SUPERNOVAE SURVEYS AND STATISTICS

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SCMA VI
2016 JUNE 8

Supernovae Have Captivated Astronomers for Millennia

- Notable supernovae include SN 1006, 1054, 1181 1572 (Tycho), 1604 (Kepler), 1700? (Cas A)
- Naked-eye visible
- Burbling evidence of a changing Universe

SN 1006 was widely seen

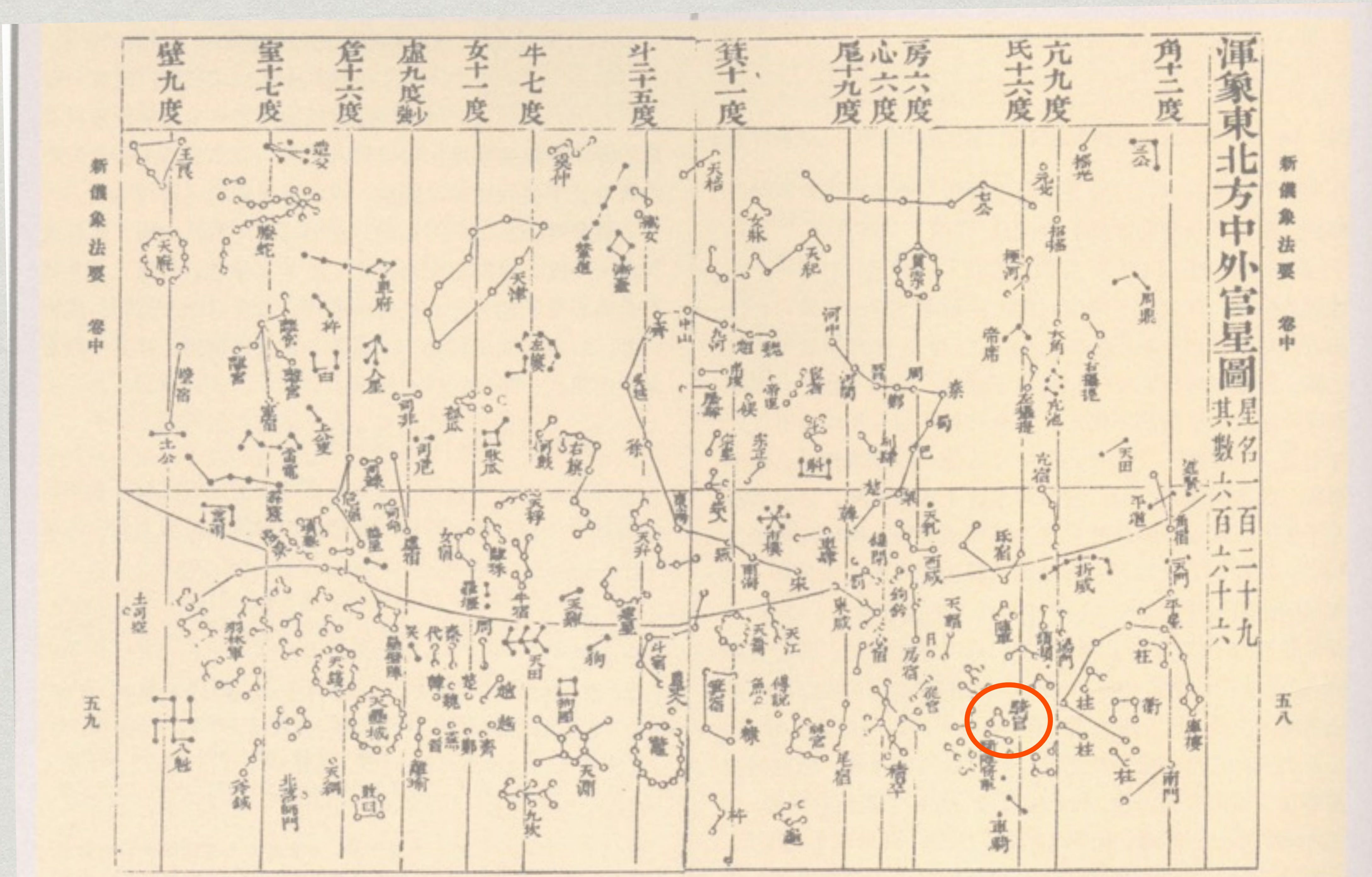


图 8-2-7 浑象东北方中外官星图——守山阁丛书本

Chinese Star map from 11th century

Modern view of SN 1006

NASA, ESA, STScI

Improved detectors brought us supernovae in other galaxies

- 20 SNe from < 1890 : Naked Eye
- 750 SNe from 1890-1990 : Plates
- 1,000 SNe from 1990-2000 : CCD
- 3,700 SNe from 2000-2010 : Cluster Computing
- 10,000s SNe from 2010-2020 : Large Cameras
- 100,000s SNe from 2020-2030 : AI Computing

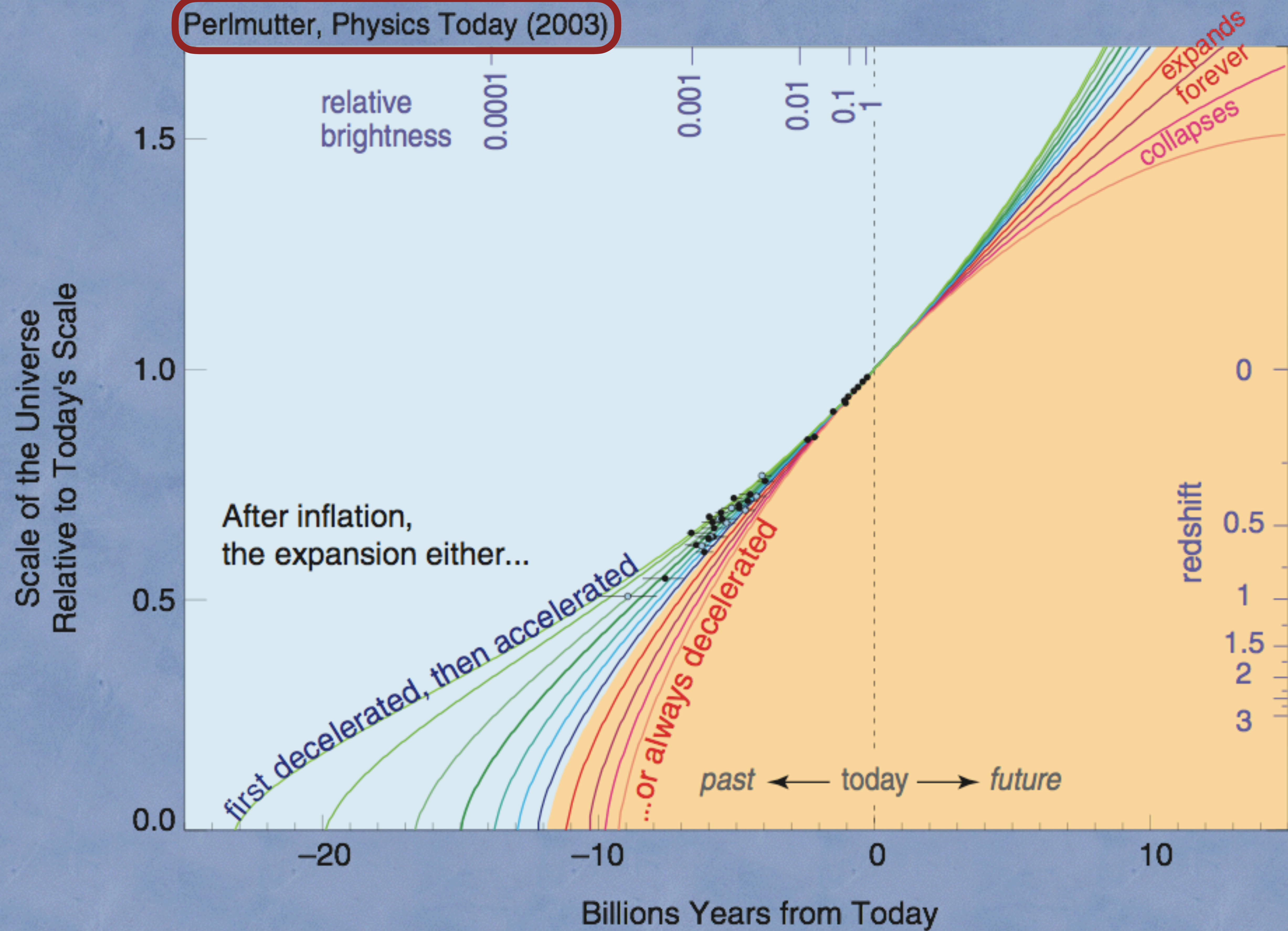
What do we learn from Supernovae?

A few examples:

- Type Ia Supernovae measure distances to points in expansion history. -> Dark Energy
- Supernovae are a dramatic marker of the end point of stars and have substantial influence on the next generation of stars.
- Supernovae probe extreme physics inaccessible on Earth. gamma-ray bursts, magnetars, pair-production supernovae, …

Expansion History of the Universe

Perlmutter, Physics Today (2003)



Distance will tell

Luminosity Distance

$$F = \frac{L}{4\pi D_L^2}$$

$$D_L = a(t_0) r (1+z)$$

- Luminosity distance:

Luminosity Distance in terms of

$$D_L(z) = \frac{c}{H_0}(1+z)\int_0^z \frac{dz'}{\sqrt{\Omega_M(1+z')^3 + \Omega_\Lambda(1+z')^{3(1+w)}}}$$

(flat, constant w)

Composition

- Density parameter

$$\Omega = \frac{8\pi G\rho}{3H^2} = 1 + \frac{k}{\dot{a}^2}$$

$$\Omega = \Omega_{\mathrm{matter}} + \Omega_{\mathrm{radiation}} + \Omega_X$$

- Flat Universe, k=0

$$\Omega = 1$$

How Stuff Evolves

$$P = w\rho$$

density	w	r	a(t)
matter	0	a^{-3}	$t^{2/3}$
radiation	1/3	a^{-4}	$t^{1/2}$
vacuum	-1	1	e^{Ht}

In a flat Universe (k=0)

The Basic Question:

Is a cosmological constant model consistent with our observations of the Universe?

The Basic Question:

(paraphrased)

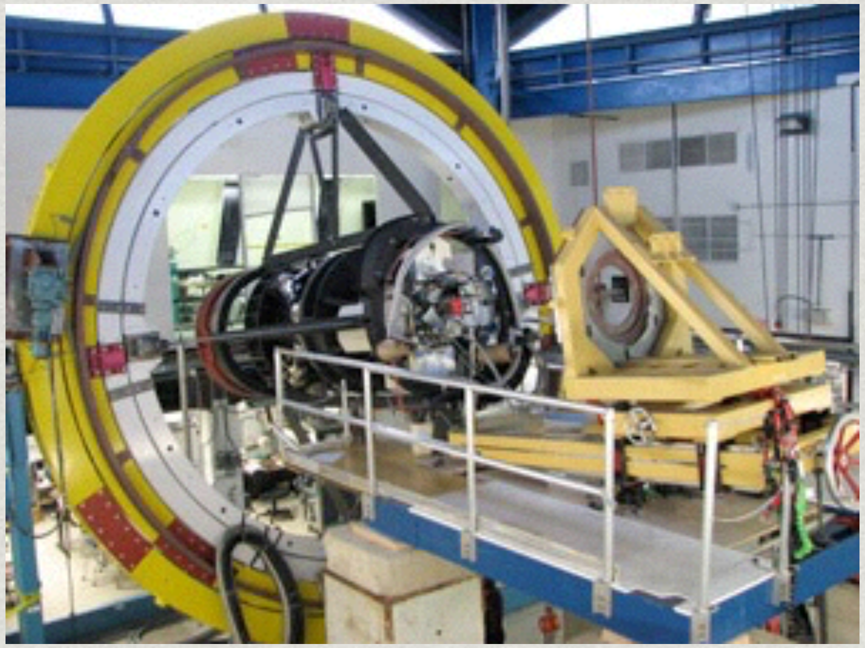
Is w = -1 ?

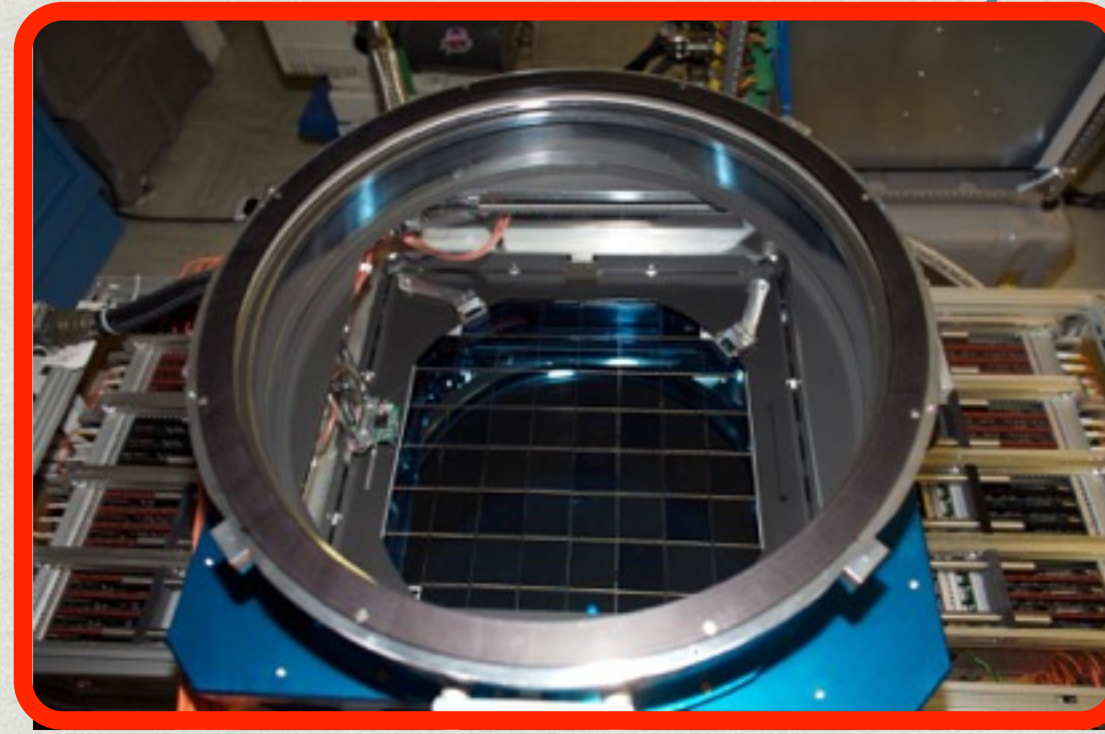
$$P = w\rho$$

Some Current and Future SN Surveys

Dark Energy Survey

photo: Rich Talcott

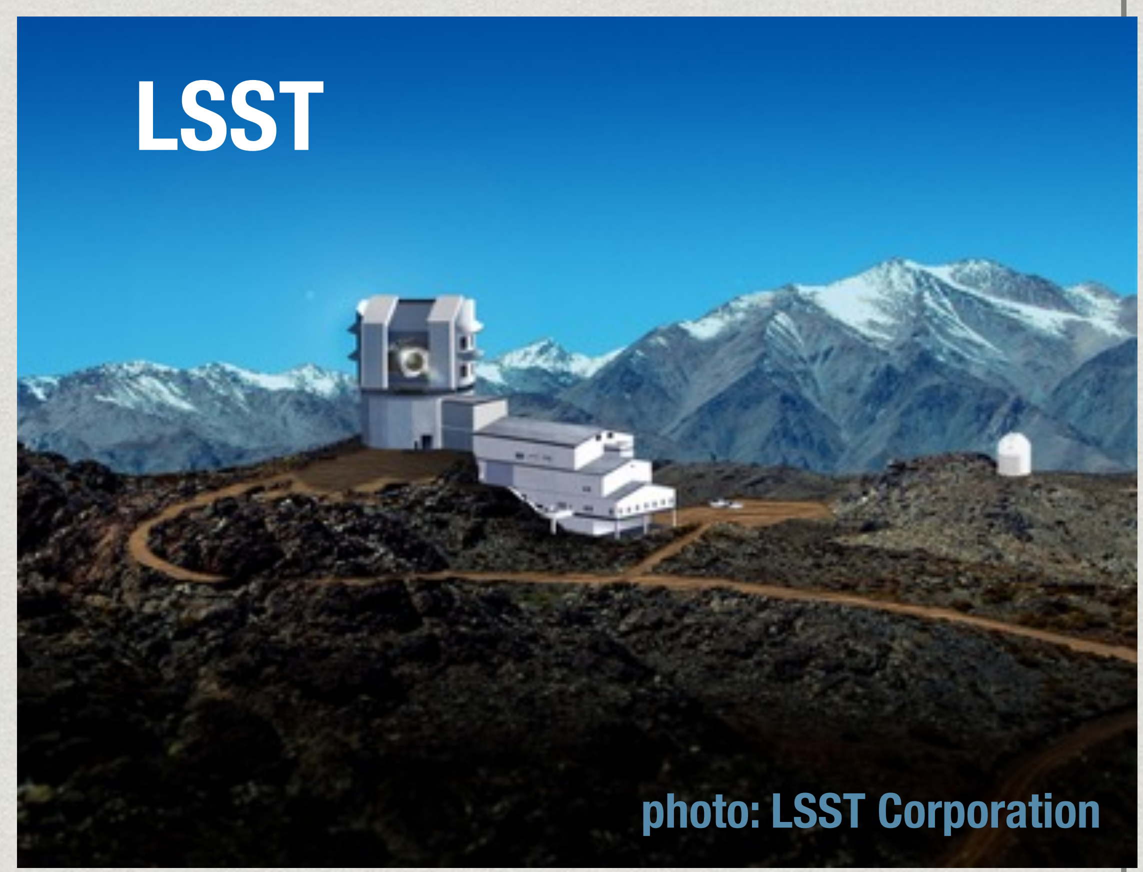




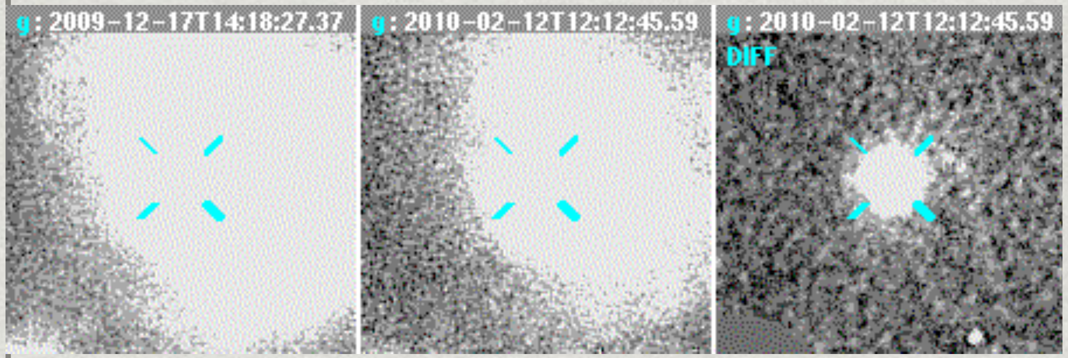
Pan-STARRS 1

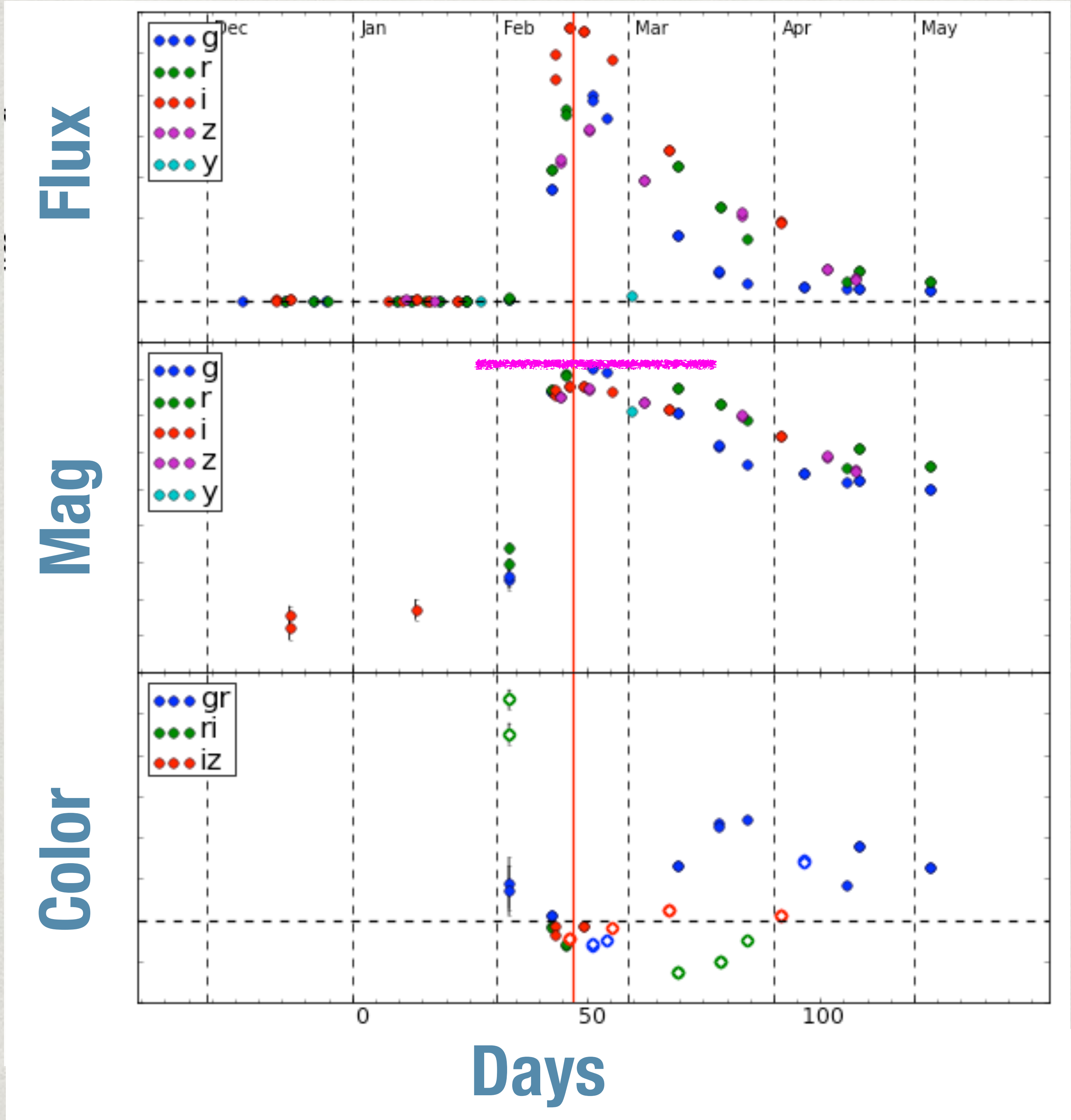
photo: John Tonry

+SkyMapper, DES, SDSS-II, KAIT, PTF, ...



PS1-1000023 SNIa @ z=0.03





Challis et al. (2010), ATel #2448

Current and Future SN Surveys

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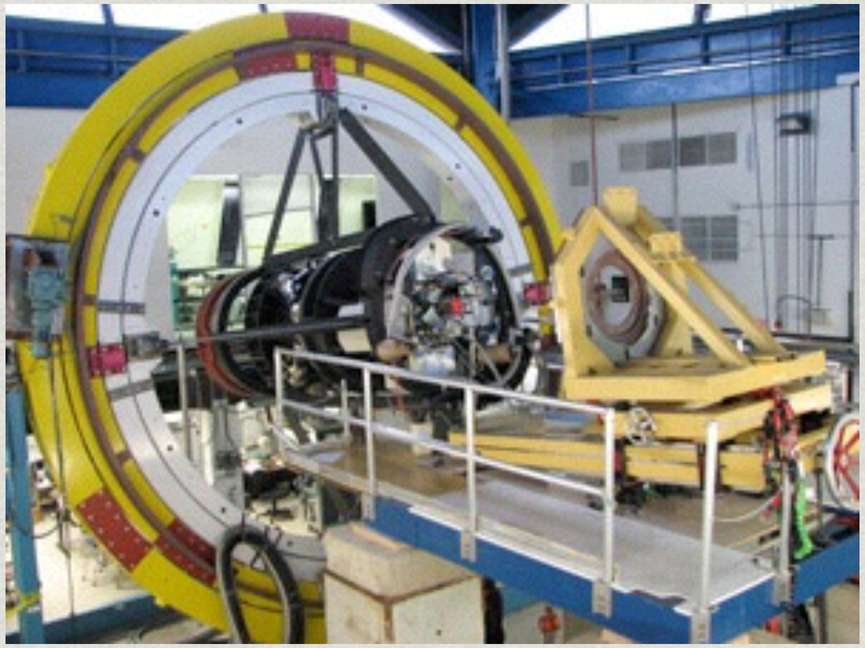

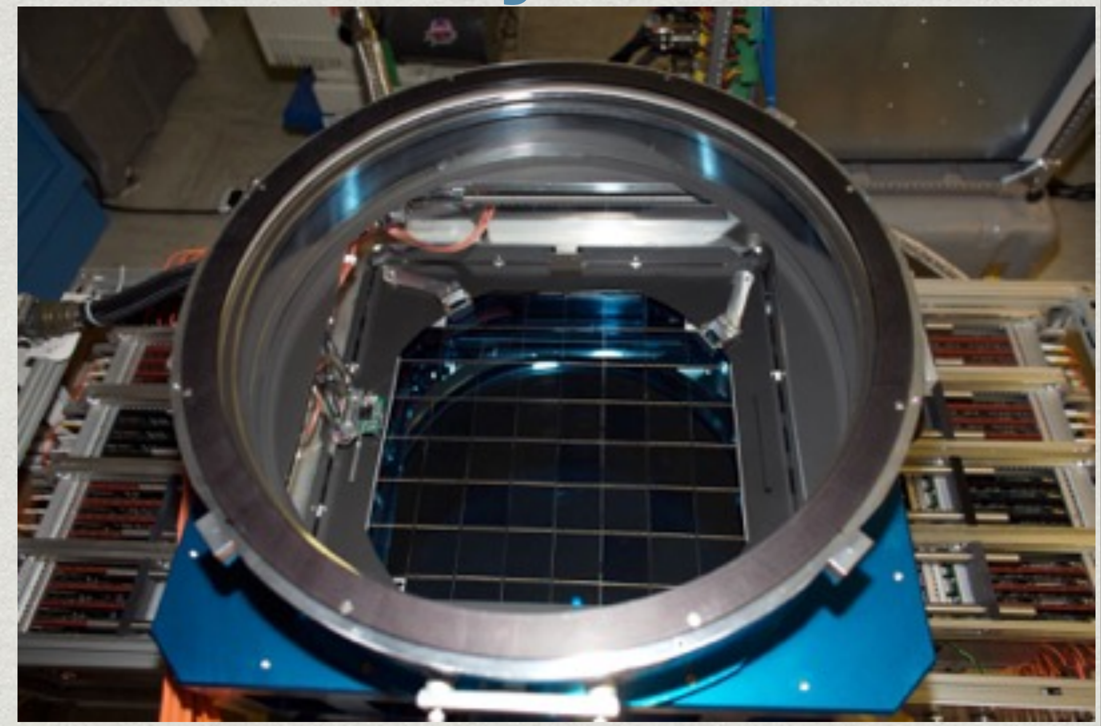

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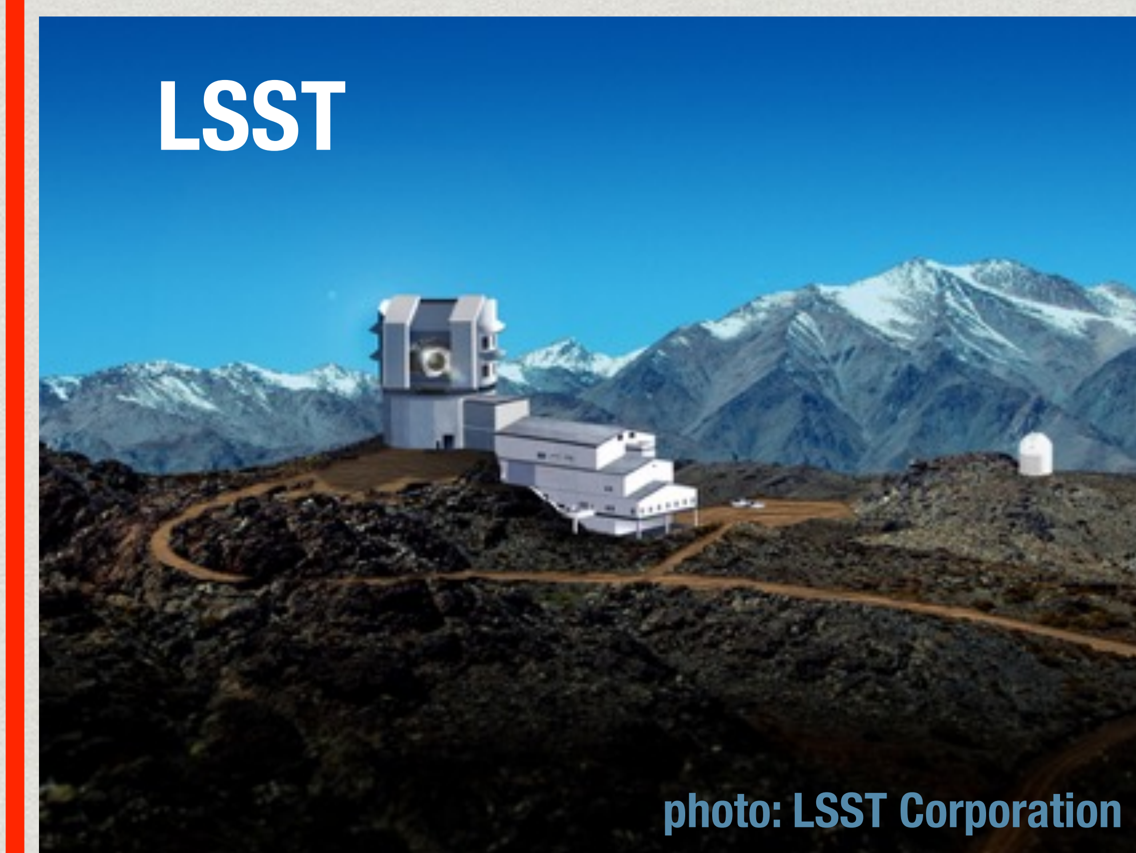
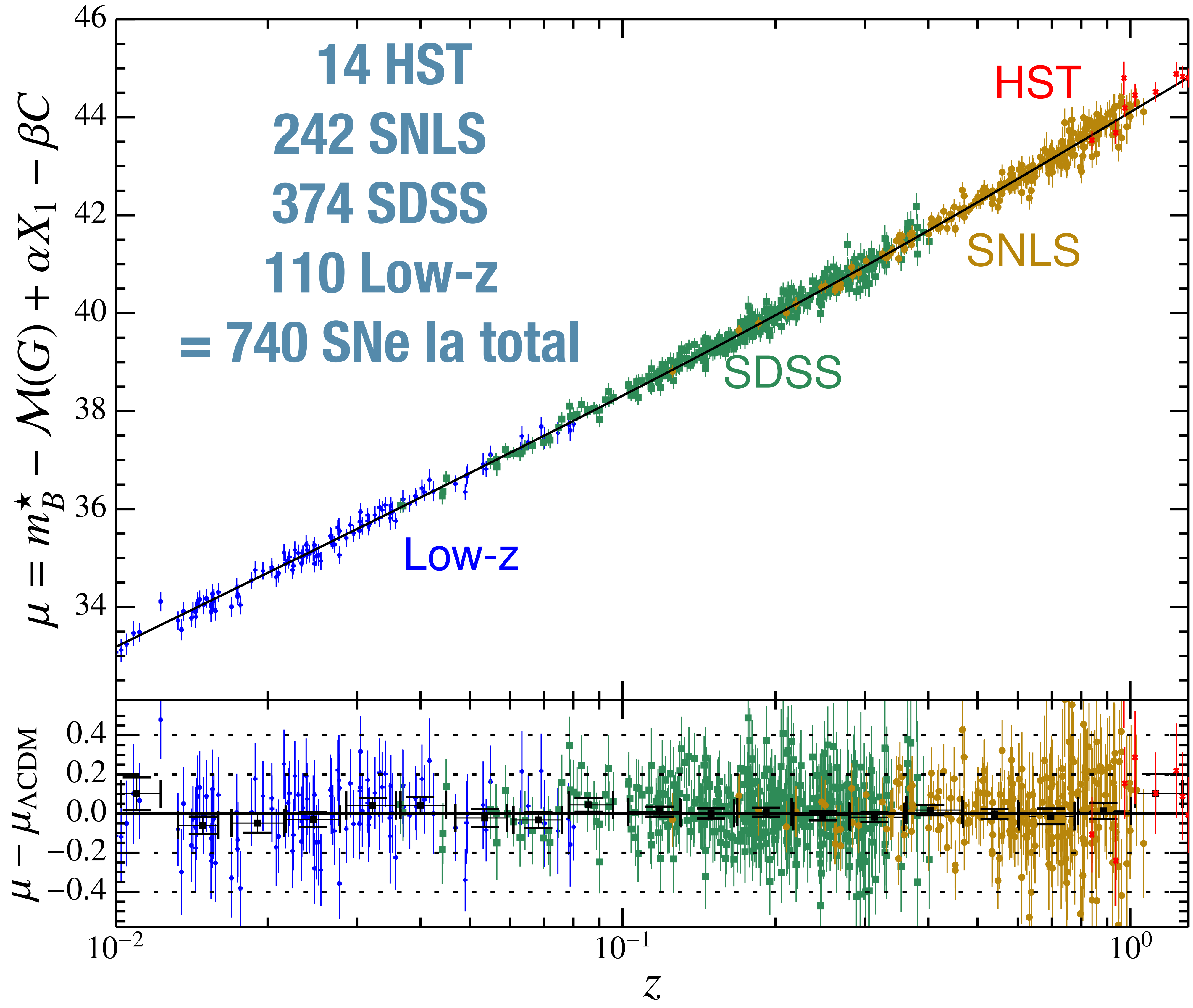


Latest SNIa Hubble diagram



Betoule et al. 2014; arXiv:1401.4064; [2014A&A, 568, 22]

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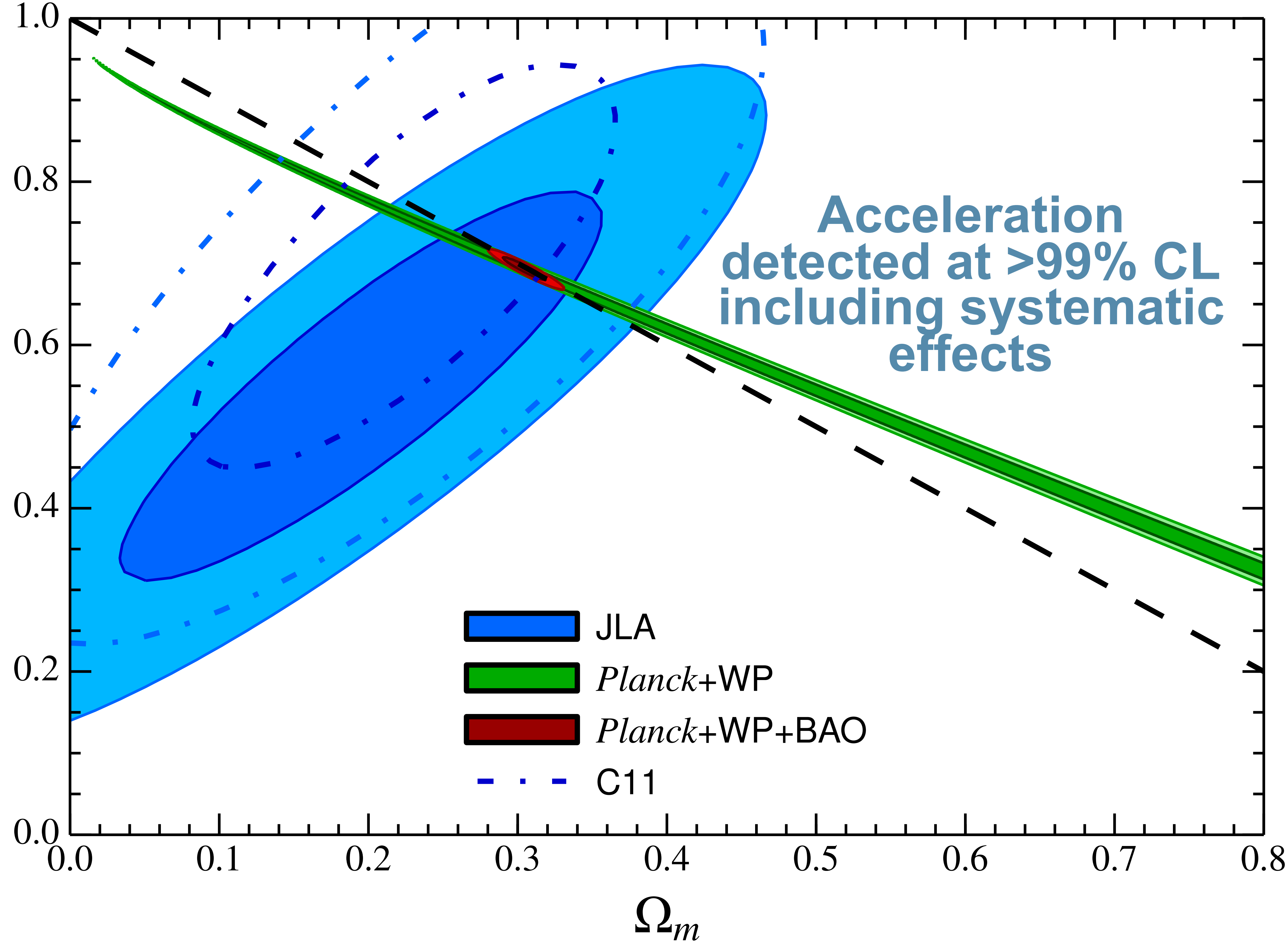
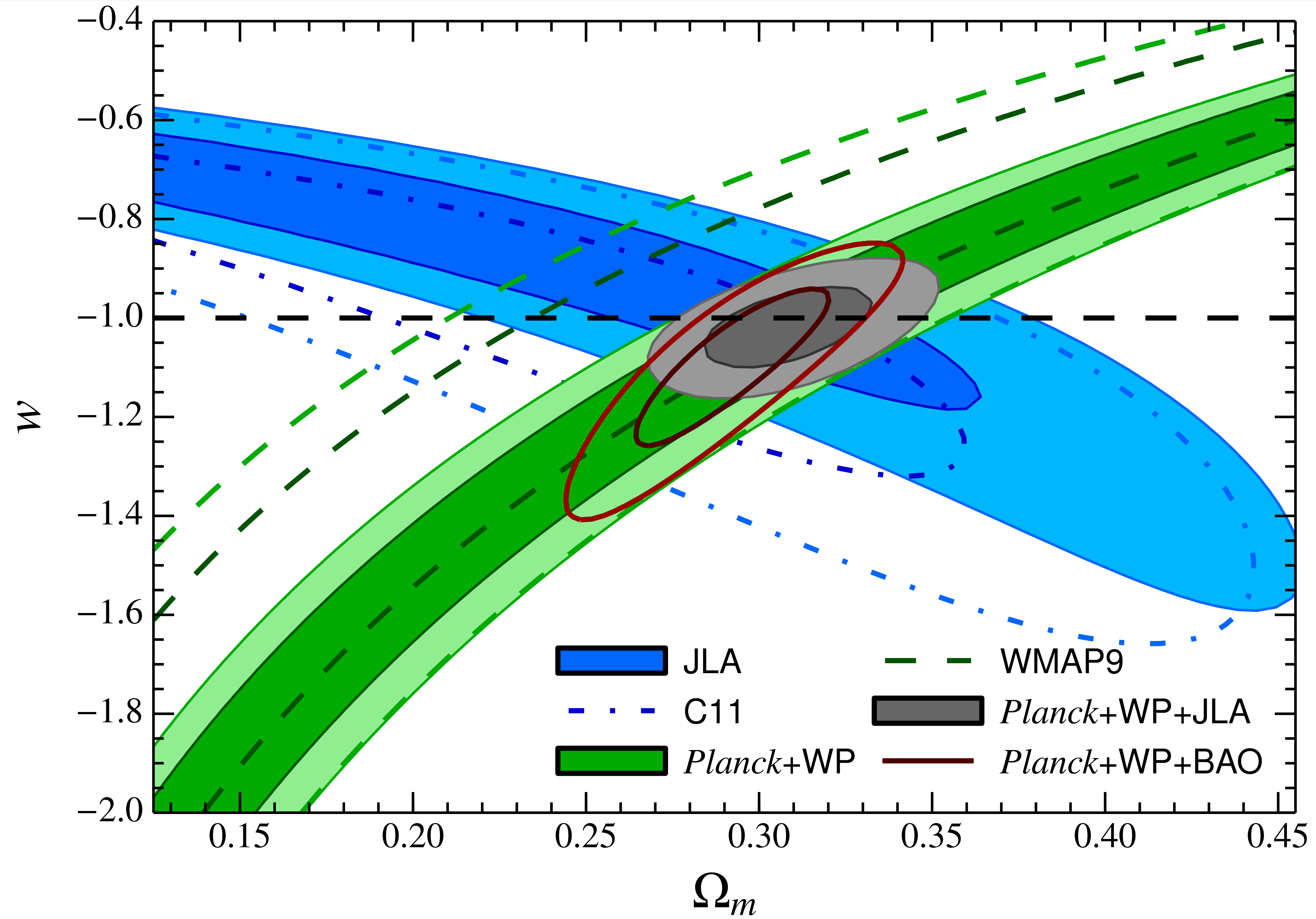
(flat, constant w)

SNeIa Alone Reveal Dark Energy



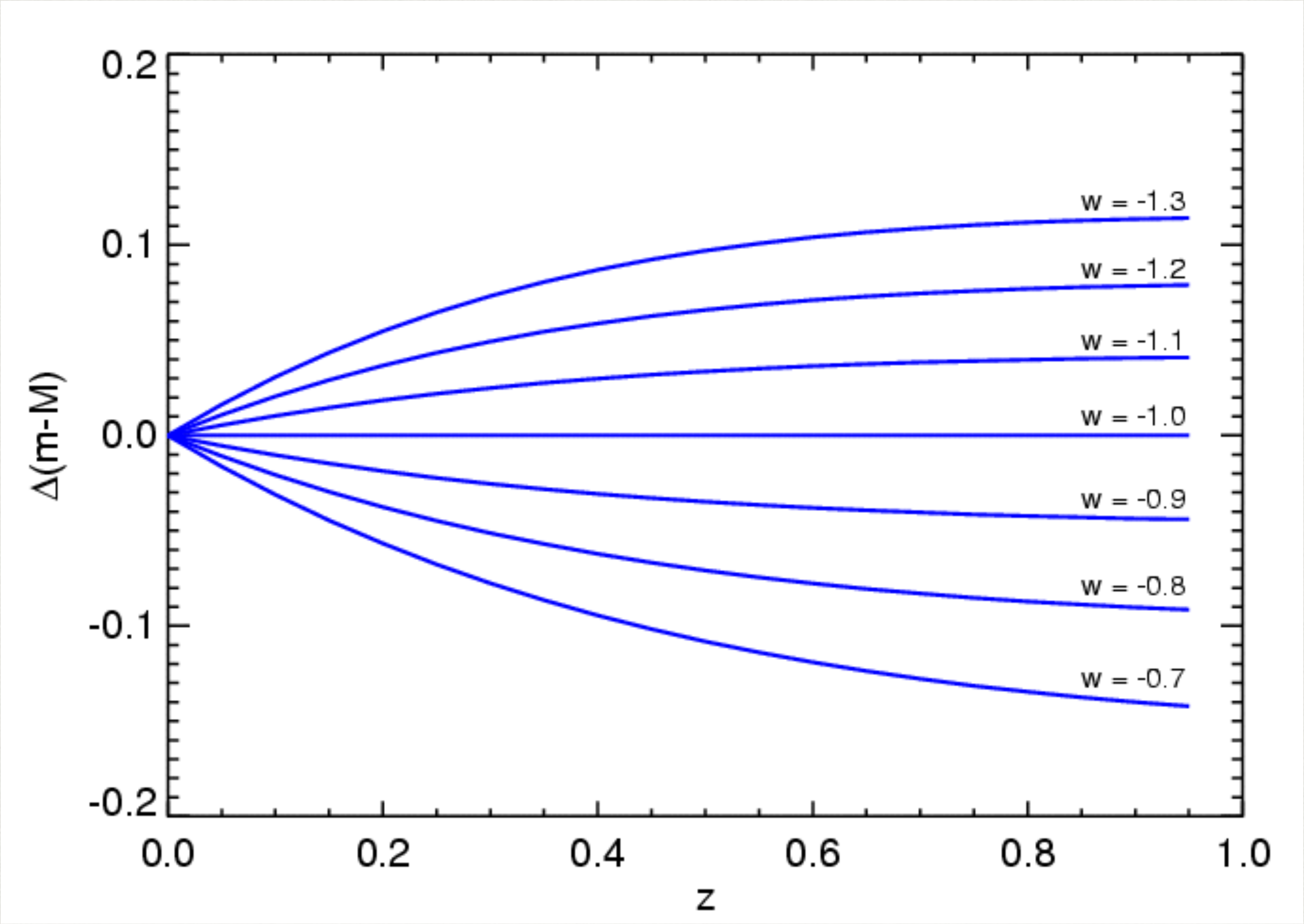
Betoule et al. 2014; arXiv:1401.4064; 2014A&A, 568, 22

SNIa+CMB [+BAO] Hints at its Nature



Betoule et al. 2014; arXiv:1401.4064; 2014A&A, 568, 22

Equation-of-State Signal



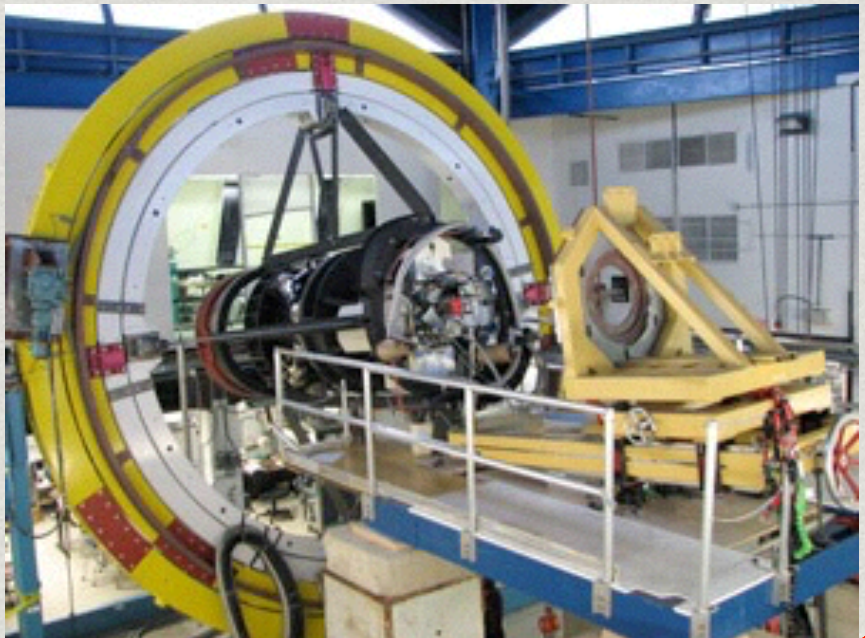
Difference in luminosity distance modulus vs. z

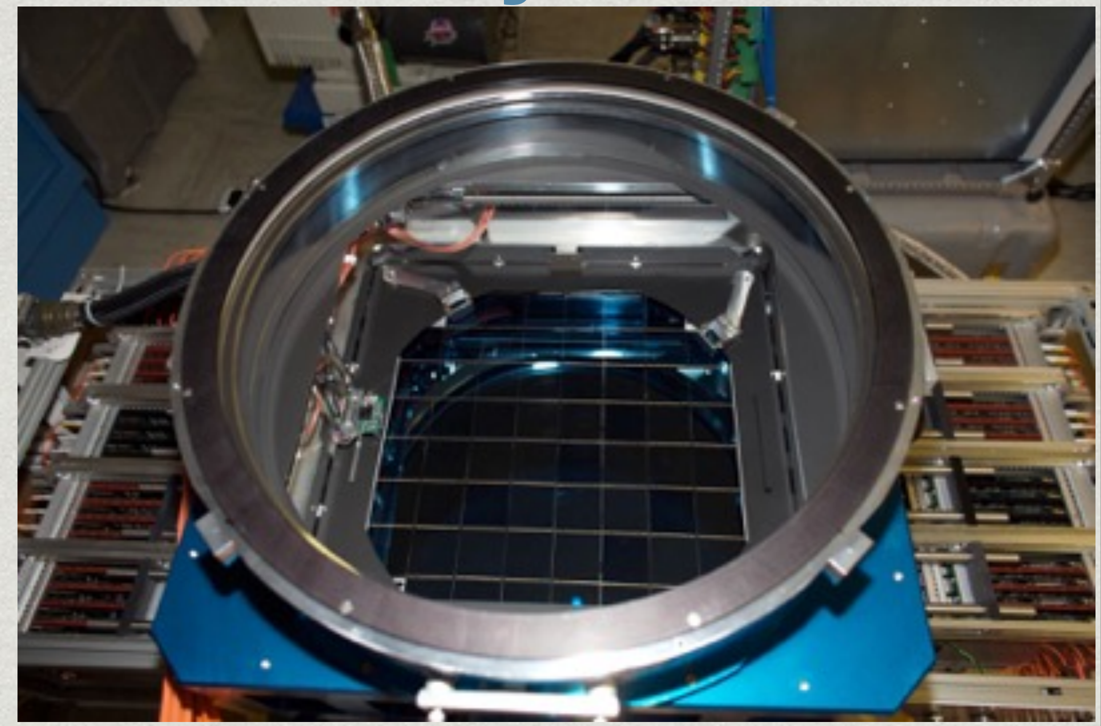
Ω

Current and Future SN Surveys

Dark Energy Survey

photo: Rich Talcott





+SkyMapper, DES, SDSS-II, KAIT, PTF, ...

Pan-STARRS 1

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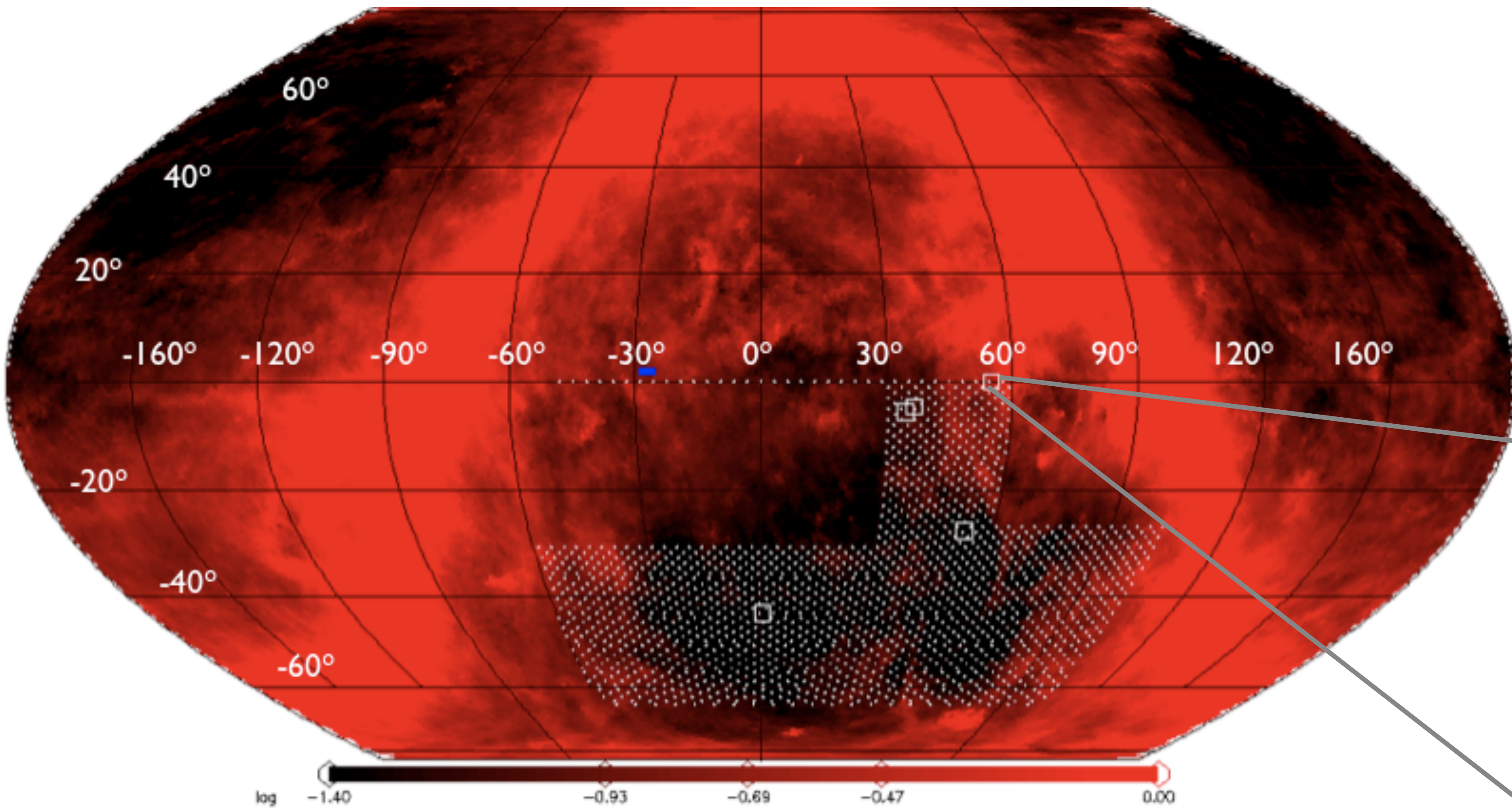
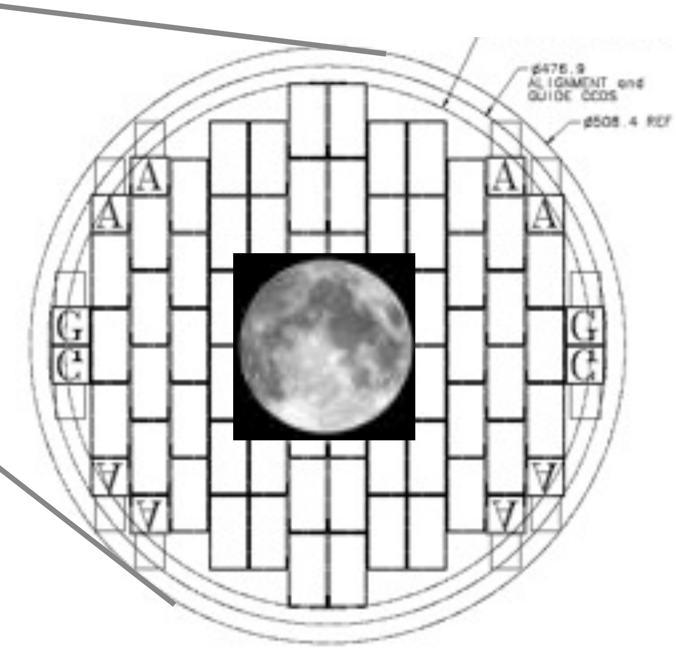
DES SN Survey

DARK ENERGY SURVEY



Fields to overlap with existing and near-future deep imaging (e.g., CDF-S, SNLS, VIDEO) and spectroscopic surveys (DEEP2, VIPERS, VVDS, WiggleZ, GAMA I/II).



10 DES fields

Visit once every ~4 days.

2 deep + 8 shallow (30 deg^2)

deep: 6600 sec per visit (*griz*)

shallow: 800 sec per visit (*griz*)

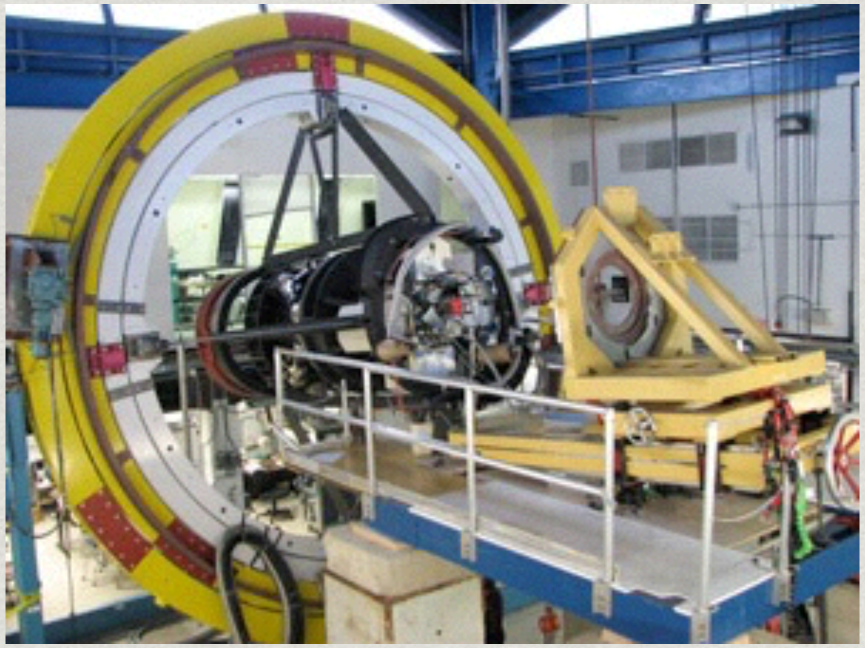
good *z*-band efficiency (~4x higher than CFHT/MegaCam) and target high-z SN Ia

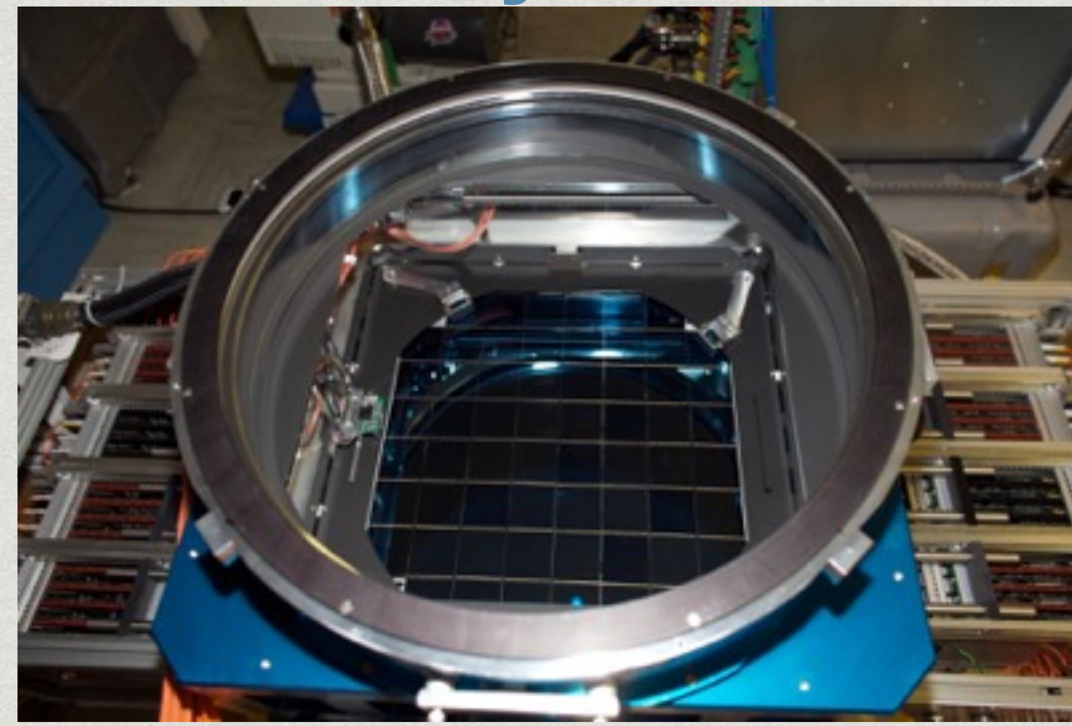
→ good rest-frame *g*-band light curves of z~1 SN Ia.

Current and Future SN Surveys

Dark Energy Survey

photo: Rich Talcott





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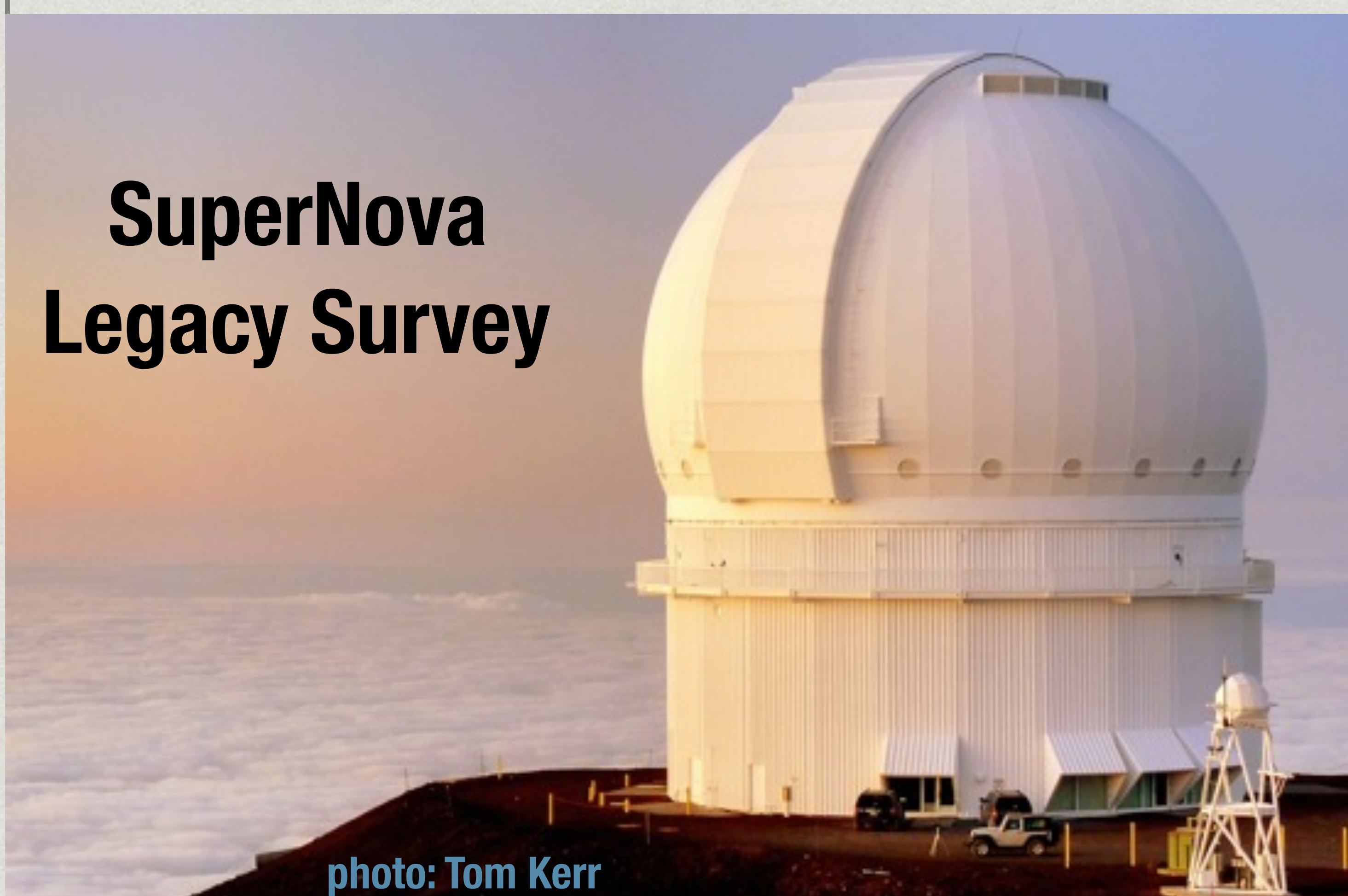
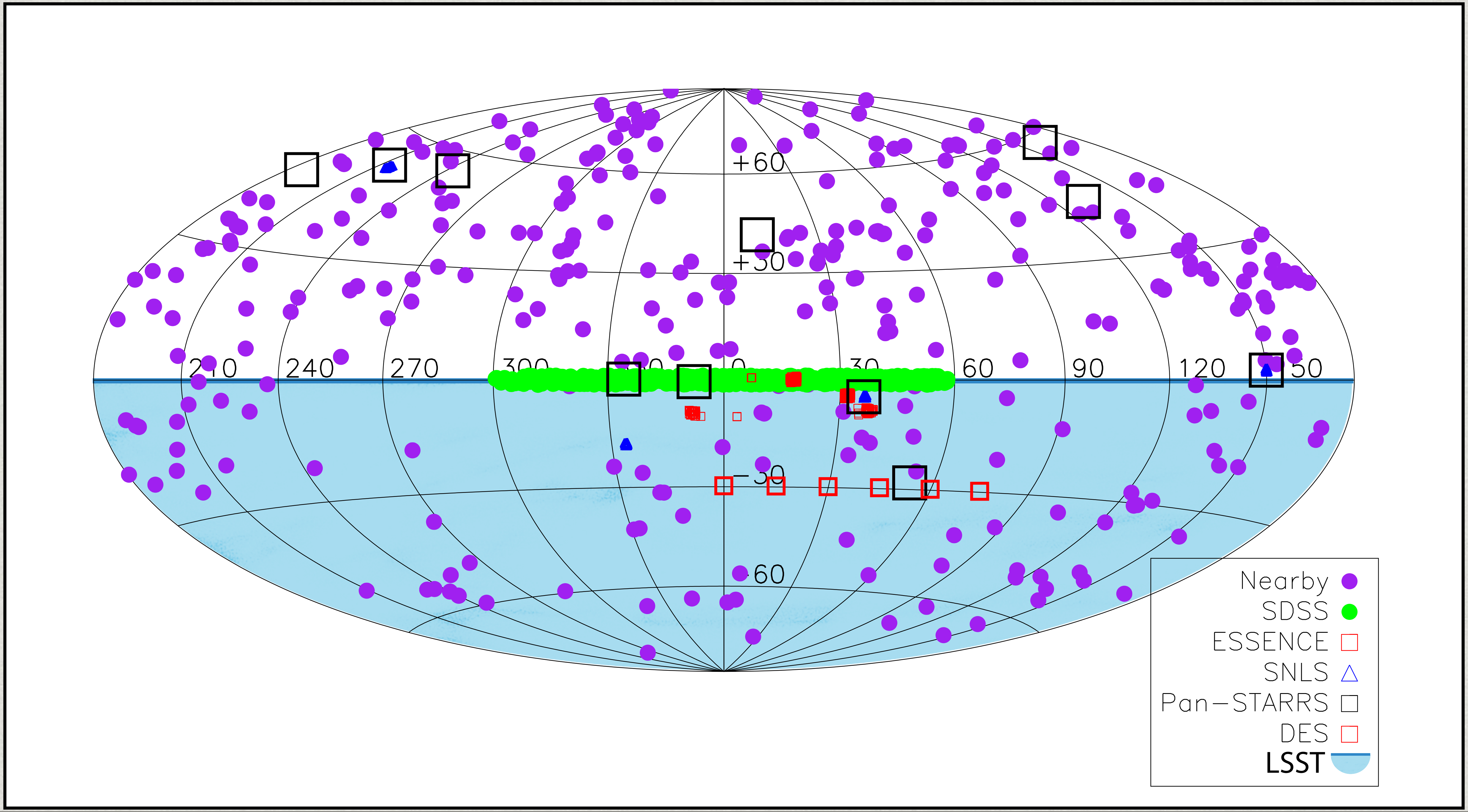
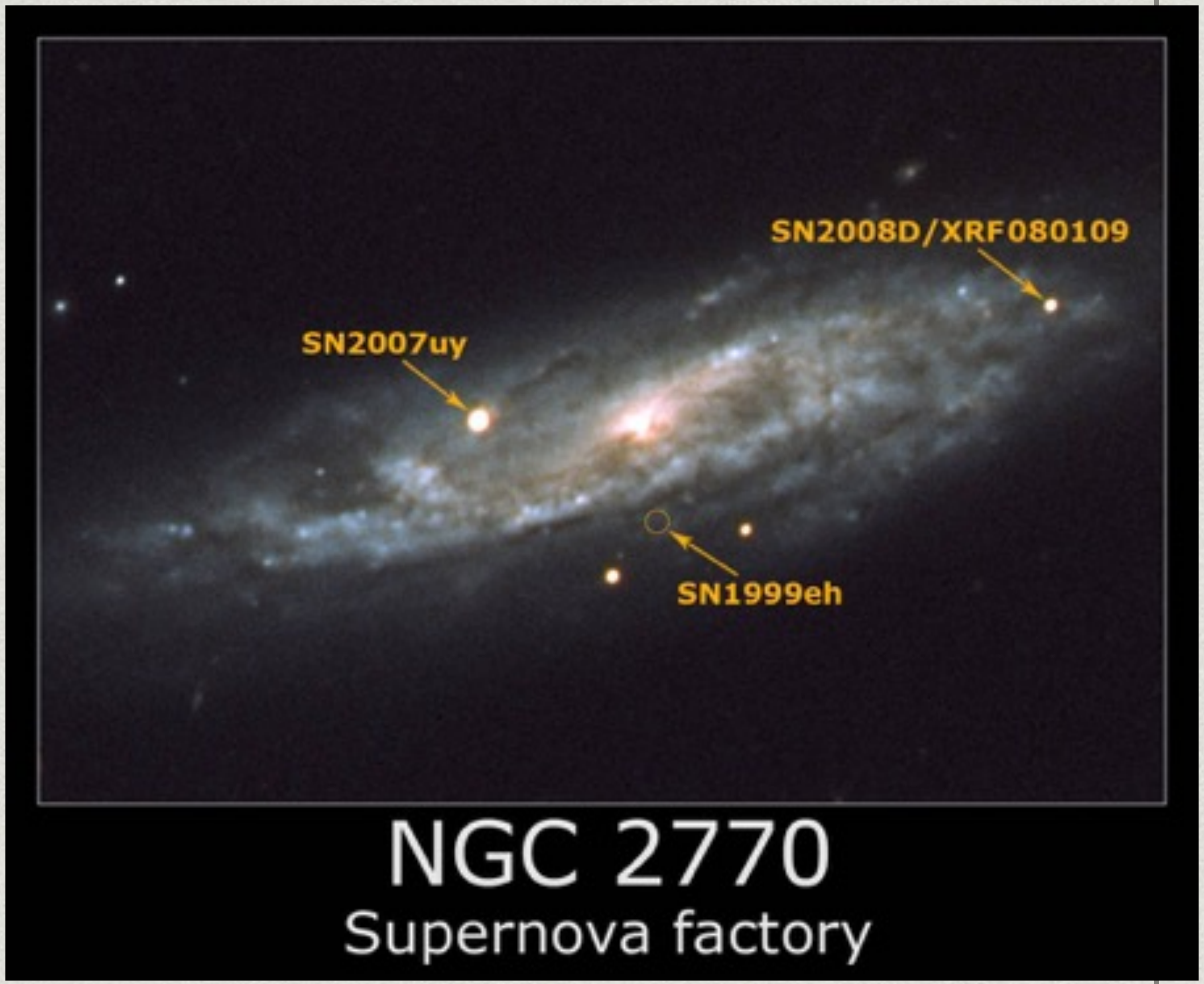


Future SN Surveys Will Cover the High-z Sky

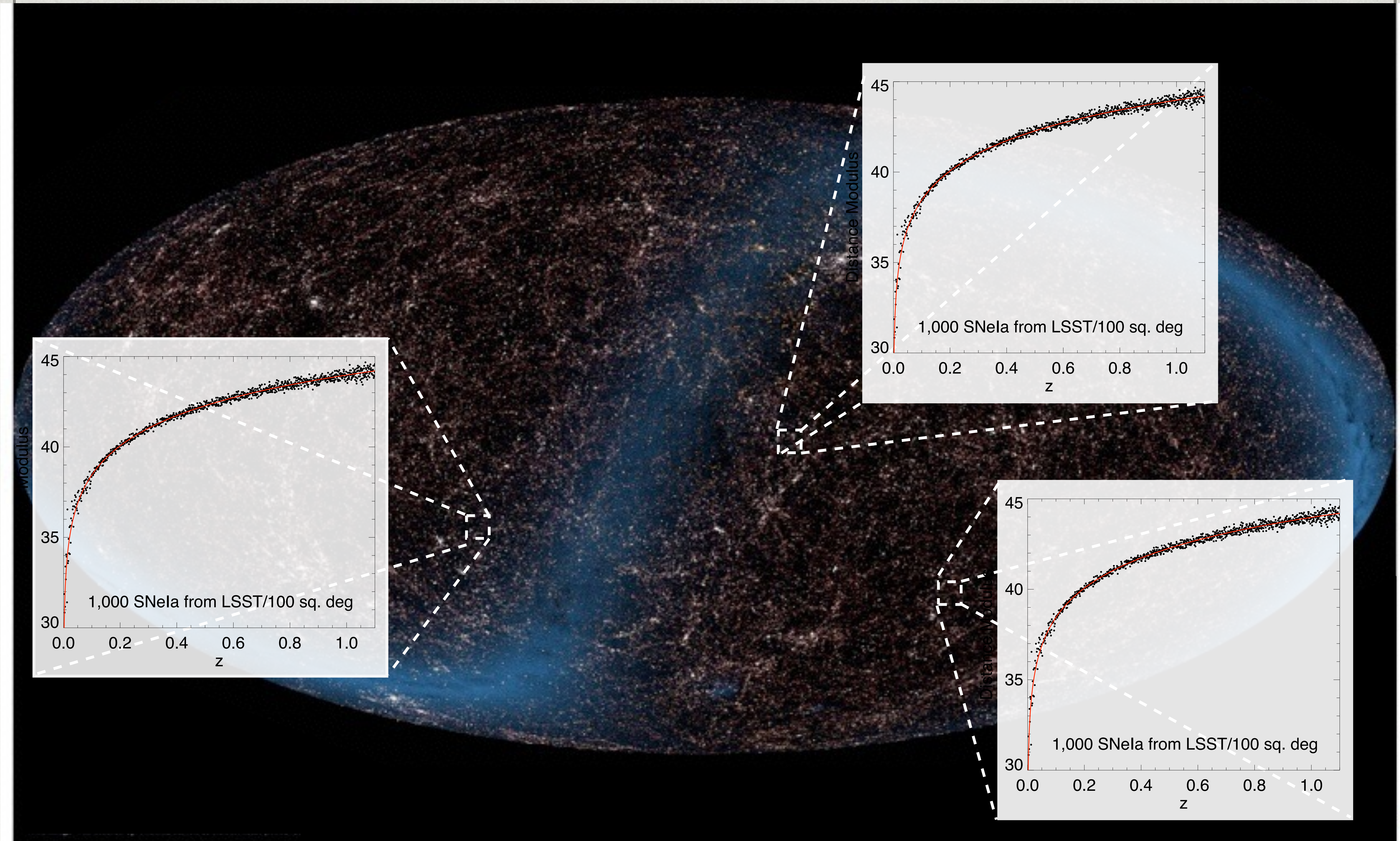


Future Wide-Field Surveys Will Provide Data for A Wide Variety of Supernova Science



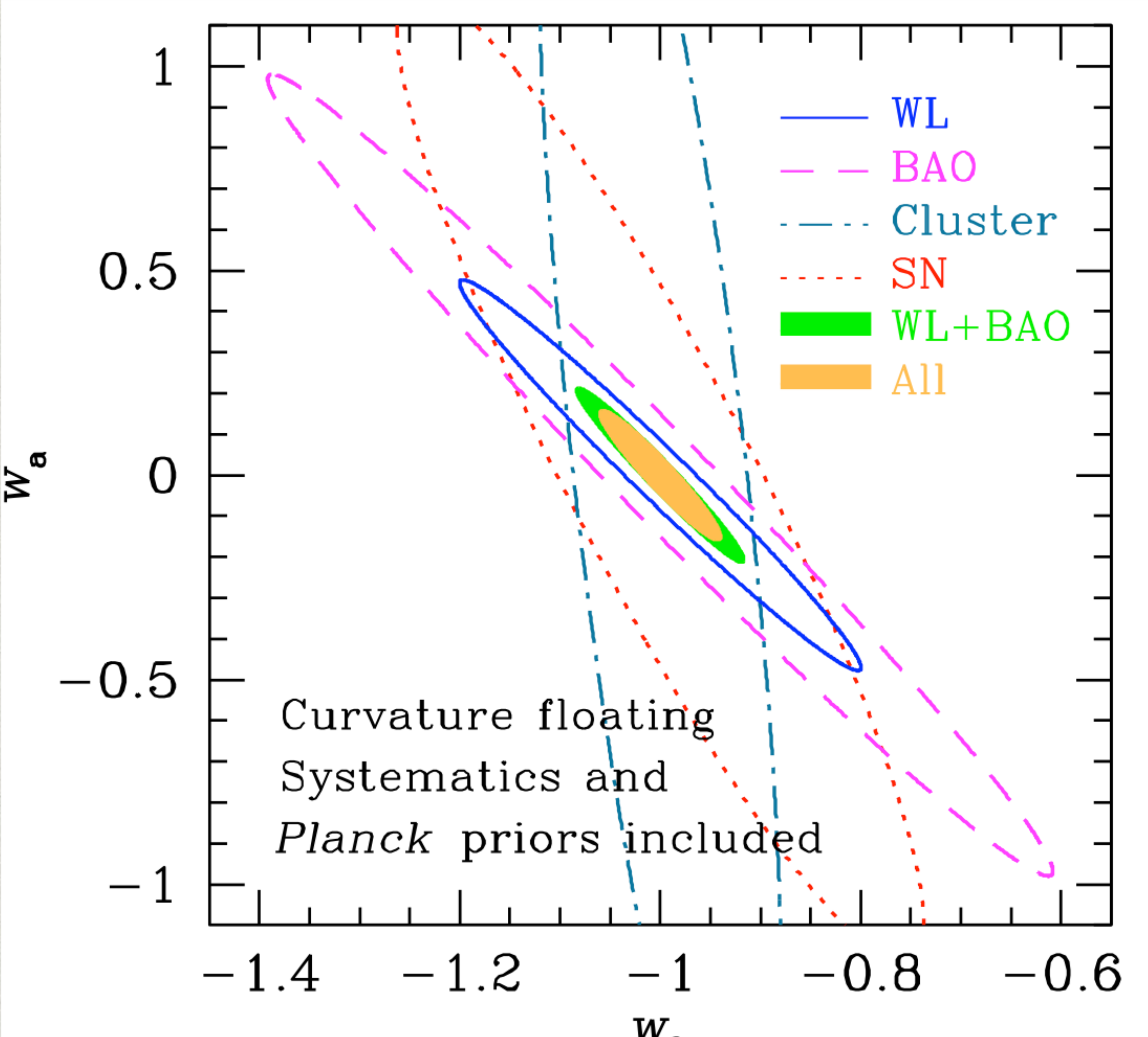
- SN Ia Cosmology
- Homogeneity & Isotropy
- SN Ia BAO
- Cosmology w/ other SNe
- SN over z, Z, environment
- Photo-z: SN + Gal
- Pre-SN outbursts
- SN rates: type, gal environment, z, SFR
- SN progenitors; Galactic SNe and precursors

LSST SNeIa Will Measure Cosmology In Many Subsets



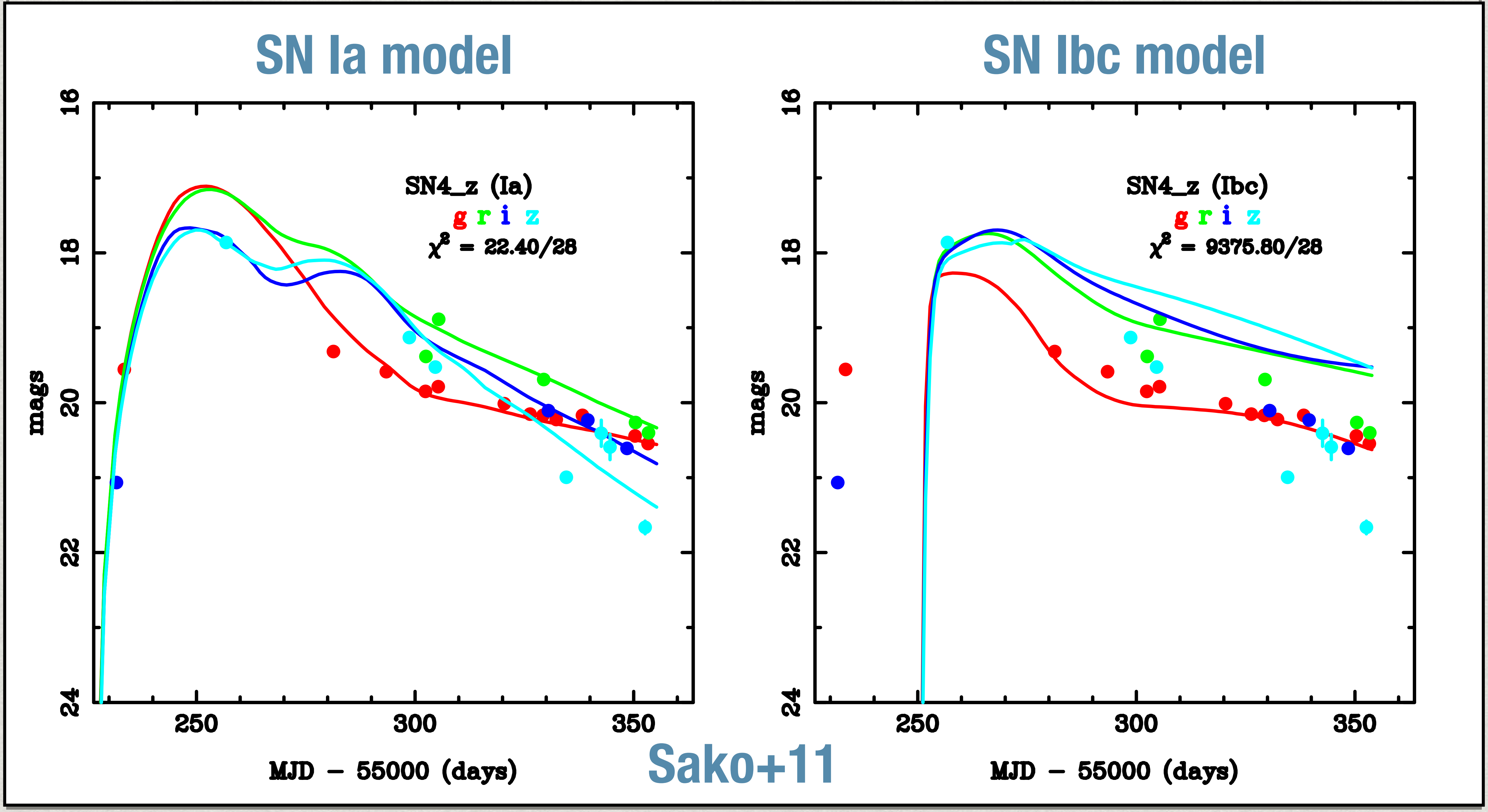
(Background is from the

SNeIa in LSST have great potential to teach us about dark energy



LSST Science Book, figure 15.3

We will need to classify SNe from light curves alone



Sako+11

To Maximize SNIa Cosmology from Future Surveys We Need:

- SN photo-z/photo-typing
- SN photo-z + Gal photo-z
- SNIa intrinsic color
- Host galaxy dust
- Simulations & Modeling
  - SN progenitors & SN explosion

Near-Infrared Observations Needed!

Challenges in SNIa Cosmology

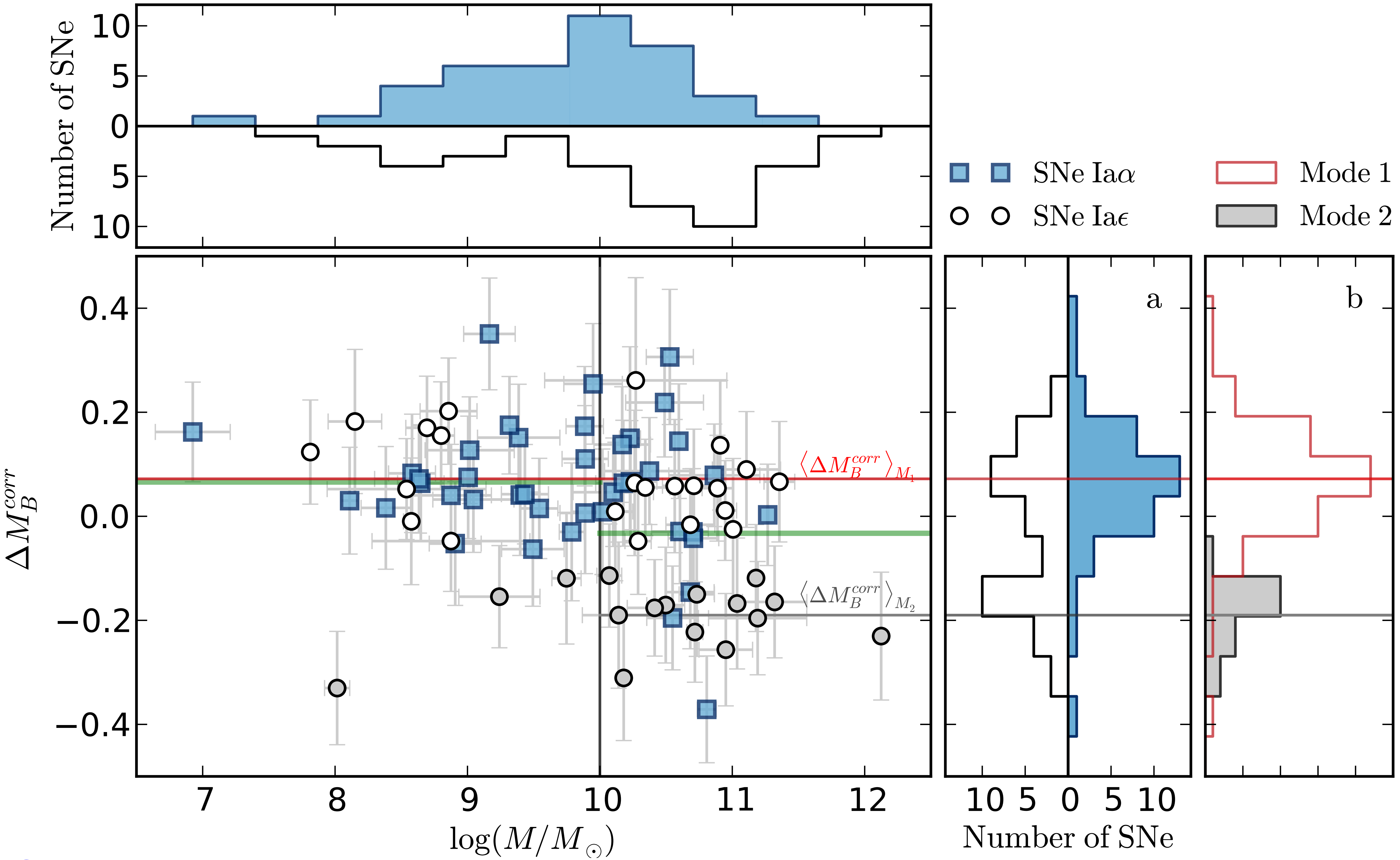
- Calibration - *Stubbs & Tonry 2006; Li+14,16*

  BayeSN **ABC** **UNITY**
- New Cosmology Analysis: *Mandel+09,11; Weyant+13; Rubin+15*

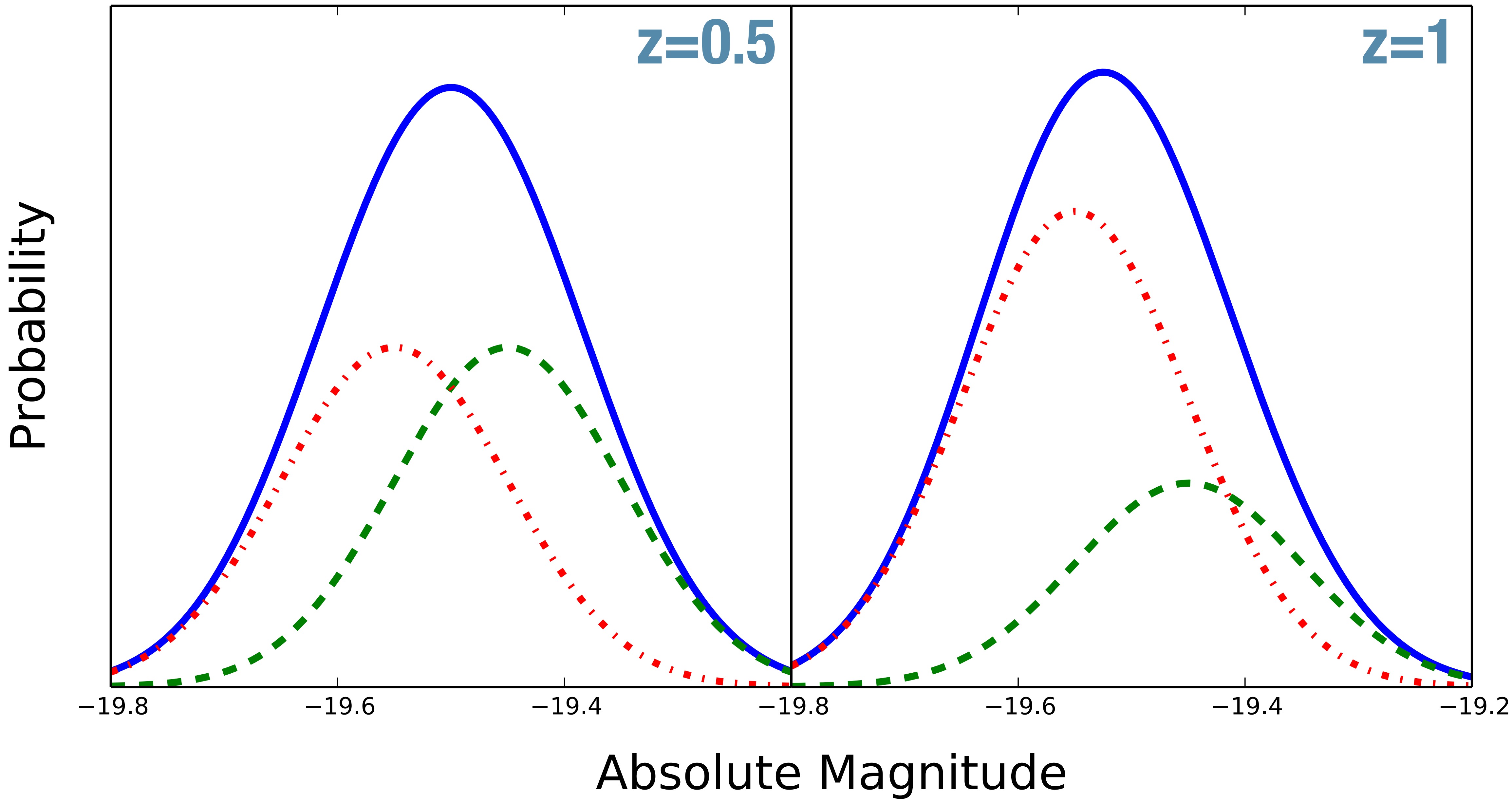
  Classification Challenge
- Photometric Classification (*Kessler+10, Lochner+16*) Möller; Vilalta

  machine learning for LSST SN
- Host Dust and Intrinsic Properties of SNeIa - Mandel
- Environment - *Kelly+10; Sullivan+10; Lampeitl+10; Gupta+11; Johansson+13; Childress+13; Rigault+13,15; Kelly+15; Jones+15*
- Evolution with z (lack of evidence): Howell+07; Bronder+08; Ellis+08; Maeda+10; Blondin+12; Maguire+12
- But if there is an environment correlation -> redshift evolution.
- Analysis techniques: *Ponder, MWV, Zentner 2016, ApJ, in press*

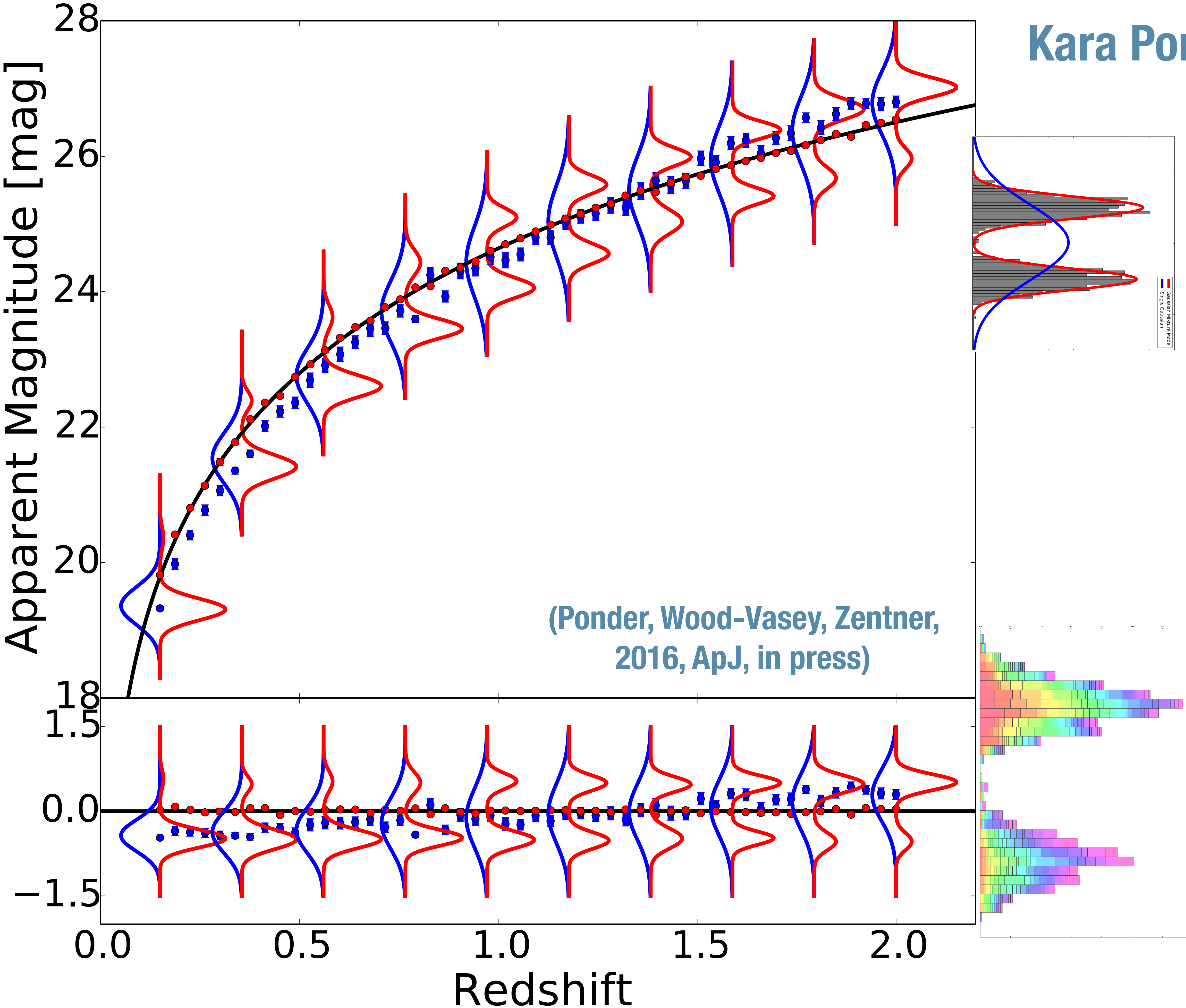
Rigault et al, 2013



Two Mock SNIa Populations with a 0.1 mag difference.



Kara Ponder



Apparent Magnitude [mag]
Redshift
(Ponder, Wood-Vasey, Zentner, 2016, ApJ, in press)
28
26
24
22
20
18
1.5
0.0
−1.5
0.0
0.5
1.0
1.5
2.0

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