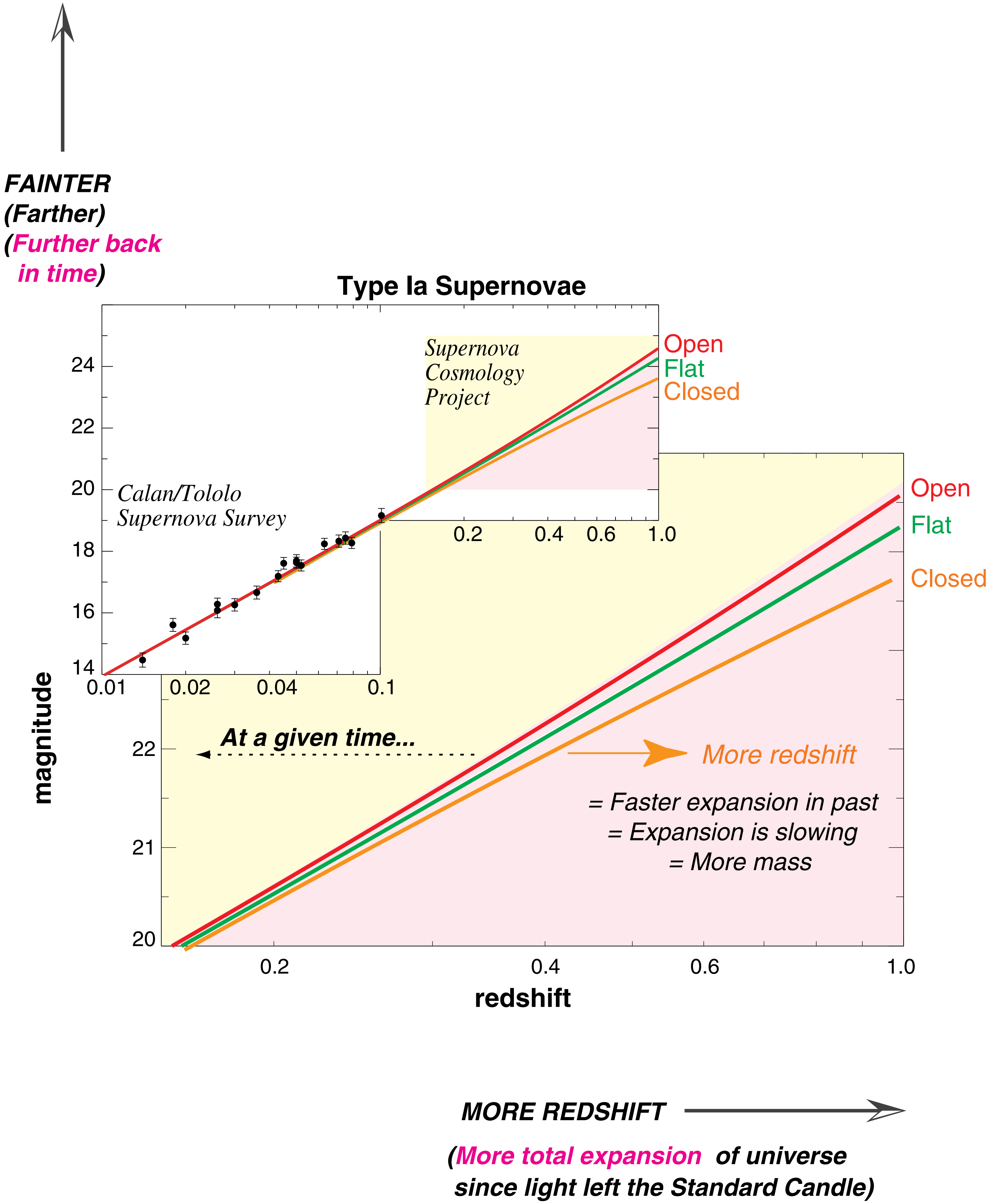
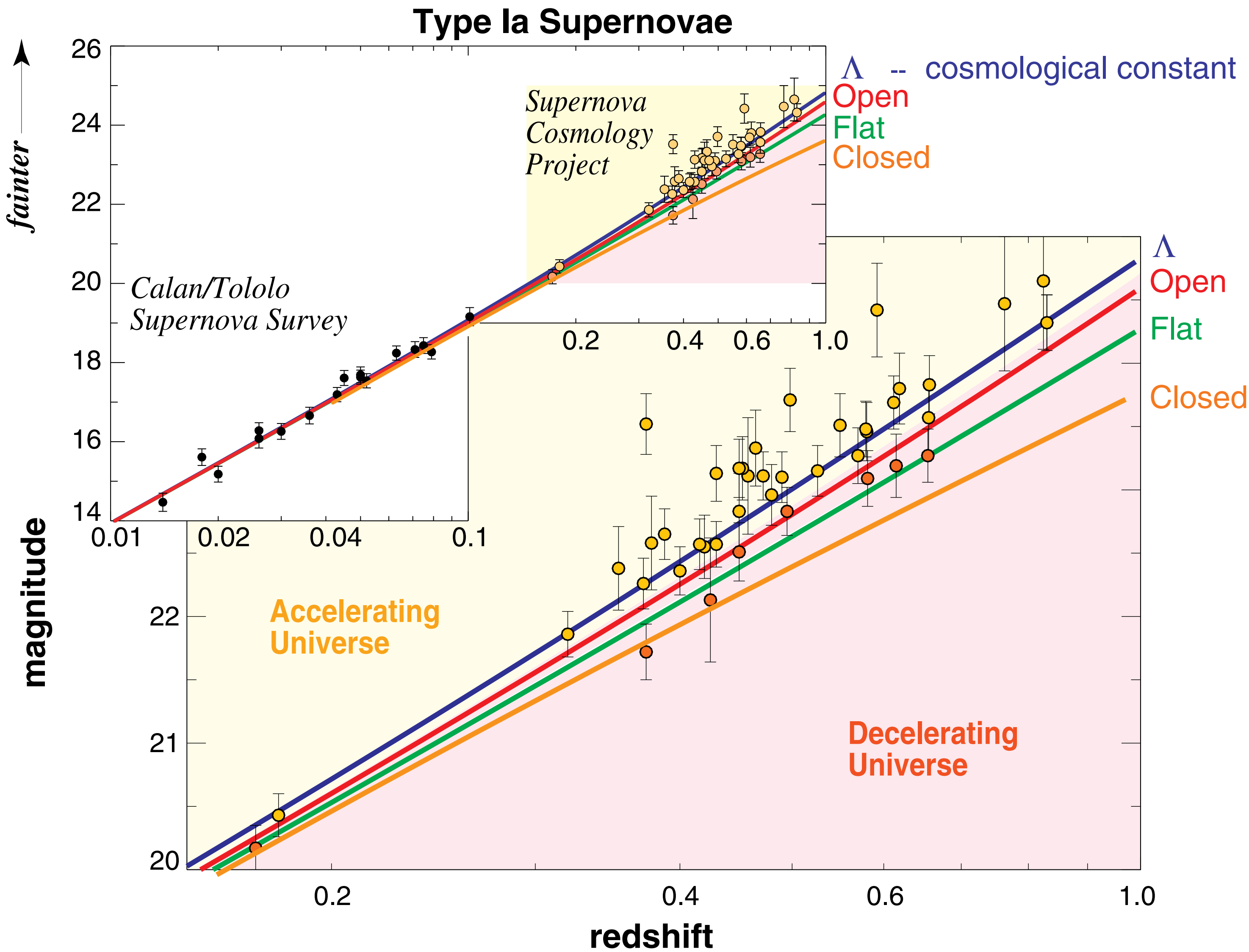
SNAP SuperNova Acceleration Probe

Presentation to the
DOE/NSF HEPAP Subpanel on
Long Range Planning for U.S. High Energy Physics
May 24, 2001

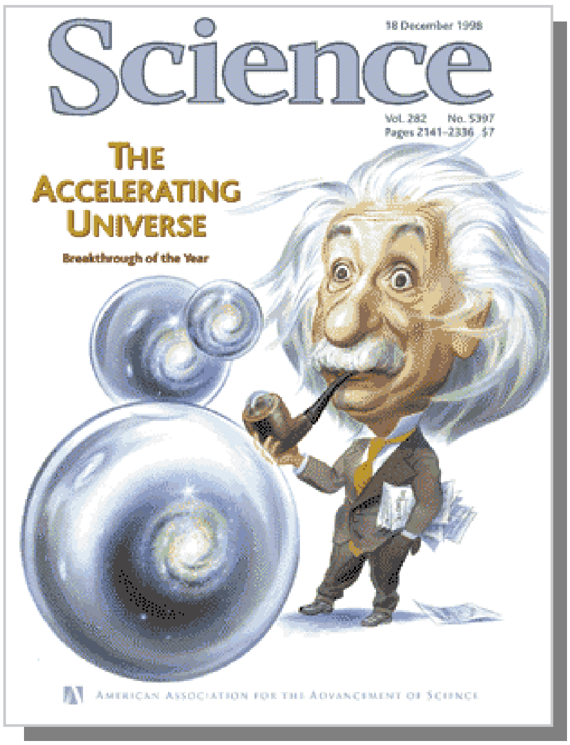
Saul Perlmutter

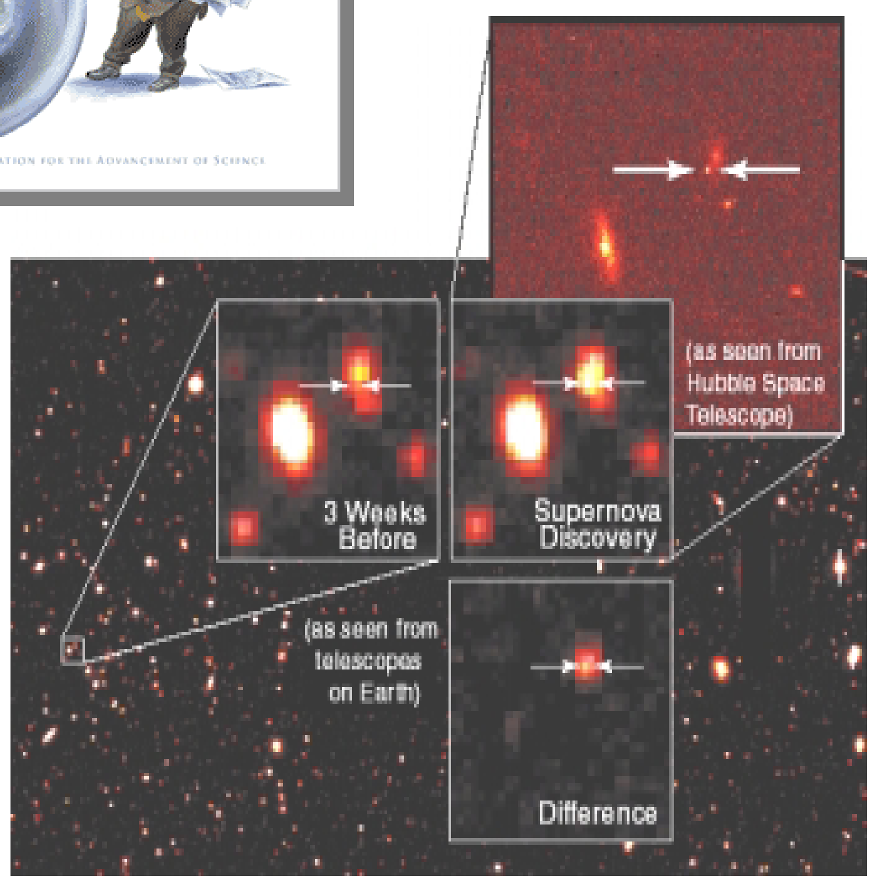


FAINTER
(Farther)
(Further back in time)
Type Ia Supernovae
Supernova Cosmology Project
Open
Flat
Closed
Calan/Tololo Supernova Survey
24
22
20
18
16
14
0.01
0.02
0.04
0.1
0.2
0.4
0.6
1.0
magnitude
At a given time...
More redshift
= Faster expansion in past
= Expansion is slowing
= More mass
22
21
20
0.2
0.4
0.6
1.0
redshift
MORE REDSHIFT
(More total expansion of universe since light left the Standard Candle)

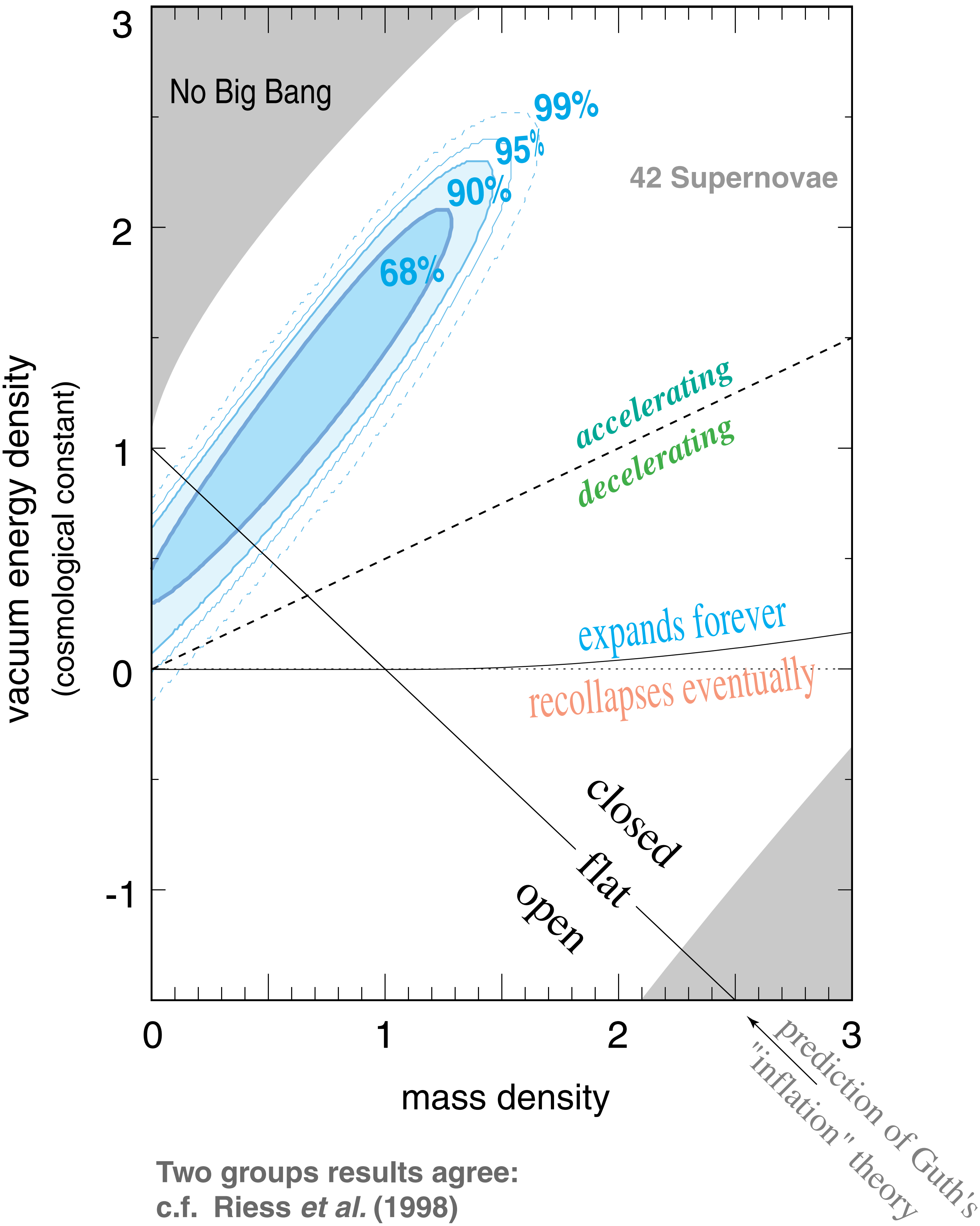

Type Ia Supernovae
fainter
magnitude
redshift
Calan/Tololo Supernova Survey
Supernova Cosmology Project
Λ -- cosmological constant
Open
Flat
Closed
Λ
Open
Flat
Closed
Accelerating Universe
Decelerating Universe
26
24
22
20
18
16
14
0.01
0.02
0.04
0.1
0.2
0.4
0.6
1.0
22
21
20
0.2
0.4
0.6
1.0

Science's Breakthrough of the Year: The Accelerating Universe

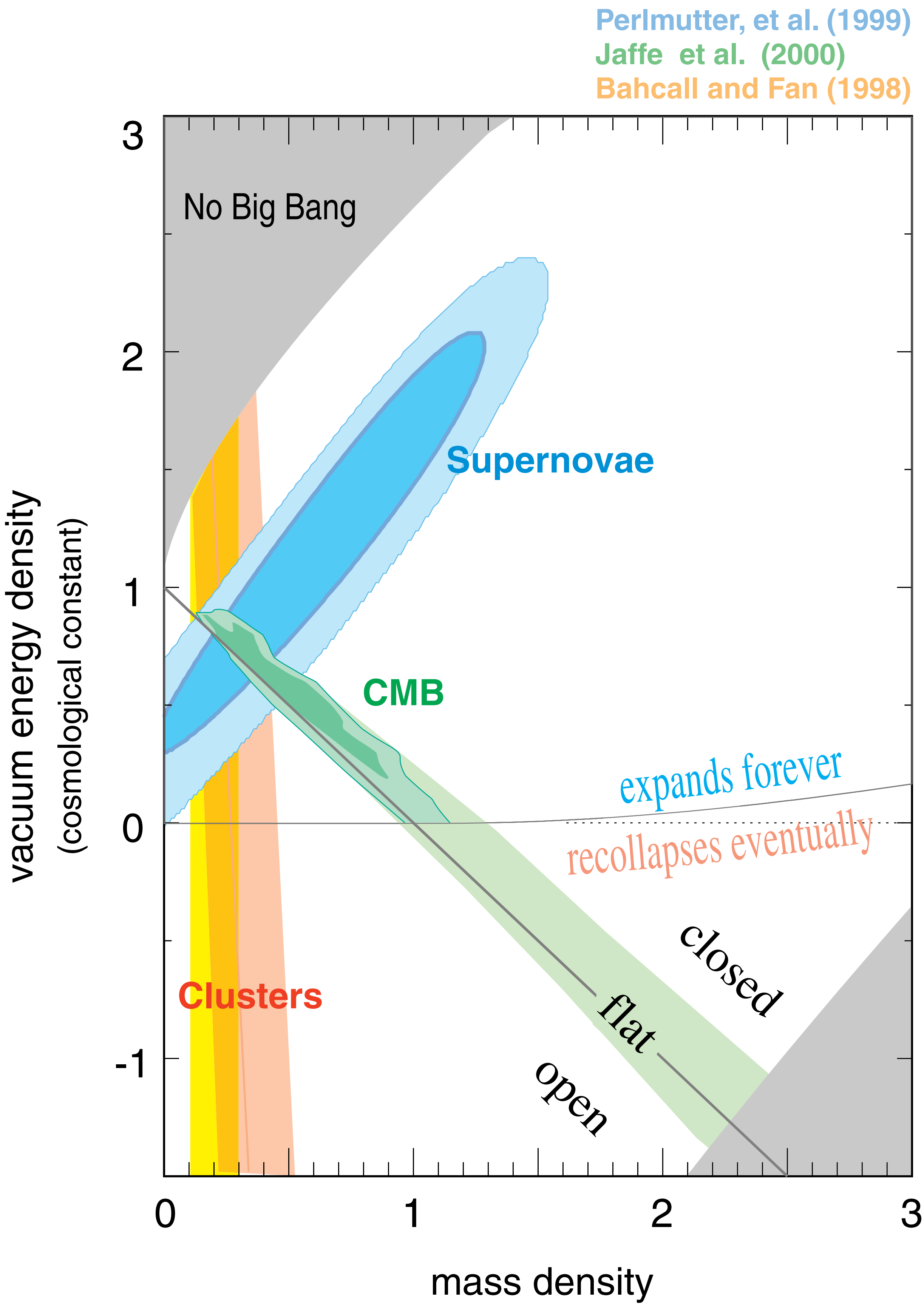




Supernova Cosmology Project
Perlmutter *et al.* (1999)



Two groups results agree:
c.f. Riess *et al.* (1998)


Perlmutter, et al. (1999)
Jaffe et al. (2000)
Bahcall and Fan (1998)
No Big Bang
Supernovae
CMB
expands forever
recollapses eventually
closed
flat
open
Clusters
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 $\frac{\Lambda}{8\pi G} \sim m^4_{\text{Planck}}$

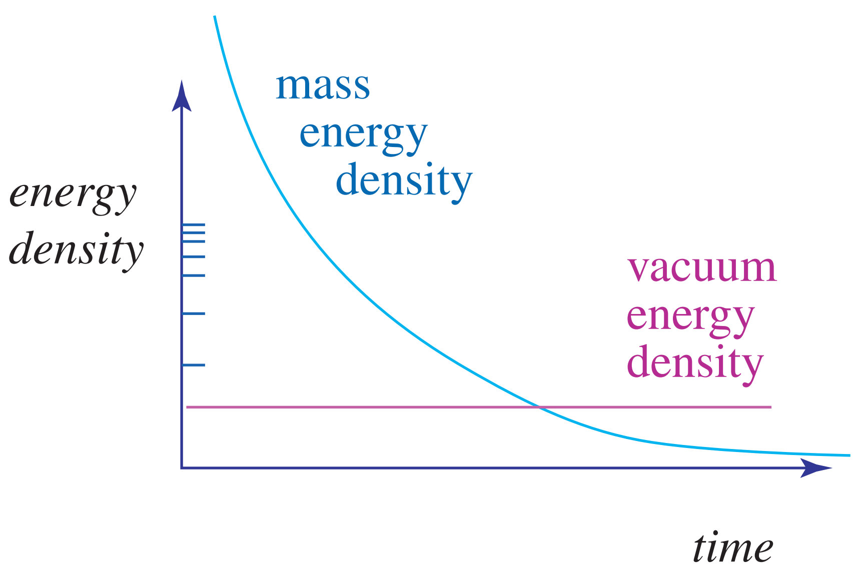
  This is off by ~120 orders of magnitude!

- ***"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: $p = -\rho \longrightarrow \rho \propto \textit{constant}$

What are the alternatives?

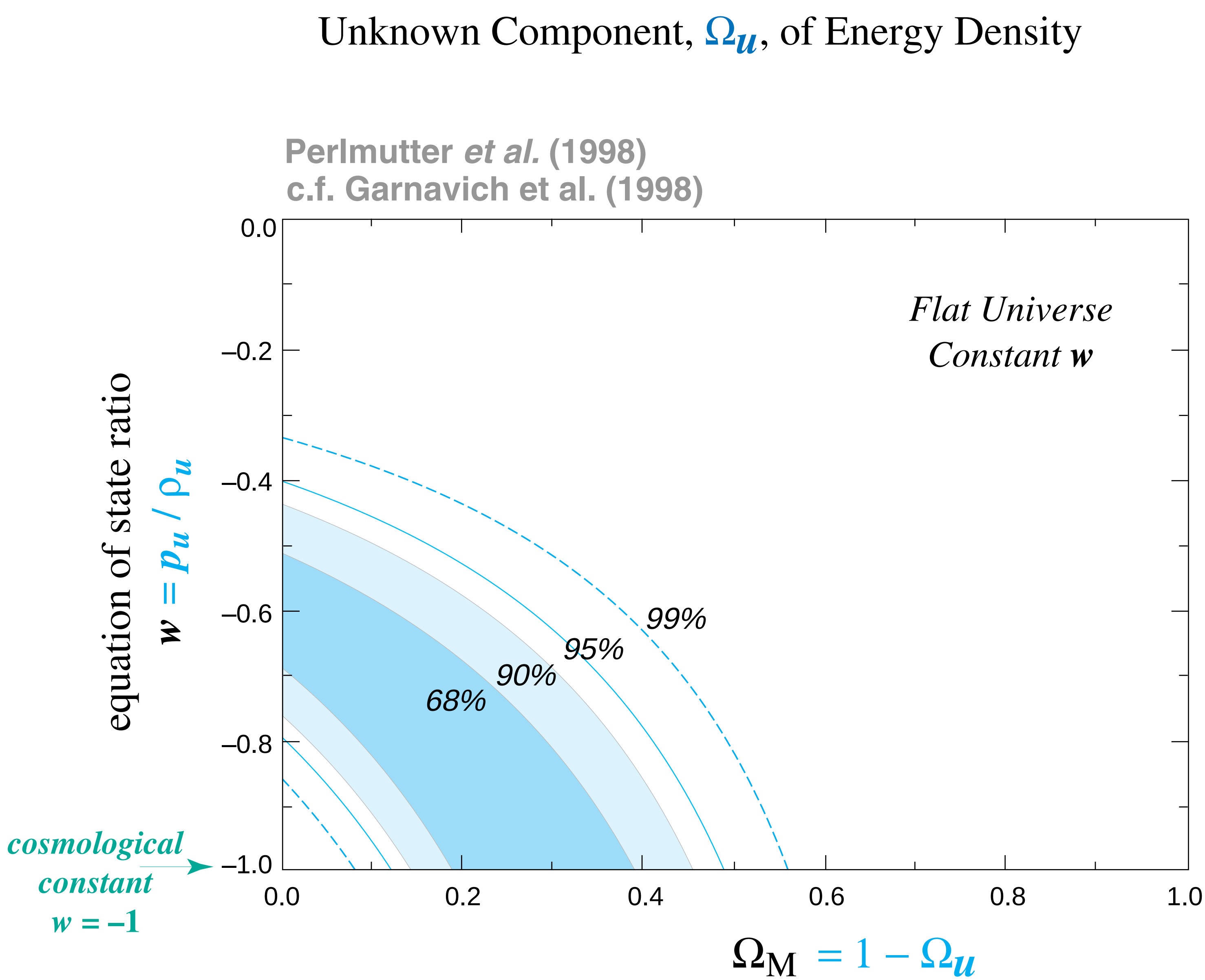
New Physics:

"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
Perlmutter *et al.* (1998)
c.f. Garnavich et al. (1998)
Flat Universe
Constant w
99%
95%
90%
68%
0.0
–0.2
–0.4
–0.6
–0.8
–1.0
0.0
0.2
0.4
0.6
0.8
1.0
equation of state ratio
$w = p_u / \rho_u$
cosmological constant
$w = -1$
$\Omega_M = 1 - \Omega_u$

There are different
levels of precision
at which one can work:

Past "standard cosmology" has been done with

10% -- 25%
uncertainties

Recent work is moving towards

<10%
uncertainties

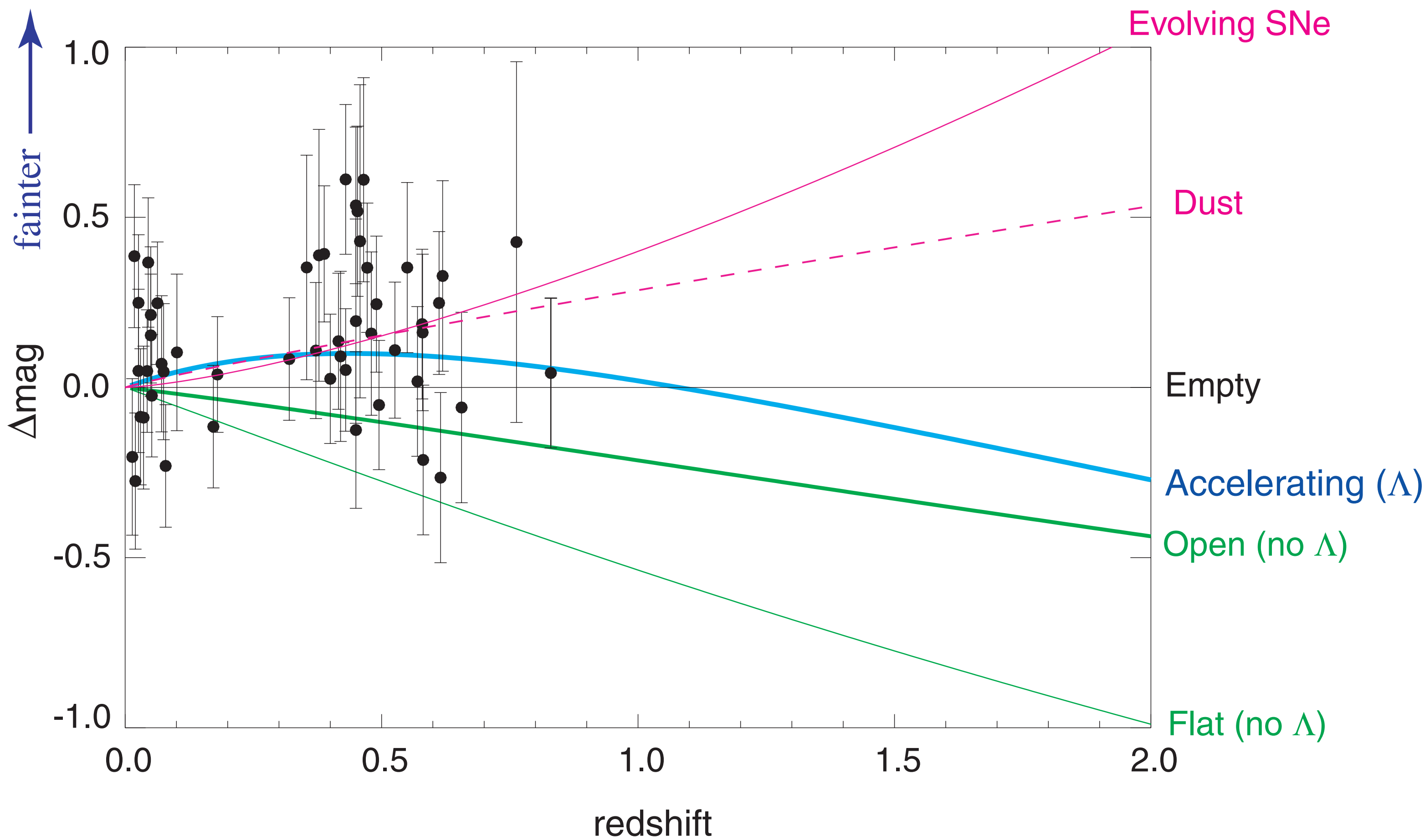
Planned CMB satellite work targets

<1% -- 2%
uncertainties

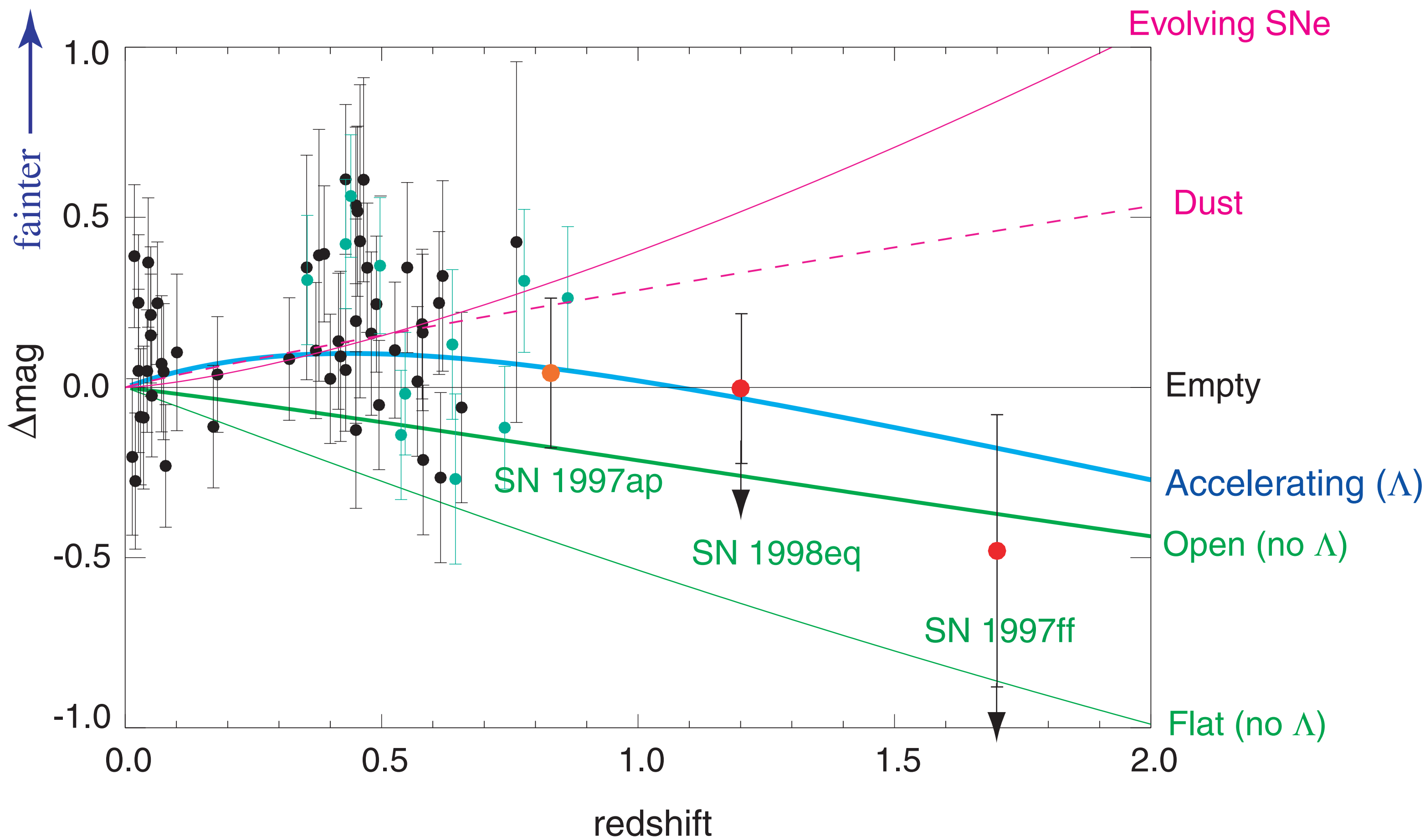
At each of these levels there are appropriately matched levels of systematic uncertainties & simplifying assumptions.

To answer "what we want to know"
we must go from 10%--25%
through the 10% and on to the <1%--2% level.

1998: Acceleration



Supernovae probing the *deceleration* era with IR measurements



Score Card of Current Uncertainties on $(\Omega_{M}^{flat}, \Omega_{\Lambda}^{flat}) = (0.28, 0.72)$

Statistical

☑	high-redshift SNe	0.05
☑	low-redshift SNe	0.065
	Total	***0.085***

Systematic

☑	dust that reddens $R_B(z{=}0.5) < 2\ R_B(\text{today})$	< 0.03
	evolving grey dust	
?	clumpy	
?	same for each SN	
☑	Malmquist bias difference	< 0.04
?	SN Ia evolution shifting distribution of prog mass/metallicity/C-O/..	
☑	K-correction uncertainty including zero-points	< 0.025
	Total identified entities/processes	***0.05***

Cross-Checks of sensitivity to

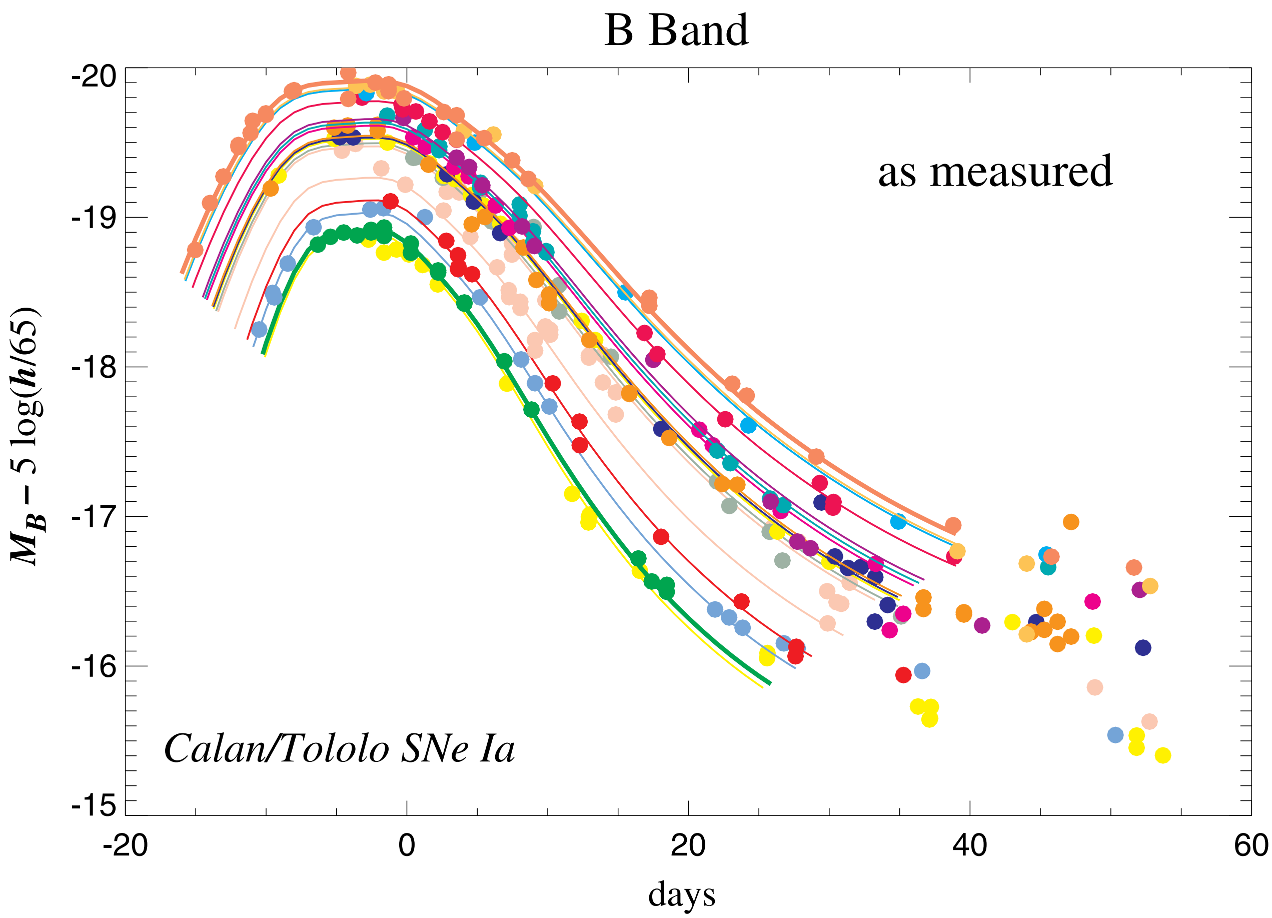
☑	Width-Luminosity Relation	< 0.03
☑	Non-SN Ia contamination	< 0.05
☑	Galactic Extinction Model	< 0.04
☑	Gravitational Lensing by clumped mass	< 0.06

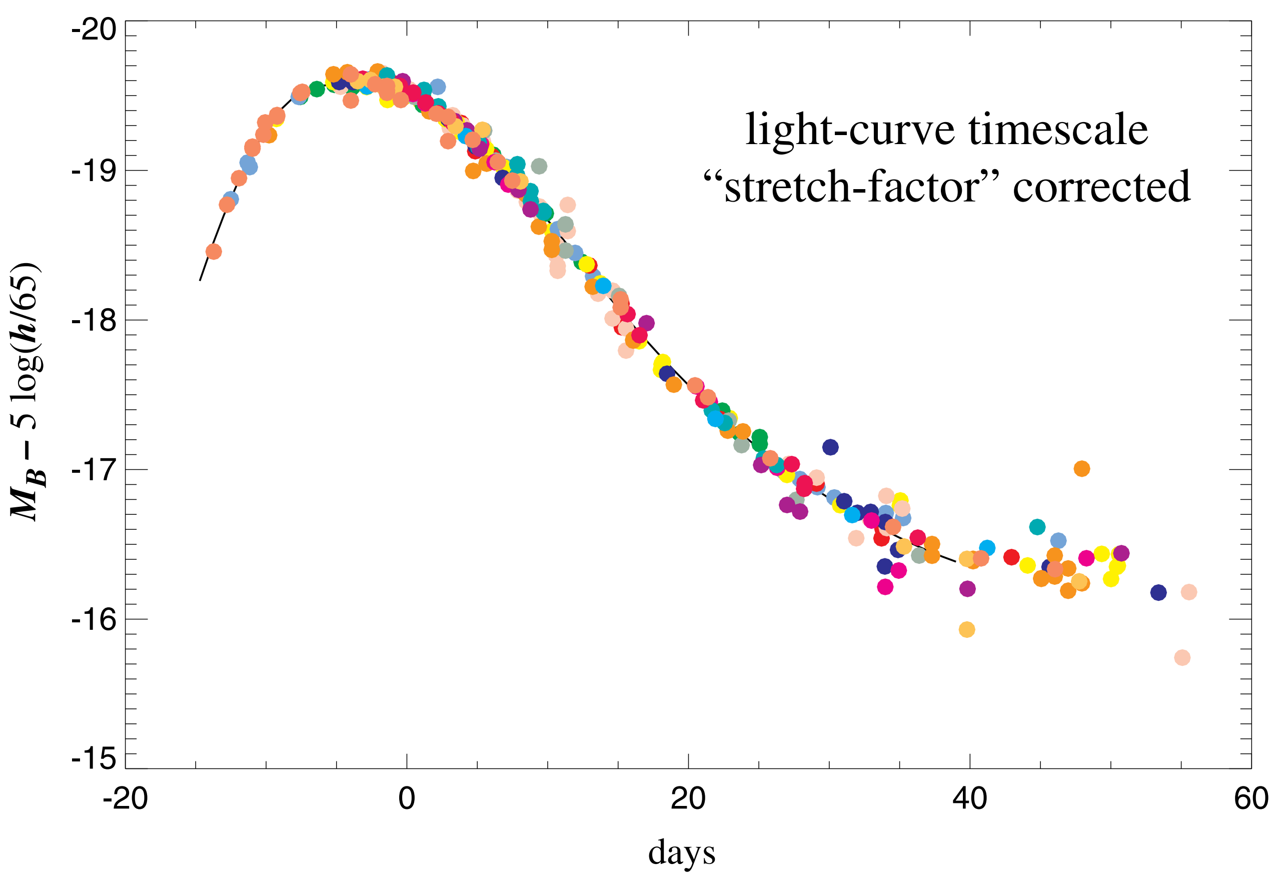
Perlmutter *et al.* (1998)
astro-ph/9812133

SNAP SuperNova Acceleration Probe

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

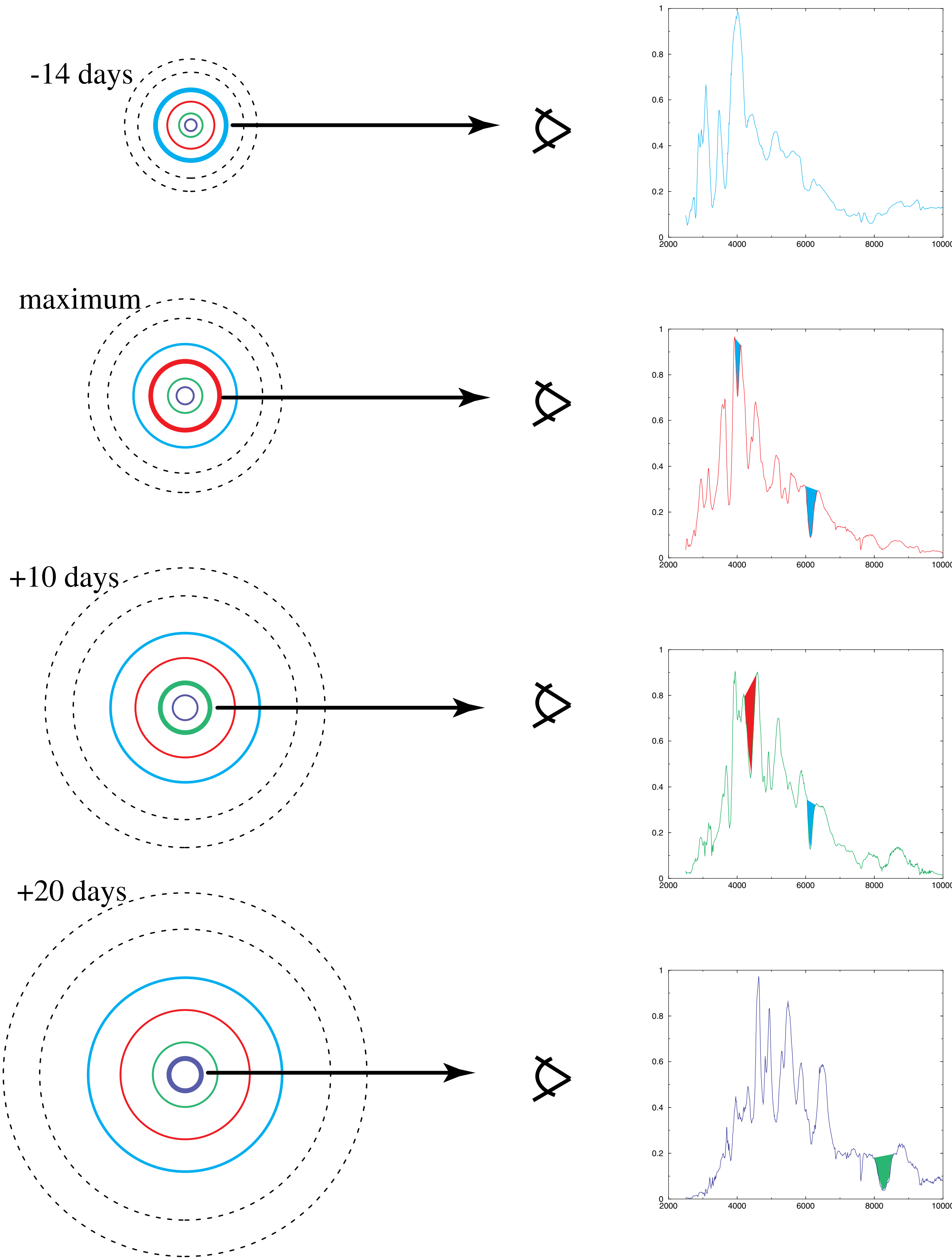
At every moment in the explosion event,
each individual supernova is "sending" us a rich stream
of information about its internal physical state.



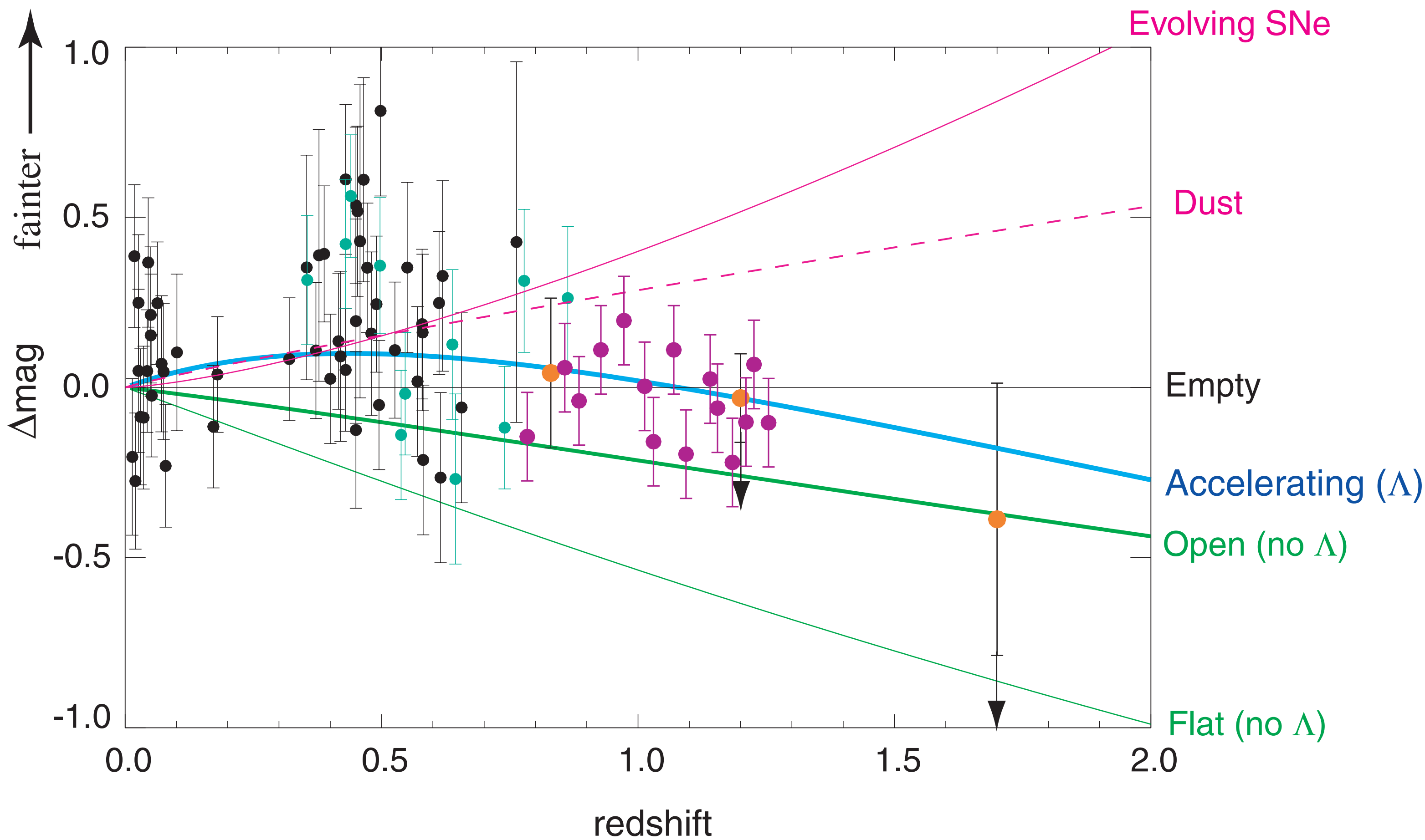


Kim, *et al.* (1997)

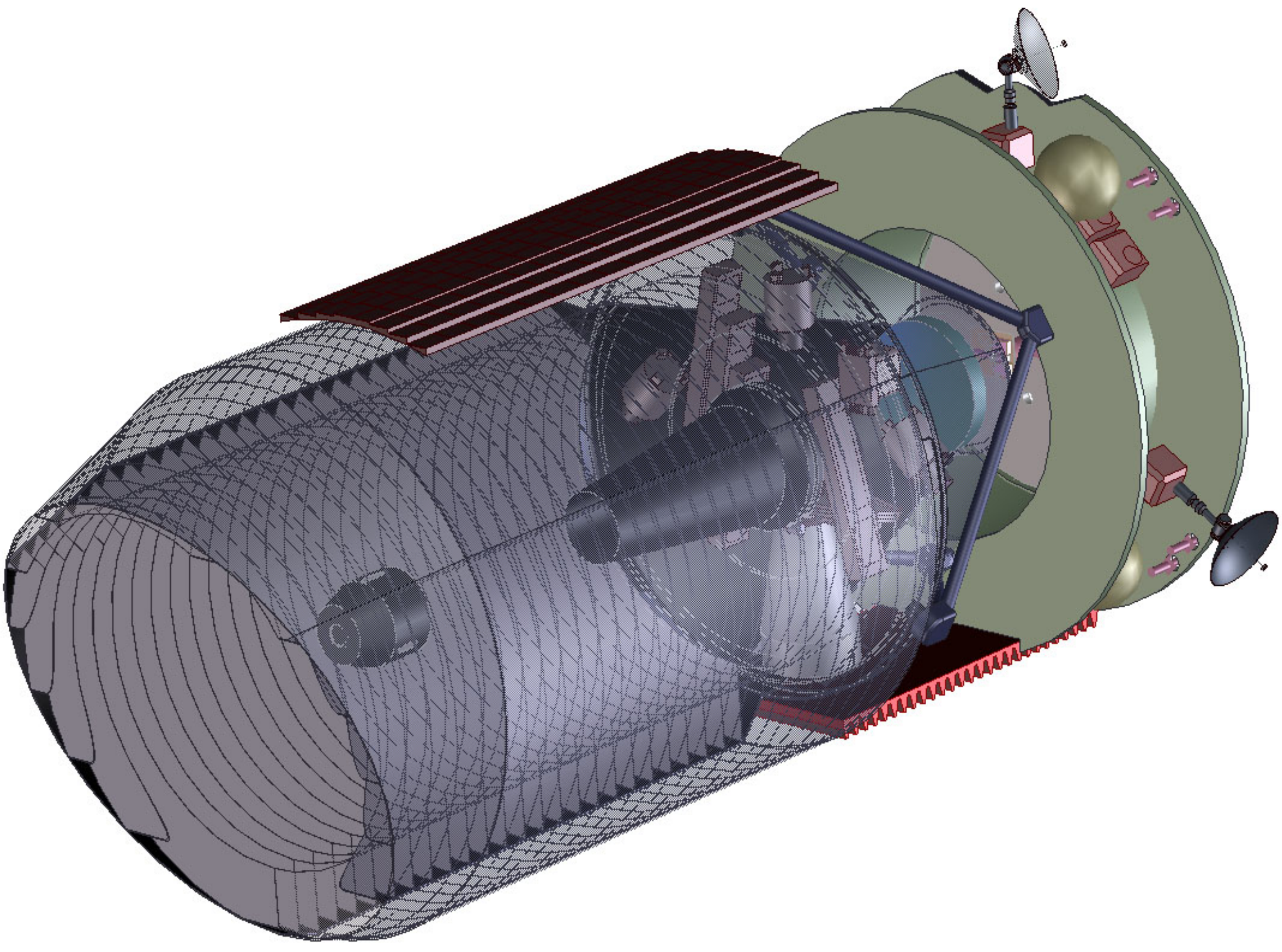
The time series of spectra is a “CAT Scan” of the Supernova



Future HST Data



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-arm spectroscopy, 0.3um -- 1.7um**
  Detailed analysis of each SN.

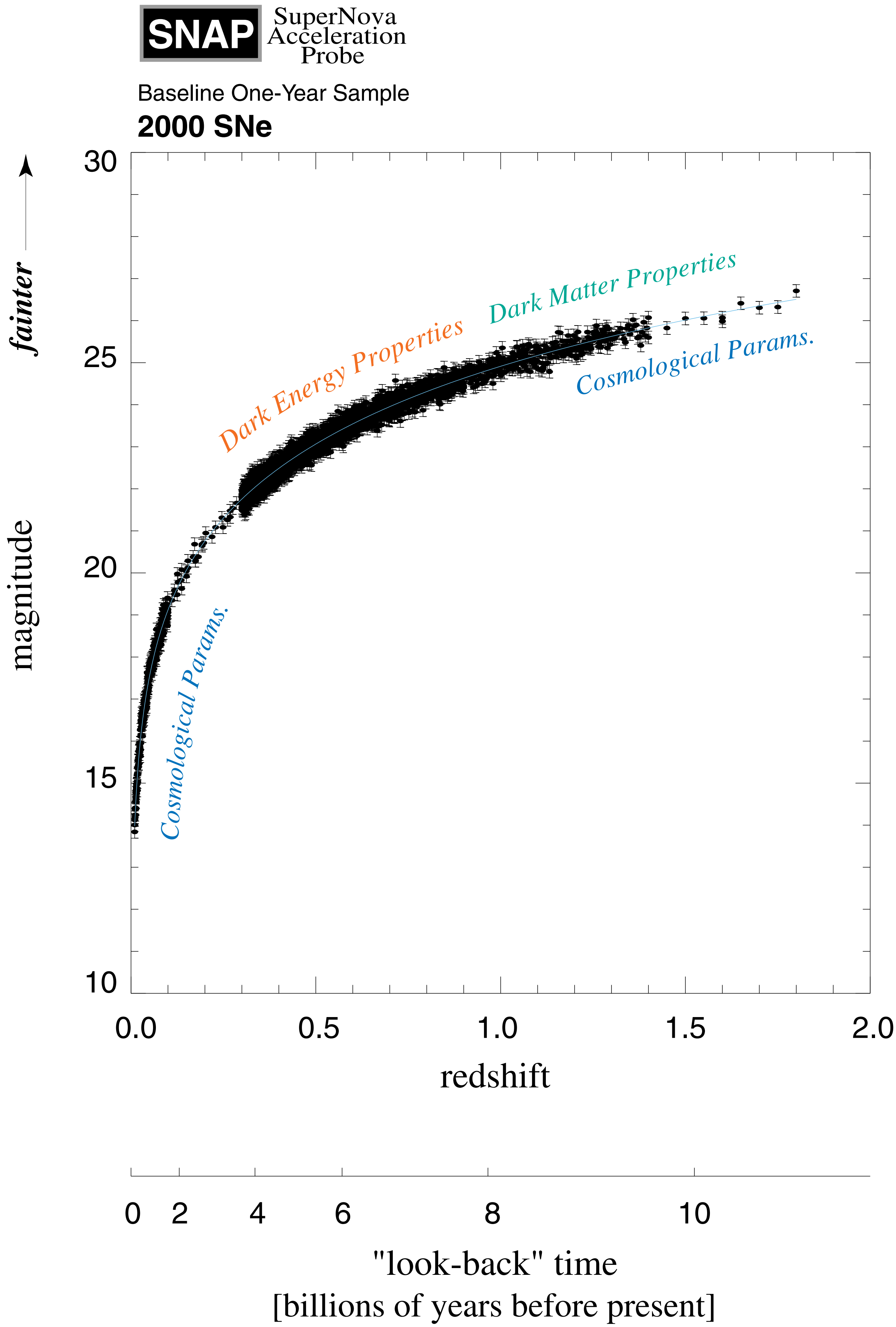
Satellite:

Dedicated instrument.

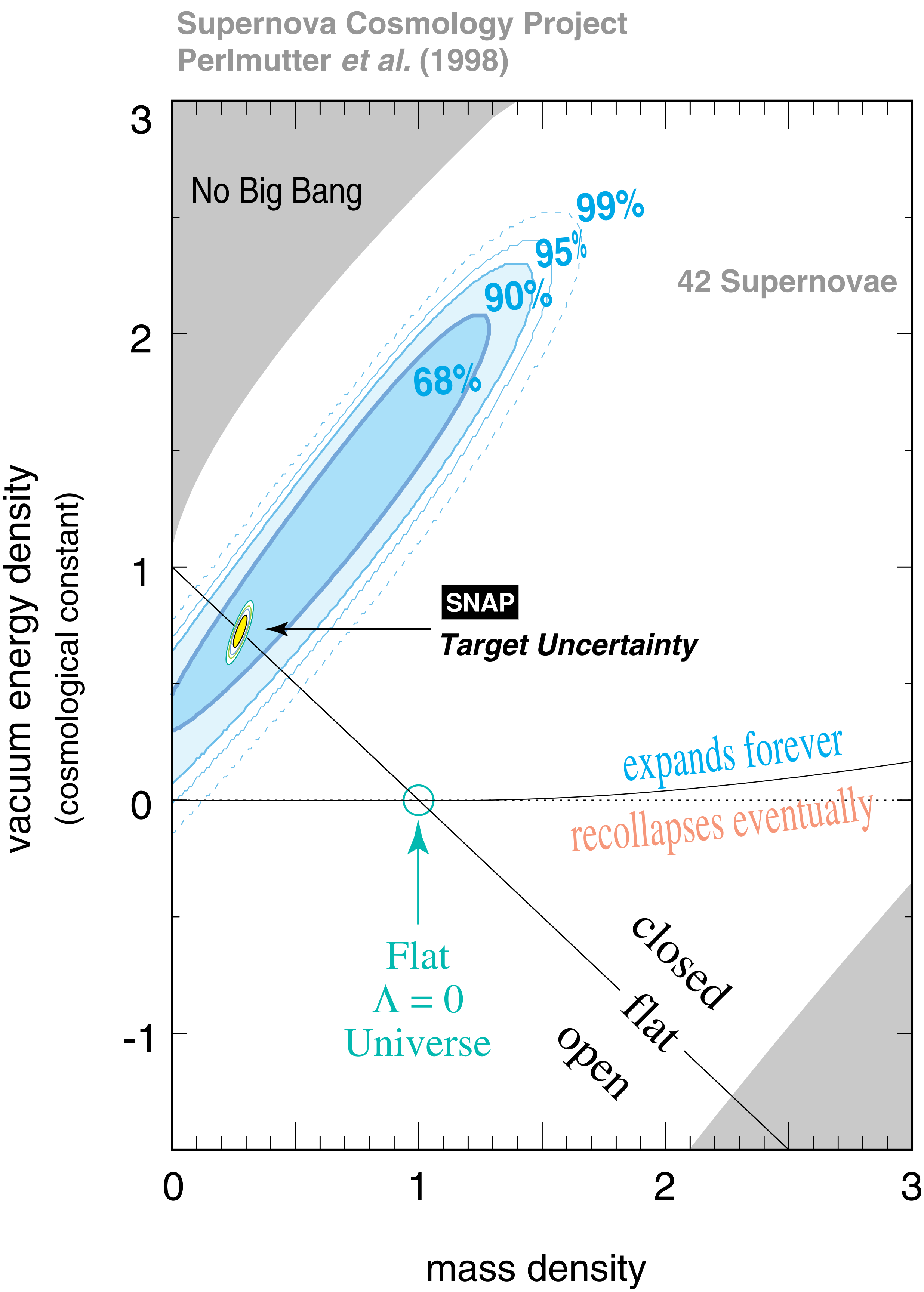
Designed to repeatedly observe an area of sky.

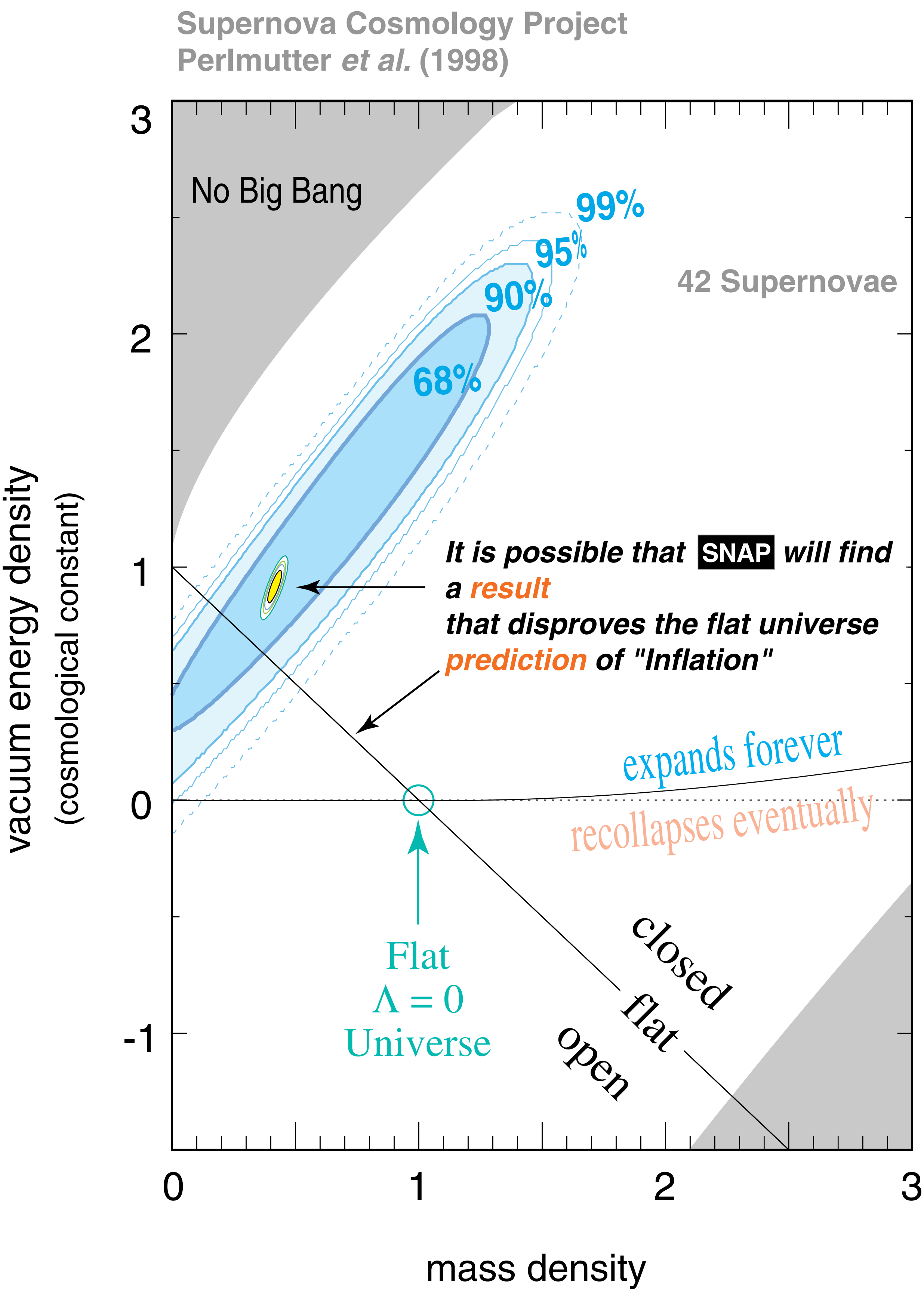
Essentially no moving parts.

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



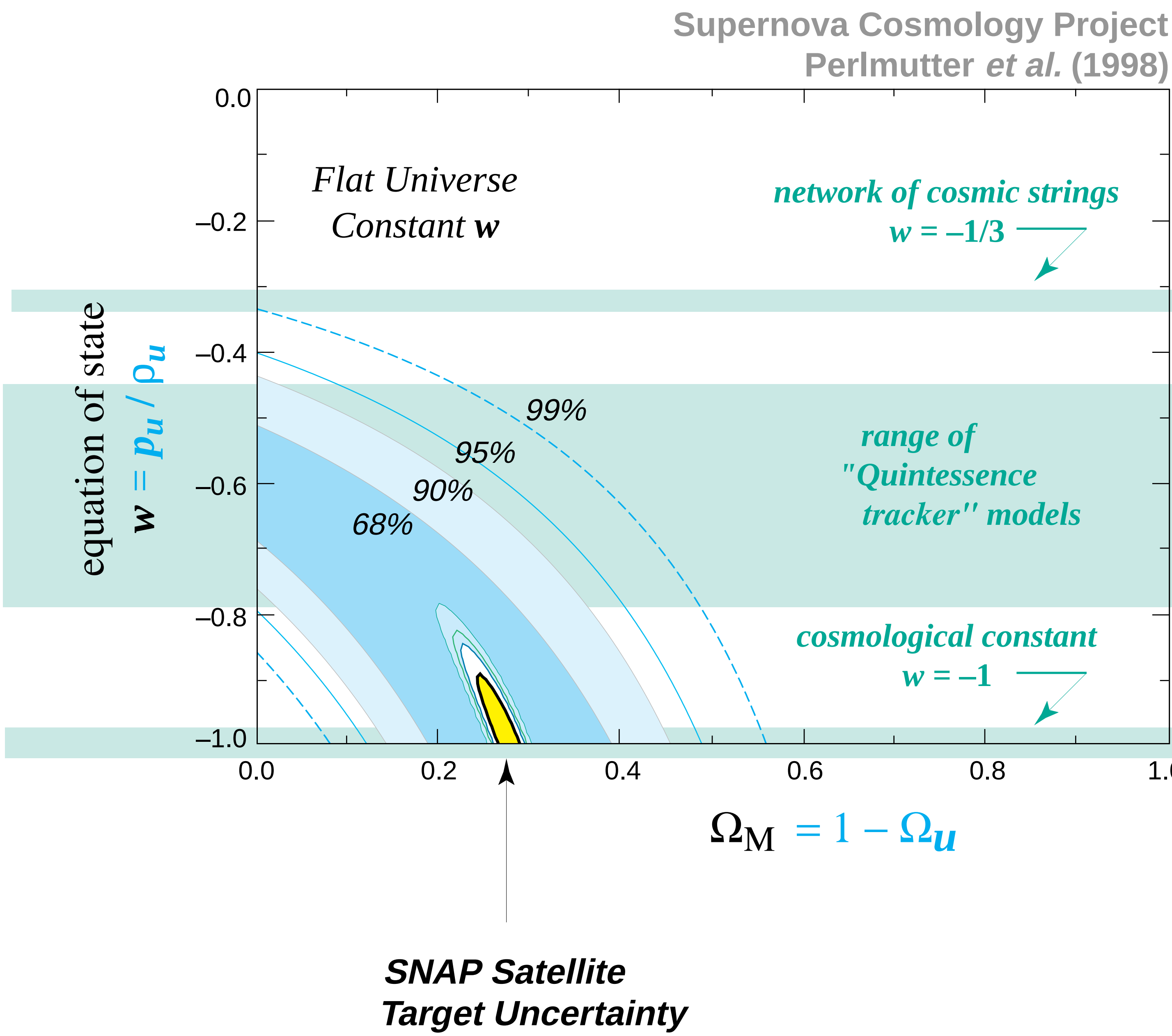
SNAP
SuperNova Acceleration Probe
Baseline One-Year Sample
2000 SNe
fainter
magnitude
30
25
20
15
10
Dark Energy Properties
Dark Matter Properties
Cosmological Params.
Cosmological Params.
0.0
0.5
1.0
1.5
2.0
redshift
0
2
4
6
8
10
"look-back" time
[billions of years before present]


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

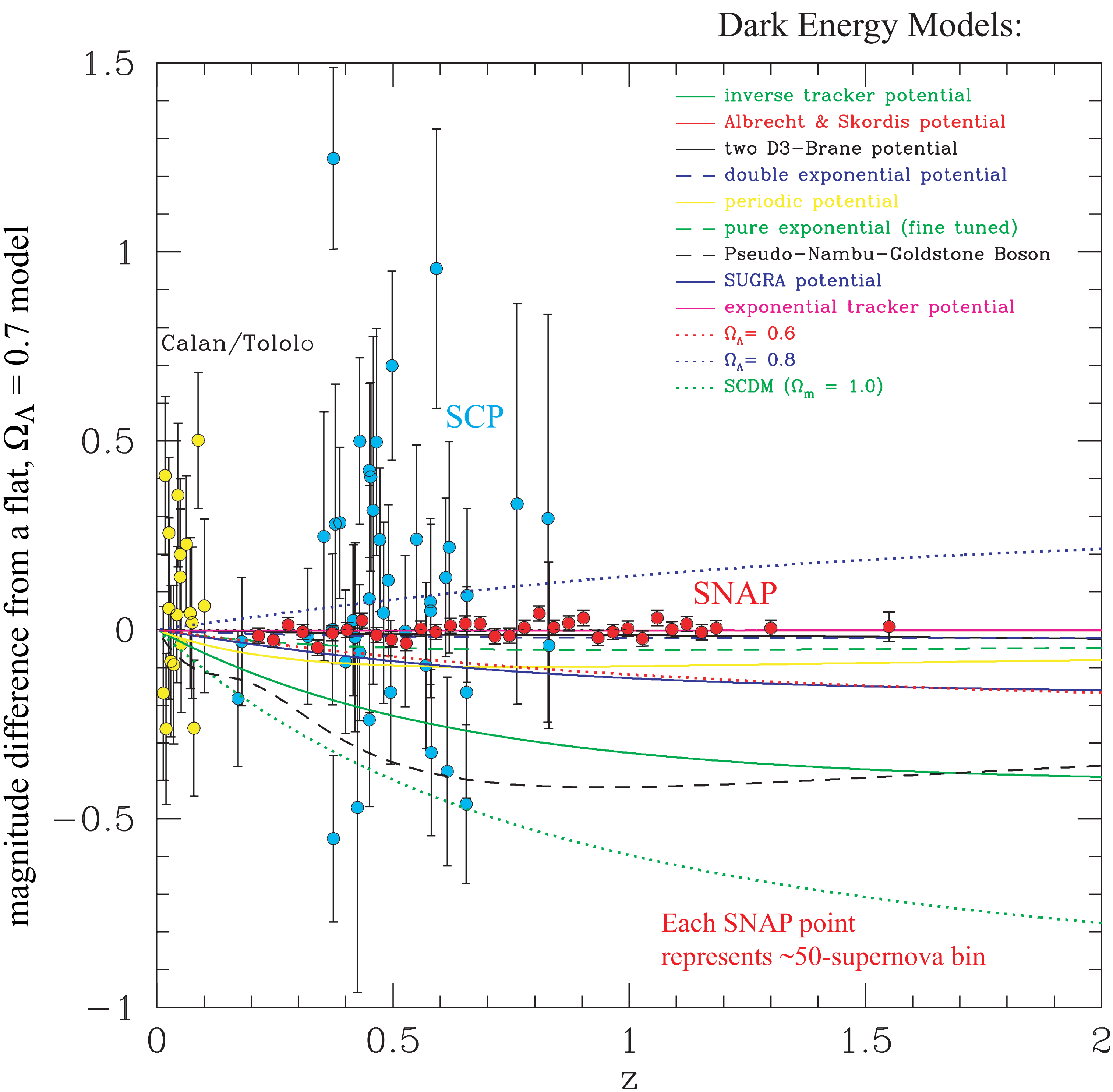
Dark Energy

Unknown Component, Ω_u, of Energy Density



SNAP SuperNova Acceleration Probe

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



The SLAC SPIRES High Energy Physics Database lists
S. Perlmutter et al., Astrophys.J.517:565-586,1999
in the 500+ citation category
(only four papers in 1999 had more citations -- all on string theory)

Here are the most recent entries:

1) SPONTANEOUS SYMMETRY BREAKING, NONMINIMAL COUPLING, AND COSMOLOGICAL CONSTANT PROBLEM.
By Je-An Gu, W.Y.P. Hwang (Taiwan, National Taiwan U.). May 2001. 7pp.

2) CAN THE QUINTESSENCE BE A COMPLEX SCALAR FIELD?
By Je-An Gu, W-Y.P. Hwang. May 2001. 8pp.

3) GENERAL RELATIVITY, COSMOLOGICAL CONSTANT AND MODULAR FORMS.
By G.V. Kraniotis (Sussex U.), S.B. Whitehouse (Royal Holloway - Bedford Coll.). SUSX-TH-01-018, RHCPP01-04T, May 2001. 38pp.

4) ACCELERATION OF THE UNIVERSE, STRING THEORY AND A VARYING SPEED OF LIGHT.
By J.W. Moffat (Toronto U.). May 2001. 8pp.

5) DETECTABILITY OF COSMIC TOPOLOGY IN ALMOST FLAT UNIVERSES.
By G.I. Gomero, M.J. Reboucas (Rio de Janeiro, CBPF), R. Tavakol (Rio de Janeiro, CBPF & Queen Mary - Westfield Coll.). May 2001. 18pp.

7) CAN WE LIVE IN A SELFTUNING UNIVERSE?
By Sean M. Carroll (Chicago U., EFI & Chicago U.), Laura Mersini (Pisa, Scuola Normale Superiore). EFI-2000-53, May 2001..

8) PERTURBATION EVOLUTION WITH A NON-MINIMALLY COUPLED SCALAR FIELD.
By Rachel Bean. Apr 2001. 7pp.

9) CONCERNING PARAMETER ESTIMATION USING THE COSMIC MICROWAVE BACKGROUND.
By M. Douspis, J.G. Bartlett (Toulouse Observtory), A. Blanchard (Toulouse Obsevatory & Strasbourg Observatory), M. Le Dour (Toulouse Observatory). Nov 2000. 15pp. Published in Astron.Astrophys.368:1-14,2001

10) TESTING QUINTESSENCE MODELS WITH LARGE-SCALE STRUCTURE GROWTH.
By K. Benabed, F. Bernardeau. SPHT-SACLAY-T01-045, Apr 2001. 11pp.

11) QUINTESSENCE WITH TWO ENERGY SCALES.
By Philippe Brax, Jerome Martin, Alain Riazuelo. Apr 2001. 16pp.

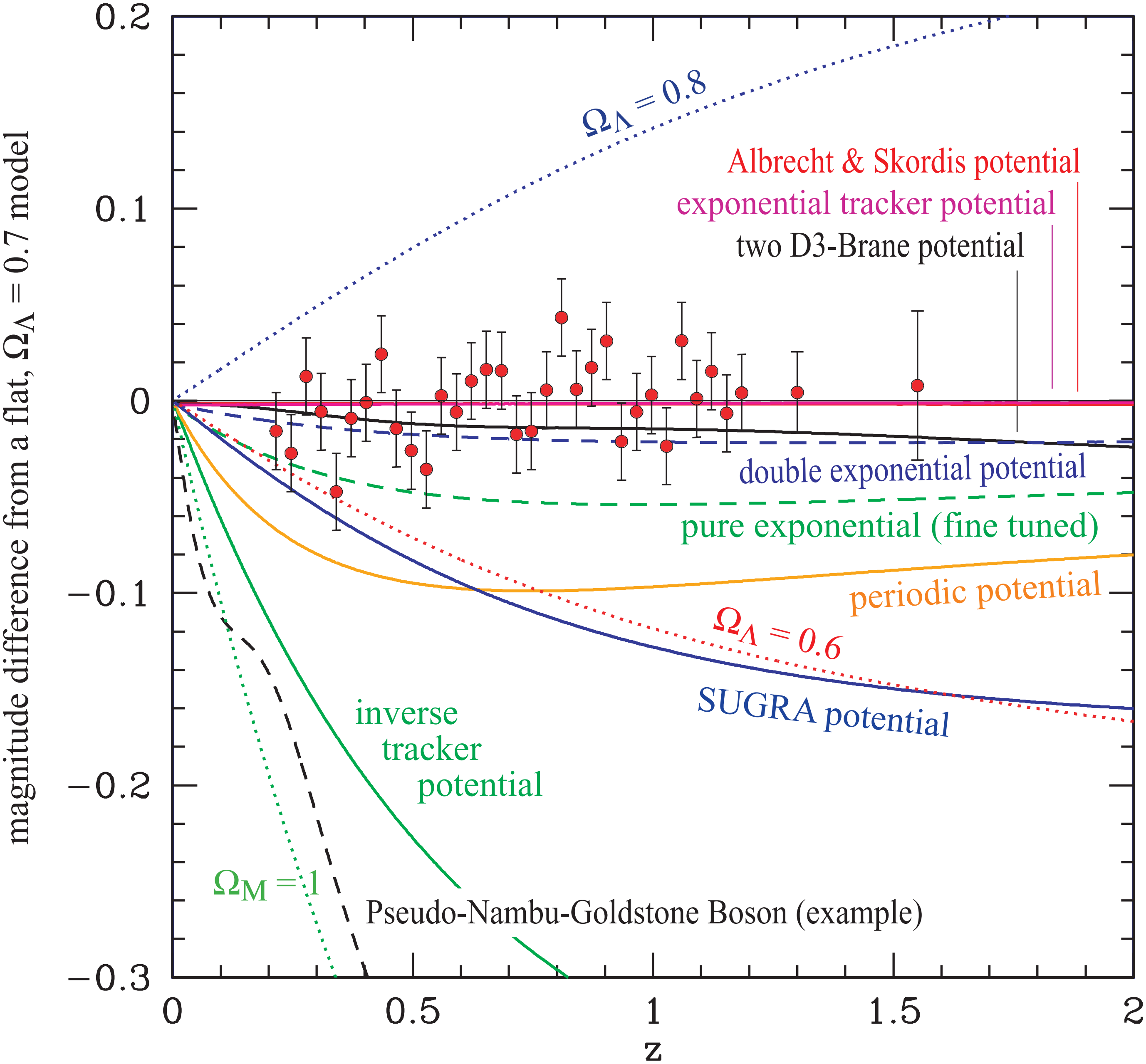
12) FUNCTIONAL SCHRODINGER PICTURE FOR CONFORMALLY FLAT SPACE-TIME WITH COSMOLOGICAL CONSTANT.
By Yurii G. Palii (Dubna, JINR & Chisinau, Inst. Appl. Phys). Apr 2001. 16pp.

13) STRING THEORY AND QUINTESSENCE.
By Simeon Hellerman (Stanford U., Phys. Dept.), Nemanja Kaloper (Stanford U., Phys. Dept. & Santa Barbara, ITP), Leonard Susskind (Stanford U., Phys. Dept.). SU-ITP-01-25, Apr 2001. 19pp.

14) NONCONSERVATION OF GLOBAL QUANTUM NUMBERS IN ANTI-RS TYPE MODELS.
By Tibor Torma (Oklahoma State U.). Apr 2001. 11pp.

SNAP SuperNova Acceleration Probe

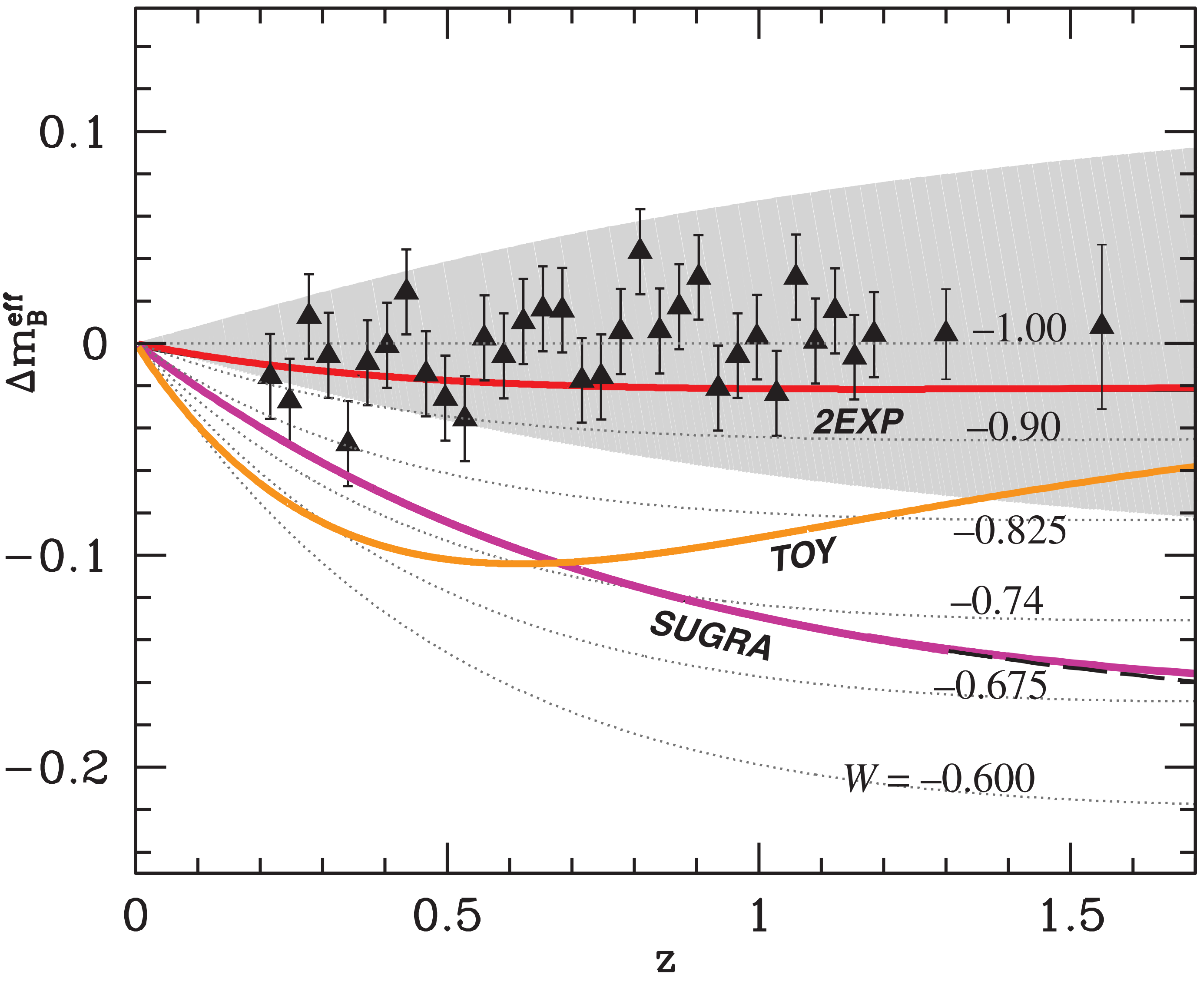
Binned simulated SNAP data compared with Dark Energy models currently in the literature.



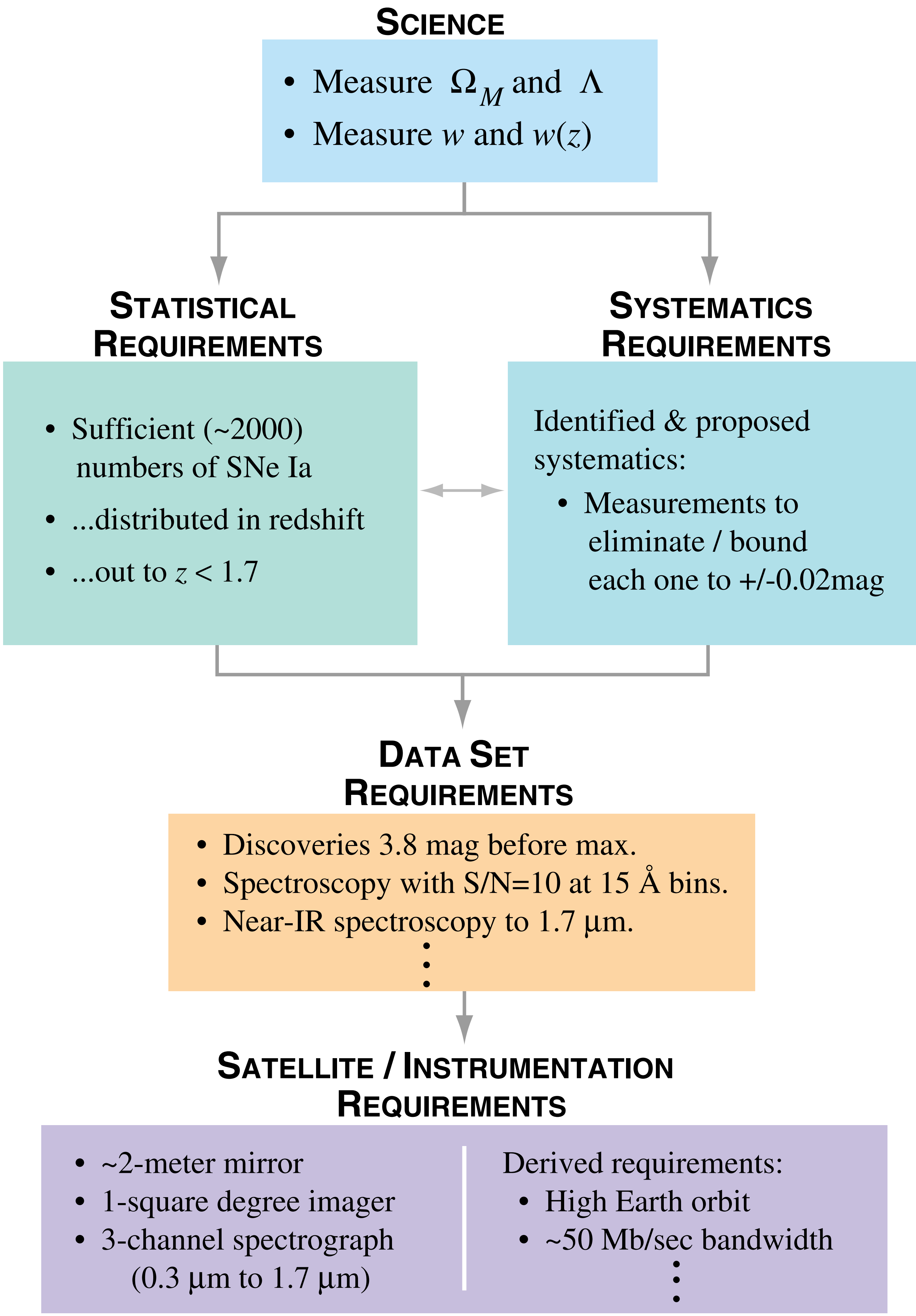
Weller & Albrecht

SNAP SuperNova Acceleration Probe

Binned simulated SNAP data
compared with Dark Energy models.



Weller & Albrecht (2000)

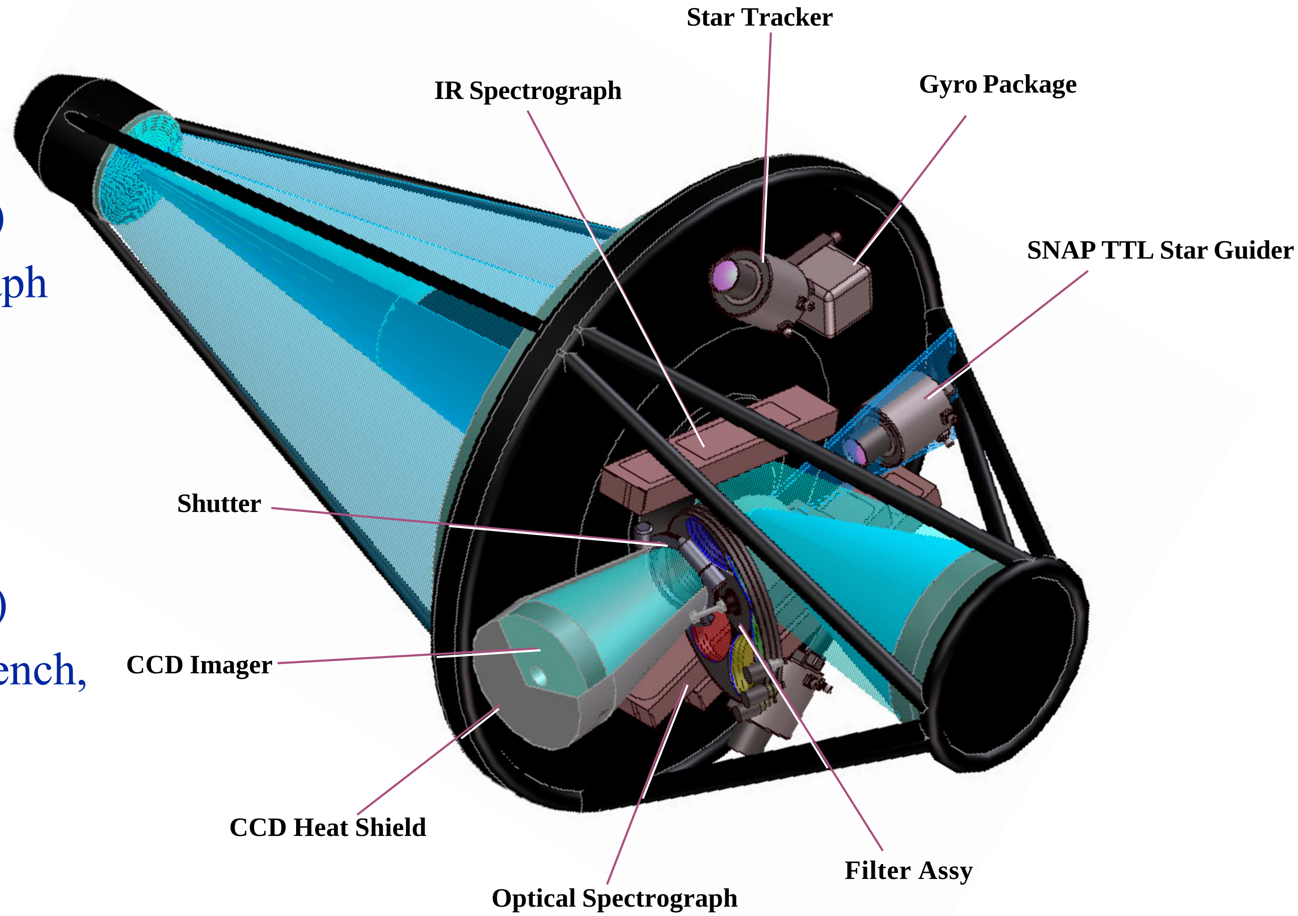


Science
Measure Ω_M and Λ
Measure w and $w(z)$
Statistical Requirements
Sufficient (~2000) numbers of SNe Ia
...distributed in redshift
...out to $z < 1.7$
Systematics Requirements
Identified & proposed systematics:
Measurements to eliminate / bound each one to +/-0.02mag
Data Set Requirements
Discoveries 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

Instrumentation Suite

Key Instruments:

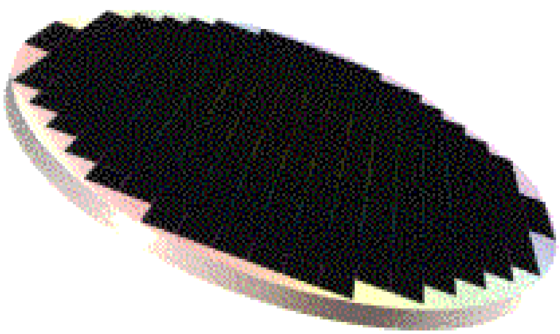
1) Wide Field Imager
   (one billion pixels)
2) IR Photometer
   (small field of view)
3) 3-channel spectrograph
   350-600 nm,
   550-1000 nm,
   900-1700 nm
4) Star Guider
   (image stabilization)
5) Telescope, Optics Bench,
   Filters, Shutters



GigaCAM

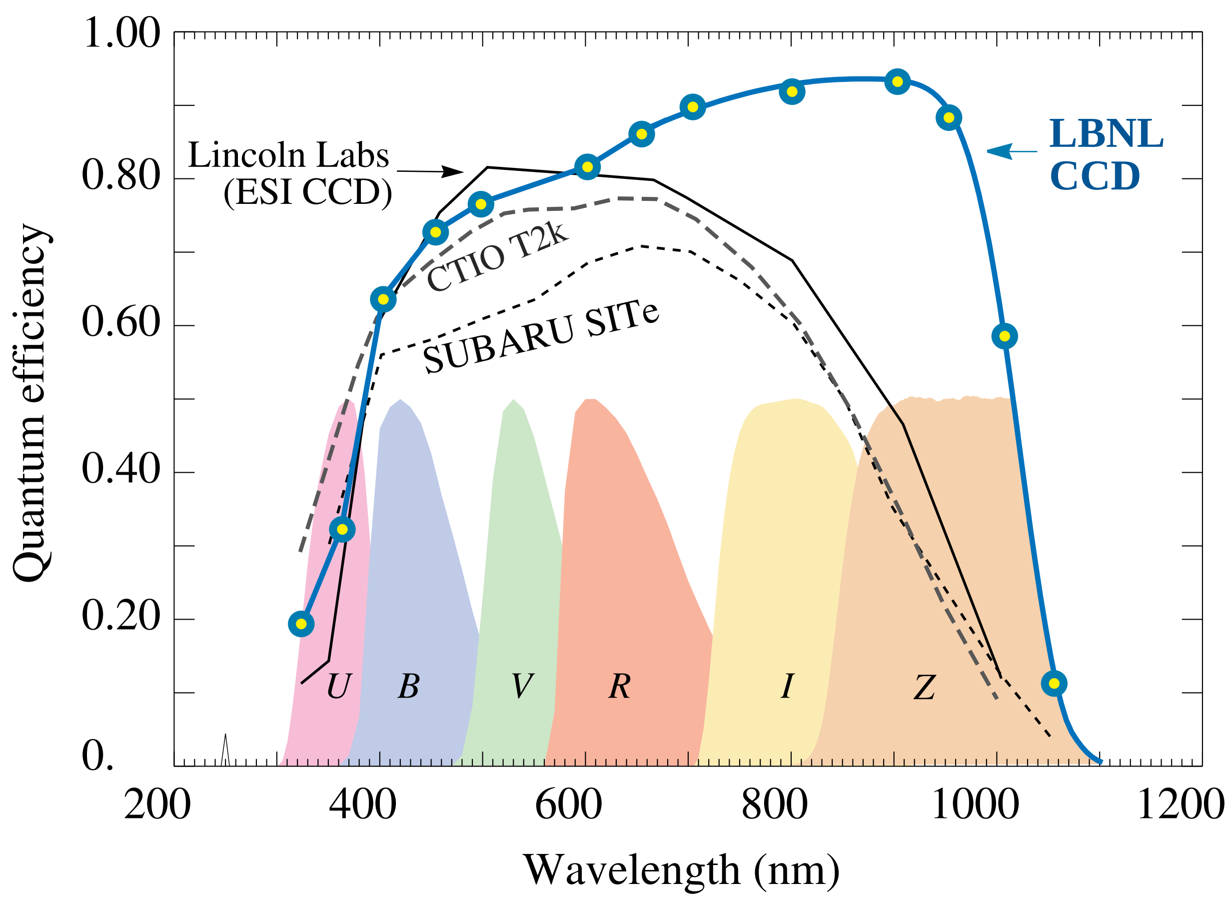
GigaCAM, a one billion pixel array

- Depending on pixel scale approximately 1 billion pixels (32k x 32k imager)
- ~200 Large format CCD detectors required
- 150K operation
- Issues: detectors, electronics, metrology
- Looks like the SLD vertex detector in Si area (0.1 - 0.2 m^2)
- Larger than SDSS camera, smaller than BaBar Vertex Detector (1 m^2)
- Collaboration has lots of experience in building very large silicon detectors and custom readout electronics including radiation hard integrated circuits (should they be necessary).

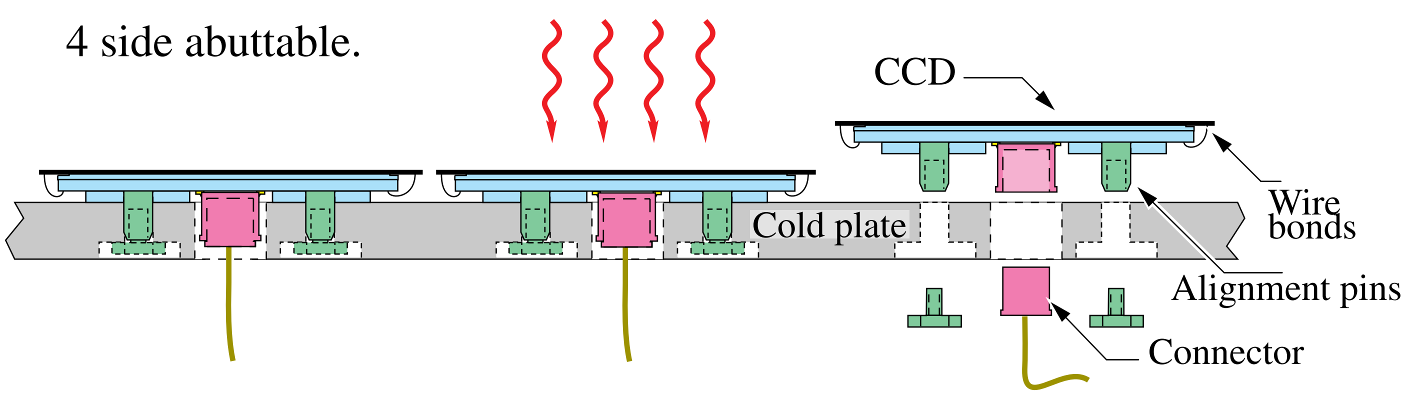


LBNL CCD Technology

High quantum efficiency from near UV to near IR
No thinning, no fringing.
High yield.
Radiation hard.



4 side abuttable.



Observatory

Simple Observatory consists of :

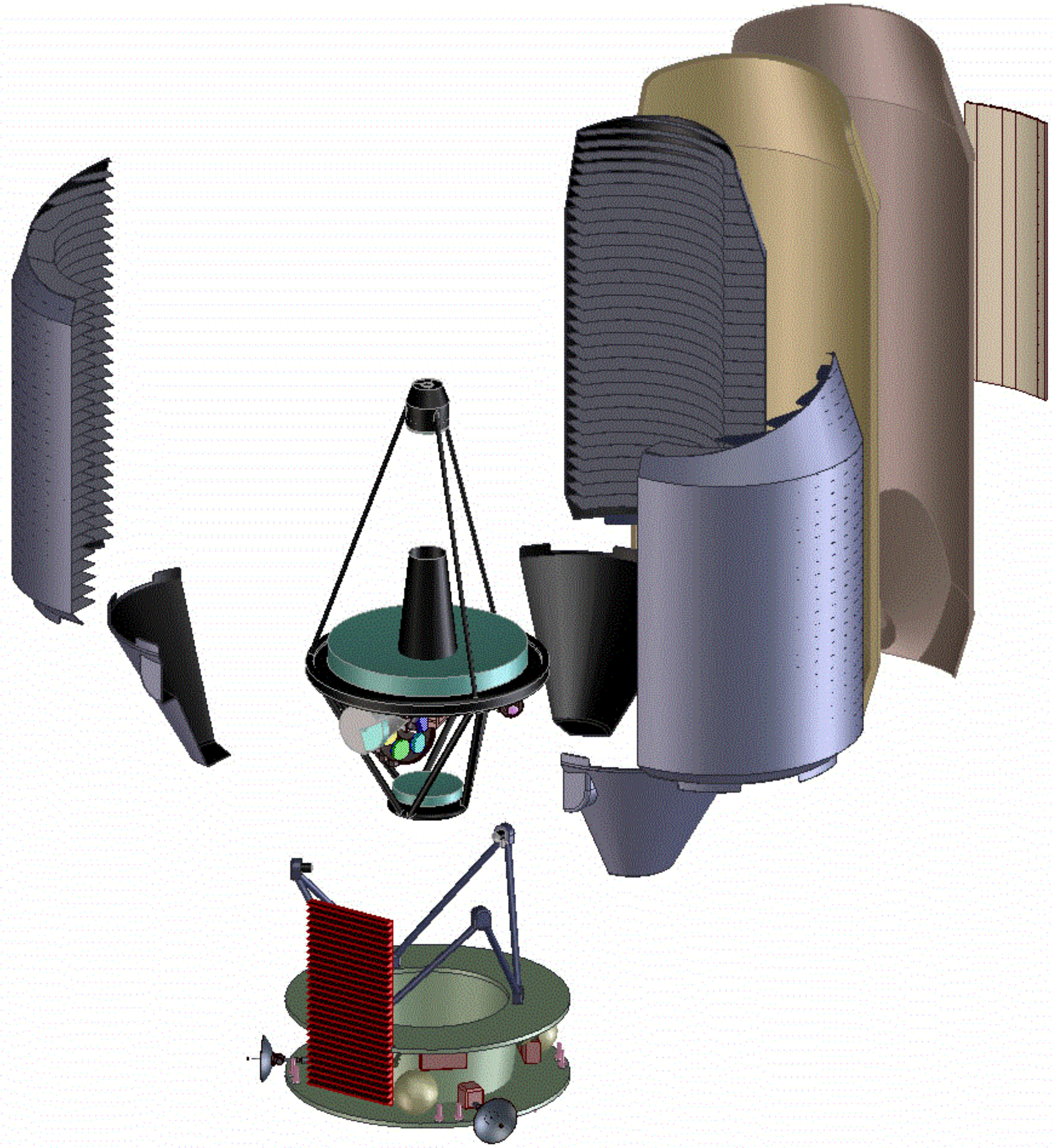
1) 3 mirror telescope w/ separable kinematic mount

2) Optics Bench w/ instrument bay

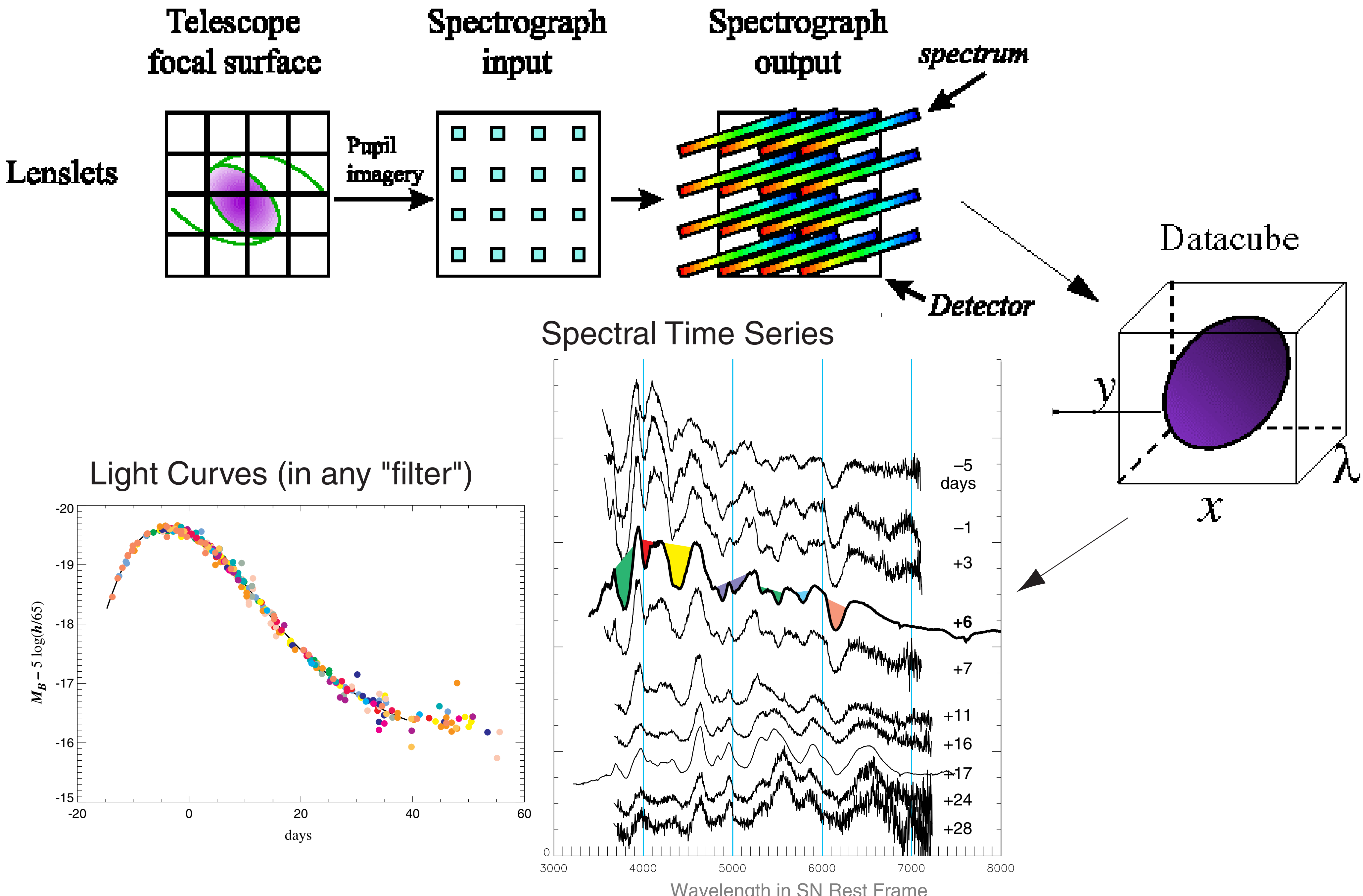
3) Baffled Sun Shade w/ body mounted solar panel and instrument radiator on opposing side

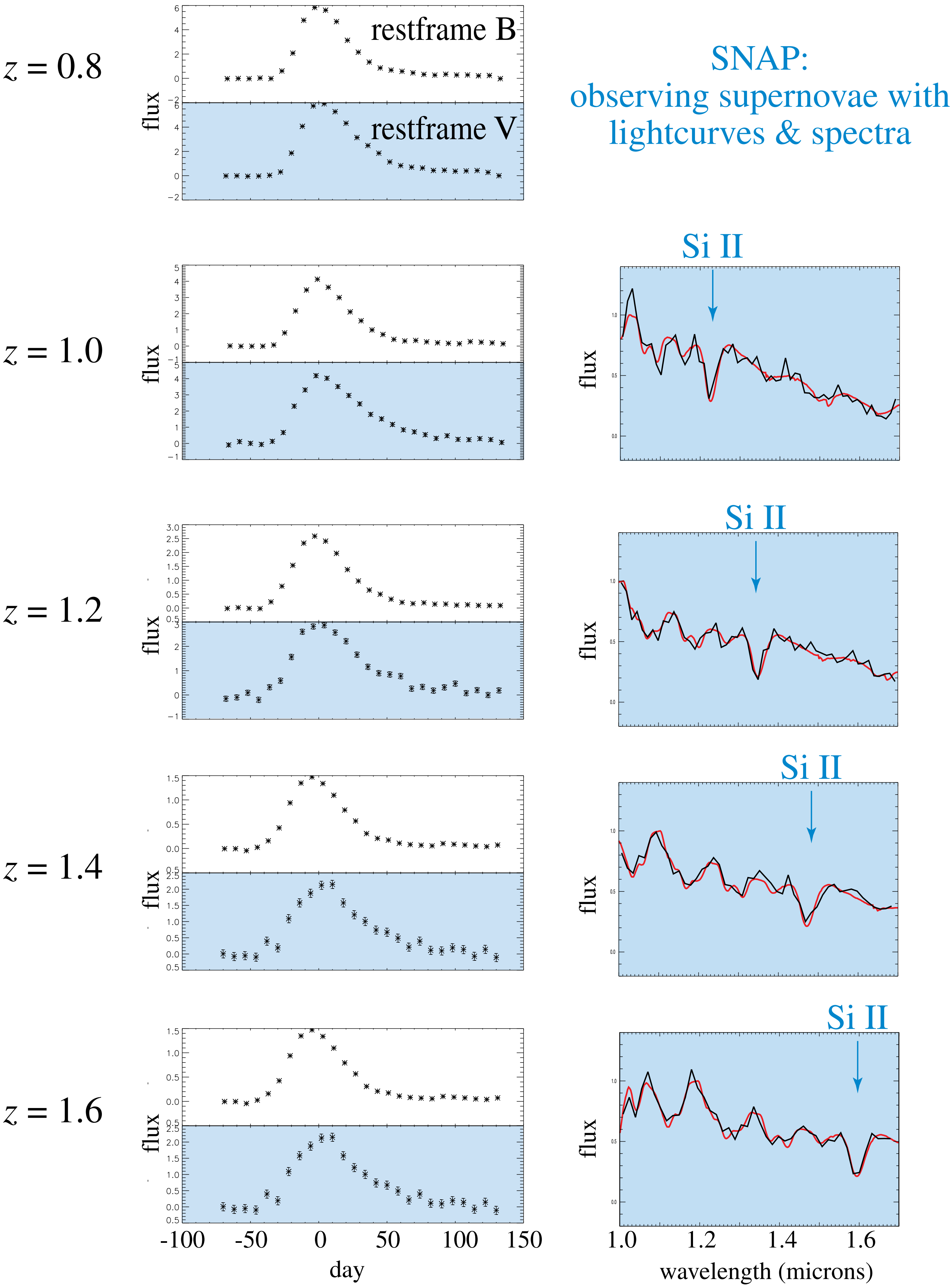
4) Spacecraft bus supporting telemetry (multiple antennae), propulsion, instrument electronics, *etc*

No moving parts (ex. filter wheels, shutters), rigid simple structure.



"Integral Field Unit" Spectrograph




z = 0.8
z = 1.0
z = 1.2
z = 1.4
z = 1.6
restframe B
restframe V
flux
SNAP:
observing supernovae with
lightcurves & spectra
Si II
-100
-50
0
50
100
150
day
1.0
1.2
1.4
1.6
wavelength (microns)

SNAP Collaboration

G. Aldering, C. Bebek, S. Deustua, W. Edwards, B. Frye, D. Groom, S. Holland, D. Kasen, R. Knop, R. Lafever, M. Levi, S. Loken, P. Nugent, S. Perlmutter, K. Robinson (Lawrence Berkeley National Laboratory)

G. Commins, D. Curtis, G. Goldhaber, J. R. Graham, S. Harris, P. Harvey, H. Heetderks, A. Kim, M. Lampton, R. Lin, D. Pankow, C. Pennypacker, A. Spadafora, G. F. Smoot (UC Berkeley)

C. Akerlof, D. Amidei, G. Bernstein, M. Campbell, D. Levin, S. McKee, M. Schubnell, G. Tarle , A. Tomasch (U. Michigan)

P. Astier, J.F. Genat, D. Hardin, J.- M. Levy, R. Pain, K. Schamahneche (IN2P3)

A. Baden, J. Goodman, G. Sullivan (U. Maryland)

R. Ellis, M. Metzger (CalTech)

D. Huterer (U. Chicago -> Case Western)

A. Fruchter (STScI)

L. Bergstrom, A. Goobar (U. Stockholm)

C. Lidman (ESO)

J. Rich (CEA/DAPNIA)

A. Mourao (Inst. Superior Tecnico,Lisbon)

Samuel Silver Space Sciences Laboratory

International collaboration is growing -- currently 15 institutions.

- Recent major addition of U. Michigan.
- Discussions with Fermilab and NASA/Goddard.

SNAP SuperNova Acceleration Probe

Working Groups (Preliminary)

Science Working Groups

- Type Ia Supernovae
- Type II Supernovae
- Weak Lensing
- Other Transients
- Other Astronomy/Astrophysics

Instrument Working Groups

- Optical Imager and Detectors
- IR Imager and Detectors
- Spectrograph System
- Calibration

SNAP SuperNova Acceleration Probe

Project Chronology

First public presentation of idea at Fermilab "Inner Space/Outer Space" symposium.	**end of May 1999**
Letter of Intent (pre-proposal) to DOE & NSF-Physics	**Nov 1999**
Review panel for Letter of Intent	**Dec 1999**
Science proposal for study phase to DOE & NSF-Physics	**Feb 2000**
SAGENAP review for DOE & NSF-Physics	**end of March 2000**
SAGENAP peer review panel report	**July 2000**
Study proposal to NSF-Physics Review in process.	**end of Sept 2000**
Dedicated session on SNAP at the 2001 AAS meeting	**Jan 2001**
Study review for DOE	**Jan 2001**
To be reviewed by NRC Comittee on the Physics of the Universe	**July 2001**
APS/DPF Snowmass meeting	**July 2001**

SNAP SuperNova Acceleration Probe

Peer Review by the DOE and NSF's SAGENAP panel.

The project was successfully reviewed by SAGENAP March 29-31, 2000; panel's report released July 21, 2000:

"In summary, the SAGENAP discussions indicate enthusiastic agreement by the panel that the **science goals** are on questions of great **importance to physics and cosmology**.

Further, it was considered that at the present stage in the measurement of the cosmological parameters, **new experimentation** is fully warranted and that the **SN Ia technique** will continue to play a crucial part.

The panel members were **favorably impressed** with the proposers' consideration of the sources of **systematic error** and were largely convinced that a fully **satellite-based experiment** is likely to be the preferred approach."

"There was unanimity on SAGENAP that a substantial R&D program is required soon to insure a successful SNAP experiment."

Recent DOE/Science & R&D Review (Jan 2001):

Implications for particle physics:

"SNAP is a science-driven project with compelling scientific goals."

"SNAP will have a unique ability to measure the variation in the equation of state of the universe."

"We believe that it is not an overstatement to say that the Type Ia supernova measurements will uniquely address issues at the very heart of the field [of particle physics]…"

Issues Raised at R&D Review:

Look at greatly increasing the near-infrared capabilities

Is the proposed IR spectrograph throughput adequate?

Look at a descoped instrument complement:
  Can the spectroscopy be done by ground-based facilities?

Develop the calibration strategy and plan.

Address relationship with NASA.

NRC Physics Survey:
Physics in a New Era: An Overview
April, 2001

"Thanks to new tools, we are now entering the age of precision cosmology. When taken together, observations of the dark matter, dark energy, and fluctuations in the remnant radiation from the Big Bang will in the next few years give us a percent-level precision on several critical cosmological parameters, testing the foundations of our understanding of the universe. Because of the profound relationship between physics at the smallest distance scales and the details of the early universe and dark mass-energy, this will open a new window for physics."

Expansion History of the Universe