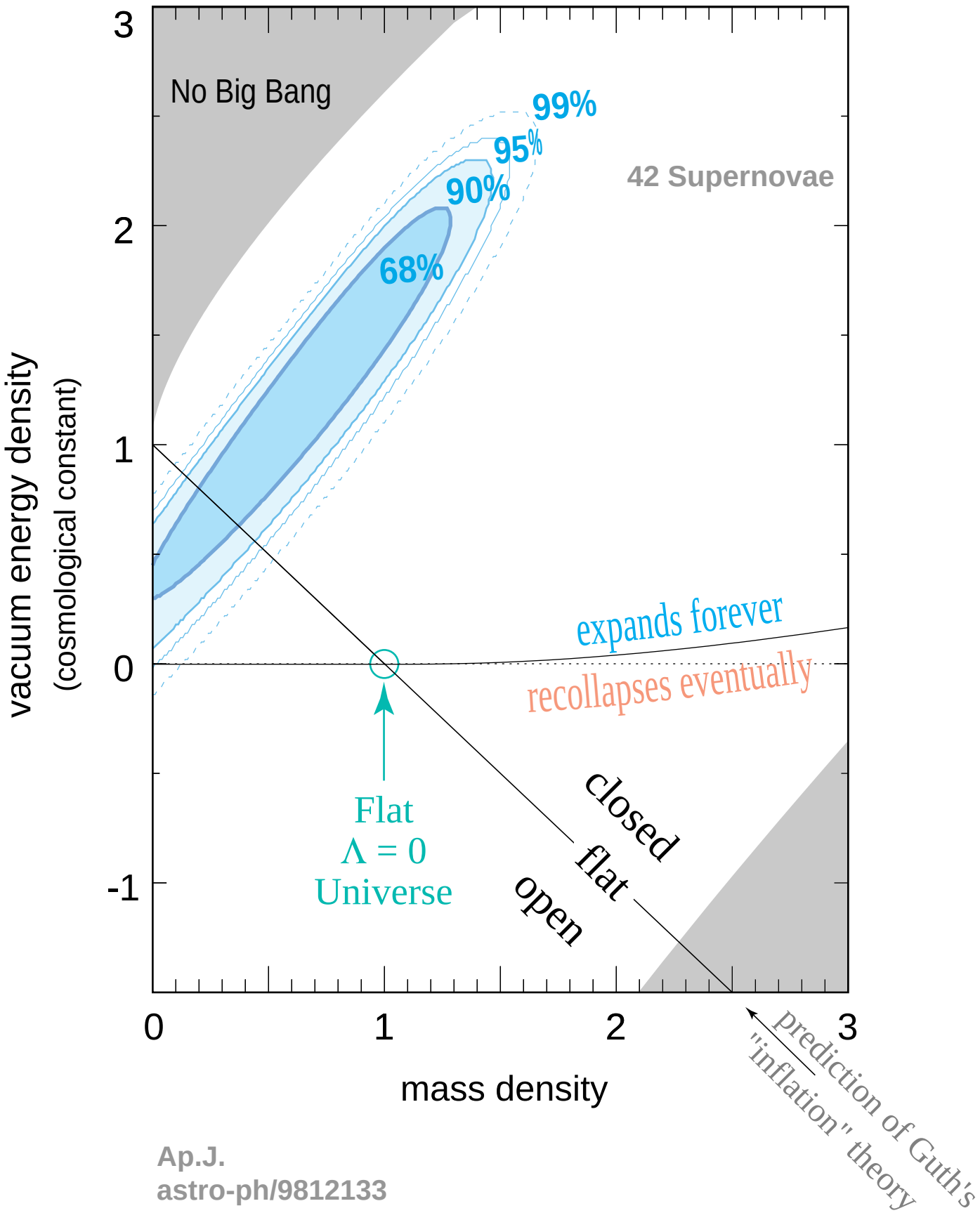
   This new accelerating energy ("dark energy") has a larger energy density than the mass density of the universe (or else the universe's expansion wouldn't be accelerating).

What we don't know is:

1. How much of mass density and dark energy density is there? I.e., how much dark matter and dark energy do we need to look for?
   The answer to this question determines the "curvature" of the universe, and can tell us about the extent of the universe: infinite or finite.

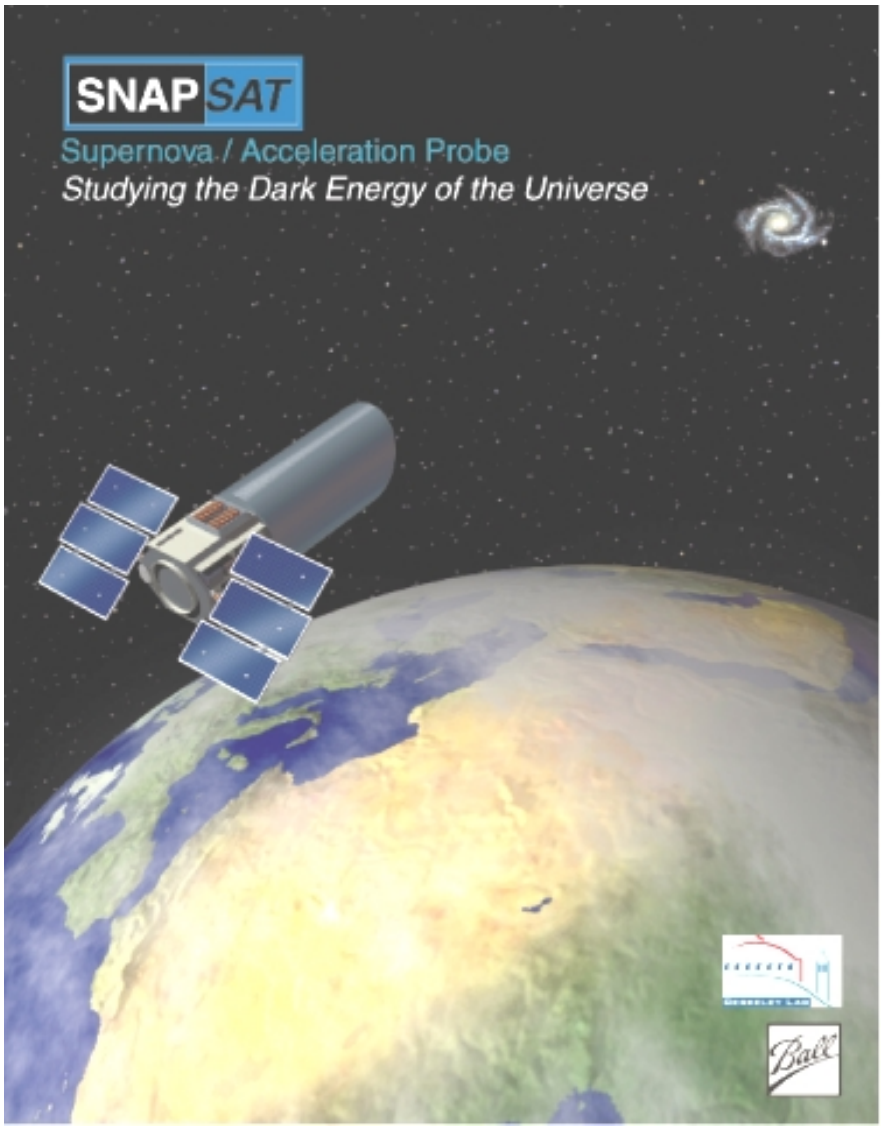
2. What is the "dark energy"? Particle physics theory proposes a number of alternatives, each with different properties that we can measure. Each of the alternative theories raises some important questions/problems of fundamental physics.

Supernova Cosmology Project
Perlmutter *et al.* (1998)



Ap.J.
astro-ph/9812133

Proposed Satellite Probe of the Fundamental Properties of the Universe



Scope

- 1.8 meter aperture
- 1 square degree mosaic camera (1 billion pixels)
- 3 channel spectroscopy 0.3 μm-1.8 μm

SNAP Dark Energy Observer

supernova / acceleration probe

satellite overview

- **1.8m aperture telescope**
  Can reach very distant SNe.
- **1 square degree mosaic camera, 1 billion pixels**
  Efficiently studies large numbers of SNe.
- **3-channel spectroscopy, 0.3um -- 1.8um**
  Detailed analysis of each SN.

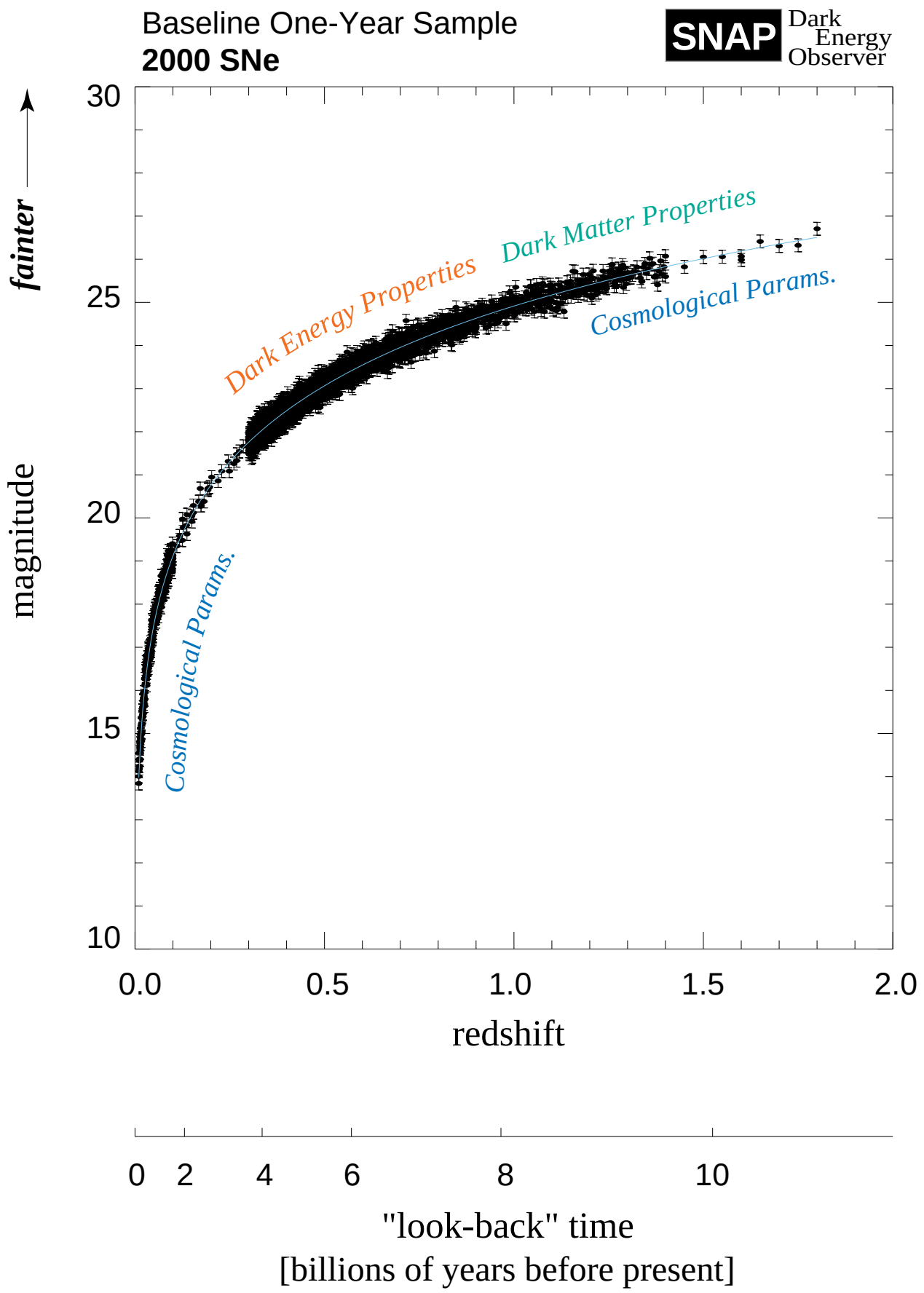
MIDEX+ class satellite:

Dedicated instrument.

Designed to repeatedly observe an area of sky.

Essentially no moving parts.

4-year construction cycle.
3-year operation for experiment
(lifetime open-ended).


Baseline One-Year Sample
2000 SNe
SNAP
Dark Energy Observer
fainter
magnitude
30
25
20
15
10
Dark Energy Properties
Dark Matter Properties
Cosmological Params.
Cosmological Params.
0.0
0.5
1.0
1.5
2.0
redshift
0
2
4
6
8
10
"look-back" time
[billions of years before present]

SNAP*SAT*

supernova acceleration probe

baseline science goals

Target Parameter	*Constraint*	*Target Statistical Uncertainty*

Determine mass density, vacuum energy density, and curvature

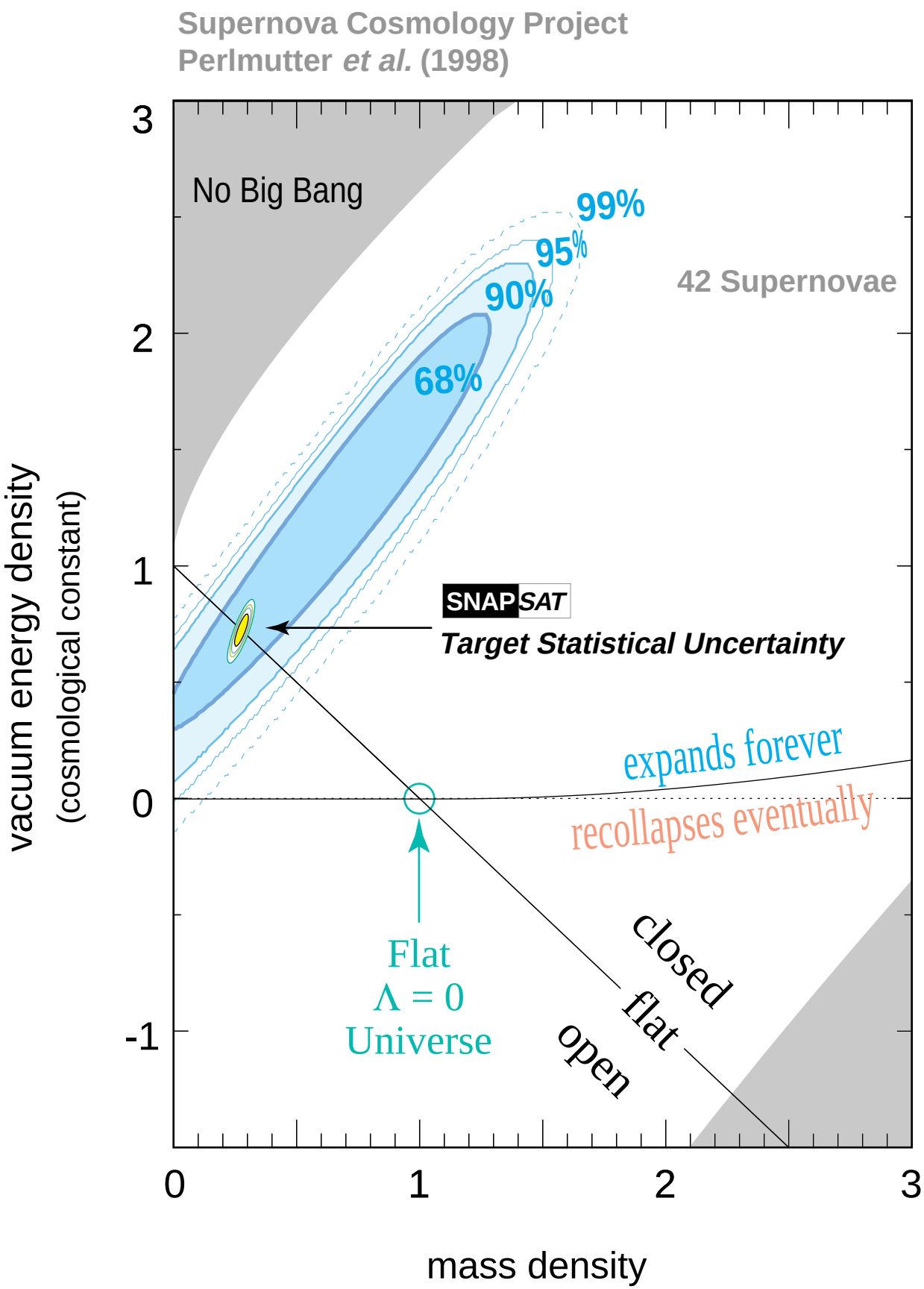
mass/vacuum energy Ω_M, Ω_Λ	in flat universe Ω_k=0	0.01

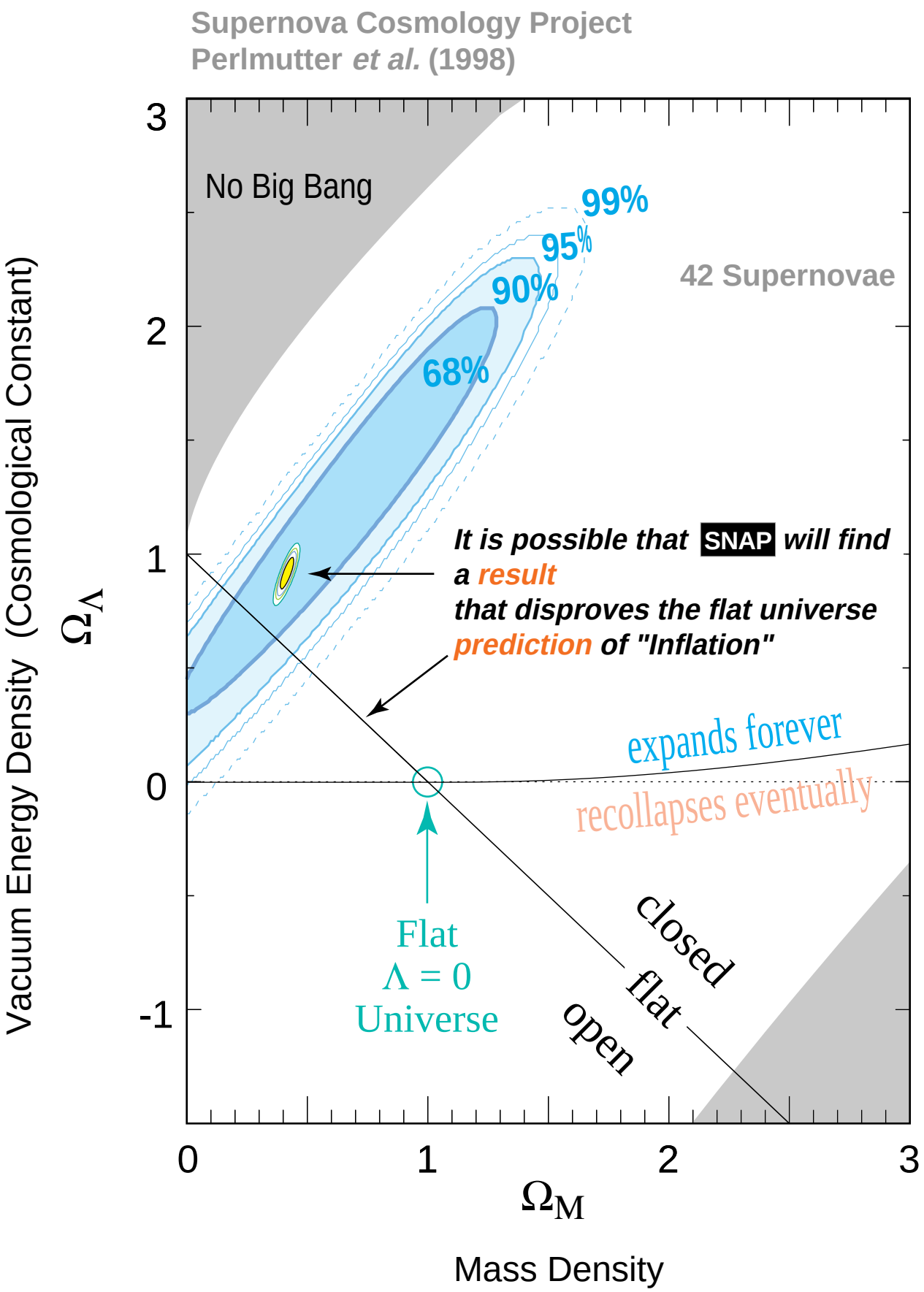
curvature Ω_k	(indep. of CMB)	0.05
mass density Ω_M	unconstrained Ω_k	0.02
vacuum energy Ω_Λ	"	0.05

Properties of Dark Energy

Eq. of State w vs Ω_M	in flat universe	
Eq. of State w	with $\Omega_M \approx 0.3$	0.05
Study time-varying $w(t)$ by studying $d_L(z)$ with $\Delta z \approx 0.03$ bins.		

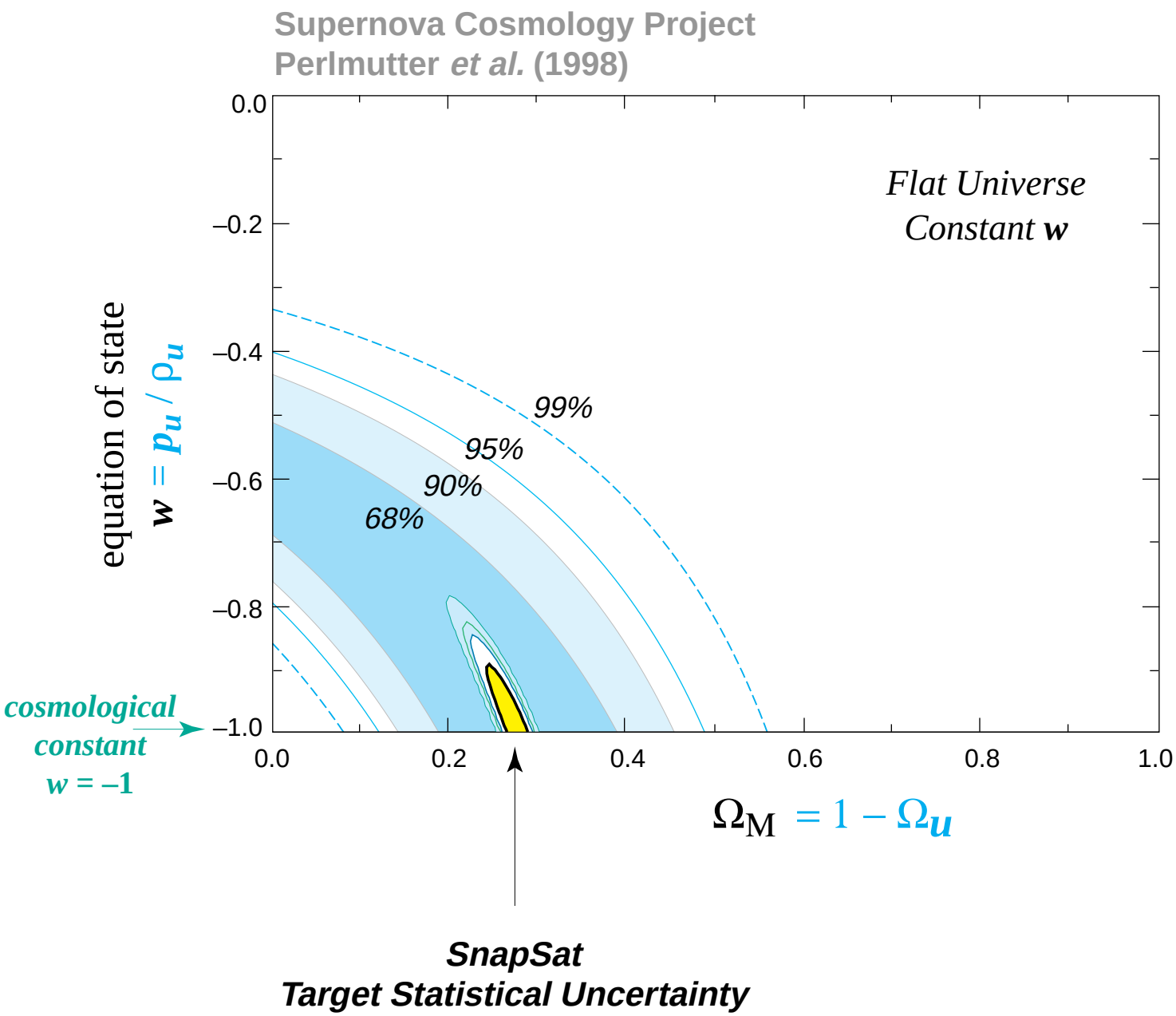
A definitive supernova cosmology measurement.


Supernova Cosmology Project
Perlmutter et al. (1998)
No Big Bang
99%
95%
90%
68%
42 Supernovae
SNAPSAT
Target Statistical Uncertainty
expands forever
recollapses eventually
Flat
Λ = 0
Universe
closed
flat
open
vacuum energy density
(cosmological constant)
mass density
3
2
1
0
-1
0
1
2
3


Supernova Cosmology Project
Perlmutter et al. (1998)
No Big Bang
99%
95%
90%
68%
42 Supernovae
It is possible that SNAP will find
a result
that disproves the flat universe
prediction of "Inflation"
expands forever
recollapses eventually
closed
flat
open
Flat
Λ = 0
Universe
Vacuum Energy Density (Cosmological Constant)
Ω_Λ
Ω_M
Mass Density
3
2
1
0
-1
0
1
2
3

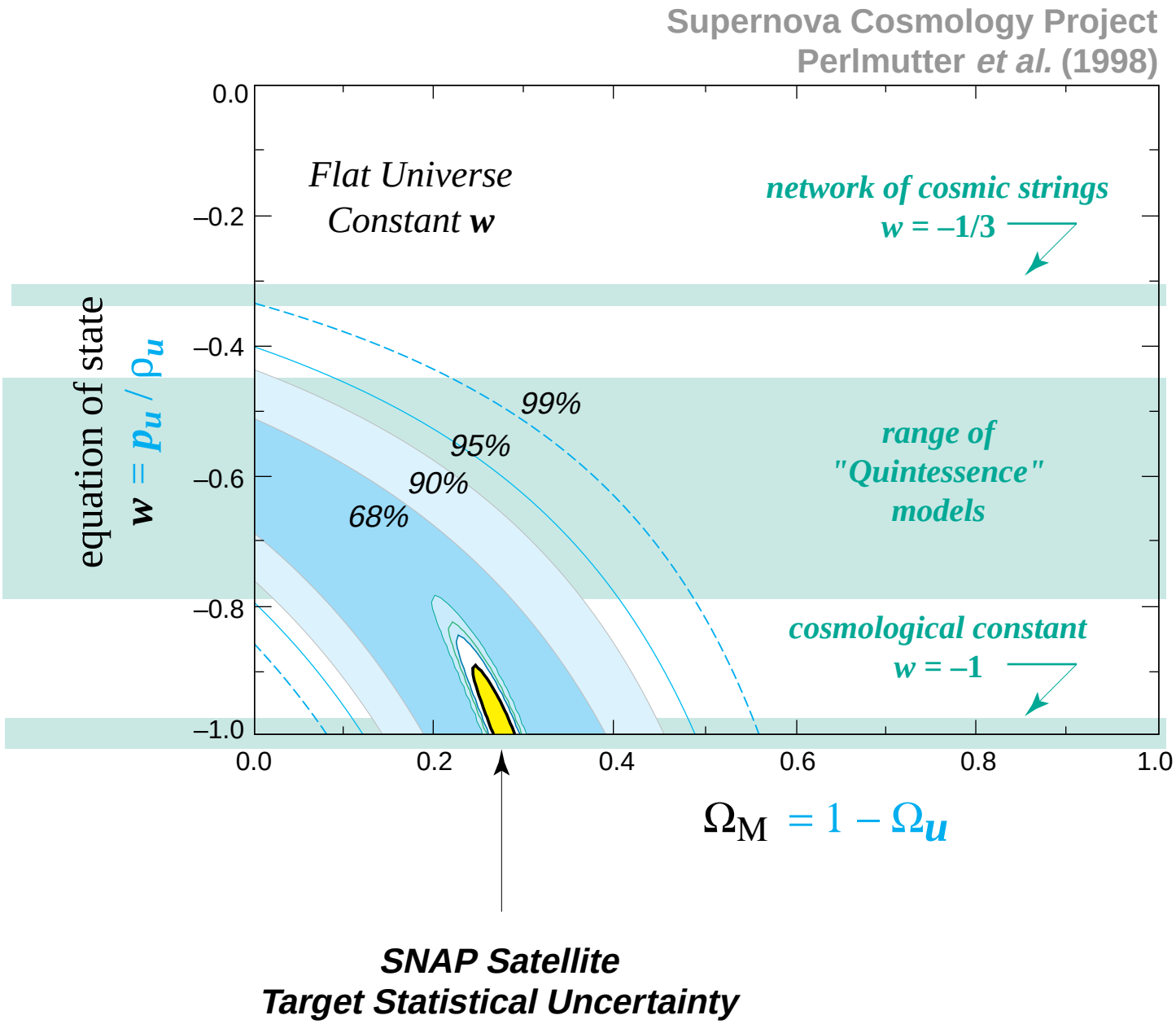
Dark Energy

Unknown Component, Ω_u, of Energy Density



Dark Energy

Unknown Component, Ω_u, of Energy Density



SNAP Satellite
Target Statistical Uncertainty

SNAP Dark Energy Observer

science cross-checks

With the little (or no) additional effort/data, we can make cross-check measurements of the cosmological parameters several ways.

(Note that these other measurements are much more model dependent.)

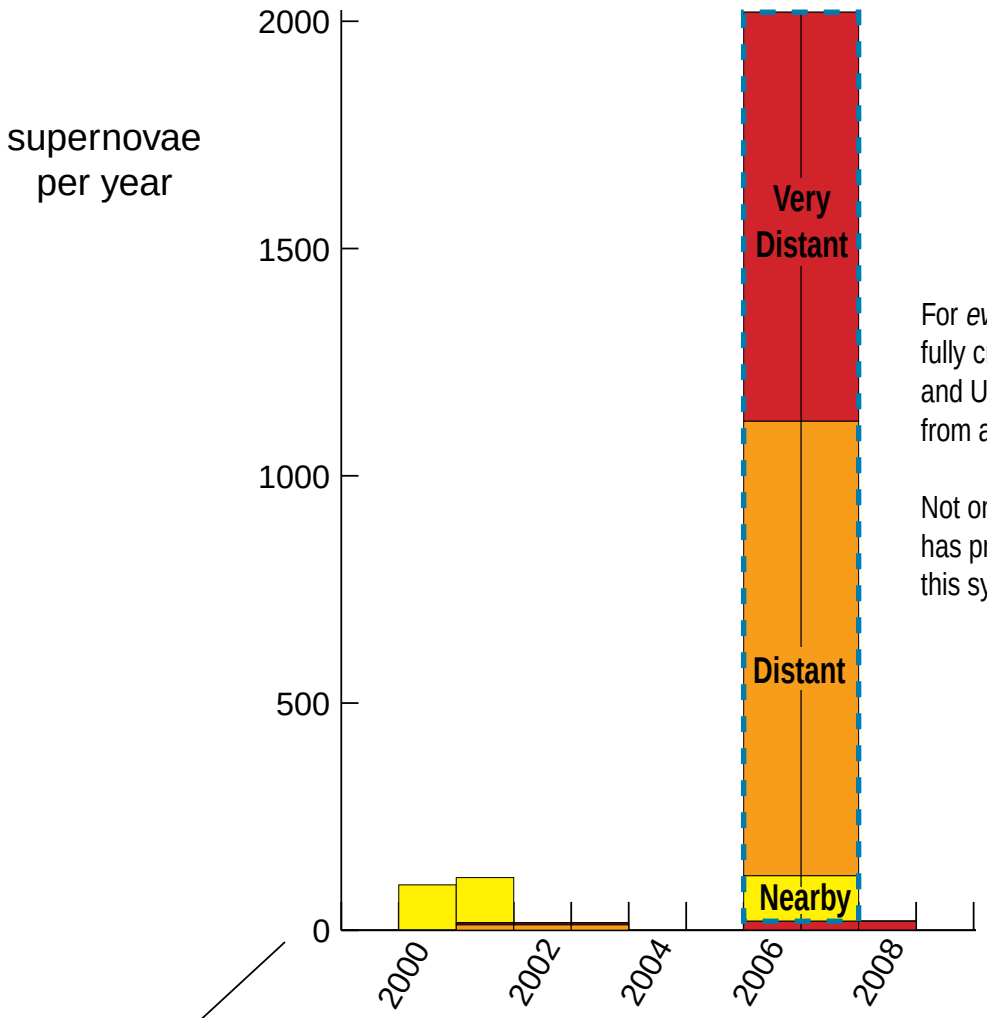
- The "other" supernovae (Type II) provide a completely independent measurement technique.
- Gravitational lensing of background galaxies in the field distorts the galaxy shapes. Studies of this phenomenon give an alternative cosmological-parameter measurement.
- Gravitational lensing can split distant quasar images into two (or more) images. The number of such events bounds the cosmological constant.
- Galaxy clustering at great distances is an indicator of the cosmological parameters.

complementary science

- What are "Gamma Ray Bursts"? Find the corresponding optical signals that can tell us where and what they are.
- What are the massive objects ("MACHOs") in the halo of our galaxy that are causing "microlensing"? Look for faint objects that move over a year in our images.
- Find the most distant objects in our Solar System.
- Discover the progenitors of supernovae, and the rates of star formation. When did the first stars form?

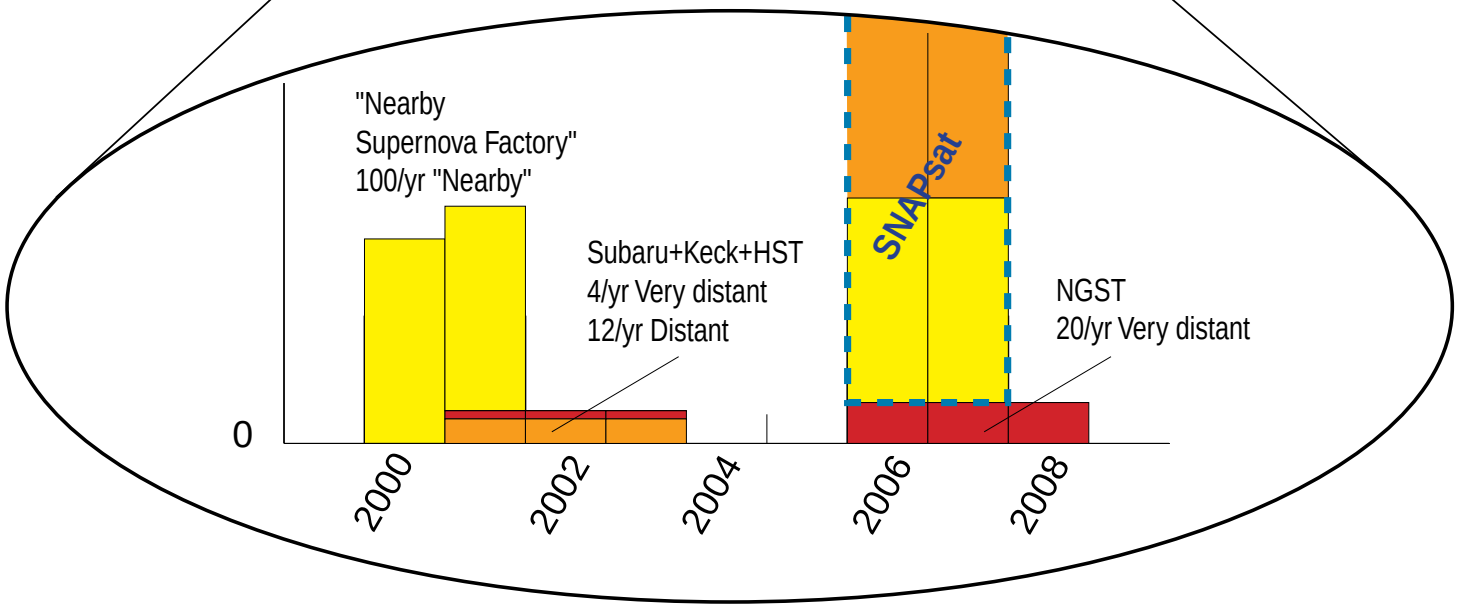
Roadmap for the Supernova Cosmology Project

SNAPsat
900/yr Very distant (~10 billion years back)
1000/yr Distant (~5 billion years back)
100/yr "Nearby" (<1 billion years back)



For *every* SNAPsat supernova:
fully cross-calibrated lightcurves
and UV-to-IR spectra
from a standard instrument set.

Not one single supernova
has previously been studied
this systematically.



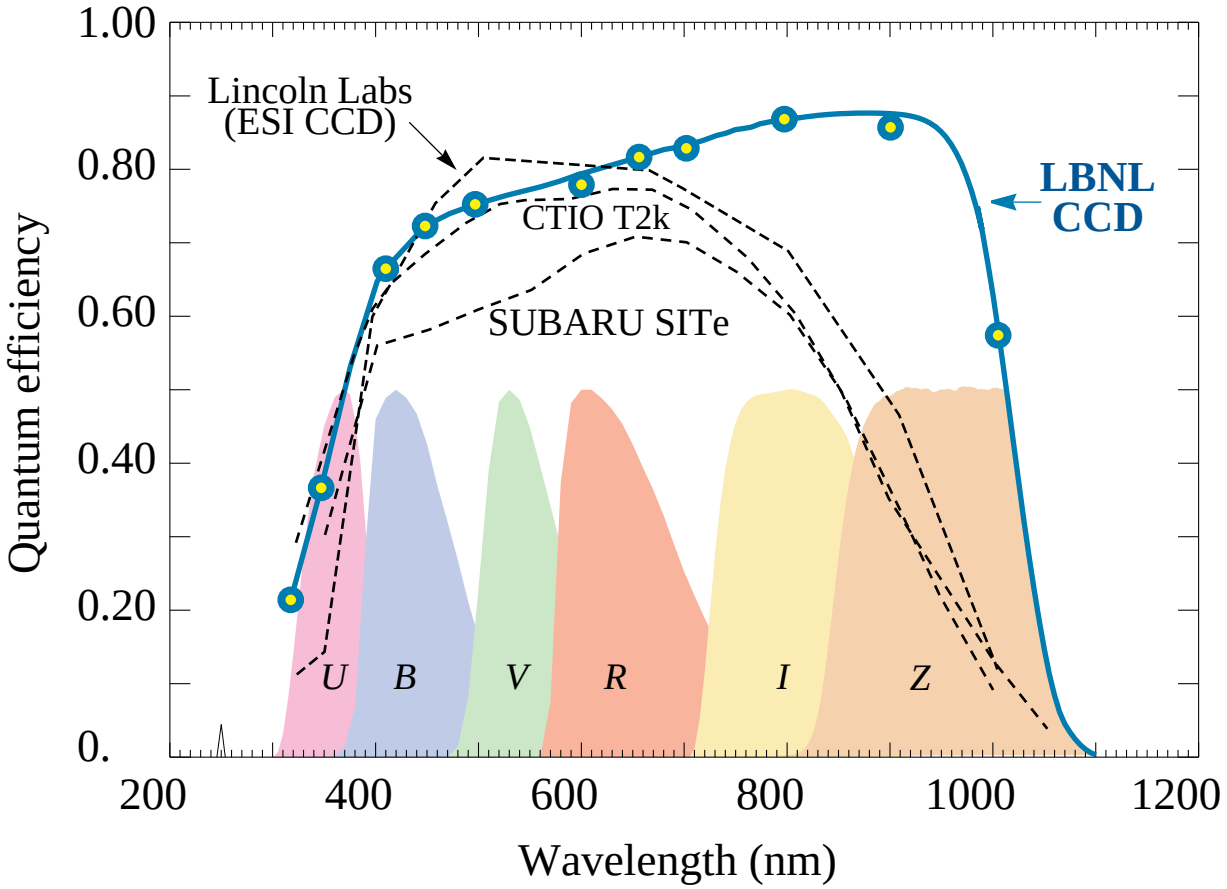
LBNL CCD Technology

- Fabricated on ultra-high purity silicon wafers,
  as used in HEP vertex detectors -- SSC heritage.

- High quantum efficiency
  from near UV to near IR.

- Better overall response than
  more costly "thinned" devices in current use.

- High-purity silicon has better radiation tolerance
  for space applications.

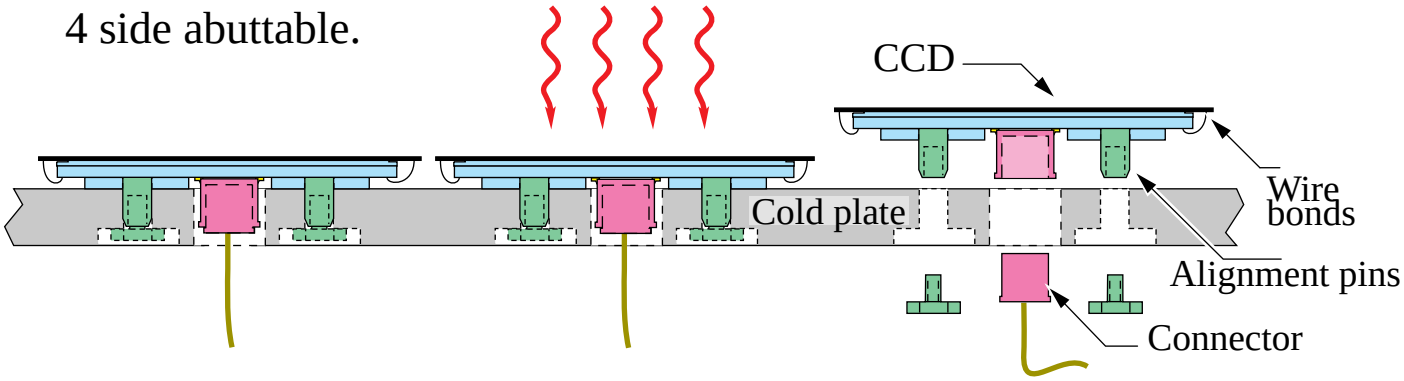


SNAP camera with LBNL CCD Technology

- SNAP imager would be largest CCD camera ever constructed
  (10 x Sloan Digital Sky Survey),
  but smaller than SLAC's SLD vertex detector.

- LBNL CCD's are mechanically stable
  and can be assembled into large array:

4 side abuttable.



NERSC Supercomputing

Computational Demand:

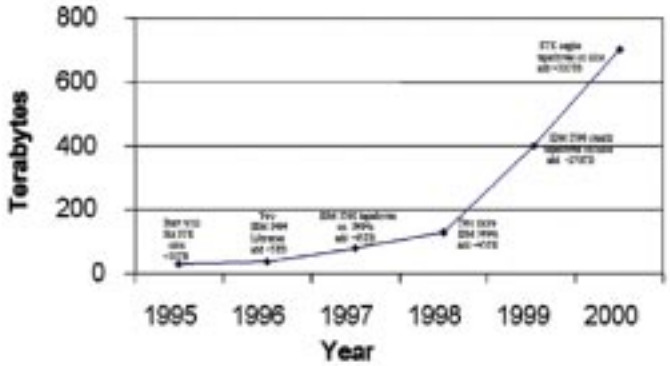
- Near real-time processing
- Data calibration and distillation

Data Handling:

- 50,000 GBytes / year
- Dataset distribution

National Energy Research Scientific Computing Center

One of the nation's most powerful unclassified computing centers: peak capacity 600 Gflop/s



High Performance Storage System (HPSS): >300 TB capacity and growing

Networked connectivity at speeds of up to 622 megabits per second

Intellectual resources: the expertise to move from raw data to scientific understanding

Necessary Groundwork

Detector development:

- **Optimized CCD fabrication.**
- **Routine CCD fabrication in quantity.**

Ground-based supernova studies:

- **Supernova factory:**
- **Routine discovery of low-redshift SNe.**
- **Routine handling of satellite-sized data set.**
- **Selection of observational features to be targeted.**

STATUS

Endorsement from Supernova Cosmology Project (SCP)

The SCP Collaboration consists of: LBNL (Lead Institution, PI - S. Perlmutter), Space Sciences Lab., U.C. Berkeley, CalTech, Fermilab, Yale, and foreign institutions: CNRS-IN2P3 (France), U. Stockholm, Royal Greenwich Obs., European Southern Obs., U. Barcelona, U. Lisbon

Concept Presented at Inner Space/Outer Space (FermiLab, May '99).

Inclusion in NASA Strategic Planning: Annual strategic planning exercise in process; study of cosmological parameters already in plan through MAP and PLANCK satellite missions.

Mission Feasibility study with Ball Aerospace. (Ball Aerospace is responsible for several key Hubble Space Telescope instruments, has an active commercial launch program.)

Cost Estimate from Ball Aerospace ($273M). DOE component $116M includes telescope and instruments ($76M without contingency or operations), NASA component $157M includes launch, spacecraft, mission operations ($123M without contingency or operations).

Next step requires "seed funding" ($250K FY99, $2.6M FY00), and mechanism to fund joint DOE/NASA mission.

DOE/NASA Joint Mission

1) Invitation for joint NASA/DOE mission: “Goldin wants high-energy physicists to propose space experiments” [Science 6/4/99 p. 1598].

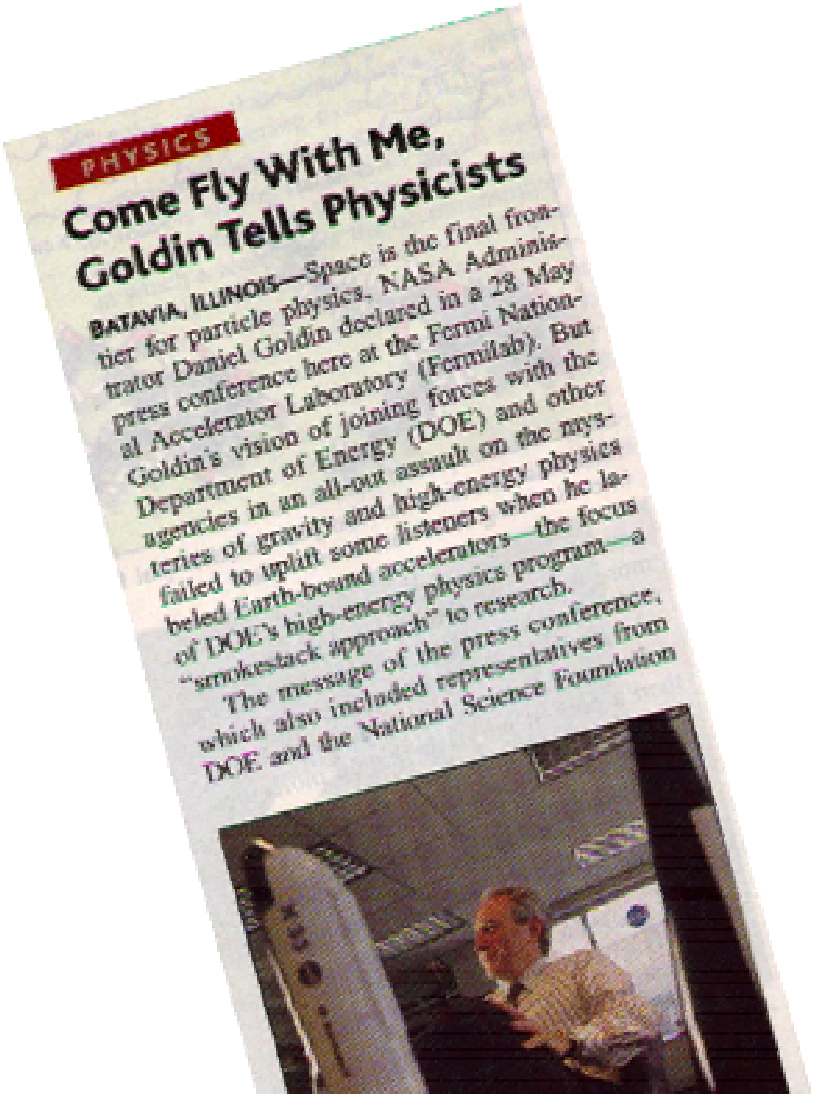
2) Strong role for DOE:

DOE initiated and funded Supernova Cosmology Project,
DOE led techniques for developing supernova search program -- in style of an H.E.P. experiment,
DOE led program in developing supercomputer codes for modeling supernovae (NERSC),
DOE enabling technology in CCD imagers,
DOE excellence in bringing new technologies to rapid application.

3) NASA heritage in rapidly deploying and operating small satellites.

4) Joint project combines the best capabilities of DOE & NASA in enabling fundamental science.

NASA Interest in New Astrophysics Probes



PHYSICS

Come Fly With Me, Goldin Tells Physicists

BATAVIA, ILLINOIS—Space is the final frontier for particle physics, NASA Administrator Daniel Goldin declared in a 28 May press conference here at the Fermi National Accelerator Laboratory (Fermilab). But Goldin's vision of joining forces with the Department of Energy (DOE) and other agencies in an all-out assault on the mysteries of gravity and high-energy physics failed to uplift some listeners when he labeled Earth-bound accelerators—the focus of DOE's high-energy physics program—a "smokestack approach" to research.

The message of the press conference, which also included representatives from DOE and the National Science Foundation

"... in the quest to quantify the expansion of the Universe, astronomers may have uncovered a new physical phenomenon -- a kind of vacuum energy they call the Cosmological Constant. This exciting discovery may have given astronomers and physicists an unexpected clue about fundamental physics."

Daniel S. Goldin, May 28, 1999
Fermilab Inner Space-Outer Space Conference

Using DOE-developed science and technology,

Supernova Cosmology Project
Keck telescope
CMB studies
LBNL CCD technology
HEP large, complex detector experience
NERSC supercomputer center
finding, analyzing, and modeling supernovae

we have an unusual opportunity
to answer fundamental questions of physics

Is the universe infinite?
Is space curved?
What is the fate of the universe?
What is the "Dark Energy" that is causing
the universe expansion to accelerate?

with a definitive, precision cosmology measurement.

The first complete calibrated supernova dataset,
2 orders of magnitude larger statistics (>2000 SNe),
extending much farther in distance and in time.
A 1% measurement of the mass density.
A 5% measurement of the vacuum energy density.
A 5% measurement of the curvature.
A 5% measurement of the Equation of State
of the "Dark Energy"

Additional Background Materials

SNAP Dark Energy Observer

supernova acceleration probe

satellite baseline specifications

Aperture	1.8m
F.O.V.	1 square degree
Launch Vehicle	Delta II 7920

Image array	36k x 36k mosaic CCD
Architecture	2k x 4k 10-micron pixels
Plate Scale	10 micron/0.10 arc-sec

Image Array Bands	B,V,R,I,Z
Q.E.	65% @ 1000nm (LBNL CCD)
	92% @ 900nm
	>85% @ 400nm-800nm
Read Noise	<2-4 e-
Dark Current	0.08 e-/min/pixel
Image Array Temp.	150K

Spectroscopy	3-channel pick-off:
	325-600nm "Blue" CCD
	+ 600-1050nm "Red" LBL CCD
	+ 1050-1800nm IR (HgCdTe)
Thermal Cooling	passive

Data Downlink	320 Mbps
Data Storage	256 Gbits solid state

Pointing Stability	<0.1 arc-sec
Image Stabilization	2-axis fast steering mirror
Satellite Mass	<900kg *
Power Consumption	<400W *

SNAP*SAT*

supernova acceleration probe

one-year baseline data package

Full sample of 2000 SNe between z = 0.3 and 1.7

Discovery within ~2 days of explosion (i.e. ~2 weeks before max).
Most dense coverage between z = 0.3 and 1.0

- Spectra at max for all SNe. (0.3 -- 1.8um)
- Lightcurve points at least 1/week (restframe)
  from -15 to +60 days (restframe)

Discover *every* SN in the field

Nearly continuous monitoring of
~2 sq. deg. to m_{AB} (@1um) ≈ 28.5+
~10 sq. deg. to m_{AB} (@1um) ≈ 25+
~100 sq. deg. to m_{AB} (@1um) ≈ 24+

Satellite follows additional 200 SNe at z < 0.15

Discovery from ground, follow-up from space to ensure matching spectroscopy/photometry across redshifts.

Subsample of 200 SNe from the full sample

Selected to span
- lightcurve timescales
- galaxy environments
  (morphology, galactocentric radius)
- redshifts

- Spectra at least 2/week (restframe) first month
  1/week (restframe) later

- Synthetic "filter-tuned" photometry from spectra
  for perfect K-corrections

SNAP*SAT*

supernova acceleration probe

controls for systematics

Dust and Extinction

Determine individual extinctions laws for a given supernova, using range of color measurements into near IR.

Determine gray dust contribution (if any), tracking $d_L(z)$ to high z.

SN Progenitor Age and Metallicity Effects

Studies of lightcurve-timescale (and spectral) luminosity indicators with significant sample of SNe in all host galaxy environments.

Measurement Systematics

Observe all SNe at all redshifts with single, calibrated, stabile photometry/spectroscopy system.
(Avoid multiple instruments with different atmospheric/moon conditions.)

Roadmap for the
Supernova Cosmology
Project

	Nearby SN Factory	Subaru +Keck+HST Key Project	NGST Key Project	SNAPSat
SNe / Year				
@ $z < 0.06$	100	.	.	100
@ $z \sim 0.5$	.	12	.	1000
@ $z > 1$	.	4	20	900
Duration	2 yrs	3 yrs	3 yrs	2 yrs
Calibrated Candle	✓	✓	✓	✓
Reddening Measure	✓	✓	✓	✓
Gray Dust Measure	✓	✓	✓	✓
Metallicity Measure	.	.	✓	✓
Evolution Checks	✓	.	.	✓
Standardized Datasets	.	.	.	✓

SNAP Dark Energy Observer - Mission Cost/DOE

ITEM	Year 1	2	3	4	5	6	7	TOTAL
Project Management	2	2	2	2				8
Focal Plane Array	3	6	5	0				14
Spectrograph	1	2	1	0				4
Instrument Electronics	3	4	4	1				12
Instrument/Software I&T	0	0	2	2				4
Telescope Optics	4	5	5	0				14
Telescope Structure	2	3	3	1				9
Pre-launch Science Data Handling	0	0	1	4				5
Ground Data System Development	0	1	2	3				6
Science	0	0	0	0	5	5	5	15
Sub-Total	15	23	25	13	5	5	5	91
Contingency (28%)								25
TOTAL								$116 M

SNAP Dark Energy Observer - Mission Cost/NASA

ITEM	Year 1	2	3	4	5	6	7	TOTAL
Systems Engineering	3	6	4	2				15
Ground Work	2	2	2	2				8
Launch Services	10	15	15	15				55
Spacecraft Bus	9	10	10	10				39
Ground Tracking	0	0	0	3				3
Ground Support Equipment	0	0	1	3				4
Mission Systems Integration & Test	0	0	3	4				7
Mission Operations					2	2	2	6
Education/Public Outreach					1	1	1	3
Sub-Total	24	33	35	39	3	3	3	140
Contengency (20% ex. launch)								17
TOTAL								$157 M

“Seed Funding”
Breakout of Costs/DOE
($K)

ITEM	FY99	FY00	cost (K)
Pre-Phase A study	100	100	200
Phase A study		650	650
CCD Commercialization	50	300	350
Scientific Support (3 Postdocs)		200	200
Demonstration Array	50	900	950
Ground Work		200	200
Electronics Technology	50	250	300
TOTAL	250	2600	2850