Recent Supernova Results

(in High-z & Low-z Experiments, SN Heterogeneity, Cosmology Systematics, Reducing Systematics, DETF Stage III & Stage IV SN Experiments, JDEM, ...)

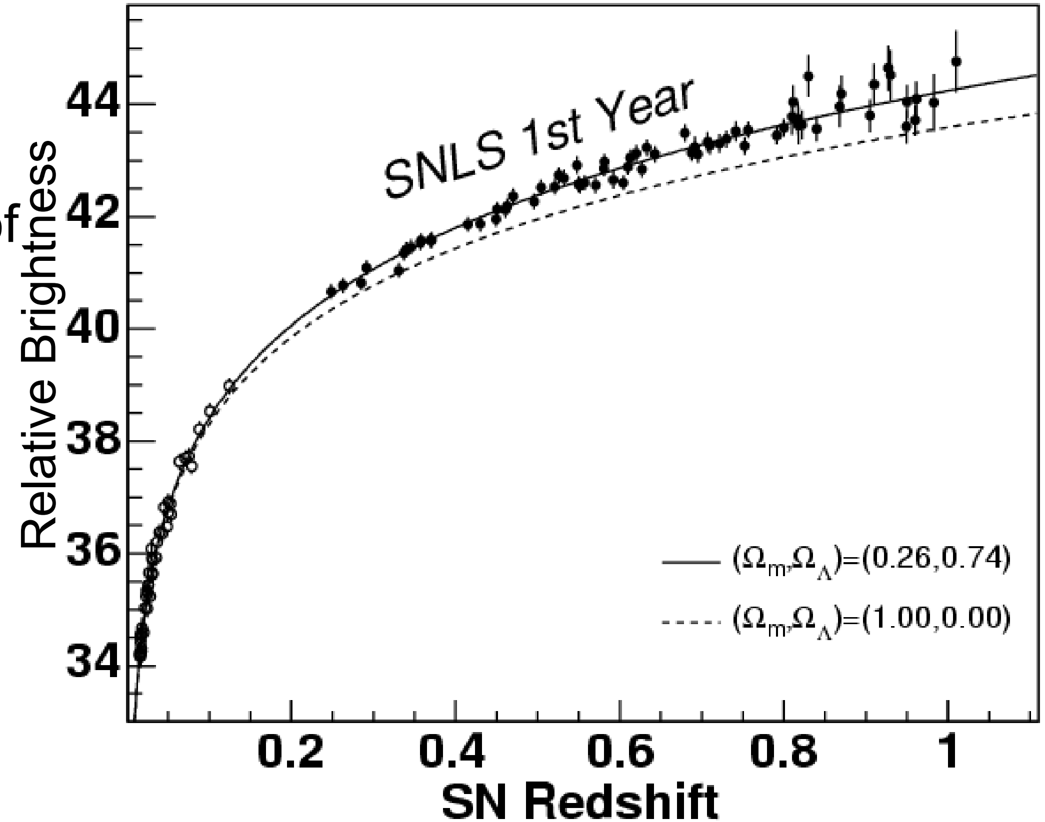
Alex Kim
LBNL

The Message

- Systematic uncertainty is and will be the limiting factor in active and future SN experiments
- Current systematic limits can be suppressed with a more comprehensive dataset and better calibrations than those being collected today
- JDEM SN experiment provides the dataset to test dark-energy models, measure dark-energy parameters, and complement other techniques
  - Necessary and sufficient? Need for a low-redshift anchor of equal or better quality supernovae

Supernova Cosmology Primer

- Type Ia supernovae (SNe Ia) have uniform luminosity at peak brightness
- Relative brightnesses measure relative distances
- The SN Ia Hubble diagram (redshift vs. brightness) maps the expansion history of the Universe
- Systematic uncertainties in relative distances principally due to:
  - Evolution in redshift of SN Ia luminosity
  - Intervening dust obscures SN light
  - Instrumental calibration – conversion from detector to physical units



Astier et al. (2006)

Recent Results: Error Budget

- Indeed these systematic uncertainties are dominant contributers to the error budgets of the two ground-based high-z SN programs SNLS & Essence
- (Believe this is true for the moderate-z SDSS)

TABLE 7

POTENTIAL SOURCES OF SYSTEMATIC ERROR ON THE MEASUREMENT OF w

Source	dw/dx	Δx	Δw	Notes
Photometric errors from astrometric uncertainties of faint objects	1/mag	0.005 mag	0.005	
Bias in differential image photometry	0.5/mag	0.002 mag	0.001	
CCD linearity	1/mag	0.005 mag	0.005	
Photometric zero-point differences in R, I	2/mag	0.02 mag	0.04	
Zero-point offset between low and high z	1/mag	0.02 mag	0.02	
K-corrections	0.5/mag	0.01 mag	0.005	
Filter passband structure	0/mag	0.001 mag	0	
Galactic extinction	1/mag	0.01 mag	0.01	
Host galaxy R_V	$0.02/R_V$	0.5	0.01	"glosz"
Host galaxy extinction treatment	0.08	Prior choice	0.08	Different priors
Intrinsic color of SNe Ia	3/mag	0.02 mag	0.06	Interacts strongly with prior
Malmquist bias/selection effects	0.7/mag	0.03 mag	[illegible]	"glosz"
SN Ia evolution	1/mag	0.02 mag	0.02	
Hubble bubble	$3/\delta H_{\rm effective}$	0.02	0.06	
Gravitational lensing	$1/\sqrt{N}$/mag	0.01 mag	<0.001	Holz & Linder (2005)
Gray dust	1/mag	0.01 mag	0.01	
Subtotal without extinction+color	...	...	0.082	
Total	...	...	0.13	
Joint ESSENCE+SNLS comparison	...	...	0.02	Photometric system
Joint ESSENCE+SNLS total	...	...	0.13	

NOTES.—The systematic error table for this first ESSENCE cosmological analysis. The issue of treatment of A_V and color distribution is clearly the dominant systematic effect and will need to be seriously addressed to reduce our systematic errors to our target of 5%.

Calibration

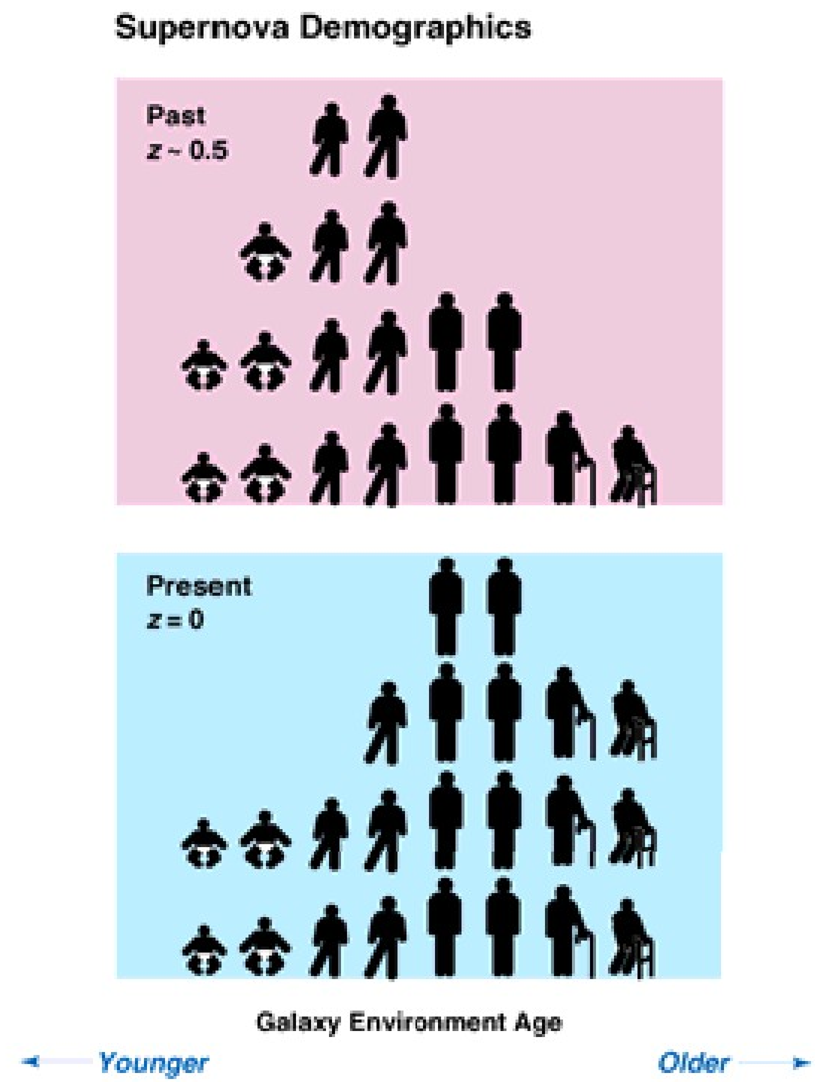
Dust

SN Luminosity Evolution

Wood-Vasey et al. 2007

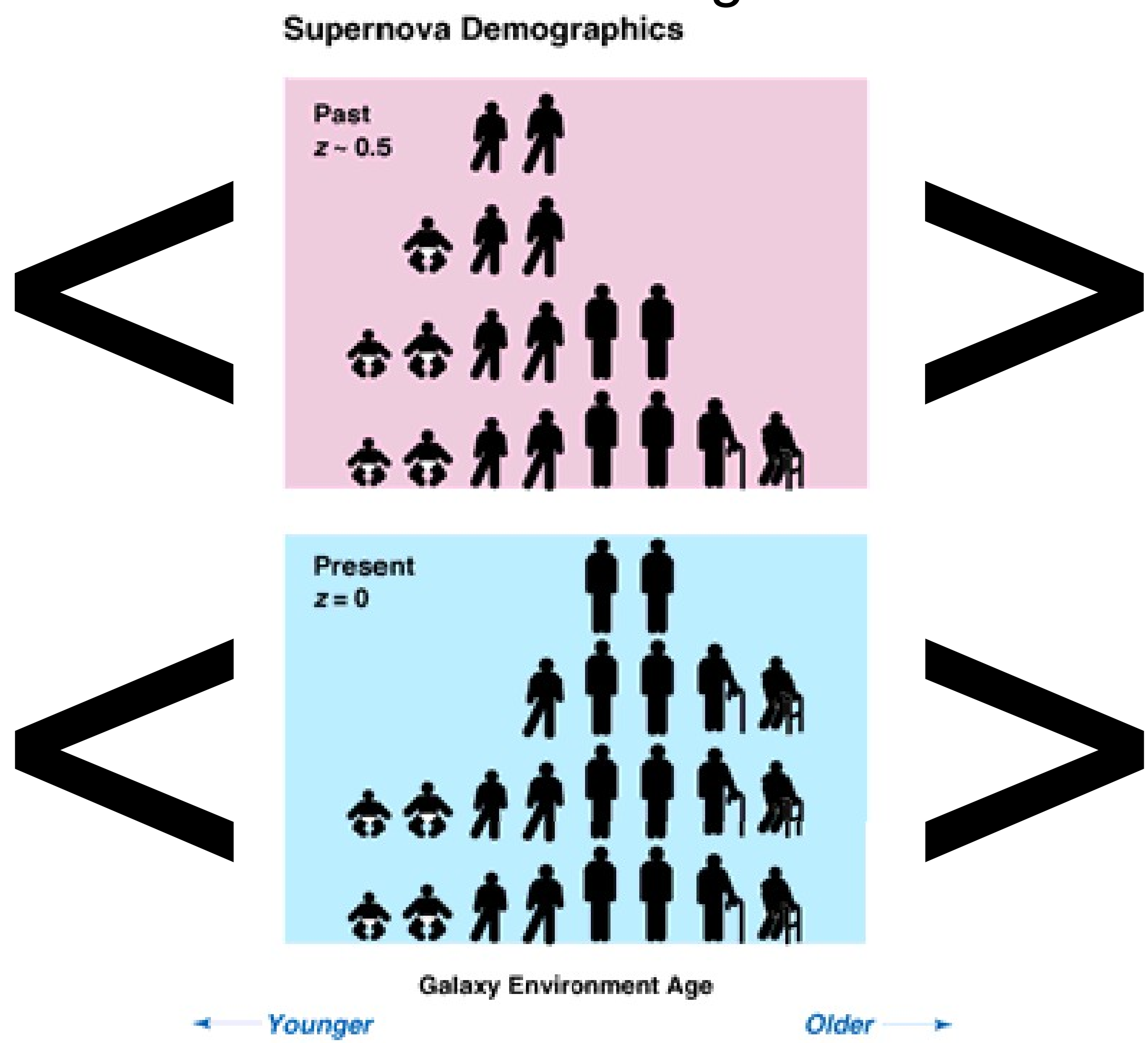
SN Ia Luminosity Evolution

- The SN Ia progenitor system is a white dwarf with a binary companion
- Progenitor systems have a range of initial conditions
- SN Ia luminosity evolution may occur
  - if the progenitor population today differs from that of the past
  - and if the populations produce SNe with different luminosity

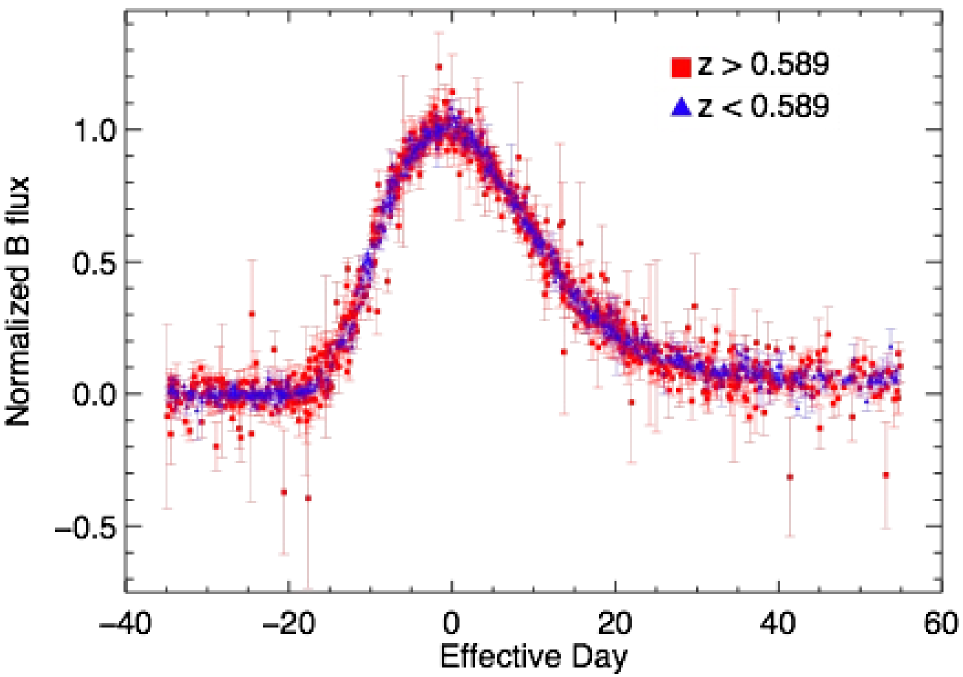


SN Ia Luminosity Evolution: Stage II

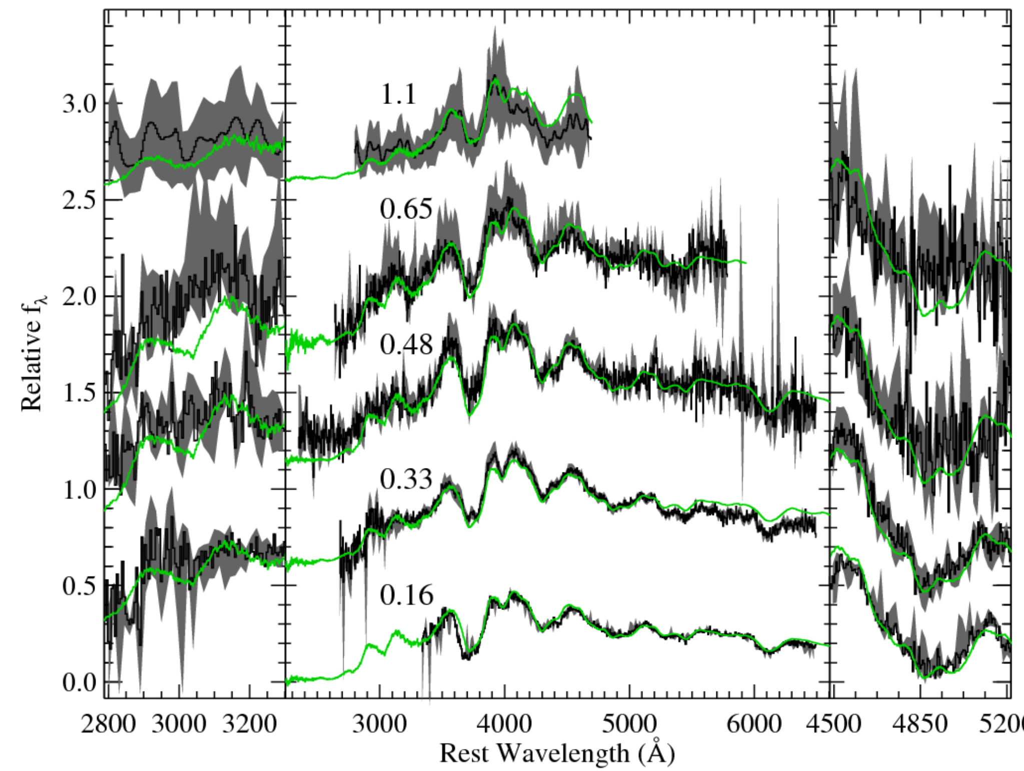
- Stage II experiments constrain evolution by comparing the mean behavior of SNe at low- and high-redshift



SN Ia Luminosity Evolution: Stage II



Conley et al. (2006)

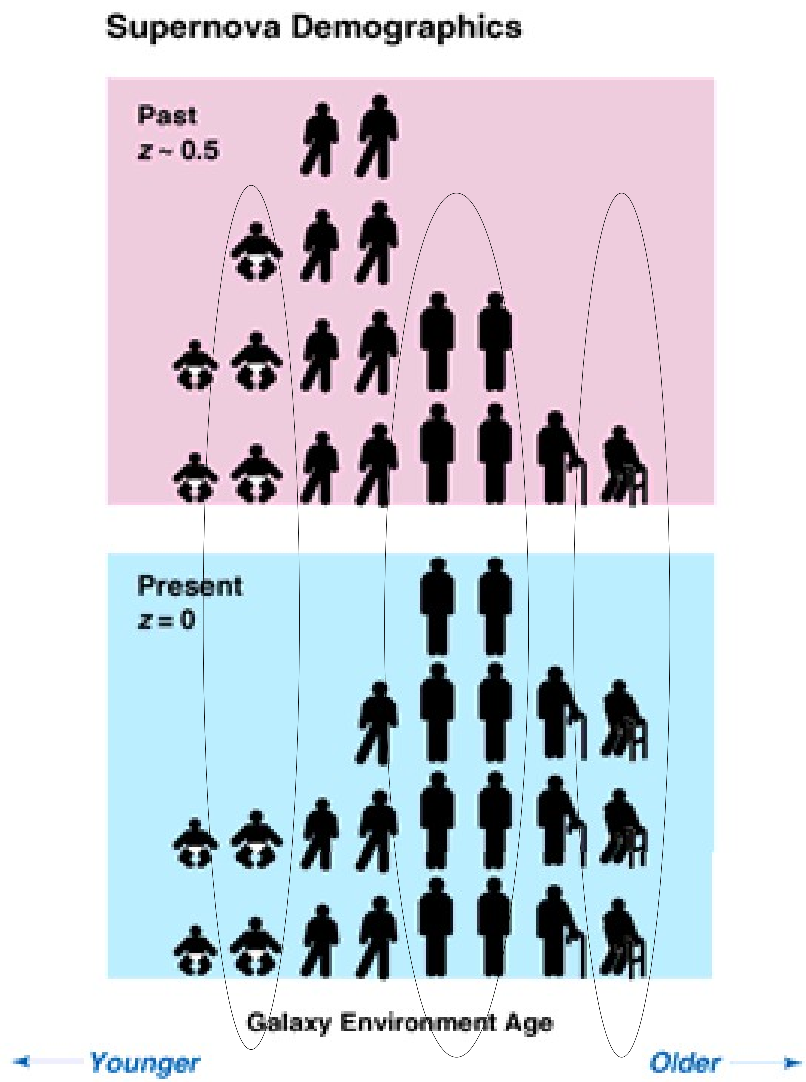


Foley et al. (2007)

- No evidence for population evolution
- Relatively small contribution to published dark-energy error budgets

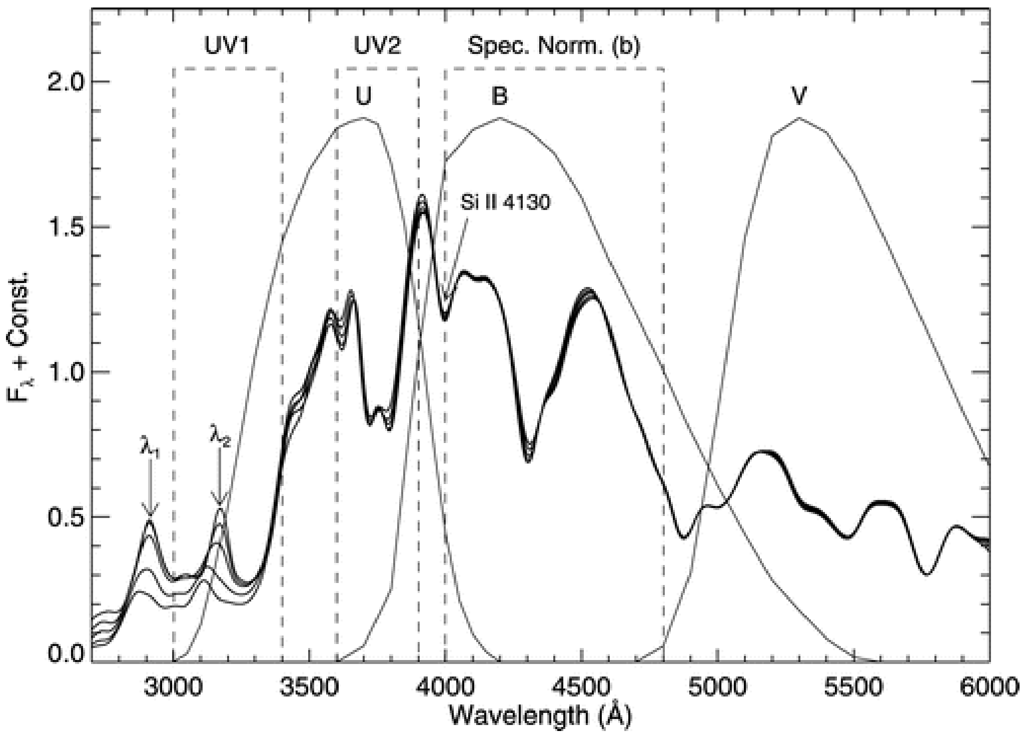
SN Ia Luminosity Evolution: Stage III & IV

- Stage III & IV experiments
  - Subclassify individual SNe
  - Build Hubble diagram(s) of SN Ia subclasses
- Subclasses are better standard candles than SNe Ia as a whole and are less sensitive to evolution



Identifying SN Ia Subclasses

- Subclasses identified through features that vary within the SN Ia class
- Different progenitor populations produce explosions with differing kinetic energies, fused elements, temperatures
- Manifest in heterogeneous time-evolving light curves and spectra

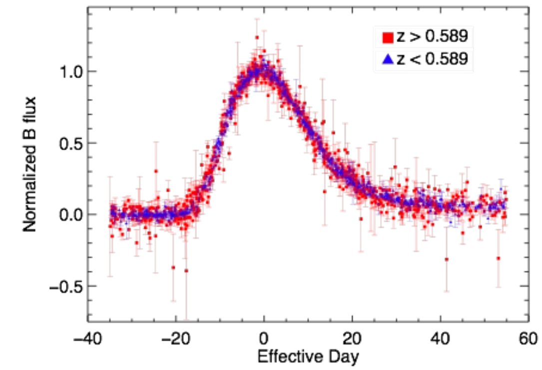


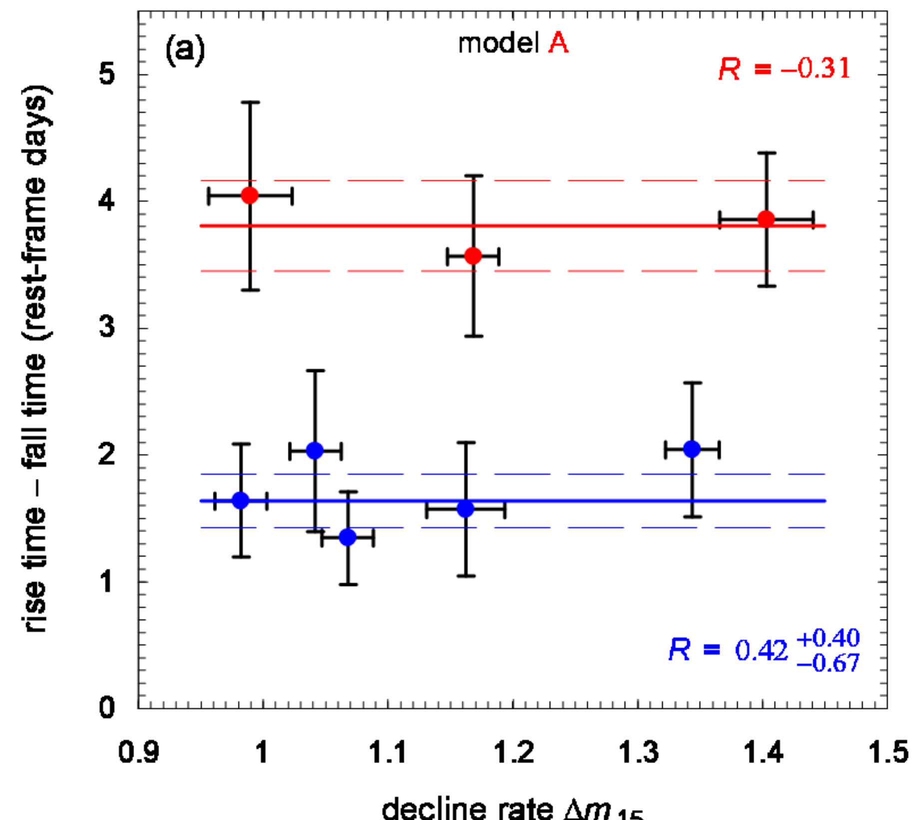
Dispersion in the UV expected theoretically related to the fraction of non-H, He in the progenitor white dwarf

Lentz et al. 2000, Ellis et al. 2008

Light Curve Risetimes

- Rise times of 8 SNe each with well-measured B-band (0.44 μm) light curves show 2 populations
- Uncorrelated with light-curve shape (Δm_{15})
- The rise times differ by ~2.2 days



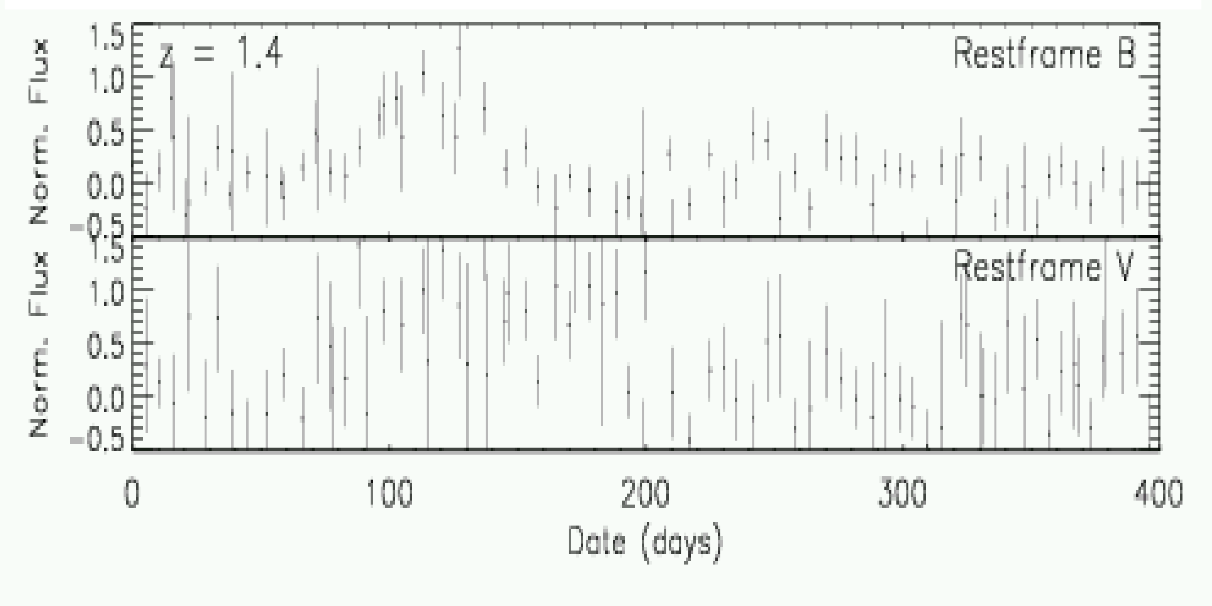


Strovink 2007

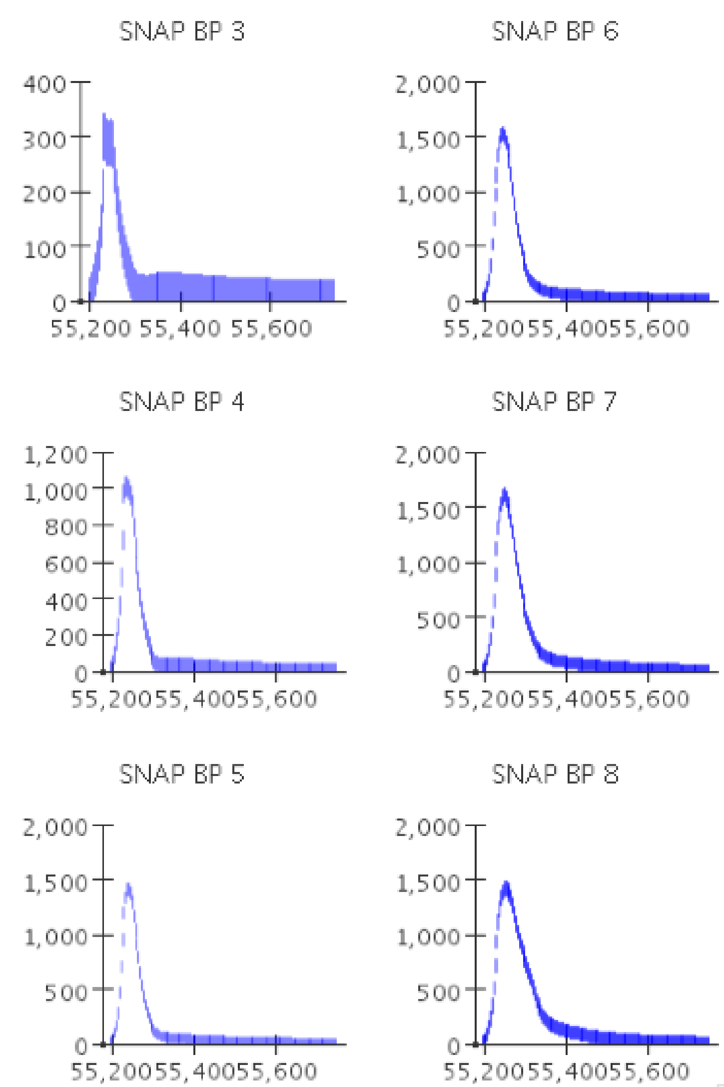
JDEM Advantage

- Ground disadvantage: small SN signal on a large sky background
- Partially why there are only 8 objects in Strovink's sample
- Background must be subtracted to better than $O(10^{-4})$ – a challenge for astronomical imaging detectors

Ground observation z=1.4

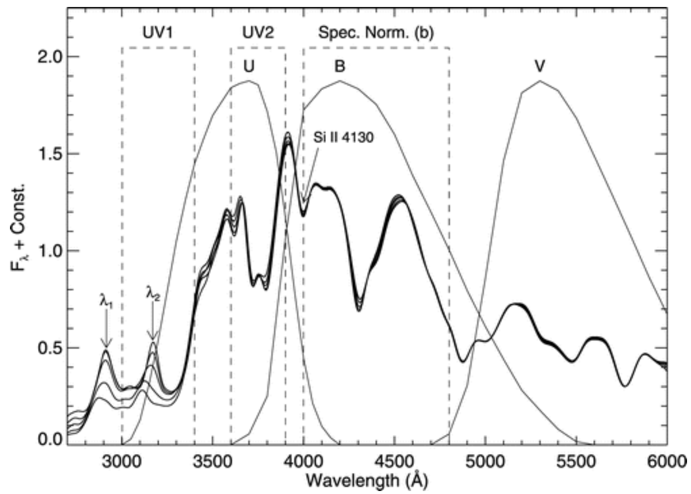


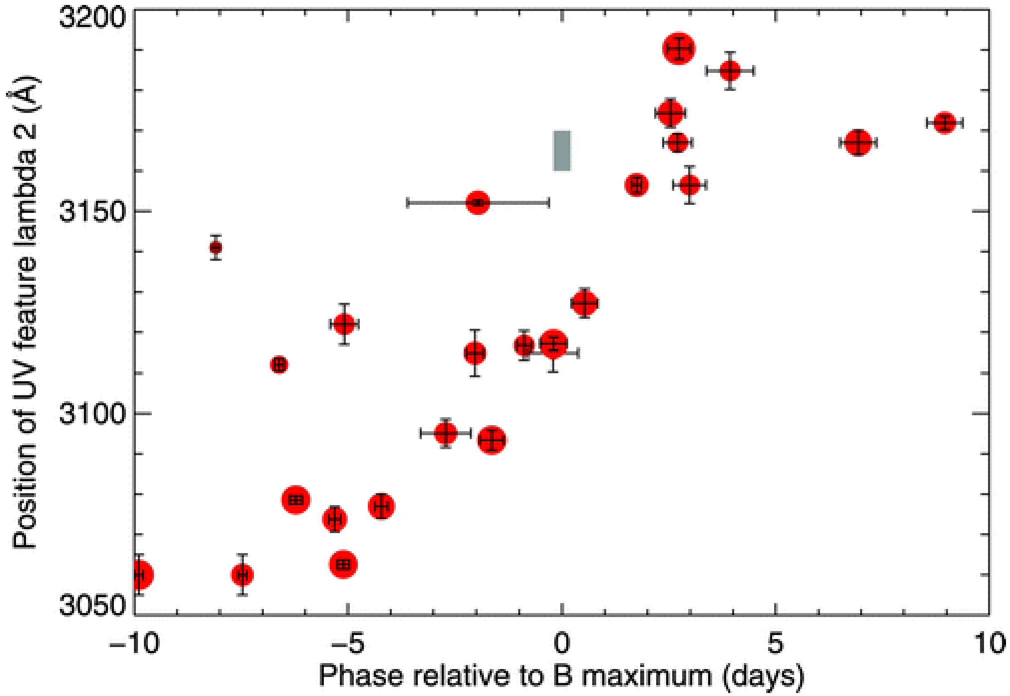
JDEM Observation z=1.6



SN-Frame UV Diversity

- Observed diversity in the UV is larger than expected from theory
- May be an important indicator of luminosity diversity (Guy et al 2007)
- Current analysis of highest-z SNe rely on the rest-frame UV because of the lack of observer-frame NIR
- JDEM advantage – If the SN-frame UV is unreliable, NIR observations provide SN-frame optical measurements for *z*>1

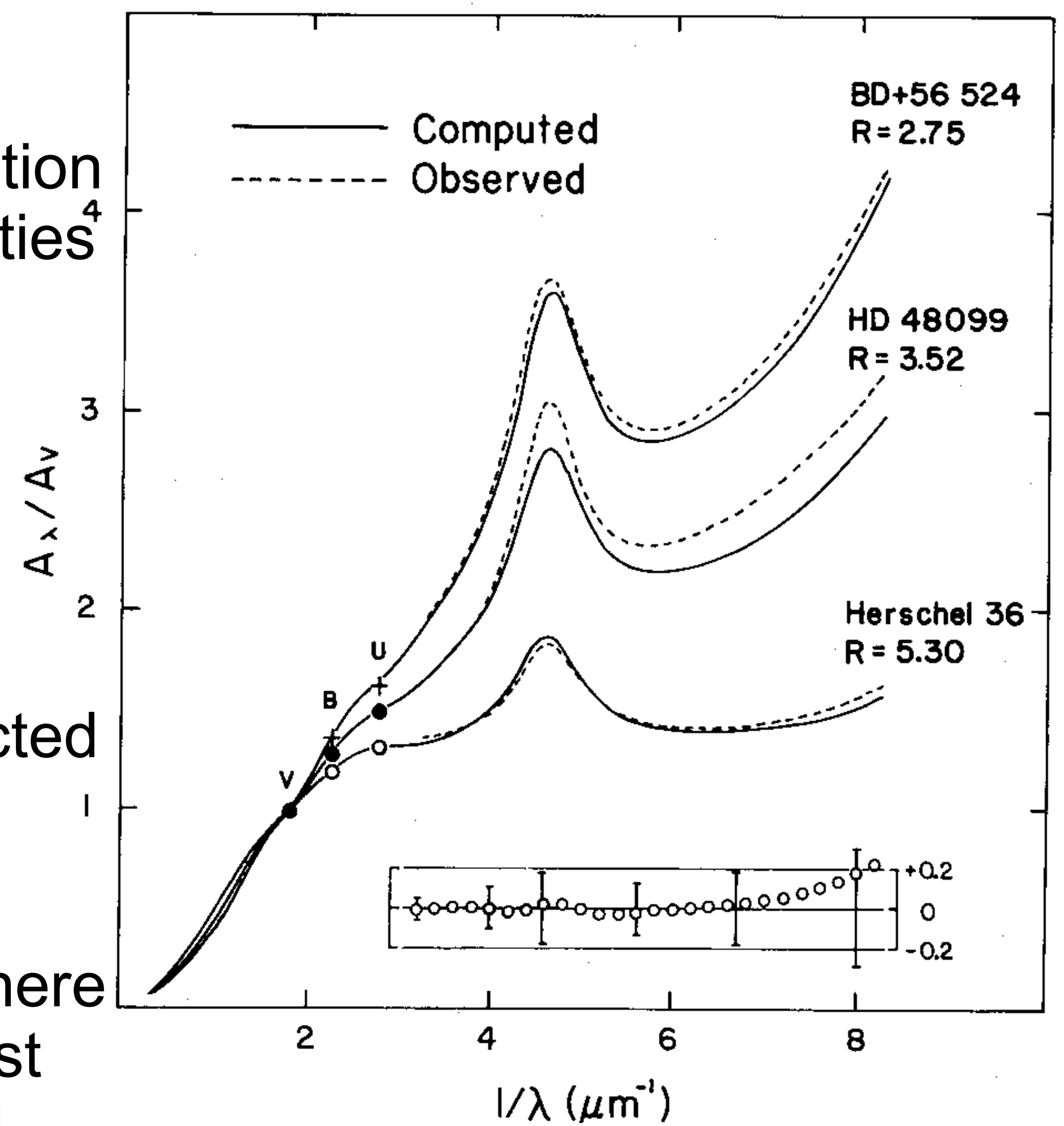




Ellis et al. (2007), see also Foley et al. (2007)

Dust Absorption

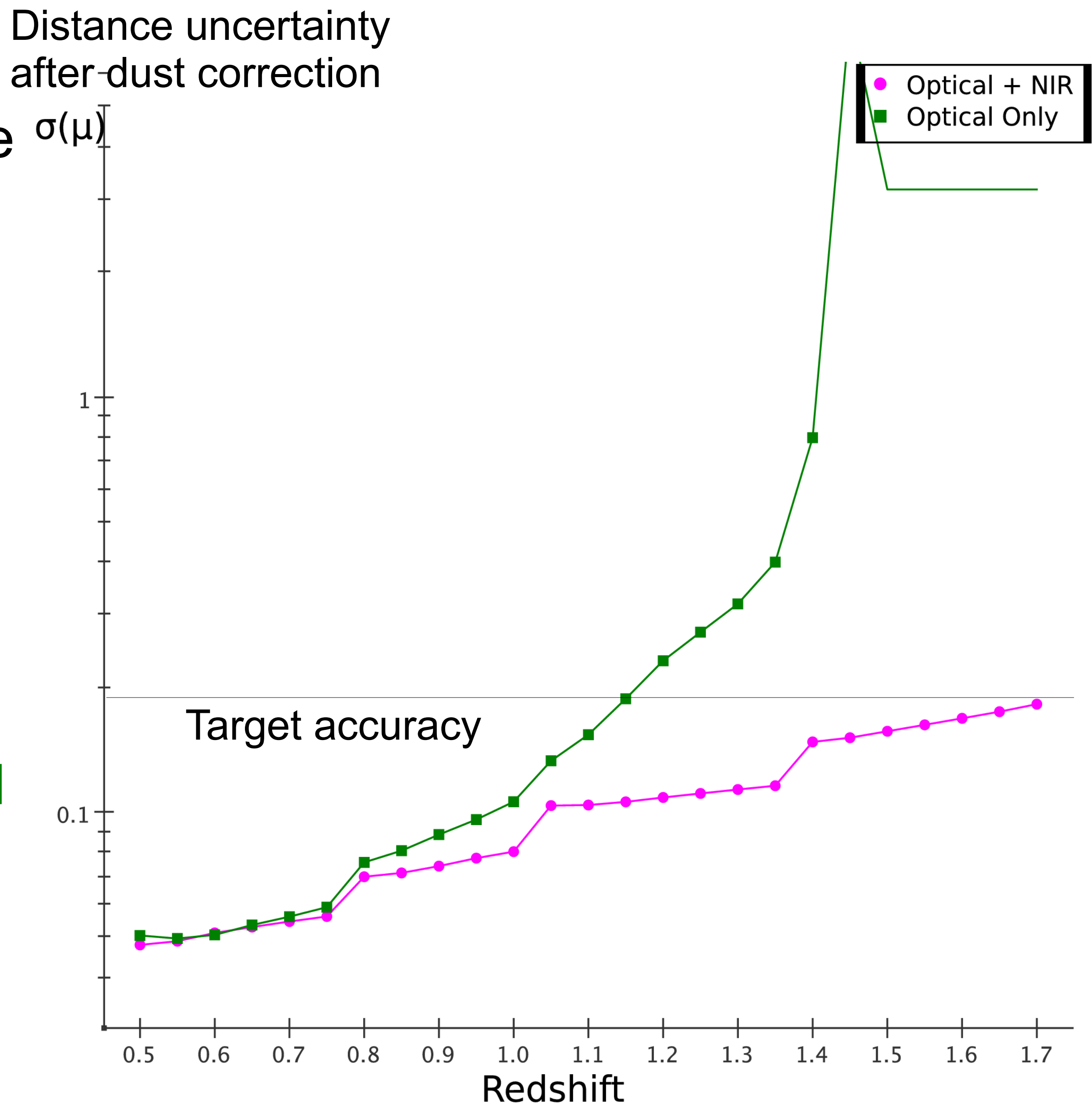
- Dust makes SNe appear fainter
- Wavelength-dependent obscuration is set by the amount and properties of the dust
- SNe Ia have standard colors
- A space-based Stage IV experiment deduces the dust properties from the SN data themselves by comparing expected and observed colors
- This is a major systematic for Stage II experiments because there is insufficient data to deduce dust properties: priors are often used



Cardelli, Clayton, & Mathis (1989)

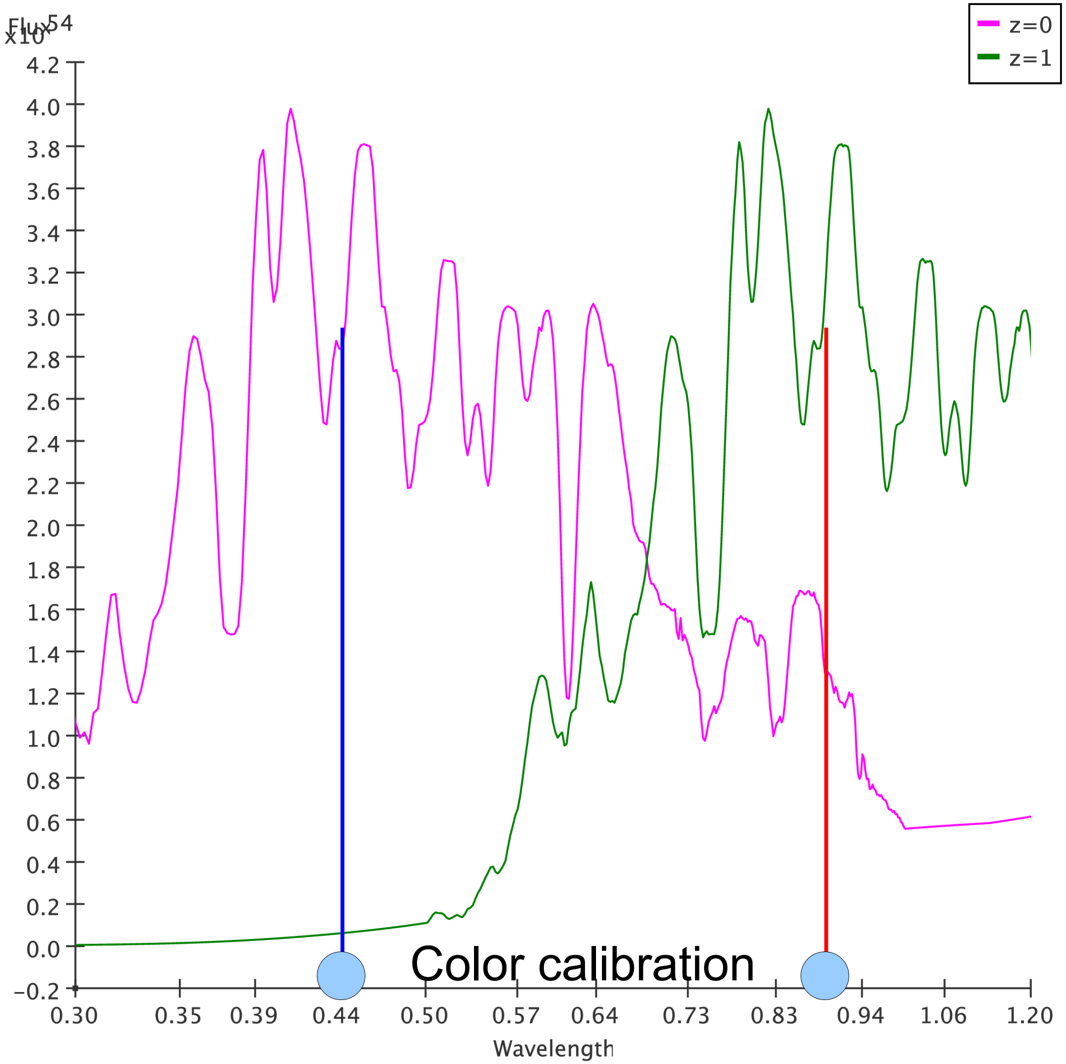
Measuring Dust Properties

- Ability to measure dust properties depends on the wavelength range of observations
- The space platform provides the wavelength coverage that allows measurement of dust properties
- The limited wavelength coverage from the ground limits the redshifts at which dust properties can be distinguished



Calibration Uncertainty

- Color calibration (relative photon transmission at different wavelengths) is important in measuring relative SN distances
  - Comparison of rest-frame fluxes of SNe at different redshifts requires comparison of fluxes at different observer-frame wavelength
  - Colors used to measure dust properties

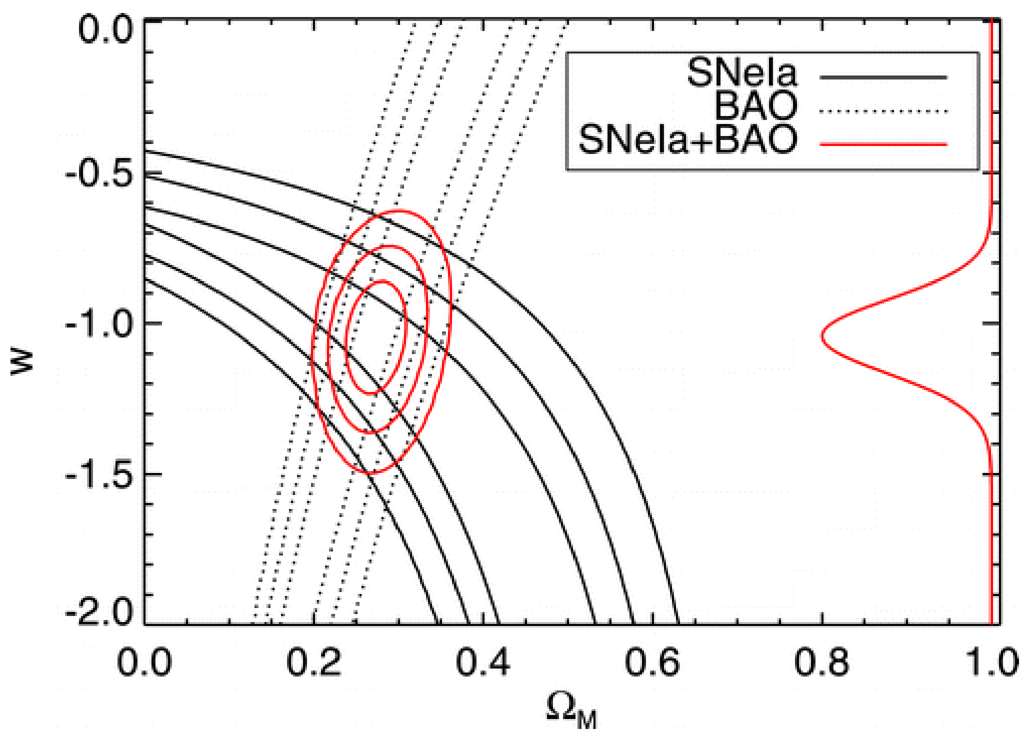


Calibration Uncertainty

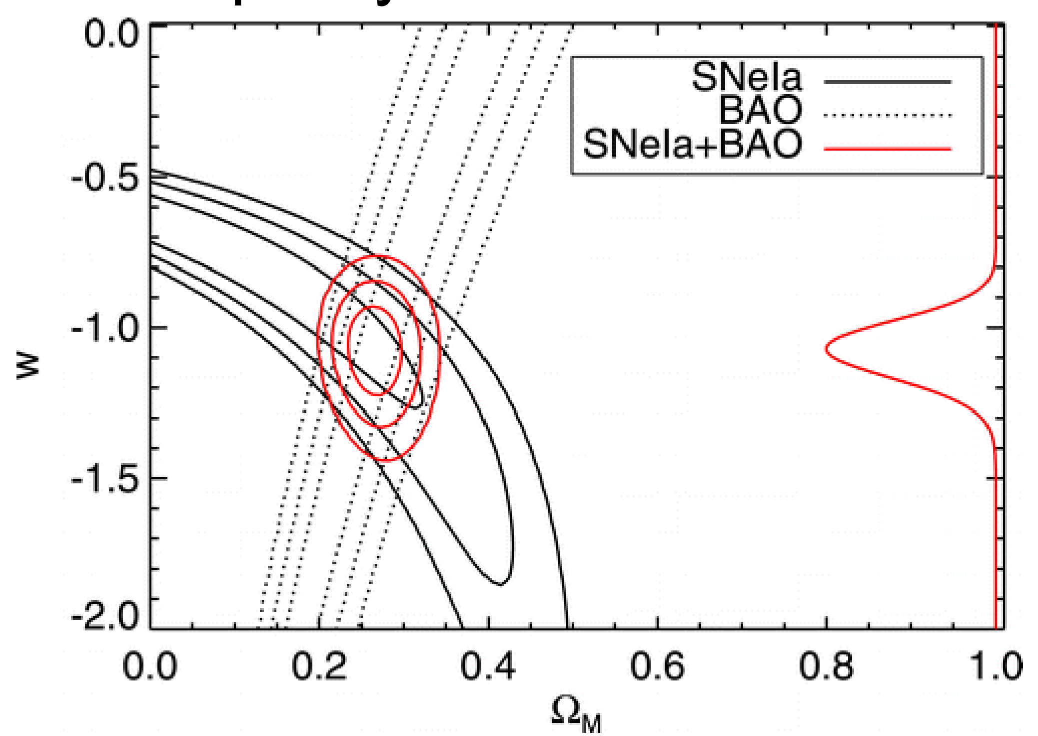
- Calibration uncertainty is common to all supernovae and does not improve with increased SN statistics (though Kim & Miquel 2006 propose a possible solution)
- Strict (~0.01 mag) color calibration requirements are necessary to achieve the Stage IV FoM
- Incremental improvement expected for DES, PanStarrs, LSST (e.g. Stubbs & Tonry 2006)
- JDEM advantage: Space allows a temporally stable optical transmission without the atmosphere

Interpretation

- There is apparent inconsistency of results obtained from different data sets
  - Frankenstein Hubble diagrams populated with SNe from disparate searches
  - Priors affect SNe with poor data quality



Nearby (45) + ESSENCE (57)



Nearby (45) + ESSENCE (57) +SNLS (60)

Wood-Vasey et al. (2007)

Interpretation

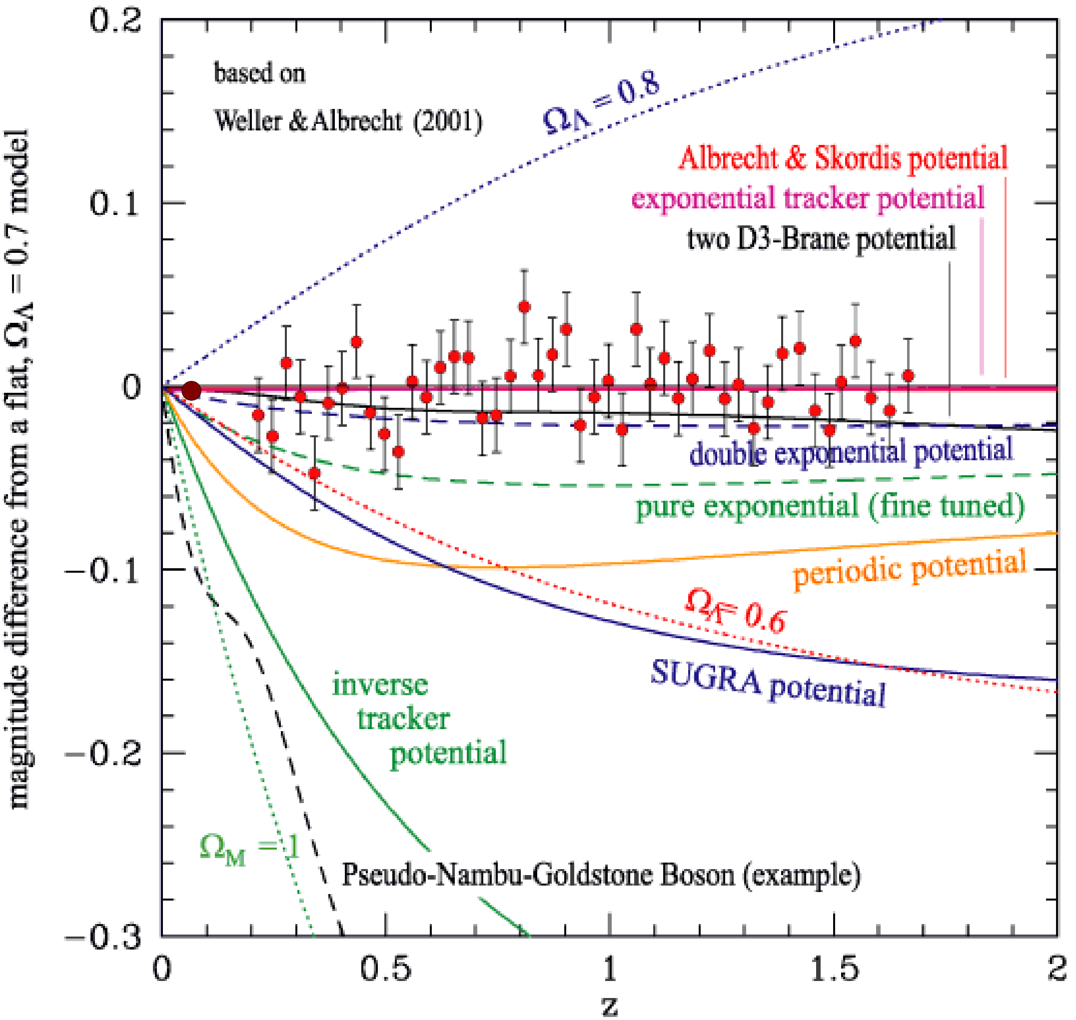
- JDEM provides a robust dataset: One survey that generates SNe at (almost) all redshifts with identical internal calibration, uniform data-quality, dust measurements, evolution tests, and no need for priors

JDEM Necessary But Sufficient?

- A low-z supernova sample anchors the Hubble diagram
- Mission requirements for low- and high-redshifts differ: the need for space observing is not compelling for low-*z*
- The local anchor must have equivalent/better systematics control as JDEM and can be calibrated to the JDEM photometric system
  - Ground-based SN Ia spectrophotometry program
  - z>~0.03 to reduce the effect of peculiar velocities

JDEM Science Reach

- JDEM-SN provides competitive tests of dark energy models, measurement of w_0-w_a
- JDEM-SN is an excellent complement to other probes
  - Small intersection regions in w_0-w_a space
  - Test gravity with probes of growth of structure



Error bars limited by calibration, dust, and SN evolution uncertainty, but at a significantly lower level than with todays limits

Selected bibliography

Papers that compare low- and high-redshift samples for evolution and estimate the impact on dark energy parameter estimation

Blondin et al. AJ, 131, 1648 (2006)
Bronder et al. A&A 477, 717 (2008)
Conley et al. AJ, 132, 1707 (2006)
Ellis et al. ApJ 674, 51 (2008)
Foley et al. astro-ph 0710.2388 (2007)
Garavini et al. A&A, 470, 411 (2007)
Hook et al. AJ, 130, 2788 (2005)
Howell et al. ApJ, 667, 37 (2007)
Wood-Vasey et al. ApJ, 666, 694 (2007)

Selected bibliography

Papers that discuss the inconsistency between Galactic and host galaxy dust, and the systematic impact on cosmology

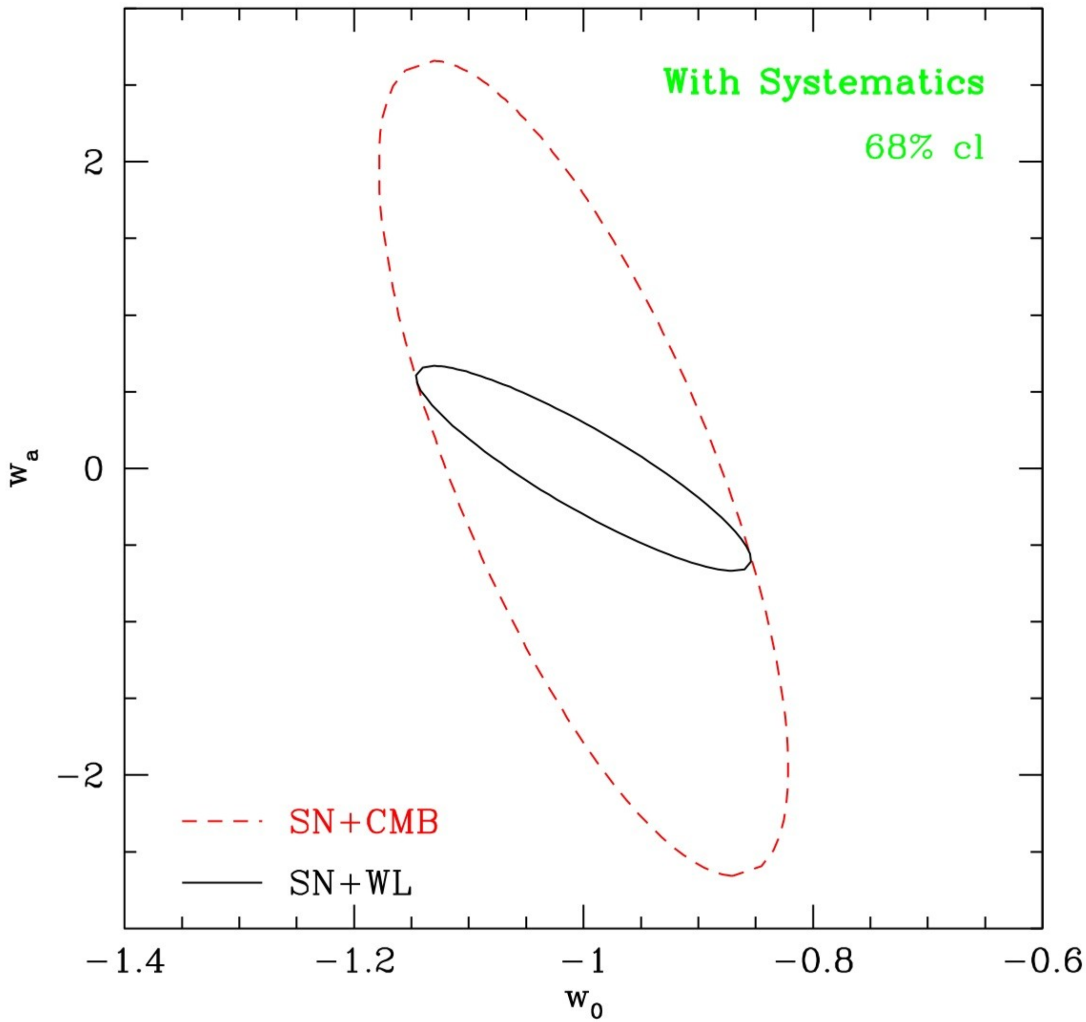
Conley et al. ApJ, 664, 13 (2007)
Elias-Rosa et al. MNRAS, 384, 107 (2008)
Elias-Rosa et al. MNRAS, 369, 1880 (2006)
Guy et al. A&A, 466, 11 (2007)
Holwerda, astro-ph:0801.4926 (2008)
Jha et al. ApJ, 659, 122 (2007)
Kim & Miquel APh, 24, 451 (2006)
Krisciunas et al. AJ, 133, 58 (2007)
Krusciunas et al. 131, 1639 (2006)
Nordin, Goorbar, & Jonsson astro-ph:0801.2484 (2008)
Riess et al. ApJ, 659, 98 (2007)
Wang et al. ApJ, 641, 50 (2006)
Wood-Vasey et al. ApJ 2007, 666, 694 (2007)

Some Backups

TABLE 1

SNAP 1-σ UNCERTAINTIES IN DARK-ENERGY PARAMETERS, WITH CONSERVATIVE SYSTEMATICS FOR THE SUPERNOVA AND A 1000 SQ. DEG. WEAK-LENSING SURVEY. NOTE: THESE UNCERTAINTIES ARE SYSTEMATICS-LIMITED, NOT STATISTICS LIMITED.

	σ_{Ω_M}	σ_{Ω_w}	σ_{w_0}	$\sigma_{w'}$
Fiducial Universe: flat, $\Omega_M = 0.3$, Cosmological Constant dark energy				
SNAP SN; $w = -1$	0.02	0.05	···	···
SNAP SN + WL; $w = -1$	0.01	0.01	···	···
SNAP SN;$\sigma_{\Omega_M} = 0.03$ prior; flat; $w(z) = w_0 + 2w'(1-a)$	···	0.03	0.09	0.31
SNAP SN;Planck prior; flat; $w(z) = w_0 + 2w'(1-a)$	···	0.01	0.09	0.19
SNAP SN + WL; flat; $w(z) = w_0 + 2w'(1-a)$	···	0.005	0.05	0.11

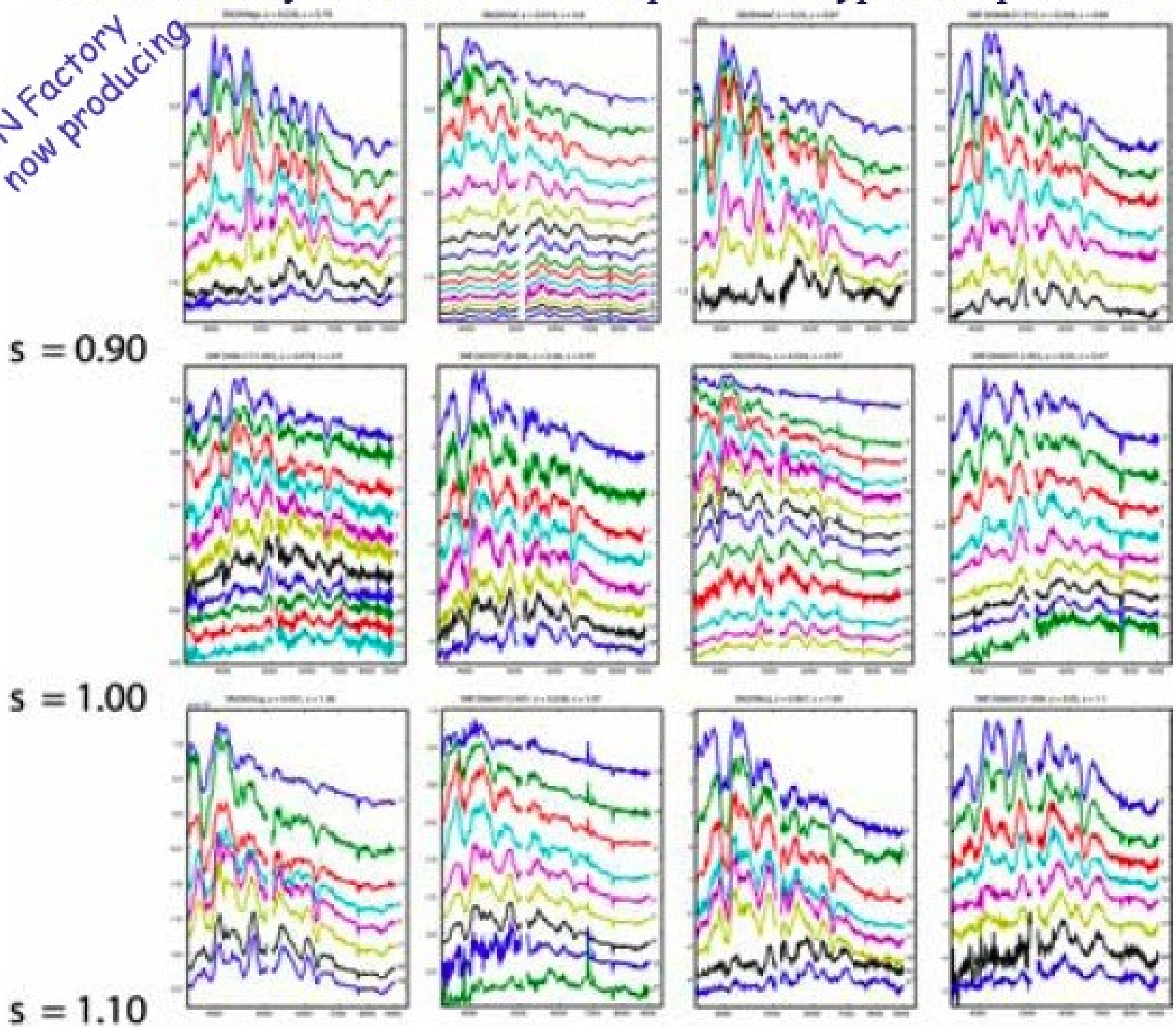


DETF
SN-IVS-o
$\sigma(w_0)=0.074$
$\sigma(w_a)=0.683$

Nearby Supernova Factory

Goal: Library of Time Series of Spectra of Type Ia Supernovae

SN Factory now producing

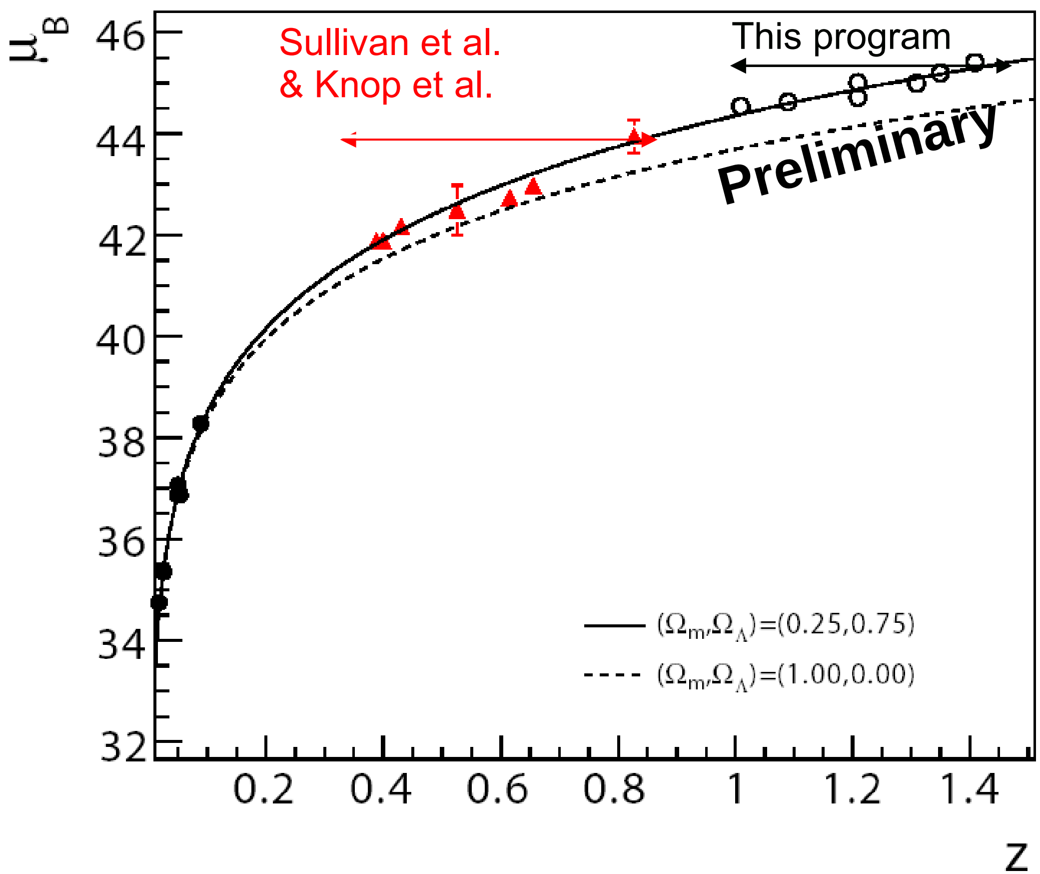


SN Factory discovered 270 SN Ia, z=0.03-0.08

2000 spectra of SN Ia

An HST SN Program

Example of E–only Hubble Diagram



Supernova Cosmology Project – HST program targeting galaxy clusters for supernova searches

Elliptical galaxies are "dust-free"

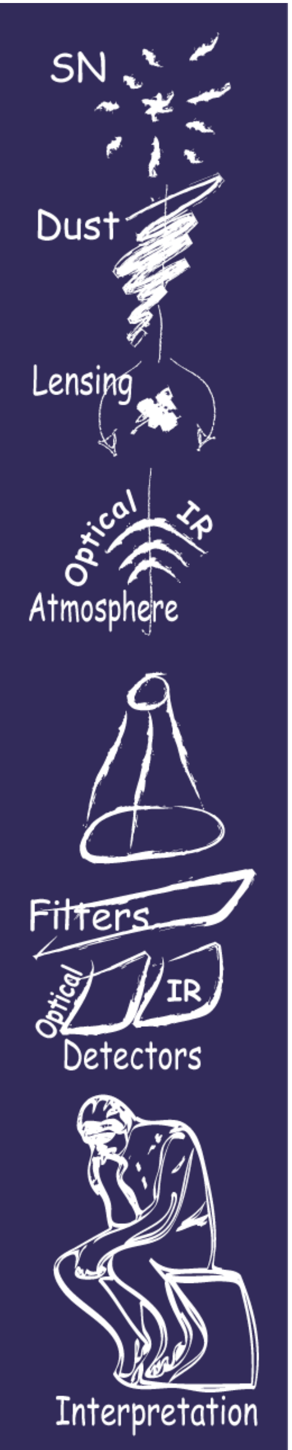
Clusters have 5x elliptical density

An indication of quality results possible with analysis of a controlled sample data from a space mission

Seven SNe Ia in elliptical galaxies observed with complete lightcurves.

No extinction correction applied

SN Ia Distance Measurement Systematics



- SN: SNe Ia may not be perfect standard nor standardizable candles
  - JDEM: Only use subsets that are standard or standardizable candles
- Dust: Obscuring host galaxy-dust has unknown absorption properties
  - JDEM: Use multi-channel observations over a broad wavelength range to measure dust absorption properties
- Lensing: Mass inhomogeneity along the light path causes de/magnification of supernova light
  - JDEM: Mean magnification is 0. Observe a sufficient number of SNe to compensate for the extra random dispersion
- Calibration: Absolute color calibration is an irreducible statistical uncertainty common to all SNe
  - JDEM: Lack of atmosphere and stable environment reduces temporal transmission variations and statistical calibration uncertainty
- Interpretation: Tension in the results from recent SN cosmology analysis
  - JDEM: Cosmology analysis for a well-calibrated experiment using weak or no priors and algorithms incorporating advanced understanding of SNe Ia avoids difficulties faced now

Interpretation Inconsistency

- Same data, different distance-determination algorithm

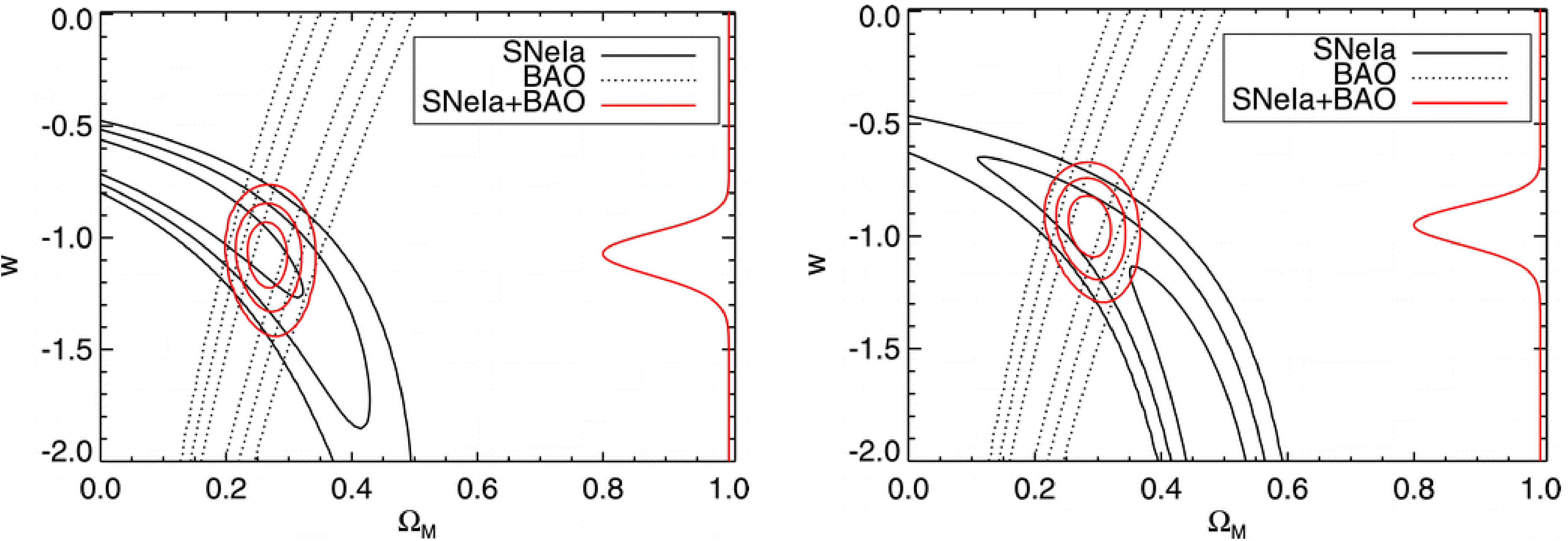
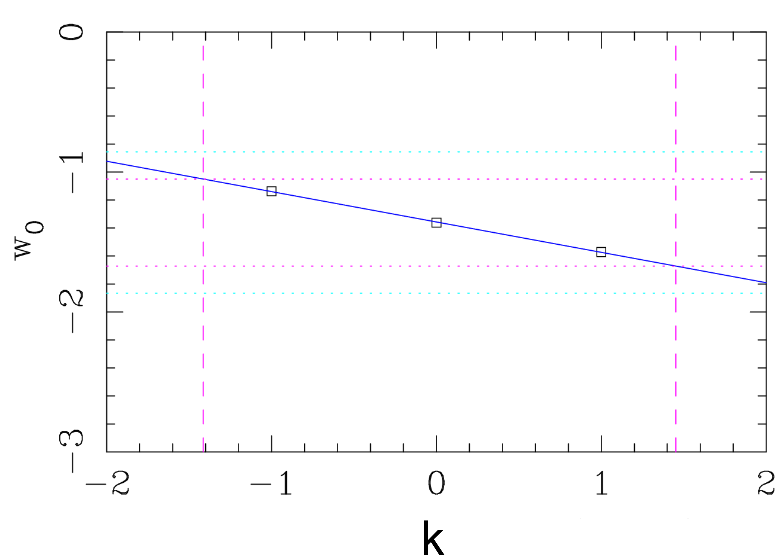


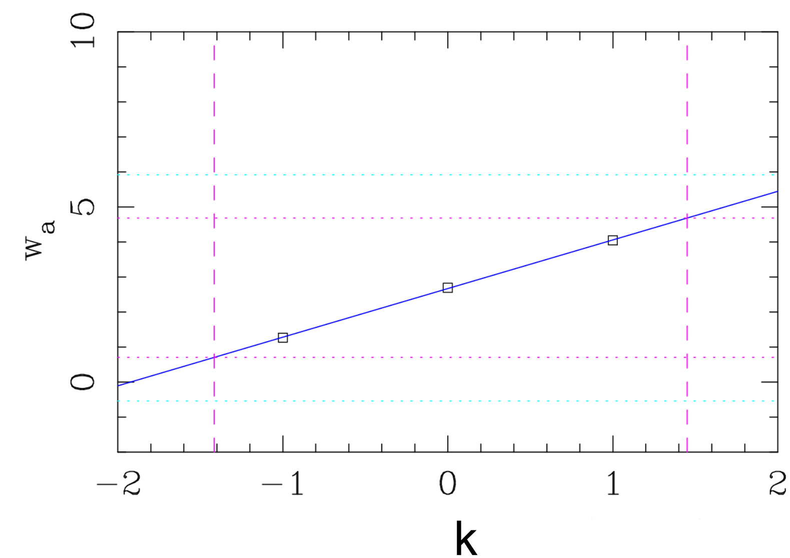
Fig. 11.— The $\Omega _{M}-w$ contours from the SNLS+ESSENCE+nearby sample for MLCS2k2 with glosz A_{V} prior and for the SALT fitter. The BAO constraints are from Eisenstein et al. (2005).

Wood-Vasey et al. (2007)

Impact of Rv Systematic on Dark Energy Measurements

- Unaccounted evolution in Rv biases the measurement of the dark-energy parameters
  - Using the redshift distribution of all supernovae used in the literature
  - Model evolution in Rv as $\Delta Rv = kz$





Nordin, Goobar, & Jonsson, 2008