SuperNova / Acceleration Probe (SNAP)

An Experiment to Measure the Properties of the Dark Energy of the Universe

The Institutions of the SNAP Collaboration

University of California, Berkeley
Lawrence Berkeley National Laboratory
CNRS-IN2P3, LPNHE, and University Paris VI & VII
University of Maryland, College Park, MD
Cornell University
Space Telescope Sciences Institute
California Institute of Technology
CEA/DAPNIA, Saclay, France
Gemini Observatory
European Southern Observatory
University of Stockholm
University of Lisbon

Executive Session 8:30

SNAP Presentation Agenda

Perlmutter - Introductions, Sat. Overview, Supernova Science 9:30
25 min + 5 min questions

Aldering - Systematics, Comparisons 10:00
25 min + 5 min questions

Break - 10 min.

Levi - Instrumentation 10:40
15 min + 5 min questions

Lin, Lampton - UCB/SSL 11:00
Optics, Spacecraft, Mission Ops.
15 min + 5 min questions

Levi - Management, Cost, Schedule 11:20
5 min + 3 min questions

(No break here.)

Deustua - Education & Public Outreach 11:30
10 min

Turner - Theorist's Perspective 11:40
15 min

Lunch 12:00

SNAP SAGENAP Attendees

Gerson Goldhaber, Prof. of Physics
Robert Lin, Prof. of Physics, HESSI satellite PI
George Smoot, Prof. of Physics, COBE/DMR PI
Alex Kim

University of California, Berkeley

Samuel Silver Space Sciences Laboratory

Peter Harvey, HESSI Project Manager
Henry Heetderks, IMAGE/FUV Project Manager
Michael Lampton, co-I EUEV, IMAGE, ex-astronaut

UC Berkeley Space Sciences Laboratory

BERKELEY LAB

Charles Shank, Director
Pier Oddone, Deputy Director

Lawrence Berkeley National Laboratory

Greg Aldering
Susana Deustua
Bill Edwards, Project Engineer
Brenda Frye
Michael Levi
Stu Loken
Peter Nugent
Saul Perlmutter
Fritz Rene, Systems Engineer

Michael Turner, Prof.of Physics, Chair Astrophys.

University of Chicago

Chris Bebek

Cornell University

Drew Baden, Prof. of Physics
Jordan Goodman, Prof. of Physics, Dept. Chair
Greg Sullivan, Prof. of Physics

University of Maryland

Andrew Fruchter

Space Telescope Science Institute

University of Stockholm

Mark Metzger, Prof. of Physics
Richard Ellis, Prof. of Physics (by phone)

California Institute of Technology

IN2P3

Michel Spiro, Assoc. Director for Astrophysics

Institut National de Physique Nuclear et de Physique des Particules

Reynald Pain
Pierre Astier

University of Paris VI & VII

Technical University of Lisbon

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.

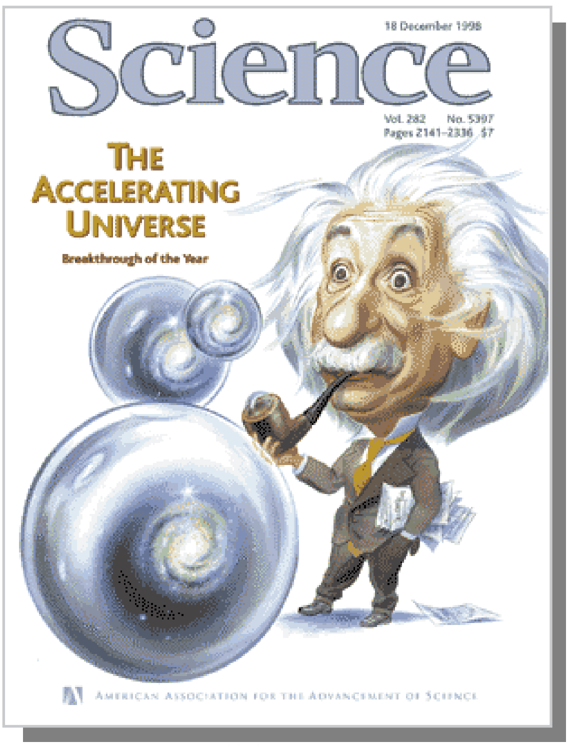
Progress is now being made with large scientific programs, including the Supernova Cosmology Project and the Cosmic Microwave Background satellites: COBE, MAP, and PLANCK.

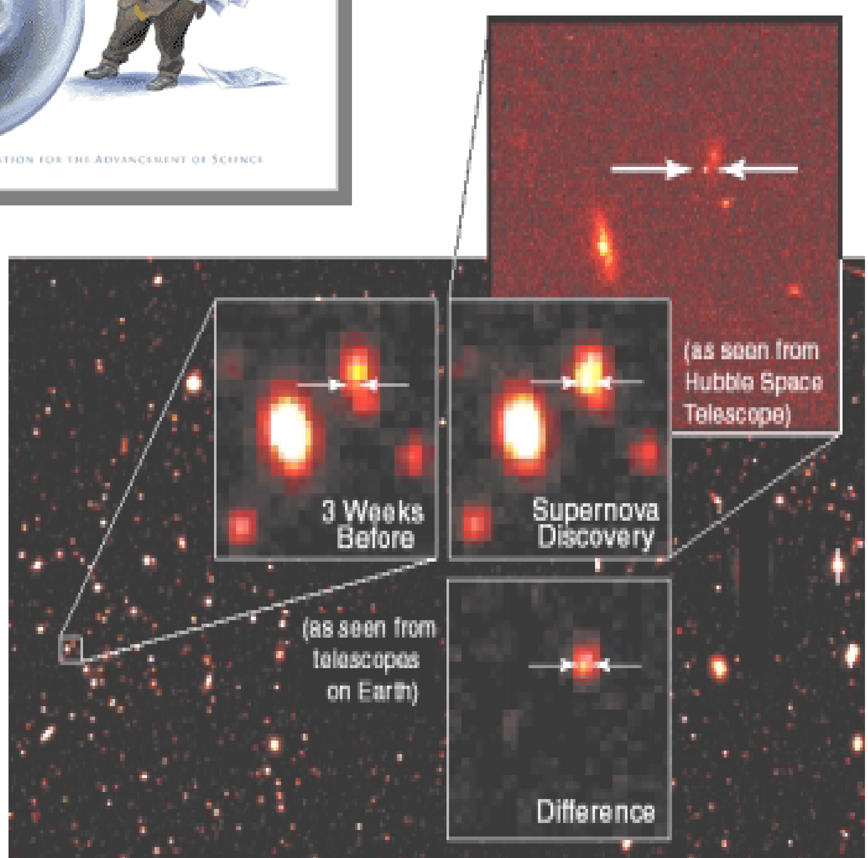
Today's Presentation:
A concept for a definitive, precision cosmology measurement.
We are proposing a **detailed study phase,**
leading to future reviews before a project start.

NSF
CENTER FOR PARTICLE ASTROPHYSICS
NSF SCIENCE & TECHNOLOGY CENTER

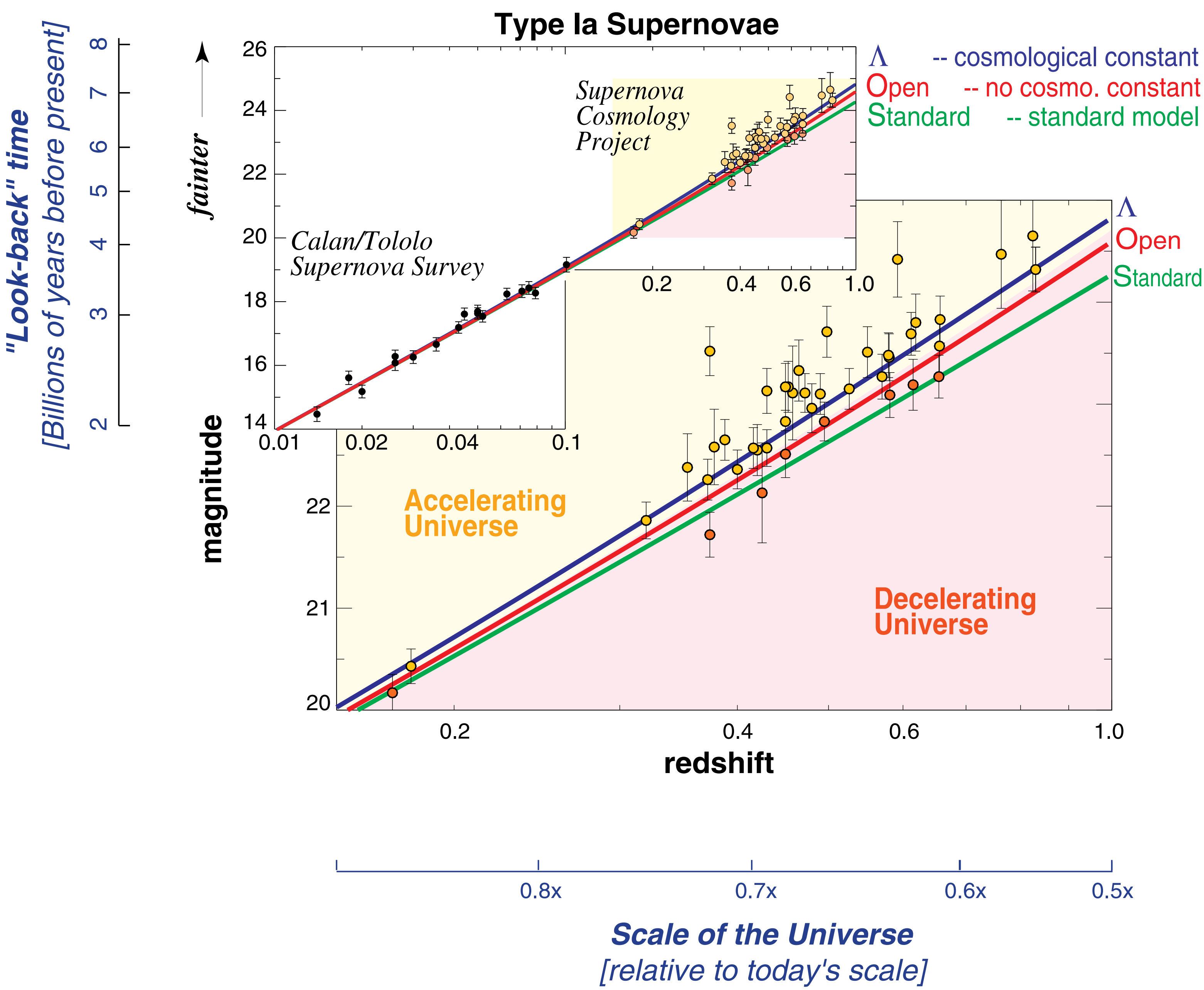
BERKELEY LAB
DOE

Science's Breakthrough of the Year: The Accelerating Universe





11 years of ground-based work:



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.

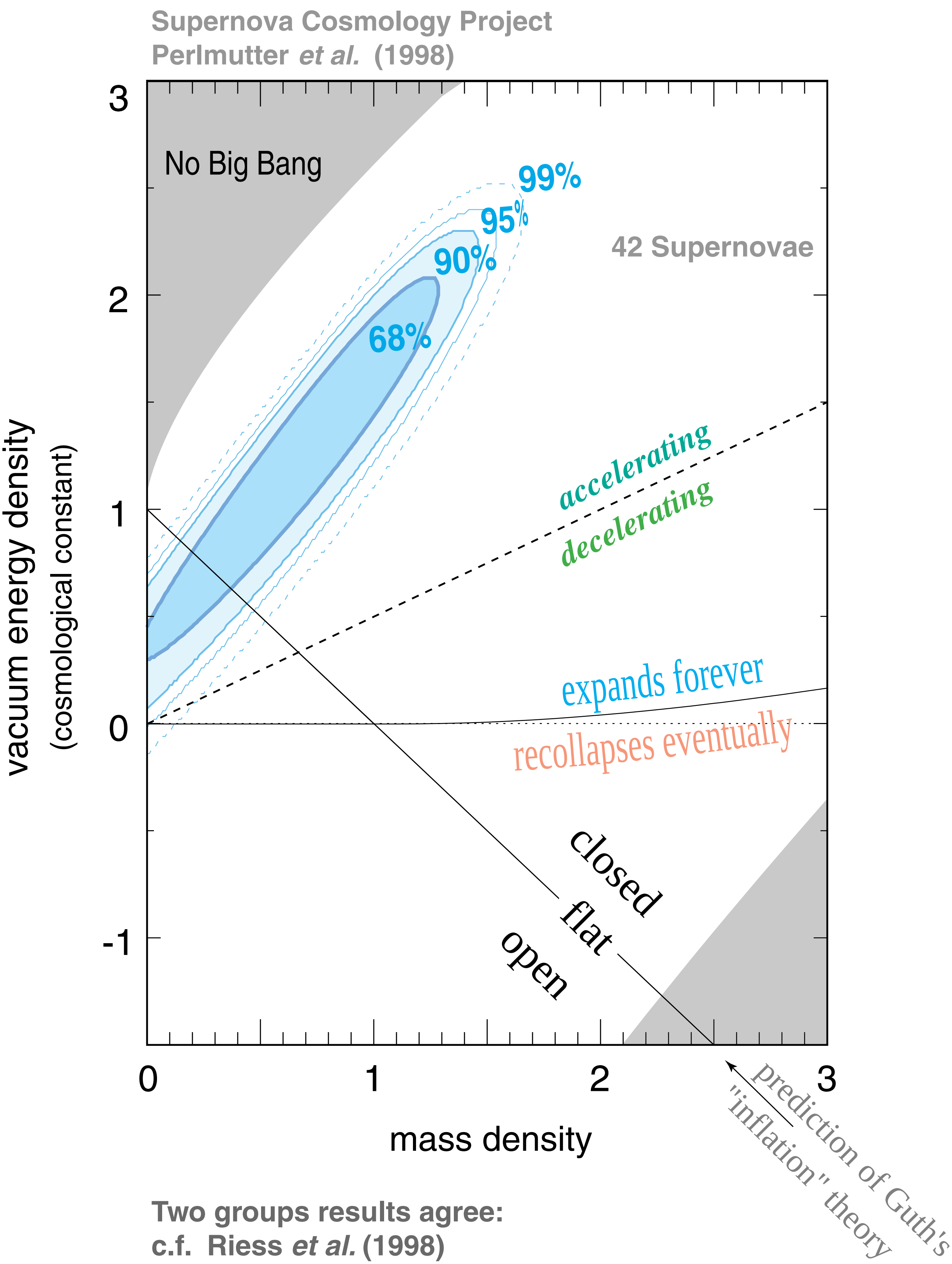
2. There is a previously unseen energy pervading all of space that accelerates the universe's expansion.

   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).

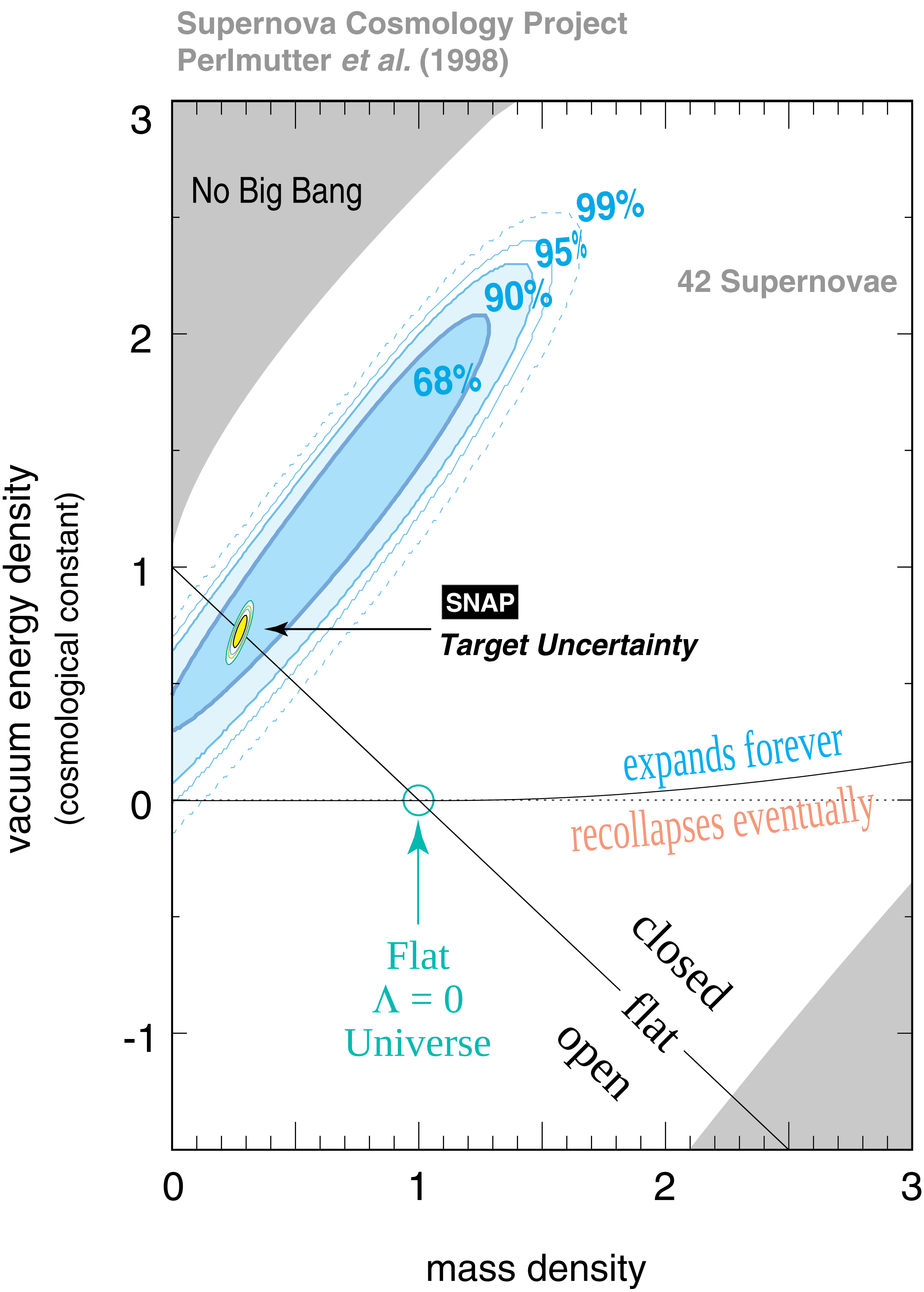
What we don't know is:

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.

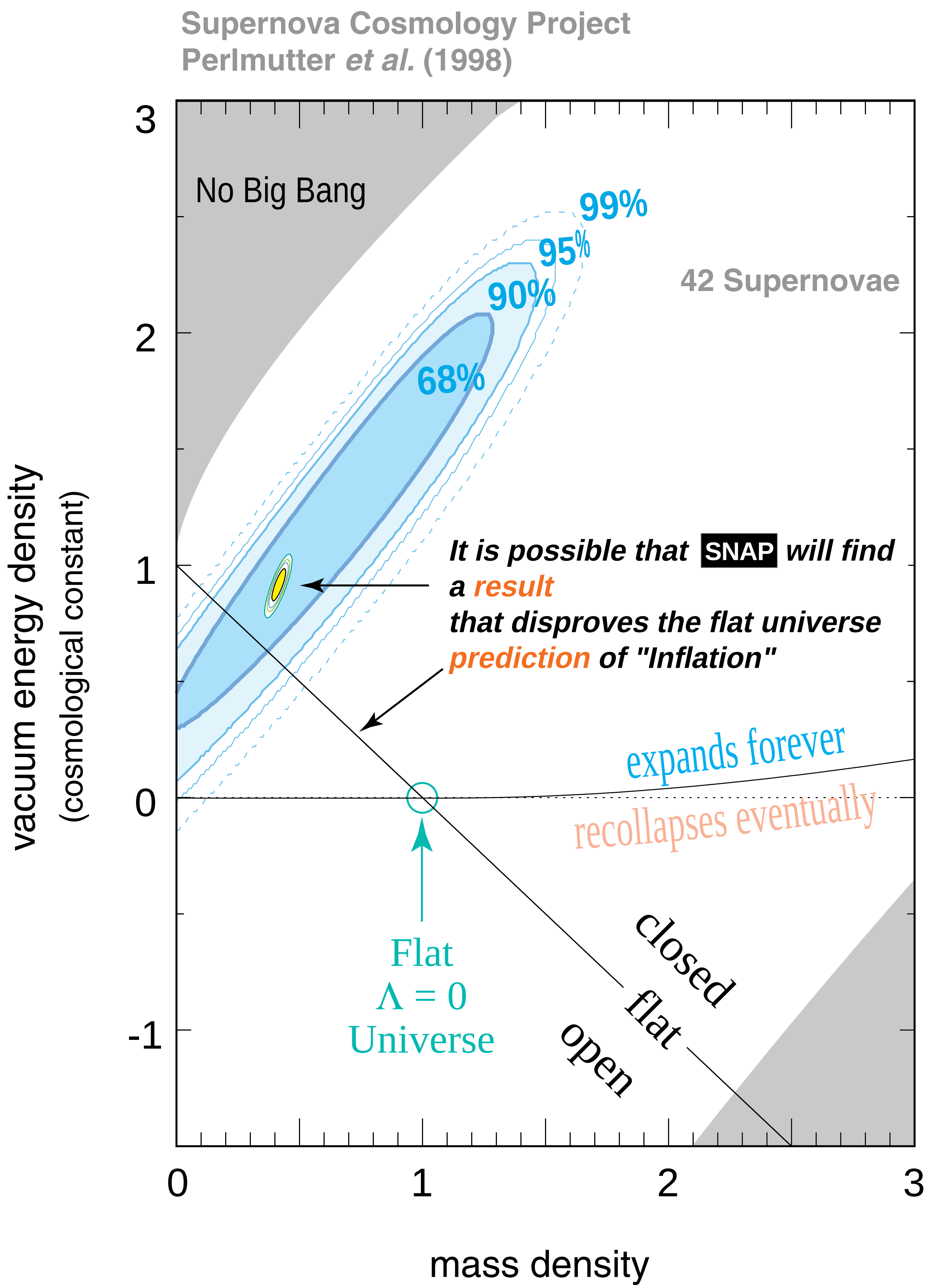
2. What is the "dark energy"? Particle physics theory proposes a number of alternatives, each with different properties that we can measure. Each of the alternative theories raises some important questions/problems of fundamental physics.



Supernova Cosmology Project
Perlmutter *et al.* (1998)
No Big Bang
99%
95%
90%
68%
42 Supernovae
accelerating
decelerating
expands forever
recollapses eventually
closed
flat
open
3
2
1
0
-1
0
1
2
3
vacuum energy density
(cosmological constant)
mass density
prediction of Guth's
"inflation" theory
Two groups results agree:
c.f. Riess *et al.* (1998)



Supernova Cosmology Project
Perlmutter *et al.* (1998)
No Big Bang
99%
95%
90%
68%
42 Supernovae
SNAP
Target 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)
mass density
3
2
1
0
-1
0
1
2
3

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

Two coincidences:

- ***Why so small?***

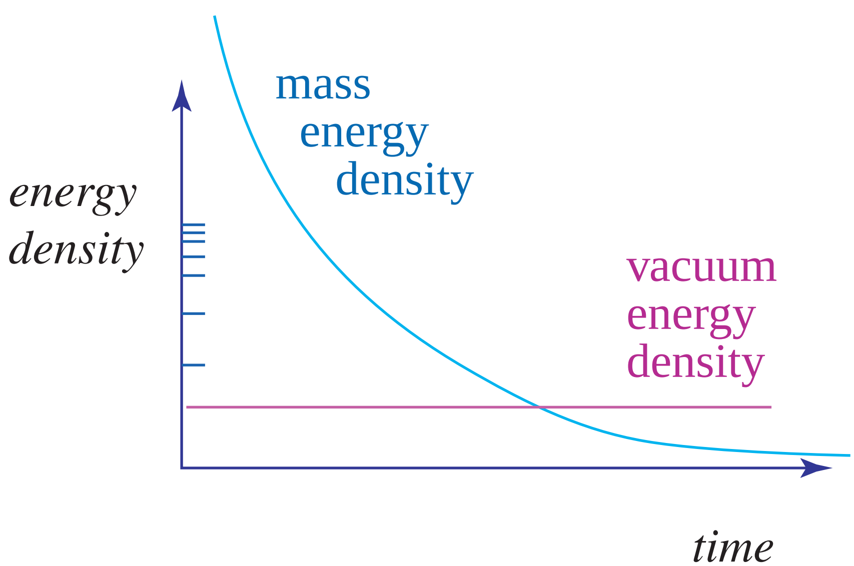
  Might expect $\frac{\Lambda}{8\pi G} \sim m^4_{\rm Planck}$

  This is off by ~120 orders of magnitude!

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

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

MATTER:	$p = 0$	$\longrightarrow$	$\rho \propto R^{-3}$
VACUUM ENERGY:	$p = -\rho$	$\longrightarrow$	$\rho \propto constant$



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

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

What are the alternatives?

New Physics:

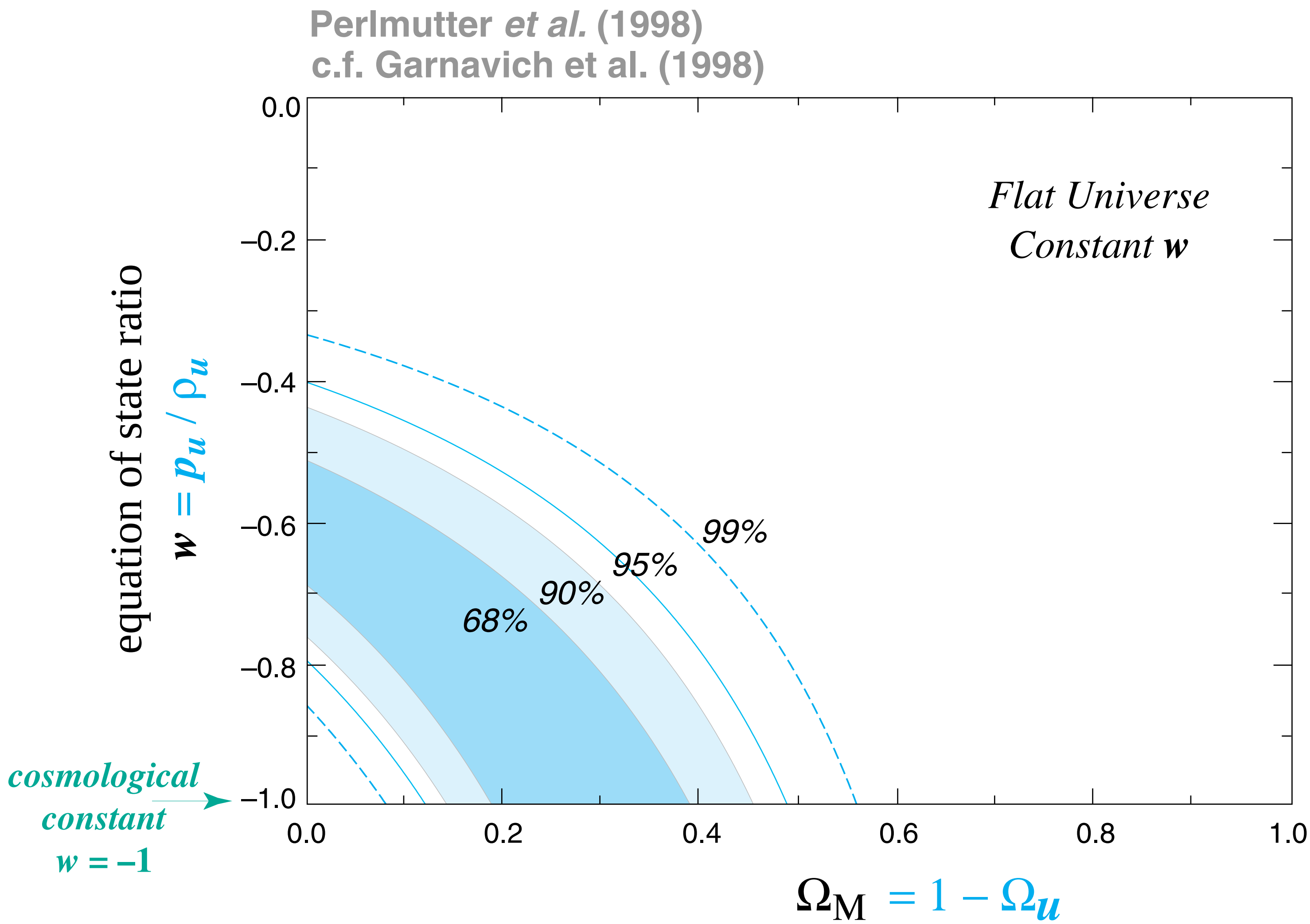
"Dark energy": Dynamical scalar fields, "quintessence",...

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

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

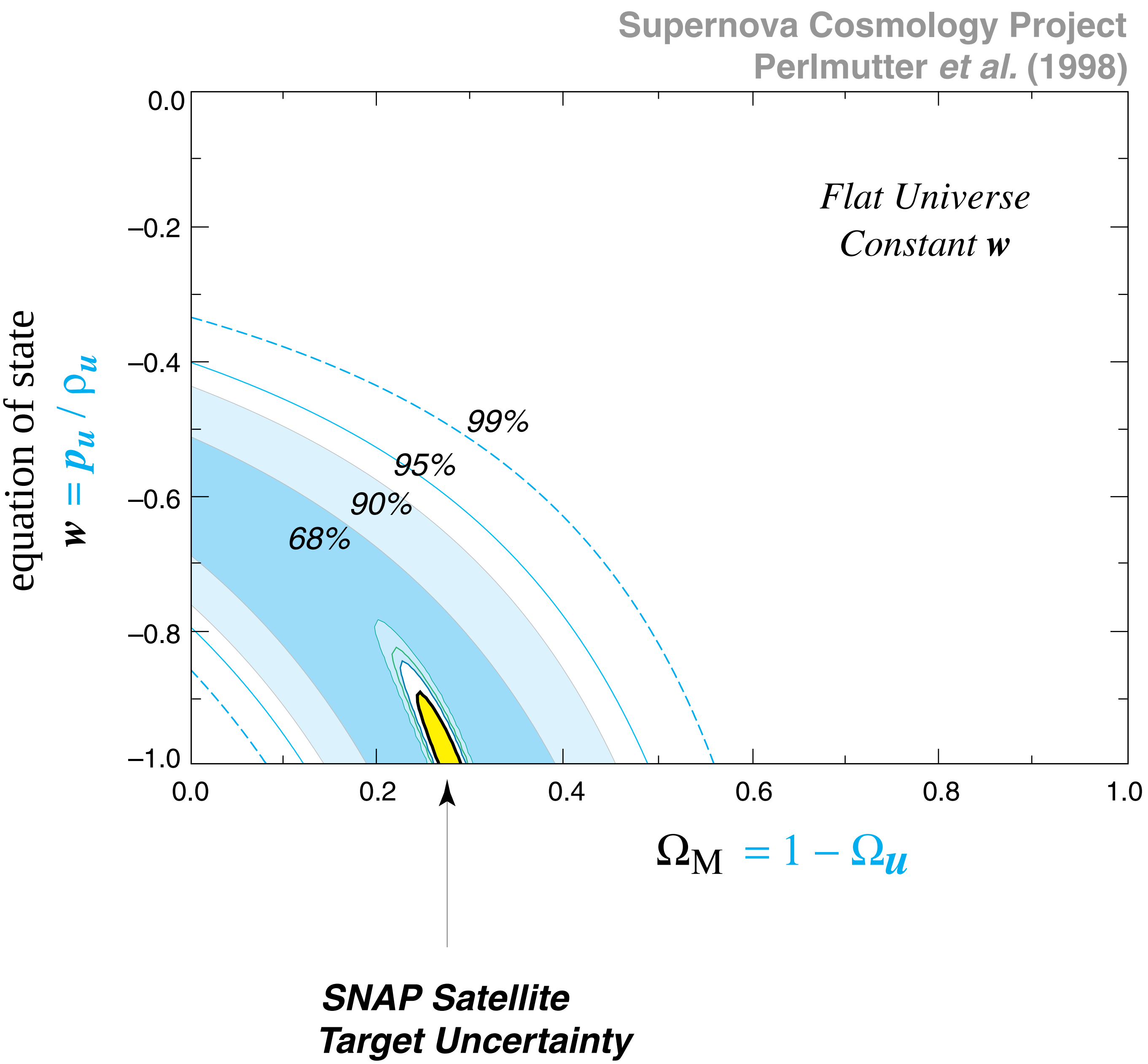
and w can vary with time

Unknown Component, Ω_u, of Energy Density



Dark Energy

Unknown Component, Ω_u, of Energy Density



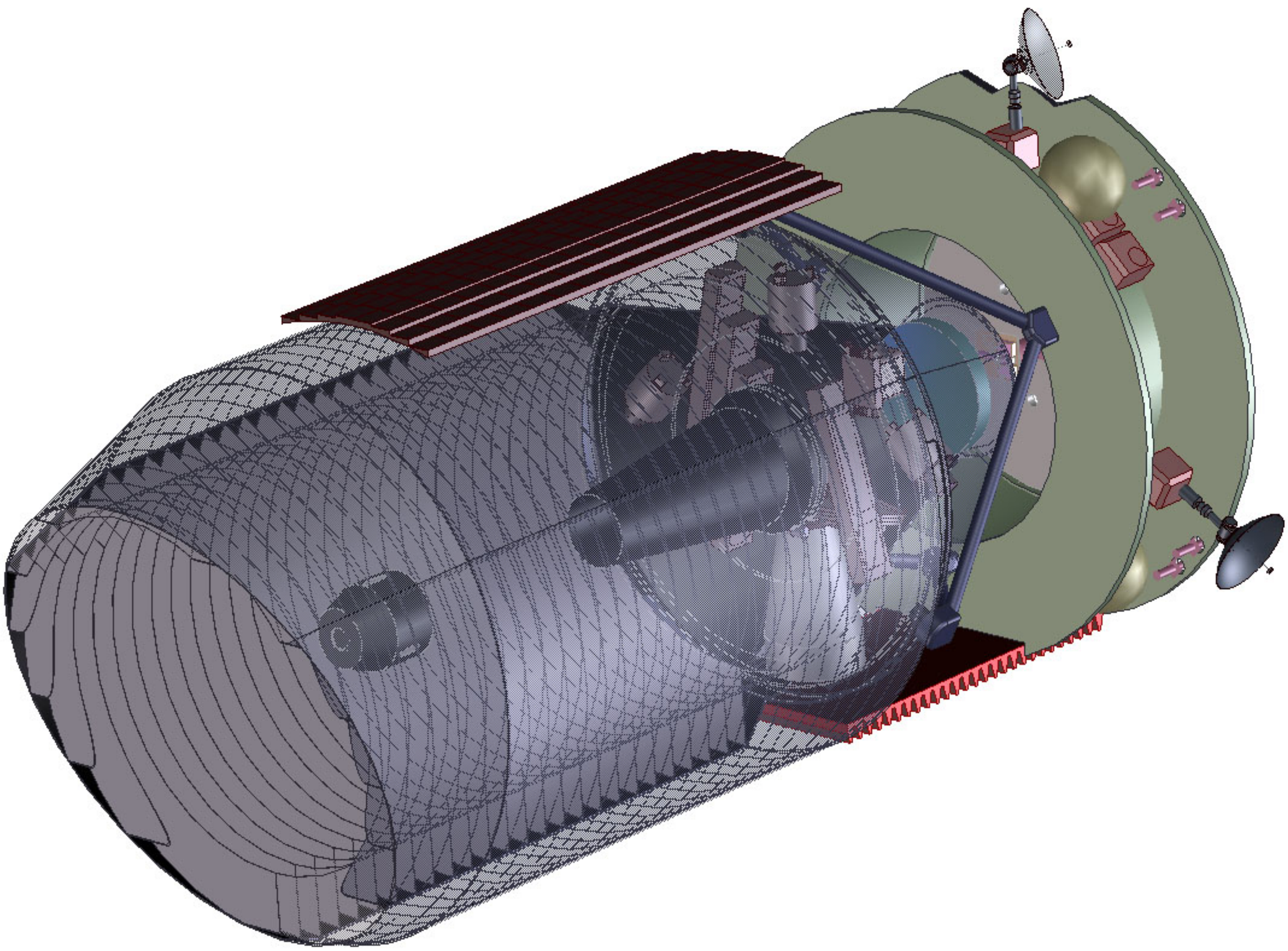
SNAP SuperNova Acceleration Probe

For a definitive measurement
to provide a pillar of our cosmological theory
requires

- a much larger statistical sample of supernovae,
- with much better controlled measurements,
- over a much larger range of redshifts,

that cannot be obtained
with existing or planned facilities.

SNAP SuperNova Acceleration Probe



SNAP SuperNova Acceleration Probe

satellite overview

Instruments:

- **~2 m 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 -- 1.7um**
  Detailed analysis of each SN.

Satellite:

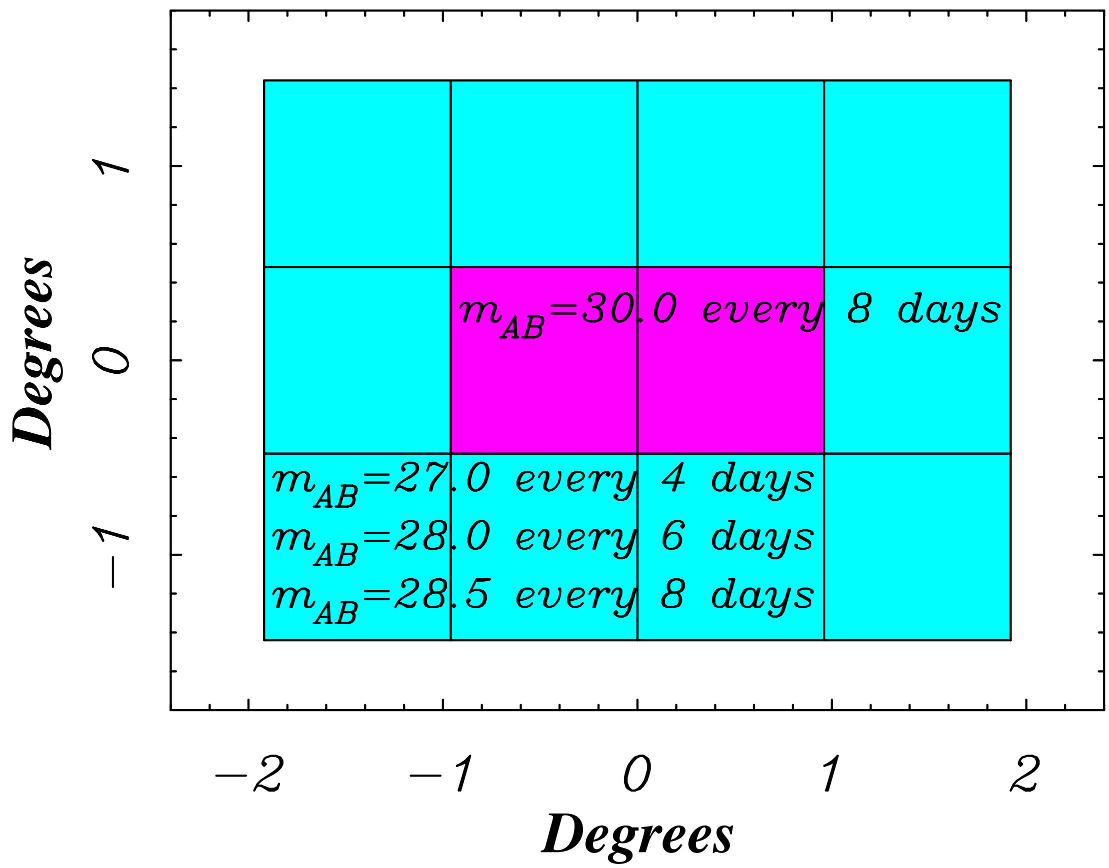
Dedicated instrument.

Designed to repeatedly observe an area of sky.

Essentially no moving parts.

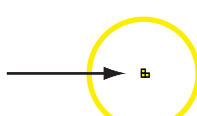
4-year construction cycle.
3-year operation for experiment
(lifetime open-ended).

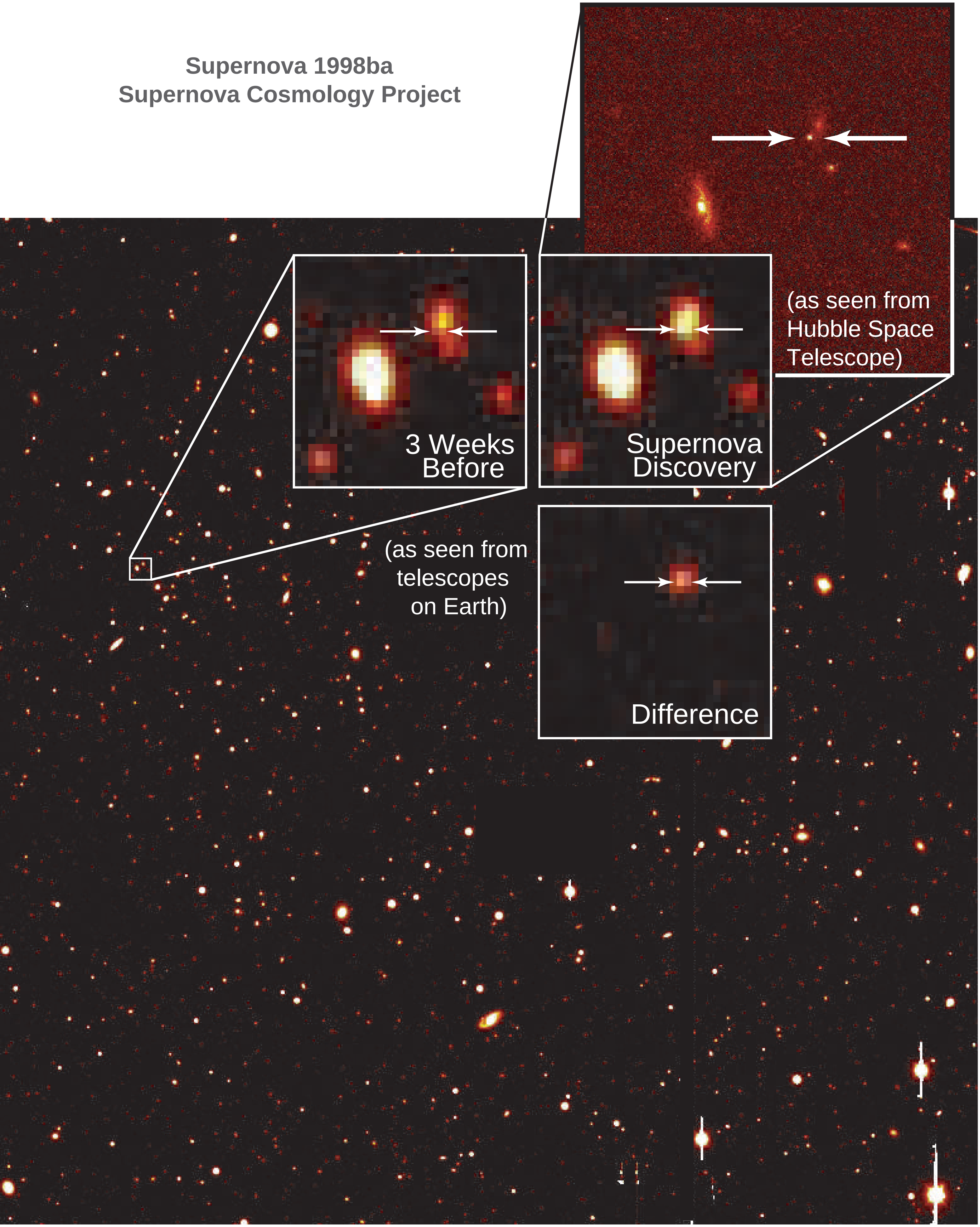
Search Strategy - Deep & Often

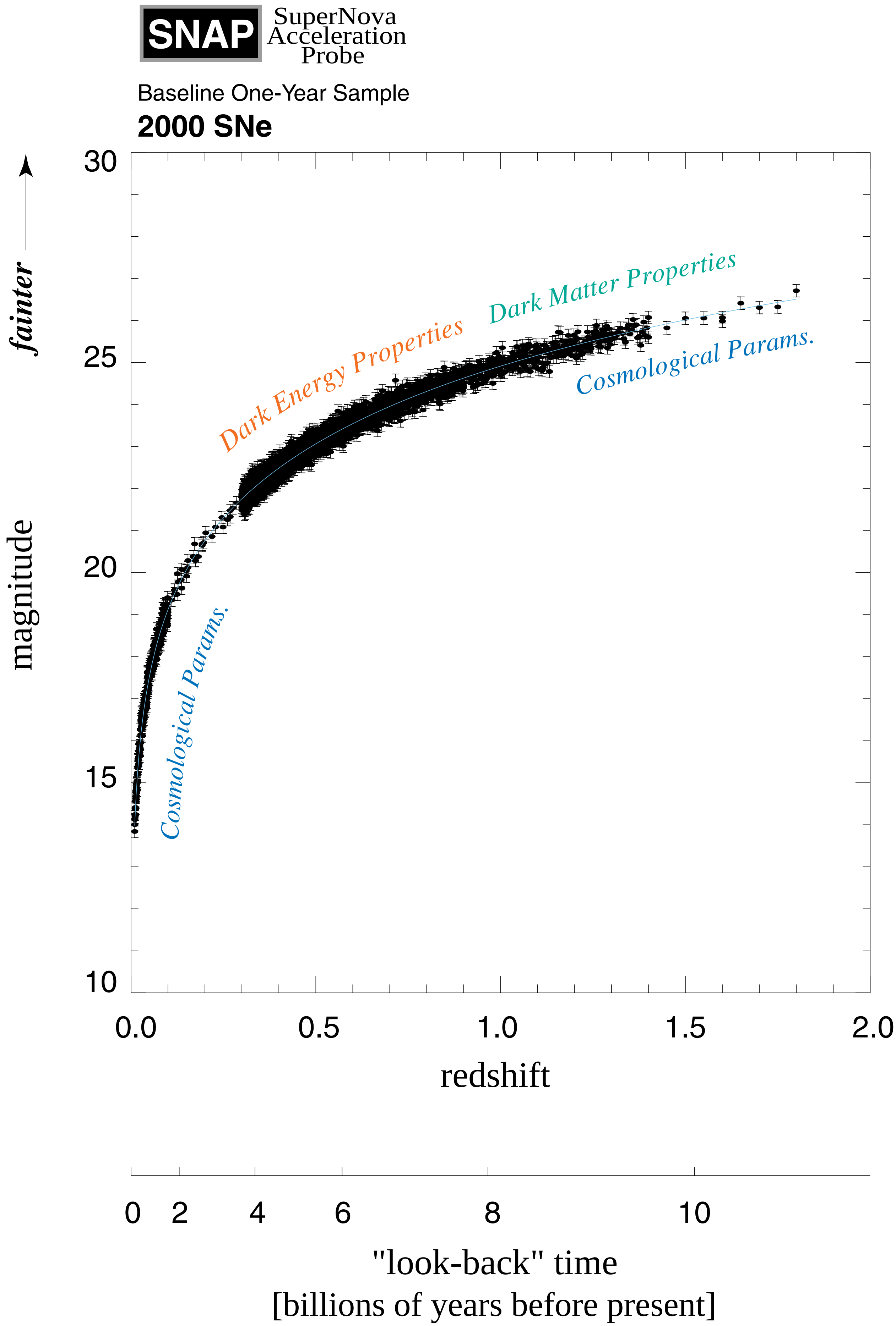


Co-added images: m_{AB} = 32.0 !

Size of
Hubble Deep Field




Supernova 1998ba
Supernova Cosmology Project
3 Weeks Before
Supernova Discovery
(as seen from Hubble Space Telescope)
(as seen from telescopes on Earth)
Difference


SNAP
SuperNova Acceleration Probe
Baseline One-Year Sample
2000 SNe
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 SuperNova Acceleration Probe

Baseline: Assuming that there are *no* improvements on our current understanding and calibration of supernovae, and that we only analyze 1 out of 3 years worth of data.

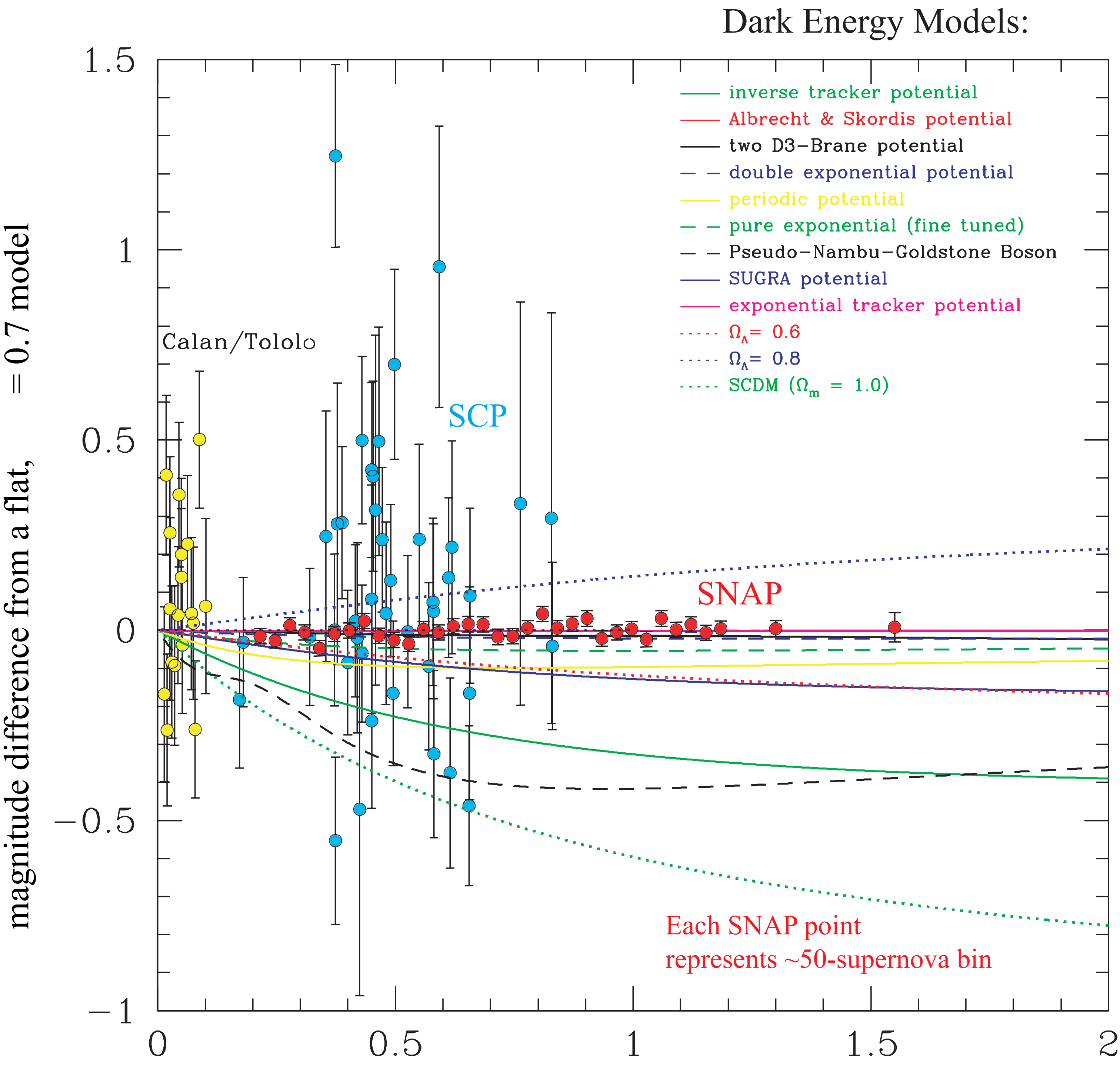
Planned 1-year baseline statistical and systematic uncertainty on...

Assuming:	Ω_M stat	Ω_M sys	Ω_Λ or $\Omega_{d.e.}$ stat	Ω_Λ or $\Omega_{d.e.}$ sys	w stat	w sys	w' stat	w' sys
$w =\ 1$	0.02	0.02	0.05	<0.01				
$w =\ 1$, flat			0.01	0.02				
$w = const.$, flat			0.02	0.02	0.05	<0.01		
Ω_M, Ω_k known $w = const.$					0.02	<0.01		
Ω_M, Ω_k known $w(z) = w + w'z$					0.08	<0.01	0.12	0.15

More Optimistic Target: With a full data set of 6000 supernovae and a reasonable improvement in calibration dispersion, expect factor of ~3 improvement in statistical uncertainties and factor of ~2 improvement in systematic uncertainties.

SNAP SuperNova Acceleration Probe

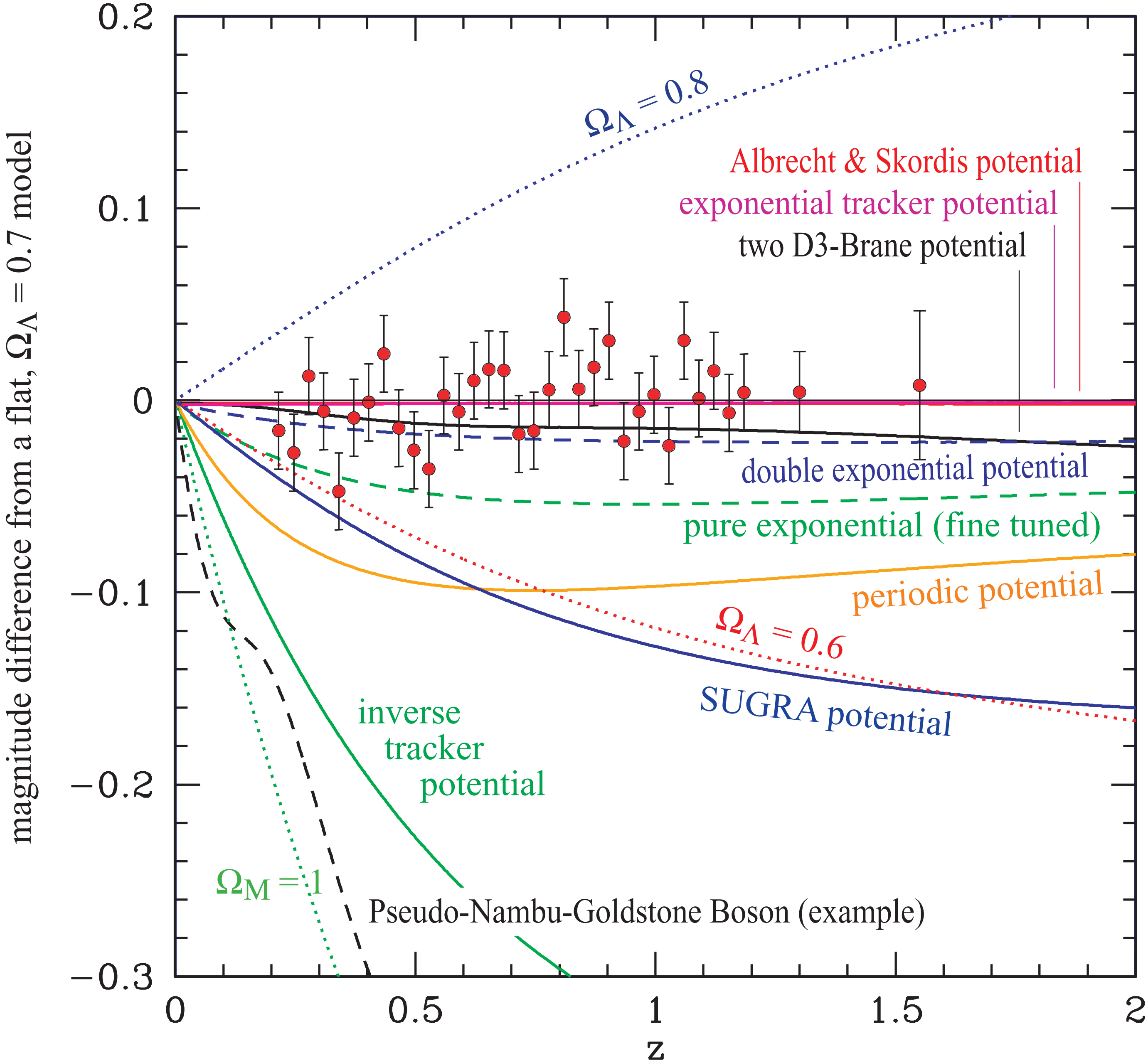
Current ground-based data
compared with binned simulated SNAP data.



Weller & Albrecht

SNAP SuperNova Acceleration Probe

Binned simulated SNAP data compared with Dark Energy models currently in the literature.



Weller & Albrecht

SNAP SuperNova Acceleration Probe

science goals

Cosmological Parameters, Dark Matter,...

Type Ia supernova calibrated candle
Type II supernova expanding photosphere
Weak lensing
Strong lensing statistics. Ω_Λ
Galaxy clustering, $P(k)$
z > 1 clusters and associated lensing
. . .

...and Beyond

GRB optical counterparts: rates, lightcurves, and spectra
MACHO optical counterparts by proper motion
Galaxy populations and morphology to co-added m = 32
Target selection for NGST
Kuiper belt objects
Supernova rates, star formation rates
Supernova phenomenology studies
Low surface brightness galaxies, luminosity function
. . .

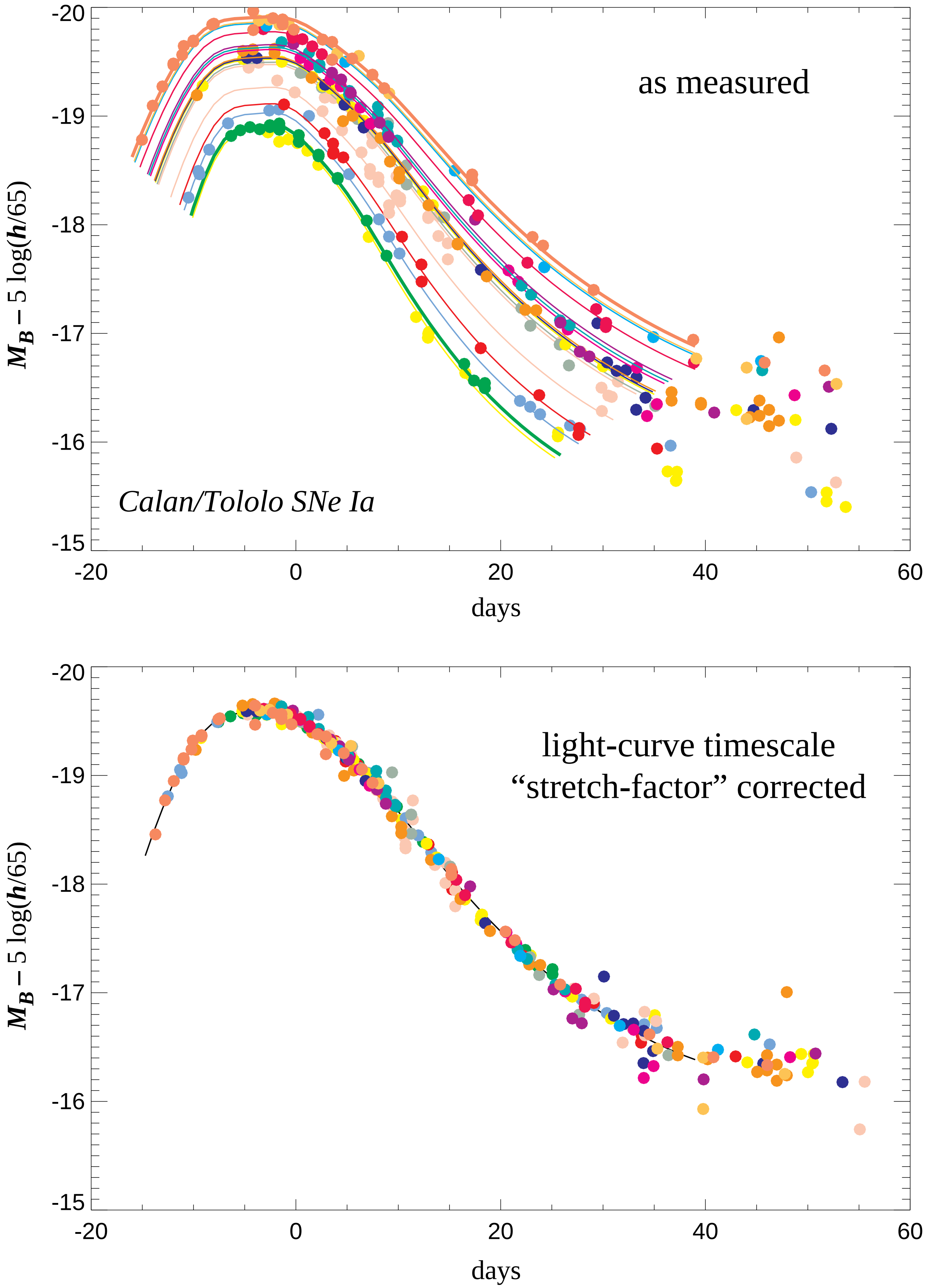
→ Archive data distributed:
deeper than Hubble Deep Field
and 7000 times larger

→ Guest Survey Program

What makes the supernova measurement special?
Control of systematic uncertainties.

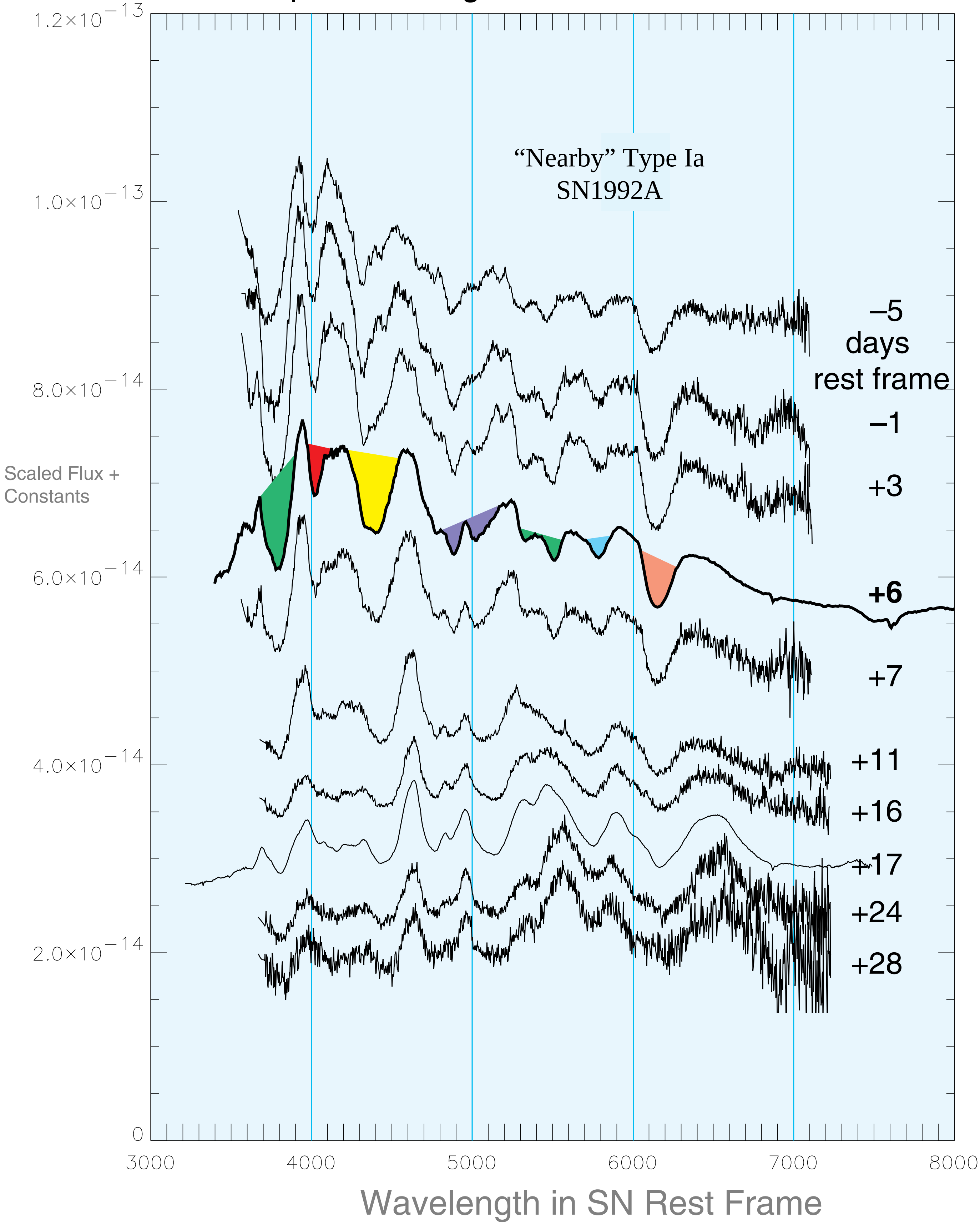
At every moment in the explosion event,
each individual supernova is "sending" us a rich stream
of information about its internal physical state.

B Band



Kim, *et al.* (1997)

Supernova spectra vary as the supernova brightens and fades



SNAP SuperNova Acceleration Probe

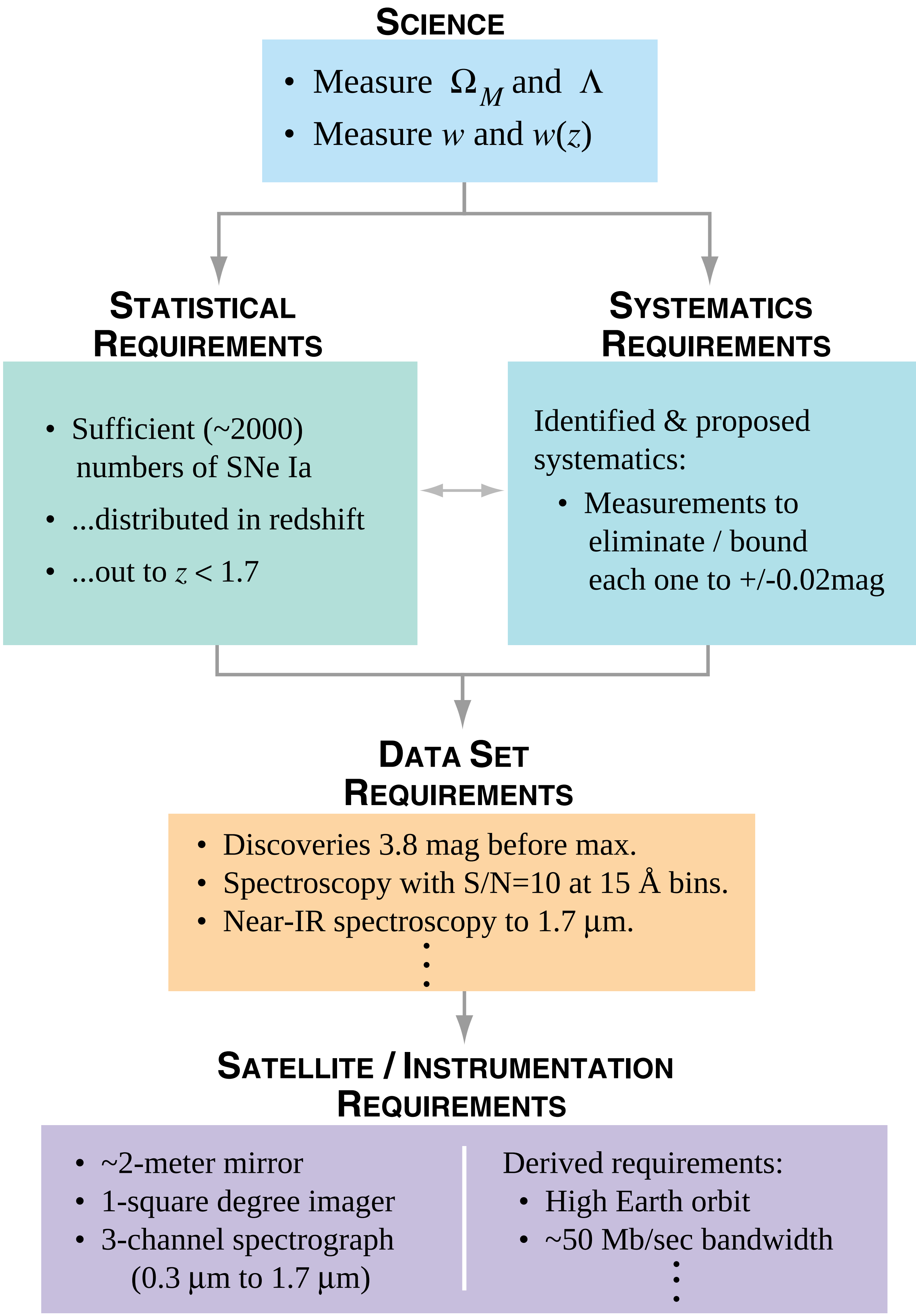
What makes the supernova measurement special?
Control of systematic uncertainties.

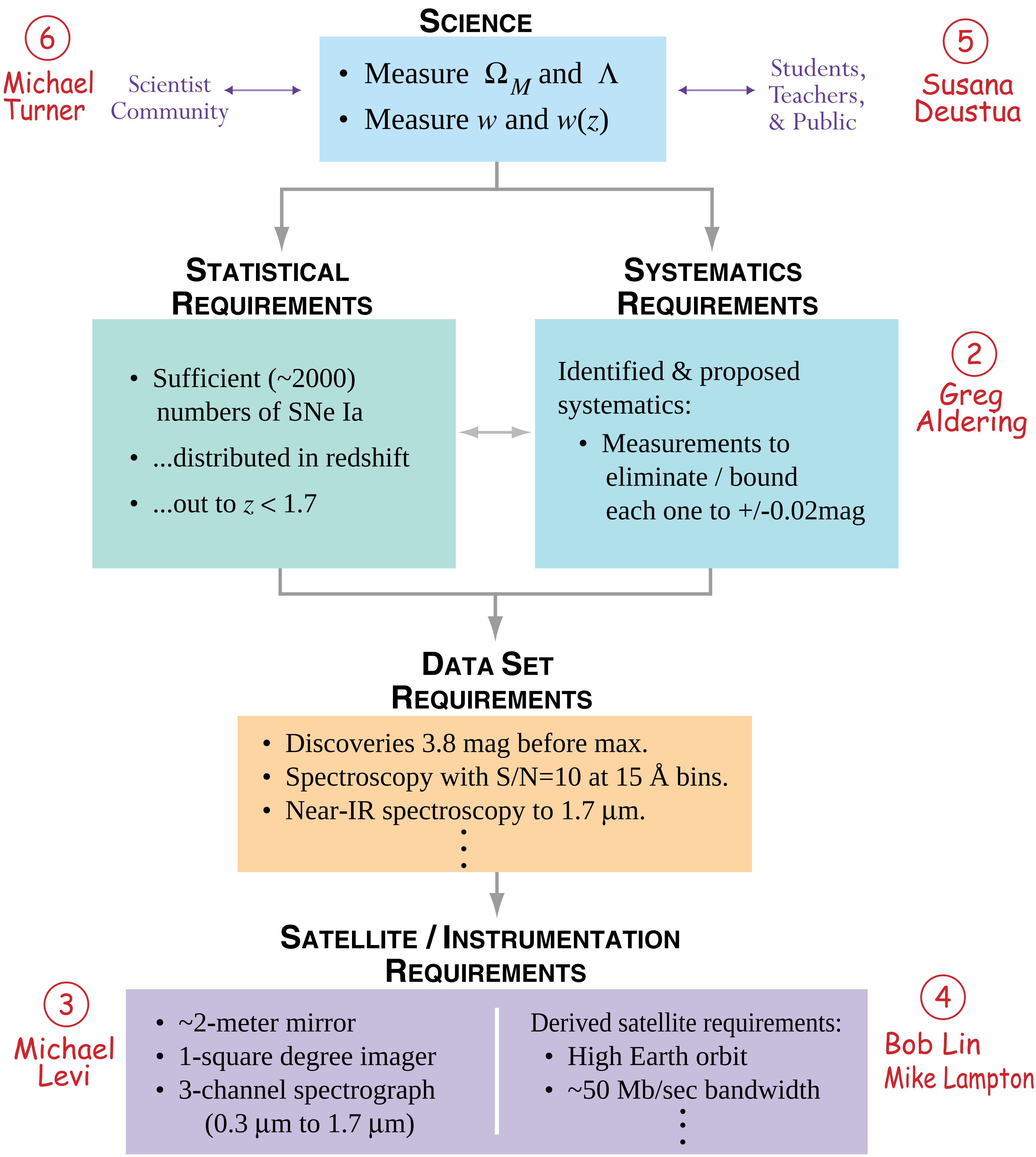
However,
for a definitive supernova cosmology measurement...

...it is necessary but NOT sufficient to find and study
- *more SNe Ia*
- *farther SNe Ia*

because the statistical uncertainty is already
within a factor of two of the systematic uncertainty.

The most demanding SNAP data requirements are devoted to eliminating and controlling all sytematic uncertainties.


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


SCIENCE
• Measure Ω_M and Λ
• Measure w and $w(z)$
6
Michael Turner
Scientist Community
Students, Teachers, & Public
5
Susana Deustua
STATISTICAL REQUIREMENTS
• Sufficient (~2000) numbers of SNe Ia
• ...distributed in redshift
• ...out to z < 1.7
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2
Greg Aldering
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SATELLITE / INSTRUMENTATION REQUIREMENTS
3
Michael Levi
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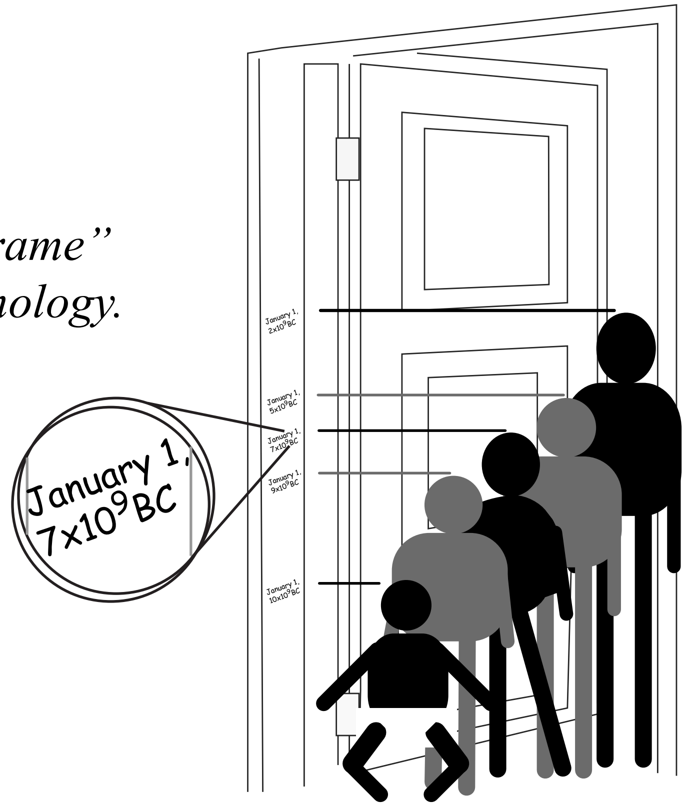
Derived satellite requirements:
• High Earth orbit
• ~50 Mb/sec bandwidth
4
Bob Lin
Mike Lampton

NSF and NASA have well-established and well-known traditions in astrophysics and cosmology.

DOE also has a long history of astrophysics and cosmology contributions, but it is less well known:

Particle physics/cosmology theory:
Inflation, Quintessence, BBN...
Supernova cosmology measurements
Keck telescope
CMB studies
CCD technology
HEP large, complex detector experience
Supernova theory/simulations
Supercomputer centers / Grand challenges

SNAP SuperNova Acceleration Probe



Height Marks on a "Cosmic Doorframe"
A fundamental measurement of cosmology.

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 ±0.02 measurement of the mass density.
A ±0.05 measurement of the vacuum energy density.
A ±0.06 measurement of the curvature.
A ±0.05 measurement of the Equation of State
of the "Dark Energy"