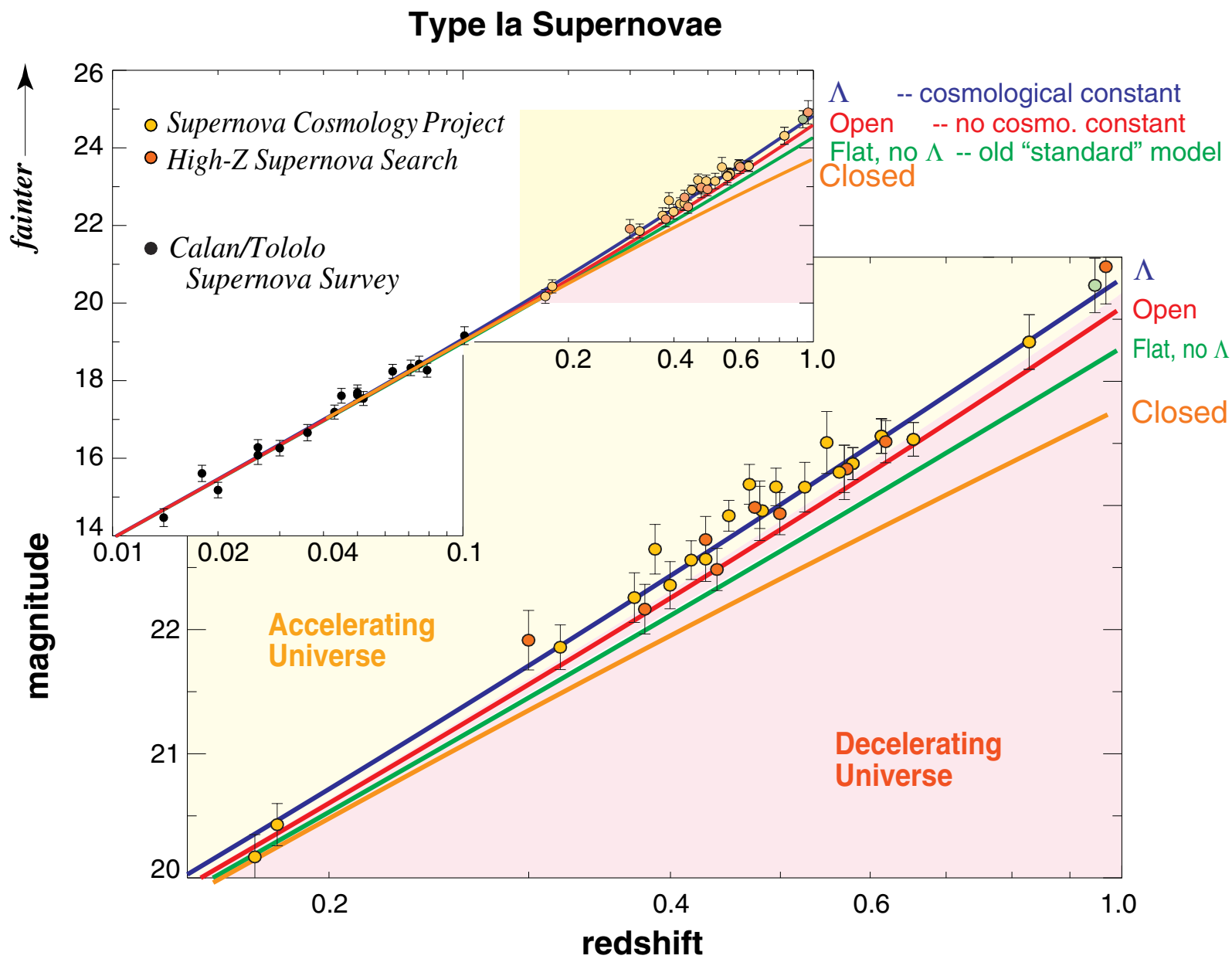
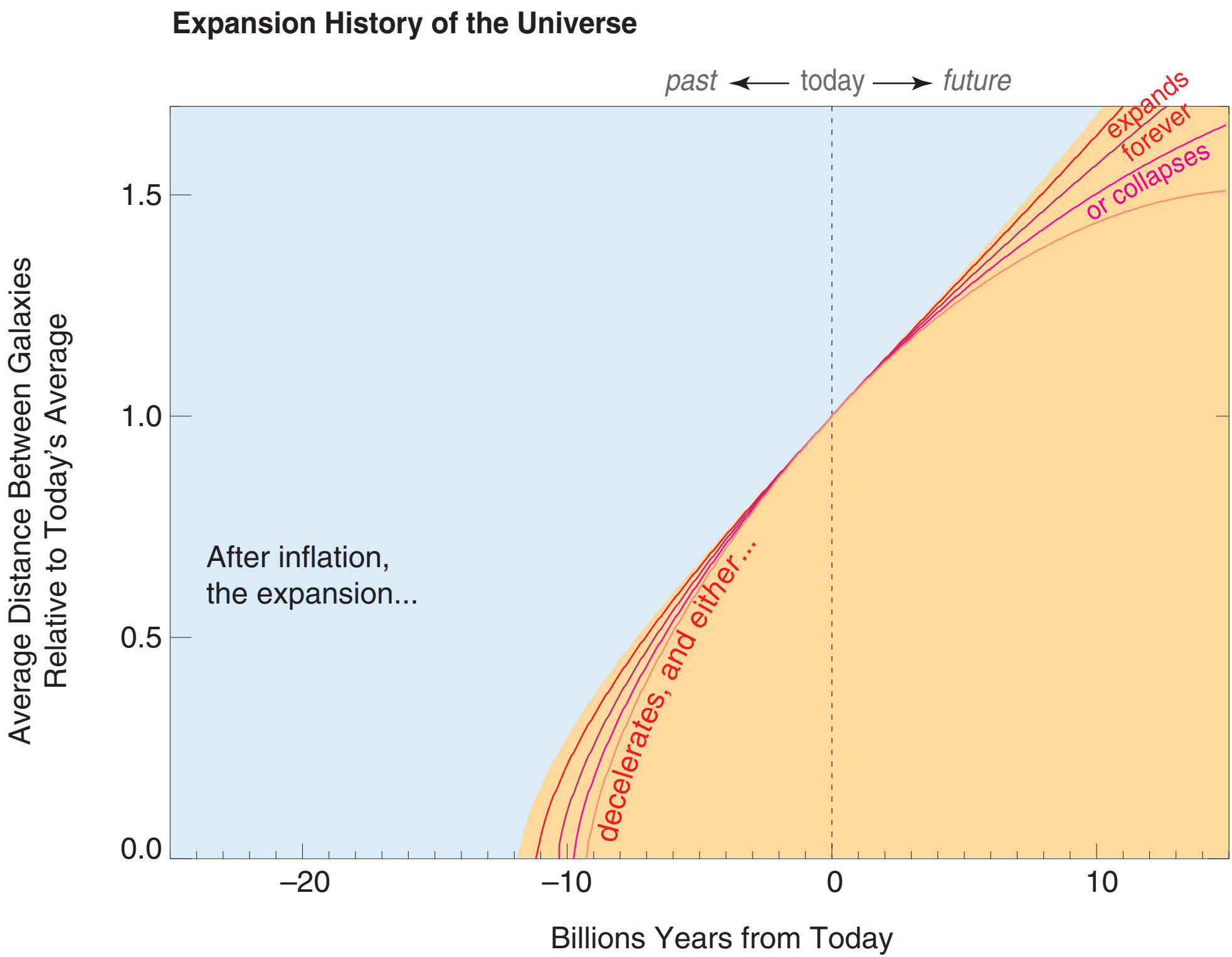
SuperNova / Acceleration Probe
DOE Review:
Science Overview

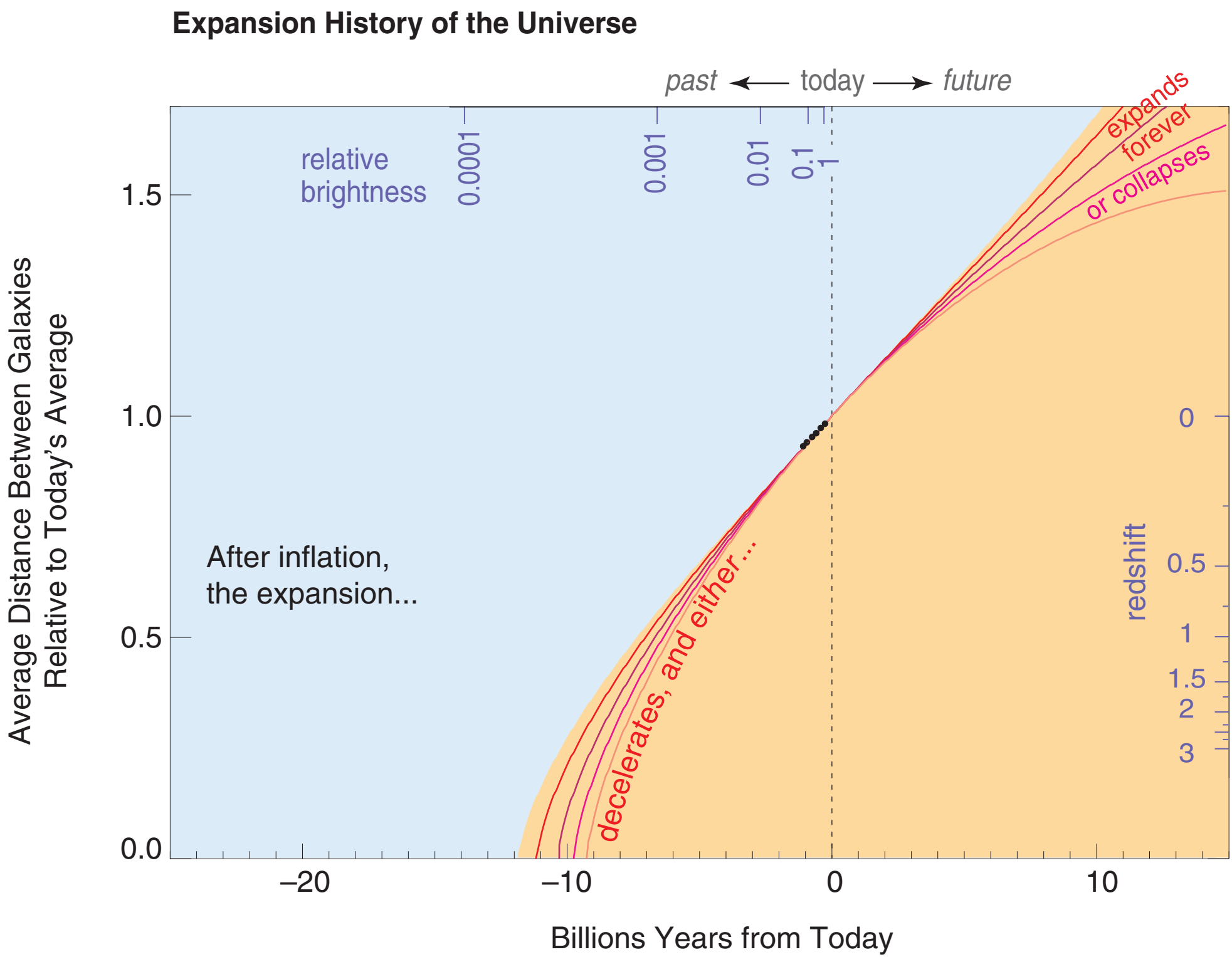
Lawrence Berkeley Laboratory
November 2003

Saul Perlmutter

0. Background: cosmology/dark energy measurements from supernovae.
1. A really hard goal: $w'(z)$.
2. An exhaustive list of systematics.
3. An unusual tool for cosmology.
4. How this tool can address systematics.
5. Project status and reviews.


Type Ia Supernovae
Supernova Cosmology Project
High-Z Supernova Search
Calan/Tololo
Supernova Survey
Λ -- cosmological constant
Open -- no cosmo. constant
Flat, no Λ -- old "standard" model
Closed
Λ
Open
Flat, no Λ
Closed
Accelerating
Universe
Decelerating
Universe
fainter
magnitude
redshift
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


Expansion History of the Universe
past
today
future
expands
forever
or collapses
decelerates, and either ...
After inflation,
the expansion...
1.5
1.0
0.5
0.0
–20
–10
0
10
Average Distance Between Galaxies
Relative to Today's Average
Billions Years from Today



Expansion History of the Universe
past
today
future
relative brightness
0.0001
0.001
0.01
0.1
1
expands forever or collapses
After inflation, the expansion...
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redshift
0
0.5
1
1.5
2
3
1.5
1.0
0.5
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–20
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0
10
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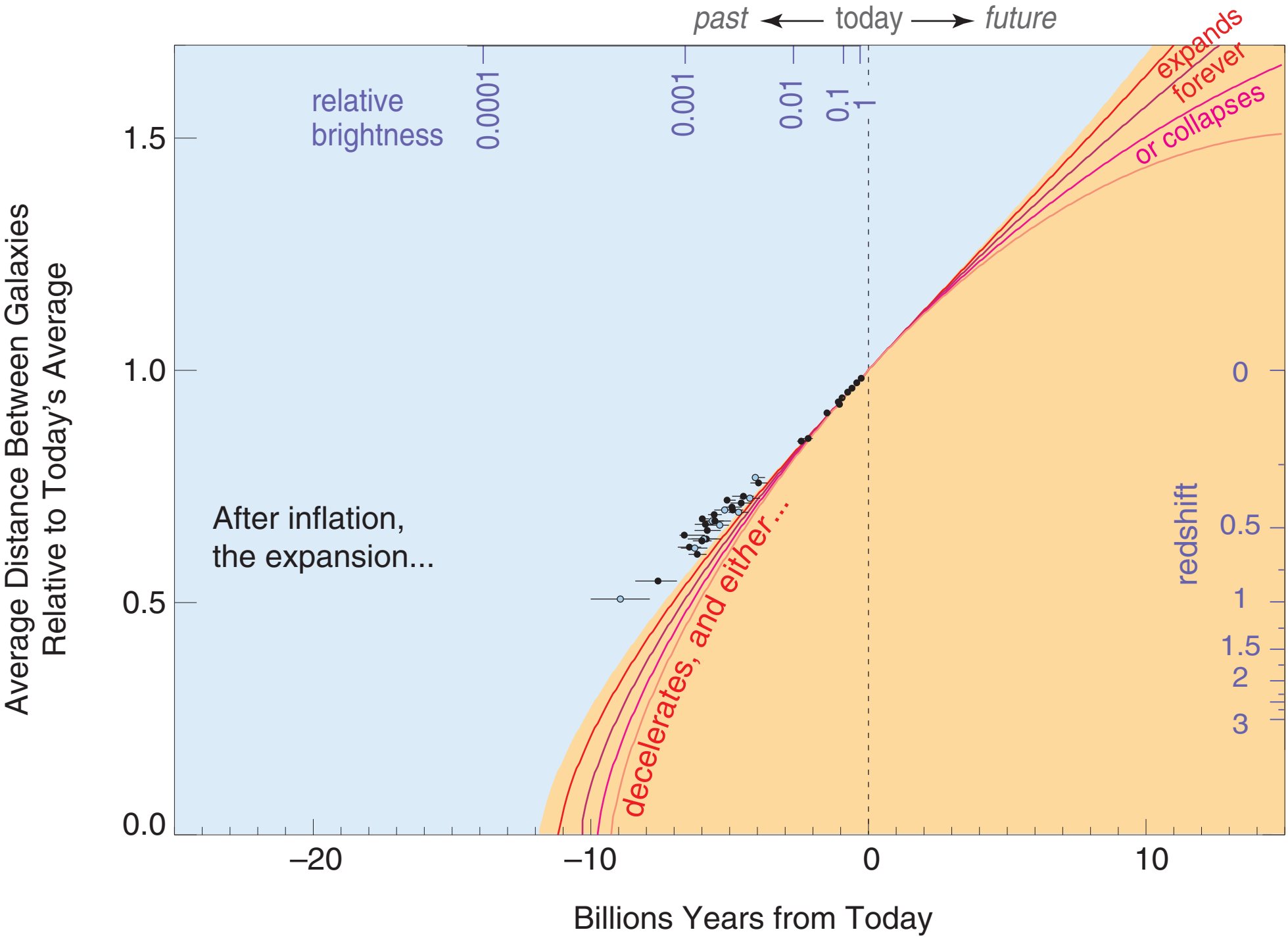

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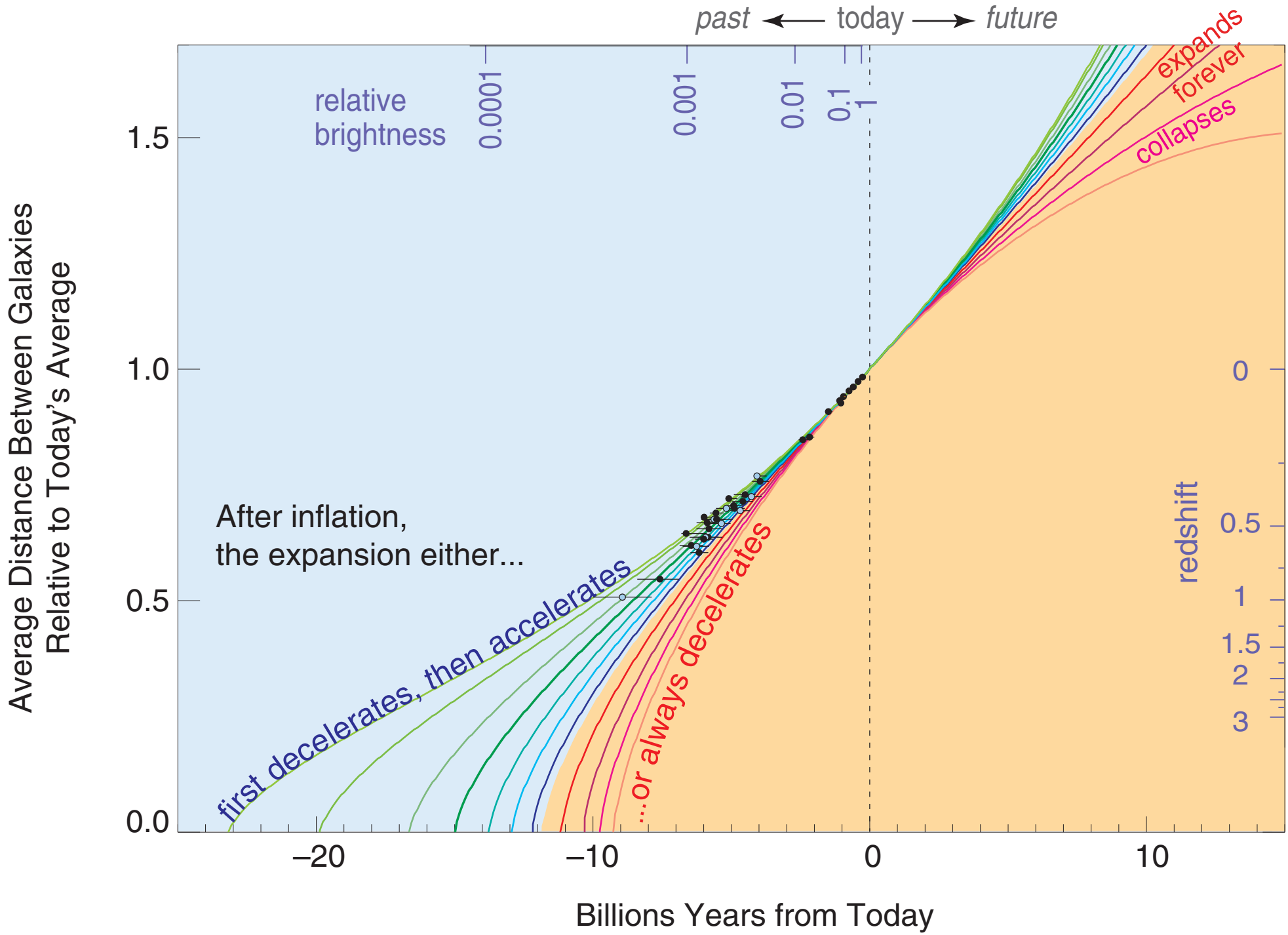
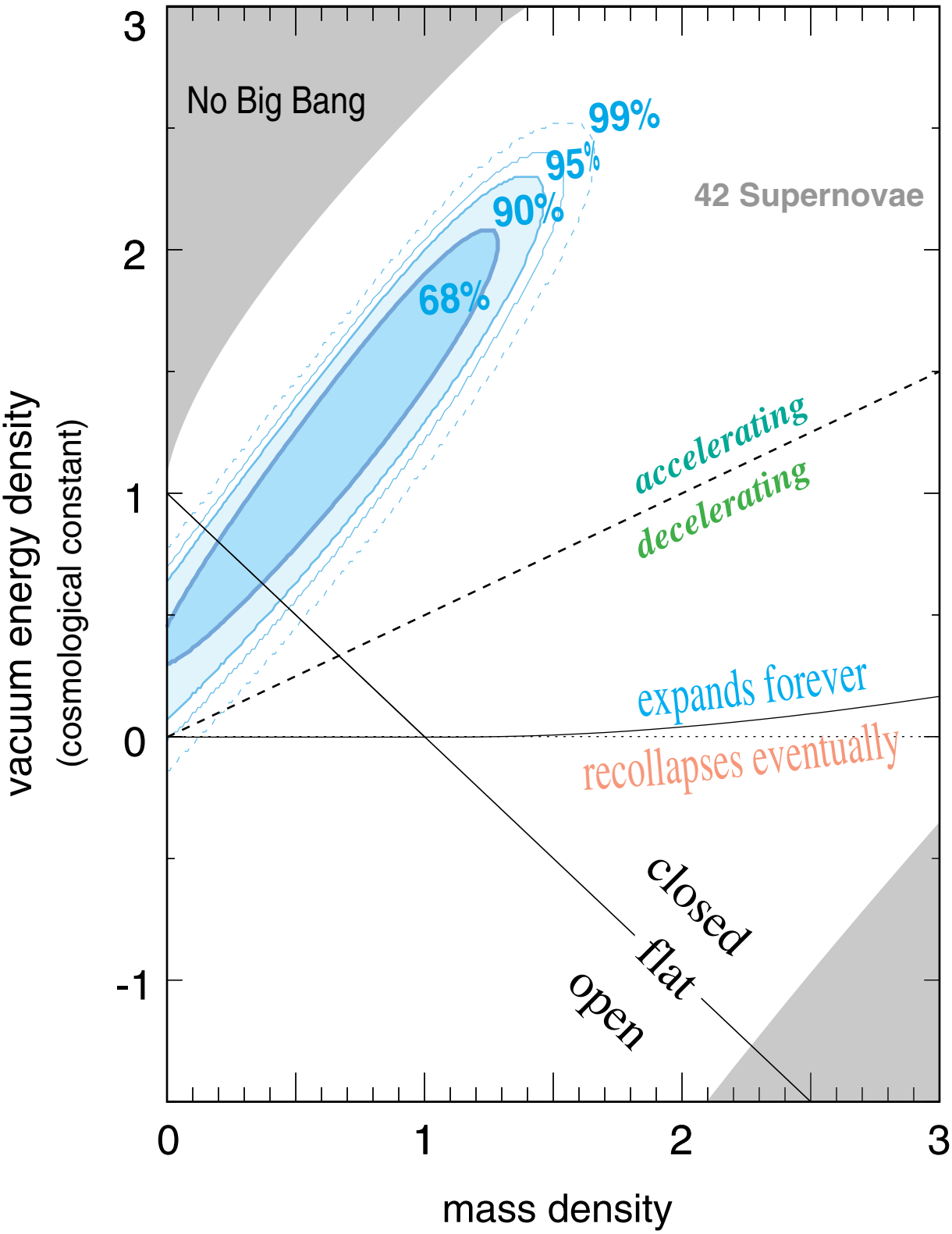
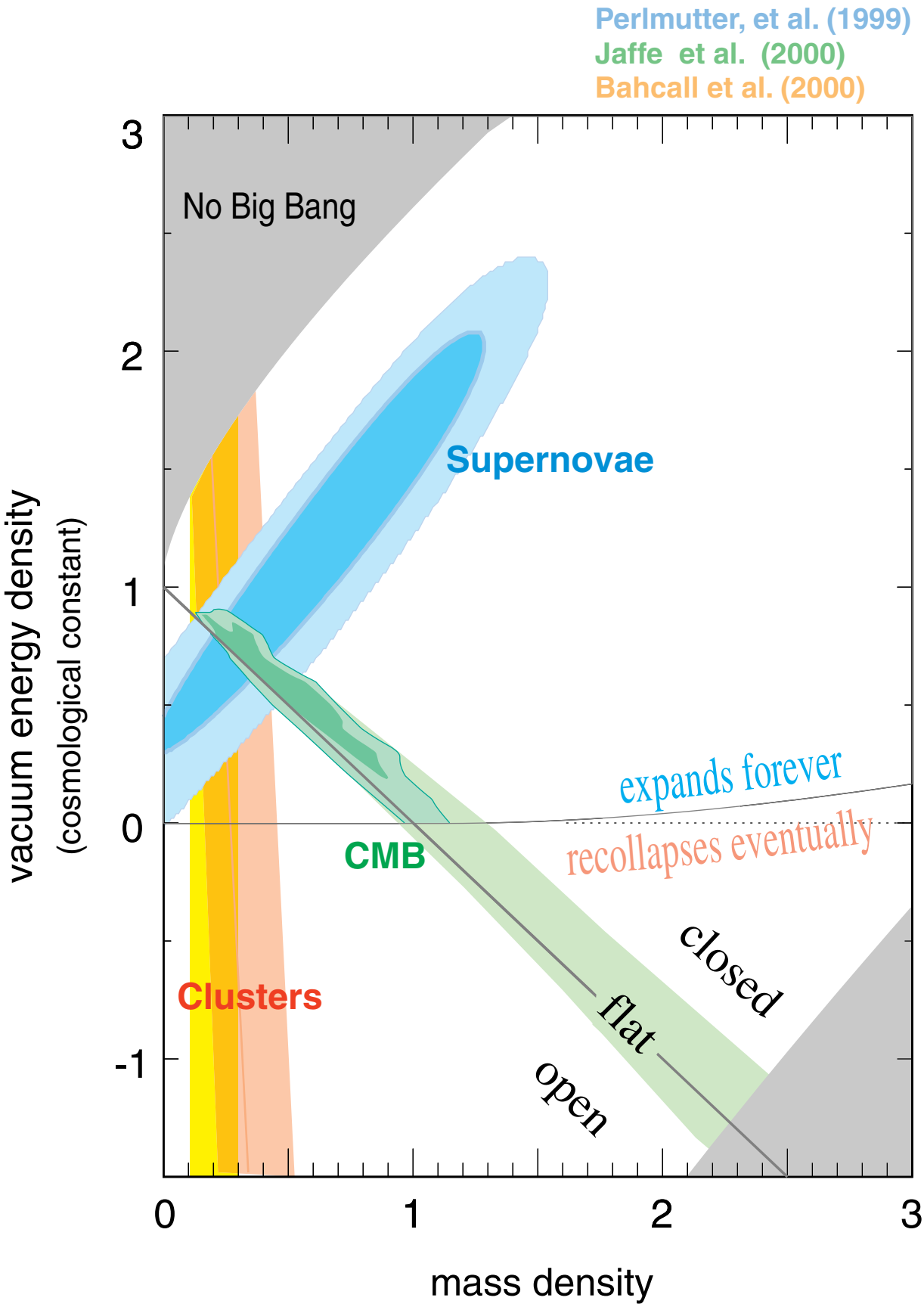
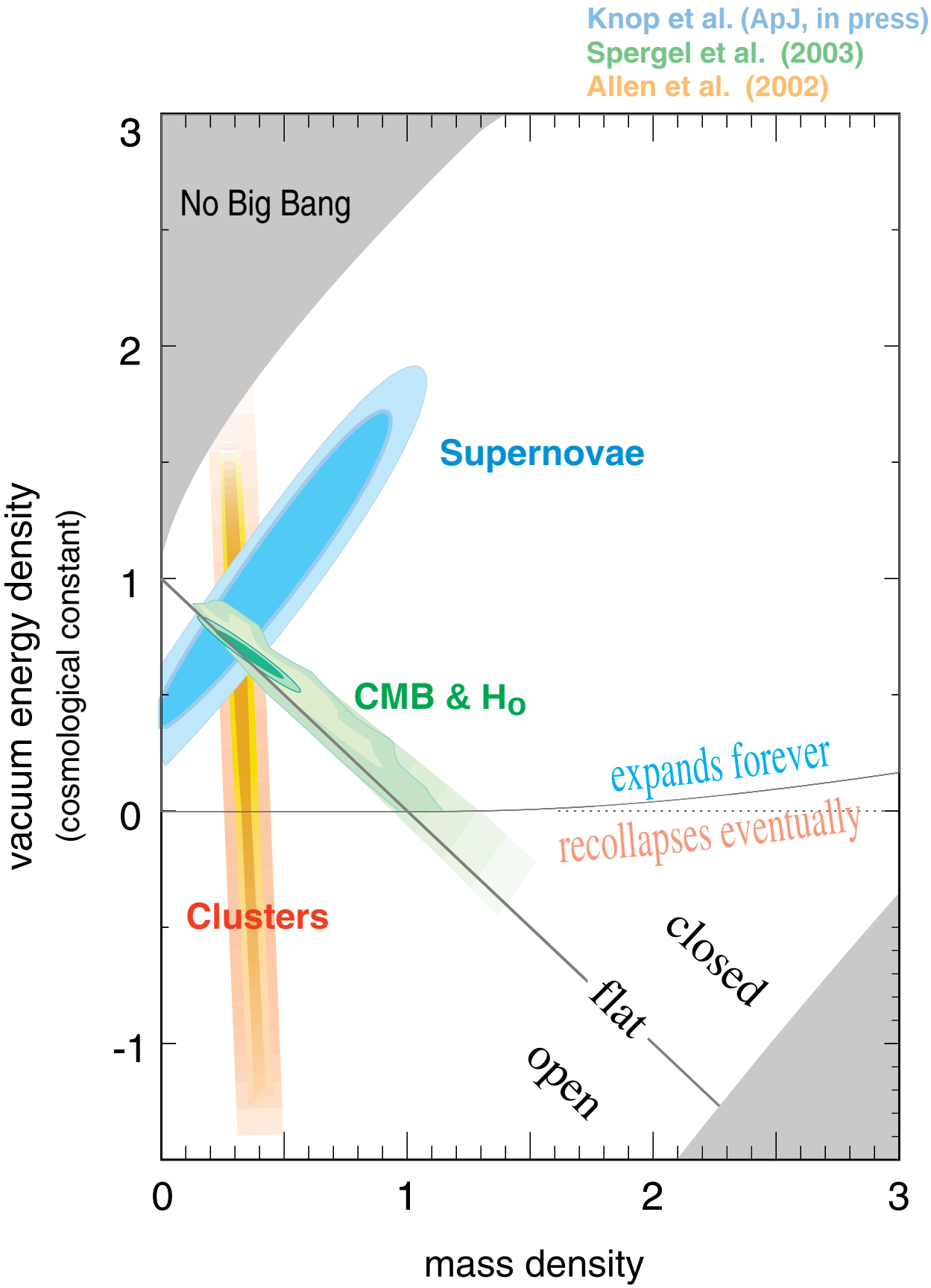


Supernova Cosmology Project



Perlmutter *et al.*
(Ap.J. 1999)
astro-ph/98 12133


Perlmutter, et al. (1999)
Jaffe et al. (2000)
Bahcall et al. (2000)
No Big Bang
Supernovae
CMB
Clusters
expands forever
recollapses eventually
closed
flat
open
vacuum energy density
(cosmological constant)
mass density
3
2
1
0
-1
0
1
2
3


Knop et al. (ApJ, in press)
Spergel et al. (2003)
Allen et al. (2002)
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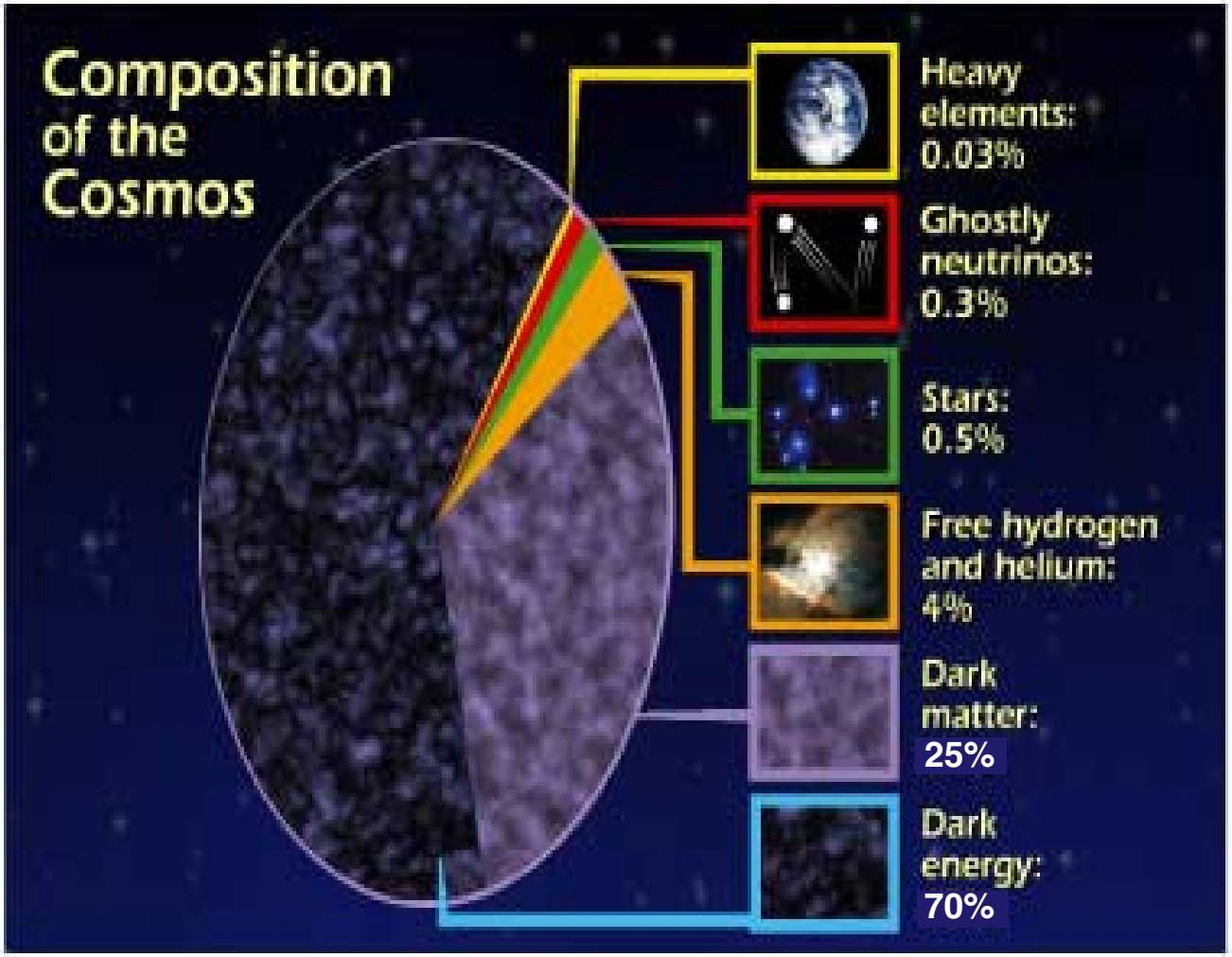

Composition of the Cosmos
Heavy elements: 0.03%
Ghostly neutrinos: 0.3%
Stars: 0.5%
Free hydrogen and helium: 4%
Dark matter: 25%
Dark energy: 70%

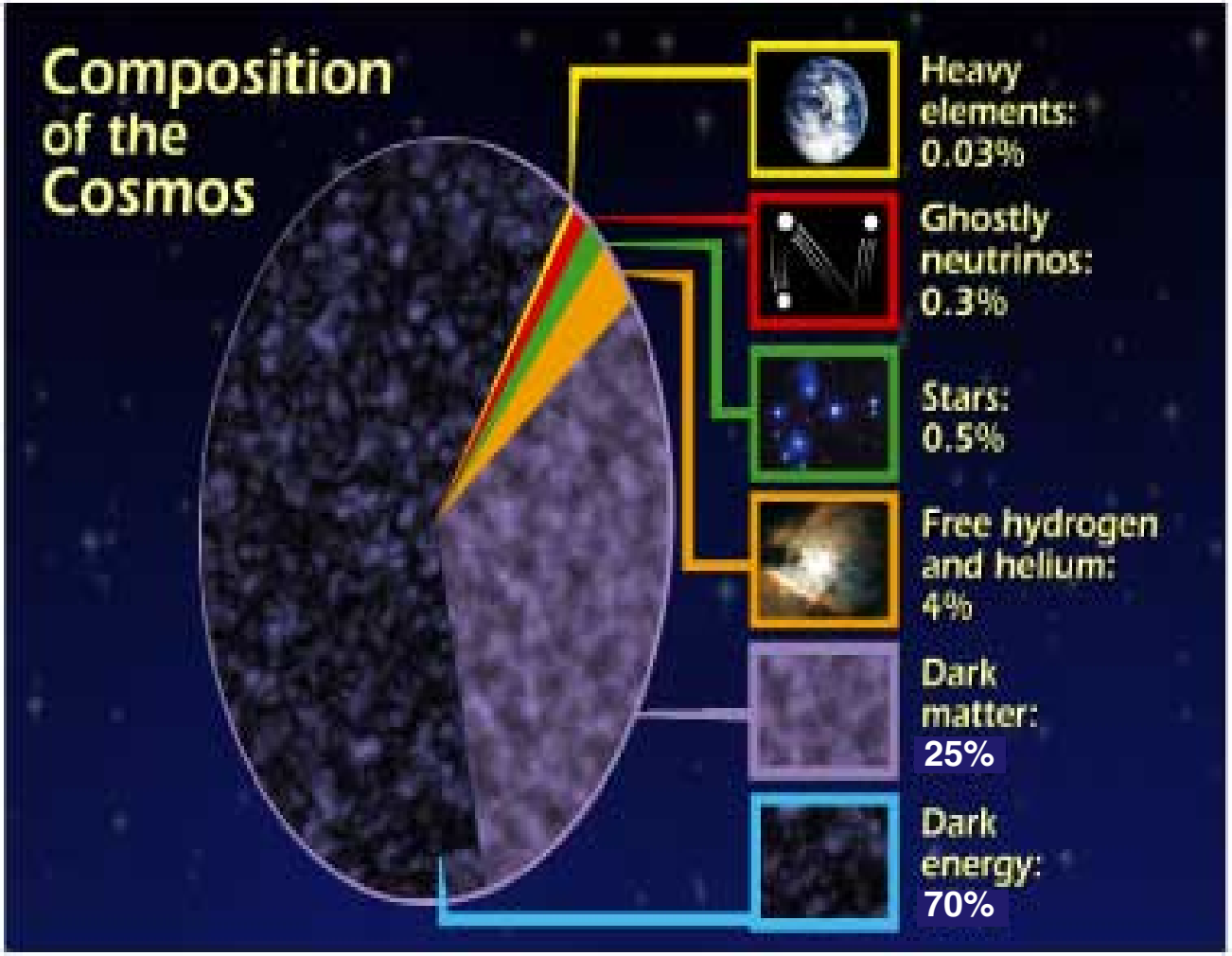
Physicists on Vacuum Energy/Cosmological Constant:

"Right now, not only for cosmology but for elementary particle theory, this is the bone in our throat."

—Steven Weinberg

"...Maybe the most fundamentally mysterious thing in basic science."

—Frank Wilczek



"...Would be No. 1 on my list of things to figure out."

—Edward Witten

"Basically, people don't have a clue as to how to solve this problem."

—Jeff Harvey

"This is the biggest embarrassment in theoretical physics,"

—Michael Turner

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

Two coincidences:

- ***Why so small?***

  Might expect $\frac{\Lambda}{8\pi G} \sim m_{\text{Planck}}^4$

  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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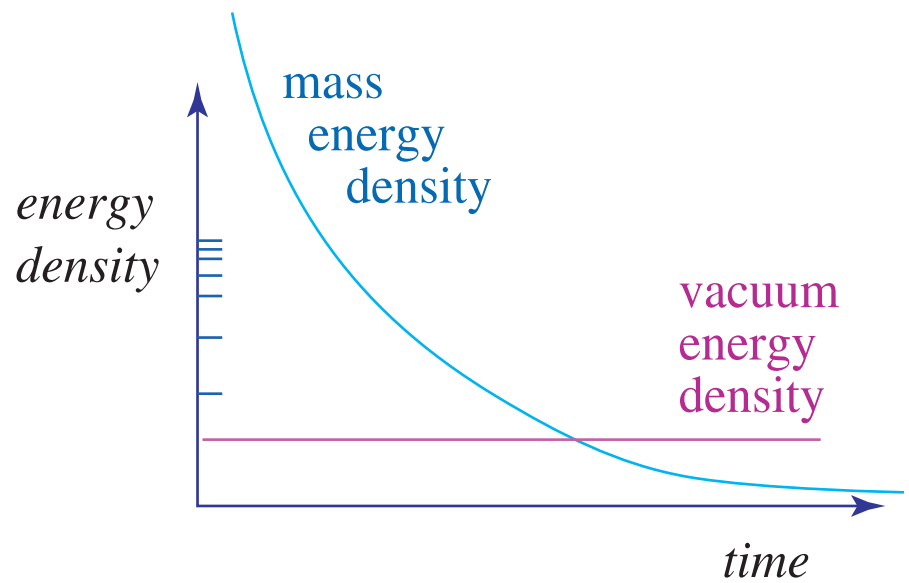

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MATTER: $p = 0 \longrightarrow \rho \propto R^{-3}$

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What are the alternatives?

New Physics: "Dark energy":

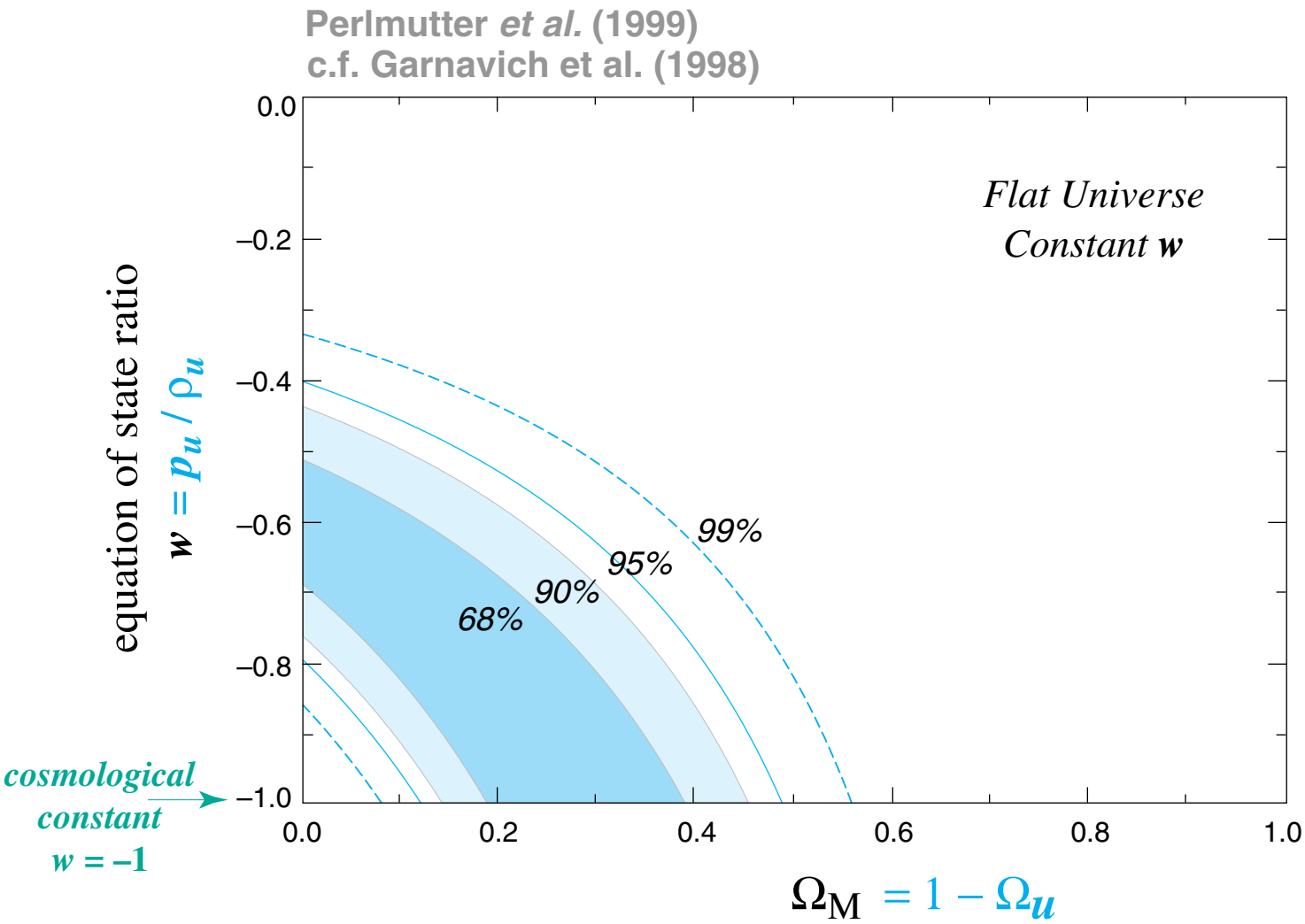
Dynamical scalar fields, "quintessence",...

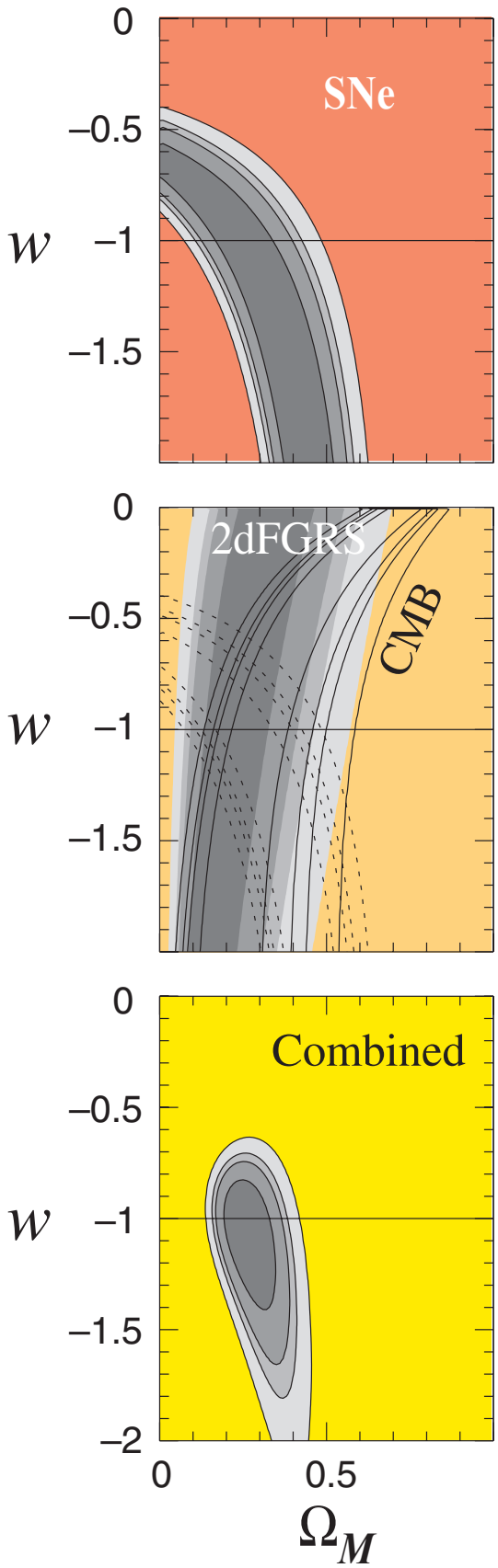
General Equation of State:

$$p = w\rho \longrightarrow \rho \propto R^{-3(1+w)}$$

and w can vary with time

Unknown Component, Ω_u, of Energy Density





Supernova Cosmology Project
Knop *et al.* (2003)

Assuming constant w

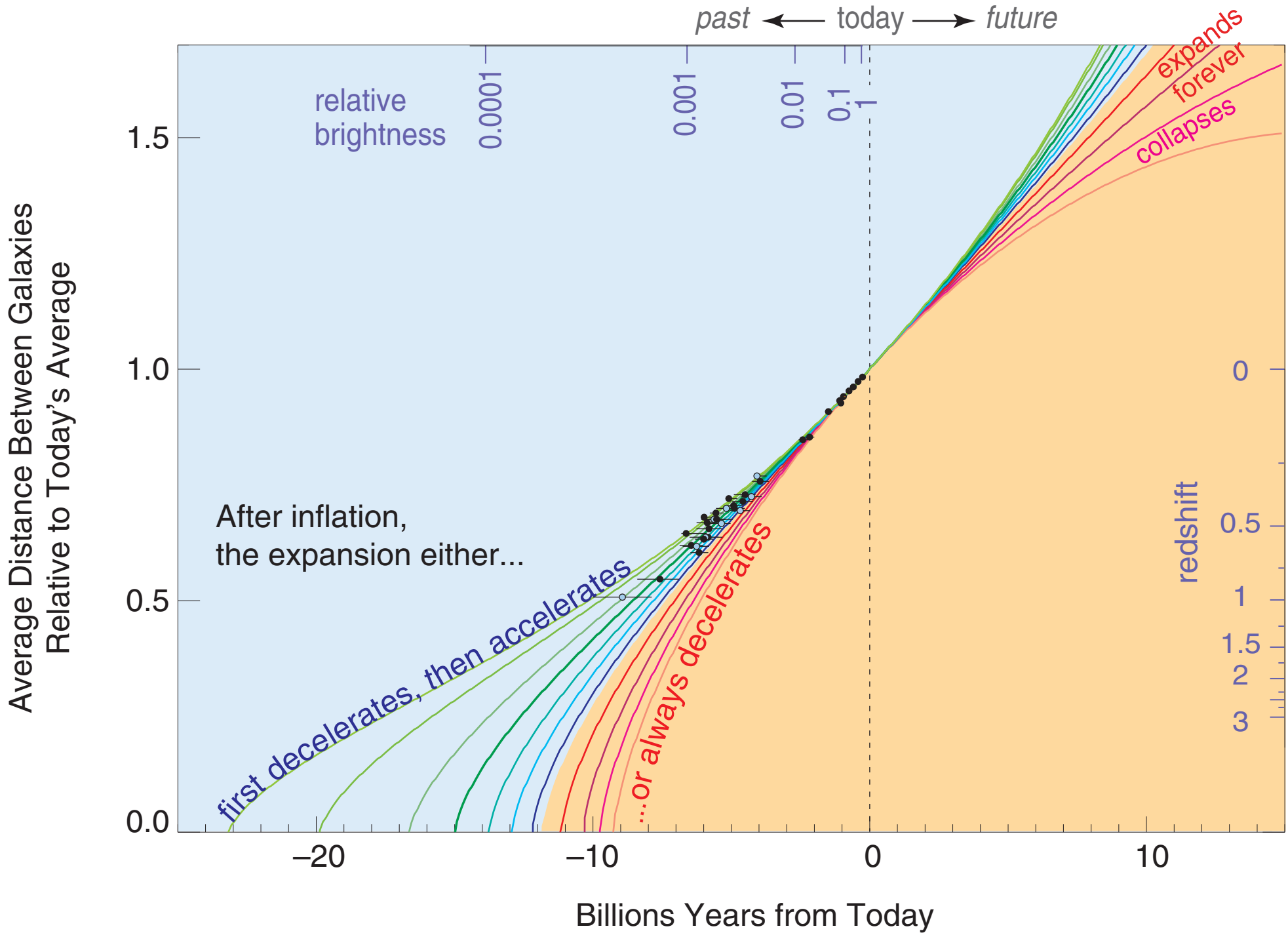
With limits from;
2dFGRS (Hawkins et al. 2002)
and CMB (Bennet et al. 2003,
Spergel et al. 2003)

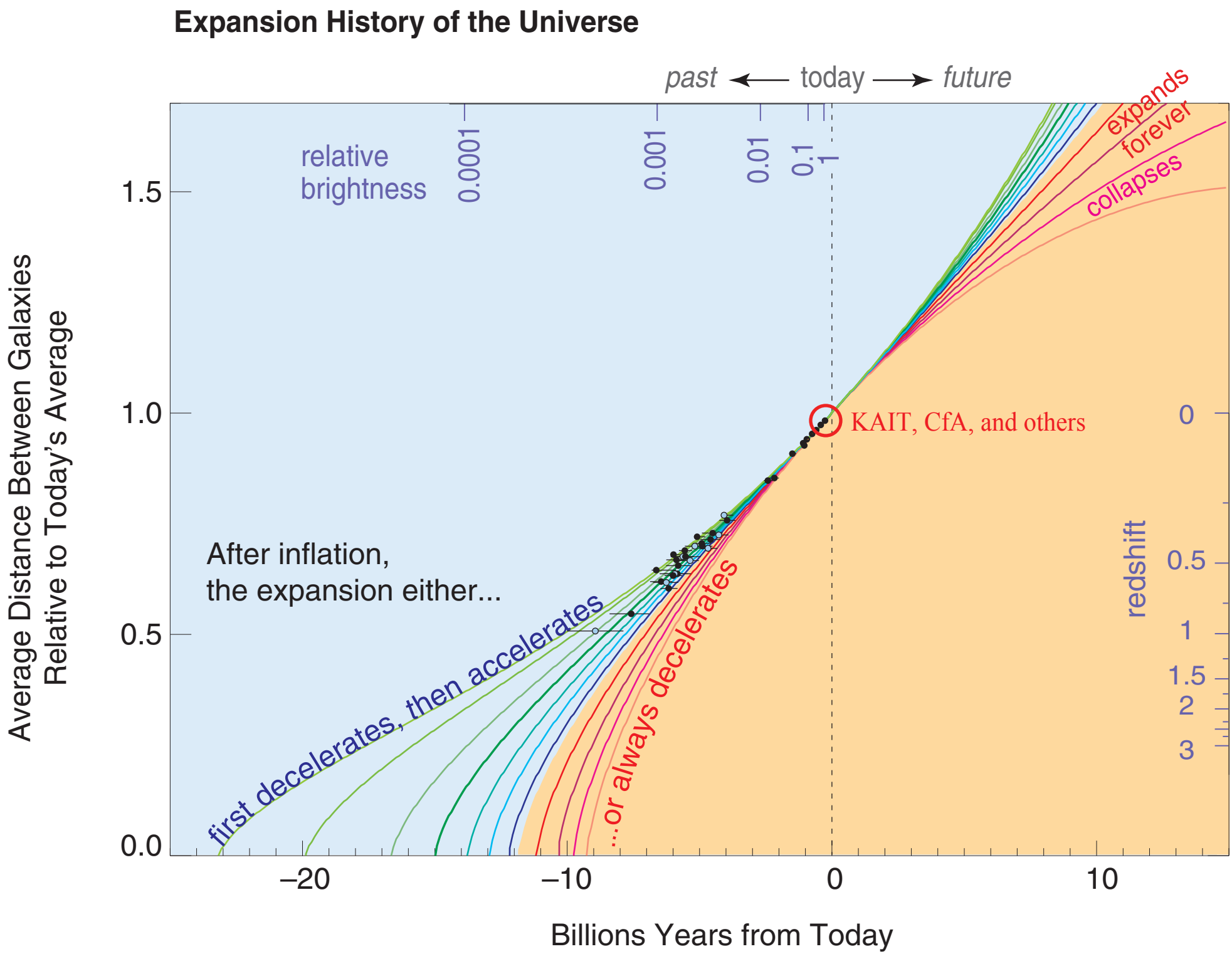
$$w = -1.05 \; {}^{+0.15}_{-0.20} \text{ (statistical)}$$
$$\pm 0.09 \text{ (systematic)}$$

1. A Really Hard Goal: $w'(z)$

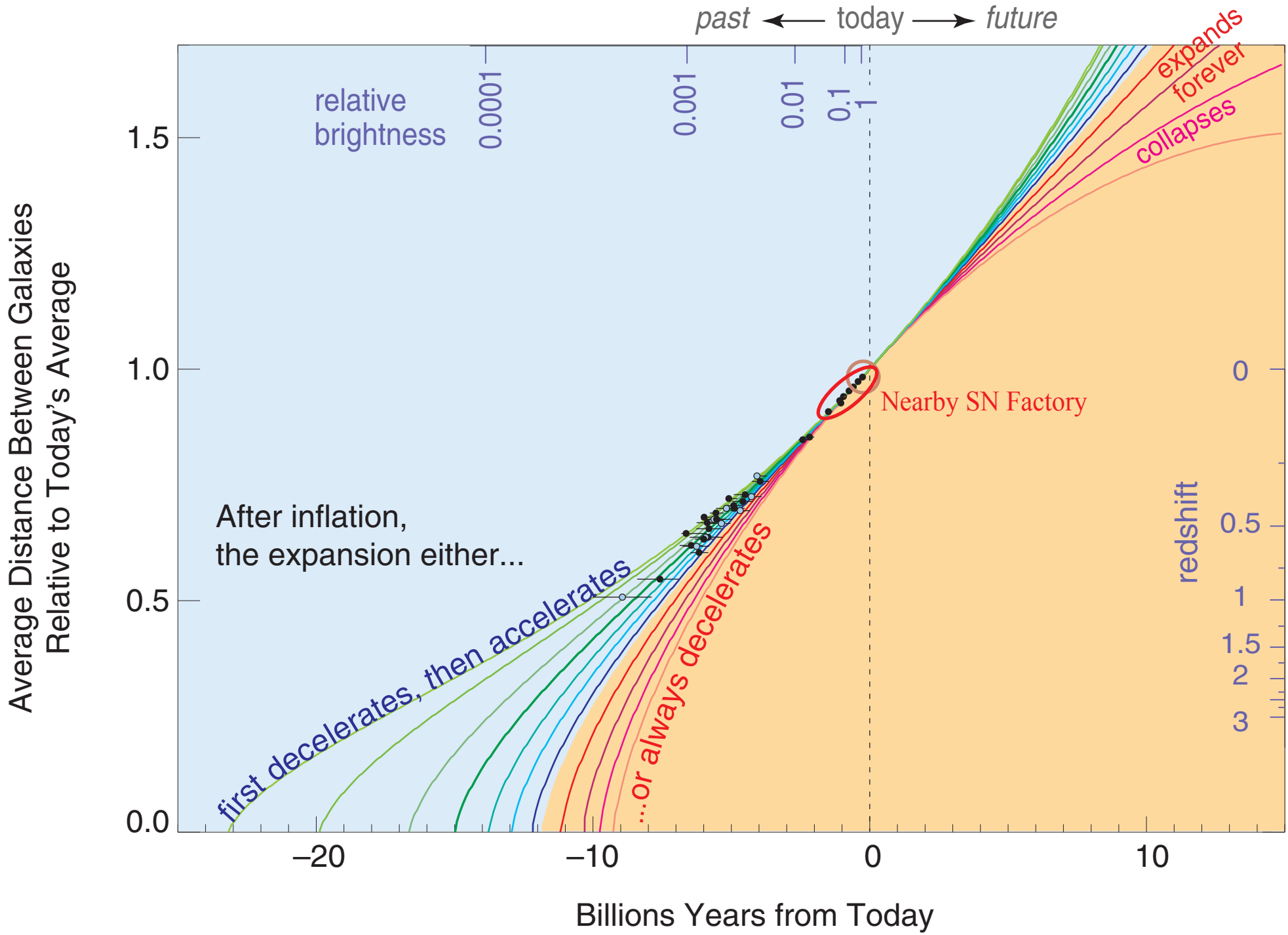
A measurement of the expansion history of the universe with enough accuracy that a measurement of a *change* in the properties of the dark energy, e.g. $w' \neq 0$, would be trusted.

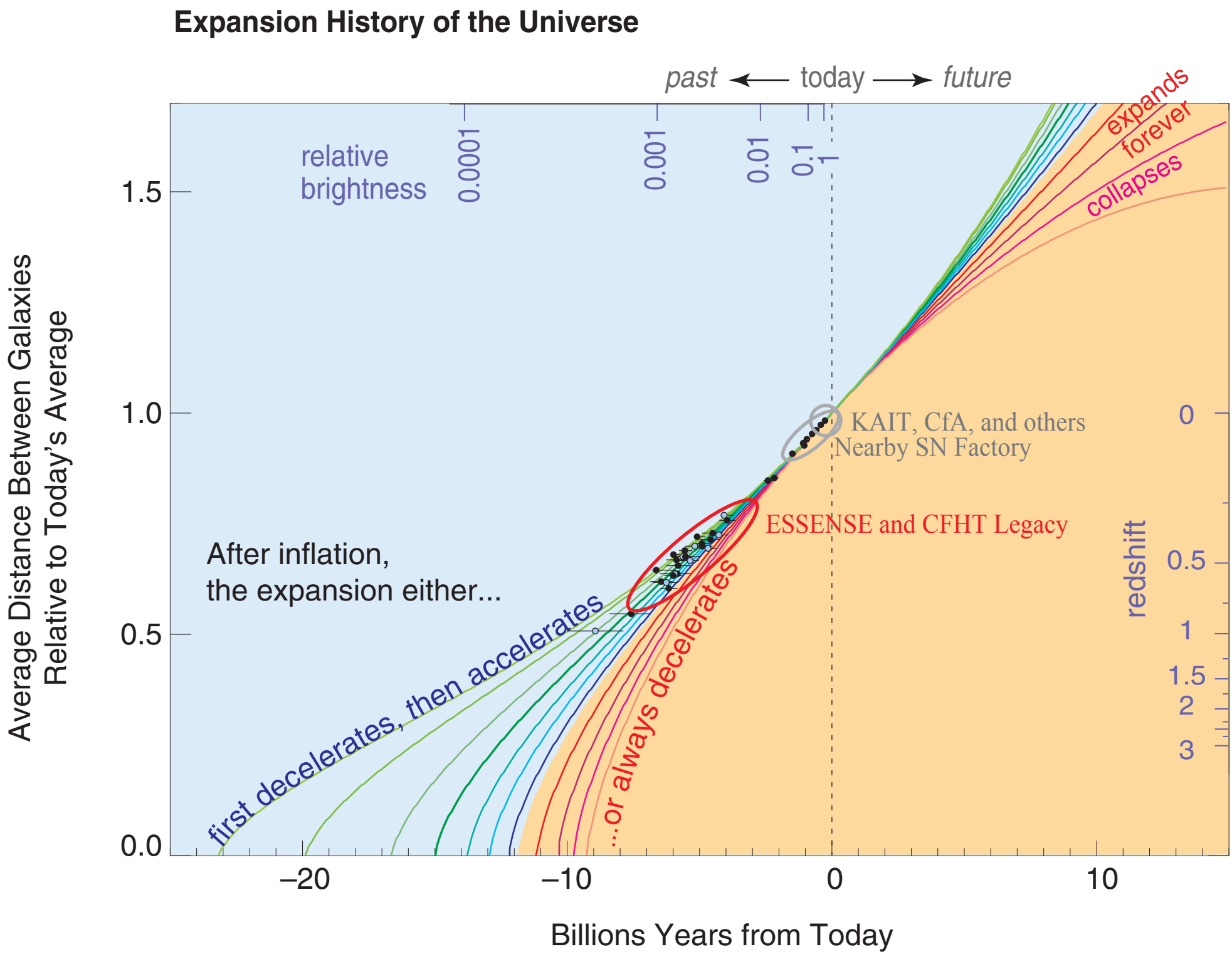
Expansion History of the Universe




Expansion History of the Universe
past
today
future
relative brightness
0.0001
0.001
0.01
0.1
1
expands forever
collapses
KAIT, CfA, and others
After inflation, the expansion either...
first decelerates, then accelerates
...or always decelerates
redshift
0
0.5
1
1.5
2
3
Average Distance Between Galaxies Relative to Today's Average
1.5
1.0
0.5
0.0
–20
–10
0
10
Billions Years from Today

Expansion History of the Universe




Expansion History of the Universe
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KAIT, CfA, and others
Nearby SN Factory
ESSENSE and CFHT Legacy
After inflation,
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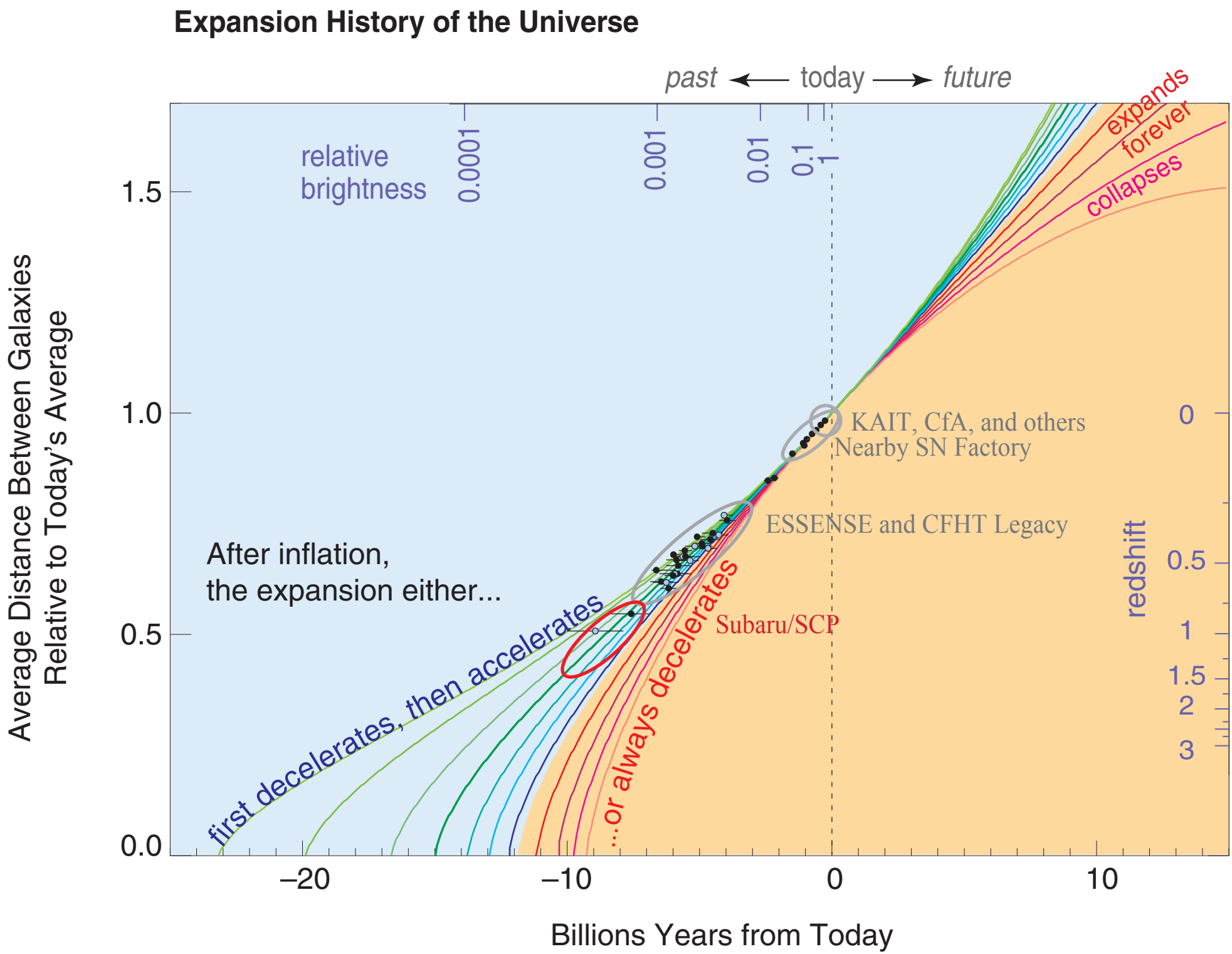
Billions Years from Today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Subaru/SCP
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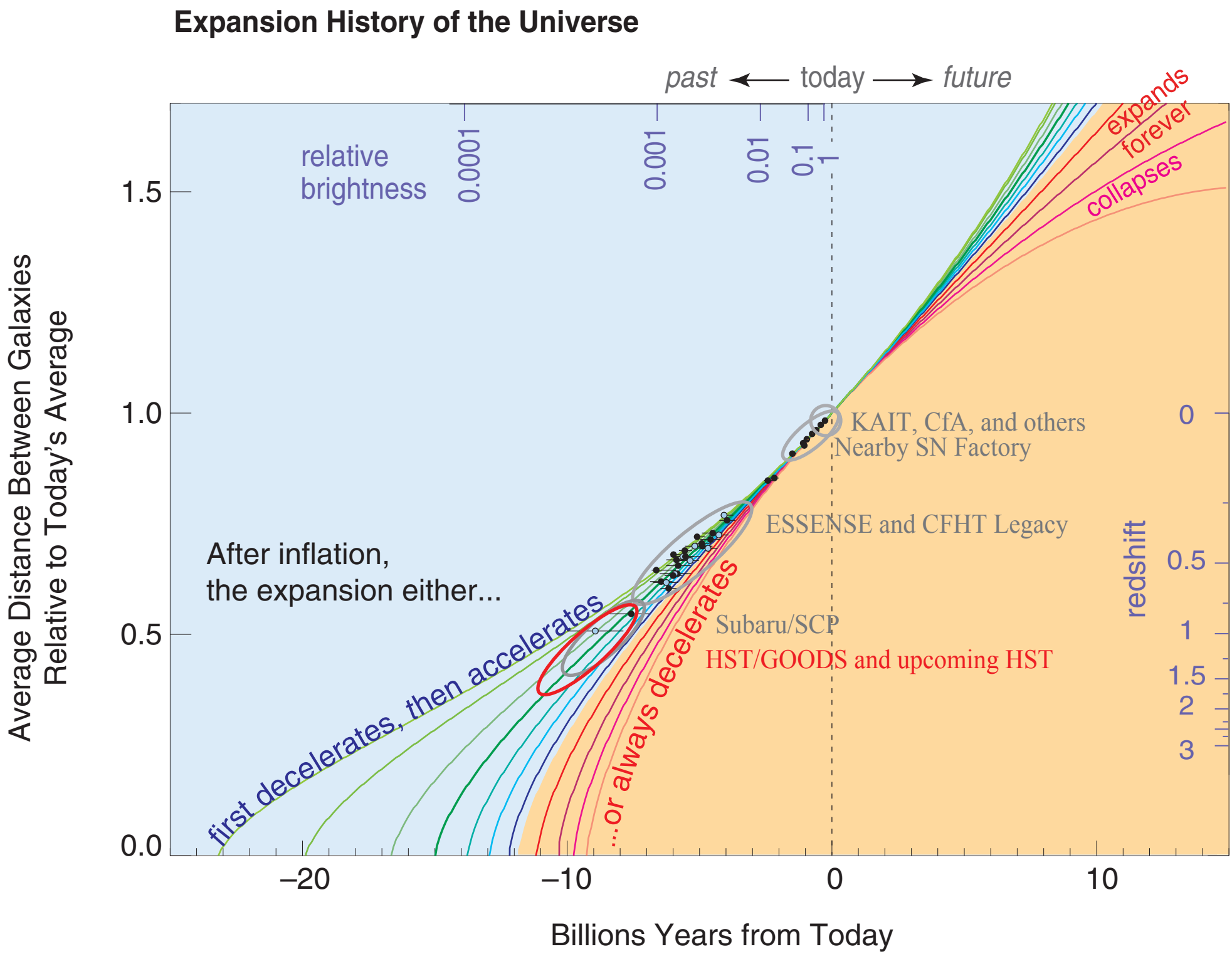
10
Billions Years from Today


Expansion History of the Universe
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relative brightness
0.0001
0.001
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0.1
1
expands forever
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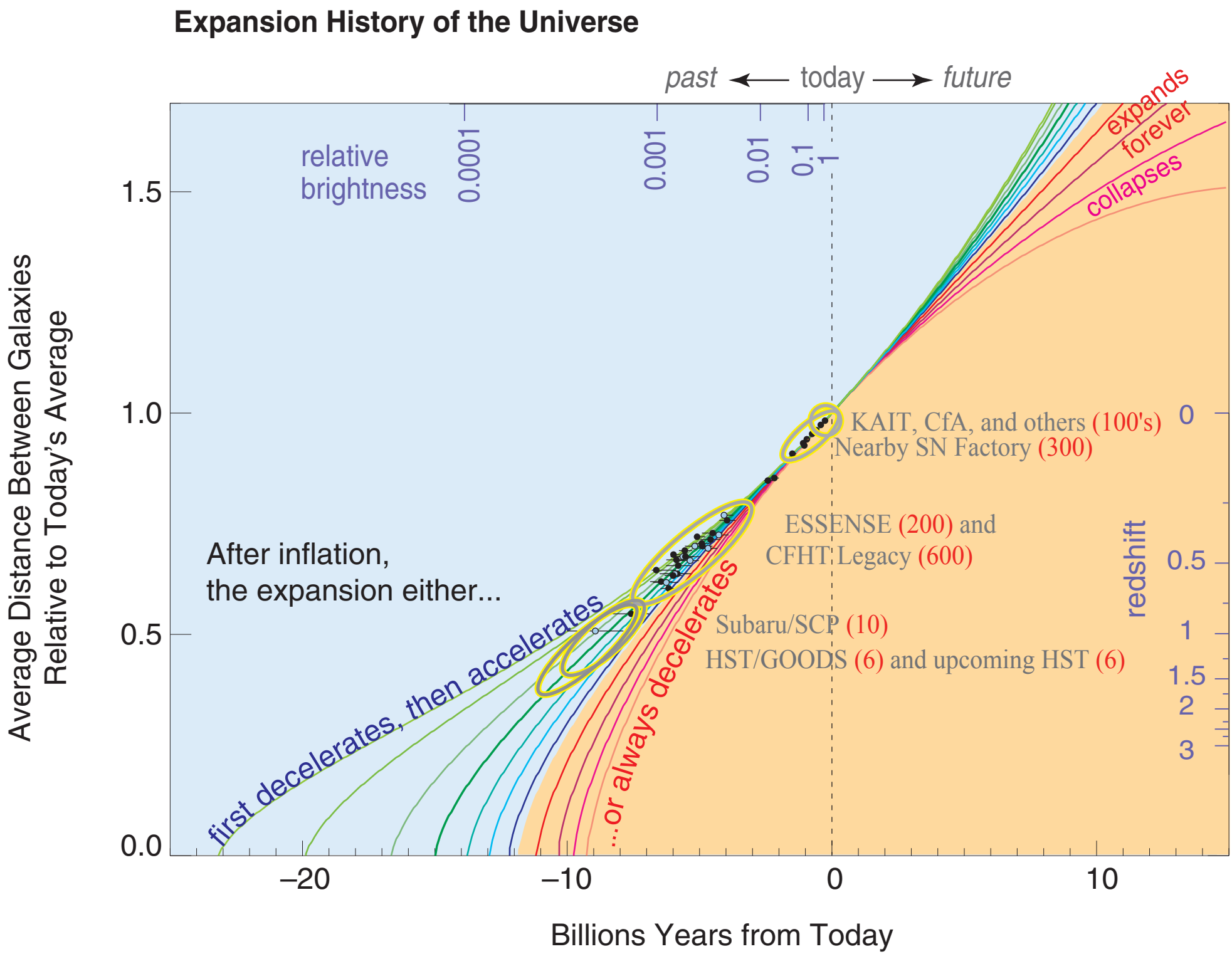
KAIT, CfA, and others
Nearby SN Factory
ESSENSE and CFHT Legacy
Subaru/SCP
HST/GOODS and upcoming HST
After inflation, the expansion either...
first decelerates, then accelerates
...or always decelerates
redshift
0
0.5
1
1.5
2
3
Average Distance Between Galaxies Relative to Today's Average
1.5
1.0
0.5
0.0
–20
–10
0
10
Billions Years from Today


Expansion History of the Universe
past
today
future
relative brightness
0.0001
0.001
0.01
0.1
1
expands forever
collapses
KAIT, CfA, and others (100's)
Nearby SN Factory (300)
ESSENSE (200) and
CFHT Legacy (600)
Subaru/SCP (10)
HST/GOODS (6) and upcoming HST (6)
After inflation,
the expansion either...
first decelerates, then accelerates
...or always decelerates
redshift
0
0.5
1
1.5
2
3
Average Distance Between Galaxies
Relative to Today's Average
1.5
1.0
0.5
0.0
–20
–10
0
10
Billions Years from Today

2. An exhaustive list of systematics.

What makes the supernova measurement special?

An exhaustive accounting of sources of SN systematic uncertainties:

SN Ia Evolution

- o shifting distribution of
  progenitor mass/metallicity/C-O
- o shifting distibution of SN physics params:
  - -- amount of Nickel fused in explosion
  - -- distribution of Nickel
  - -- kinetic energy of explosion
  - -- opacity of atmosphere's inner layers
  - -- metallicity

Gravitational Lensing (de)amplification

Dust/Extinction

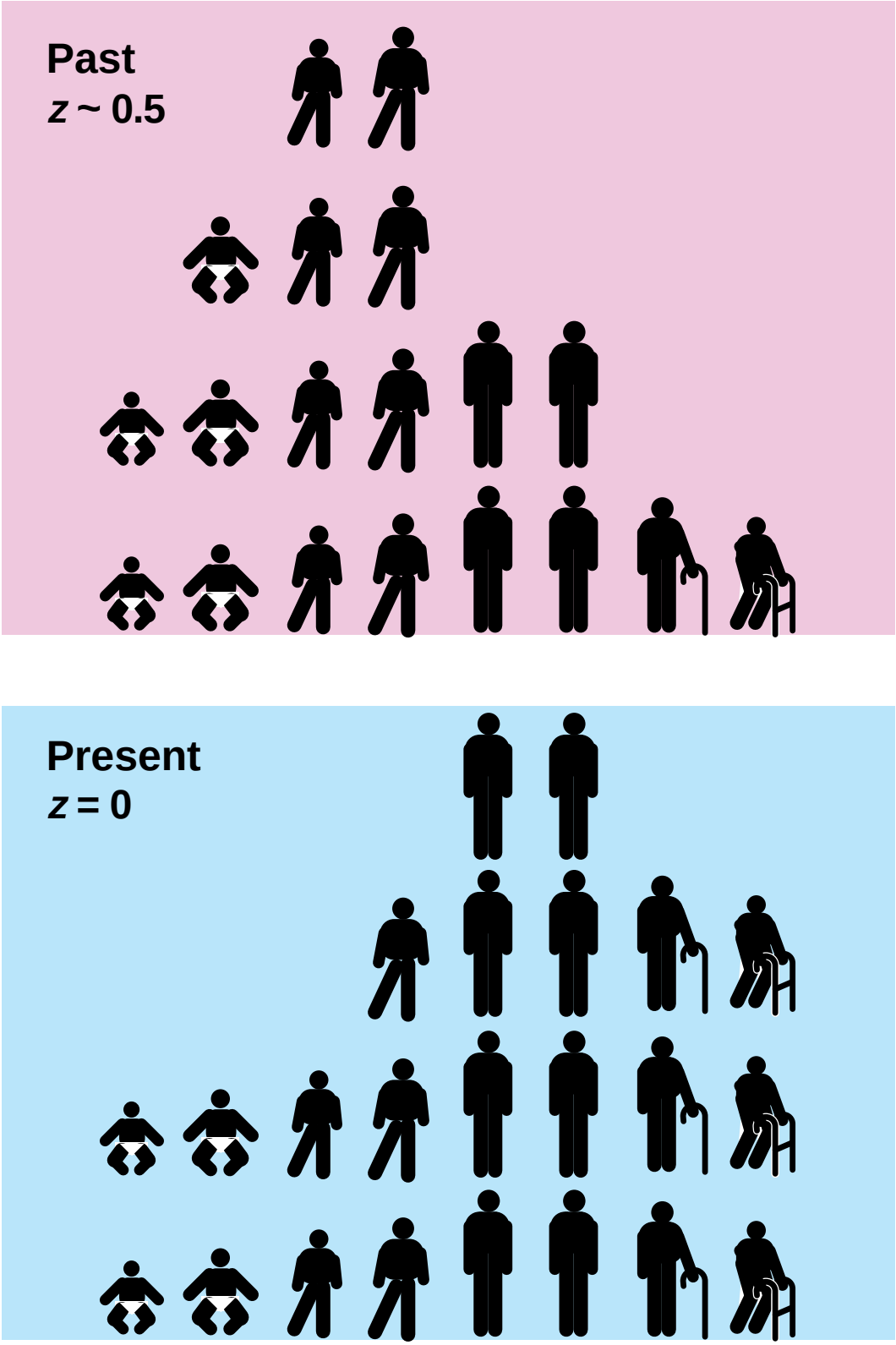
- o dust that reddens
- o evolving gray dust
  - -- clumpy
  - -- homogeneous
- o Galactic extinction model

Observational biases

- o Malmquist bias differences
- o non-SN Ia contamination
- o K-correction uncertainty
- o color zero-point calibration

Perlmutter et al. (1999)

Supernova Demographics

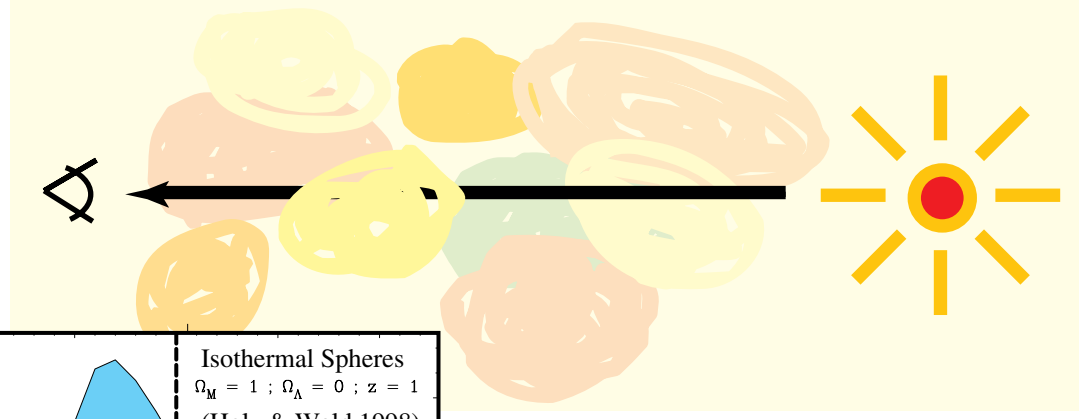


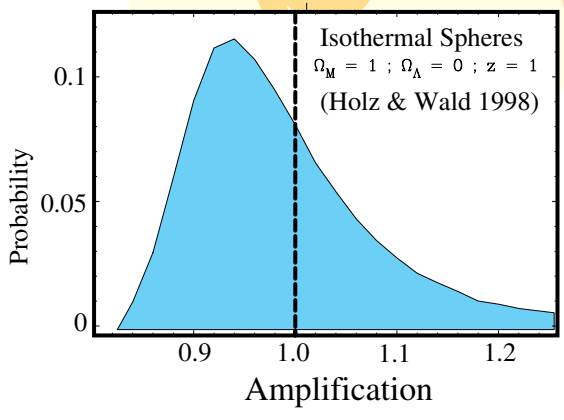
Galaxy Environment Age

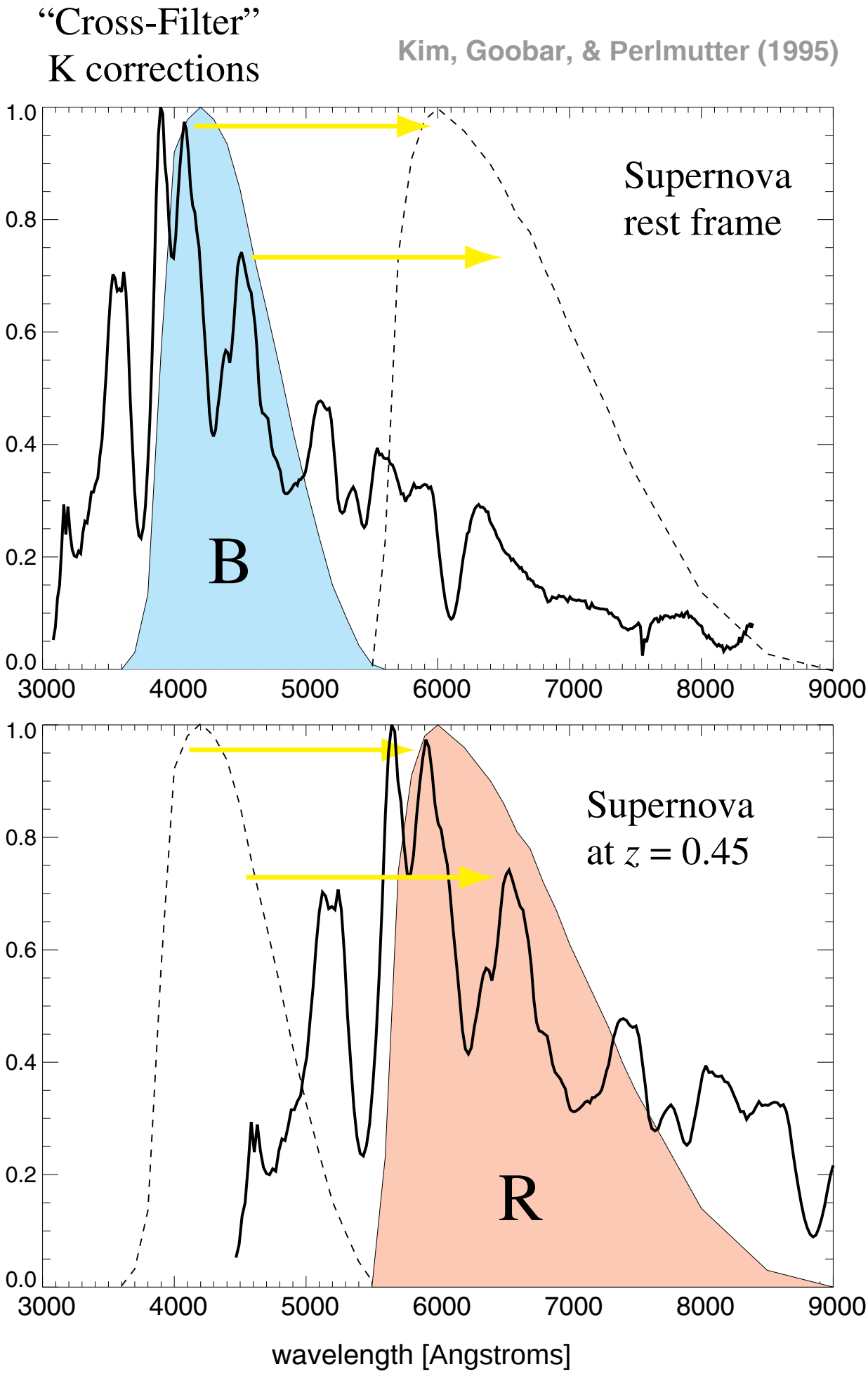
← *Younger* *Older* →

Gravitational Lensing in a Clumpy Universe

"Weak Lensing" Approx:
Power spectrum of mass density in relatively smooth universe.

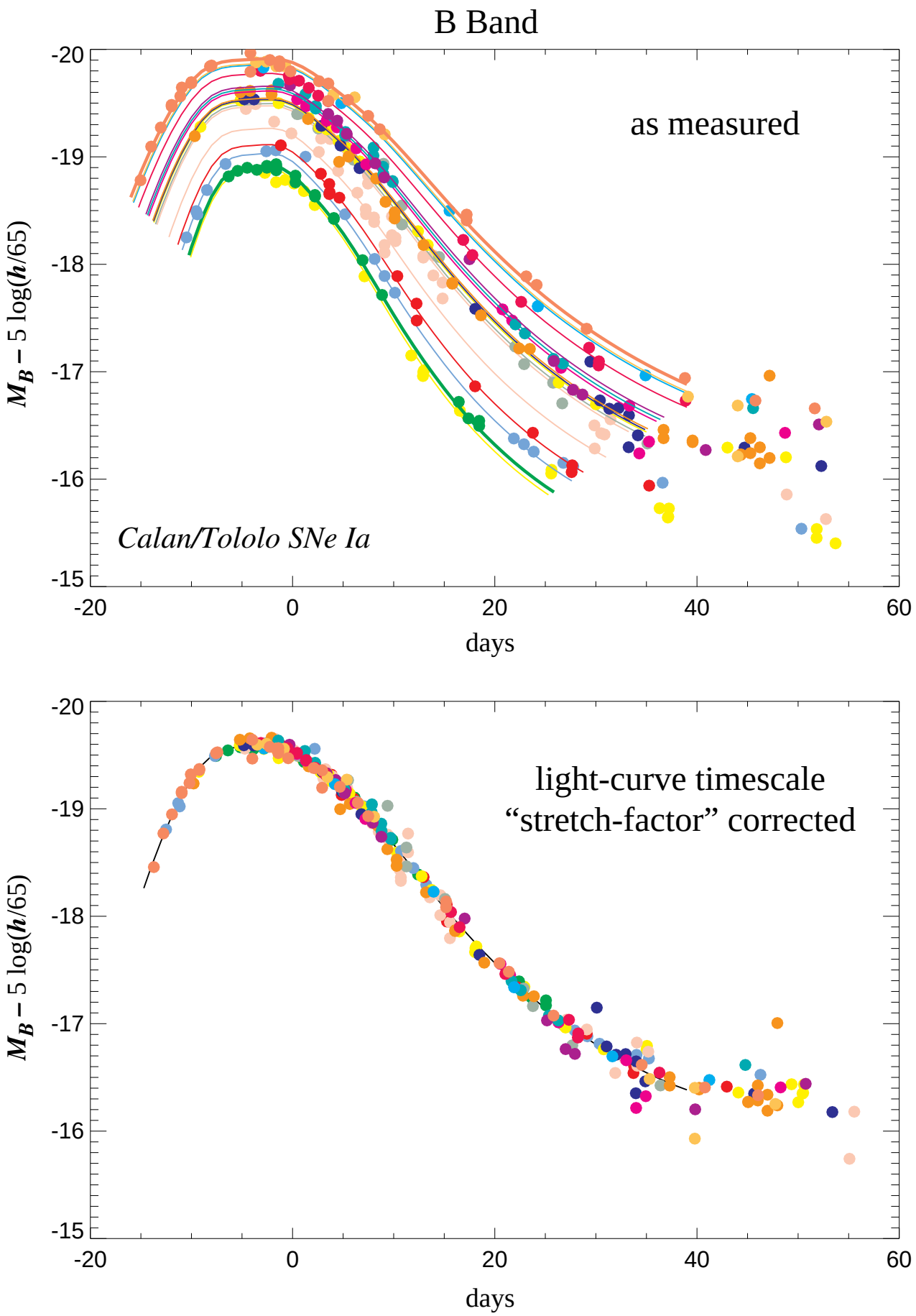






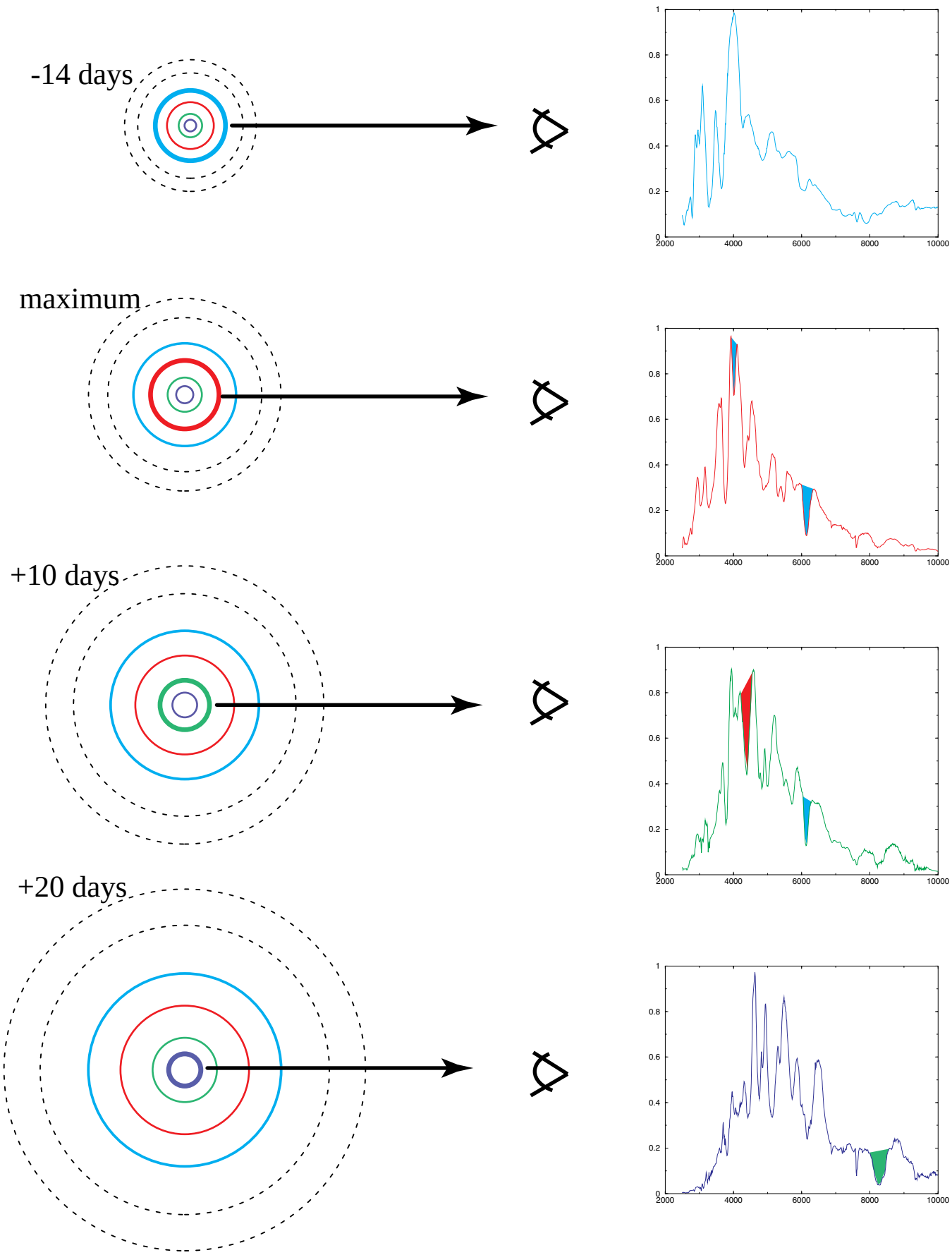
"Cross-Filter"
K corrections
Kim, Goobar, & Perlmutter (1995)
Supernova
rest frame
B
Supernova
at $z = 0.45$
R
1.0
0.8
0.6
0.4
0.2
0.0
3000
4000
5000
6000
7000
8000
9000
wavelength [Angstroms]

3. SN Ia: An unusual tool for cosmology.

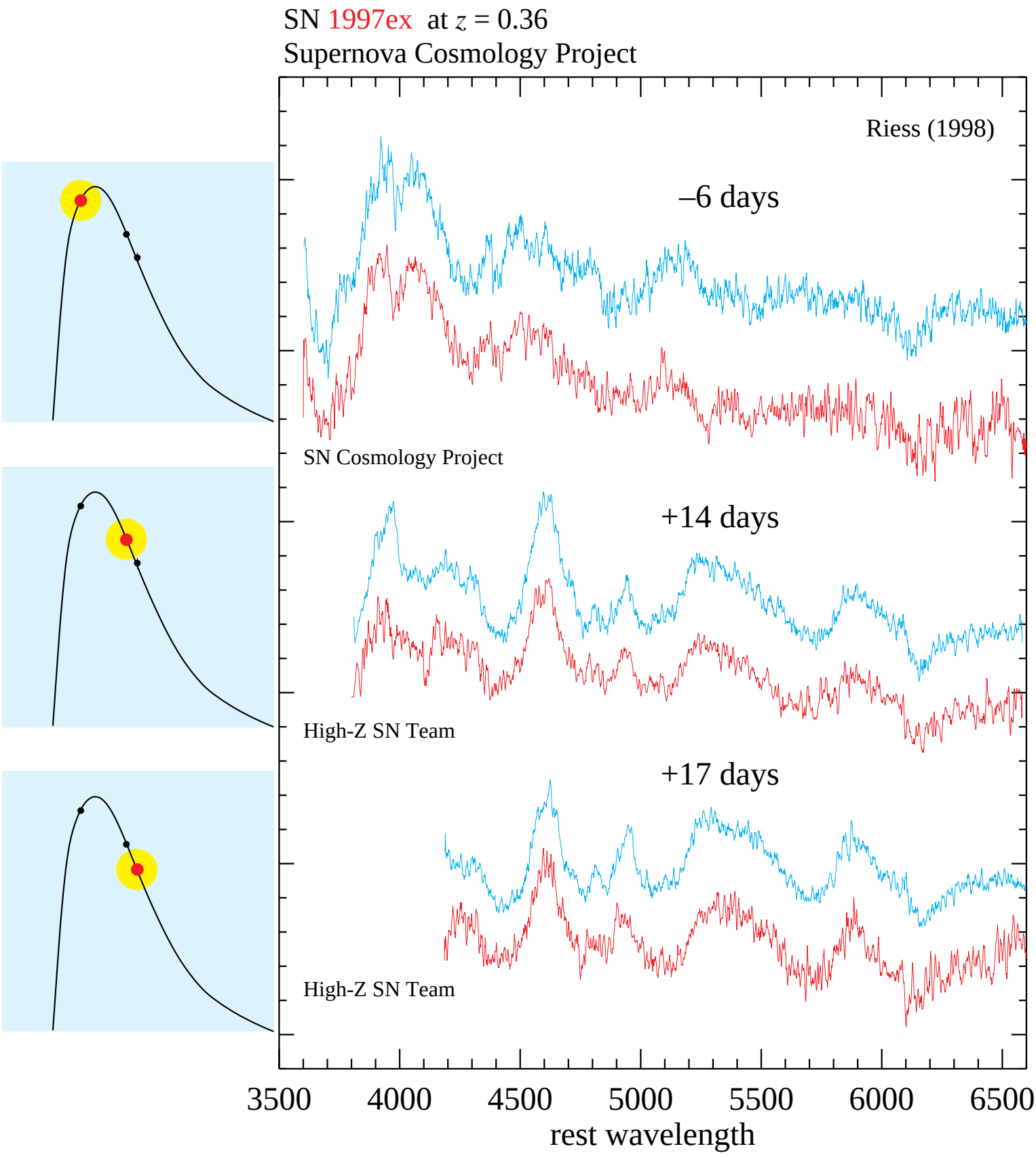


Kim, *et al.* (1997)

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 Host Galaxy's Star Formation History

SN Progenitor Stars:

- progenitor mass
- heavy element abundance
- binary star system parameters
- white dwarf's carbon/oxygen ratio

SN Physical Properties:

- Amount of Nickel fused in explosion
- Distribution of Nickel
- Opacity of atmosphere's inner layers
- Kinetic energy of the explosion
- Metallicity

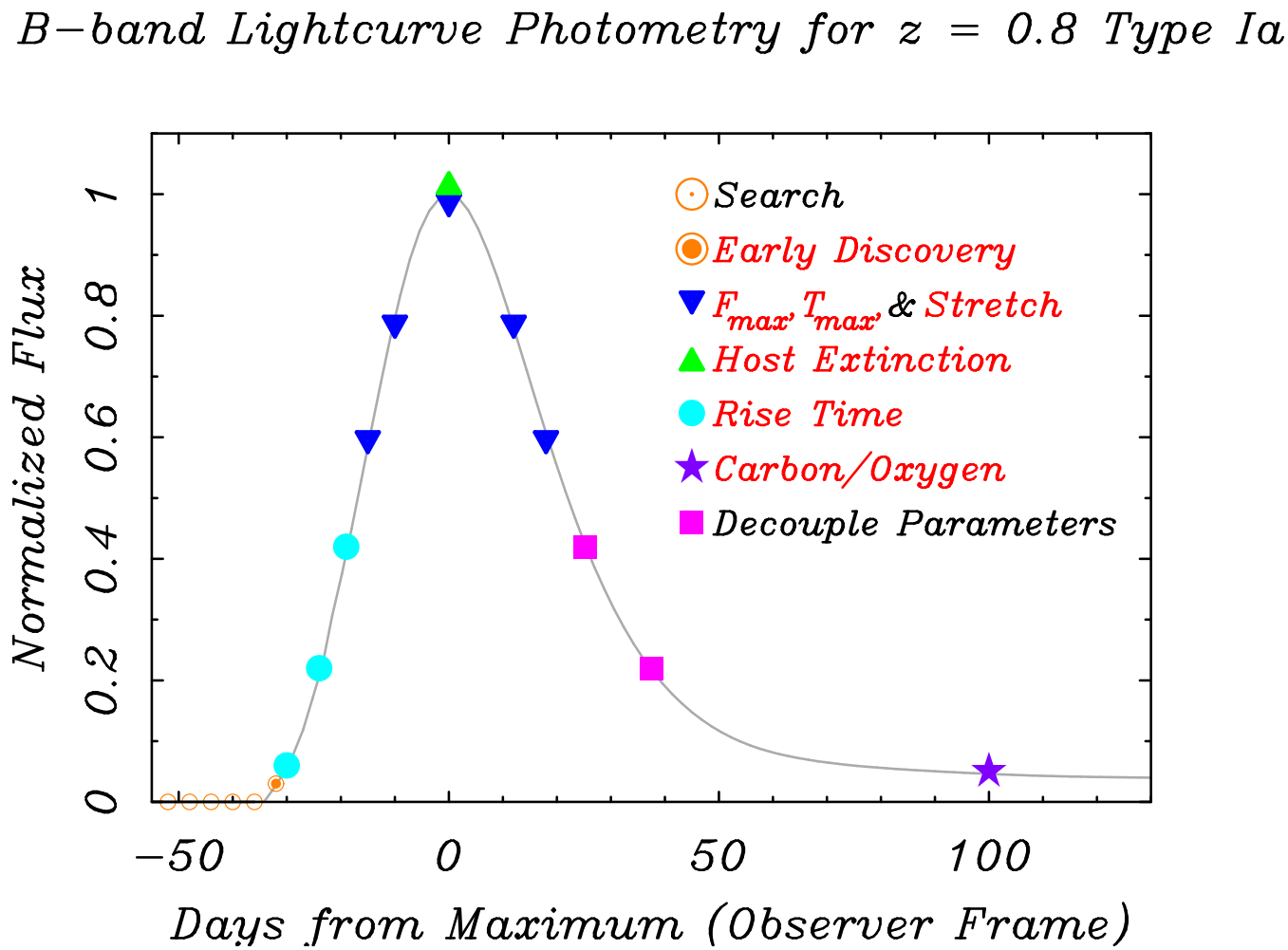
SN Observables

- Spectral feature widths & minima
- Spectral feature ratios
- Lightcurve rise time
- Lightcurve stretch
- Lightcurve plateau level

Galaxy Observables

- Color vs. luminosity
- Absorption/emission lines
- 4000 A break
- Galaxy morphology
- SN location in host galaxy

SNAP SuperNova Acceleration Probe



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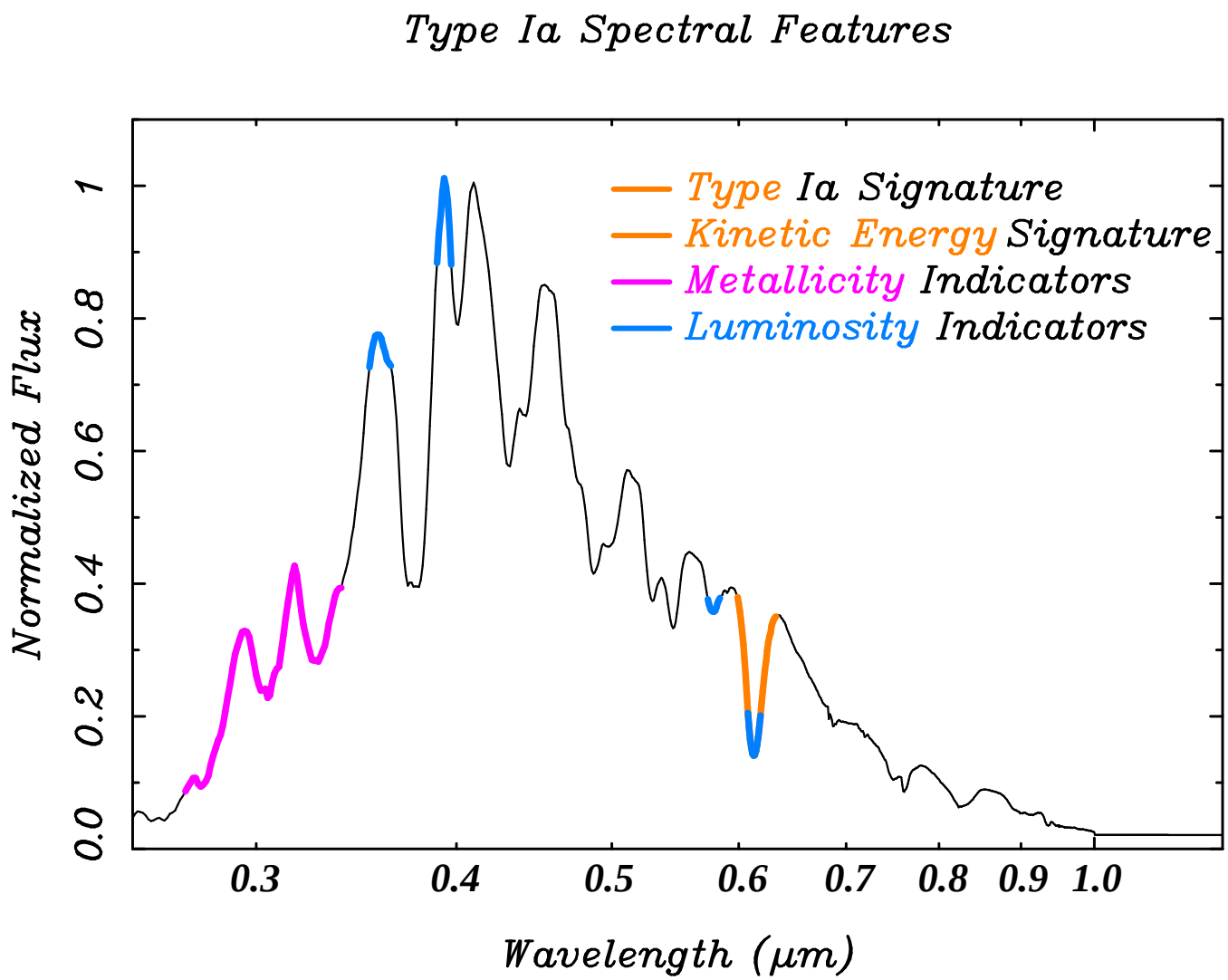

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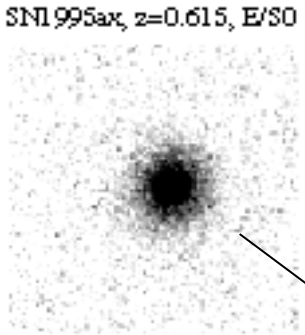
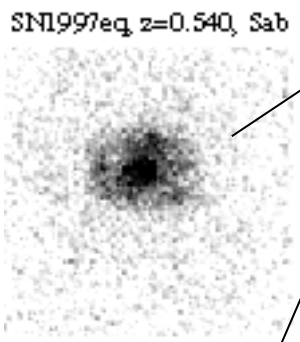
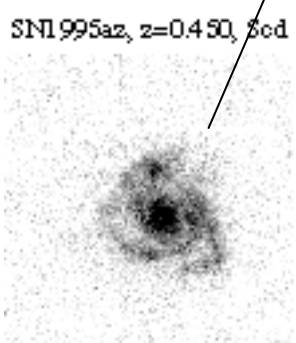
Host galaxy morphology, from space-based imaging with HST / STIS

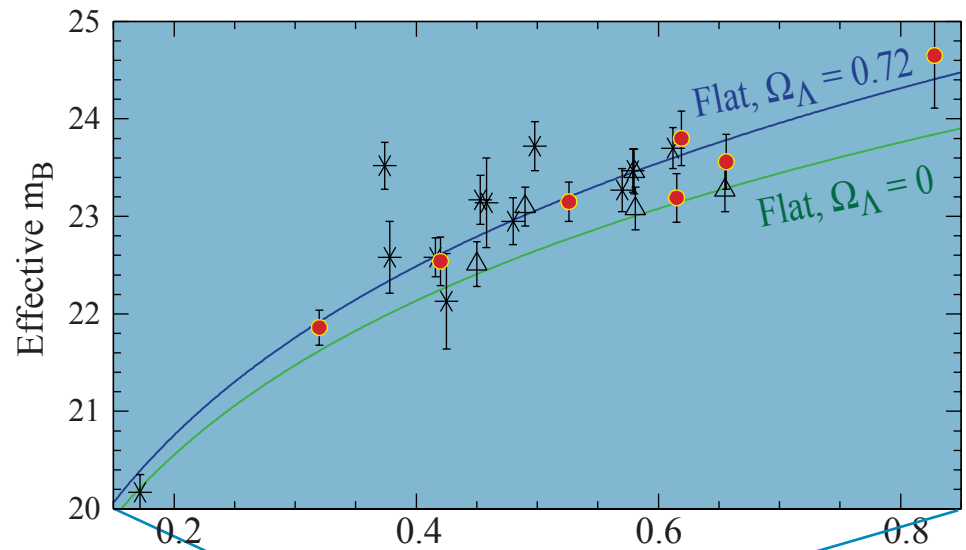
Result from elliptical host galaxy subsample agrees with flat, $\Omega_\Lambda = 0.72$ result from whole dataset.
(Elliptical best flat universe fit: $\Omega_\Lambda = 0.58 \pm 0.2$)

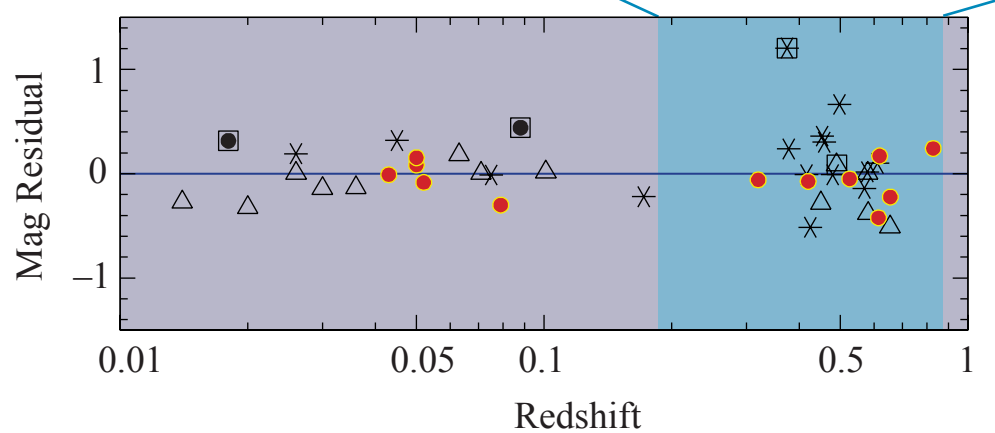






galaxy type	dispersion from flat, $\Omega_\Lambda = 0.72$
● Elliptical: E/S0	$\sigma = 0.19$ mag
△ Spiral: Sa/Sb/Sc	$\sigma = 0.27$ mag
✳ Late/Irregular: Scd/Irr	$\sigma = 0.30$ mag





Ellis et al. (astro-ph/0011369)
Supernova Cosmology Project

4. How this tool can address systematics.

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 $\lambda/\delta\lambda \sim 100$.
- Near-IR spectroscopy to 1.7 μm.

⋮

Satellite / Instrumentation Requirements

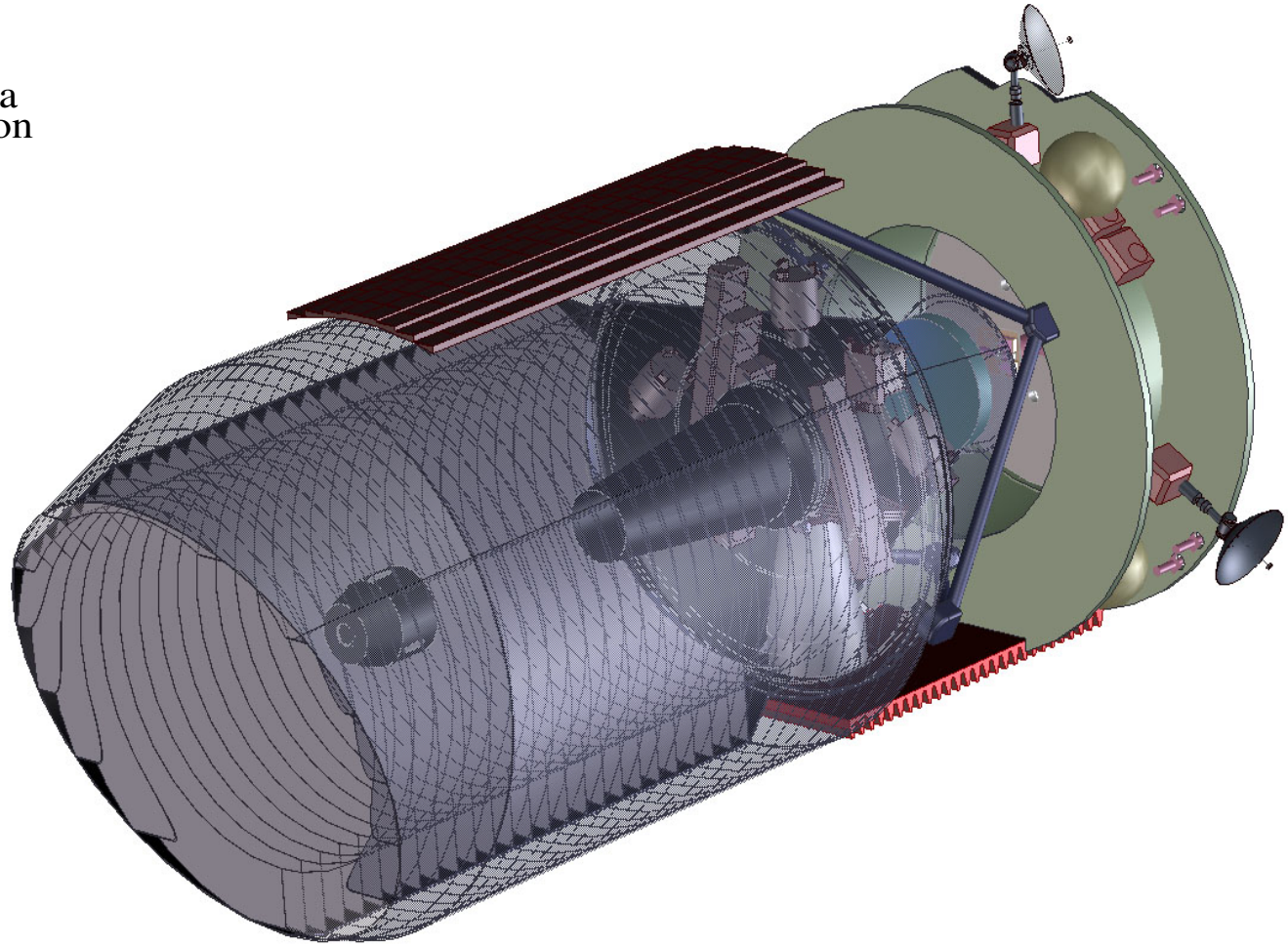
- ~2-meter mirror
- ~1-square degree imager
- low-resolution spectrograph (0.35 μm to 1.7 μm)

Derived requirements:

- High Earth orbit
- ~300 Mb/sec bandwidth

⋮

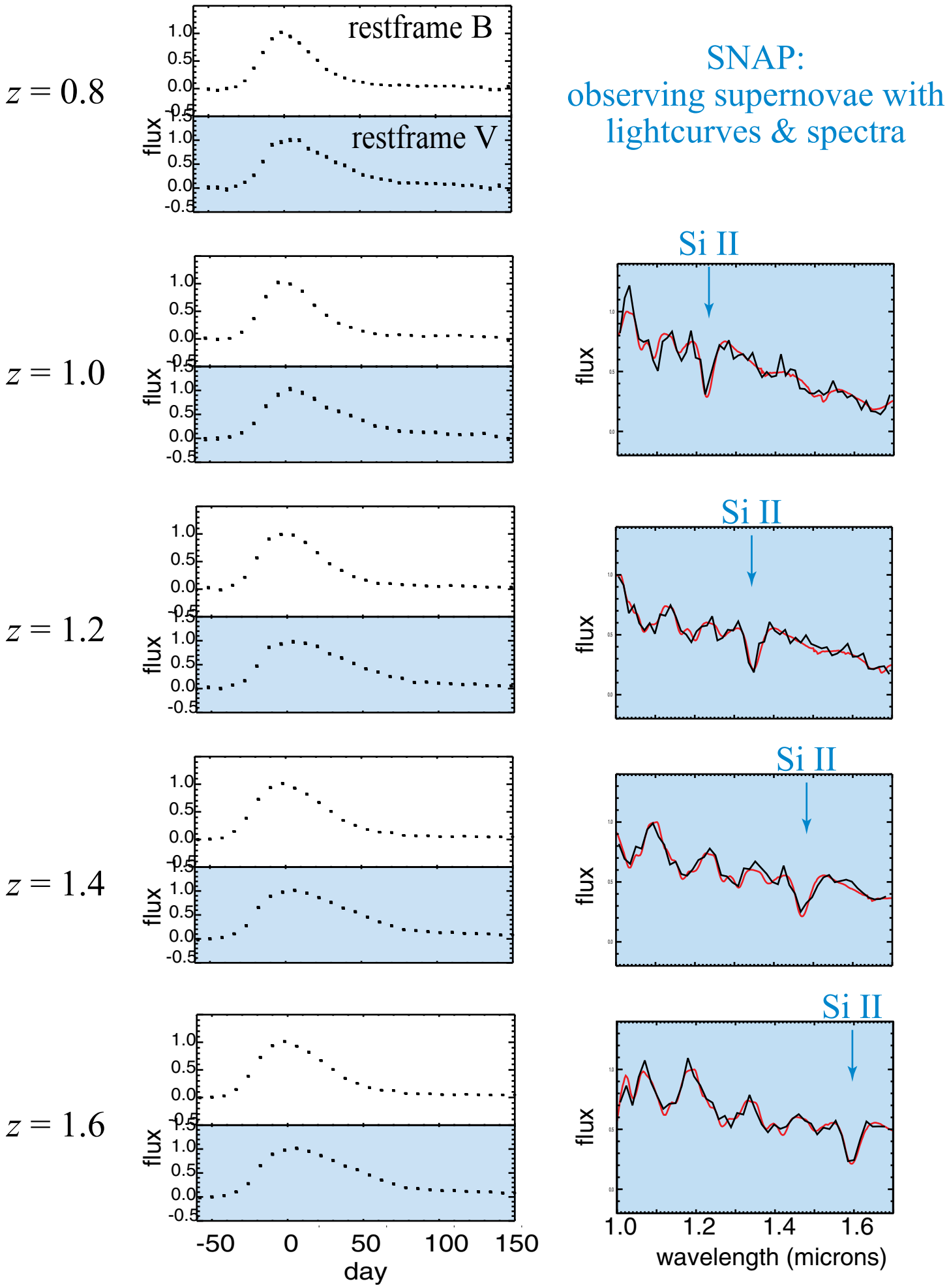
SNAP SuperNova Acceleration Probe



- **~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.


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

An exhaustive accounting of sources of SN systematic uncertainties:

SN Ia Evolution

- o shifting distribution of
  progenitor mass/metallicity/C-O
- o shifting distibution of SN physics params:
  - -- amount of Nickel fused in explosion
  - -- distribution of Nickel
  - -- kinetic energy of explosion
  - -- opacity of atmosphere's inner layers
  - -- metallicity

Gravitational Lensing (de)amplification

Dust/Extinction

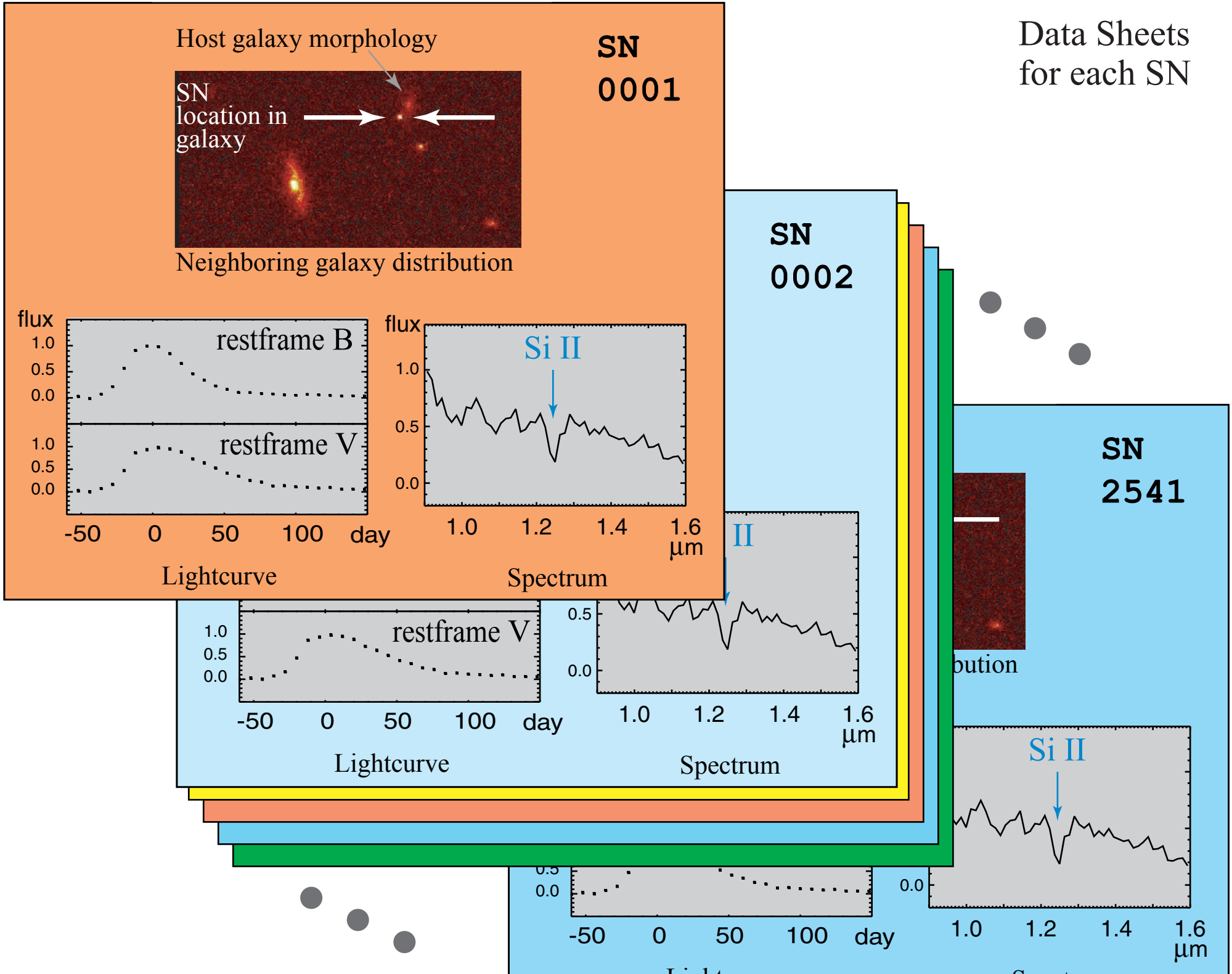
- o dust that reddens
- o evolving gray dust
  - -- clumpy
  - -- homogeneous
- o Galactic extinction model

Observational biases

- o Malmquist bias differences
- o non-SN Ia contamination
- o K-correction uncertainty
- o color zero-point calibration

Perlmutter et al. (1999)

Data Sheets
for each SN



1

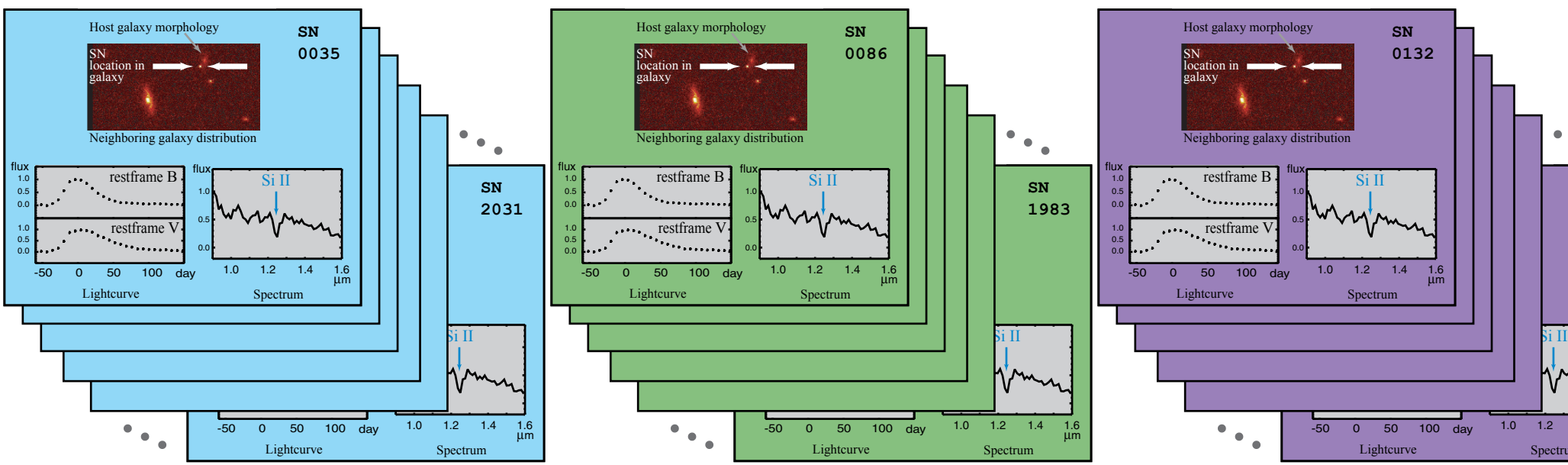
Sort into Like Subsets

Group A:
* Si II in spectrum: type Ia
* elliptical host
* faint UV: high metallicity
* fast rise time: low Ni56 mass
* spectral feature velocities
  9000 < v < 10000 km/s

Group B:
* Si II in spectrum: type Ia
* in core of late-type spiral host
* bright UV: low metallicity
* fast rise time: low Ni56 mass
* spectral feature velocities
  9000 < v < 10000 km/s

Group C:
* Si II in spectrum: type Ia
* in outskirts of late-type spiral host
* bright UV: low metallicity
* long rise time: high Ni56 mass
* spectral feature velocities
  8000 < v < 9500 km/s

Gro
* Si II i
* in cor
* bright
* short
* spectr
  8000



2

Each subset gets its own extinction-corrected Hubble diagram:

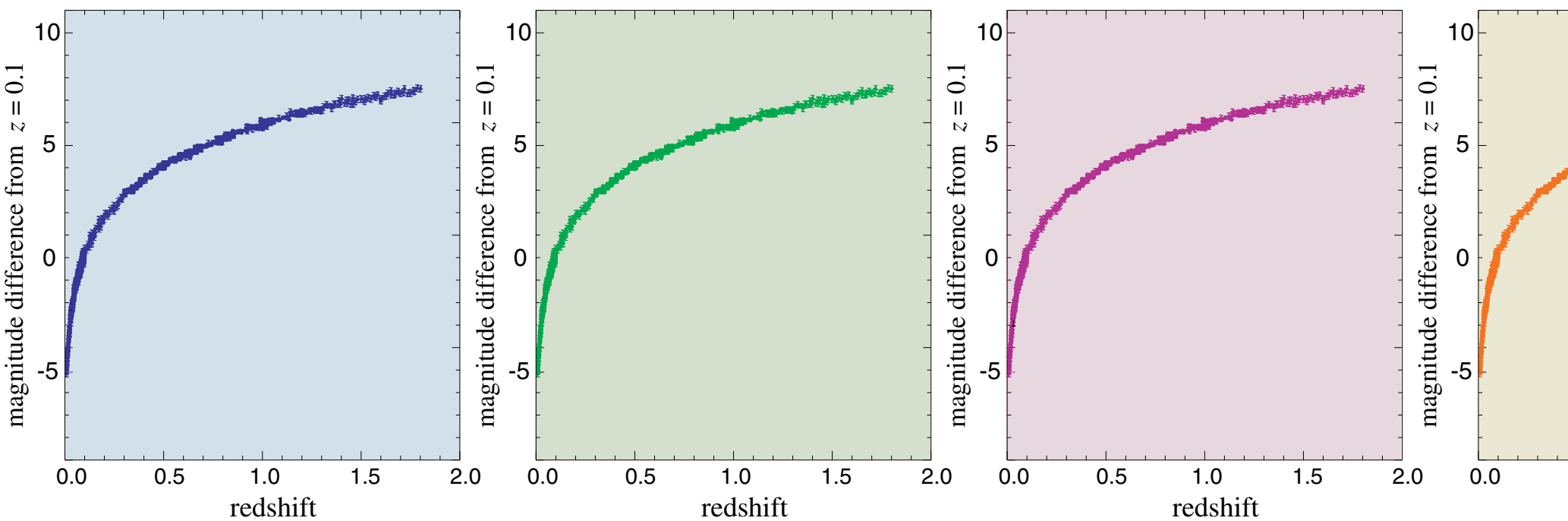
Group A:
* Si II in spectrum: type Ia
* elliptical host
* faint UV: high metallicity
* fast rise time: low Ni56 mass
* spectral feature velocities
  9000 < v < 10000 km/s

Group B:
* Si II in spectrum: type Ia
* in core of late-type spiral host
* bright UV: low metallicity
* fast rise time: low Ni56 mass
* spectral feature velocities
  9000 < v < 10000 km/s

Group C:
* Si II in spectrum: type Ia
* in outskirts of late-type spiral host
* bright UV: low metallicity
* long rise time: high Ni56 mass
* spectral feature velocities
  8000 < v < 9500 km/s

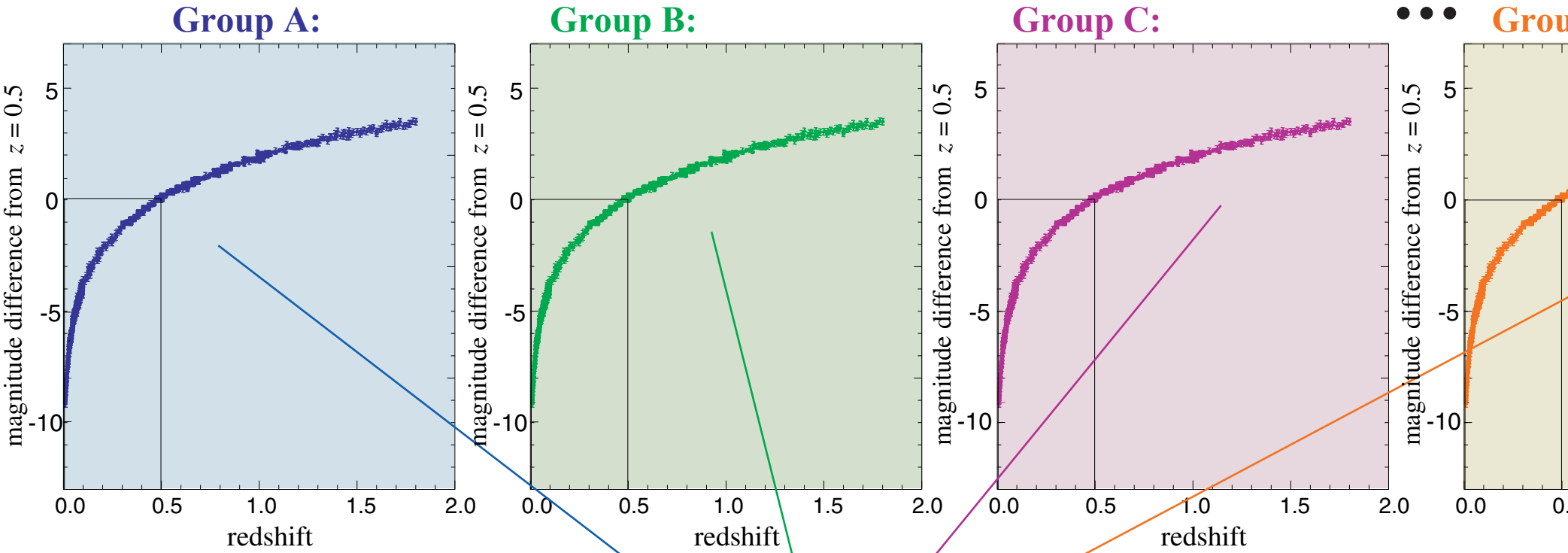
• • •

Gro
* Si II i
* in cor
* bright
* short
* spectr
  8000



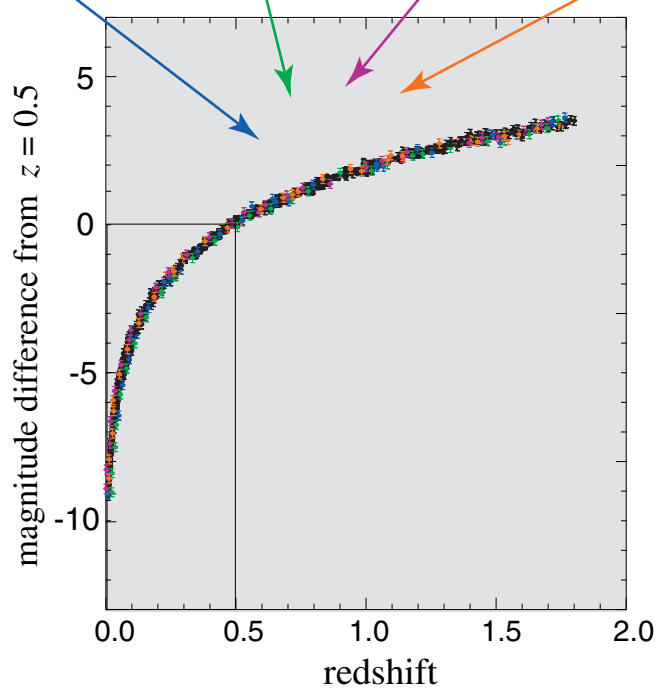
2

Each subset gets its own extinction-corrected Hubble diagram:

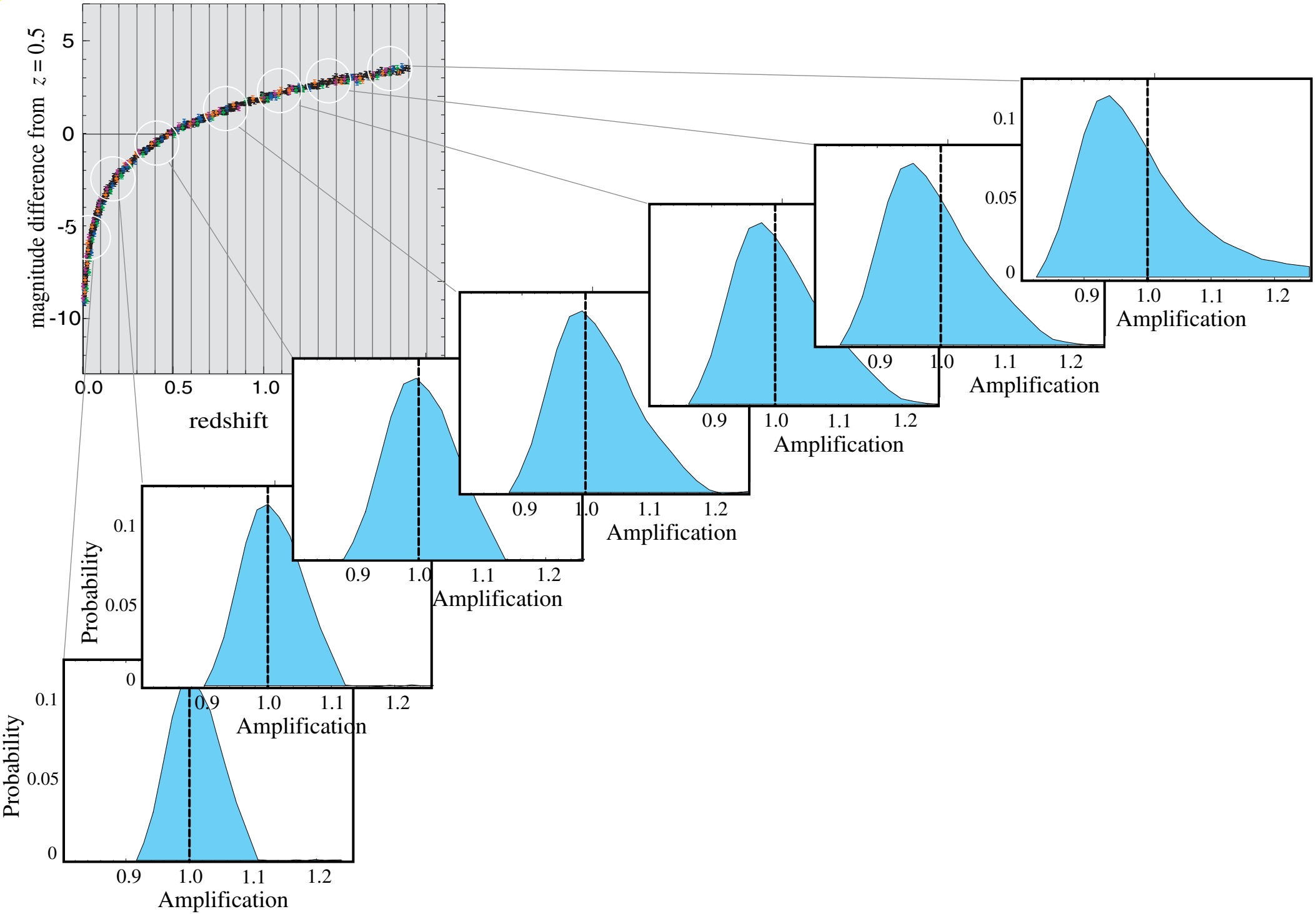


Combine into one Hubble diagram

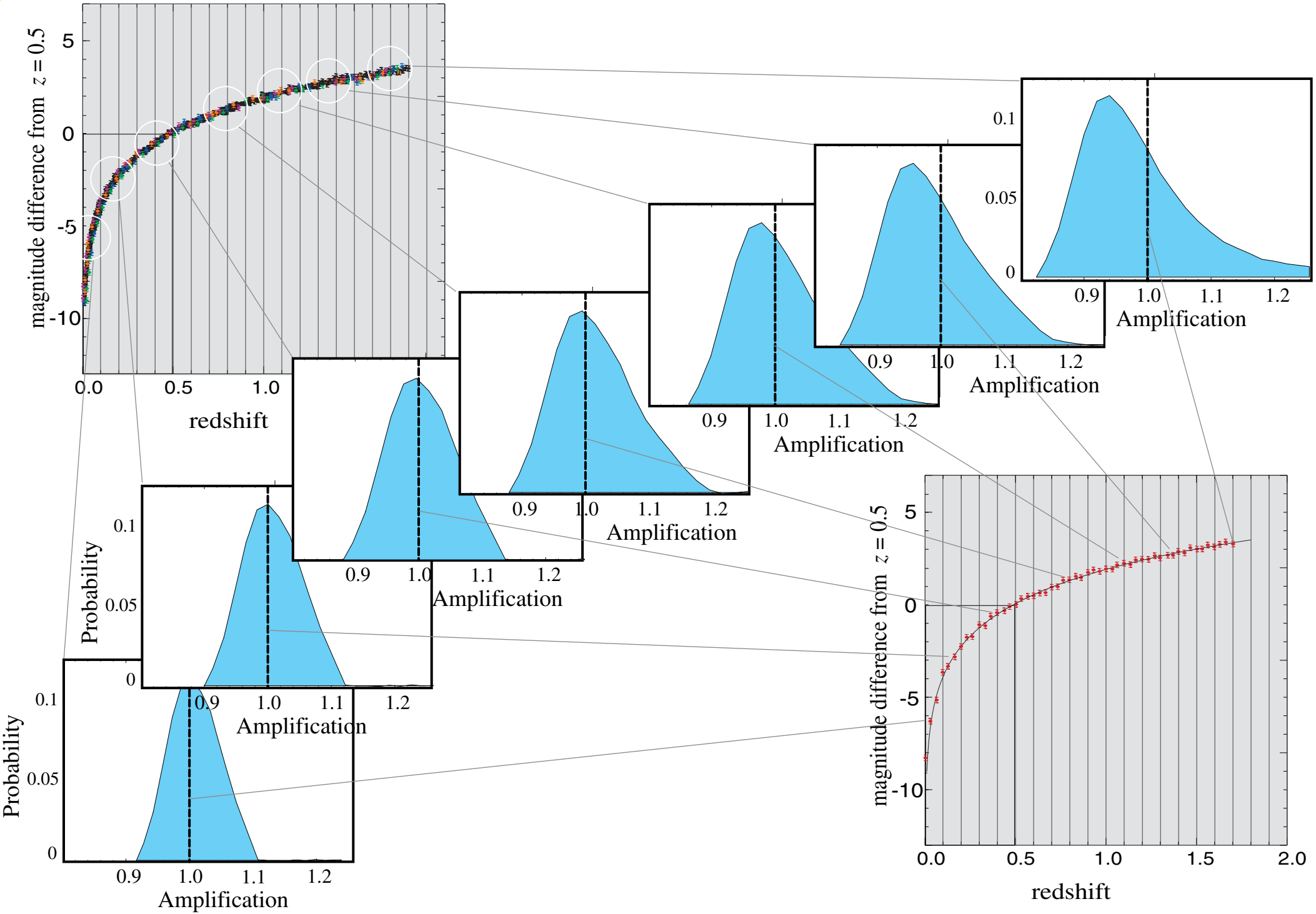
with magnitude difference from $z = 0.5$



3 Break Hubble diagram into z slices to study lensing (de)amplification distribution:



3 Fit/average lensing distributions to construct redshift-binned Hubble diagram:



Example Measurement Requirements for Each Step

Sort into Like Subsets

1

Spectrum:

Si II feature $\lambda/\Delta\lambda \sim 100$ resolution

UV features 5σ per bin

Lightcurve:

Rise time 3σ measurement
3.8 mag before max

Peak fit 15σ measurement
2 mag after max

Image:

Host galaxy morphology <0.1" dithered resolution

Extinction-corrected Hubble diagram

2

Spectrum & Lightcurve:

Cross-wavelength calibrated colors for photometry and spectroscopy from near-UV to near-IR (0.35 -- 1.7 μm)

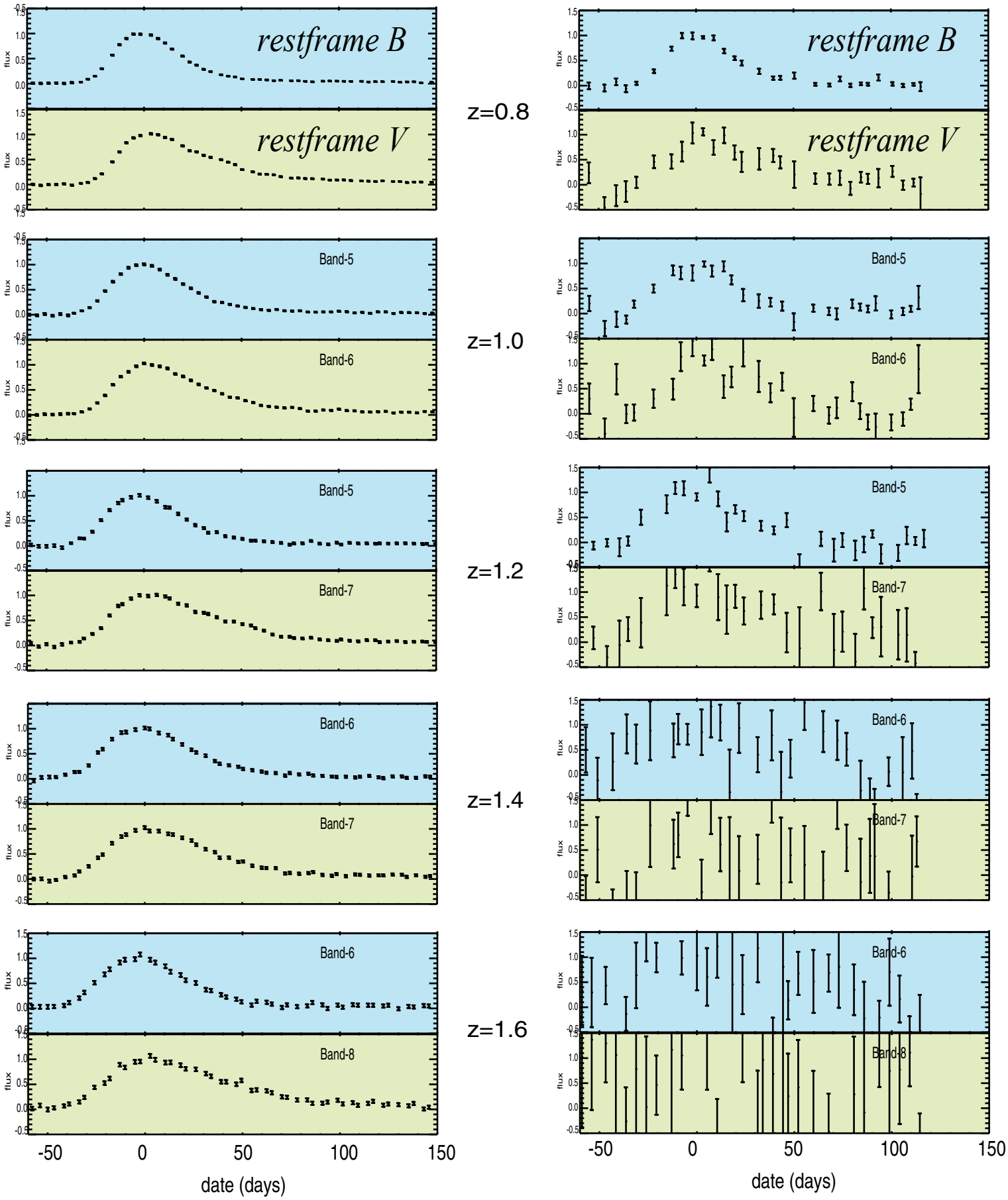
Correct for lensing distributions

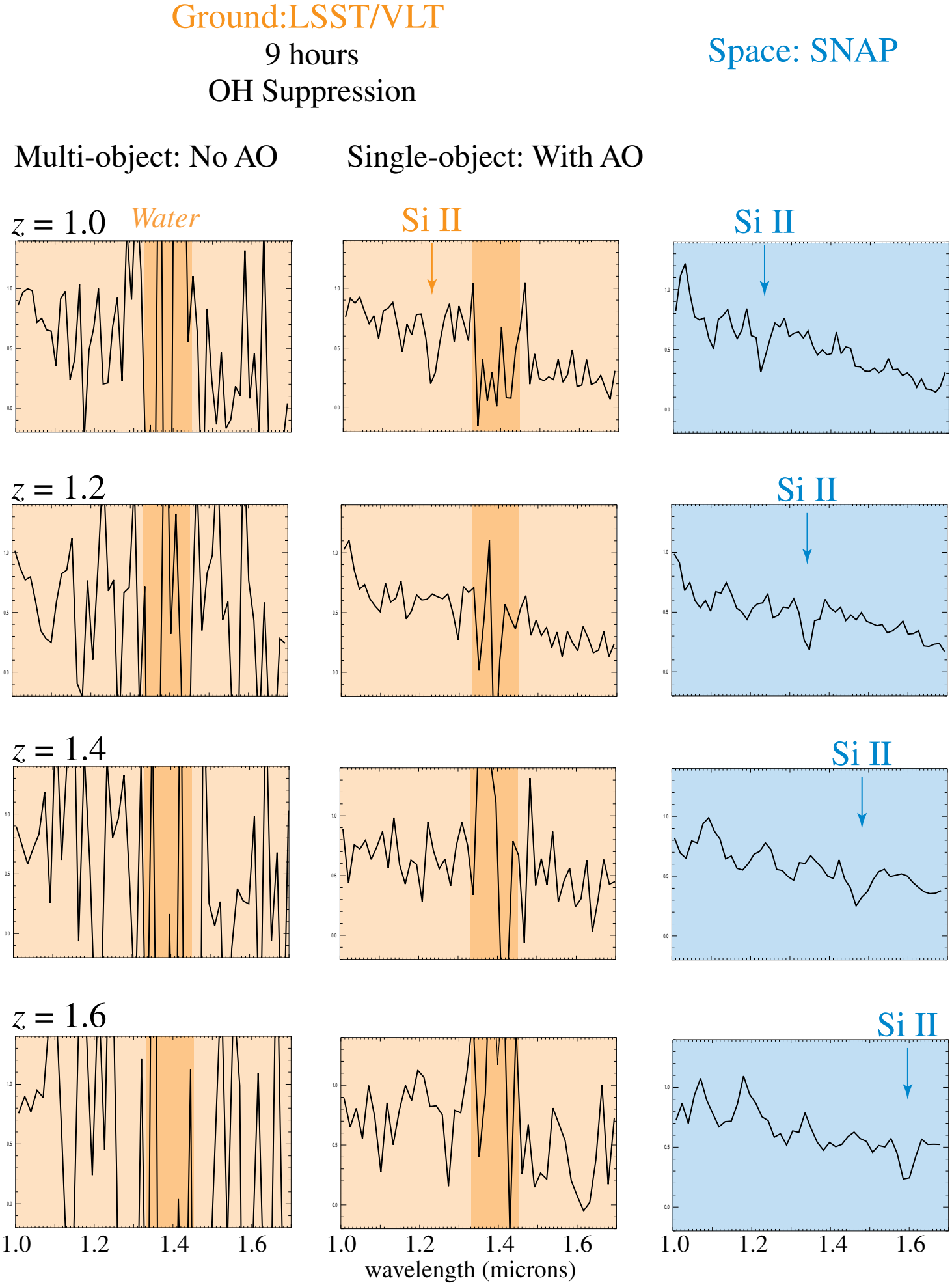
3

Image quality:

<0.1" dithered resolution for neigboring galaxy gravitational lensing map

Redshift range & statistics:
>~50 SNe per bin to obtain lensing distribution


SNAP
LSST
with NIR camera added
restframe B
restframe V
z=0.8
Band-5
Band-6
z=1.0
Band-5
Band-7
z=1.2
Band-6
Band-7
z=1.4
Band-6
Band-8
z=1.6
flux
date (days)

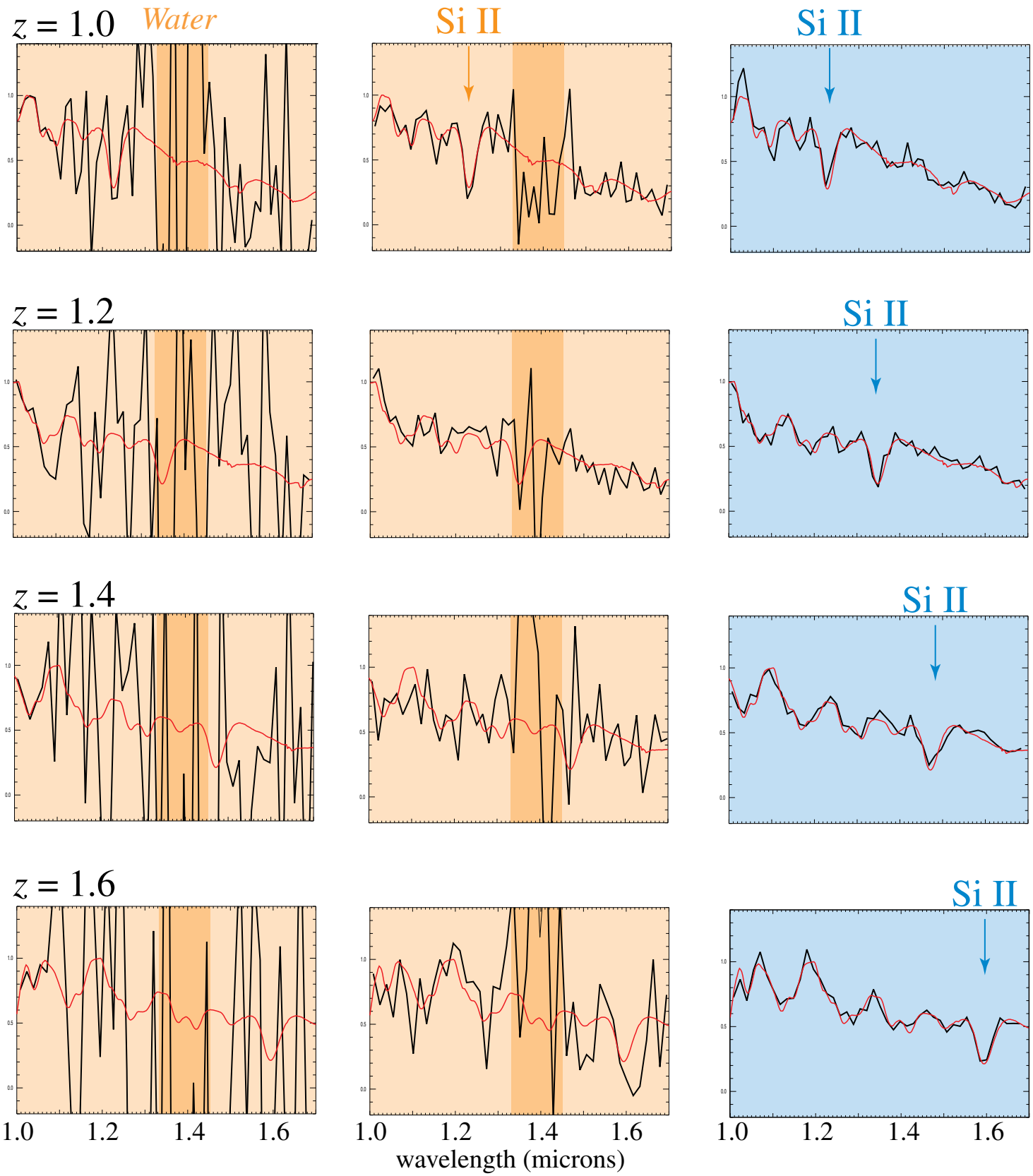

Ground:LSST/VLT
9 hours
OH Suppression
Space: SNAP
Multi-object: No AO
Single-object: With AO
z = 1.0
Water
Si II
Si II
z = 1.2
Si II
z = 1.4
Si II
z = 1.6
Si II
1.0
1.2
1.4
1.6
wavelength (microns)

Ground:LSST/VLT
9 hours
OH Suppression

Space: SNAP

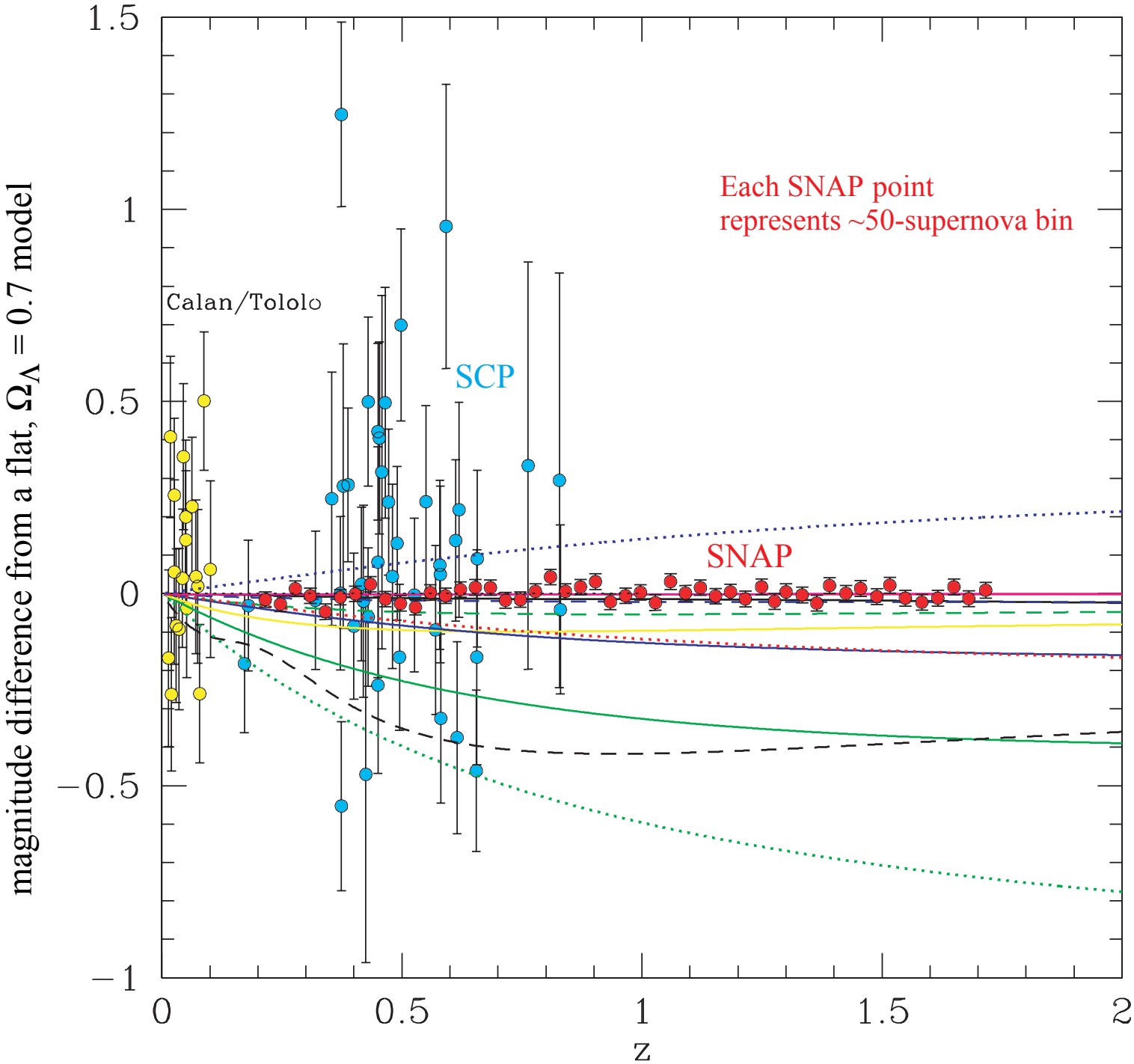
Multi-object: No AO

Single-object: With AO



SNAP SuperNova Acceleration Probe

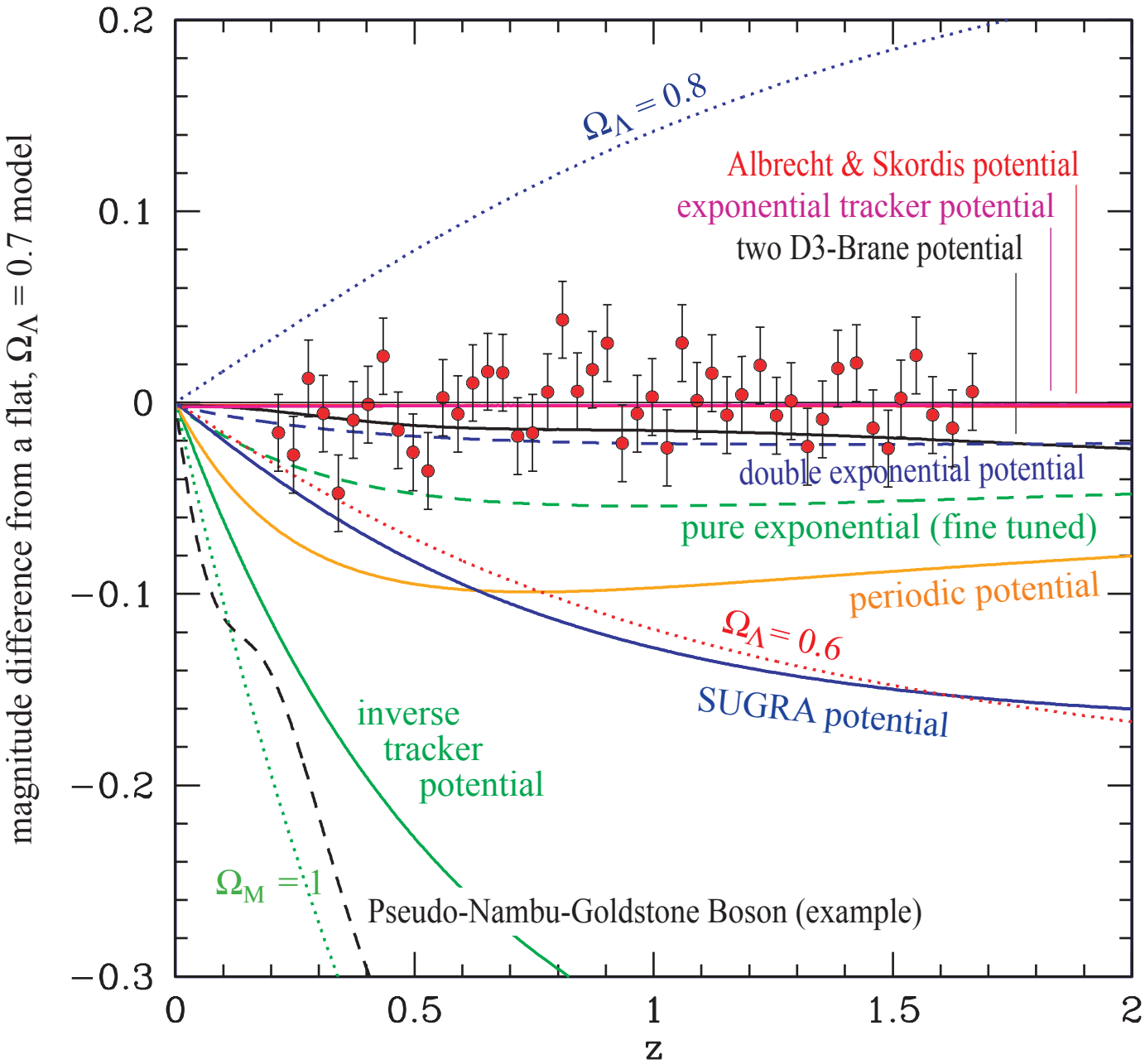
Current ground-based data
compared with binned simulated SNAP data
and a sample of Dark Energy models.



based on
Weller & Albrecht (2001)

SNAP SuperNova Acceleration Probe

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

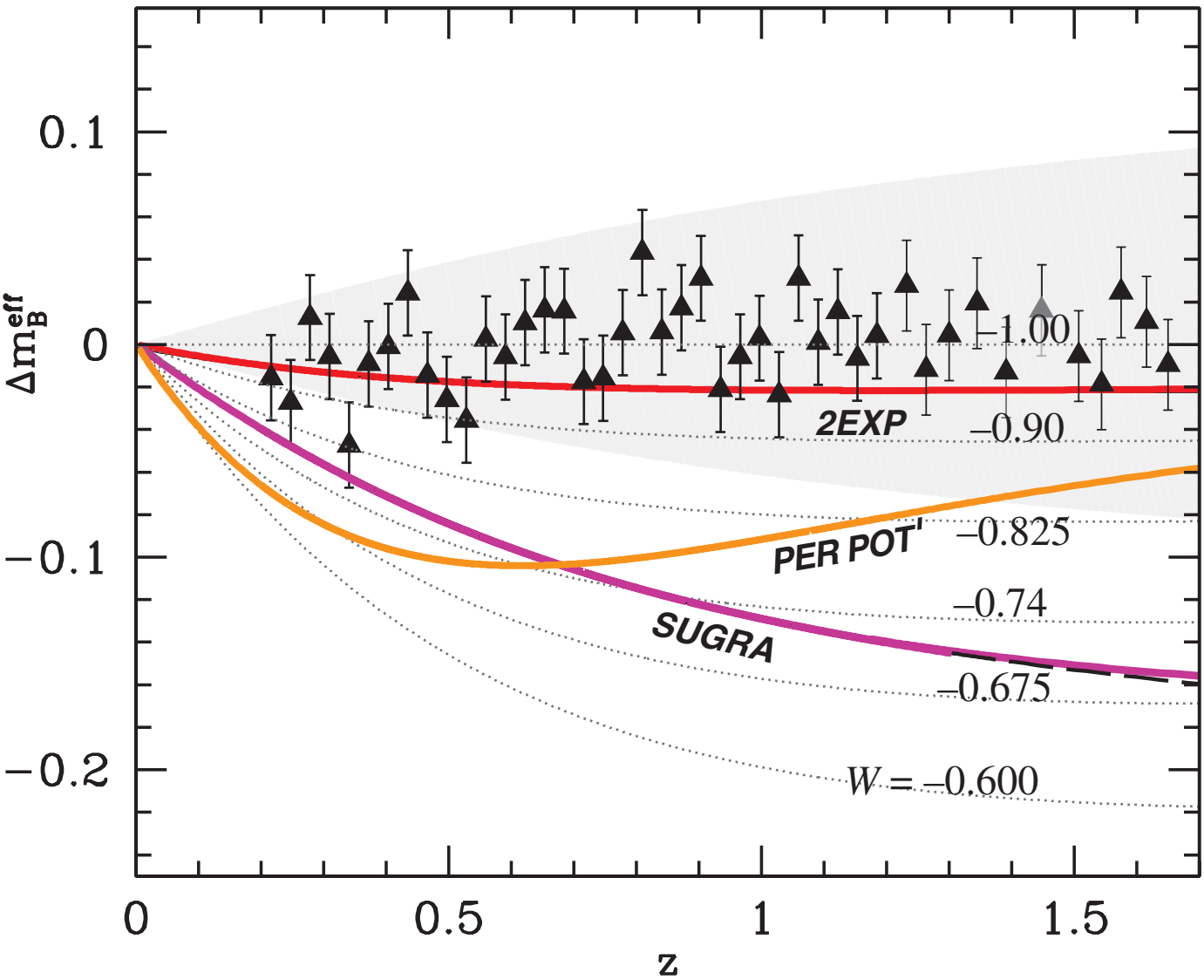


based on

Weller & Albrecht (2001)

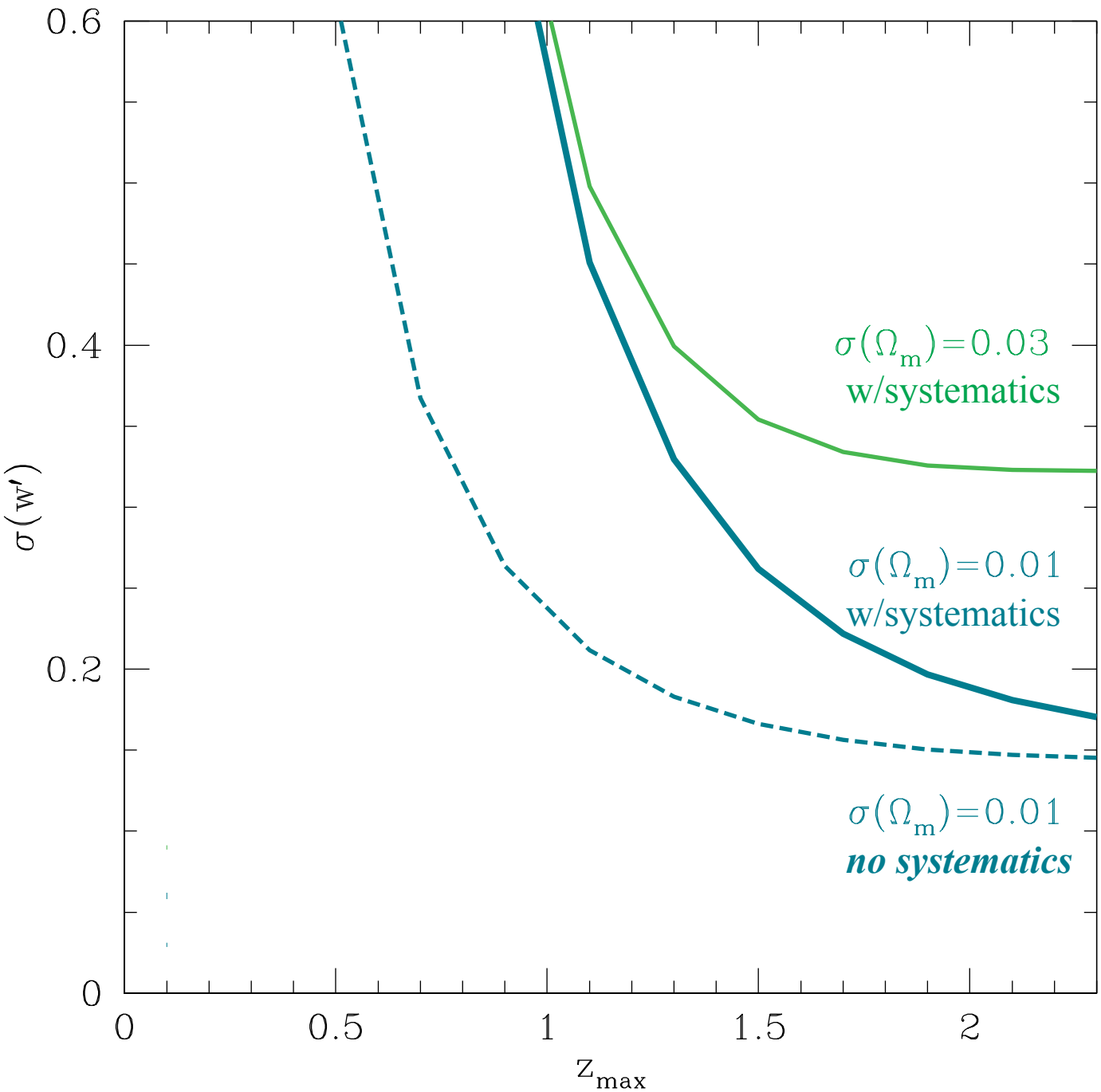
SNAP SuperNova Acceleration Probe

Binned simulated SNAP data
compared with Dark Energy models.

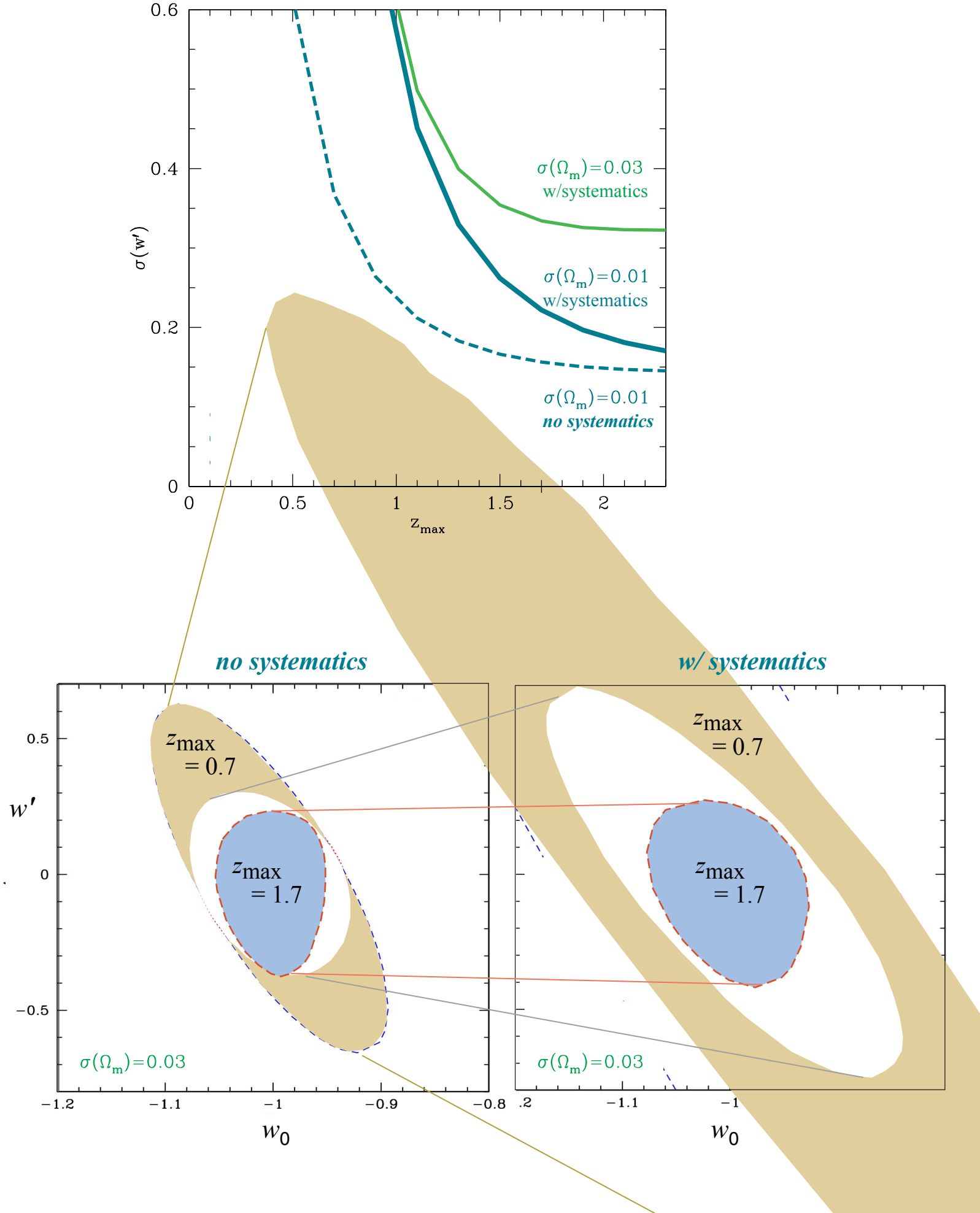


based on
Weller & Albrecht (2000)

How the uncertainty improves as we extend the redshift range.



How the uncertainty improves
as we extend the redshift range.



SNAP SuperNova Acceleration Probe

Primary Science Mission

Requiring complementary measurements of cosmological parameters, Dark Matter, Dark Energy,...

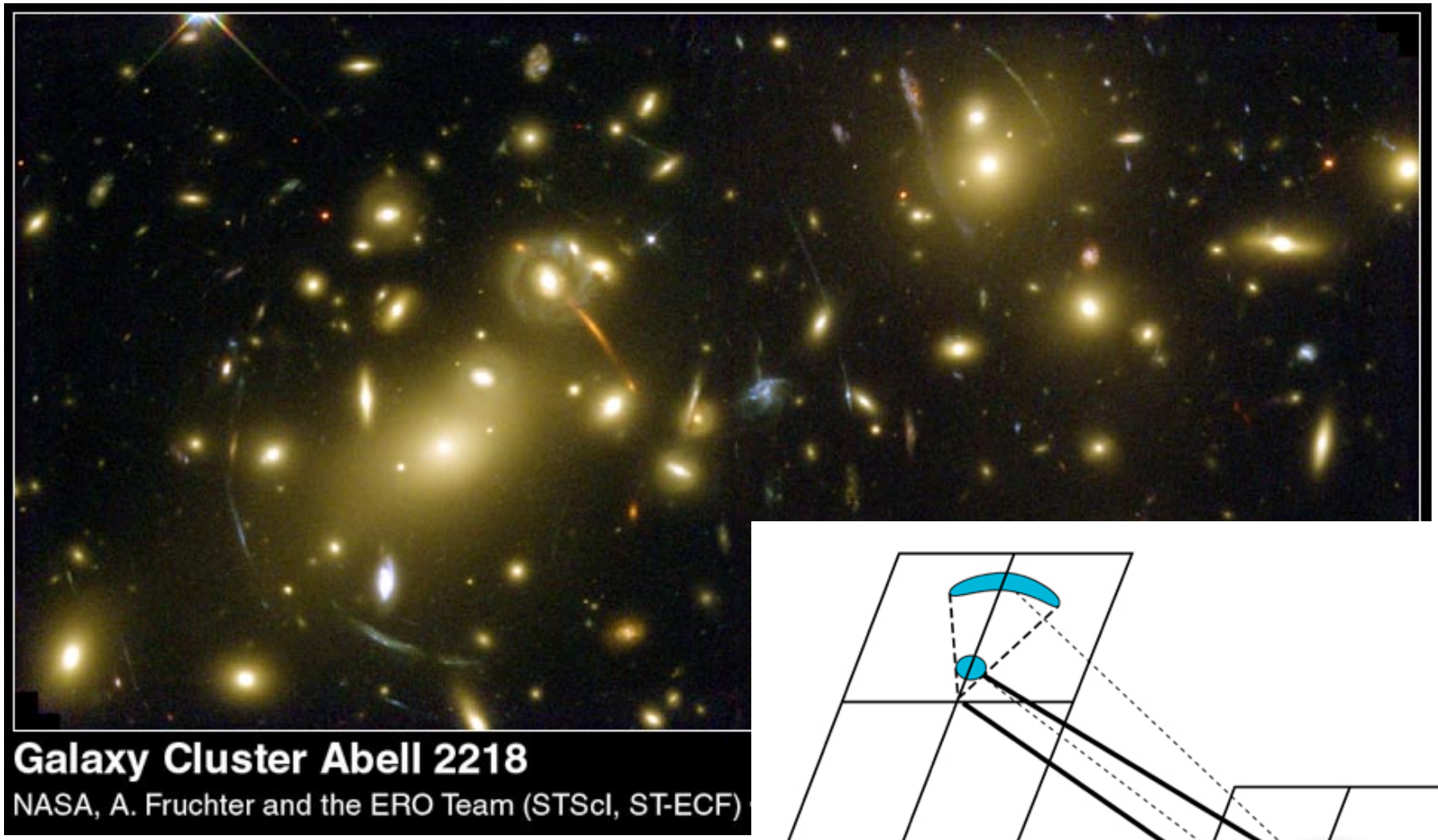
Type Ia supernova calibrated candle:
Hubble diagram to $z = 1.7$

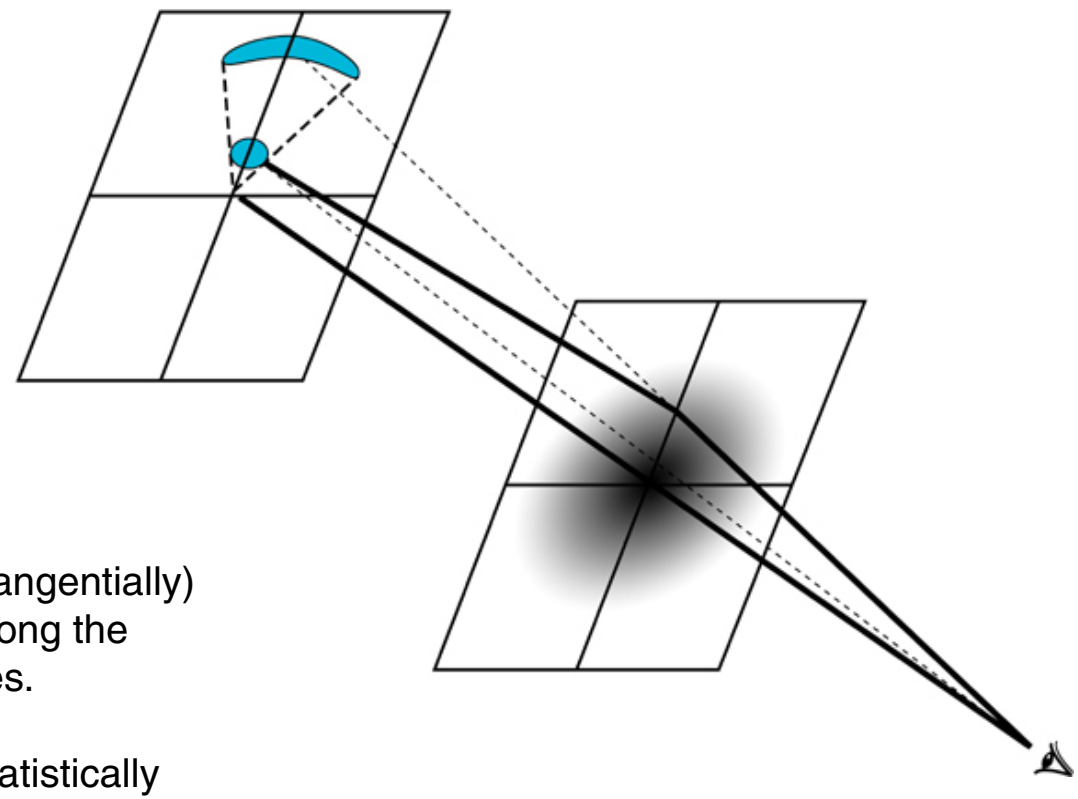
Type II supernova expanding photosphere:
Hubble diagram to $z = 1$ and beyond.

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



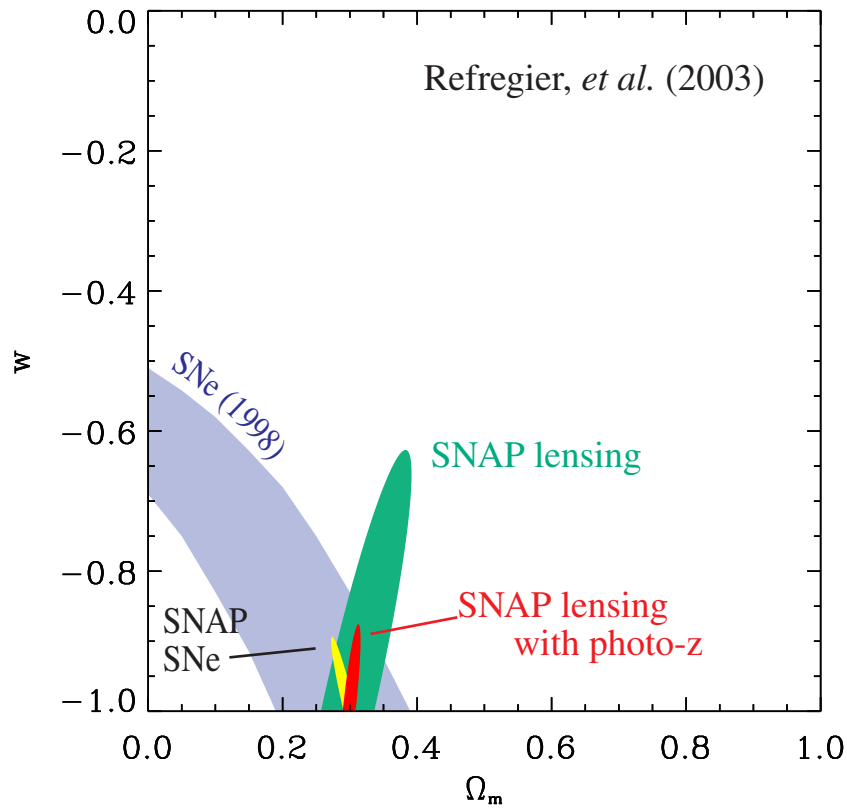


Gravitational Weak Lensing

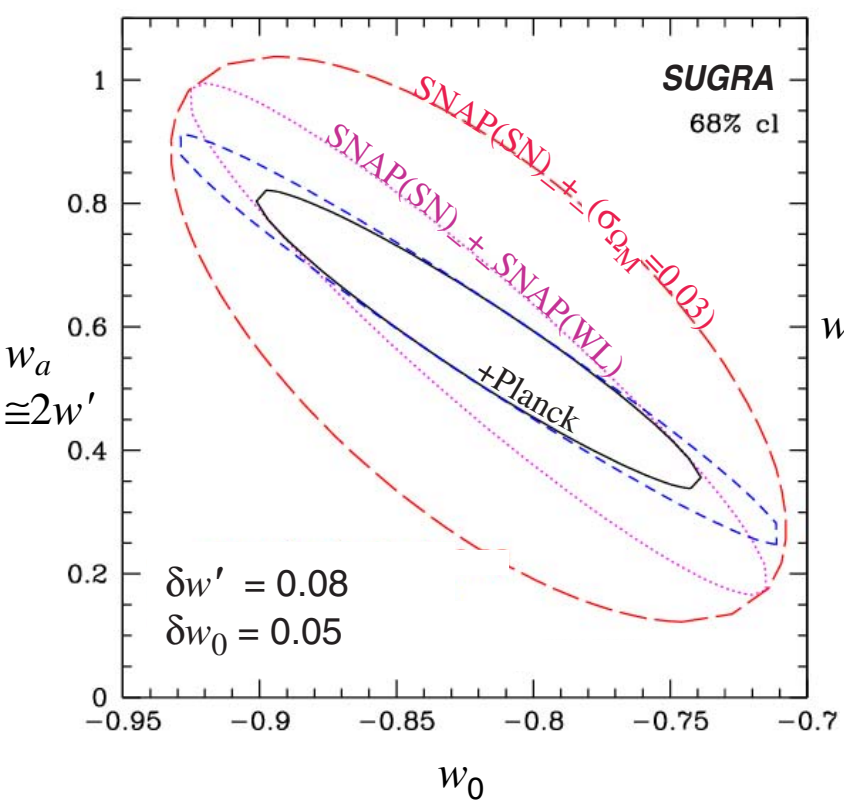
Observed galaxy shapes are distorted (smeared tangentially) by the gravitational field of mass concentrations along the line-of-sight between the galaxy and our telescopes.

This effect can be very small and yet detectable statistically after averaging over the measured ellipticity of many galaxies.

Weak Lensing Constraints

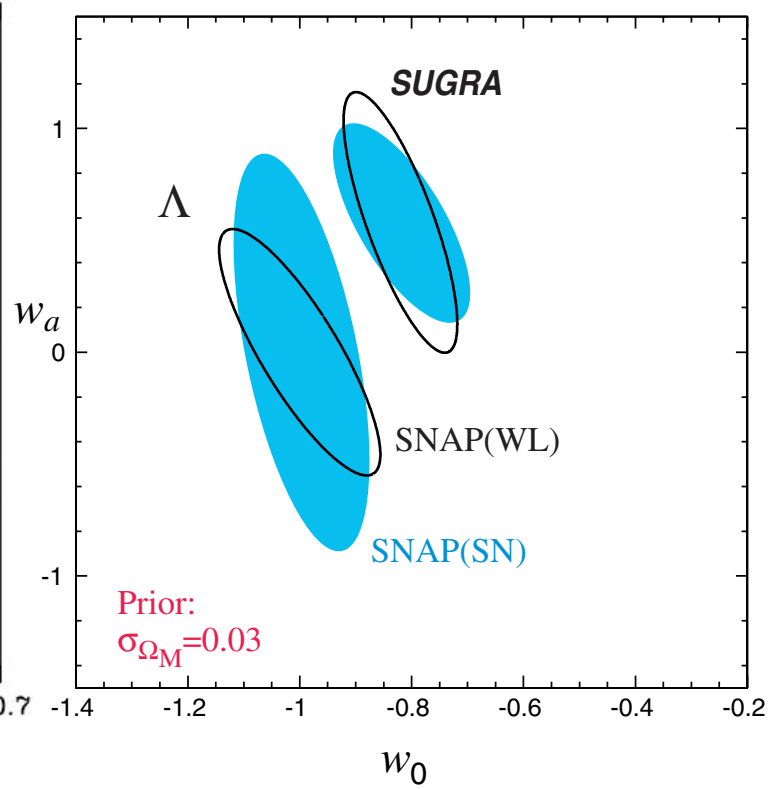


5% measure of C_λ (linear only)



Linder (2003)

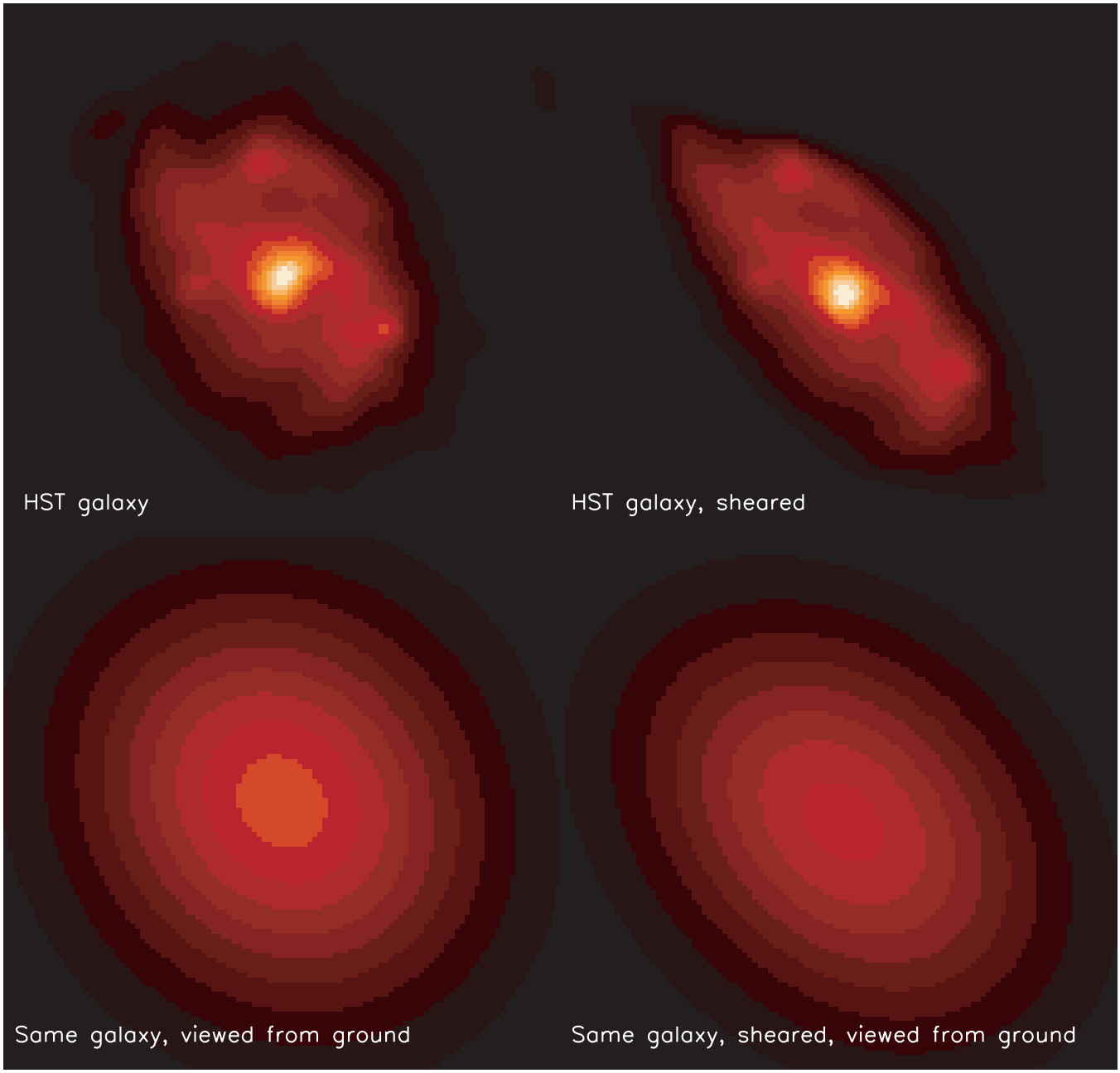
WEAK-LENSING
CROSS-CORRELATION
COSMOGRAPHY



Bernstein & Jain (2003)

SNAP SuperNova Acceleration Probe

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



(Bacon, Ellis, Refregier, Nov. 2000)

SNAP SuperNova Acceleration Probe

5. Project status & reviews.

Active SNAP Collaboration

LBNL: G. Aldering, C. Bebek, J. Bercovitz, W. Carithers, C. Day, R. DiGennaro, S. Deustua*, D. Groom, S. Holland, D. Huterer*, W. Johnston, A. Karcher, A. Kim, W. Kolbe, B. Krieger, G. Kushner, N. Kuznetsova, R. Lafever, J. Lamoureux, M. Levi, E. Linder, S. Loken, R. Miquel, P. Nugent, H. Oluseyi, N. Palaio, S. Perlmutter, V. Prasad, N. Roe, A. Spadafora H. von der Lippe, J-P. Walder, G. Wang

UC Berkeley: M. Bester, E. Commins, G. Goldhaber, H. Heetderks, M. Lampton, D. Pankow, M. Sholl, G. Smoot

CalTech: J. Albert, R. Ellis, R. Massey, A. Refregier, J. Rhodes, R. Smith, K. Taylor

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

IN2P3/INSU (France): P. Astier, E. Barrelet, J-F. Genat, R.Pain, D. Vincent

LAM (France): S. Basa, A. Bonissent, A. Ealet, D. Fouchez, R. Malina, A. Mazure, E. Prieto, G. Smajda, A. Tilquin

U. Michigan: C. Akerlof, B. Bigelow, M. Brown, M. Campbell, D. Gerdes, W. Lorenzon, T. McKay, S. McKee, M. Schubnell, G. Tarle, A. Tomasch

U. Penn: G. Bernstein, L. Gladney, B. Jain, D Rusin

U. Stockholm: R. Amanullah, L. Bergström, M. Eriksson, A. Goobar, E. Mörtsell

STScI: R. Bohlin, A. Fruchter, A. Umoto*

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

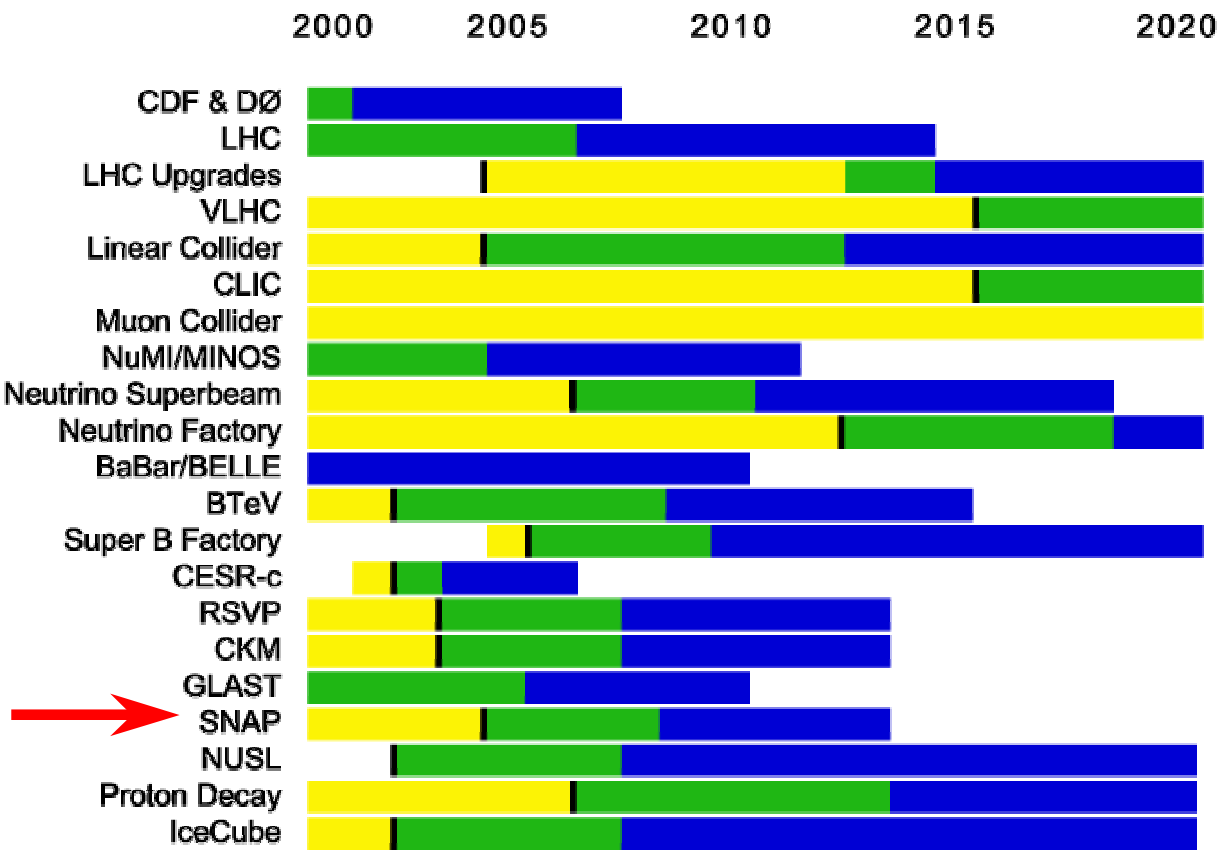
*affiliated institution

SNAP Reviews/Studies/Milestones

Nov 1999	Preproposal ad hoc committee review
Mar 2000	SAGENAP-1 (recommends R&D)
Sep 2000	NASA Structure and Evolution of the Universe (SEU)
Dec 2000	NAS/NRC Committee on Astronomy and Astrophysics
Jan 2001	DOE-HEP Review R&D (SNAP is uniquely able)
Mar 2001	DOE High-Energy Physics Advisory Panel (HEPAP)
Jun 2001	NASA Integrated Mission Design Center (determines feasibility)
July 2001	Snowmass Workshop (Community analysis)
July 2001	NAS/NRC Committee on Physics of the Universe
Nov 2001	CNES (France Space Agency)
Dec 2001	NASA/SEU Strategic Planning Panel
Dec 2001	NASA Instrument Synthesis & Analysis Lab
Jan 2002	Two Special Sessions at AAS Meeting
Jan 2002	HEPAP subpanel report: HEP Long Range Planning
Mar 2002	SAGENAP-2
Apr 2002	NRC/Committee on Physics of the Universe releases report
July 2002	DOE/SC-CMSD R&D (Lehman)
Oct 2002	CNES Review
Dec 2002	JPL Team-X Study (studies potential NASA cost)
Jan 2003	Two Special Sessions at AAS Meeting
Jan 2003	NASA releases SEU roadmap: Beyond Einstein
Feb 2003	DOE HEP Facilities Prioritization Panel
Feb 2003	SNAP R&D in the President's DOE budget
Mar 2003	DOE HEP releases Facilities 20 Year Roadmap

HEPAP Subpanel Report

"We endorse R&D funding for SNAP from the high-energy physics program."



Timelines for Selected Roadmap Projects.Approximate decision points are marked in black.R&D is marked in yellow,construction in green,and operation in blue.

SNAP SuperNova Acceleration Probe

Three National Prioritization Panels' Recommendations

Astronomy & Astrophysics

NRC Decadal Survey:

"One of the most exciting developments of the past decade has been the discovery that the cosmological constant may not be zero — our universe appears to be filled with dark energy."

"The committee identified several key problems that are particularly ripe for advances in the coming decade. These problems are … properties of the universe: the amount and distribution of its matter and energy, its age, and the history of its expansion."

SNAP was formulated after the Decadal Survey's data collection phase.

Physics

HEPAP 20-Year Planning Report:

"Modern cosmology is closely connected with particle physics. For example, cosmological measurements of dark energy and particle dark matter have direct implications for particle physics."

"Dark energy can be probed by a number of techniques. Among the most powerful are measurements of the expansion rate of the universe from observations of Type Ia supernovae."

Report gives a strong endorsement for continued development of SNAP.

Intersection of Physics and Astronomy

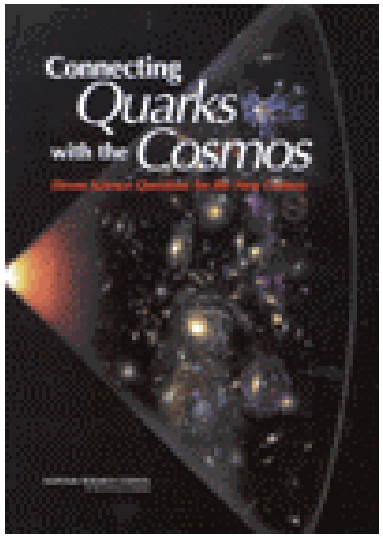
NRC Committee on the Physics of the Universe:

"Deciphering the nature of dark matter and dark energy is one of the most important goals in the physics of the universe. Resolving both puzzles is key to advancing our understanding not only of cosmology but also fundamental physics."

"Observations of distant supernovae can probe the detailed expansion history directly back to redshifts of around 2.... Large-field-of-view telescopes are needed to find larger and more uniform samples of supernovae."

Committee reviewed SNAP in July 2001 as part of their Phase II study of specific projects (released this spring).

Report from the NRC Committee on the Physics of the Universe



Connecting Quarks with the Cosmos

- "To fully characterize the expansion history and probe the dark energy will require a wide-field telescope in space (such as the Supernova/Acceleration Probe)."

- "The Committee further recommends that NASA and DOE work together to construct a wide-field telescope in space to determine the expansion history of the universe and fully probe the nature of the dark energy."

Lehman Review

- Full Lehman review of SNAP R&D plan in July 2002 - passed with flying colors

- The Committee agreed that "the need for a space based large field of view mission like SNAP to elucidate the nature of Dark Energy via the study of Type Ia supernovae has been convincingly established" and that "the proposed instruments and observing strategy is appropriate and sufficient to carry out the scientific objectives of the mission."

- The committee recommended that "The R&D effort necessary to move this project forward should be pursued with all possible speed" and that "SNAP is ready to go to CD-0 (start of the R&D phase), when deemed appropriate by DOE."

- …and other very positive comments…

HEPAP/Facilities Prioritization

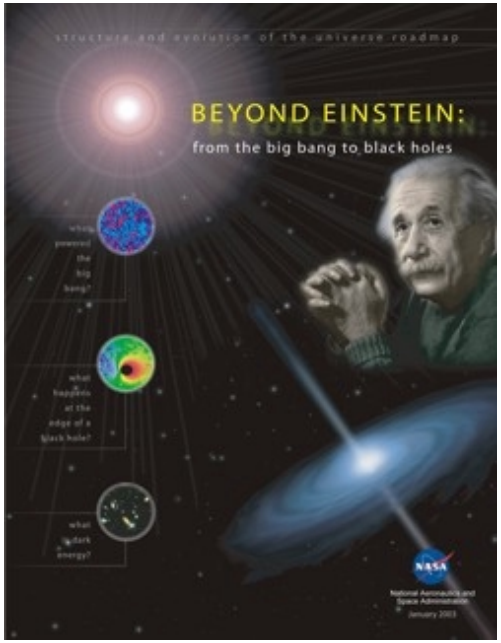
Resolving the mystery of what is the dark energy that constitutes more than two-thirds of the energy of the present universe is one of the leading scientific questions in physics and astronomy. ….. By observing thousands of Type Ia supernovae with better precision than any single supernova has ever been measured so far, SNAP will measure the history of the growth of the universe over the past 10 billion years. The science addressed by SNAP in exploring the nature of dark energy is ***absolutely central***. It would be carried out by an international collaboration and would be supported by both the DOE and NASA in the U.S. The project is now in the ***R&D phase***, with plans calling for project engineering and design starting in two years, and launch in 2009.

Priorities

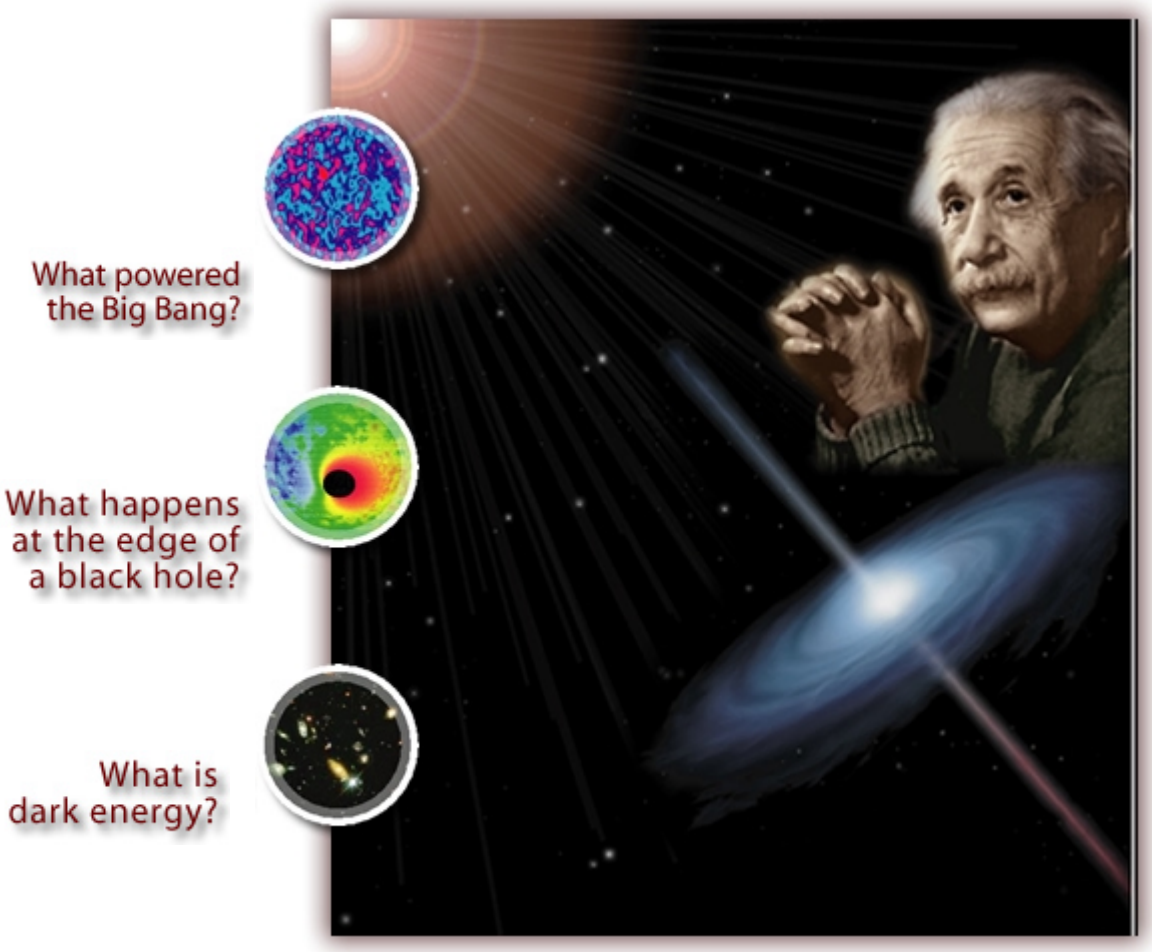
Project	Type	Physics	Cost	Scientific Potential	Proposed Facility	State of Readiness	Possible Time Scale
Linear Collider	Facility	Energy Frontier	$5B – $7B	Absolutely Central	Absolutely Central	R&D	2015 Operation
LHC Luminosity Upgrade	Facility	Energy Frontier	$150M (US Part)	Absolutely Central	Absolutely Central	R&D	2014 Operation
LHC Energy Upgrade	Facility	Energy Frontier	Unknown	Don't Know Enough Yet	Don't Know Enough Yet	R&D	Decision in Next Decade
SNAP	Experiment	Cosmology	$400M – $600M	Absolutely Central	Absolutely Central	R&D	2009 Launch
BTEV	Experiment	Quark Physics	$120M	Important	Important	Ready for Decision on Construction	2008 Operation
CKM	Experiment	Quark Physics	$100M	Important	Important	Ready for Decision on Construction	2008 Operation
Super-B Factory	Facility	Quark Physics	Unknown	Don't Know Enough Yet	Don't Know Enough Yet	R&D	Decision Later This Decade
Double-Beta Decay	Experiment	Neutrino Physics	$100M	Absolutely Central	Don't Know Enough Yet	R&D	2005 Prototype
Off-Axis Neutrino Detector	Experiment	Neutrino Physics	$120M	Important	Important	Project Engineering and Design	2010 Operation
Neutrino Super Beam	Facility	Neutrino Physics	$250M – $500M (Accelerator and Beam Only)	Absolutely Central	Don't Know Enough Yet	Project Engineering and Design	Decision Later This Decade
Underground Detector	Facility	Neutrino Physics and Proton Decay	$500M	Absolutely Central	Don't Know Enough Yet	R&D	Decision Later This Decade
Neutrino Factory	Facility	Neutrino Physics	Unknown	Don't Know Enough Yet	Don't Know Enough Yet	R&D	Decision in Next Decade

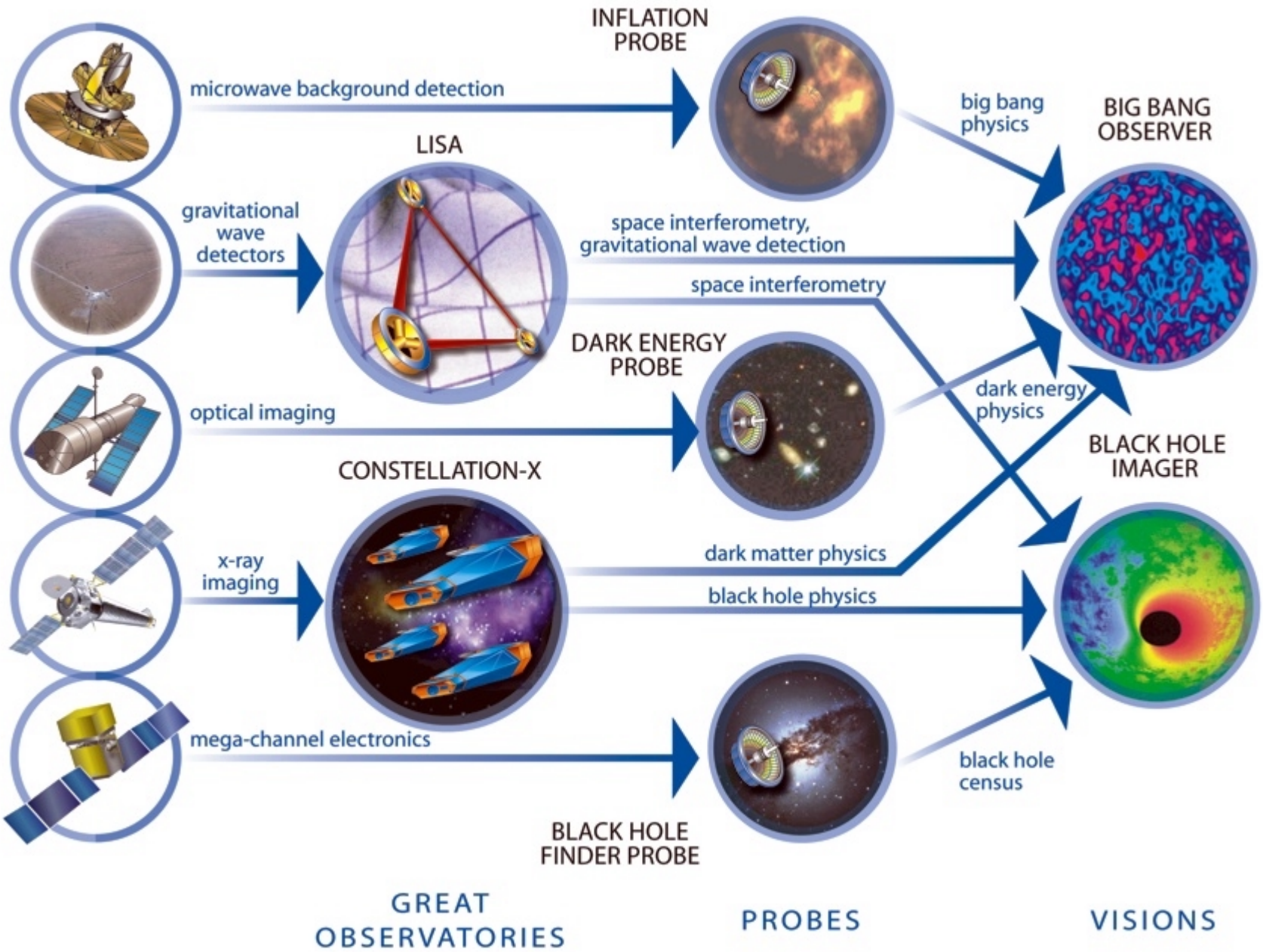
Federal Budget

The FY 2004 SNAP program ($8,256,000) will focus on developing a conceptual design, the beginning of engineering design, and fabrication and testing of prototypes for the principal SNAP instrument. *The goal of this R&D effort is to produce a complete Conceptual Design Report by 2006, and funding is increased by $6,876,000 to provide the significant resources needed to successfully begin the detailed design and prototyping phase. This increase is consistent with the 2002 HEPAP Subpanel recommendation that the physics of SNAP (the "dark energy" phenomenon) is exciting and relevant to HEP, and that the R&D effort should be supported; and the recent National Research Council report ("Quarks to the Cosmos") which identified this interdisciplinary research area as a high priority for an interagency initiative.* DOE is actively engaged with NASA to develop a successful research effort in this new and exciting field.



NASA/SEU Roadmap: Beyond Einstein




INFLATION PROBE
microwave background detection
big bang physics
BIG BANG OBSERVER
LISA
gravitational wave detectors
space interferometry, gravitational wave detection
space interferometry
DARK ENERGY PROBE
optical imaging
dark energy physics
BLACK HOLE IMAGER
CONSTELLATION-X
x-ray imaging
dark matter physics
black hole physics
mega-channel electronics
black hole census
BLACK HOLE FINDER PROBE
GREAT OBSERVATORIES
PROBES
VISIONS

NASA NRA

A Multi-Agency Approach to the Dark Energy Probe

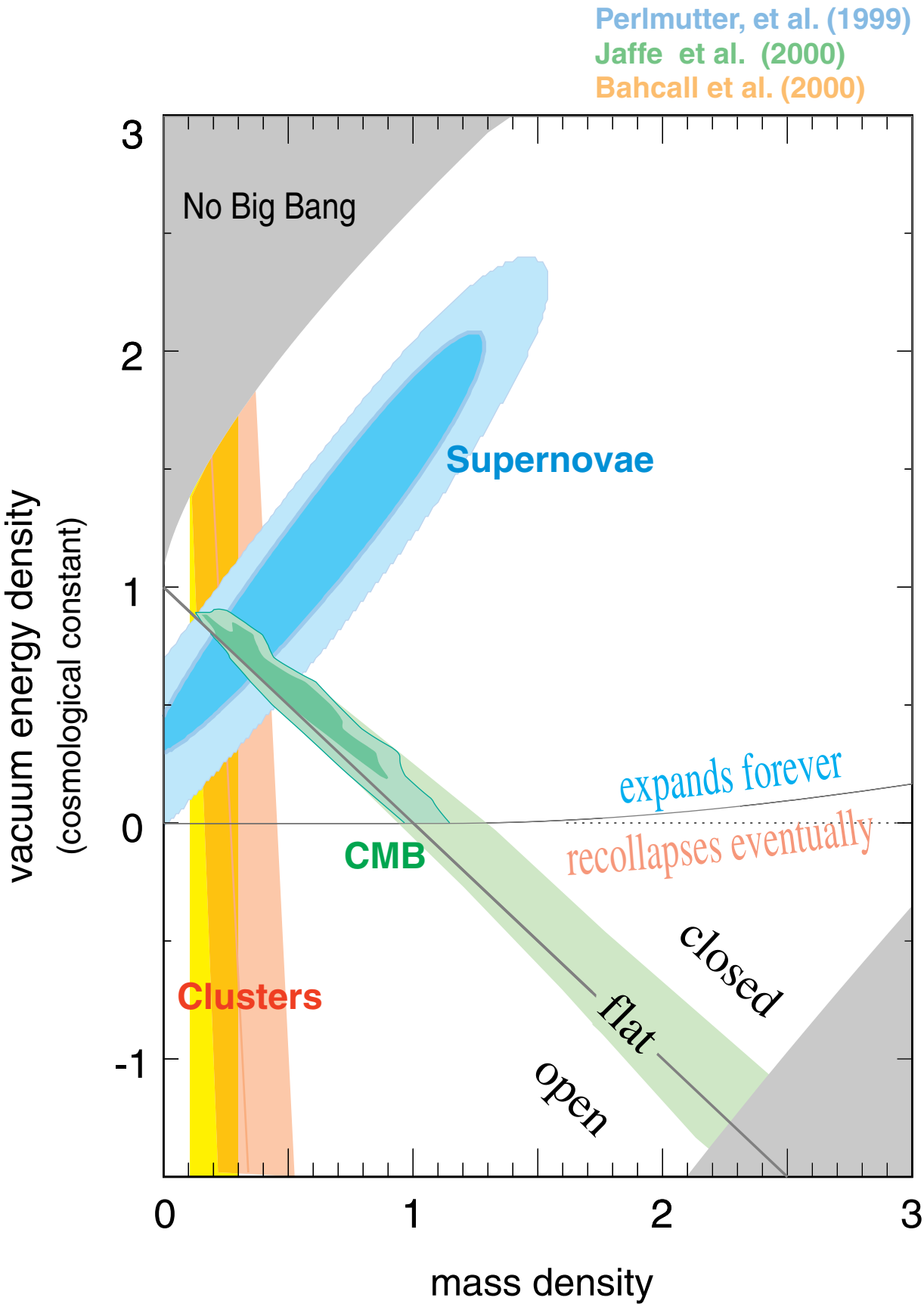
The U.S. Department of Energy (DOE) has made the mystery of dark energy a high science priority and, under the leadership of its Lawrence Berkeley National Laboratory, is funding a study of a possible space mission entitled the Supernova Acceleration Probe (SNAP) to address this topic. Therefore, in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

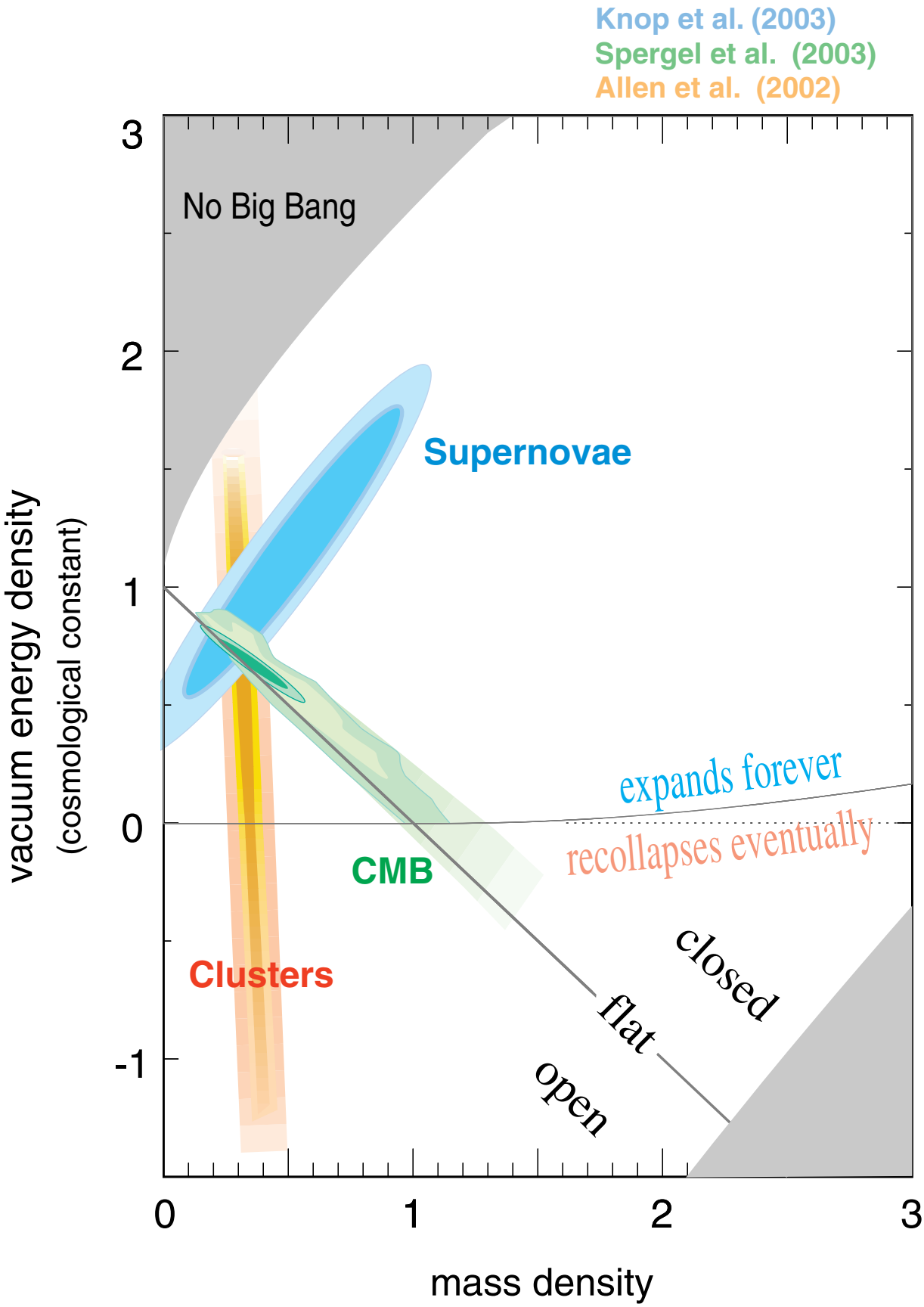
Type 1: Proposals for a full mission investigation concept that uses any technique to meet the science goals of the Dark Energy Probe; and

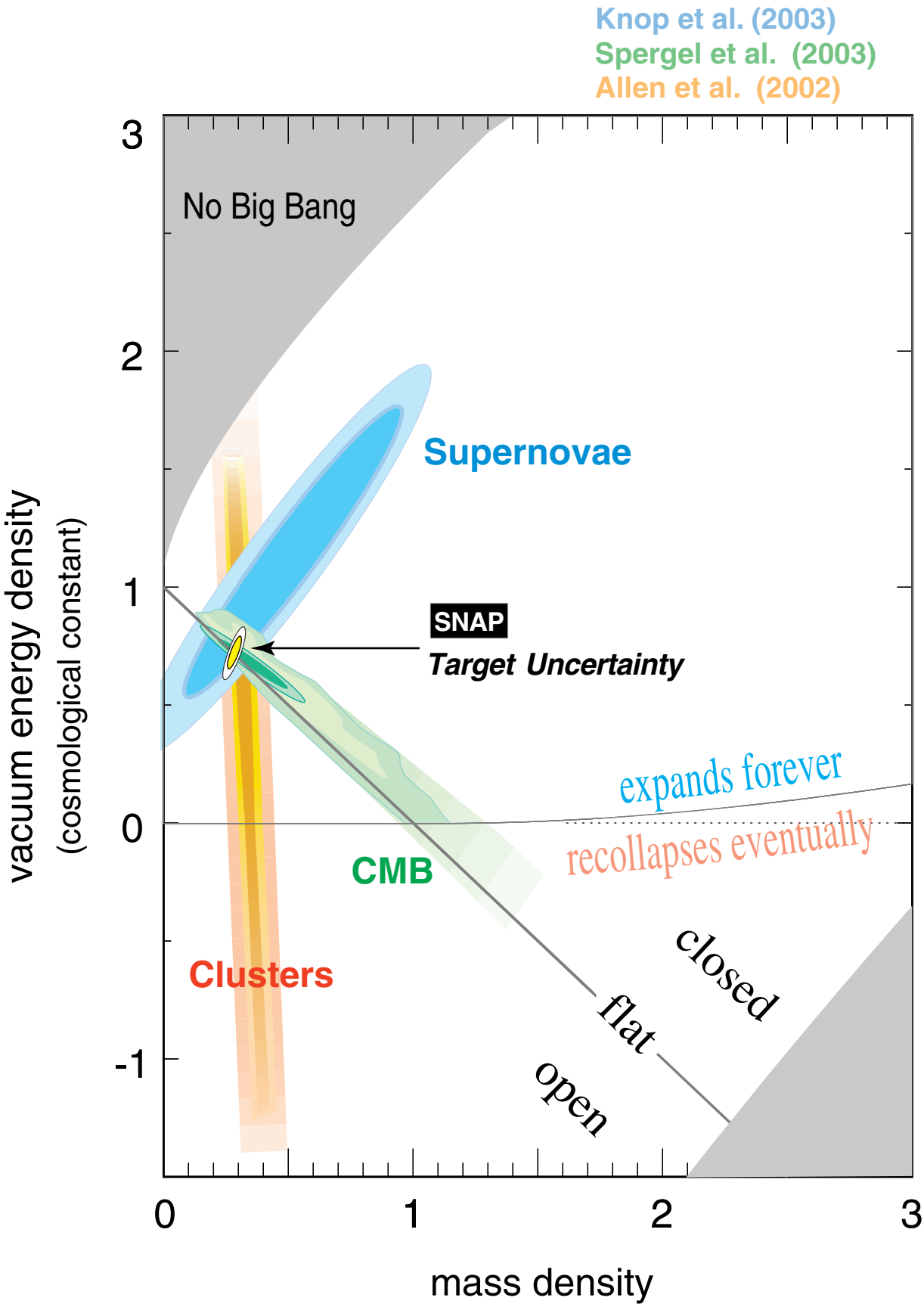
Type 2: Proposals involving a significant NASA contribution (> 25% of the total mission cost) to the existing DOE SNAP concept mission. Note that prior endorsement from the SNAP team or DOE is not required, but the proposal must clearly state how the proposal team envisions working with the SNAP team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

Joint Dark Energy Mission

- NASA-DOE Joint Announcement of JDEM (Staffin, Hertz)
- Project is joint at the agency, DOE minority funder.
  - Launch in 2014
  - NASA assigned mission management
  - ~3 year DE investigation defined to be 50-50
  - Succeeding 3 year program NASA defined
  - Science archive assigned to NASA
- Below agency, at operational level, identical to GLAST
  - Mission scientist and project manager assigned to GSFC
  - Cost competitive proposals for PI-led dark energy investigation in 2-3 years
- New way of business for DOE-HEP
  - Full cost accounting of scientists
  - Cost of science and operations in total project cost


Perlmutter, et al. (1999)
Jaffe et al. (2000)
Bahcall et al. (2000)
No Big Bang
Supernovae
CMB
Clusters
expands forever
recollapses eventually
closed
flat
open
vacuum energy density
(cosmological constant)
mass density
3
2
1
0
-1
0
1
2
3


Knop et al. (2003)
Spergel et al. (2003)
Allen et al. (2002)
No Big Bang
Supernovae
CMB
Clusters
expands forever
recollapses eventually
closed
flat
open
vacuum energy density
(cosmological constant)
mass density
3
2
1
0
-1
0
1
2
3


Knop et al. (2003)
Spergel et al. (2003)
Allen et al. (2002)
No Big Bang
Supernovae
SNAP
Target Uncertainty
expands forever
recollapses eventually
CMB
Clusters
closed
flat
open
vacuum energy density
(cosmological constant)
mass density
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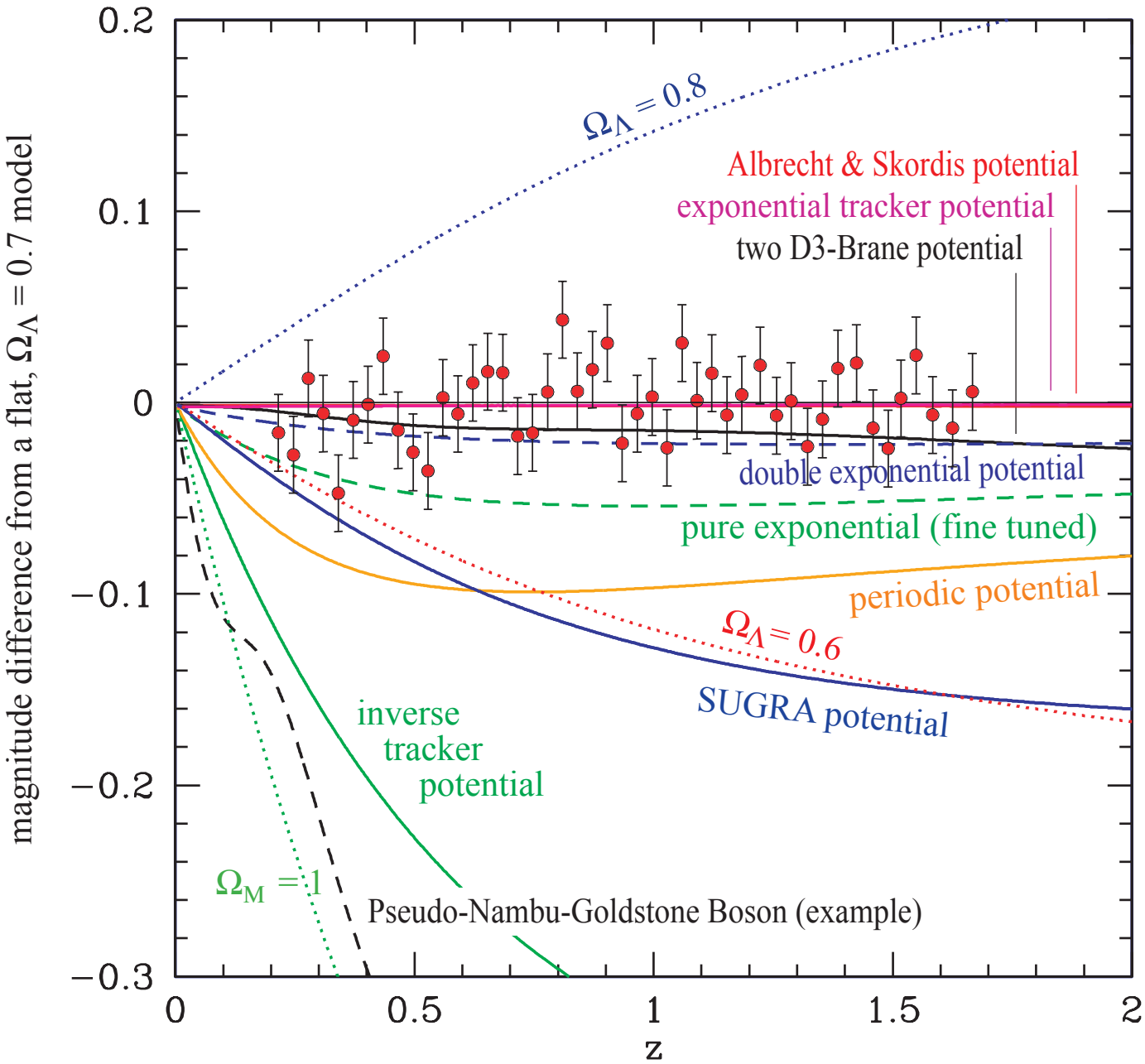
3

SNAP SuperNova Acceleration Probe

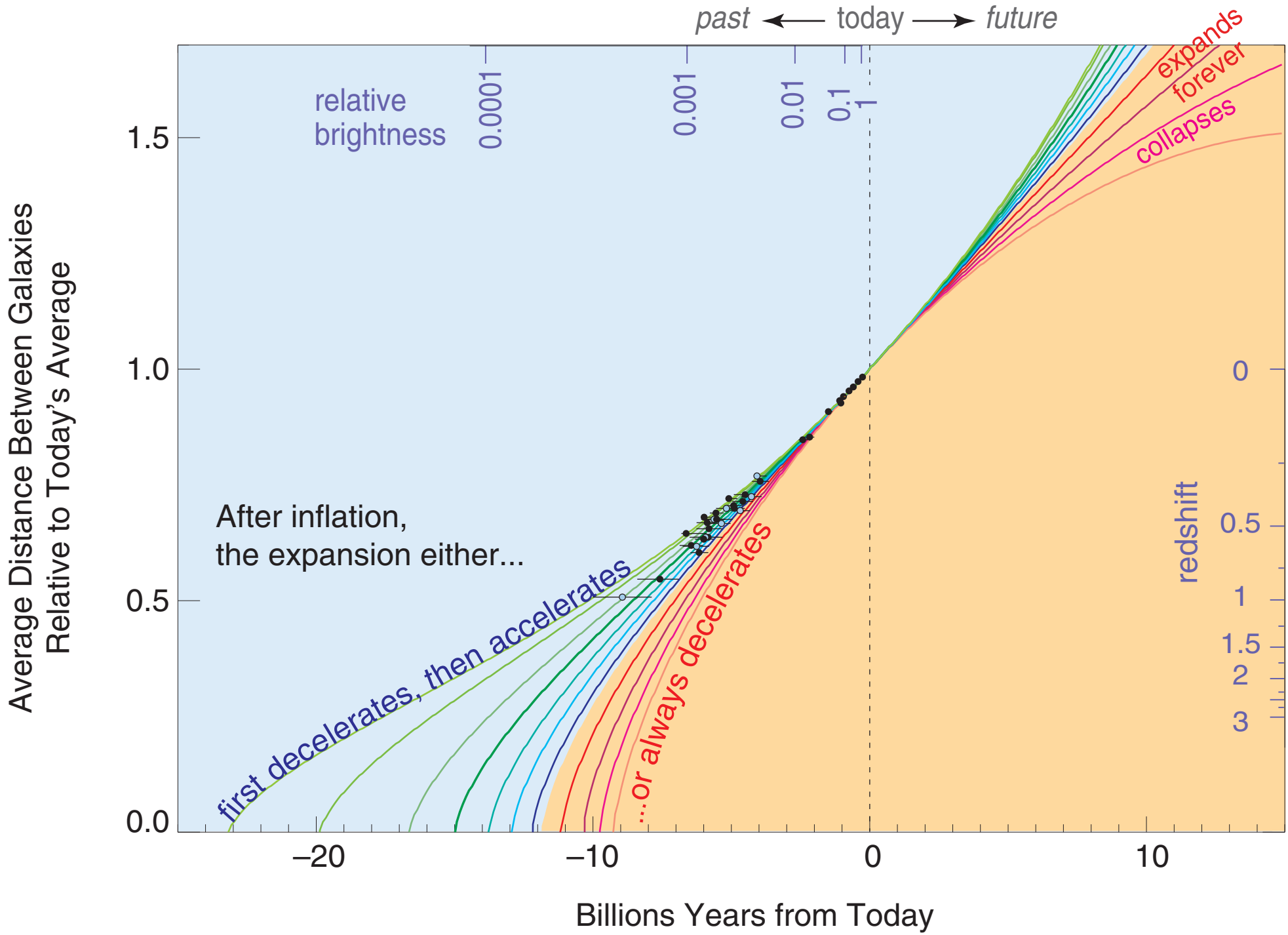
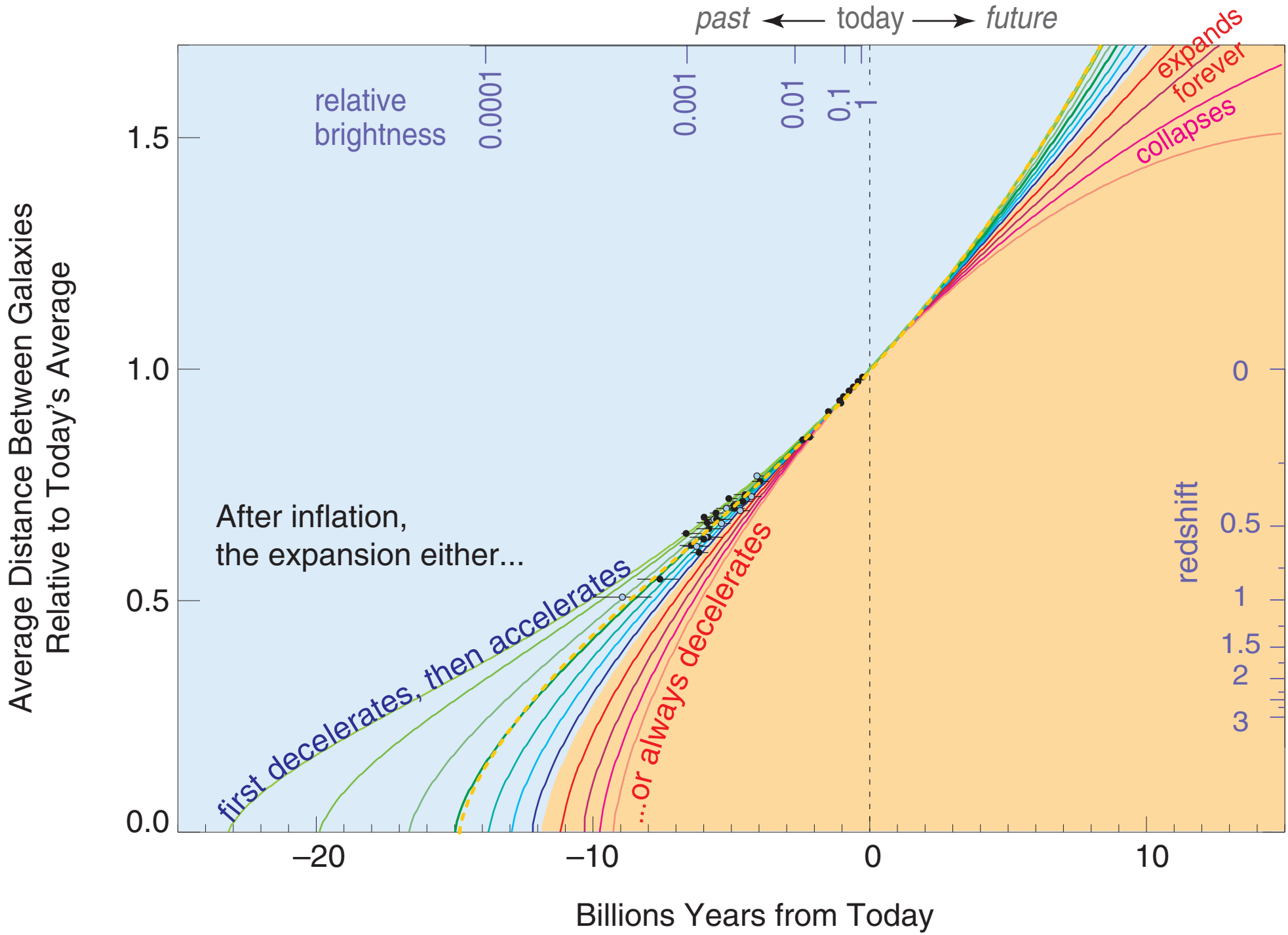
Binned simulated SNAP data compared with Dark Energy models currently in the literature.



based on

Weller & Albrecht (2001)

Expansion History of the Universe



Expansion History of the Universe