SNAP SuperNova Acceleration Probe

Presentation to the NRC's
Committee on the Physics of the Universe
July 2001

Saul Perlmutter
for the SNAP Collaboration

0. Background on cosmology measurements from supernovae.

1. The science reach of SNAP for dark energy and dark matter.

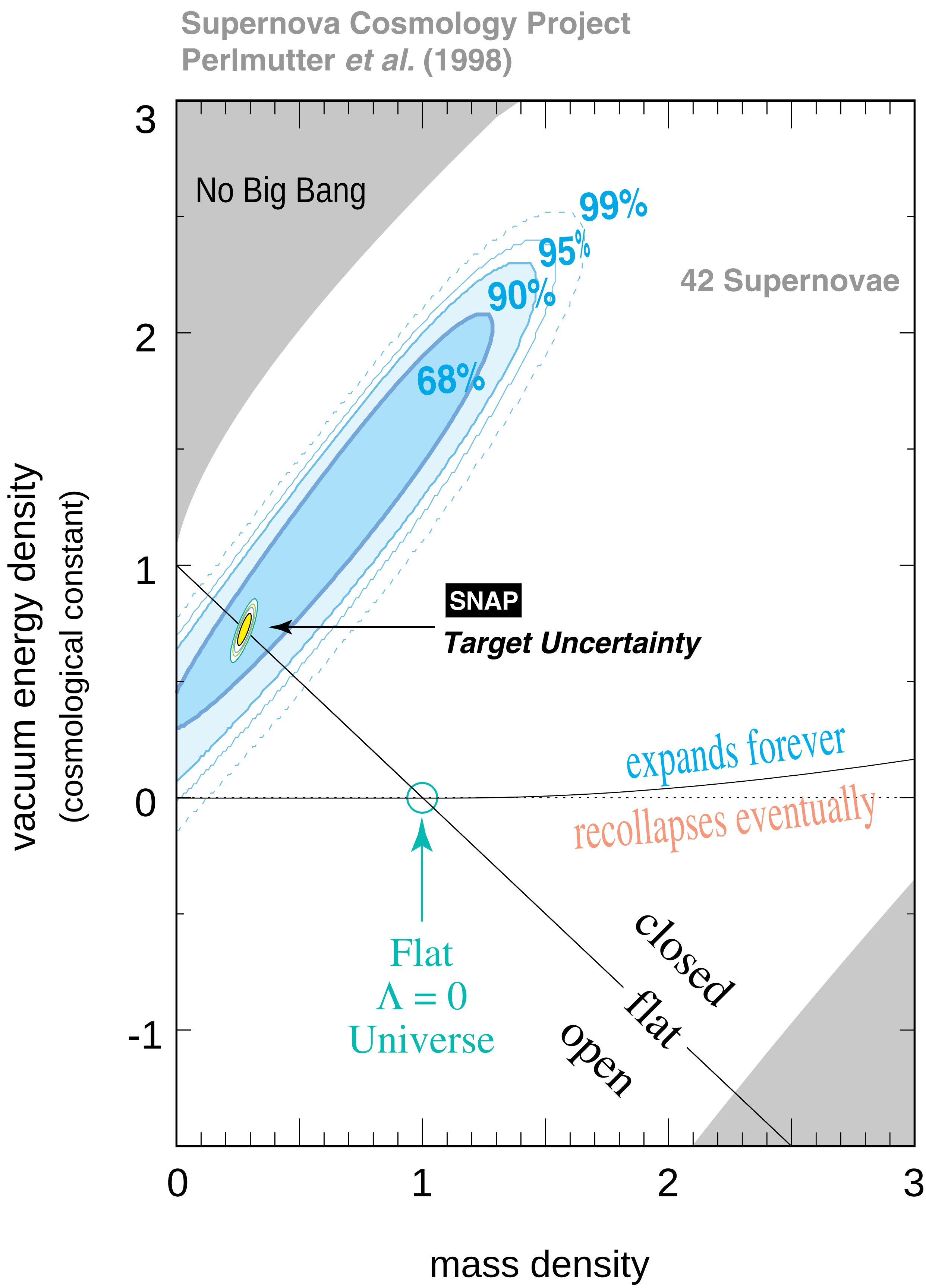
2. The complementarity of space based and ground based approaches.

3. Systematic uncertainties -- the key to this science: supernova systematics.

4. SNAP technology readiness and technical status.

5. SNAP cost estimates.

6. Necessary interagency cooperation.


Supernova Cosmology Project
Perlmutter et al. (1998)
No Big Bang
99%
95%
90%
68%
42 Supernovae
SNAP
Target Uncertainty
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

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

Past "standard cosmology" has been done with

~50%
uncertainties

Recent work is moving towards

~10%
uncertainties

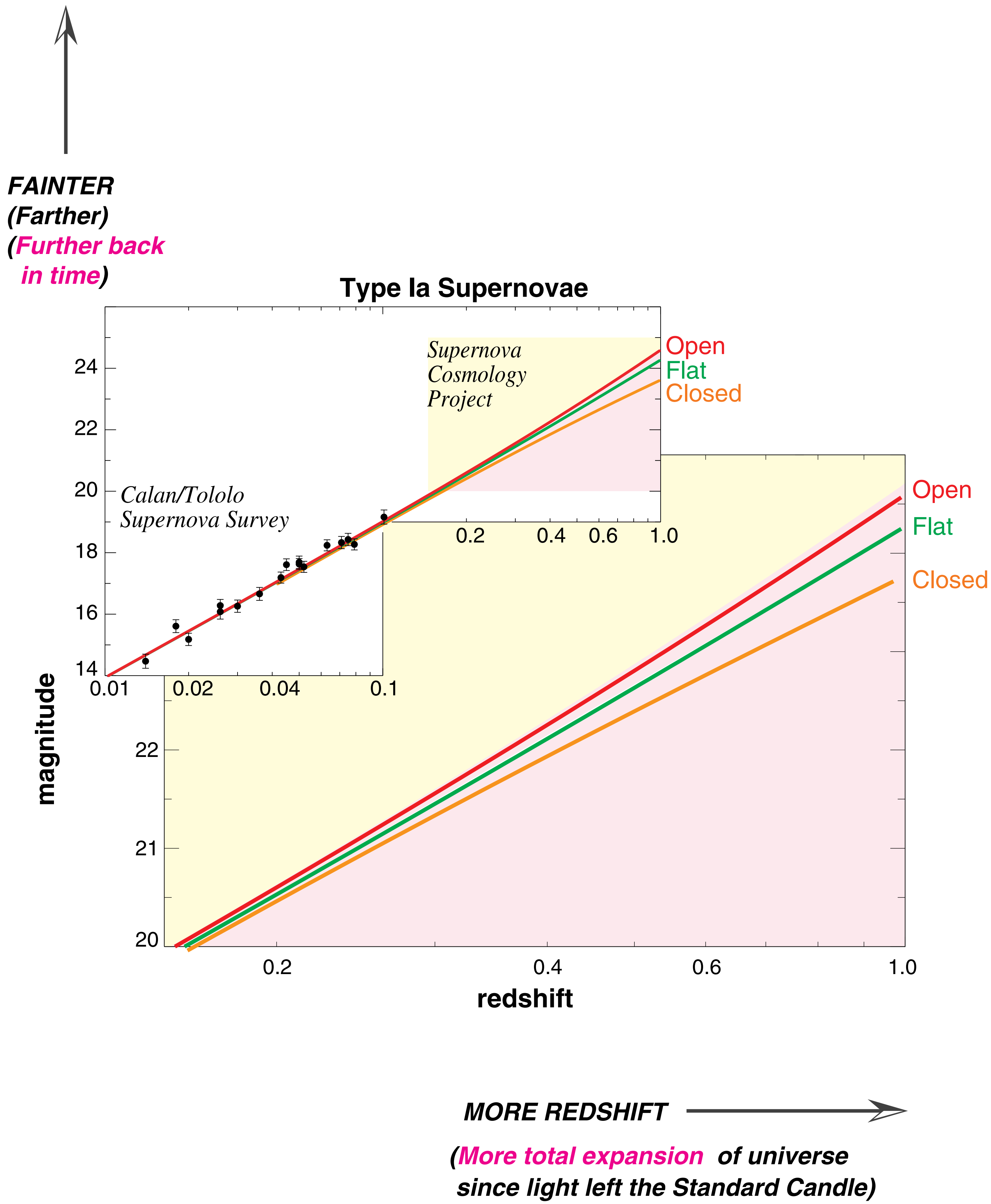
Planned CMB satellite work targets

~1%
uncertainties

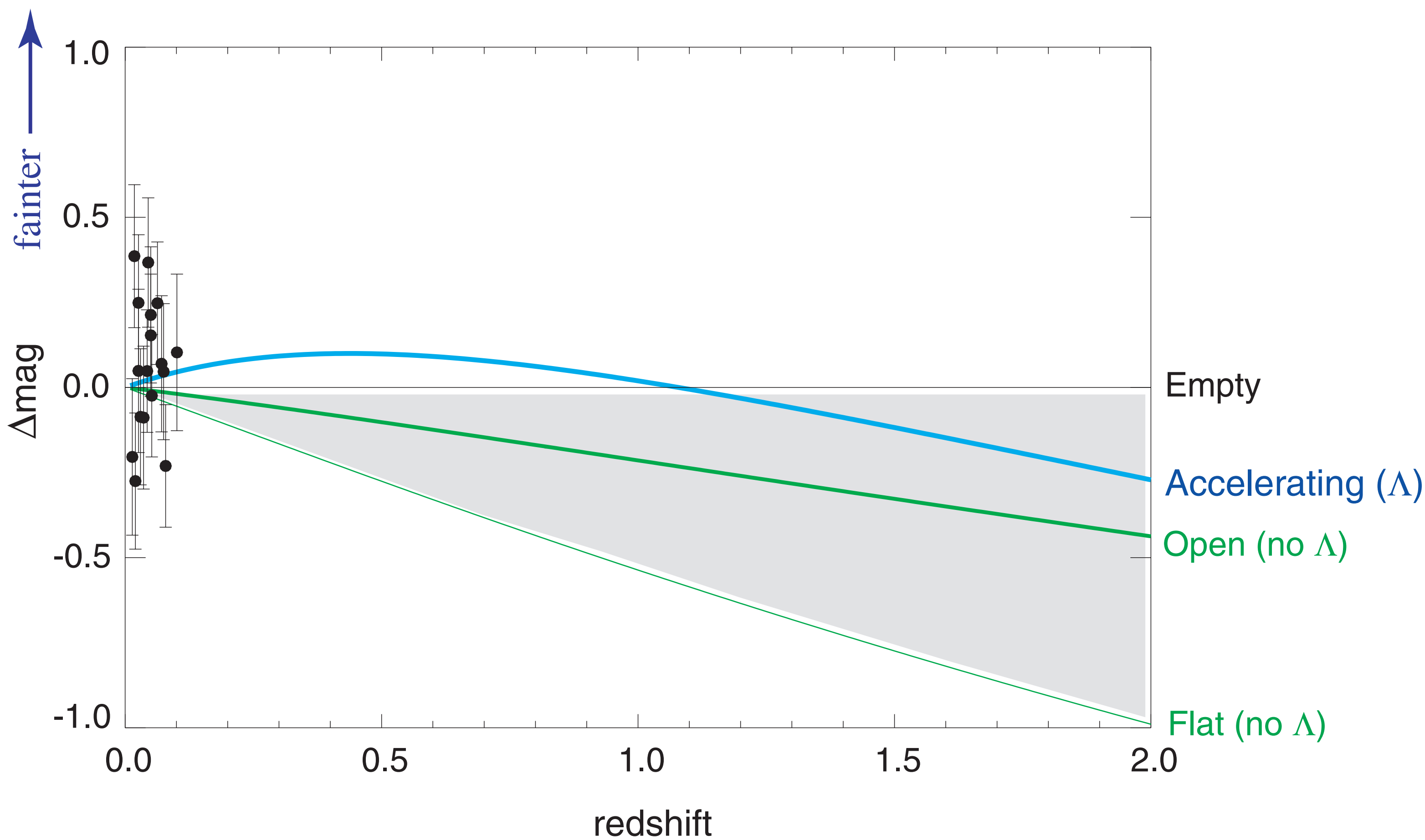
At each of these levels there are appropriately matched levels of systematic uncertainties & simplifying assumptions.

To answer "what we want to know"
we must go from 50%
through the 10% and on to the 1% level.

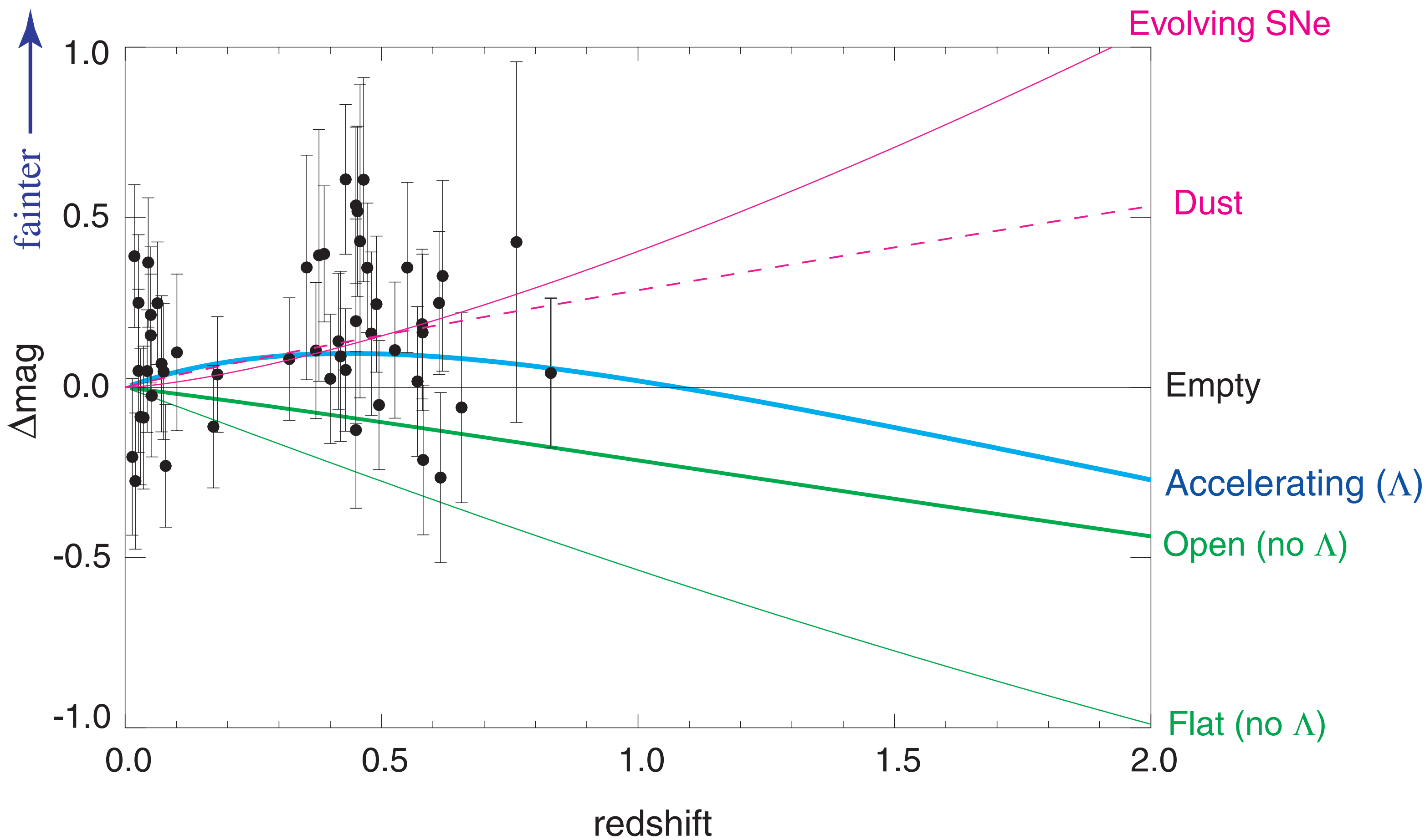
Additional Material

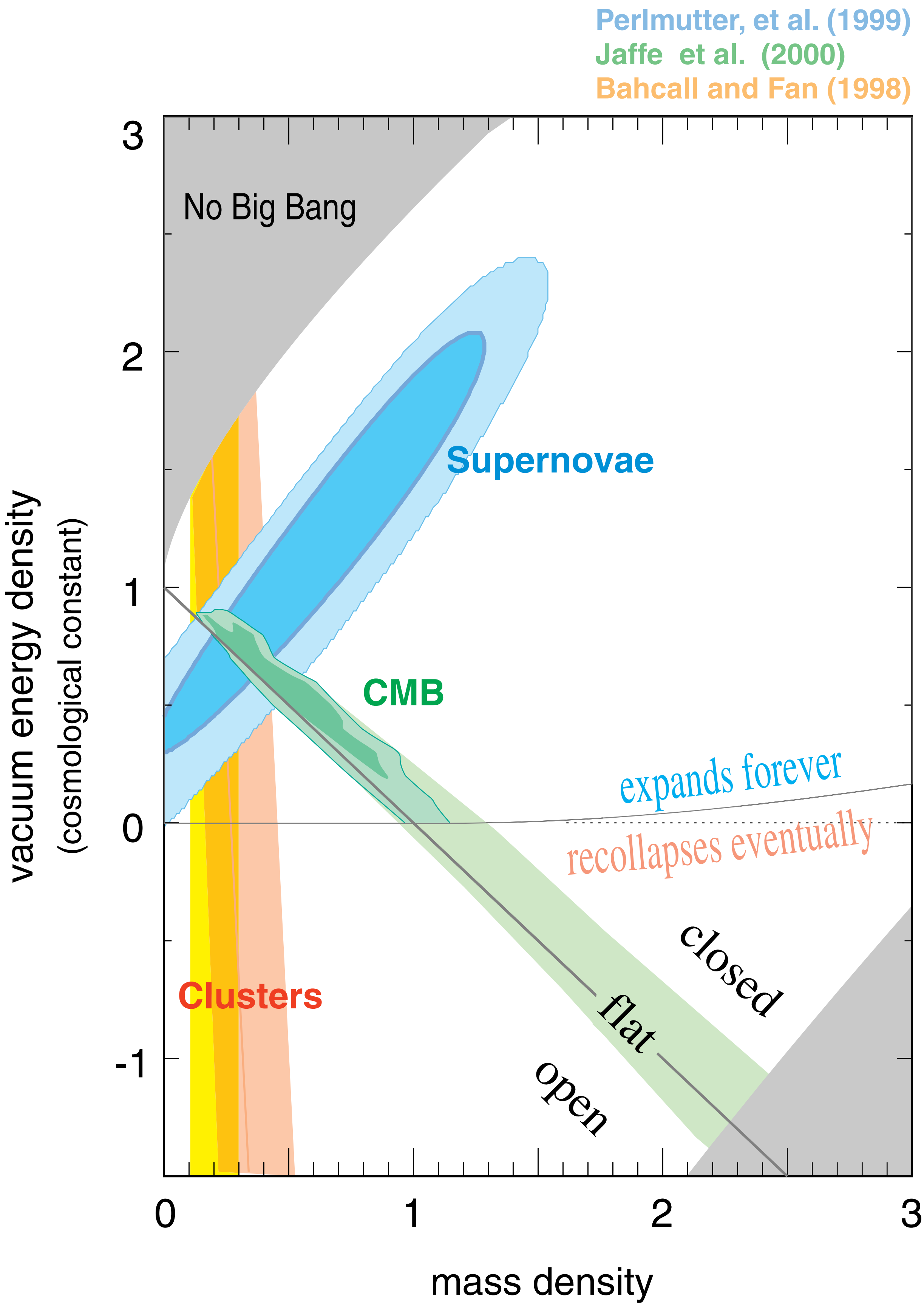


FAINTER
(Farther)
(Further back in time)
Type Ia Supernovae
Supernova Cosmology Project
Open
Flat
Closed
Calan/Tololo Supernova Survey
24
22
20
18
16
14
0.01
0.02
0.04
0.1
0.2
0.4
0.6
1.0
magnitude
22
21
20
0.2
0.4
0.6
1.0
Open
Flat
Closed
redshift
MORE REDSHIFT
(More total expansion of universe since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


fainter
Δmag
1.0
0.5
0.0
-0.5
-1.0
0.0
0.5
1.0
1.5
2.0
redshift
Empty
Accelerating (Λ)
Open (no Λ)
Flat (no Λ)

1998: Acceleration





Perlmutter, et al. (1999)
Jaffe et al. (2000)
Bahcall and Fan (1998)
No Big Bang
Supernovae
CMB
expands forever
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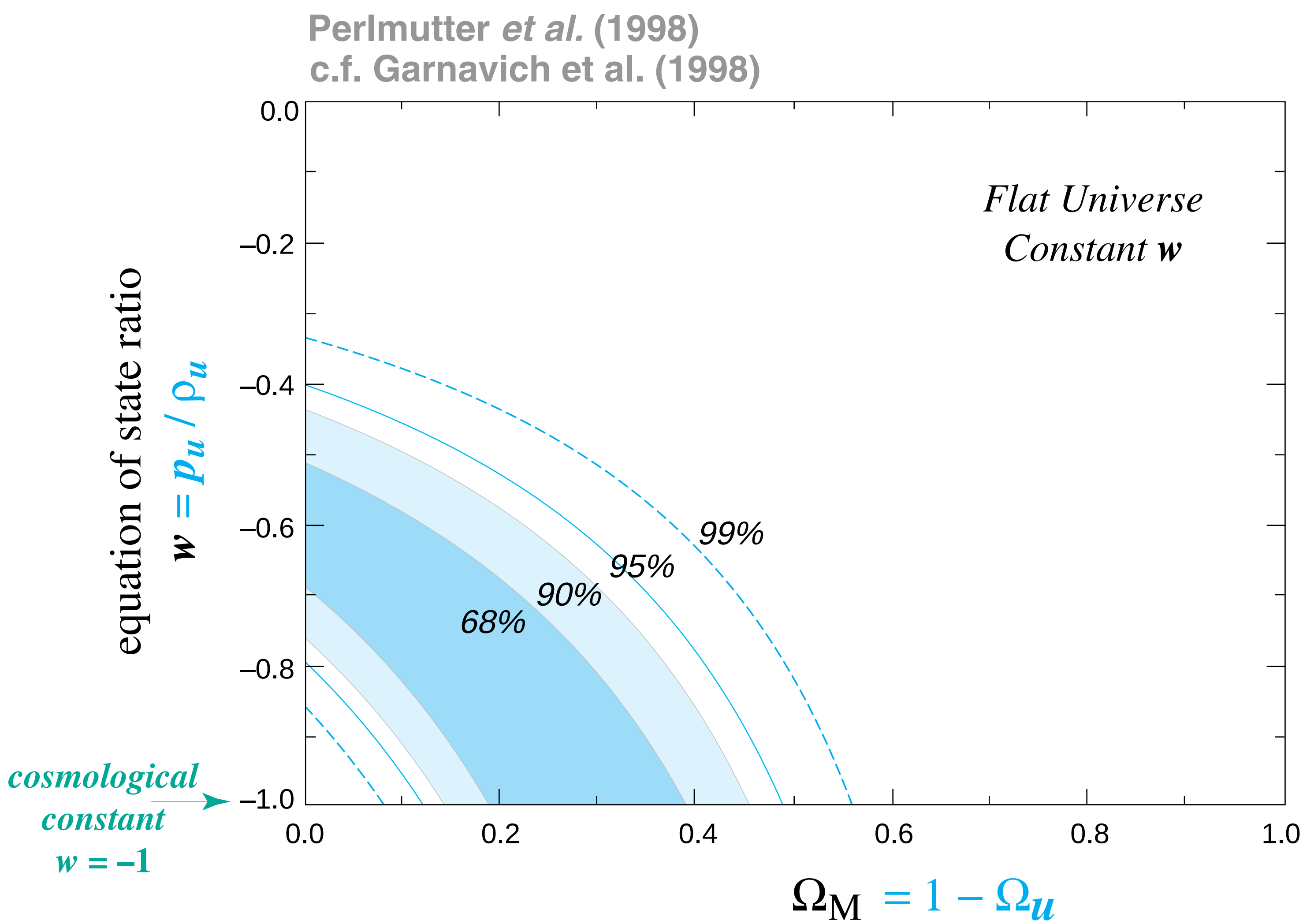
Clusters
vacuum energy density
(cosmological constant)
mass density
3
2
1
0
-1
0
1
2
3

Unknown Component, Ω_u, of Energy Density



What do we now want to know?

- Is our simple cosmological picture on the right track?

  Do we find the same Ω_k @ $z = 1$ and $z = 1000$?

- Strength of our conviction that $\Omega_\Lambda > 0$.

  Find a redshift when
  $m(z)$ for $\Lambda>0$ is **not** fainter than $m(z)$ with no Λ
  i.e. the "deceleration era."

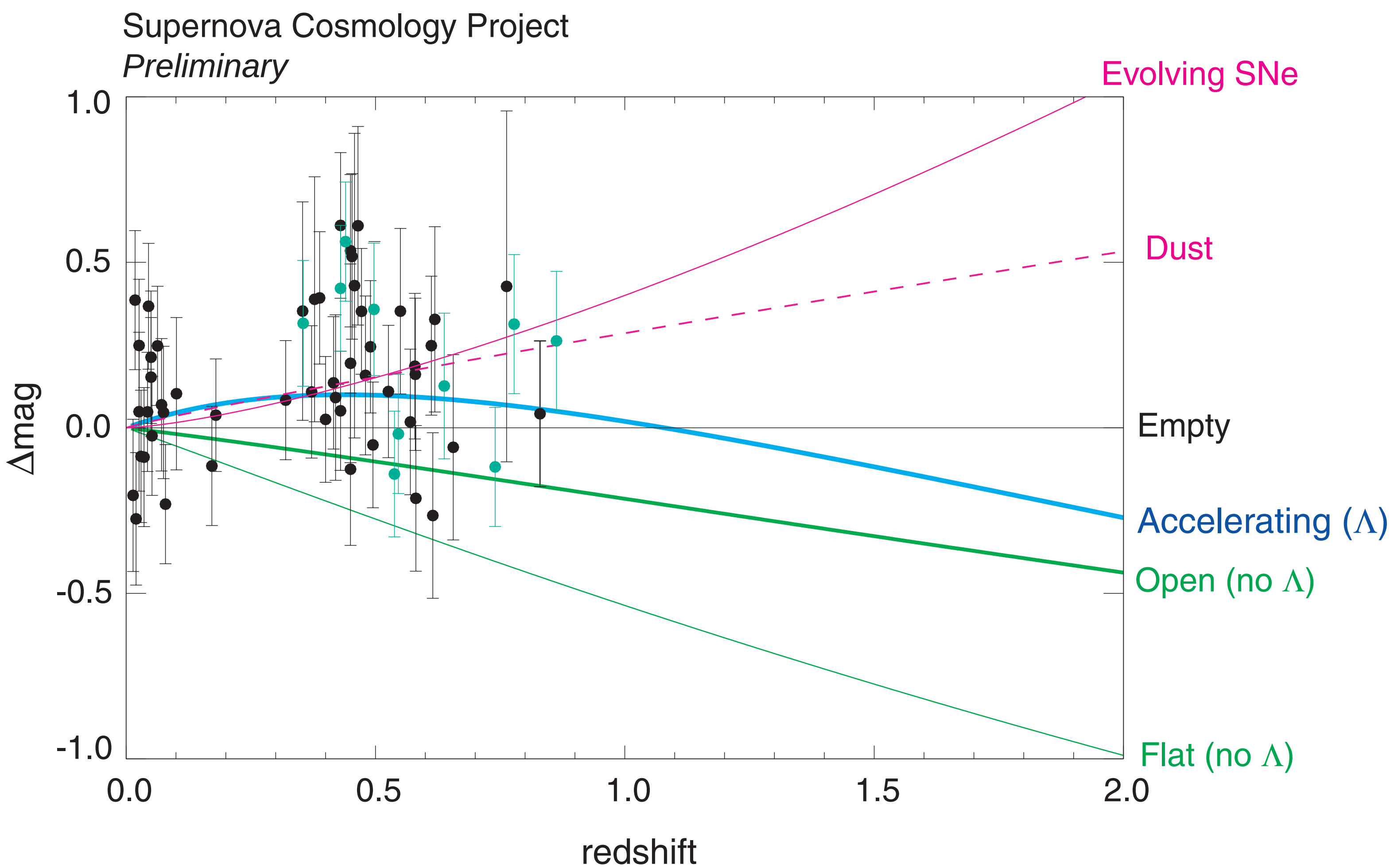
  Get tighter constraints on:
  -- gray dust & other non-standard dust
  -- any SN Ia evolution
  -- gravitational lensing of SNe.

- Identity of, and properties of, "Dark Energy"
  that is apparently accelerating the universe.

  Measure over a range of redshifts
  to look for varying properties.

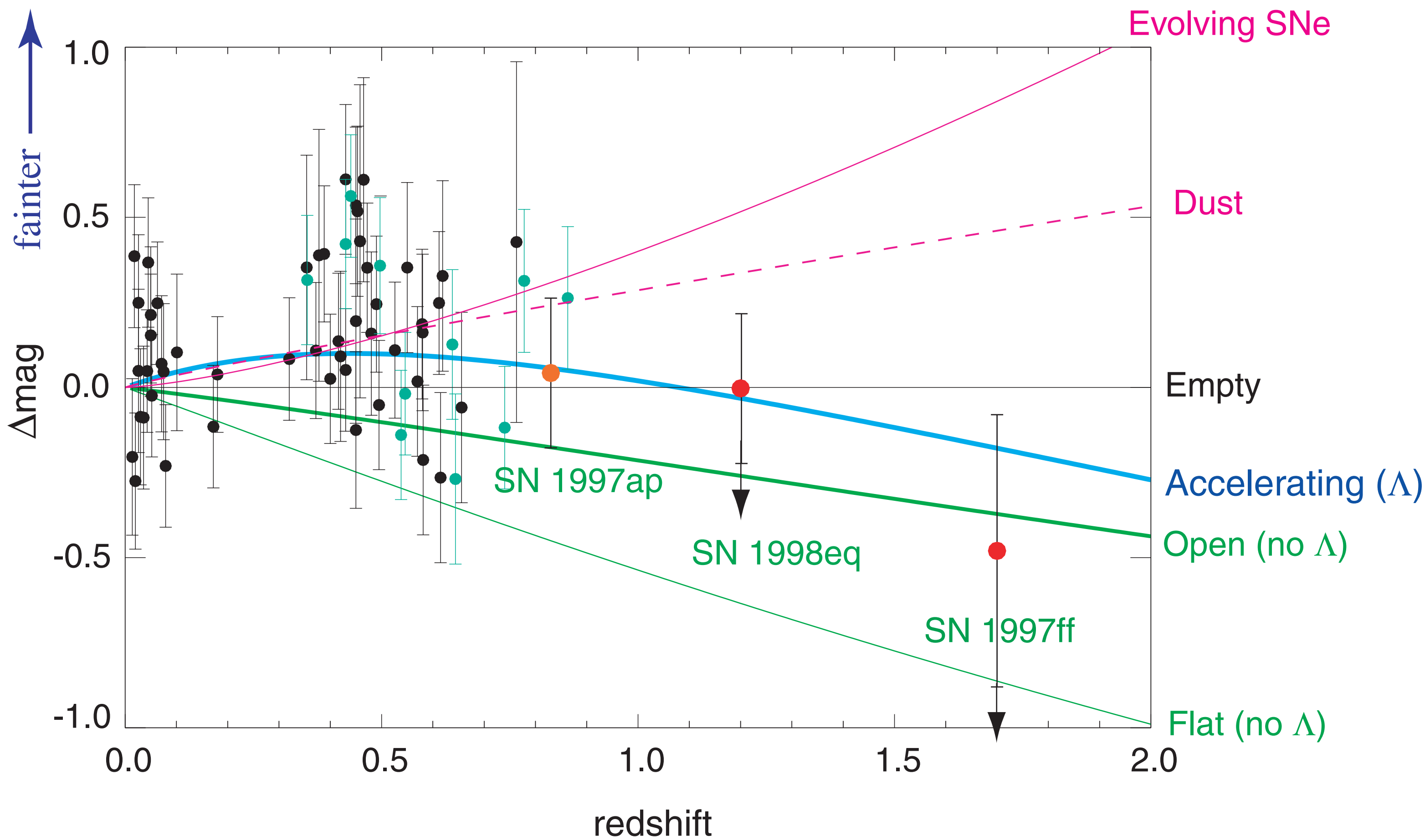
A Basic Measurement:
The History of the Universe's Expansion

New HST data

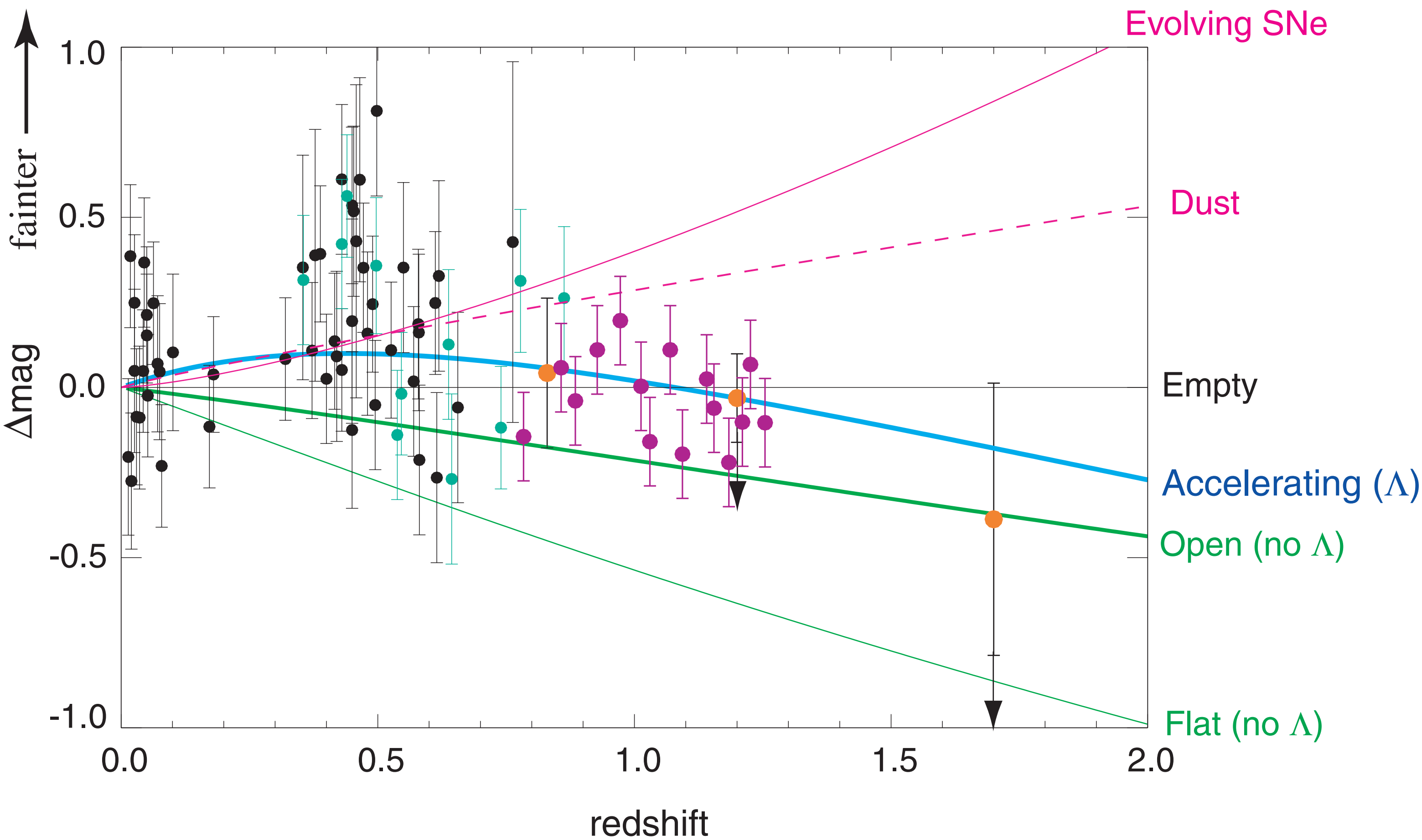


Supernova Cosmology Project
Preliminary
Evolving SNe
Dust
Empty
Accelerating (Λ)
Open (no Λ)
Flat (no Λ)
Δmag
redshift
1.0
0.5
0.0
-0.5
-1.0
0.0
0.5
1.0
1.5
2.0

Supernovae probing
the *deceleration* era
with NICMOS



Future HST Data



(This year's Supernova Cosmology Project search is now in progress.)

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***

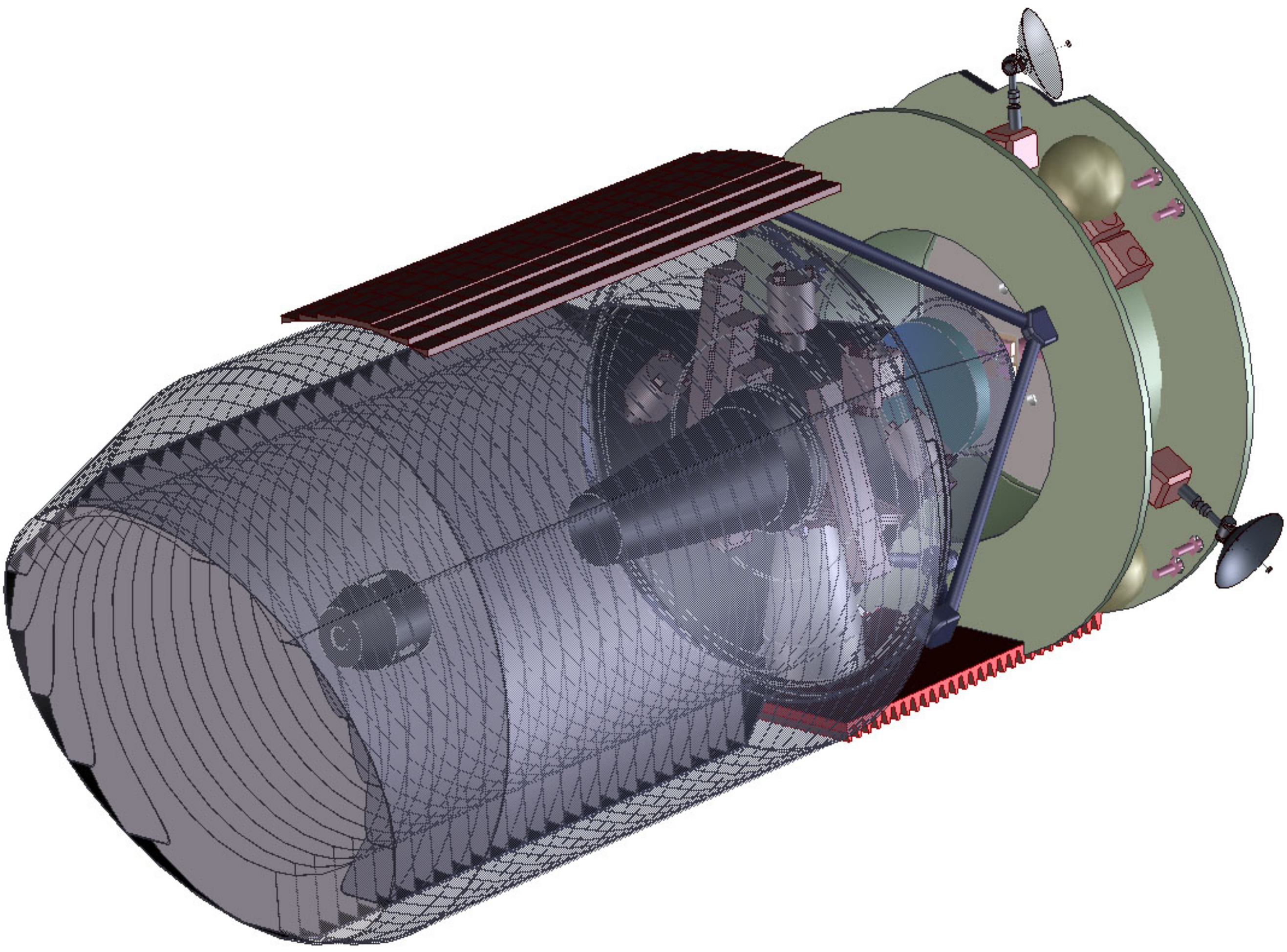
Cross-Checks of sensitivity to

☑	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

Additional Material

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.
- **0.35um -- 1.7um spectrograph**
  Detailed analysis of each SN.

Satellite:

Dedicated instrument.

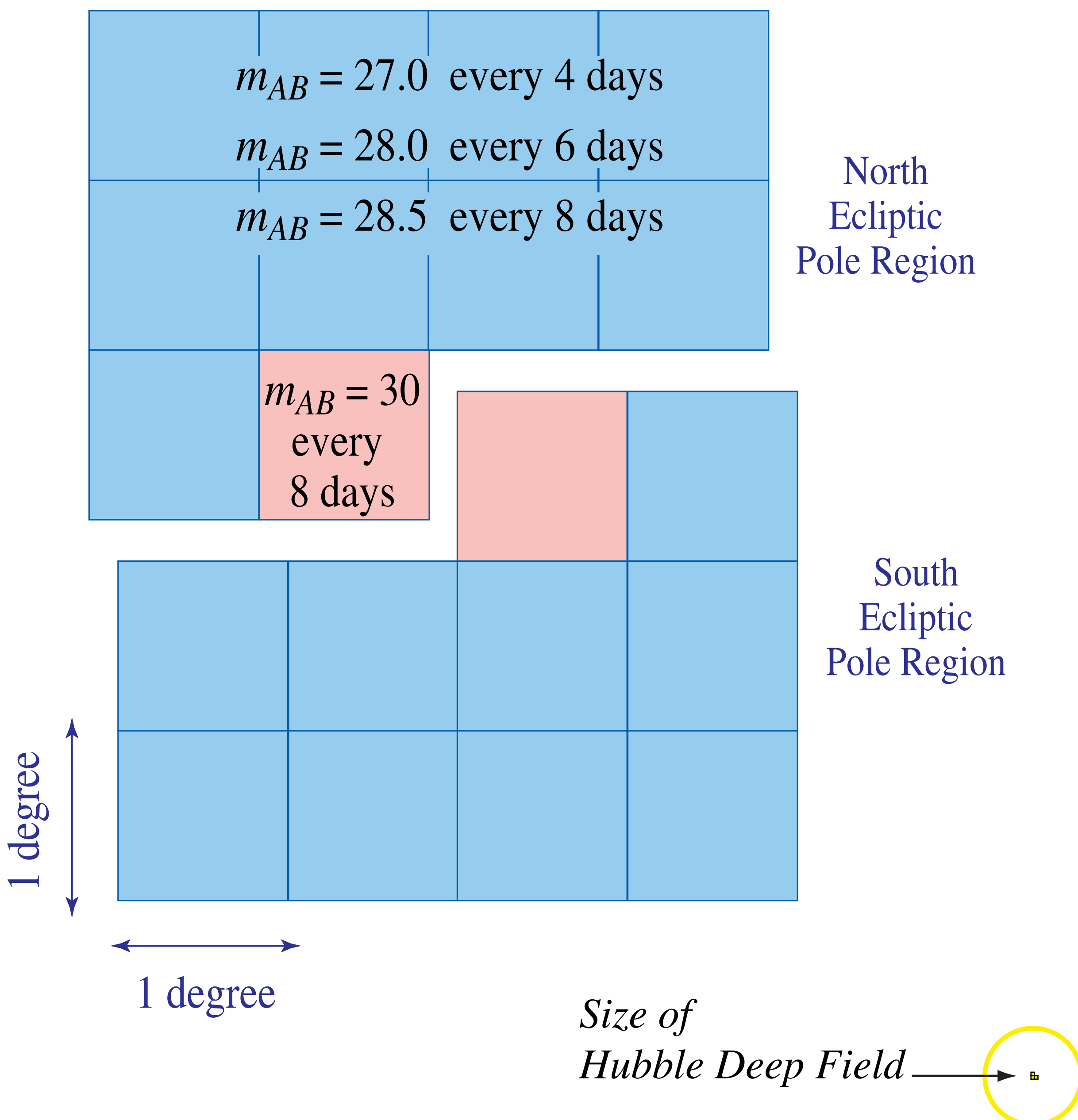
Designed to repeatedly observe an area of sky.

Essentially no moving parts.

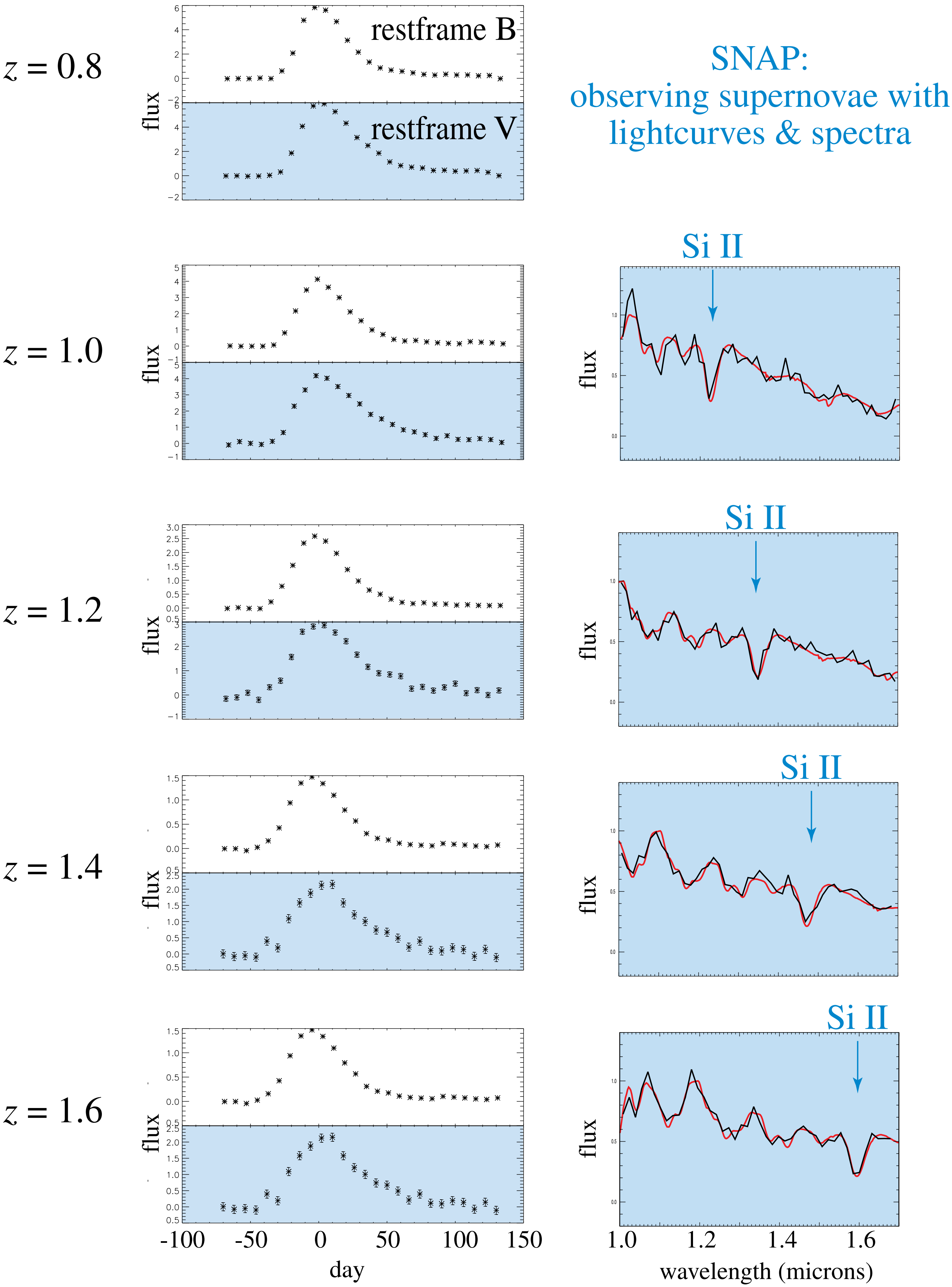
4-year construction cycle.
3-year operation for experiment
(lifetime open-ended).

SNAP SuperNova Acceleration Probe

Survey scale



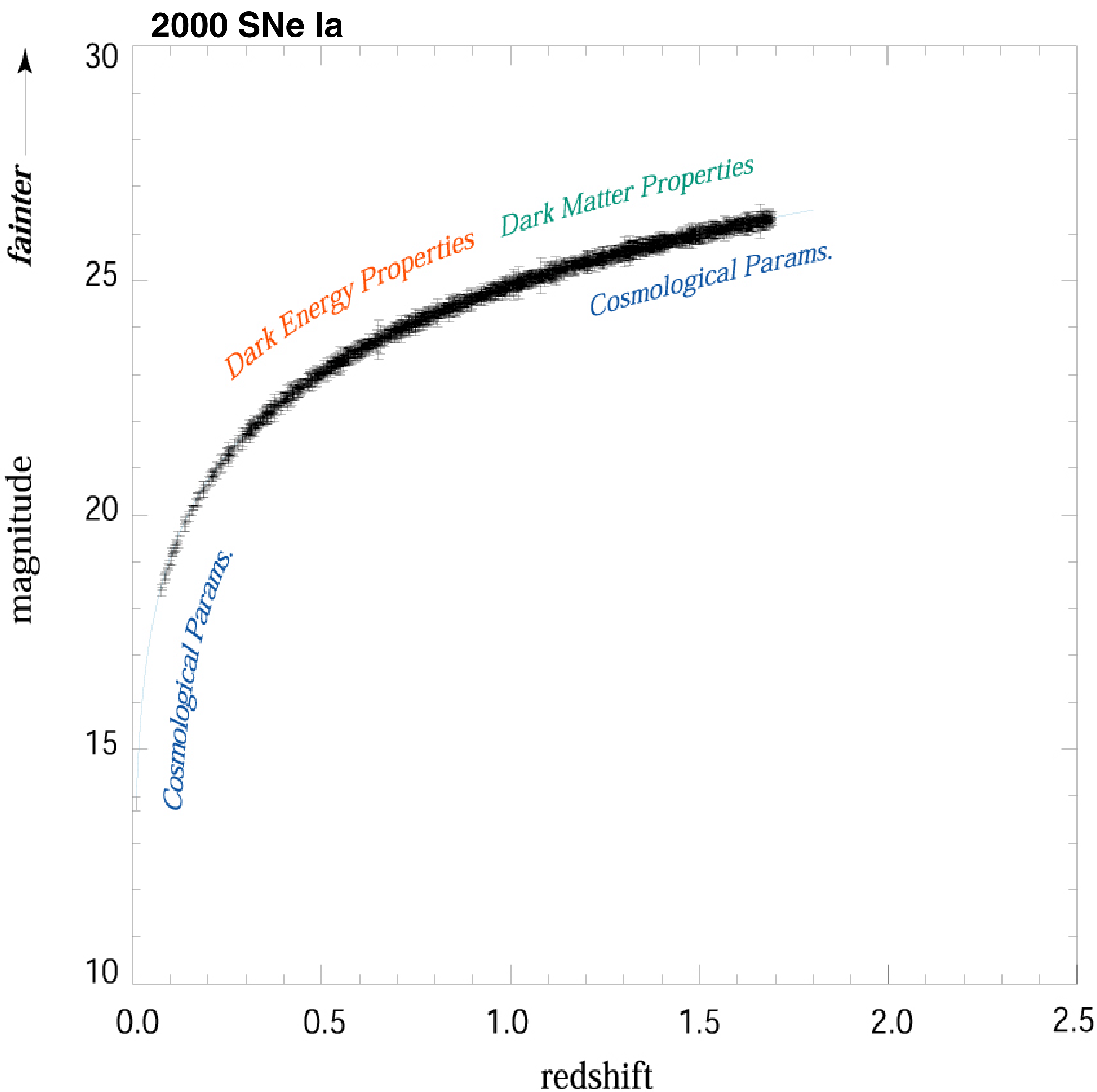
Co-added images: $\boldsymbol{m_{AB}} = 32.0$!

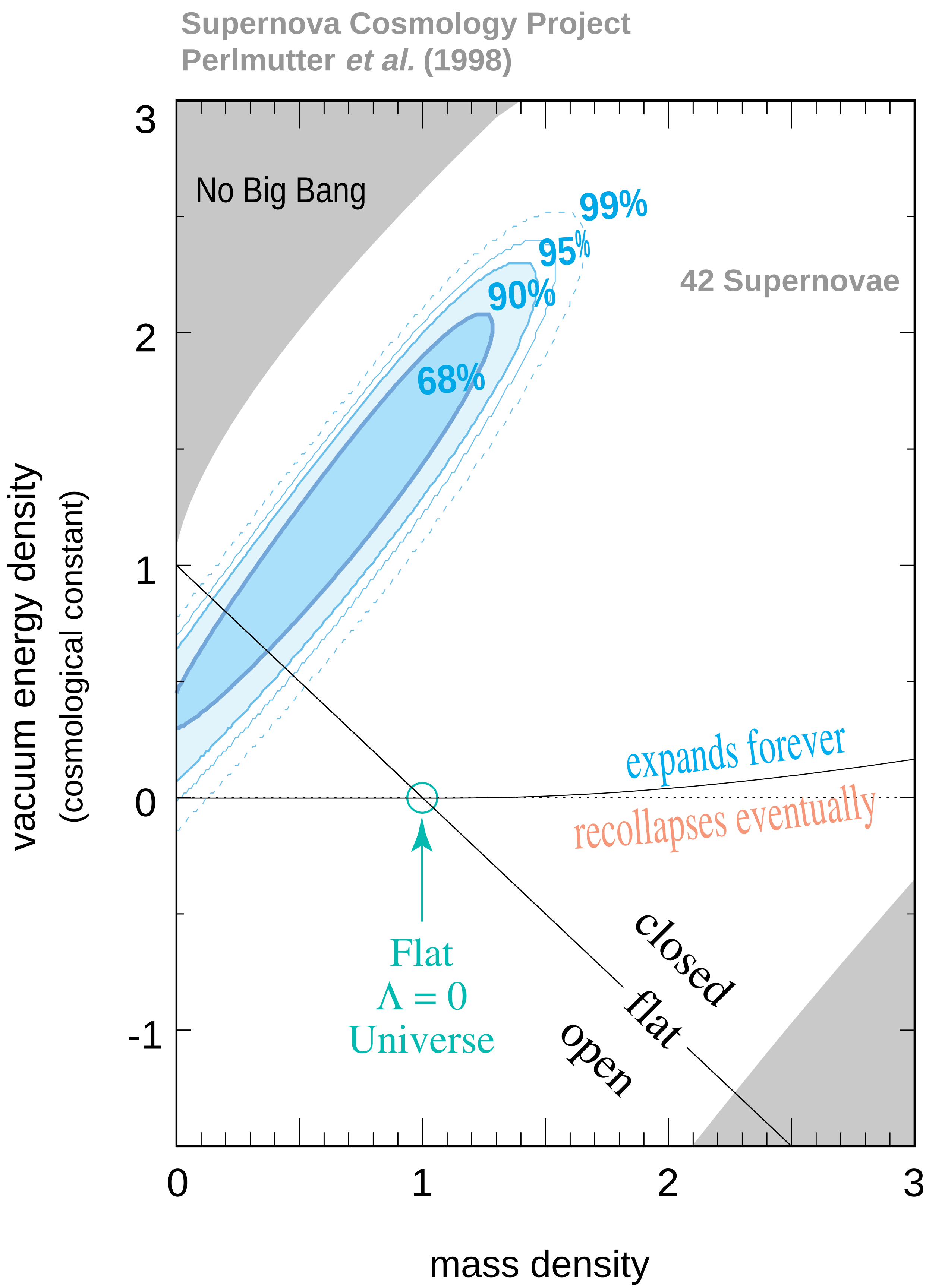


SNAP:
observing supernovae with
lightcurves & spectra
z = 0.8
z = 1.0
z = 1.2
z = 1.4
z = 1.6
restframe B
restframe V
flux
Si II
-100
-50
0
50
100
150
day
1.0
1.2
1.4
1.6
wavelength (microns)

SNAP SuperNova Acceleration Probe

Baseline One-Year Sample





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Λ = 0
Universe
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(cosmological constant)
mass density
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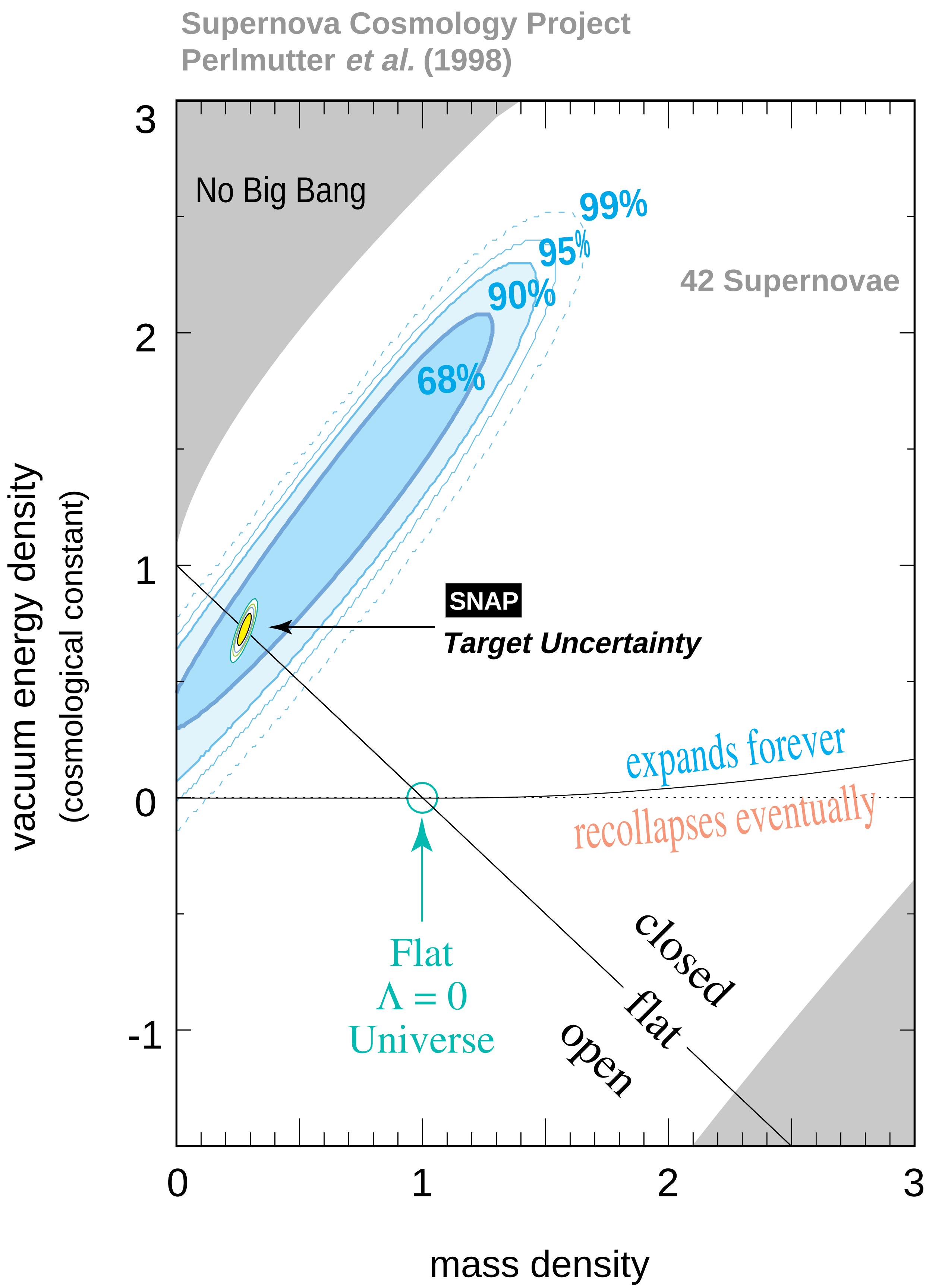
1
2
3



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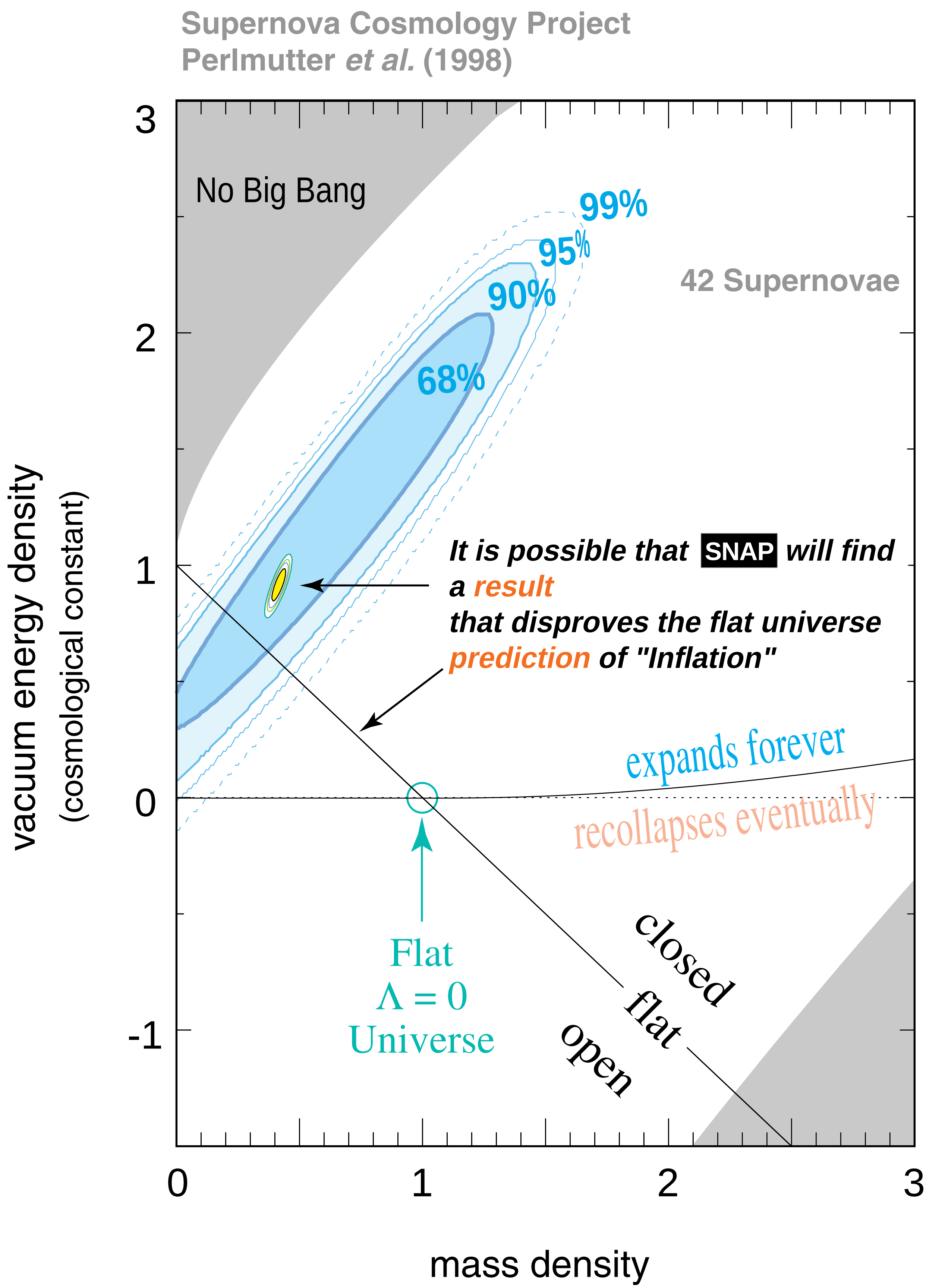

Supernova Cosmology Project
Perlmutter et al. (1998)
No Big Bang
99%
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68%
42 Supernovae
It is possible that SNAP will find a result that disproves the flat universe prediction of "Inflation"
expands forever
recollapses eventually
closed
flat
open
Flat
Λ = 0
Universe
vacuum energy density
(cosmological constant)
mass density
3
2
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0
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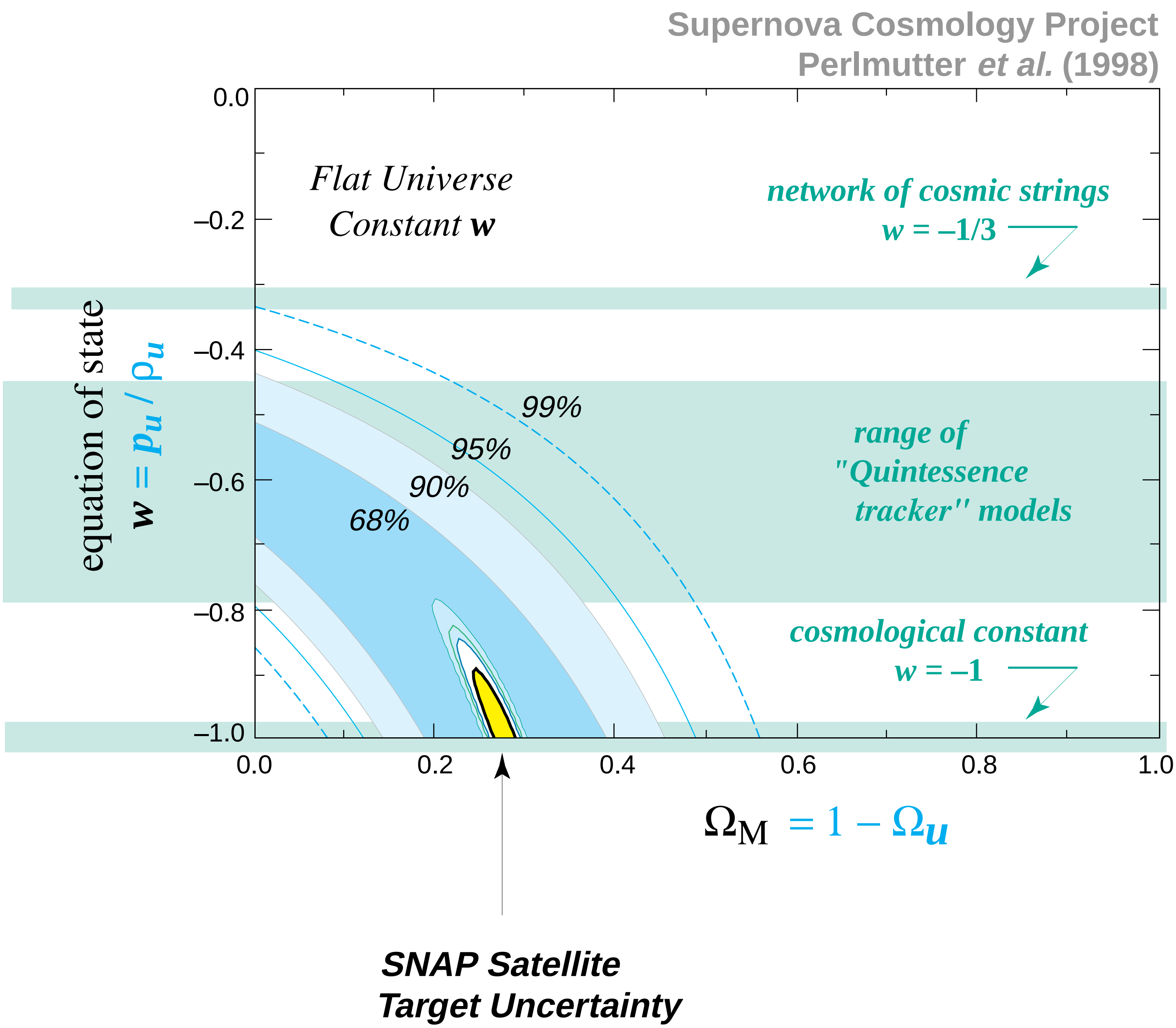
Dark Energy

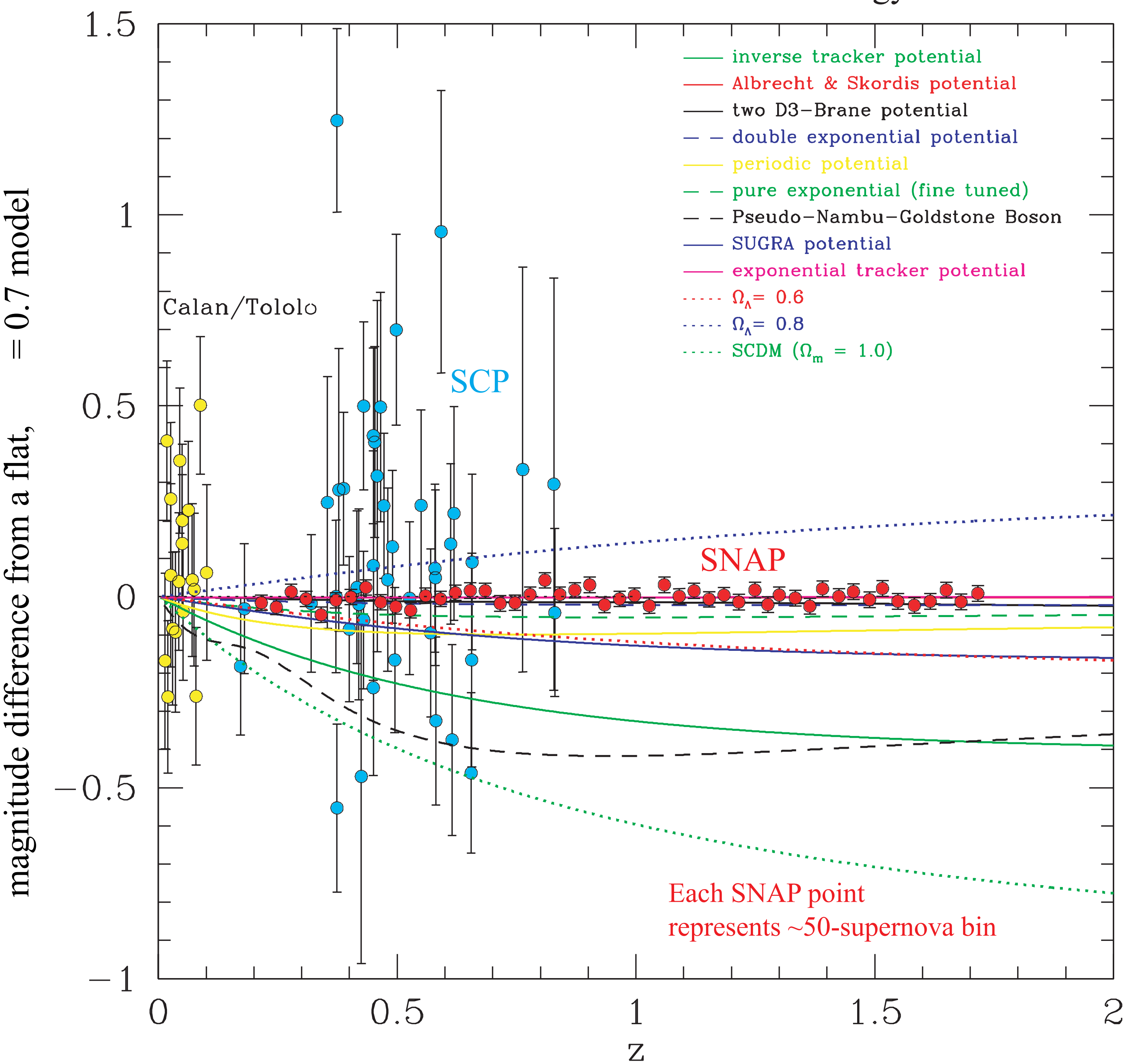
Unknown Component, Ω_u, of Energy Density



SNAP SuperNova Acceleration Probe

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

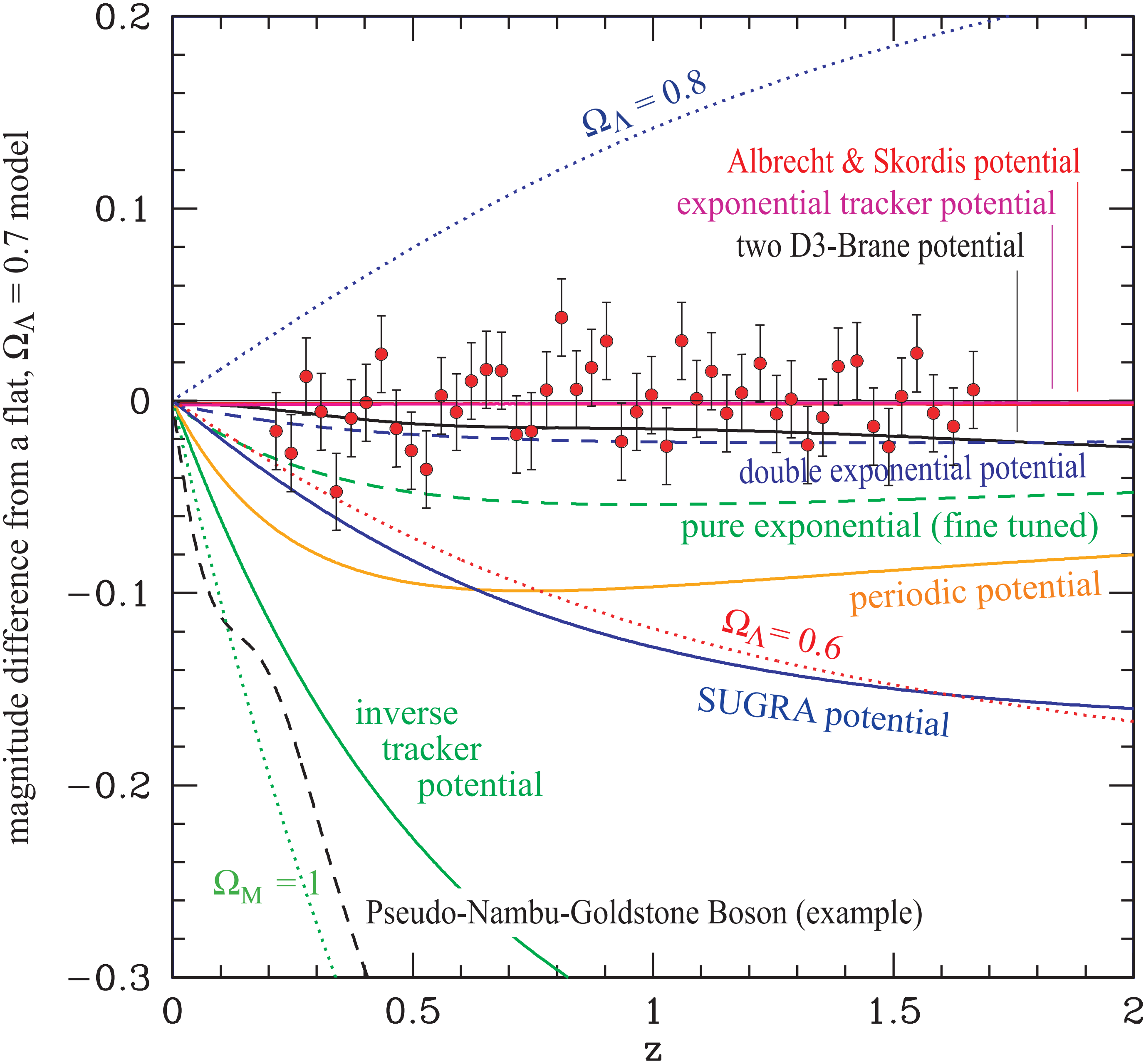
Dark Energy Models:



based on
Weller & Albrecht (2001)

SNAP SuperNova Acceleration Probe

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



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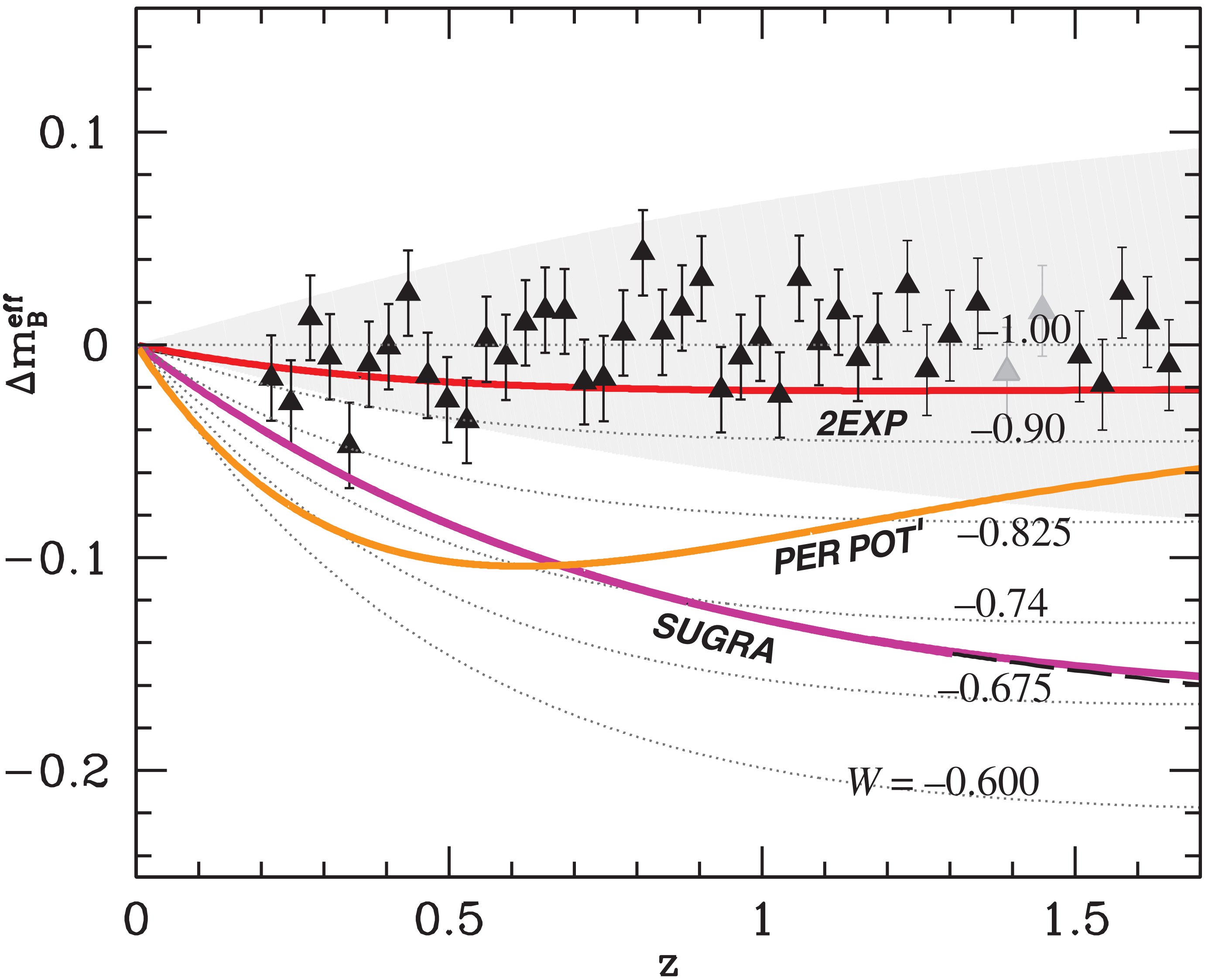

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SNAP SuperNova Acceleration Probe

Science Goals for The First Wide-field Survey in Space

Primary Cosmology Mission:
Cosmological Parameters, Dark Matter, Dark Energy,...

Type Ia supernova calibrated candle:
Hubble diagram to $z = 1.7$

Type II supernova expanding photosphere:
Hubble diagram to $z = 1$ and beyond.

Weak lensing:
Direct measurements of $P(k)$ vs z
Mass selected cluster survey vs z

Strong lensing statistics: Ω_Λ
10x gains over ground based optical resolution, IR channels + depth.

Galaxy clustering:
$W(\Theta)$ angular correlation vs redshift from 0.5 to 3.0

Weak Lensing Material

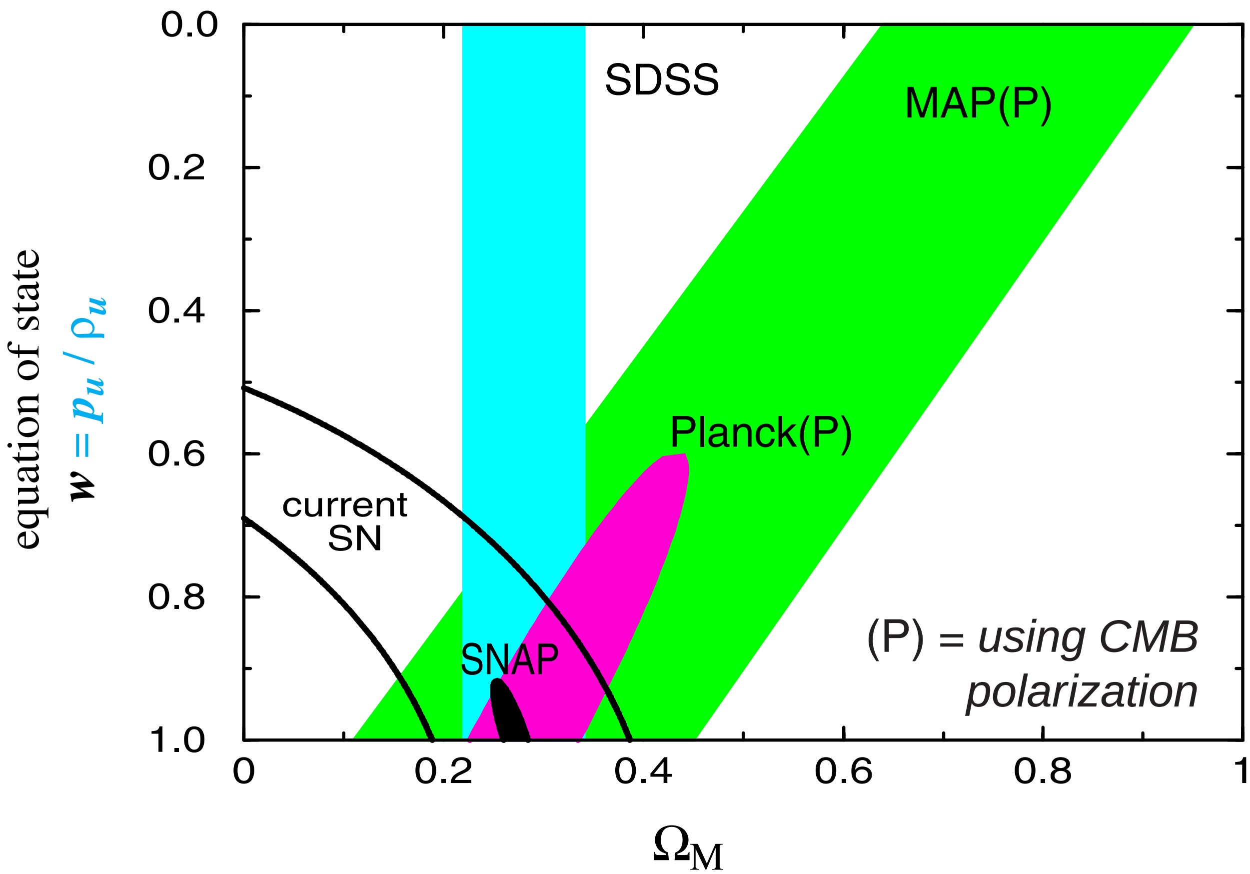
Recap of Science Reach

Science Prerequisites are the systematics

the identification of tools to constrain evolution

SNAP SuperNova Acceleration Probe

Expected cosmological measurements at time of SNAP results



Other cosmological measurement approaches

Weak Lensing*

Number Counts, $N(z)$

clusters*

galaxies

-- selected by rotation velocity

S-Z angular size

*SNAP measurements using this approach

Score Card of Current Uncertainties

on $(\Omega_{M}^{flat}, \Omega_{\Lambda}^{flat}) = (0.28, 0.72)$

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? clumpy

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shifting distribution of

prog mass/metallicity/C-O/..

K-correction uncertainty < 0.025

including zero-points

Total ***0.05***

identified entities/processes

Cross-Checks of sensitivity to

Width-Luminosity Relation < 0.03

Non-SN Ia contamination < 0.05

Galactic Extinction Model < 0.04

Gravitational Lensing < 0.06

by clumped mass

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

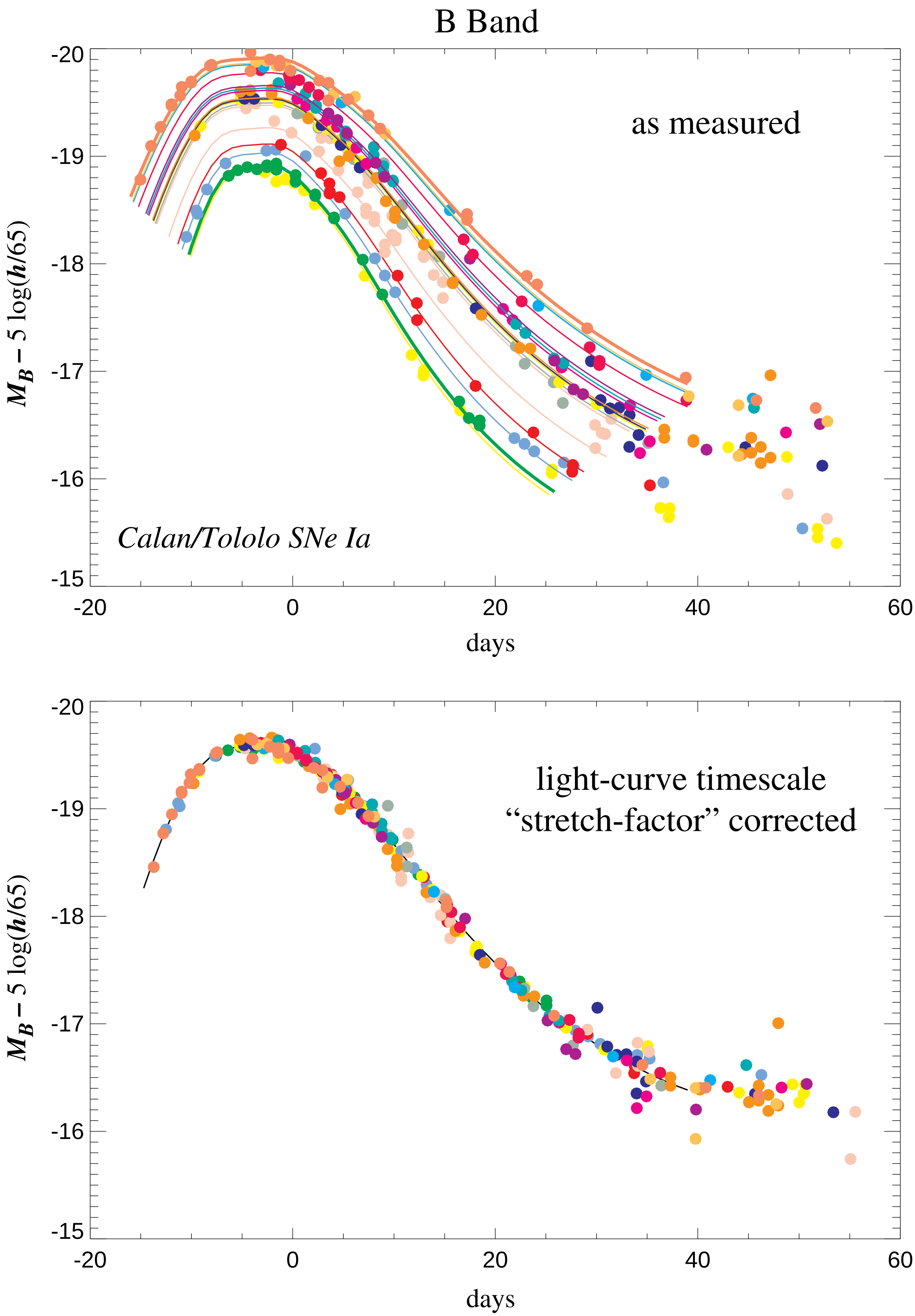
Identified Systematic Uncertainties become Negligible or Statistical Uncertainties

Systematic	Current δM	Requirement to satisfy $\delta M < 0.02$
Malmquist bias	0.04	Detection of every supernova well below peak over entire redshift range
K-Correction and Cross-Filter Calibration	0.03	Spectral time series of representative SN Ia and cross-wavelength relative flux calibration
Non-SN Ia Contamination	< 0.05	Spectrum for every supernova at maximum covering the rest frame Si II 6150Å feature
Milky Way Galaxy extinction	< 0.04	SDSS & SIRTF observations; SNAP spectra of Galactic subdwarfs
Gravitational lensing by clumped mass	< 0.06	Average out the effect with large statistics ($\sim$ 75 SNe Ia per 0.03 redshift bin). SNAP microlensing measurements.
Extinction by "ordinary" dust outside the Milky Way	0.03+	Optical+NIR calibrated spectra to observe wavelength dependent absorption

SNAP SuperNova Acceleration Probe

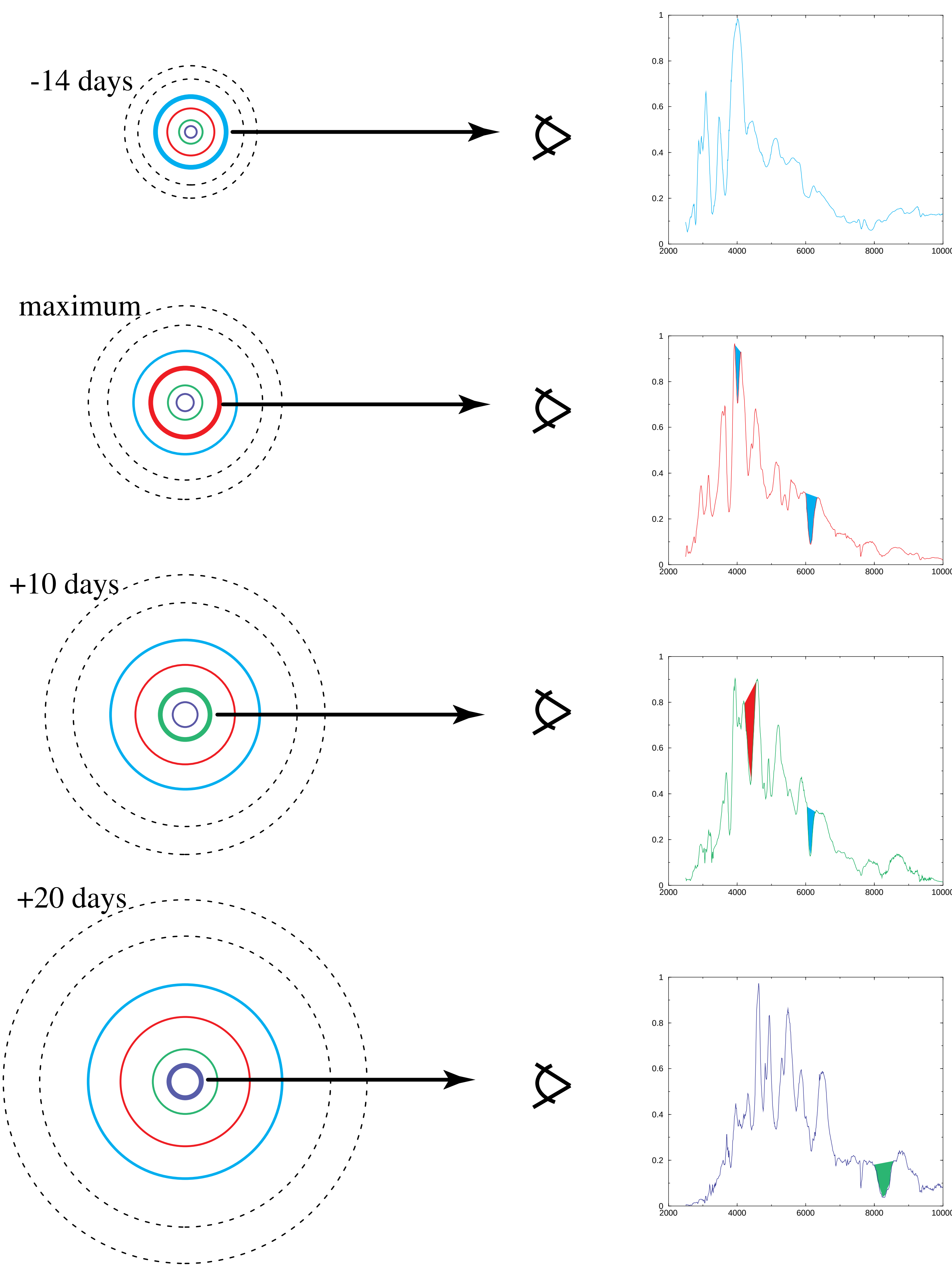
What makes the supernova measurement special?
Control of systematic uncertainties.

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

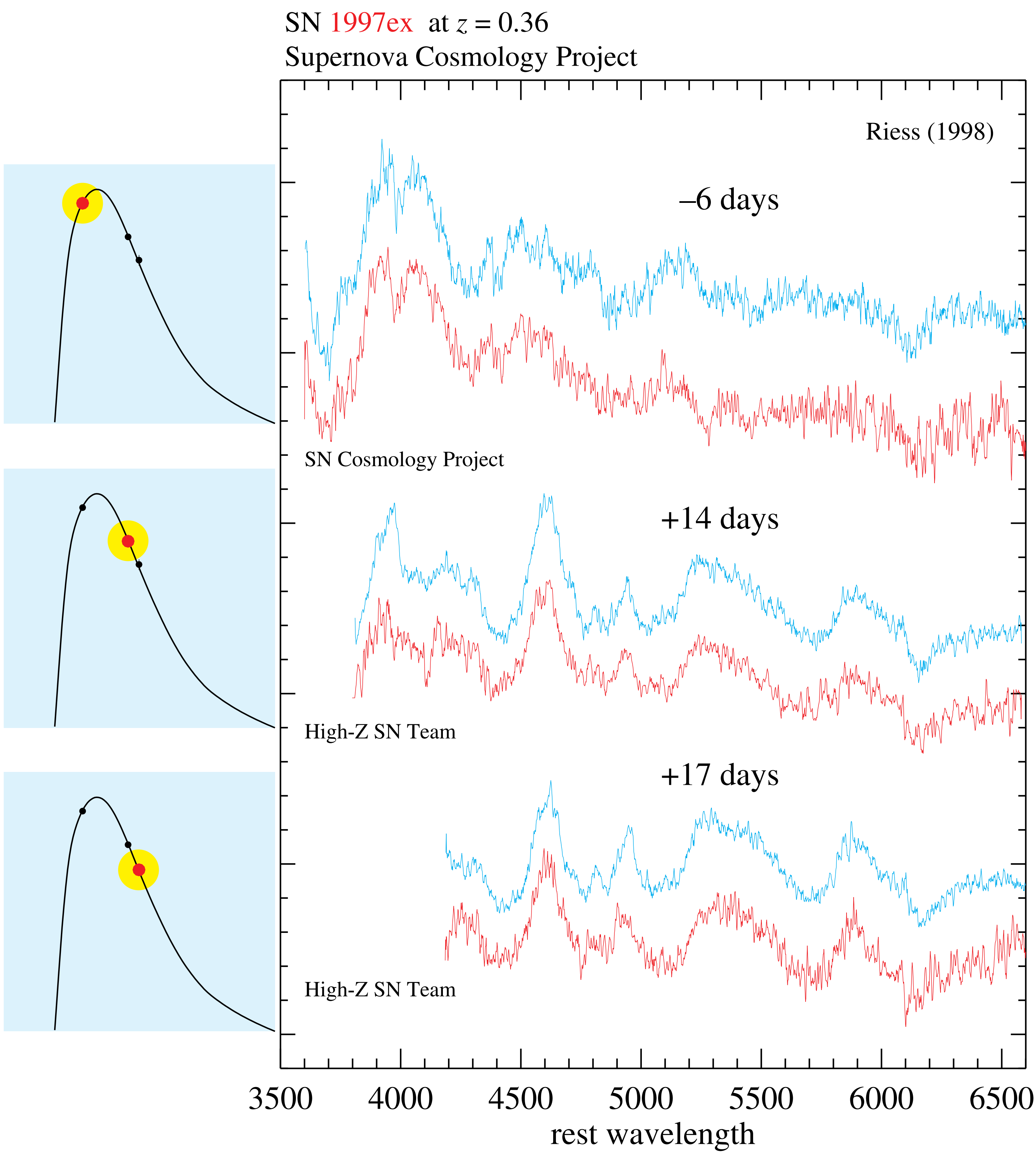


Kim, *et al.* (1997)

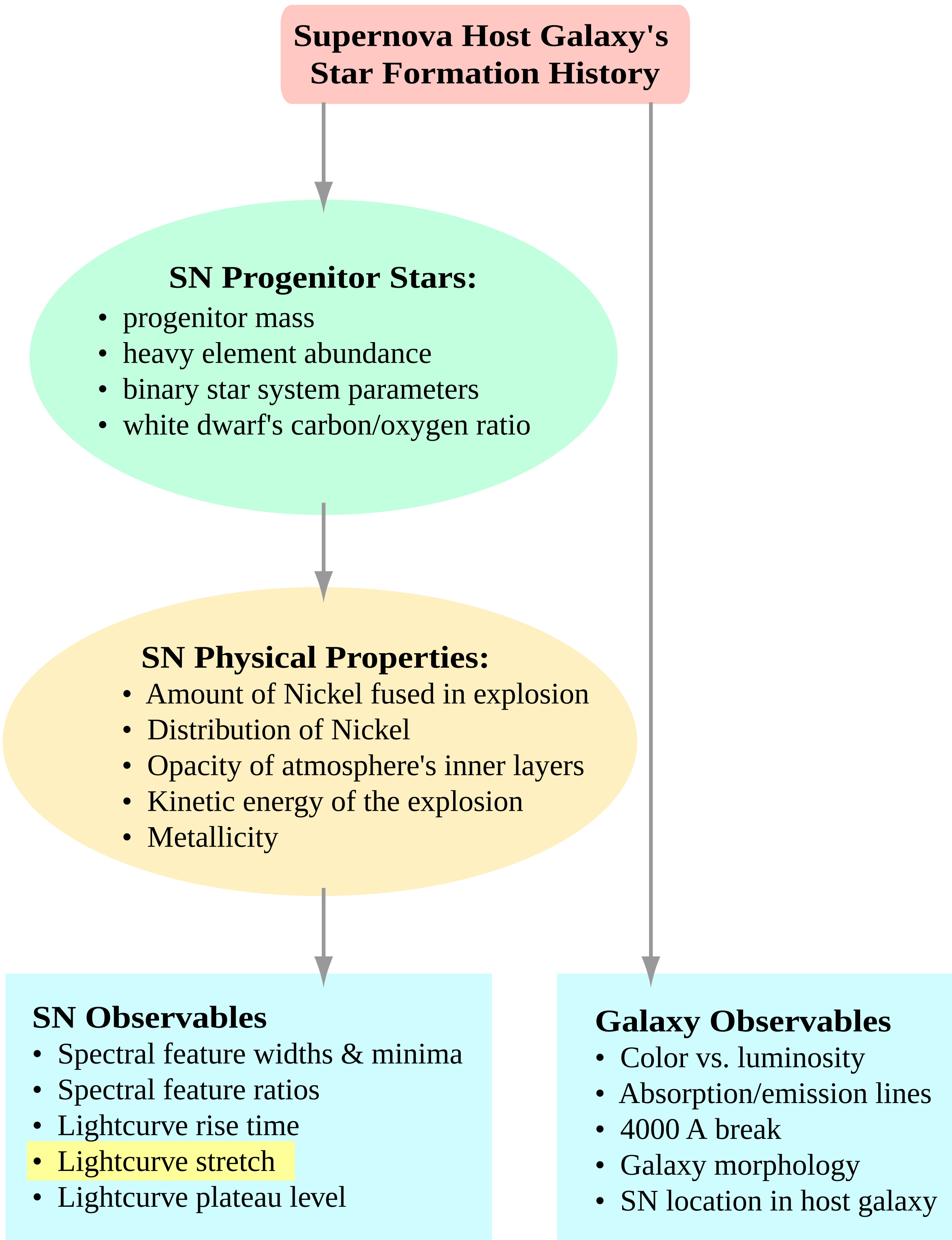
The time series of spectra is a “CAT Scan” of the Supernova



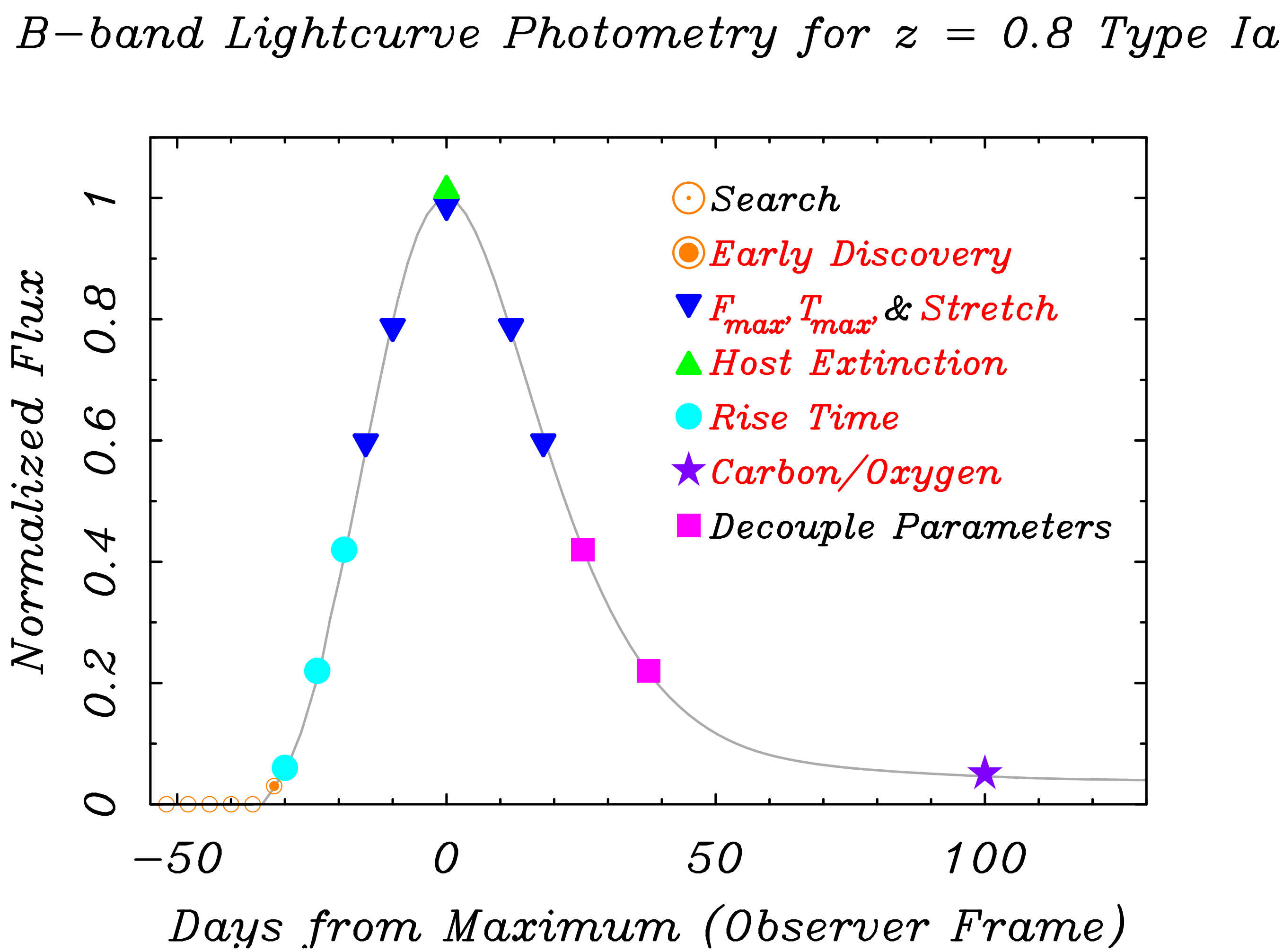
Time Series of Low-Redshift and High-Redshift Spectra



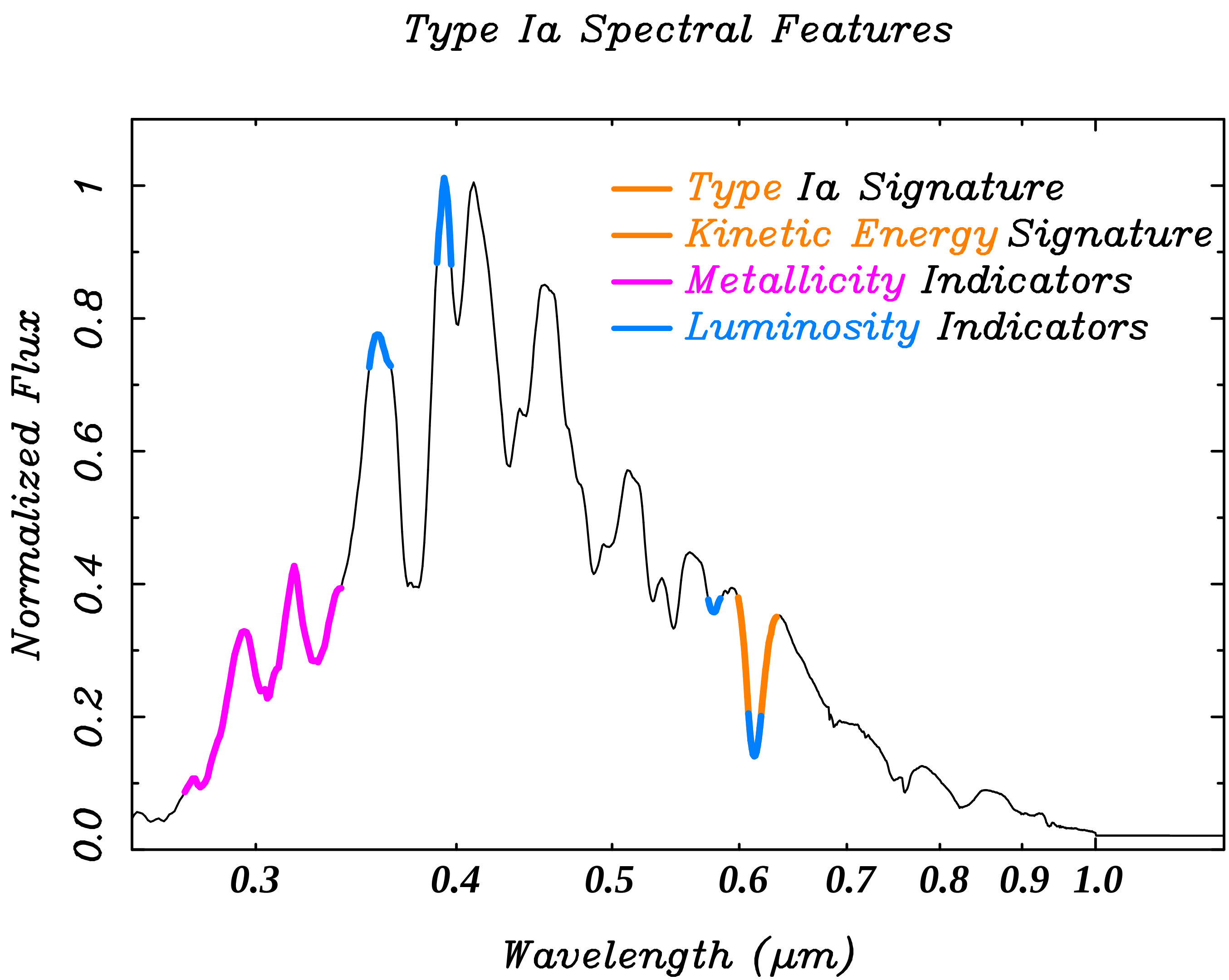
Control of Evolution Systematics: Matching Supernovae



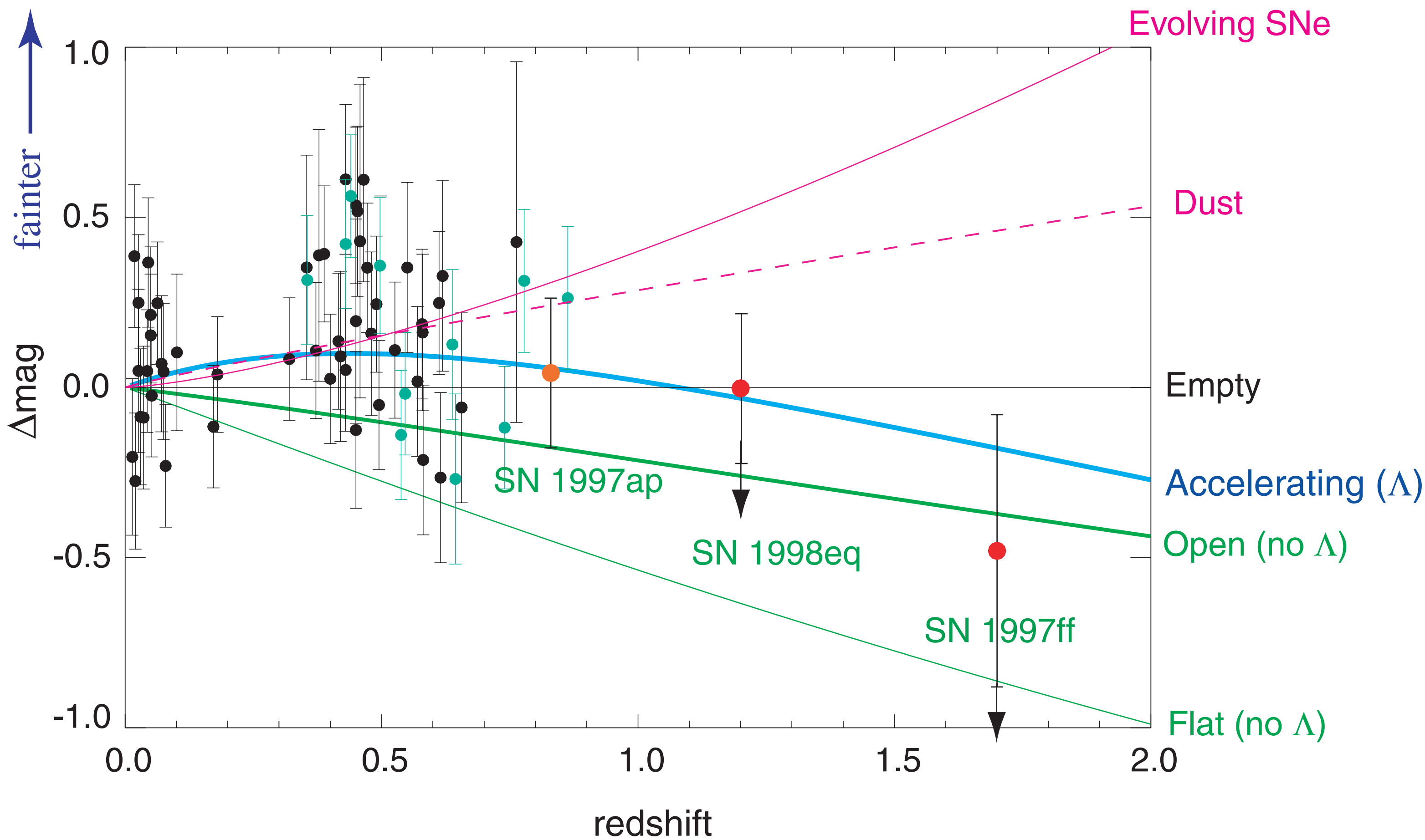
SuperNova Acceleration Probe



SNAP SuperNova Acceleration Probe



Supernovae probing
the *deceleration* era
with NICMOS



Additional Material

SNAP SuperNova Acceleration Probe

First-principles comparison: space vs. ground

		SNAP	LSST/DMT	Space / Ground Efficiency Ratio	
Telescope Aperture	D	**2 m**	**6.5 m**	$\left(\frac{D_{space}}{D_{ground}}\right)^2 =$	**1/10**
Seeing (RMS avg)	σ	**0.1''**	**0.5''**	$\left(\frac{\sigma_{space}}{\sigma_{ground}}\right)^{-2} =$	**25**
Sundown Fraction	f	**98%**	**40%**	$\frac{f_{space}}{f_{ground}} =$	**2.5**
Field size (solid angle)	Ω_{field}	**1 sq-deg**	**7 sq-deg**	$\frac{\Omega_{space}}{\Omega_{ground}} =$	**1/7**
Sky background (n_γ)	Σ_B Σ_V Σ_R Σ_I Σ_Z Σ_J	4.1×10^{-7} 4.8×10^{-7} 4.9×10^{-7} 4.6×10^{-7} 4.0×10^{-7} 3.1×10^{-7}	4.7×10^{-6} 3.6×10^{-6} 4.4×10^{-6} 7.8×10^{-6} 2.0×10^{-5} 1.3×10^{-4}	$\left(\frac{\Sigma_{space}}{\Sigma_{ground}}\right)^{-1} =$	11 7 9 17 50 441

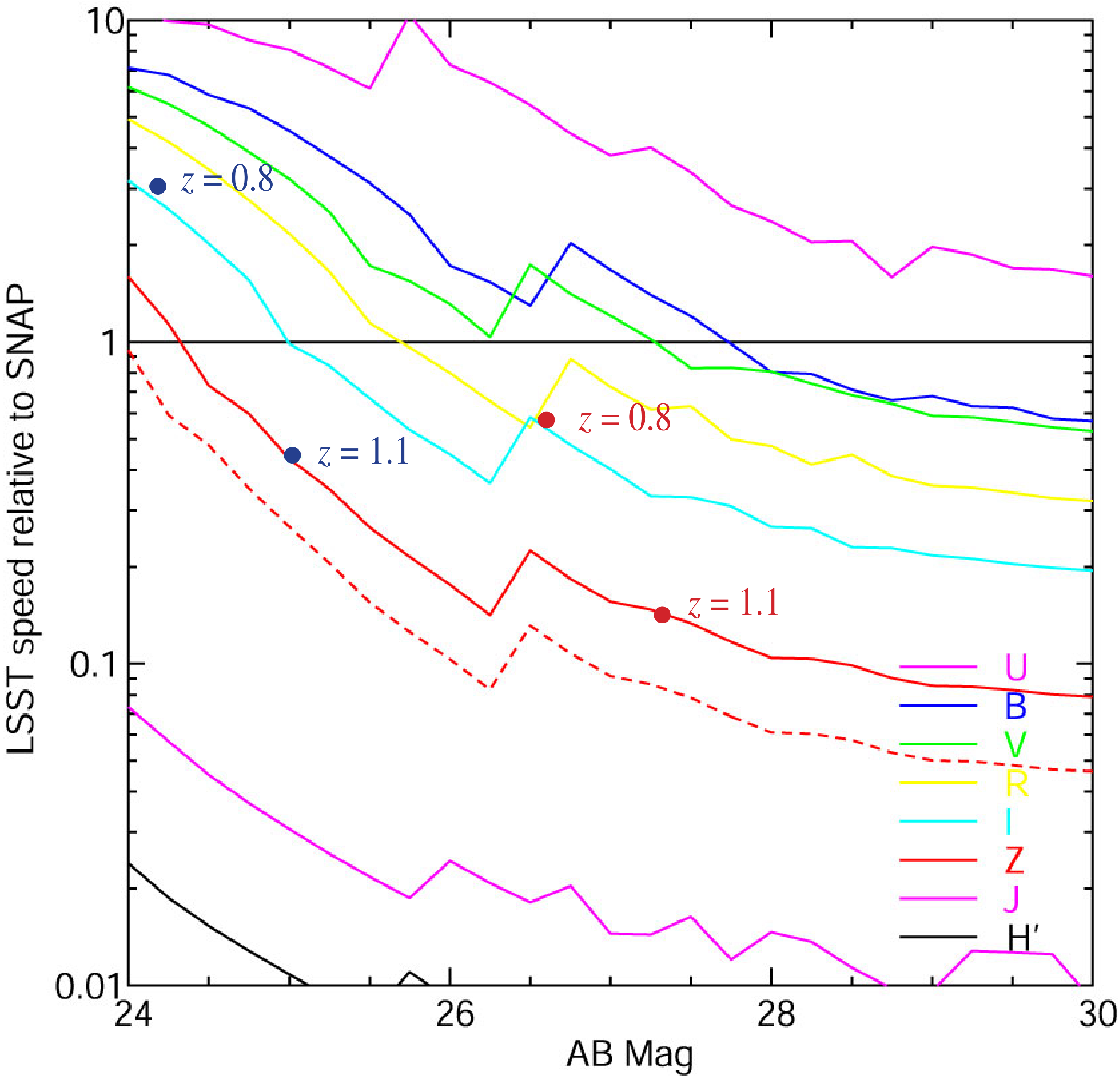
Multi-object photometry & discovery

 # SNe measured
at a given s/n
in a given time
(for sky-noise limited case):

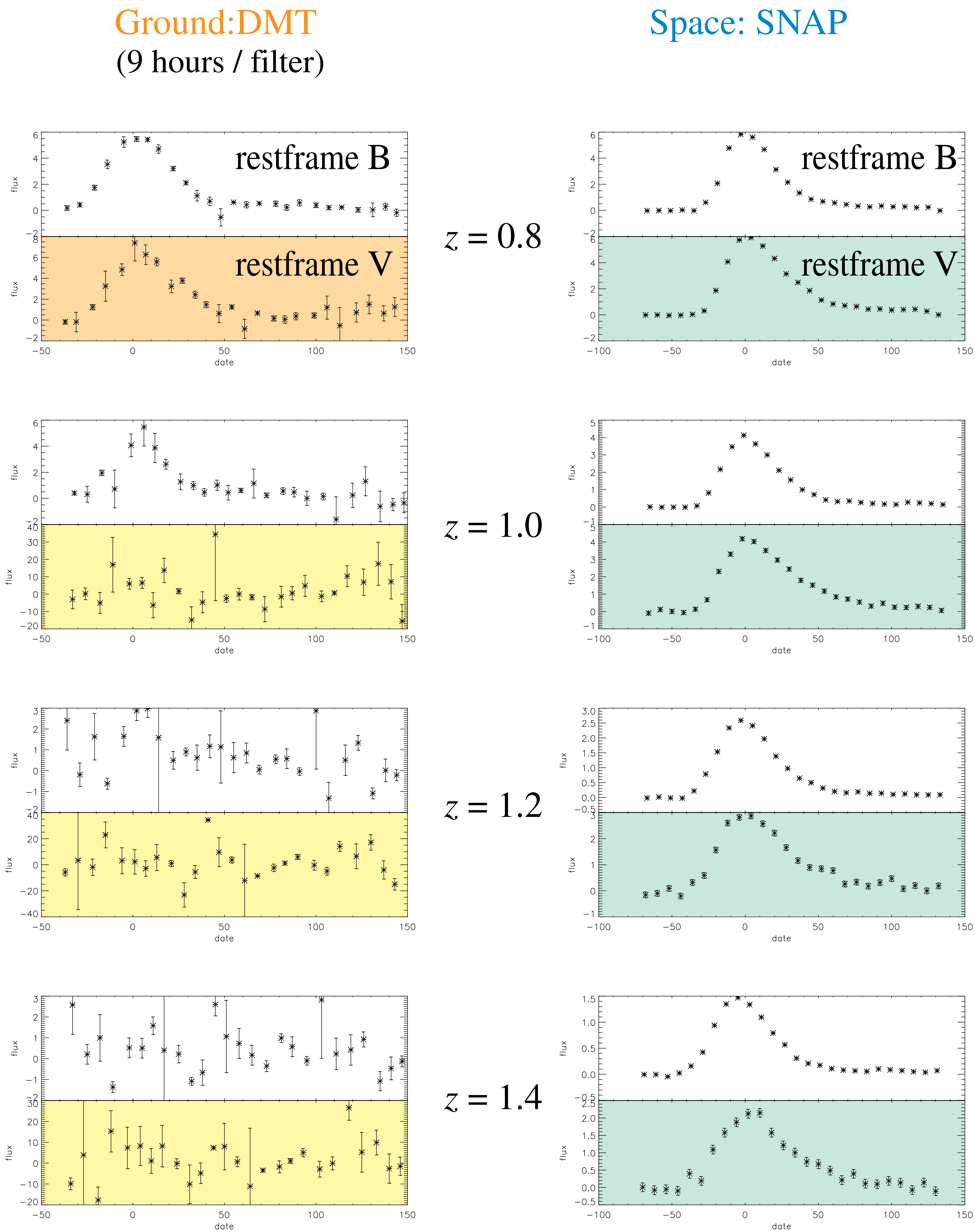
$$\propto \frac{D^2\, f\, \Omega_{field}}{\sigma^2\, \Sigma} \qquad \sim\Sigma^{-1}$$

SNAP SuperNova Acceleration Probe

Supernova survey efficiency for SNAP and LSST

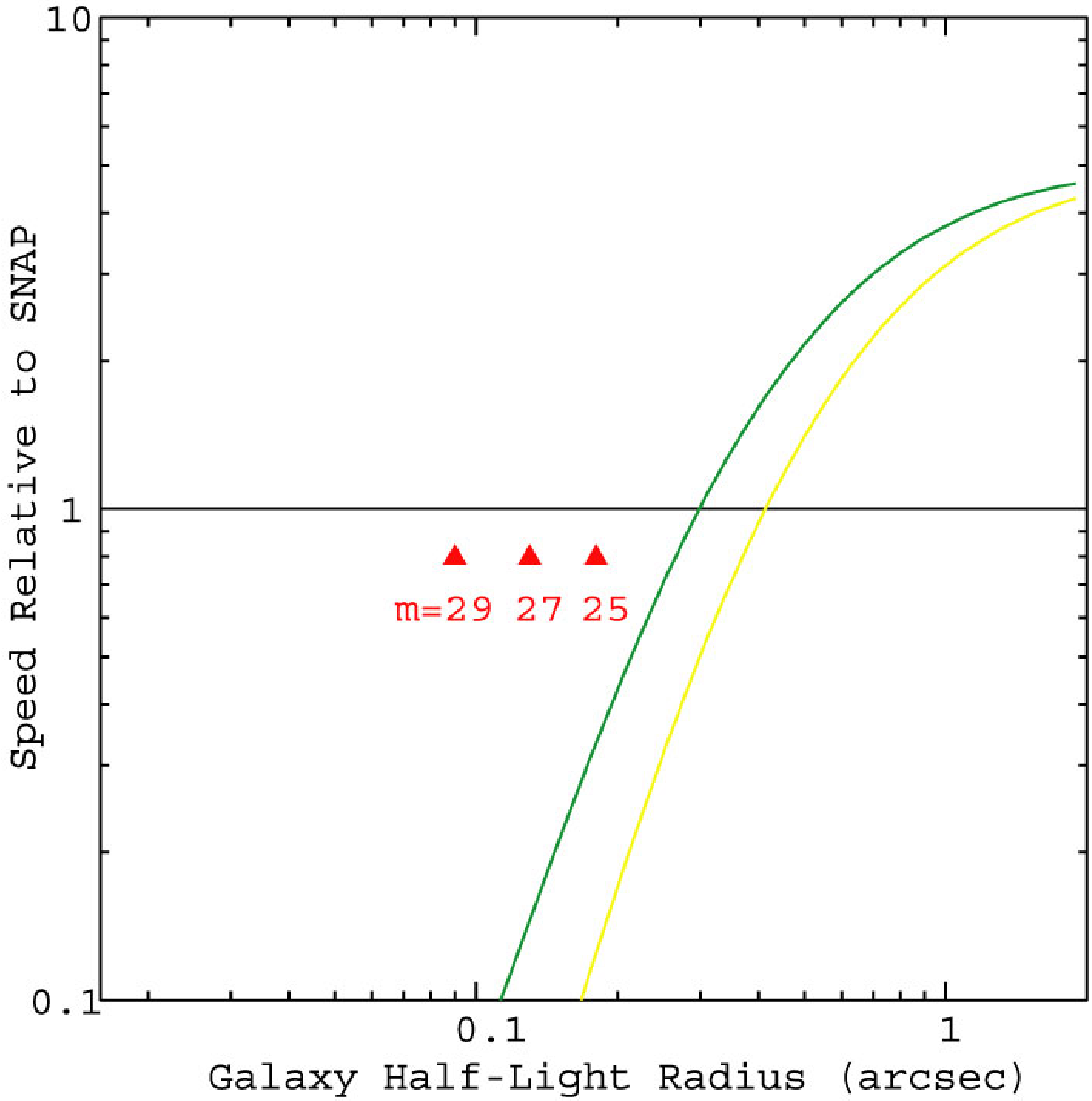


- Brightness and B band wavelength of Sne Ia at peak
- Discovery brightness to prevent Malmquist bias


Ground:DMT
(9 hours / filter)
Space: SNAP
restframe B
restframe V
restframe B
restframe V
z = 0.8
z = 1.0
z = 1.2
z = 1.4
flux
date

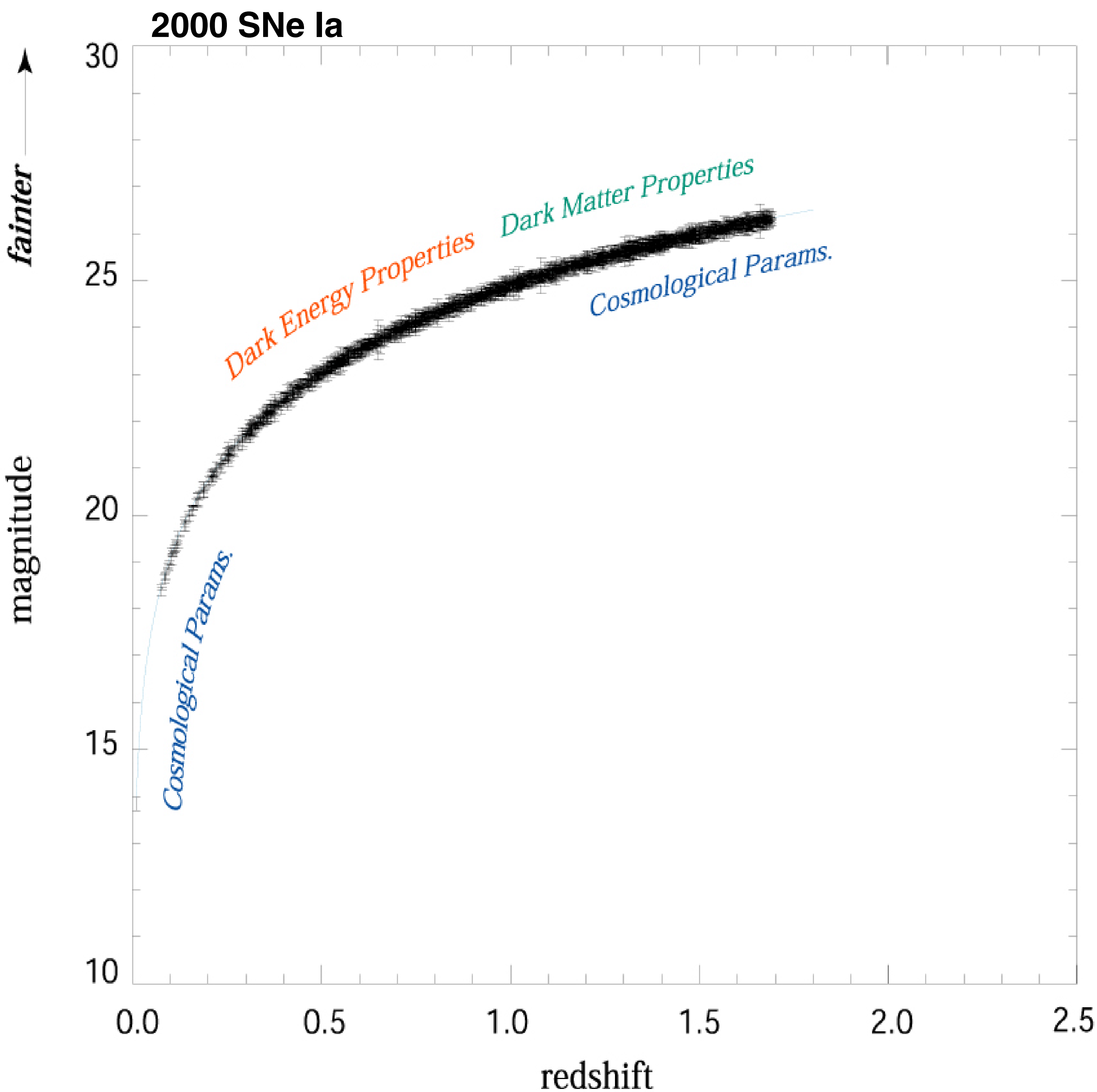
SNAP SuperNova Acceleration Probe

Survey Speed for Weak Lensing
Relative to SNAP



SNAP SuperNova Acceleration Probe

Baseline One-Year Sample



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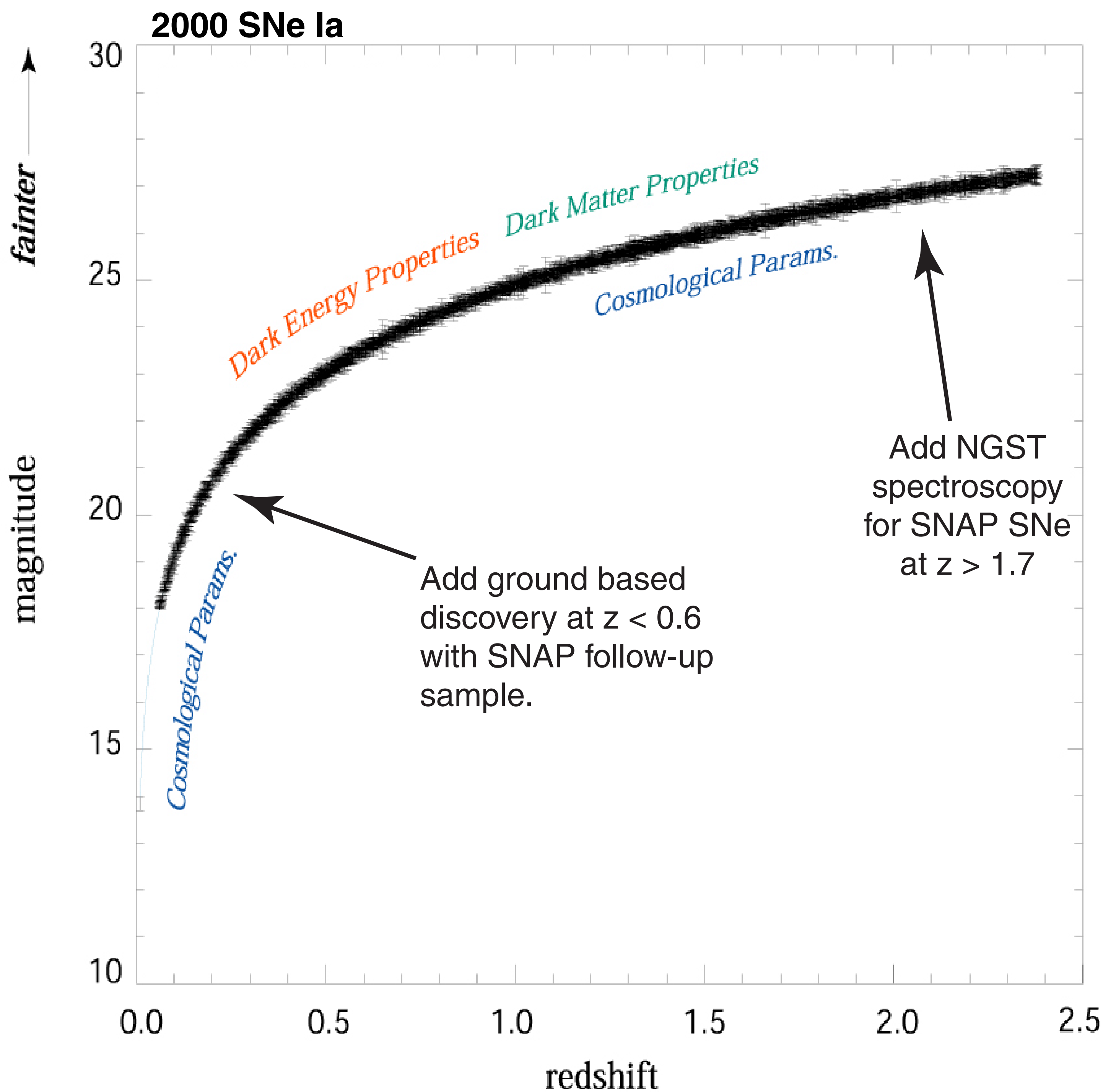

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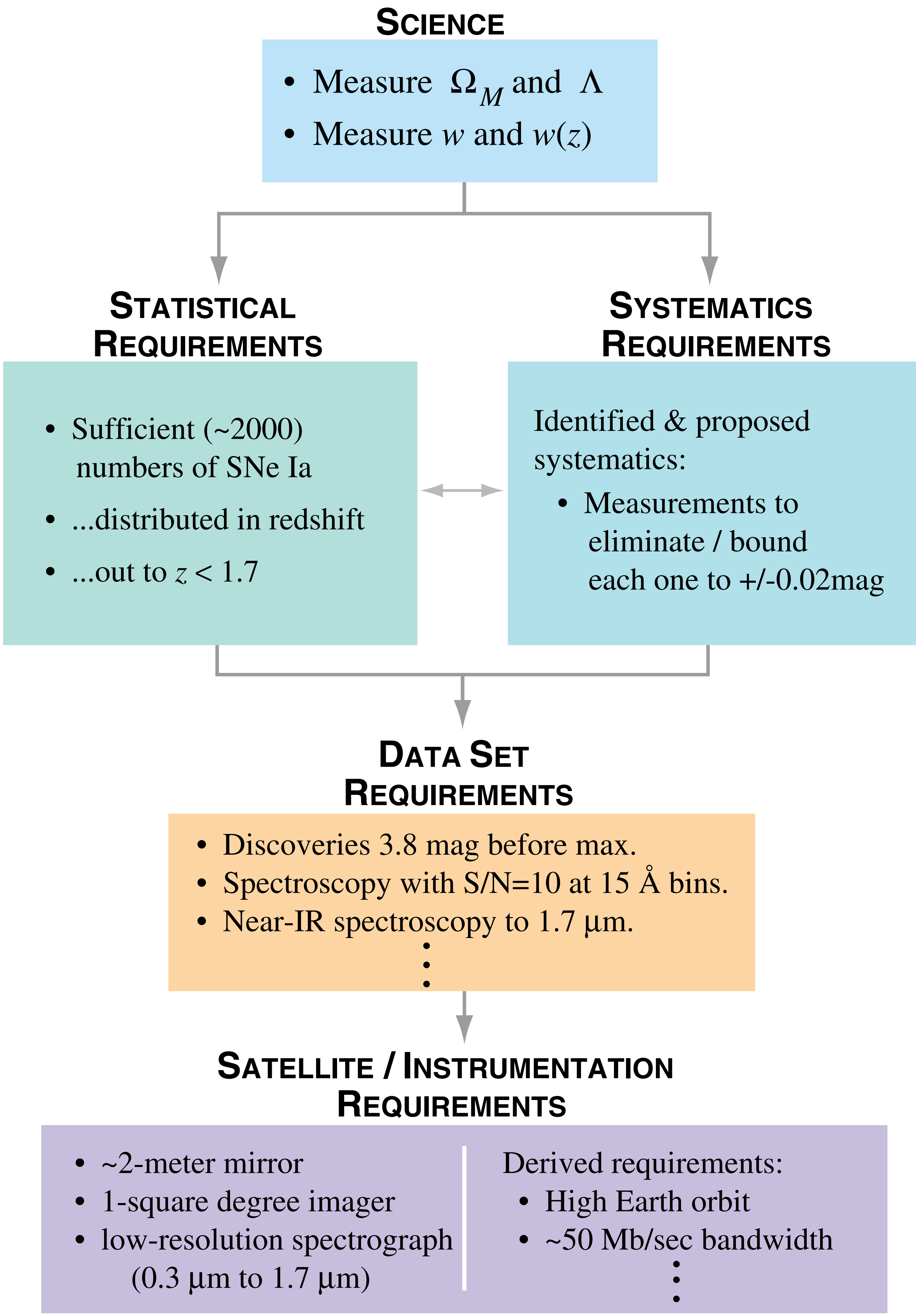

SCIENCE
• Measure Ω_M and Λ
• Measure w and $w(z)$
STATISTICAL REQUIREMENTS
• Sufficient (~2000) numbers of SNe Ia
• ...distributed in redshift
• ...out to $z < 1.7$
SYSTEMATICS REQUIREMENTS
Identified & proposed systematics:
• Measurements to eliminate / bound each one to +/-0.02mag
DATA SET REQUIREMENTS
• 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
• low-resolution spectrograph (0.3 μm to 1.7 μm)
Derived requirements:
• High Earth orbit
• ~50 Mb/sec bandwidth
⋮

Observatory

Simple Observatory consists of :

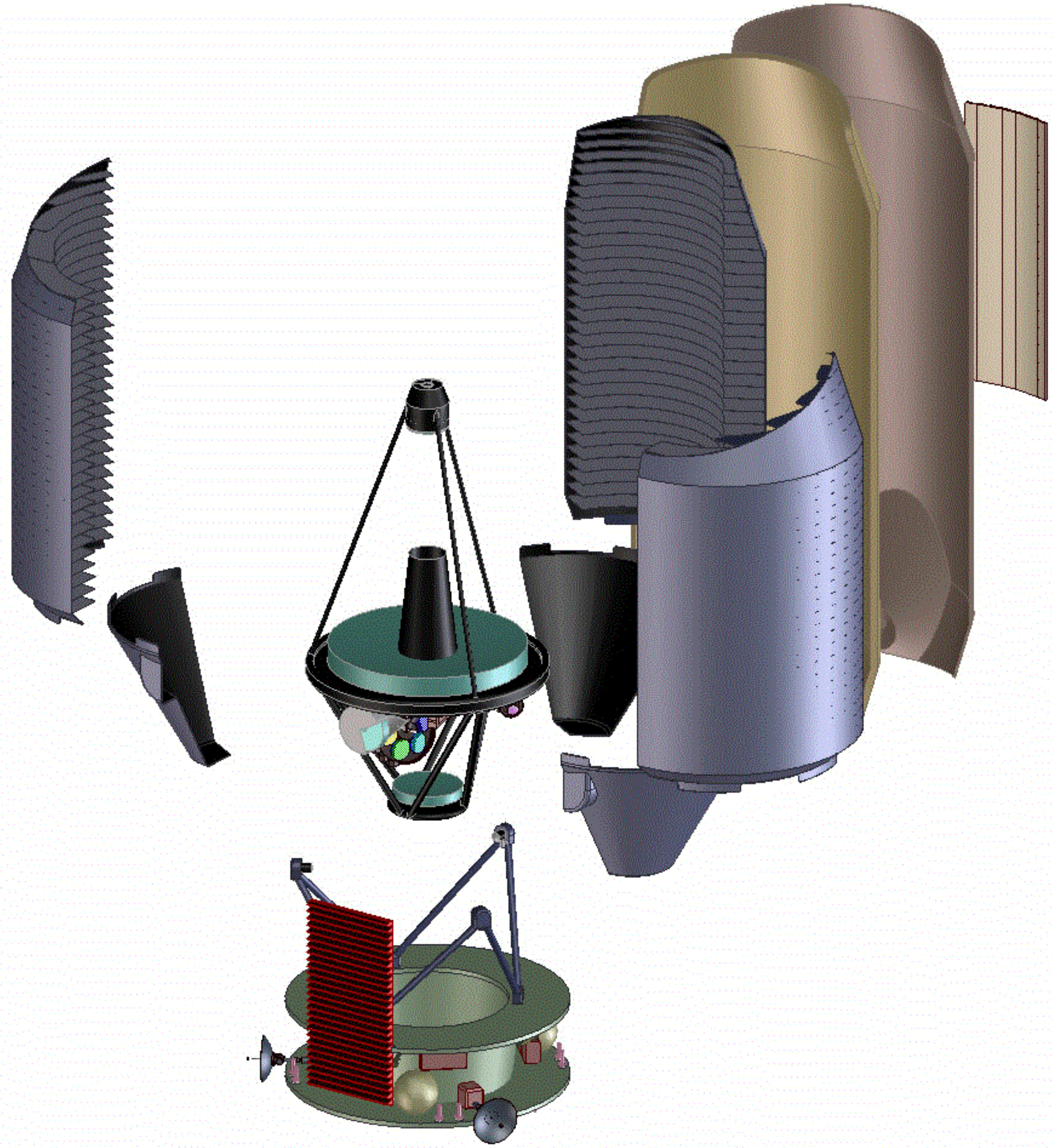
1) 3 mirror telescope w/ separable kinematic mount

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.



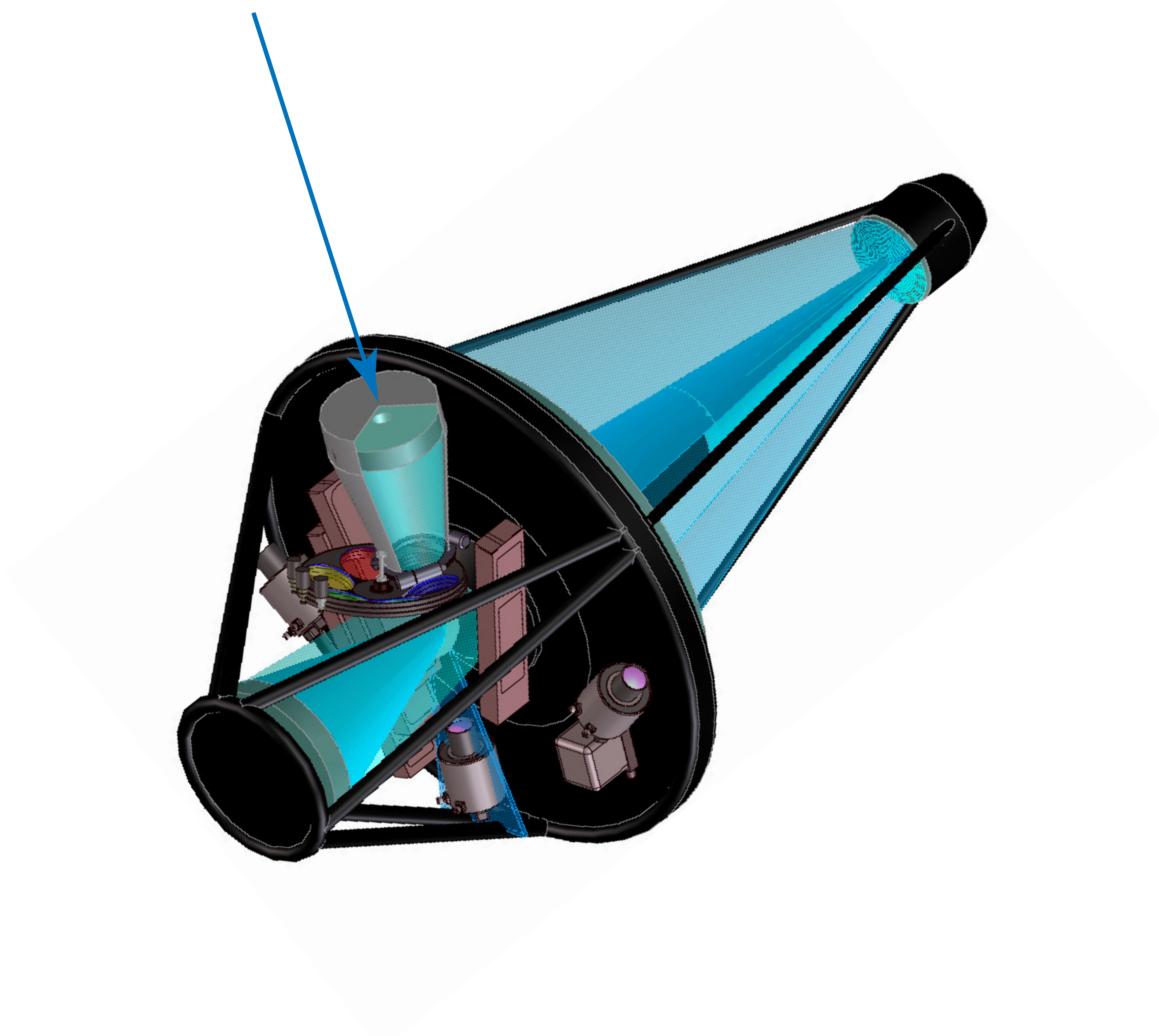
SNAP SuperNova Acceleration Probe

instrumentation

GigaCam Imager & **Spectrograph**

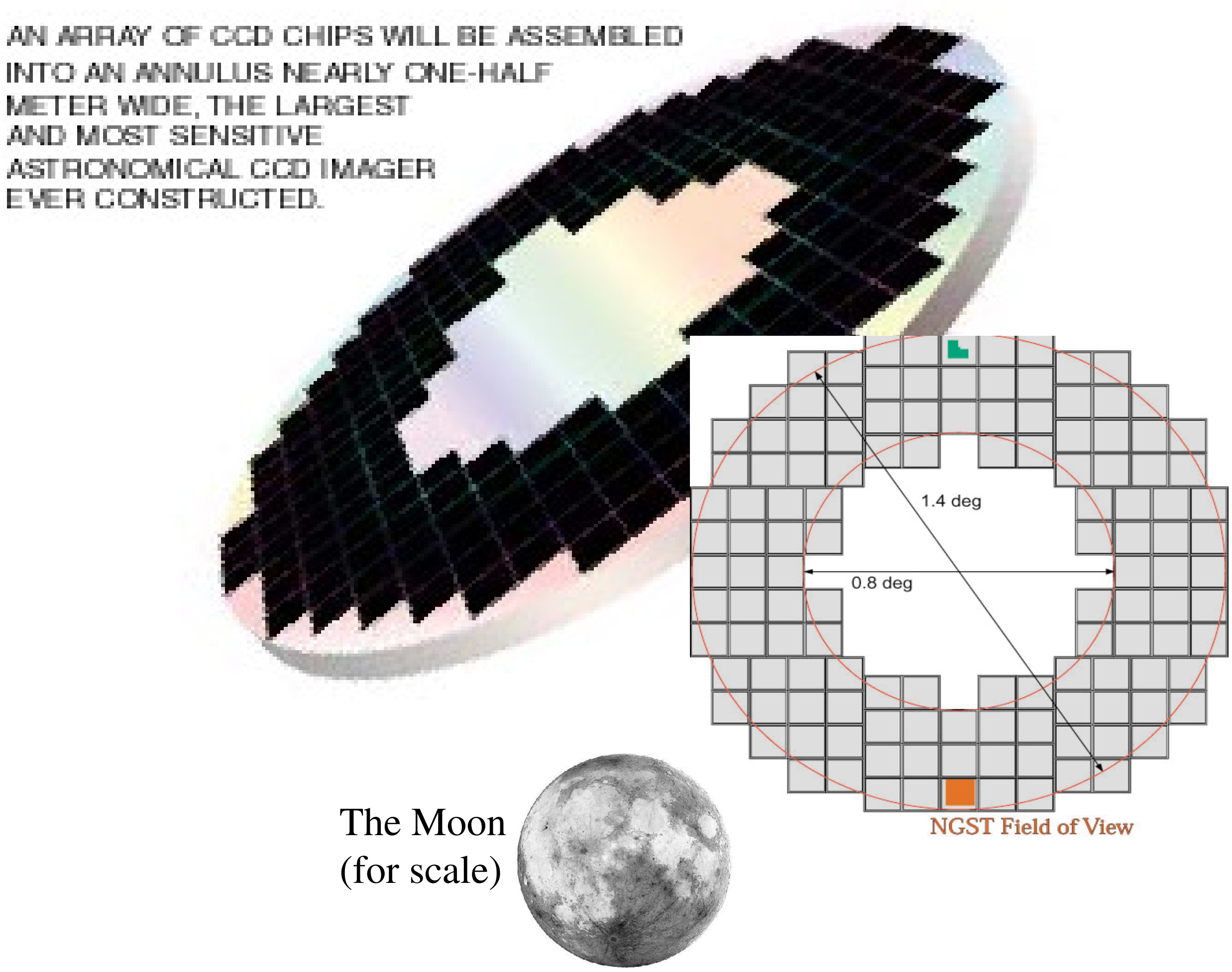
1 square degree field of view
128 3k x 3k CCD's
+ HgCdTe

low resolution
high throughput
350 nm -- 1700 nm



GigaCAM, a one billion pixel array

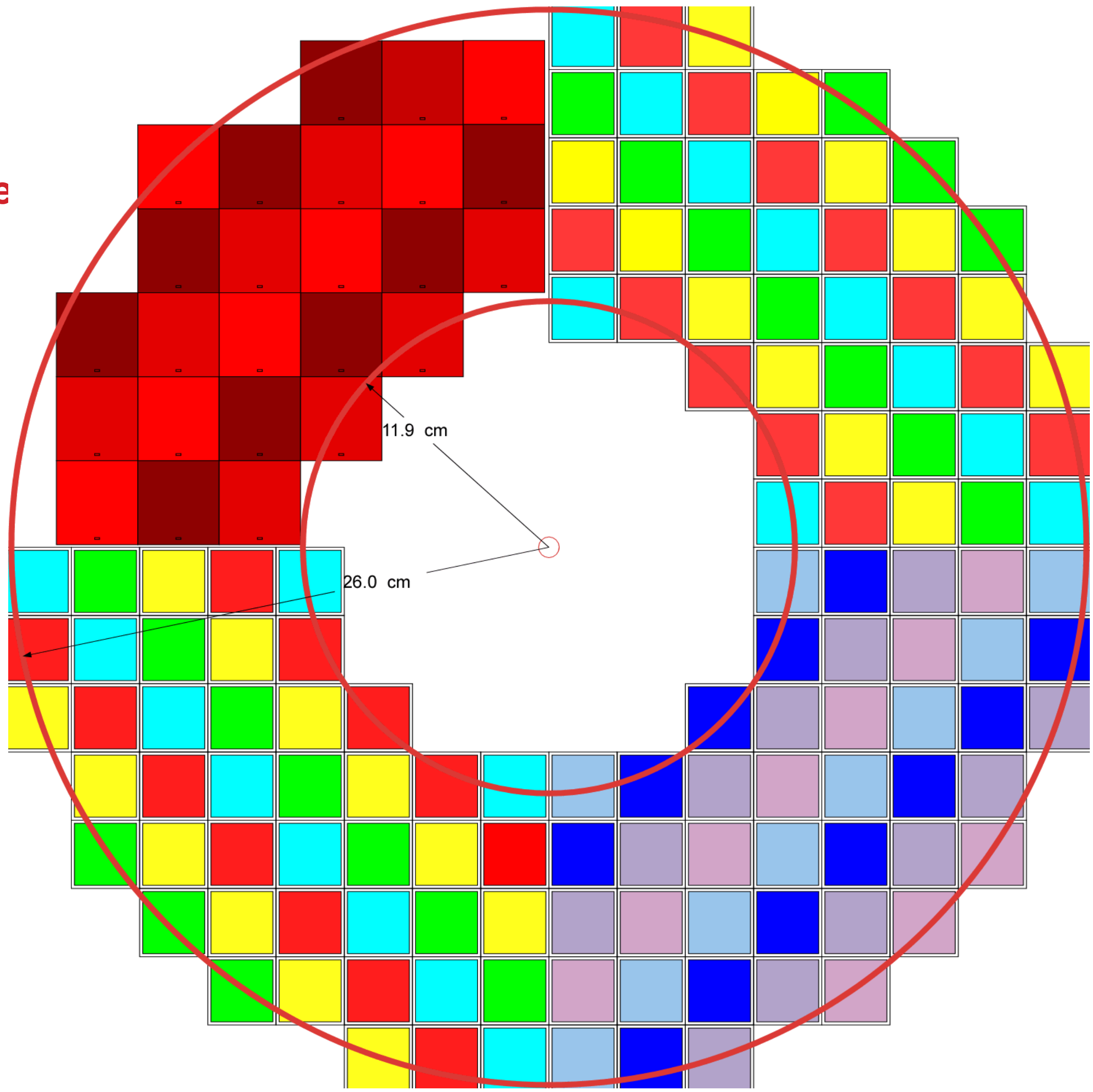
- Depending on pixel scale approximately 1 billion pixels
- ~140 Large format CCD detectors required
- Looks like the SLD vertex detector in Si area (0.1 - 0.2 m^2)
- Larger than SDSS camera, smaller than BaBar Vertex Detector (1 m^2)



SNAP SuperNova Acceleration Probe

GigaCam "directly deposited" filter concept

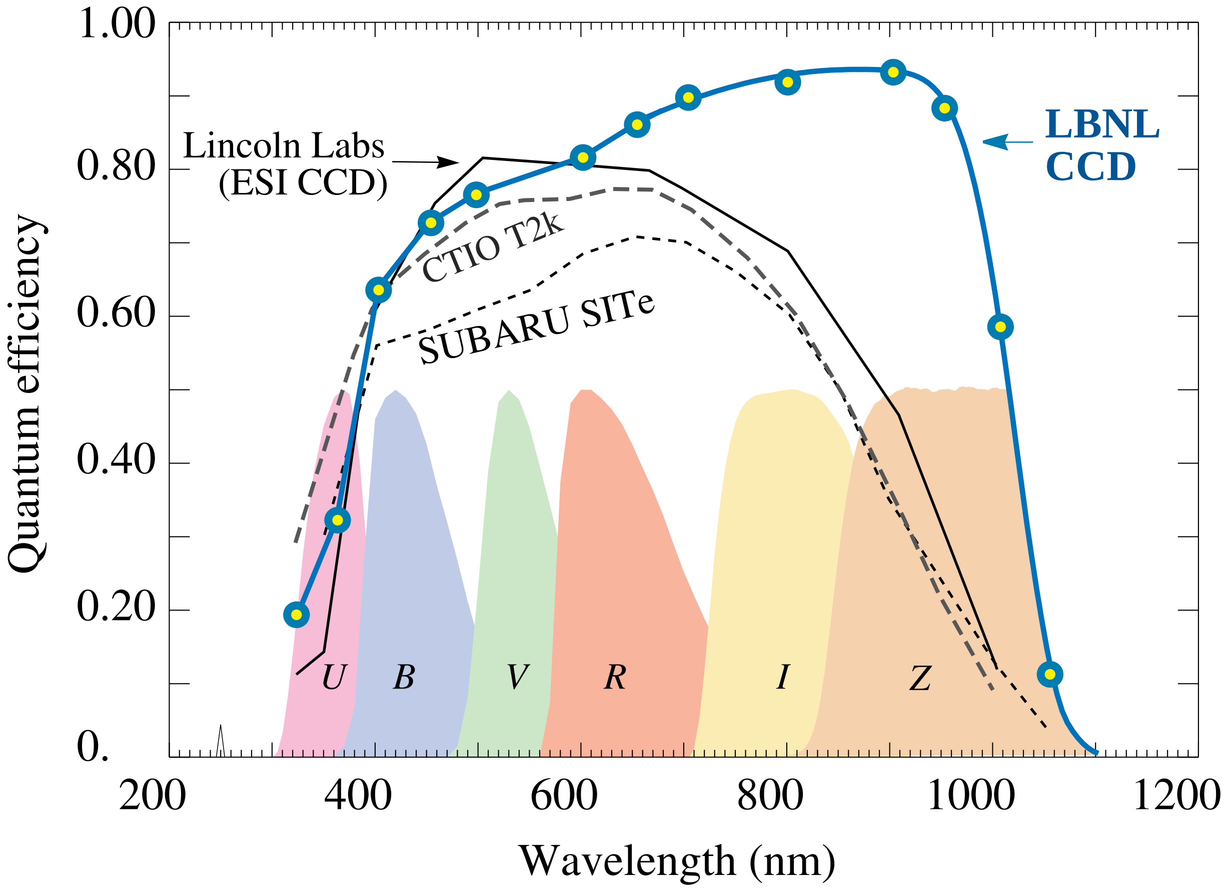
HgCdTe



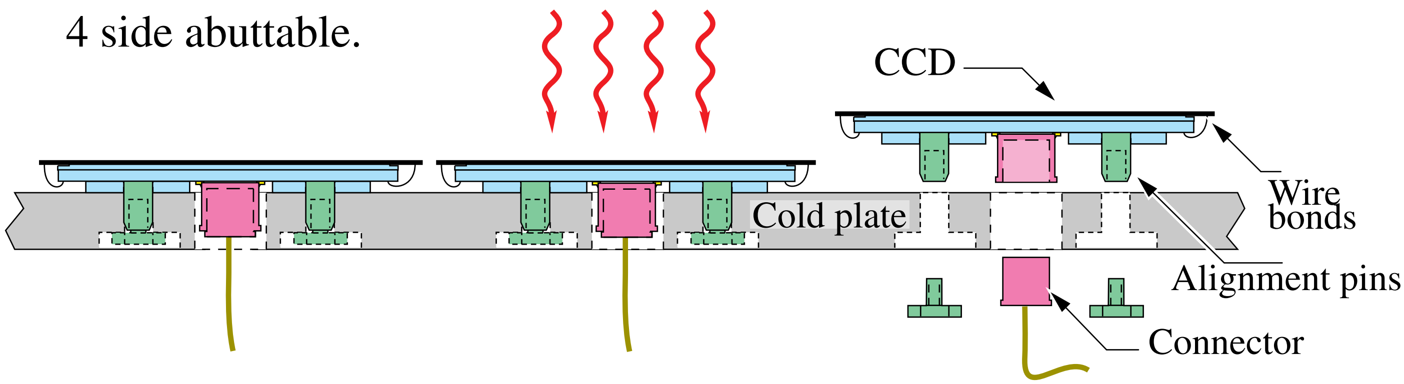
High-resistivity CCD

LBNL CCD Technology

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

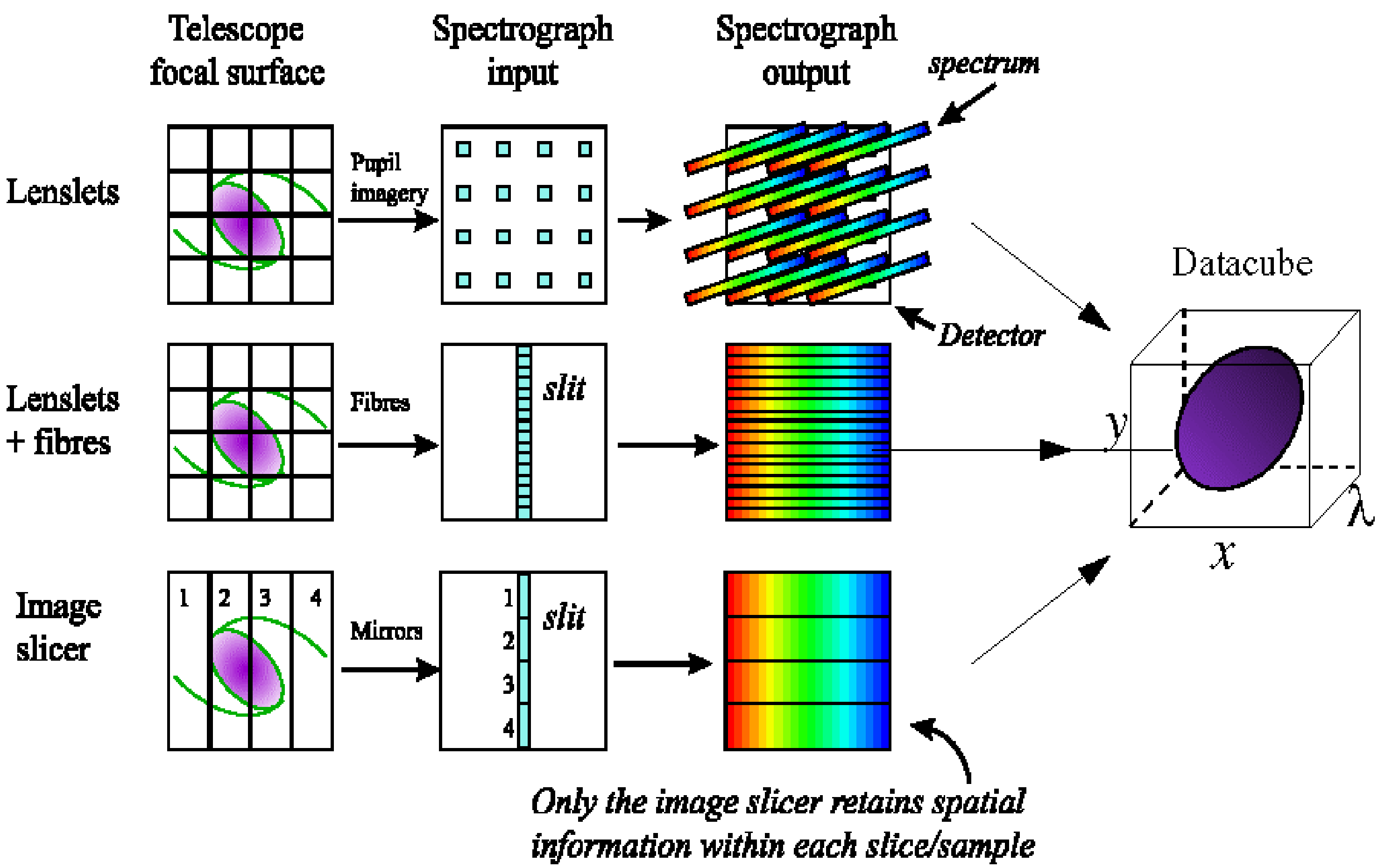


4 side abuttable.



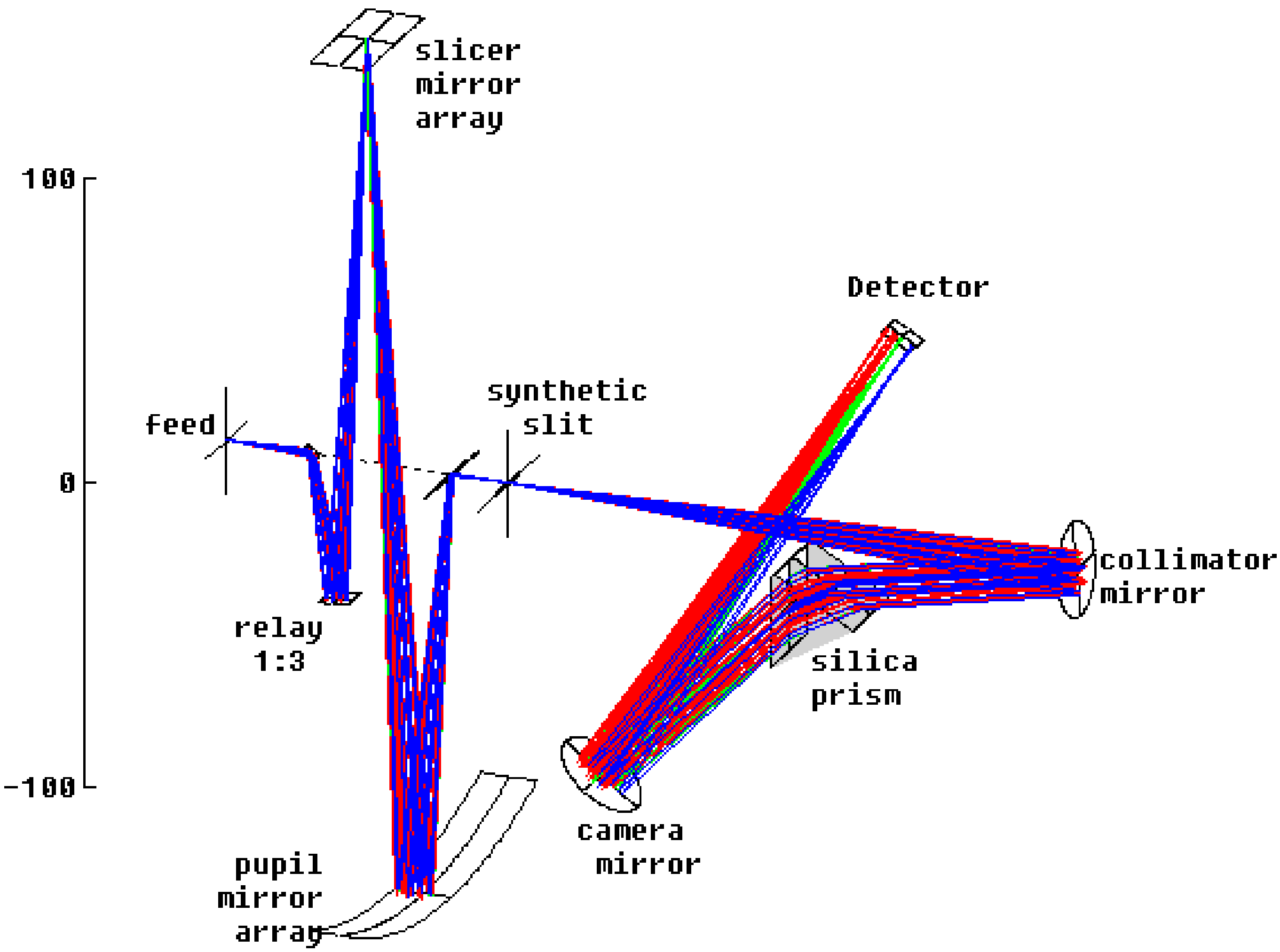
SNAP SuperNova Acceleration Probe

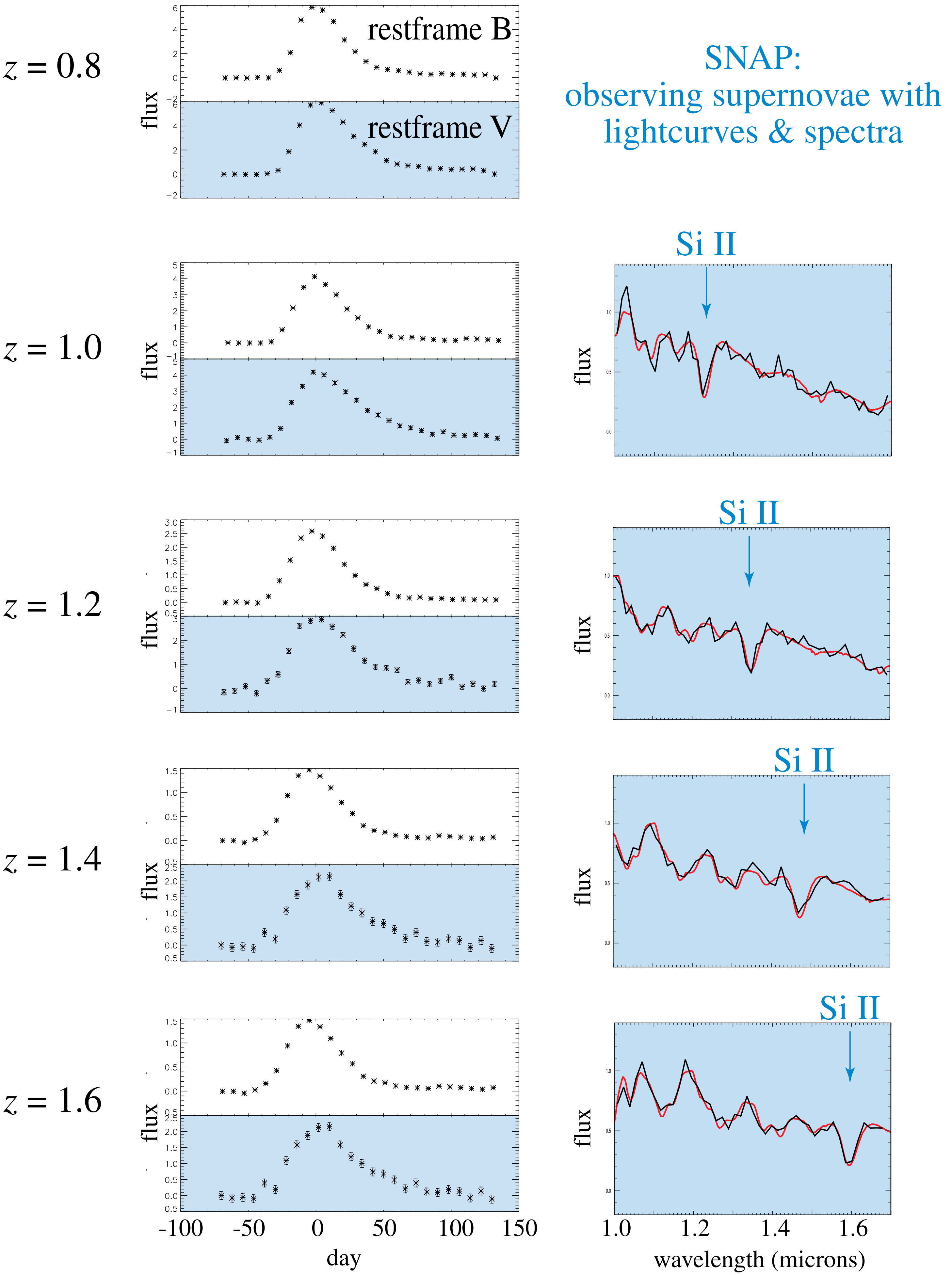
"Integral Field Unit" Spectrographs



SNAP SuperNova Acceleration Probe

IFU Spectrometer Concept

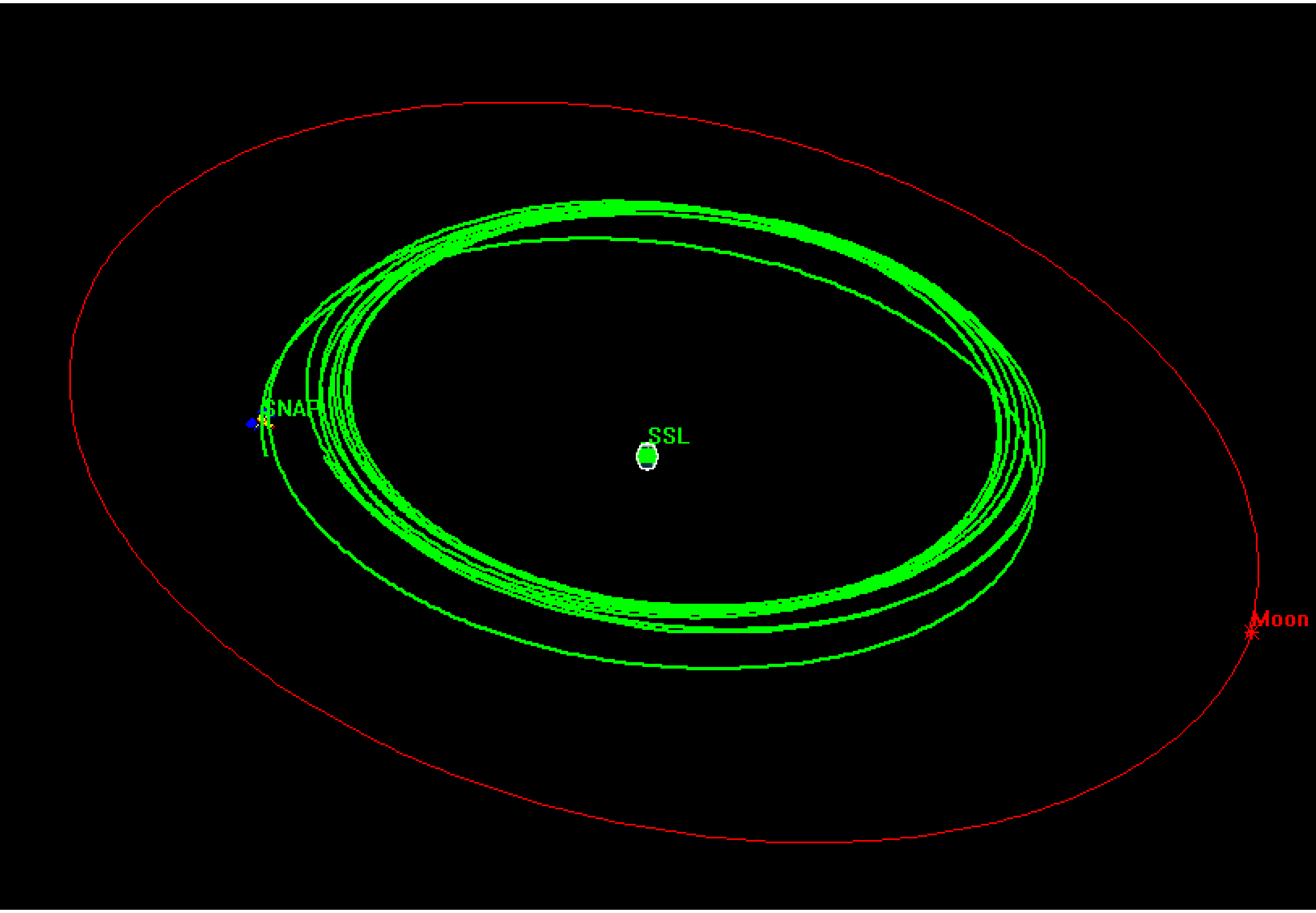


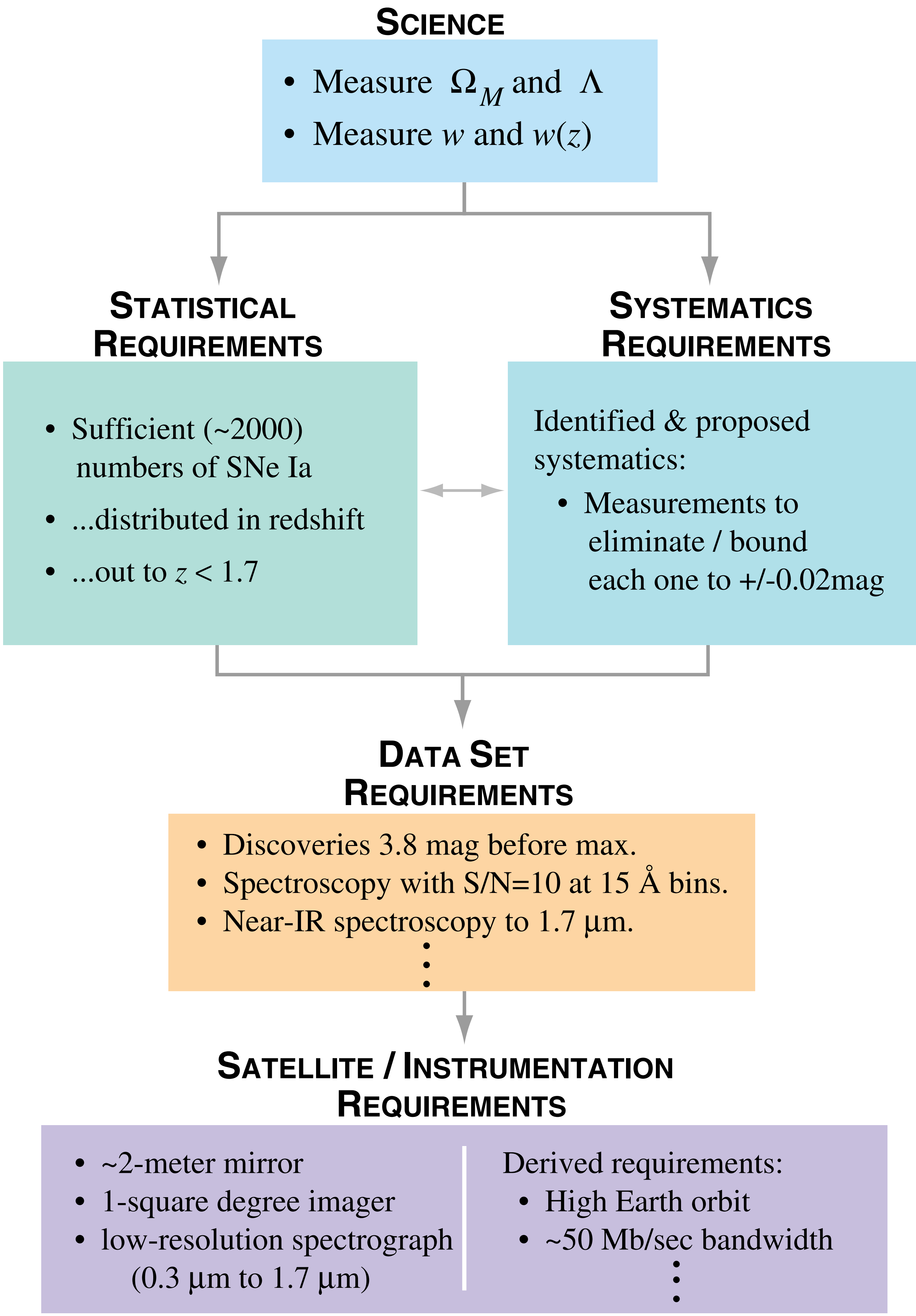


SNAP:
observing supernovae with
lightcurves & spectra
z = 0.8
z = 1.0
z = 1.2
z = 1.4
z = 1.6
restframe B
restframe V
flux
Si II
-100
-50
0
50
100
150
day
1.0
1.2
1.4
1.6
wavelength (microns)

SNAP SuperNova Acceleration Probe

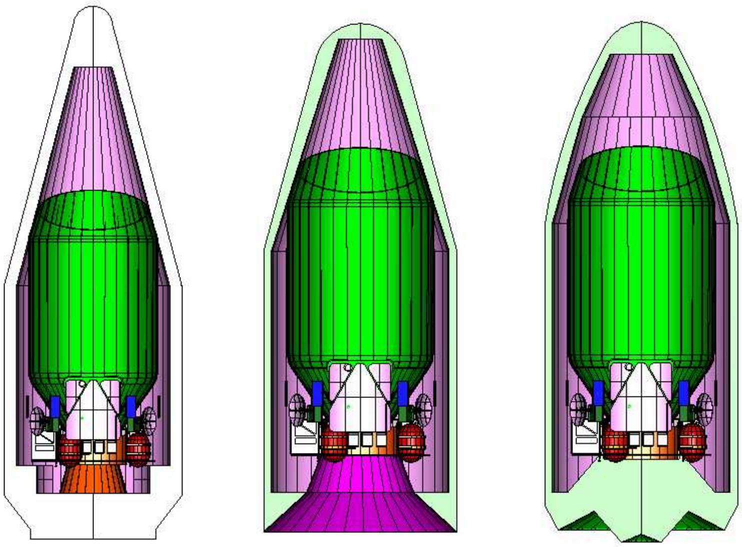
Lunar Assist Orbit



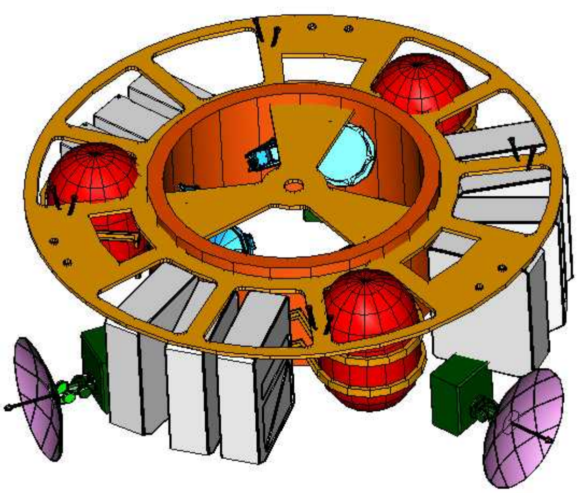

SCIENCE
• Measure Ω_M and Λ
• Measure w and $w(z)$
STATISTICAL REQUIREMENTS
• Sufficient (~2000) numbers of SNe Ia
• ...distributed in redshift
• ...out to $z < 1.7$
SYSTEMATICS REQUIREMENTS
Identified & proposed systematics:
• Measurements to eliminate / bound each one to +/-0.02mag
DATA SET REQUIREMENTS
• 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
• low-resolution spectrograph (0.3 μm to 1.7 μm)
Derived requirements:
• High Earth orbit
• ~50 Mb/sec bandwidth

SNAP SuperNova Acceleration Probe

NASA Goddard Integrated Mission Design Center



Atlas-EPF Delta-III Sea Launch



SNAP intensive design study

Additional Material

SNAP SuperNova Acceleration Probe

Independent Cost Estimates

NASA Goddard Integrated Mission Design Center:	**$ 308 M**
Lockheed:	**$ 385 M**
Swales Aerospace:	**$ 384 M**

- All studies included some contingency
- Delta III with launch services @ $85M per Kennedy Space Center
- All studies included operations
- All studies included data processing
- Scientists' salaries not included
- All costs in FY01 $ -- no inflation

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*)

Samuel Silver Space Sciences Laboratory

E. 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*)

A. Fruchter (*STScI*)

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

C. Lidman (*ESO*)

J. Rich (*CEA/DAPNIA*)

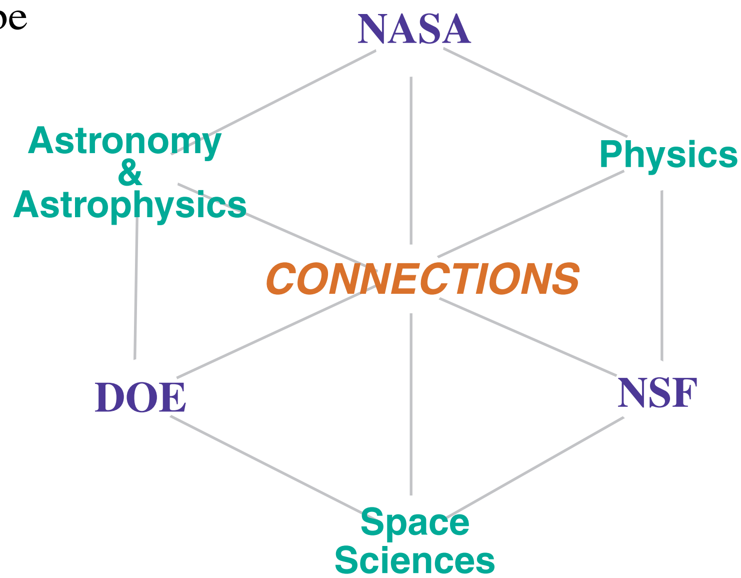
A. Mourao (*Inst. Superior Tecnico,Lisbon*)

International collaboration is growing -- currently 15 institutions.

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



How does a project get proposed and prioritized by peer-review in this multi-disciplinary, multi-agency "Connections" environment?

The NRC astronomy decadal survey suggested a mechanism for such multi-agency cooperation:

"The survey committee recommends that each agency build on its own unique capabilities while recognizing those of related agencies, taking steps toward collaborations that it believes will prove fruitful. Each agency should have a strategic plan (such as DOE and NSF's SAGENAP and NASA's SScAC) available to evaluate proposed interagency collaborations. The Office of Science Technology and Technology Policy (OSTP) could facilitate such interagency collaborations."

Ultra-deep 11 band imaging survey

Galaxy populations and morphology to co-added $m = 32$
Low surface brightness galaxies in H' band
Quasars to redshift 10 (when is this, how old is universe)
Epoch of reionization through Gunn-Peterson effect
Galaxy evolution studies, merger rate
Evolution of stellar populations
Ultraluminous infrared galaxies
Globular clusters around galaxies
Extragalactic stars (in clusters or otherwise)
Intracluster objects (globulars, dwarf galaxies, etc.)
Lensing projects:
- Mass selected cluster catalogs
- Evolution of galaxy-mass correlation function and its scaling relations
- Maps of mass in filaments

SNAP SuperNova Acceleration Probe

Science Goals for
The First Wide-field Survey in Space

Time-Domain Survey

GRB optical counterparts: rates, lightcurves, and spectra
=> GRB afterglows with or without GR satellite
=> unknown fast transients

Kuiper belt objects

Supernova rates of all types vs. galaxy type
Supernova phenomenology studies for all types

Proper motions for halo objects
L and T dwarfs
Cool white dwarfs and other rare halo objects

Faint comets

SNAP SuperNova Acceleration Probe

Science Goals for
The First Wide-field Survey in Space

A Resource for the Science Community

The biggest HST deep survey will be the ACS survey:
6300x smaller than SNAP main survey
and almost as deep
Discovery potential ~6000x greater than ACS deep

Complementary to NGST: target selection for rare objects
1950s+1960s: Palomar 48” feeds 200”
2000: SDSS feeds 8 and 10 meter telescopes
2010: SNAP feeds NGST

→ Archive data distributed

→ Guest Survey Program

Whole sky can be observed every few months

SNAP SuperNova Acceleration Probe

Science Goals for
The First Wide-field Survey in Space

A Resource for the Science Community:
The *only* wide-field deep survey in space.

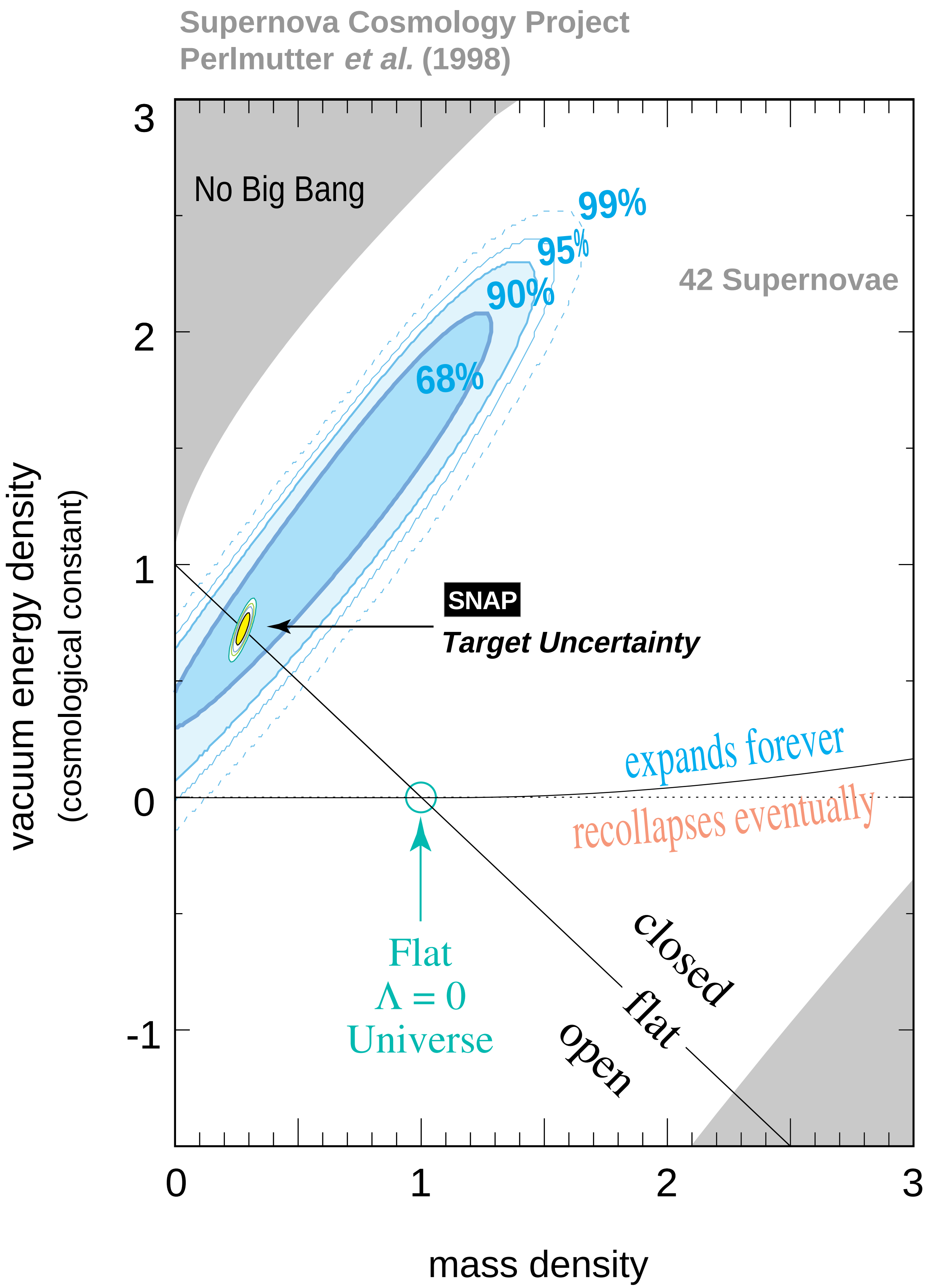
The biggest HST deep survey will be the ACS survey:
6300x smaller than SNAP main survey
and almost as deep
Discovery potential ~6000x greater than ACS deep

Complementary to NGST: target selection for rare objects
1950s+1960s: Palomar 48” feeds 200”
2000: SDSS feeds 8 and 10 meter telescopes
2010: SNAP feeds NGST

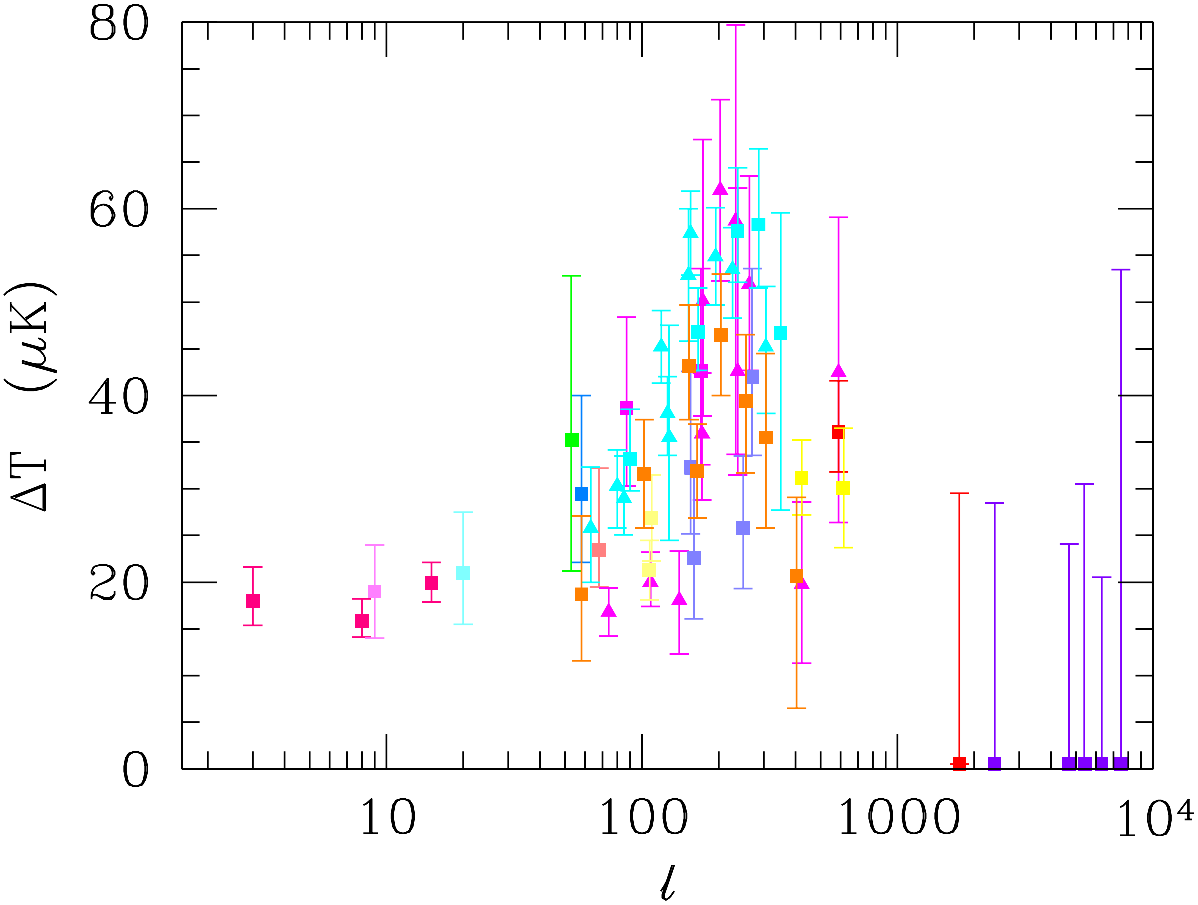
Archive data distributed

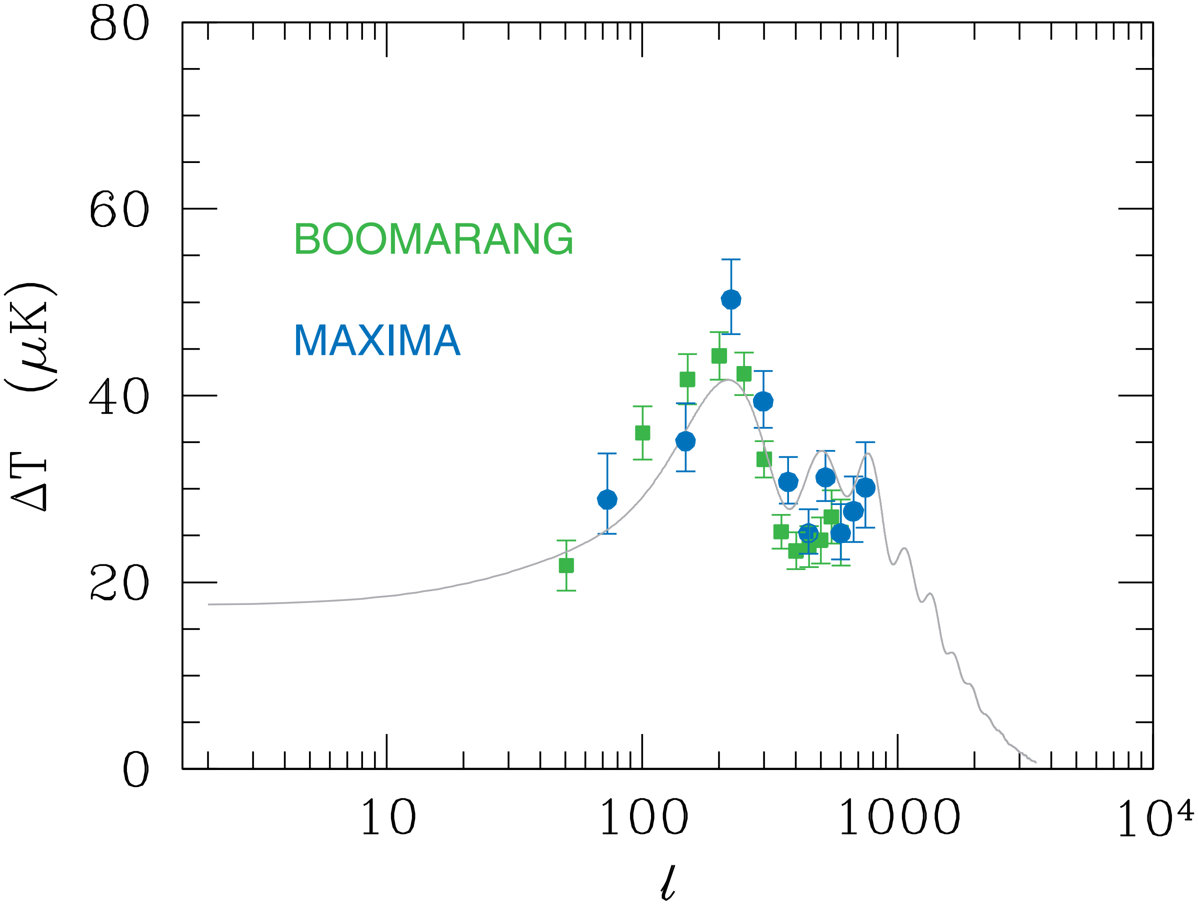
Guest Survey Program

Whole sky can be observed every few months

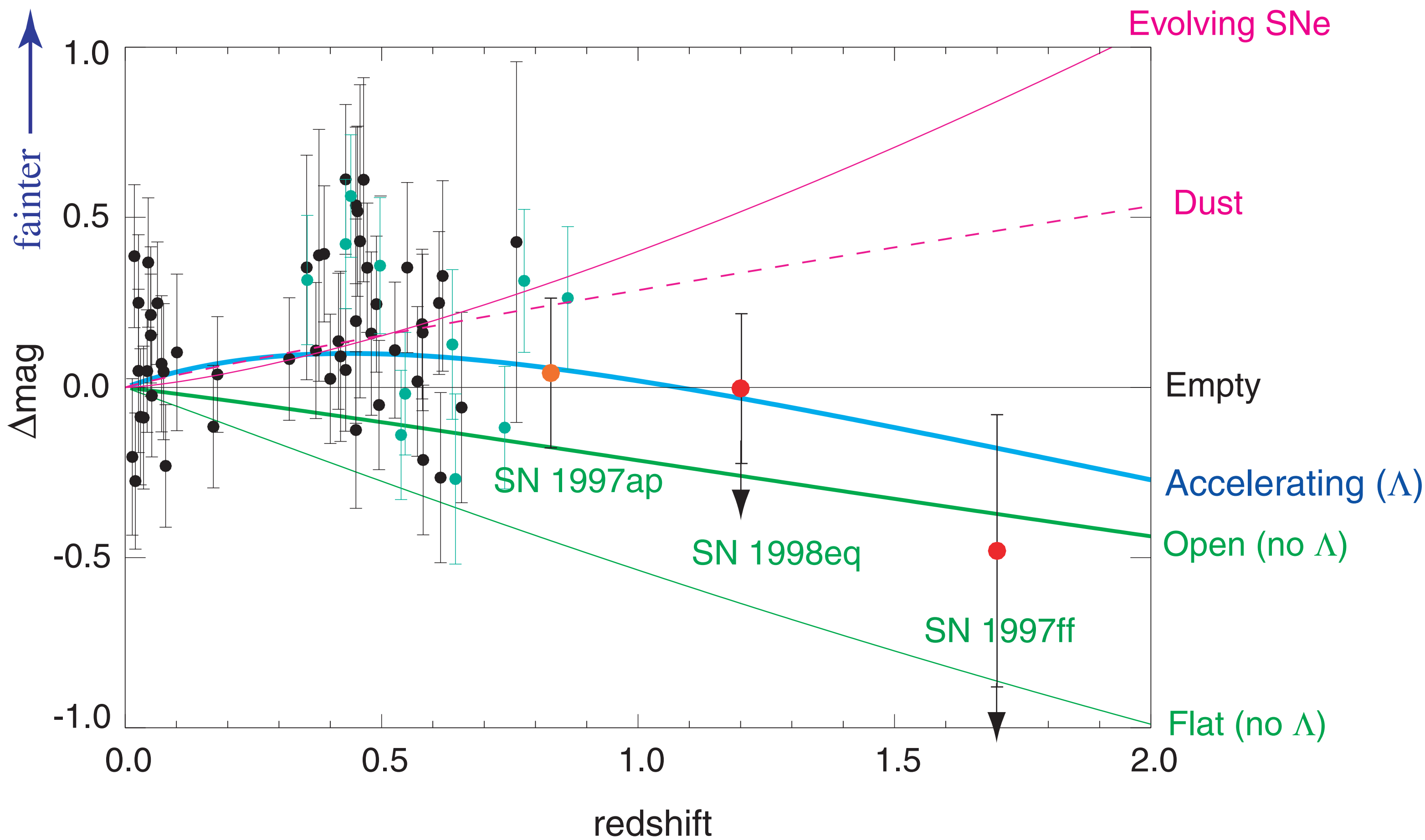

Supernova Cosmology Project
Perlmutter *et al.* (1998)
No Big Bang
99%
95%
90%
68%
42 Supernovae
SNAP
Target Uncertainty
expands forever
recollapses eventually
Flat
Λ = 0
Universe
closed
flat
open
vacuum energy density
(cosmological constant)
mass density
3
2
1
0
-1
0
1
2
3

CMB data before BOOMARANG and MAXIMA



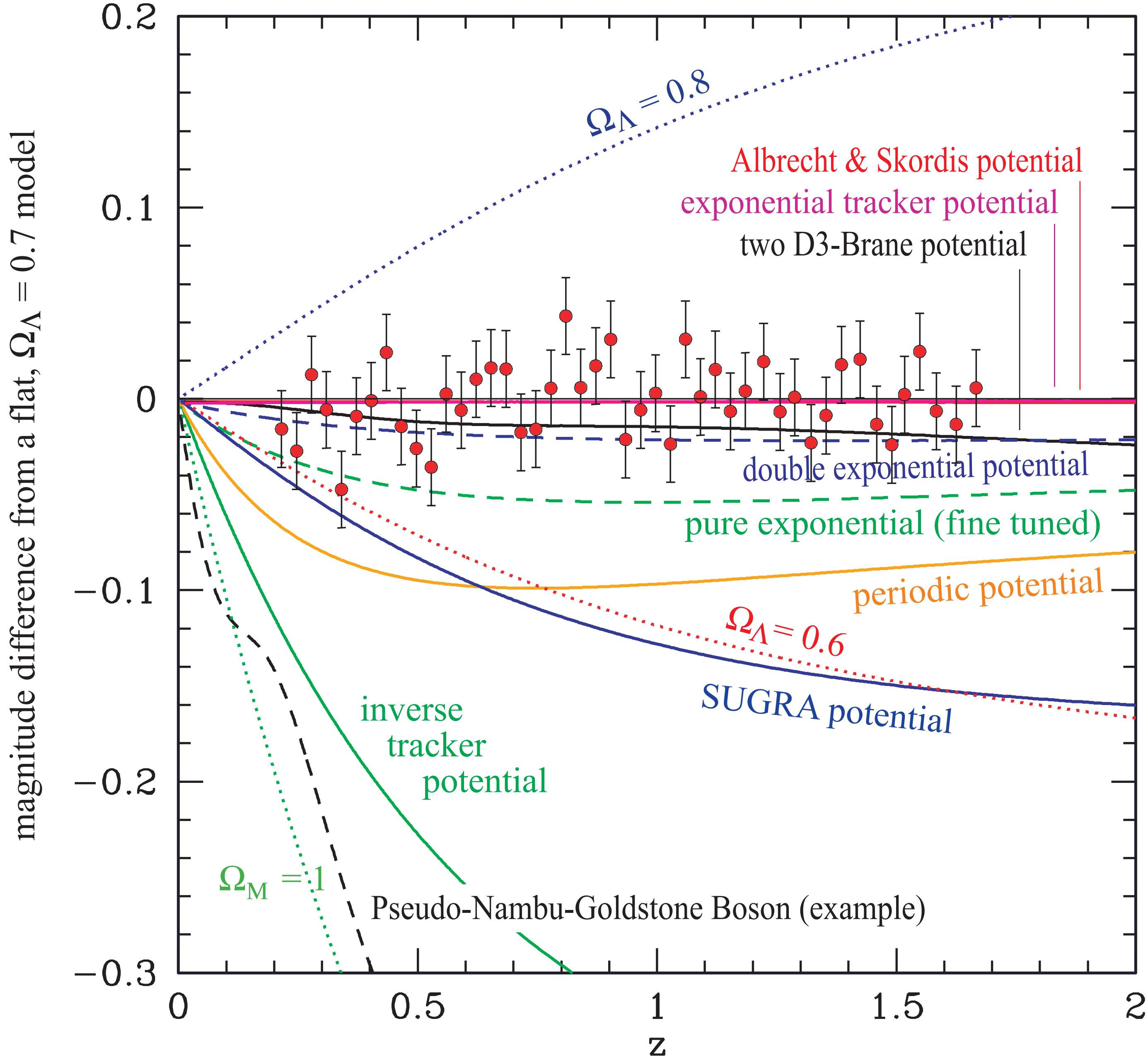


Supernovae probing the *deceleration* era with NICMOS



SNAP SuperNova Acceleration Probe

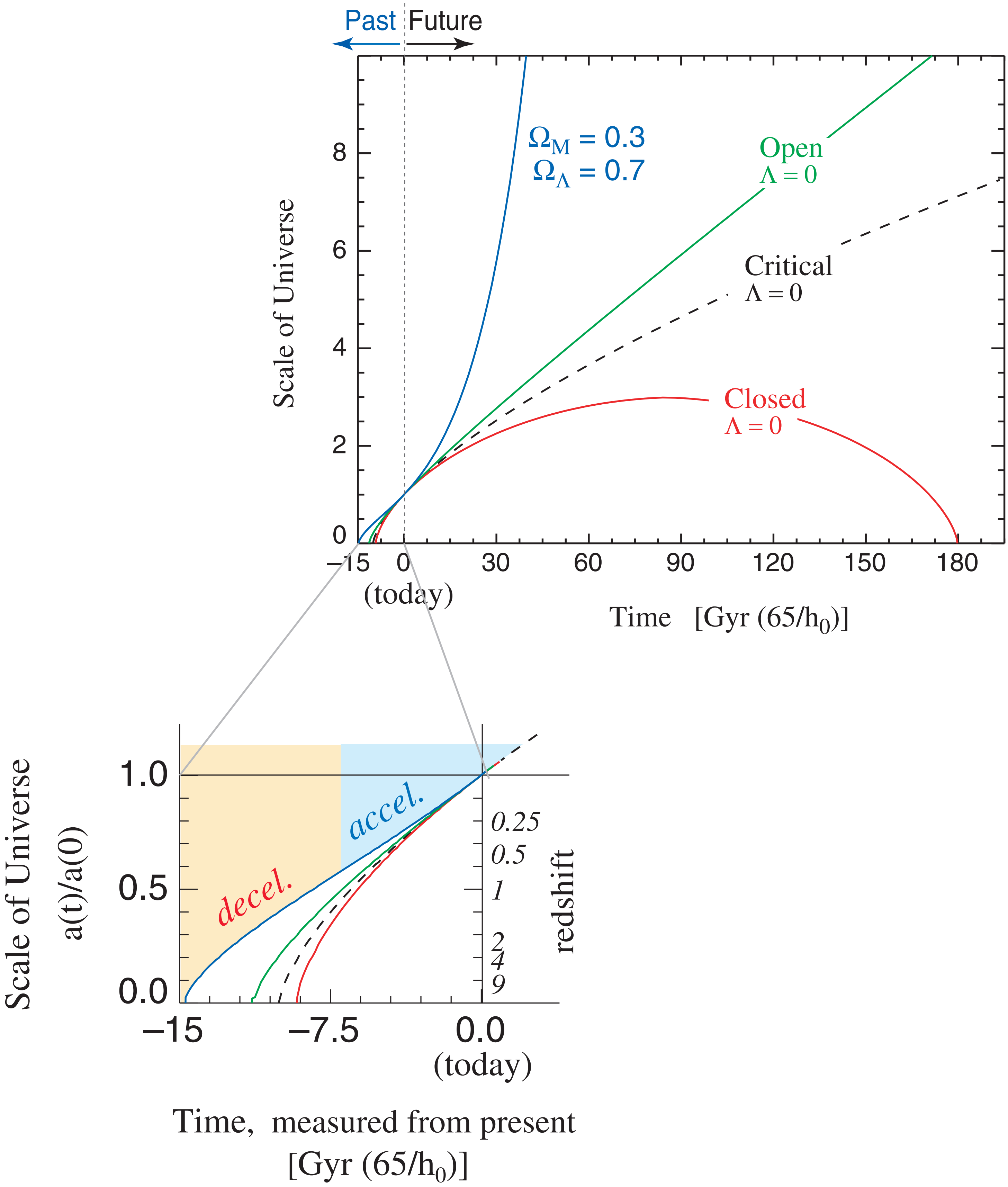
Binned simulated SNAP data compared with Dark Energy models currently in the literature.



based on

Weller & Albrecht (2001)

Expansion History of the Universe



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."

SNAP SuperNova Acceleration Probe

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

(Reports to HEPAP to establish High Energy Physics' priorities, parallel to Decadal Survey establishing Astronomy's priorities).

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."

SNAP SuperNova Acceleration Probe

Weak Gravitational Lensing from Space

Weak gravitational lensing by large-scale structures in the universe produces coherent distortions in the shapes of background galaxies.
It can be used to

directly map the projected distribution of dark matter,
measure cosmological parameters (esp. σ_8 and Ω_M)
and the power spectrum of matter density fluctuations
--- and thus constrain the nature of dark matter.

This effect has recently been detected from the ground by 4 independent groups.
These experiments require high precision measurements
of the shape of faint galaxies and are thus limited by seeing;
they are already within a factor of three of being systematics limited
(which will be reached within ~1 year).

They can thus can be dramatically improved by SNAP's wide-field observations with a much reduced PSF. Based on HST studies, this will lead to:

a larger surface density of resolved galaxies	n_g: 15 --> 50 -- 100
a larger median redshift for the galaxies	z_g: 0.8 --> 1.1 --1.4
a smaller scatter in the deconvolved ellipticities of the galaxies (more shape information)	σ_ε: 0.4 --> 0.2 -- 0.3

An improved sensitivity to the weak lensing shear:

$$SNR\gamma \sim n_g^{0.5} \; z_g^{0.7} \; \sigma_\varepsilon^{-1}$$

larger by a factor of about 3--8. This corresponds to an improvement for the SNR for $\Omega_M \; \sigma_8^{1.7}$ of about 1.5 x SNRγ = ~5--11, for the same survey area.

In addition, the smaller PSF will make the shear measurement less sensitive to systematics (esp. uncertainty in the PSF shape).

SNAP SuperNova Acceleration Probe

Weak Gravitational Lensing from Space

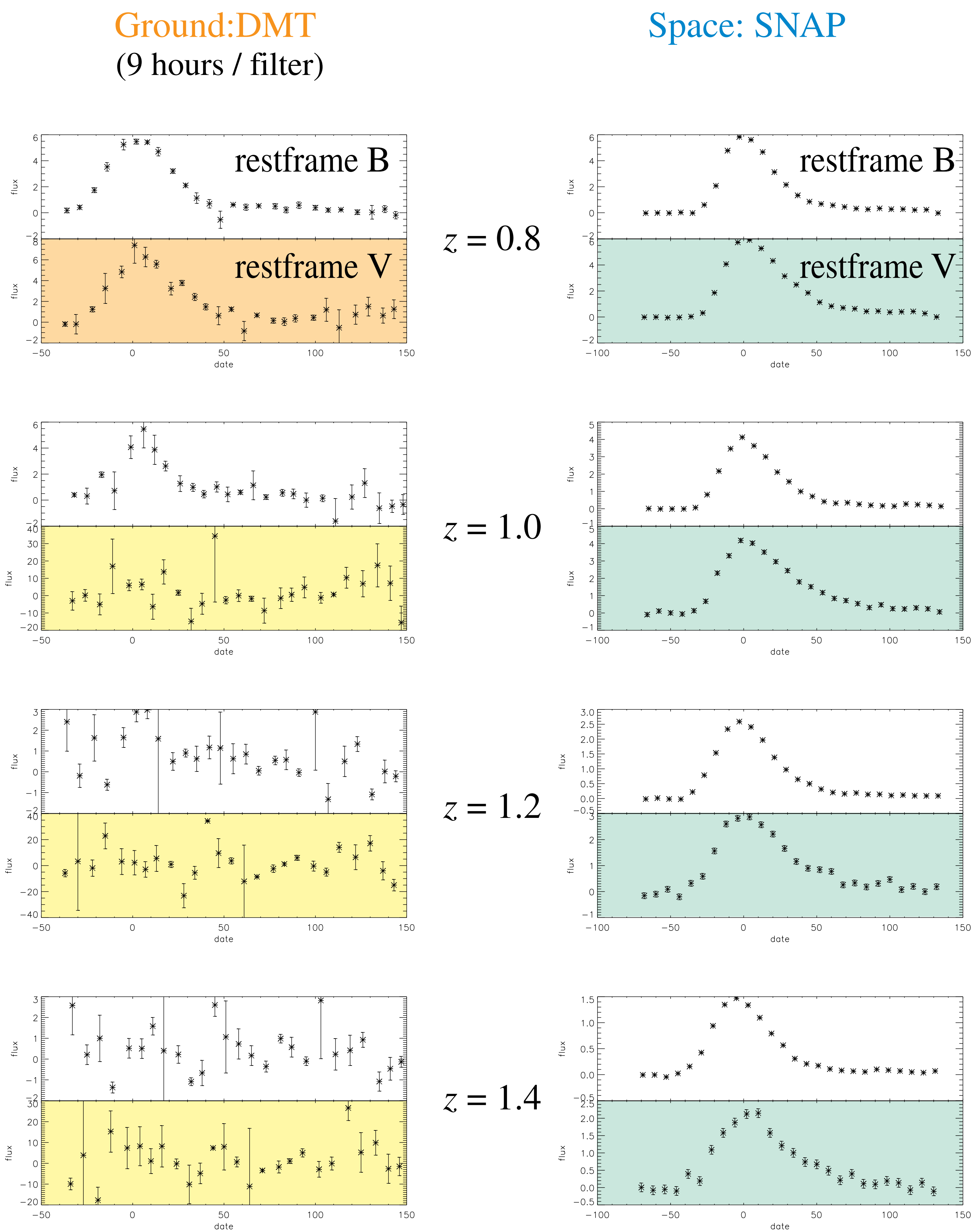
will achieve the following goals, which are unfeasible from the ground:

A high sensitivity map of the projected dark matter density.
-- resolving the cosmic web (filaments, voids, etc).

A high-precision, reliable measurements of the lensing power spectrum.
-- Improvement in SNR for $\Omega_M\ \sigma_8^{1.7}$ of 5 -- 11 for a given survey area.

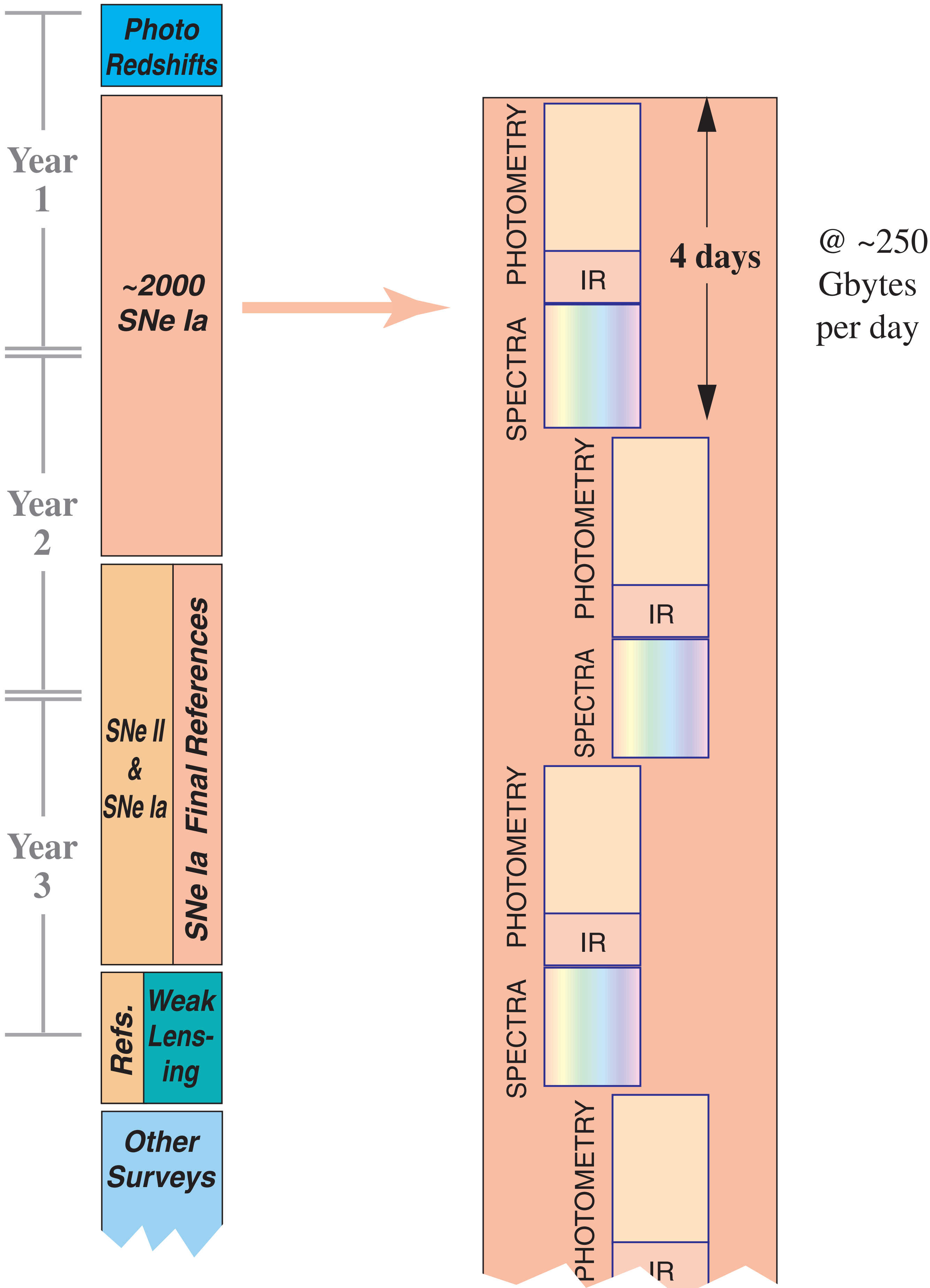
A precise and reliable measurement of the higher-order statistics of the dark matter distribution (skewness, kurtosis, etc).
-- measurement of Λ, and test of the gravitational instability paradigm.

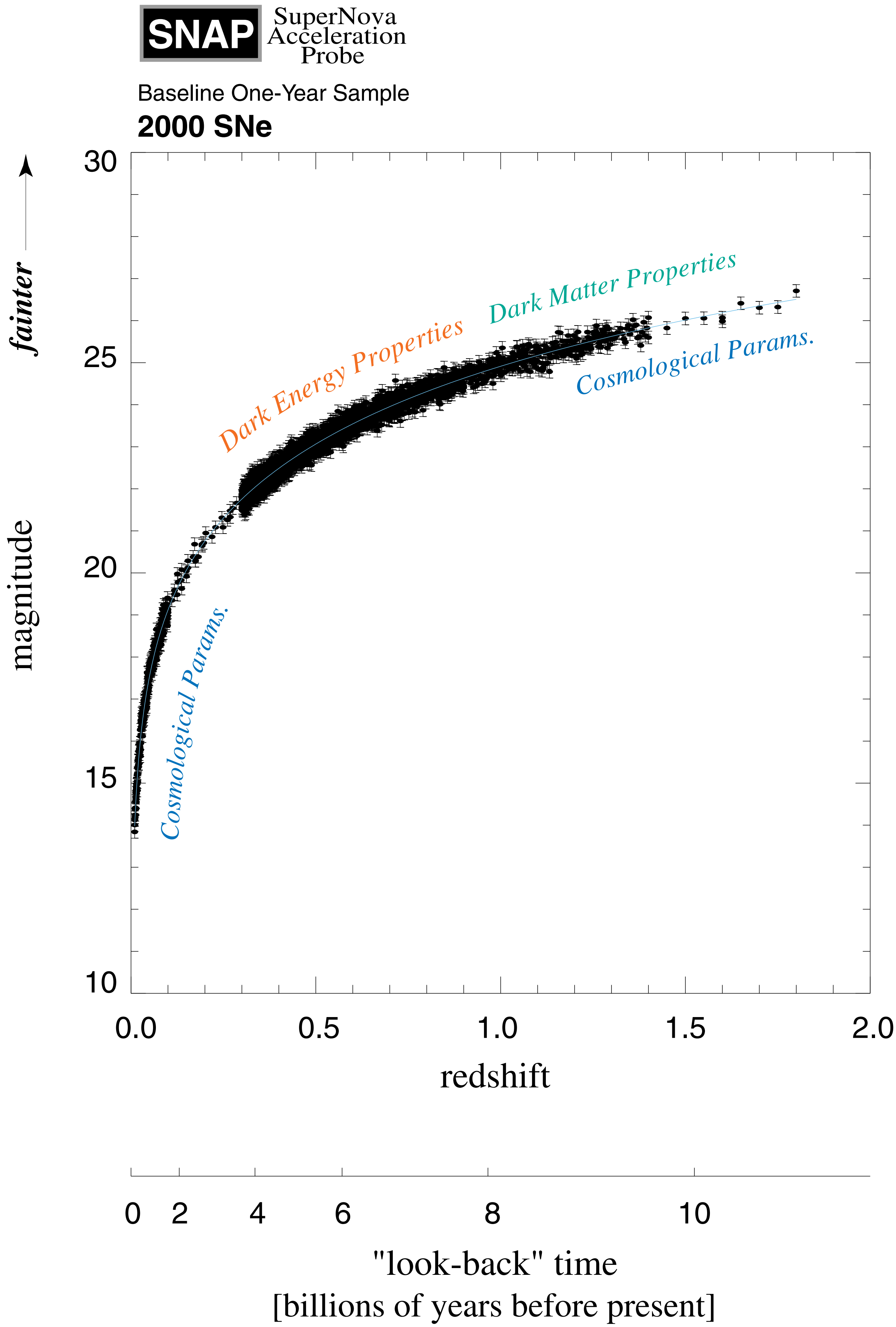
Using colors, a measurement of weak lensing at different redshift slices.
-- measurement of the evolution of structures from z ~ 1 to 0.



Ground:DMT
(9 hours / filter)
Space: SNAP
restframe B
restframe V
z = 0.8
z = 1.0
z = 1.2
z = 1.4
flux
date

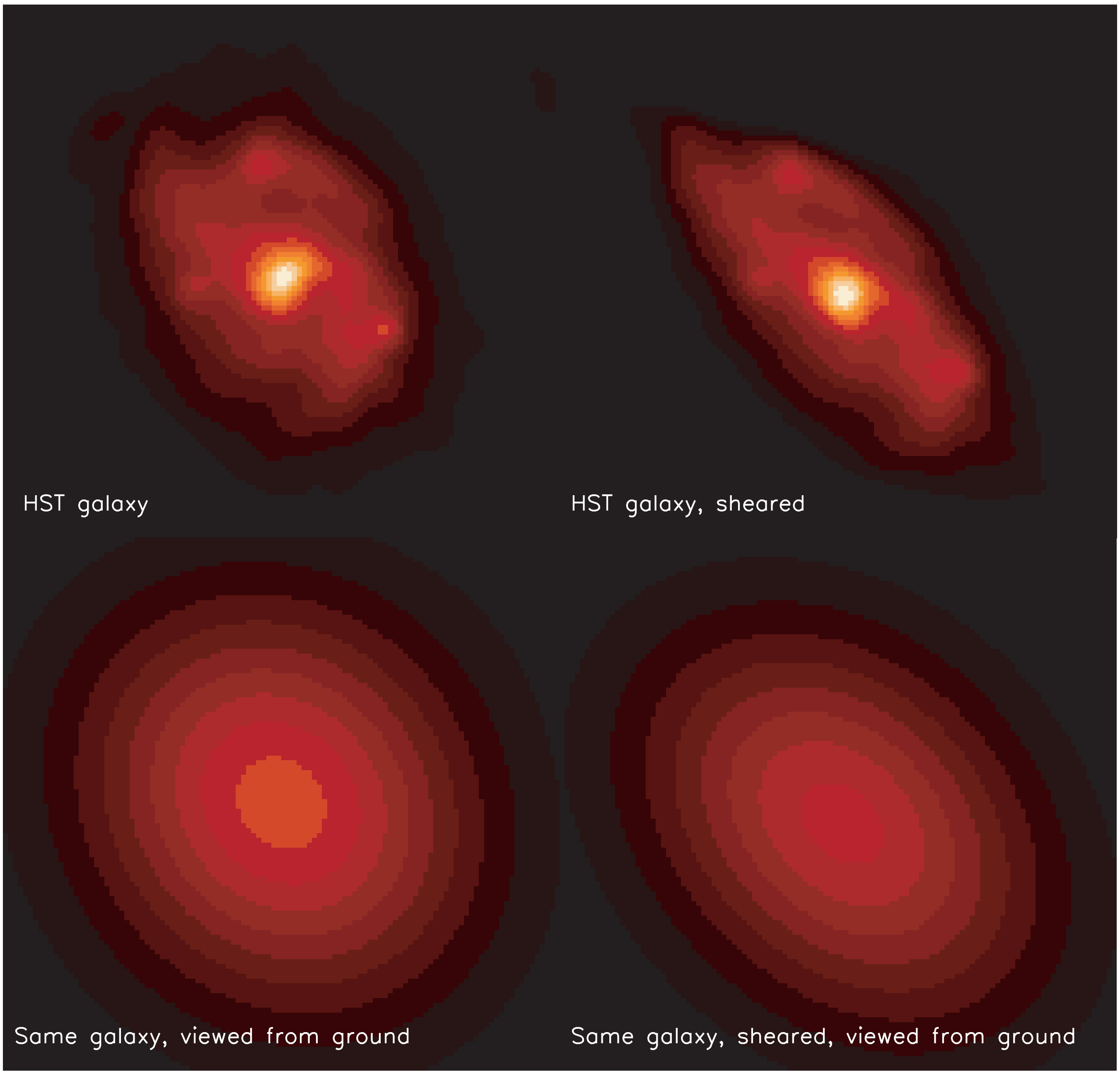
Sample Observation Schedule




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

SuperNova Acceleration Probe

Weak lensing galaxy shear observed from space
versus
Weak lensing galaxy shear observed from the ground.



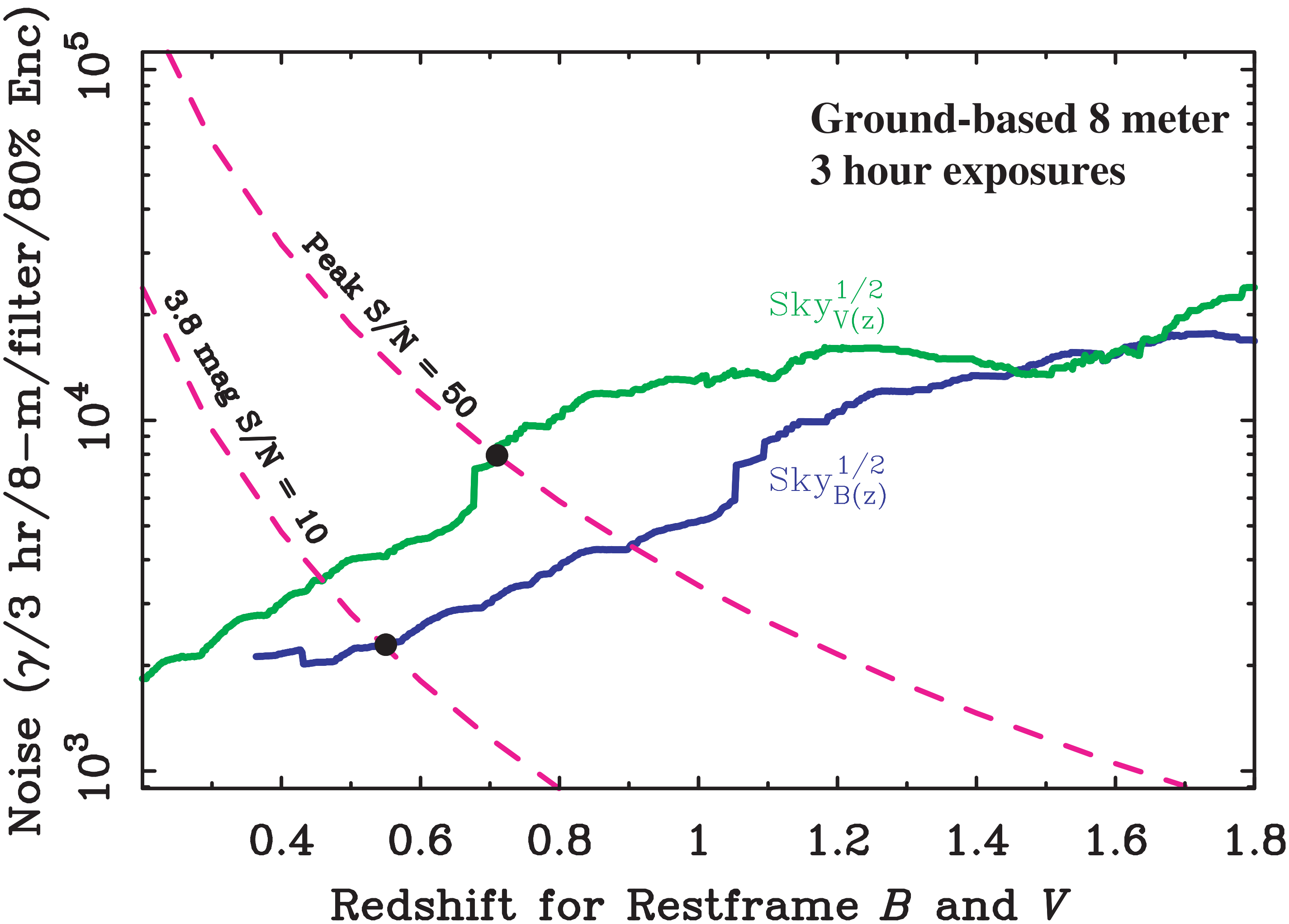
(Bacon, Ellis, Refregier, Nov. 2000)

Why a New Satellite?

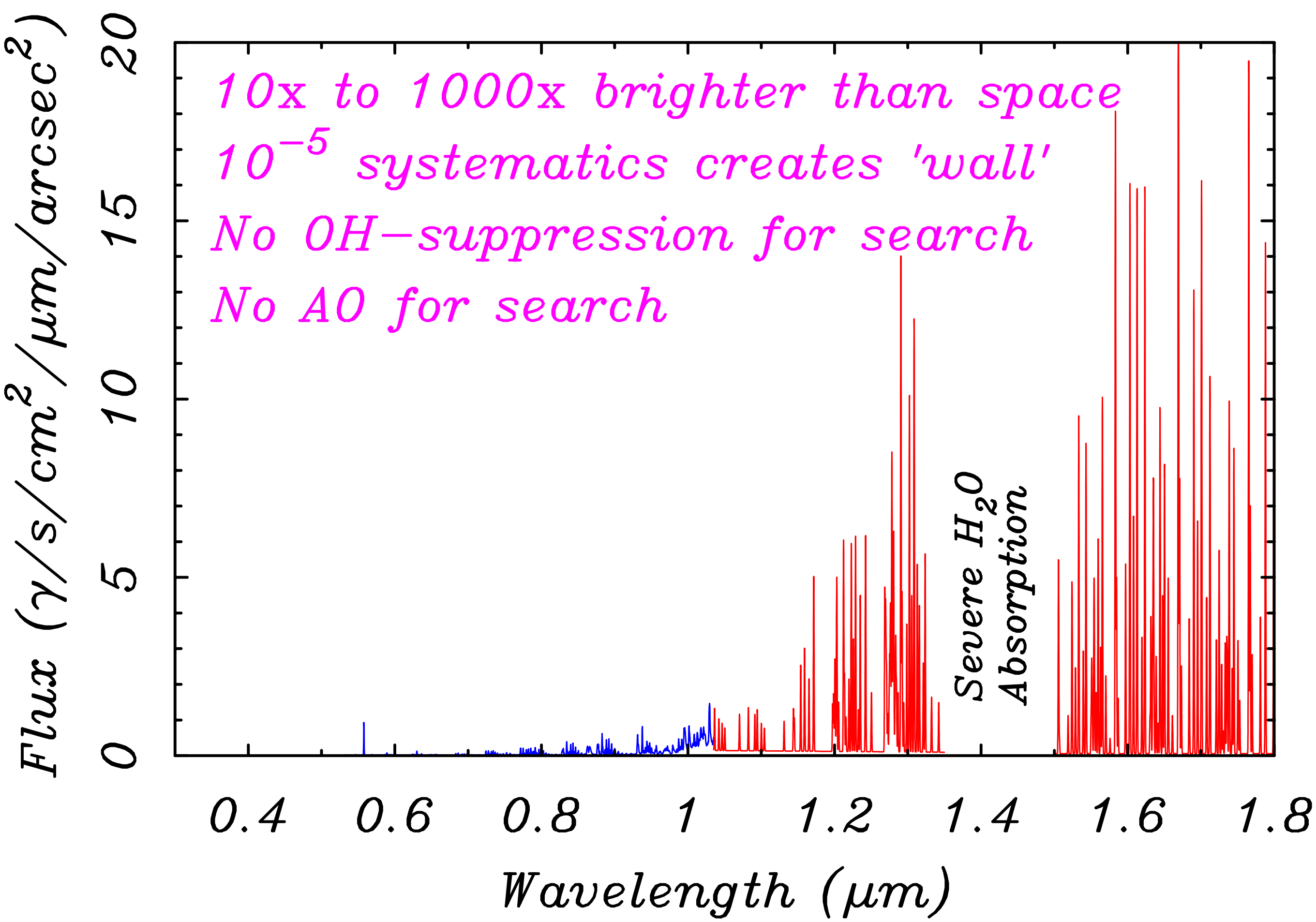
From the ground, the sky photon noise limits the range of redshifts to:

--- $z \sim 0.55$ for discovery near explosion date.

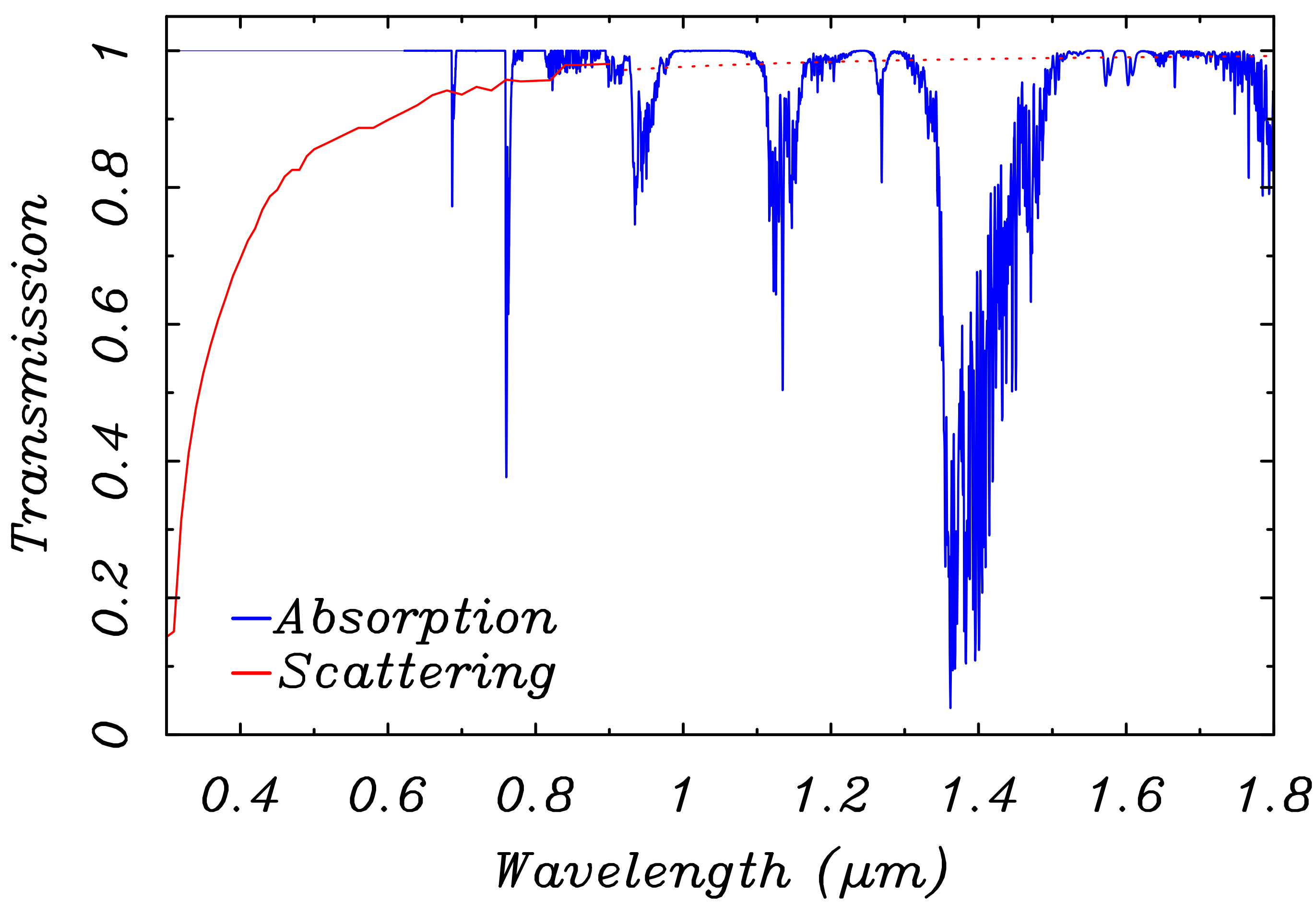
--- $z \sim 0.7$ for 2% photometry of color at max.



the Tremendous Sky Brightness compared to SNe



Atmosphere Compromises Quality & Homogeneity



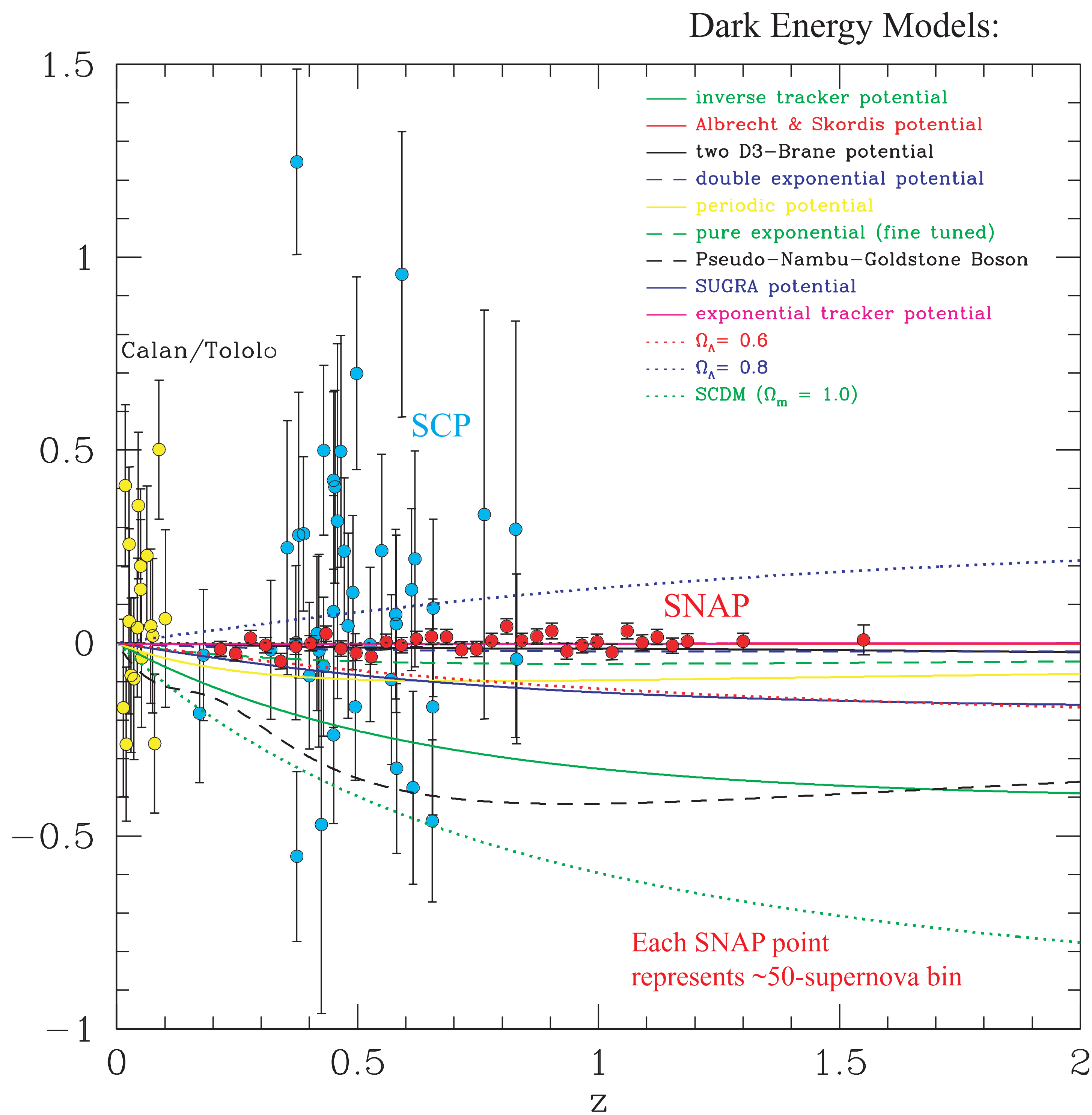
Among the few tools at our disposal,
SNe Ia are not the **most** simple/elegant
     (e.g. lens delay, SN II photosphere)
but they are also not the messiest/most statistical

--and they provide us an interesting route to
obtaining a well-constrained and calibrated tool:

	Forward Understanding *starting from (unobservable) 1st principles*	**Backward Understanding** *starting from observable final states and working back till you reach unobservable past*
Big Bang	*We have* ***no idea*** *what happens with physics before the Planck era.*	*We have a rather impressive (at least, to us easily impressed scientists) understanding of what has happened in the "visible era" since the CMB.*
SNe Ia	*Magneto-hydrodynamics is making slow headway in understanding the early explosion states.*	*We have a detailed trace of the properties of the expanding material working back in time from nebular phase to first visible spectra.*

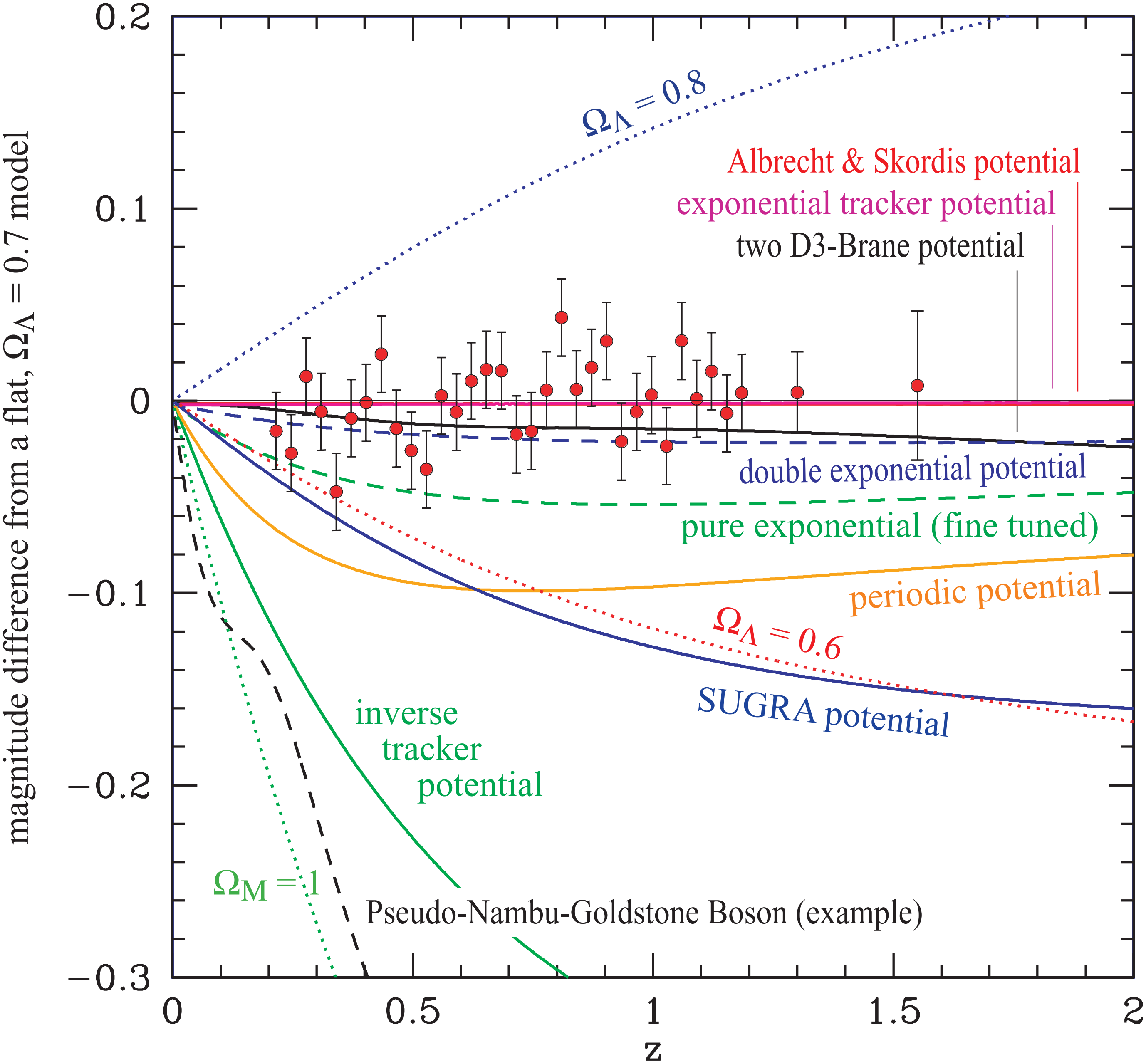
SNAP SuperNova Acceleration Probe

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



SNAP SuperNova Acceleration Probe

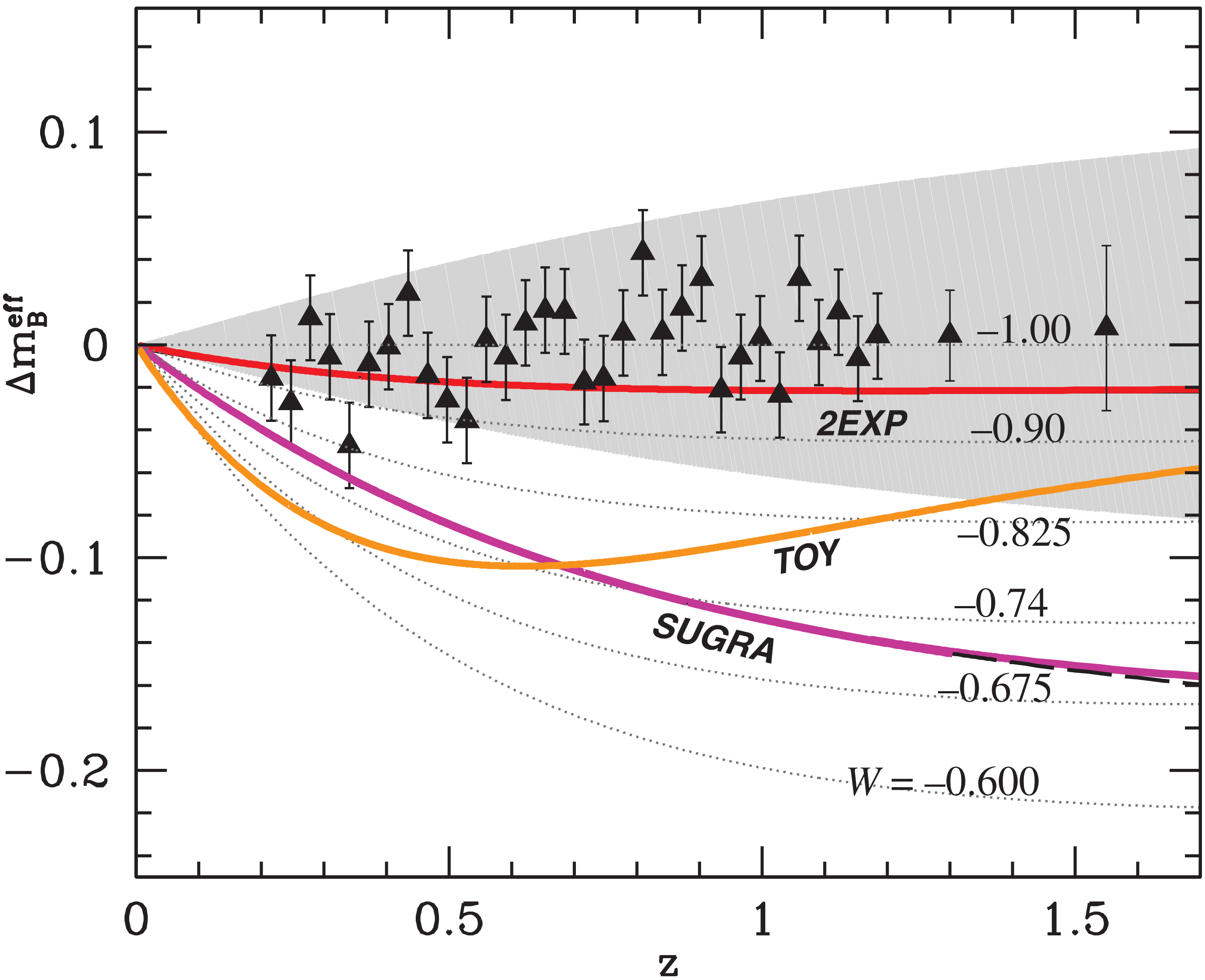
Binned simulated SNAP data compared with Dark Energy models currently in the literature.



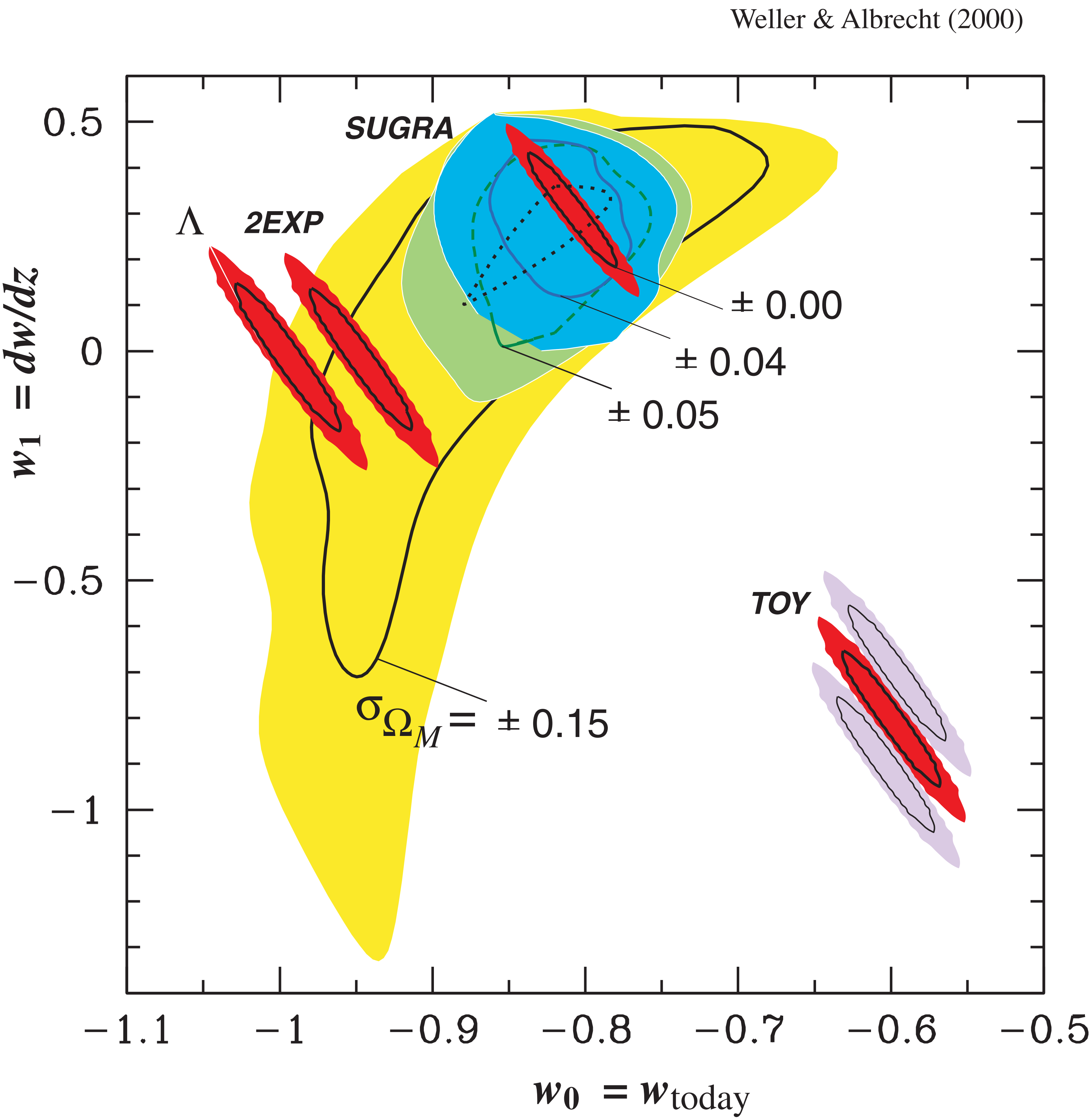
Weller & Albrecht

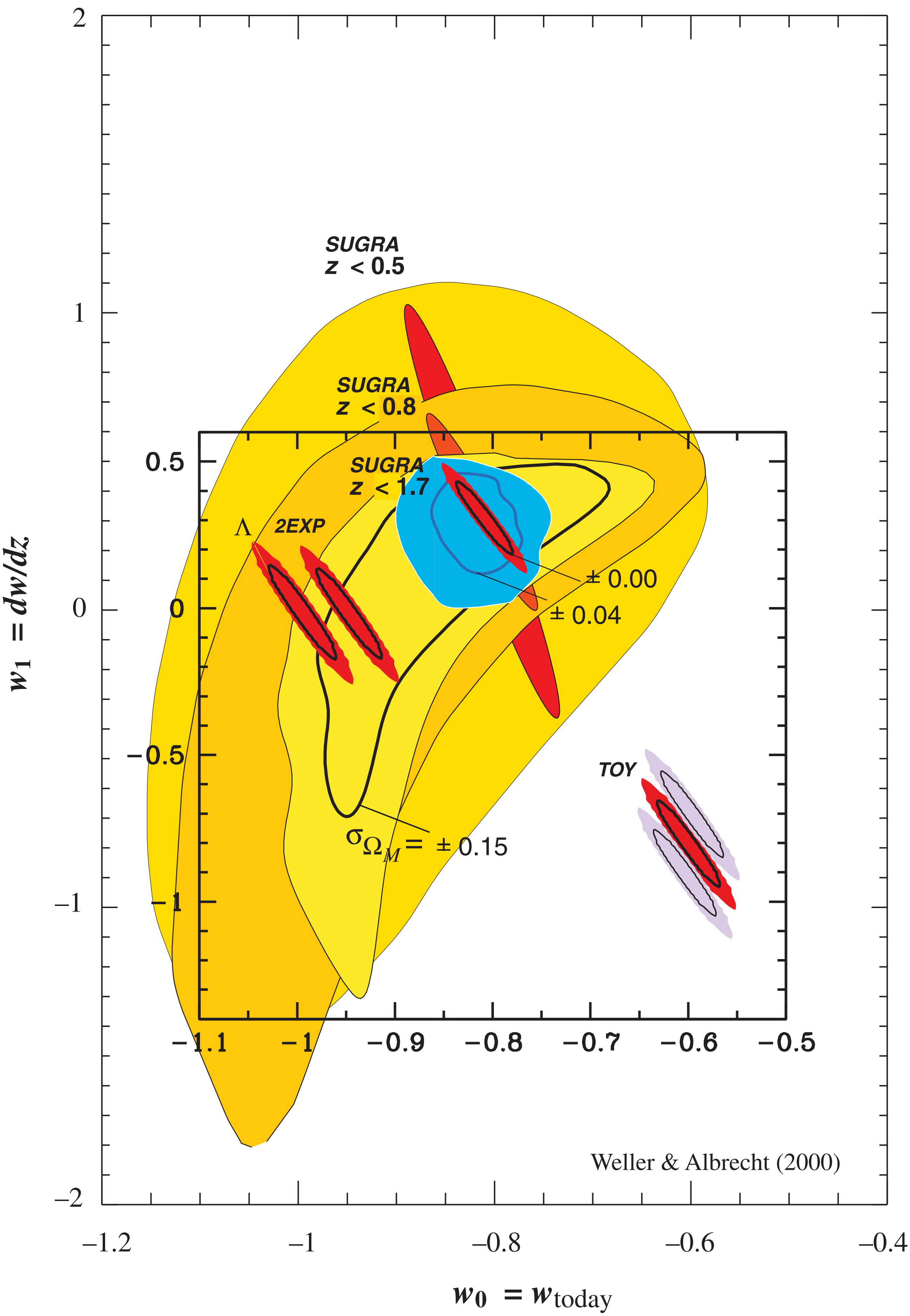
SNAP SuperNova Acceleration Probe

Binned simulated SNAP data
compared with Dark Energy models.



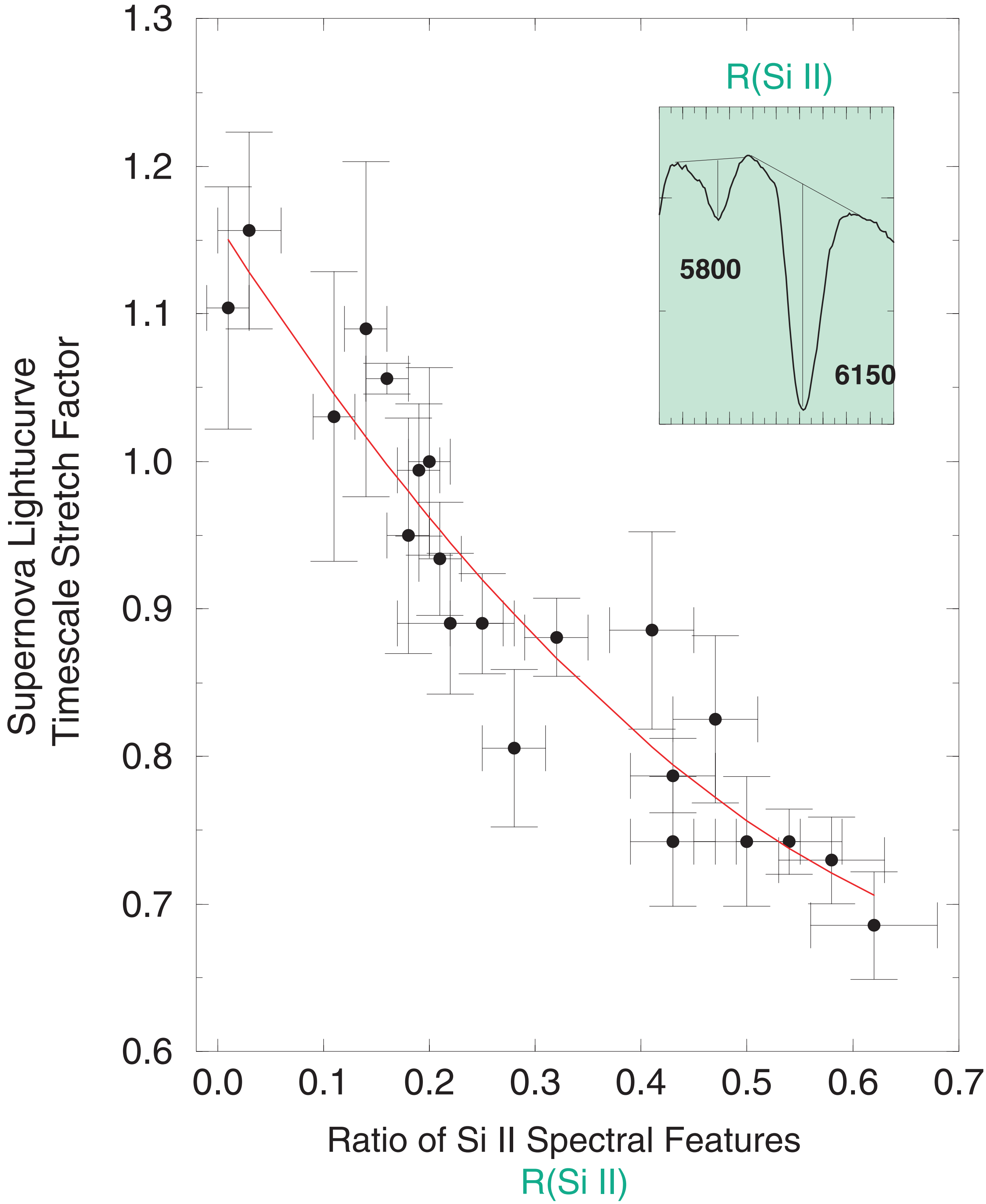
Weller & Albrecht (2000)


Weller & Albrecht (2000)
SUGRA
Λ
2EXP
TOY
± 0.00
± 0.04
± 0.05
$\sigma_{\Omega_M} = \pm 0.15$
0.5
0
−0.5
−1
−1.1
−1
−0.9
−0.8
−0.7
−0.6
−0.5
$w_1 = dw/dz$
$w_0 = w_{\rm today}$



SUGRA
z < 0.5
SUGRA
z < 0.8
SUGRA
z < 1.7
Λ
2EXP
± 0.00
± 0.04
$\sigma_{\Omega_M} = \pm 0.15$
TOY
$w_1 = dw/dz$
$w_0 = w_{\text{today}}$
Weller & Albrecht (2000)

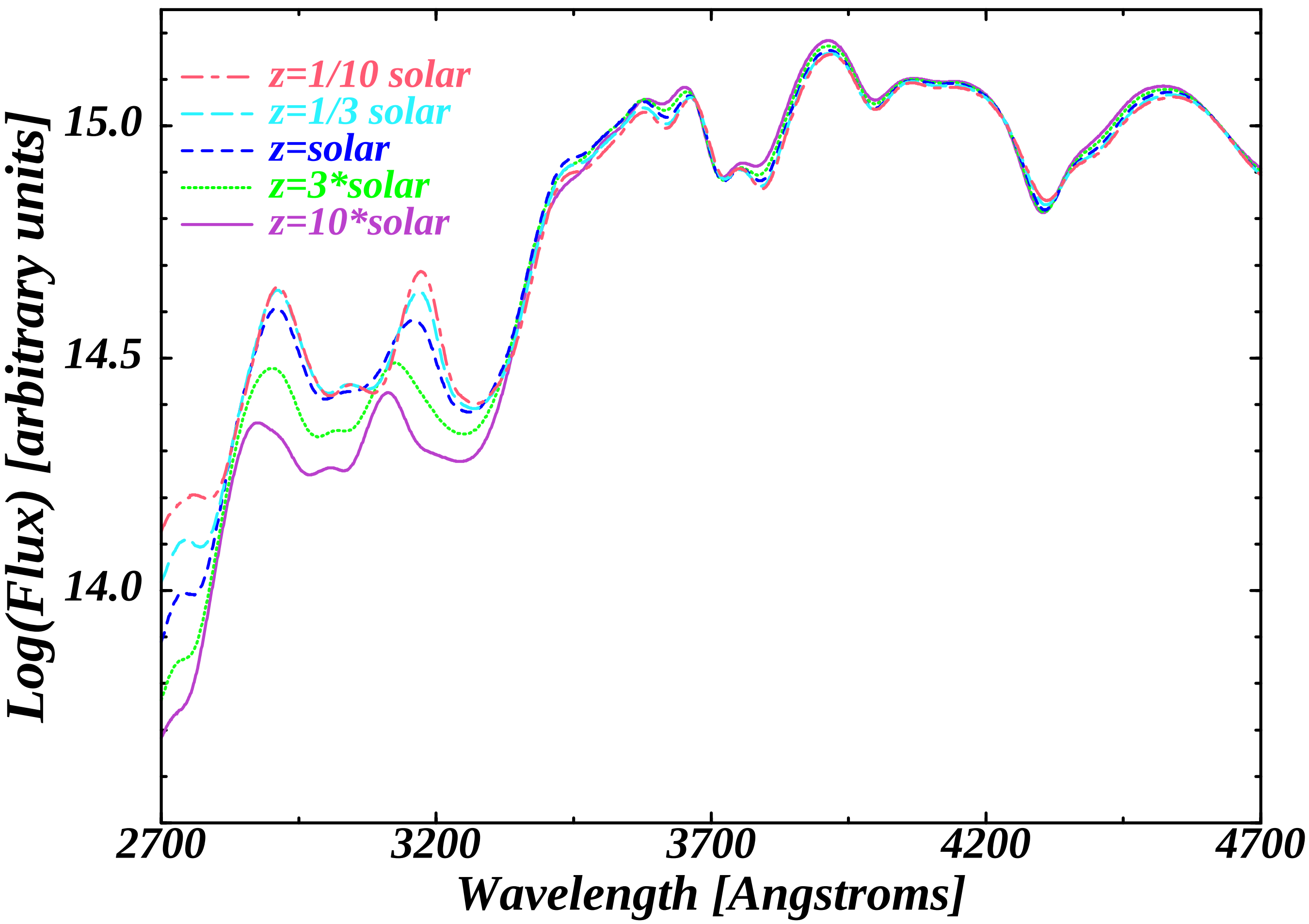
Control of SN Ia Systematics
Using High Signal-to-Noise Spectra



SNAP SuperNova Acceleration Probe

Explosion Parameters from Spectrum:

Kinetic Energy from *Line Velocities*
Metallicity from *UV Continuum*
Nickel Mass from *Line Ratios*



Spectrum & Lightcurve Reveal Explosion Initial Conditions

Observables	^{56}Ni Mass	^{56}Ni Distribution	Kinetic Energy	Opacity	Metal-licity
Spectral feature minima	○	—	●	○	●
Spectral feature widths	○	—	●	○	●
Spectral feature Ratios	●	—	○	○	●
Lightcurve Stretch	●	○	○	●	—
Lightcurve Rise Time	●	●	○	○	○
Lightcurve Peak/Tail	○	—	○	●	—

● = directly related to model parameter

○ = indirectly related to model parameter

— = slightly related to or no relation to the model parameter

SNAP will measure all of these Observables

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

Science Goals for The First Wide-field Survey in Space

*The **only** wide field deep survey in space:*
Deeper than the HDF (esp. IR) and 7000x larger,
with broad wavelength coverage, and high resolution.

Primary Cosmology Mission:
Cosmological Parameters, Dark Matter, Dark Energy,...

Type Ia supernova calibrated candle:
Hubble diagram to $z = 1.7$

Type II supernova expanding photosphere:
Hubble diagram to $z = 1$ and beyond.

Weak lensing:
Direct measurements of $P(k)$ vs z
Mass selected cluster survey vs z

Strong lensing statistics: Ω_Λ
10x gains over ground based optical resolution, IR channels + depth.

Galaxy clustering:
$W(\Theta)$ angular correlation vs redshift from 0.5 to 3.0

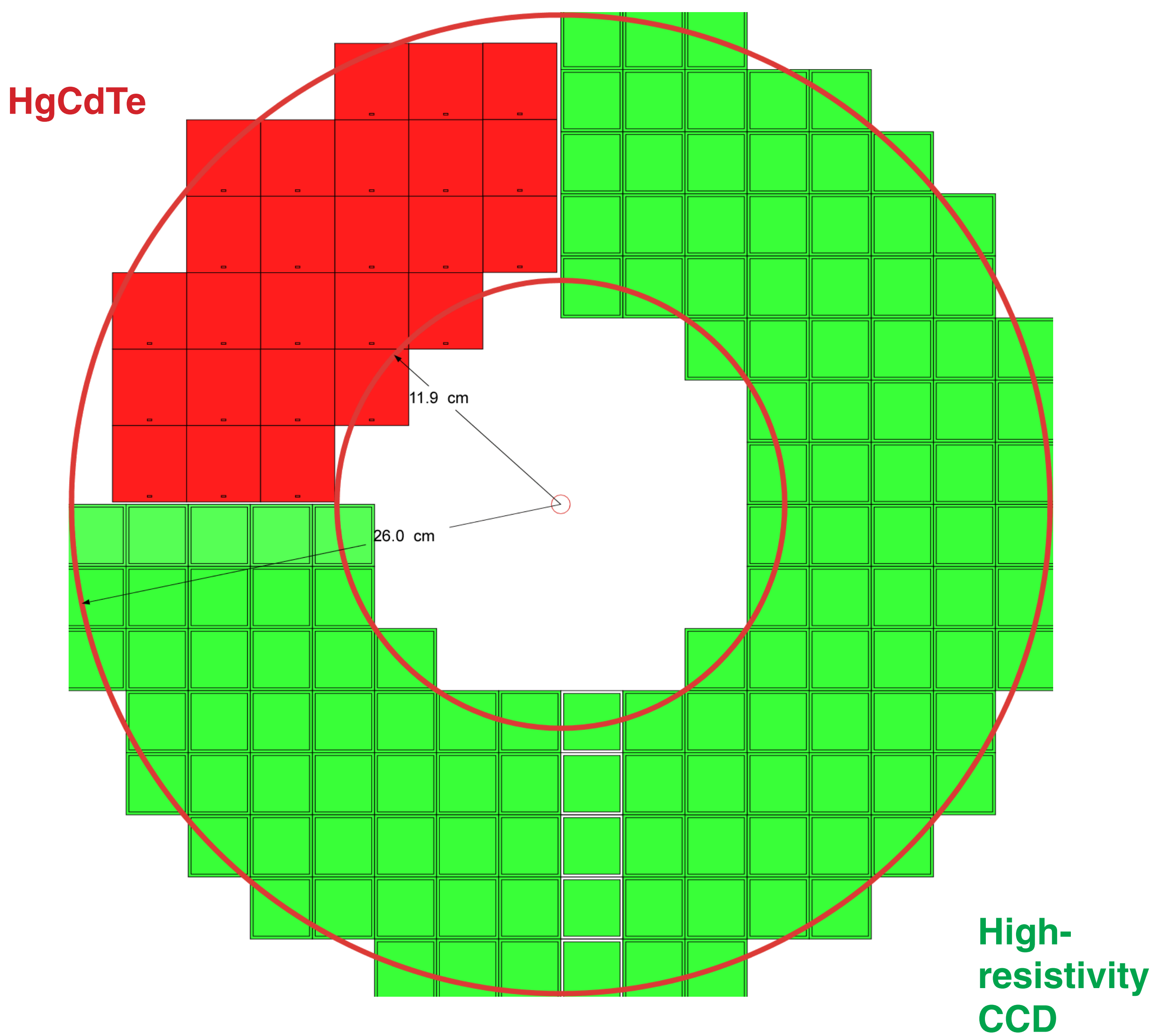
Magnitudes given are for S/N>=5 detections for 95% of point sources. 2x2 interlacing has been enforced under the assumption that this is a survey mode, so we will want to have minimal aliasing. All magnitudes are AB system.

Band	1000s	10,000s	100,000s (3)
H' (1)	26.4	27.85	29.25
J	26.6	28.1	29.4
Z	27.35	28.85	30.2
I	27.4	28.9	30.25
R	27.55	29.1	30.4
V	27.25	28.85	30.25
B	27.65	29.3	30.65
U (3)	26.6	28.5	29.9

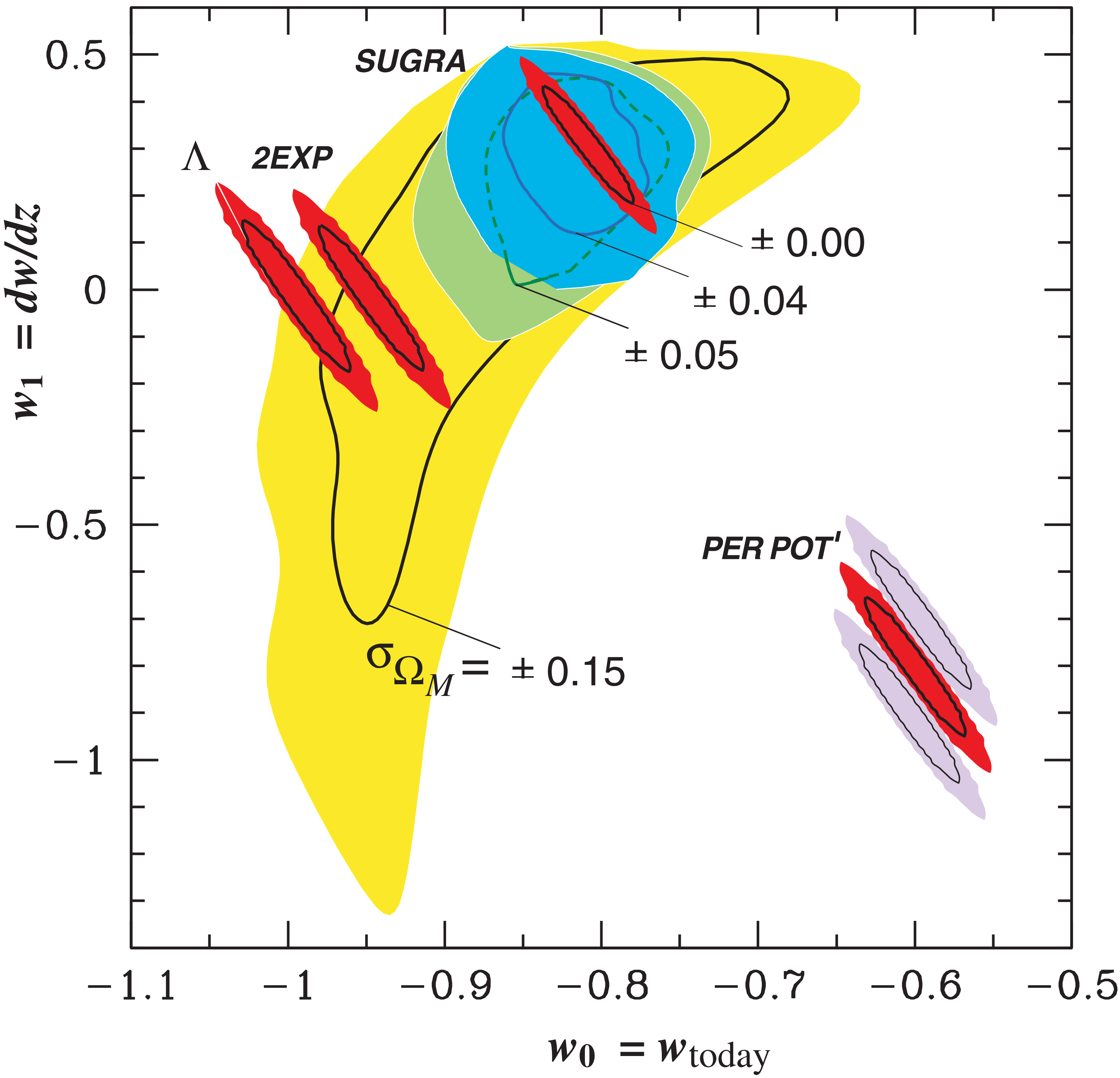
NOTES:
1) H' filter is 1.5-1.7 um rectangular bandpass.
2) Optical efficiency of 83% is now assumed, as might be reached for a Ag-coated mirror set and good interference filters. This is clearly too optimistic for U-band. I've used 50% for U.
3) Exp. times for NIR want to be ~900s for deep exposure sequences. ~600s for deep Z/I/R, 900s for V/B, 1800s U.

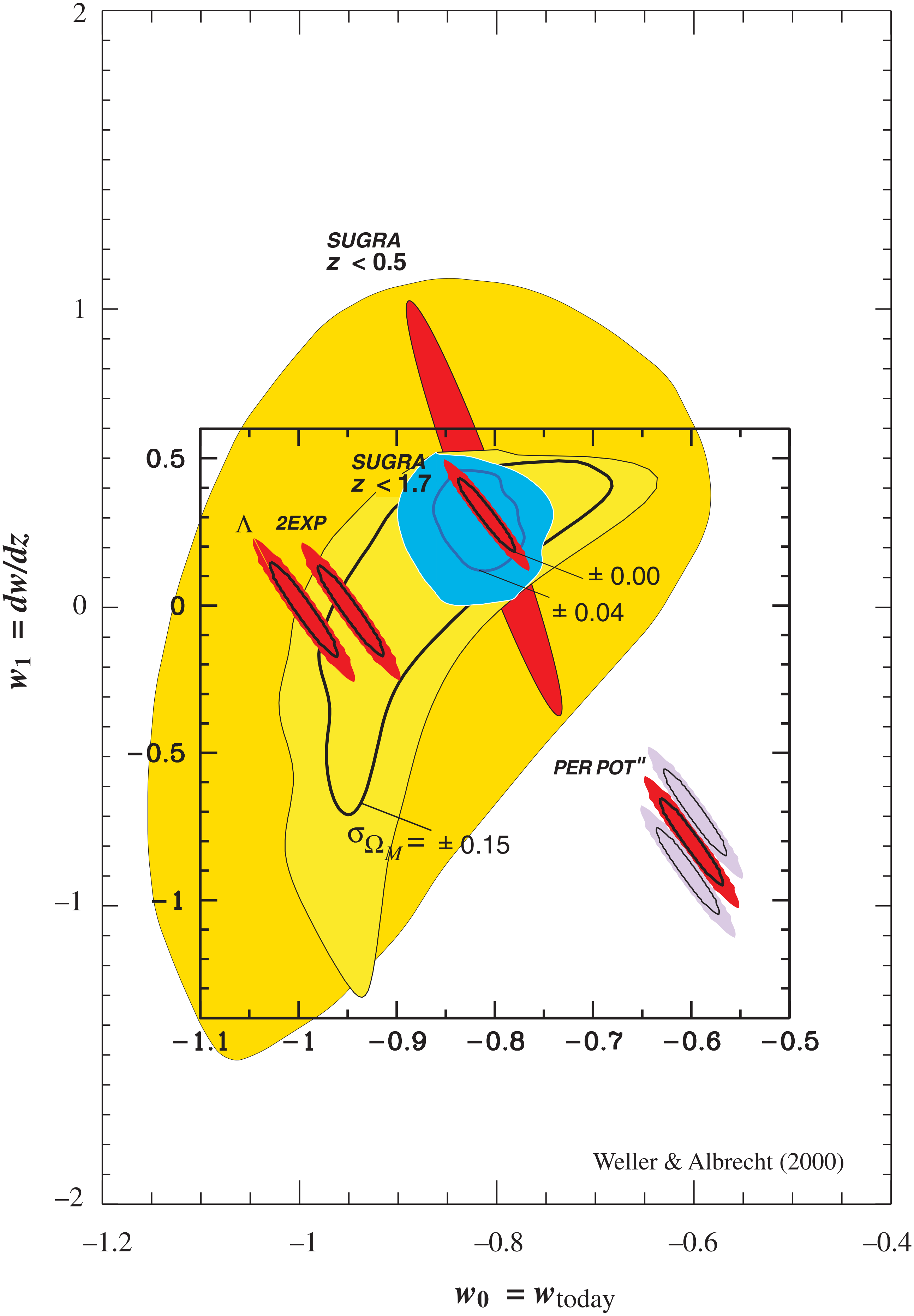
SNAP SuperNova Acceleration Probe

GigaCam focal plane detectors



Weller & Albrecht (2000)





SUGRA
z < 0.5
SUGRA
z < 1.7
Λ
2EXP
± 0.00
± 0.04
σ_{Ω_M} = ± 0.15
PER POT"
0.5
0
−0.5
−1
−1.1
−1
−0.9
−0.8
−0.7
−0.6
−0.5
2
1
0
−1
−2
−1.2
−1
−0.8
−0.6
−0.4
$w_1 = dw/dz$
$w_0 = w_{\rm today}$
Weller & Albrecht (2000)