Supernovae Systematics

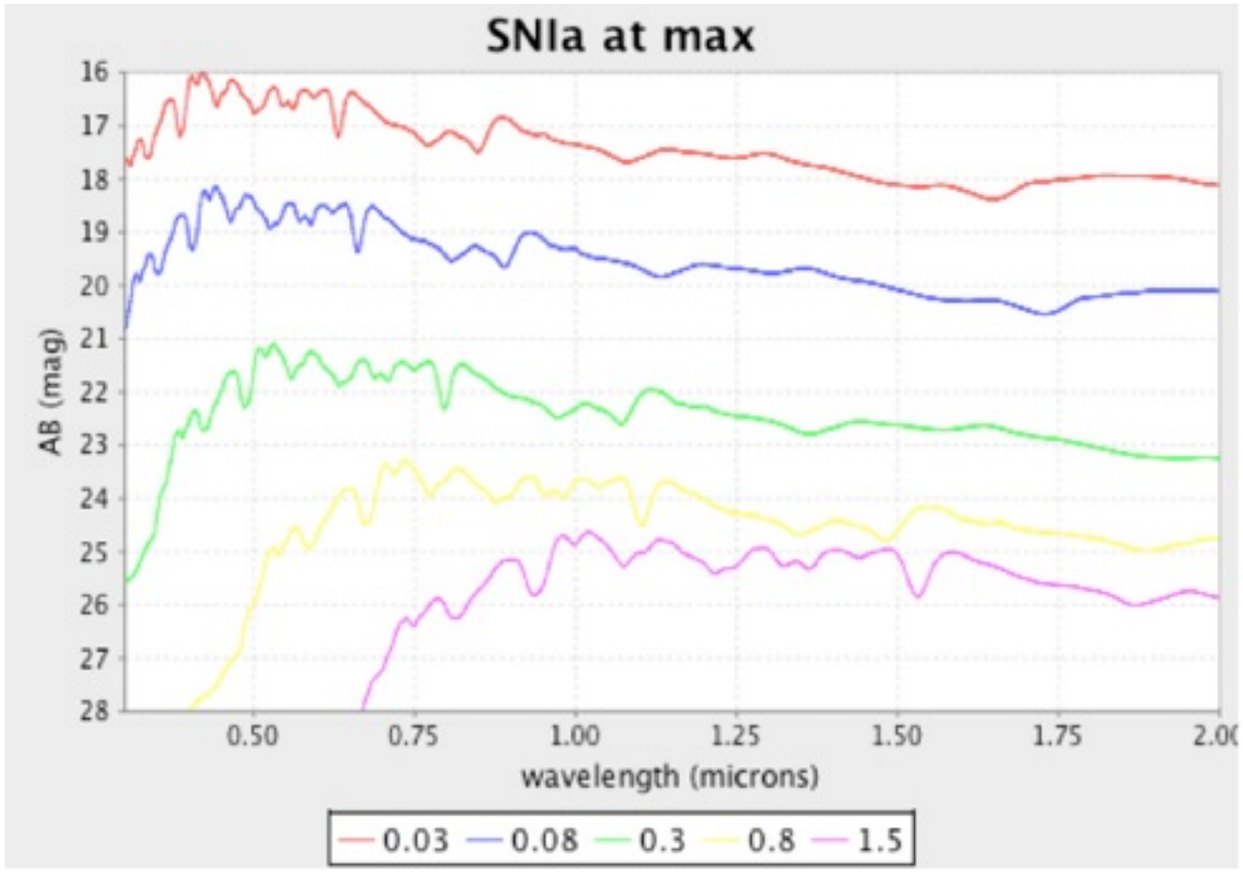
Alex Kim
Lawrence Berkeley National Laboratory

SN Surveys Parameter Comparison

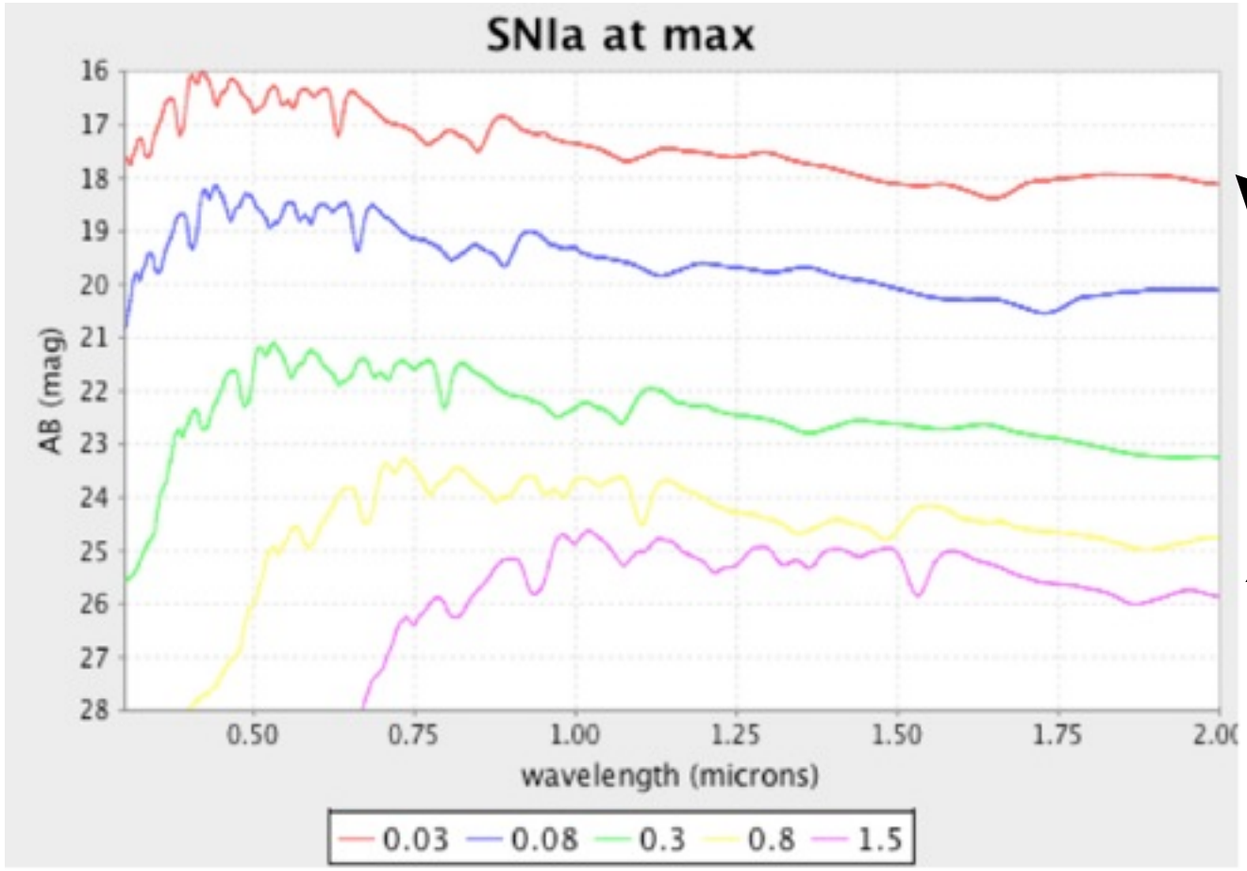
	DES SN		LSST	
	Wide	Deep	Main	Deep Drilling
Duration	5 CTIO Semesters		10 years	
Solid Angle	8x3 sd	2x3 sd	18,000 sd	O(10)x9.6 sd
Depth/visit	24 *griz*	25 *griz*	24/25/24/23/22 *u/gr/i/z*	26.5/26/25.5/24.5 *gr/i/z/y*
Cadence	5 days/band	5 days/band	3 days	4 days/band
Numbers	2500	500	10^6	50,000

Bernstein et al. , 2012, ApJ, 753, 152
LSST Science Book v2.0, arXiv:0912.0201
Astier et al., 2014, A&A, submitted

Sources of Systematic Uncertainty

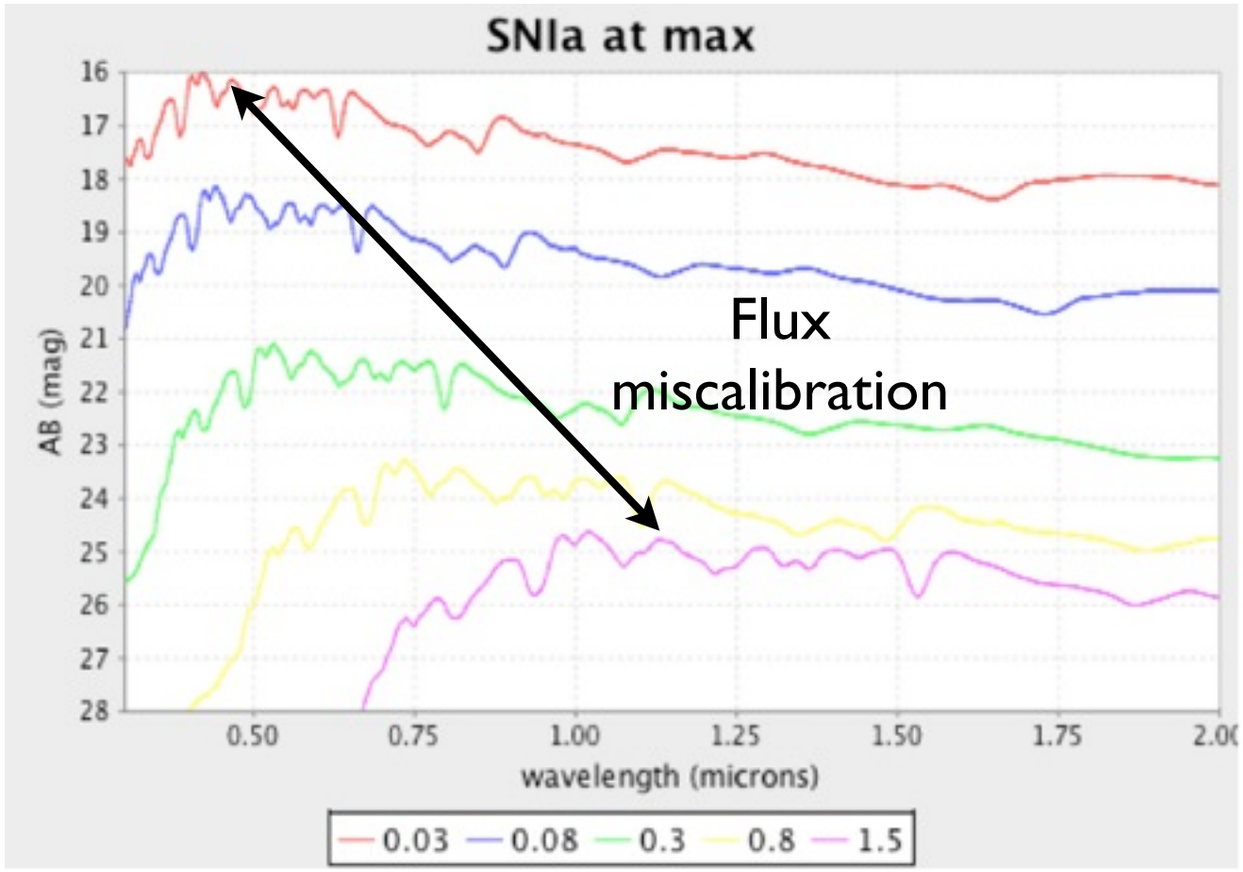


Sources of Systematic Uncertainty

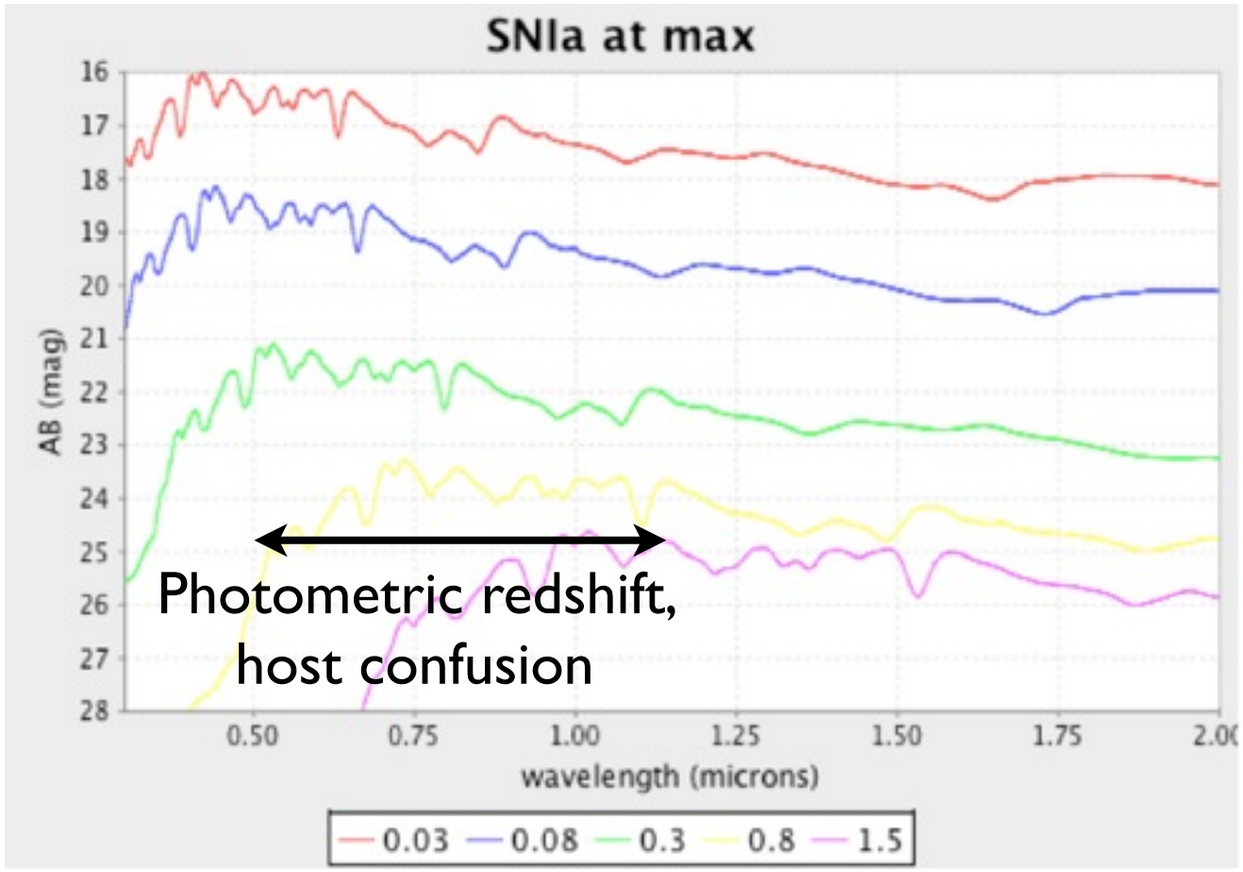


SNe at low- and high-z are different

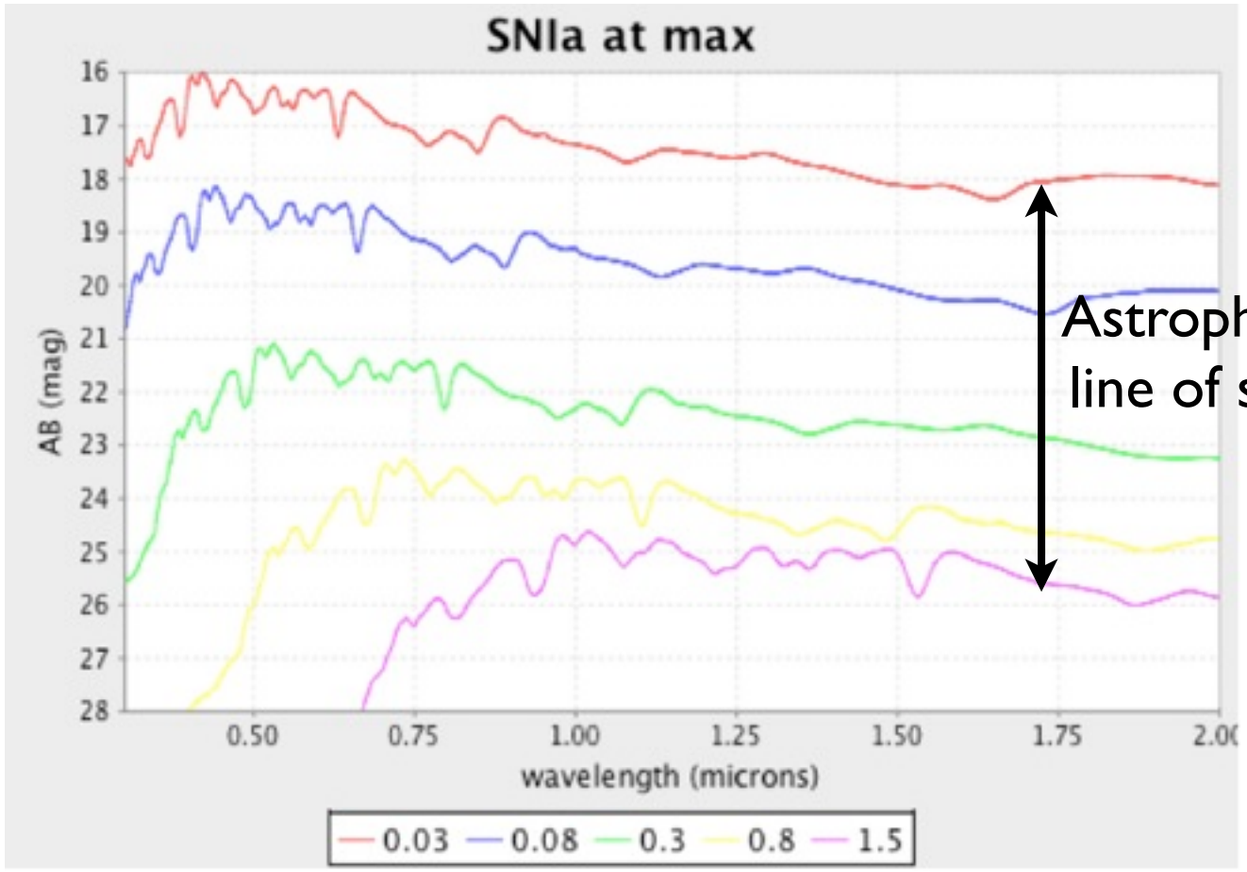
Sources of Systematic Uncertainty



Sources of Systematic Uncertainty

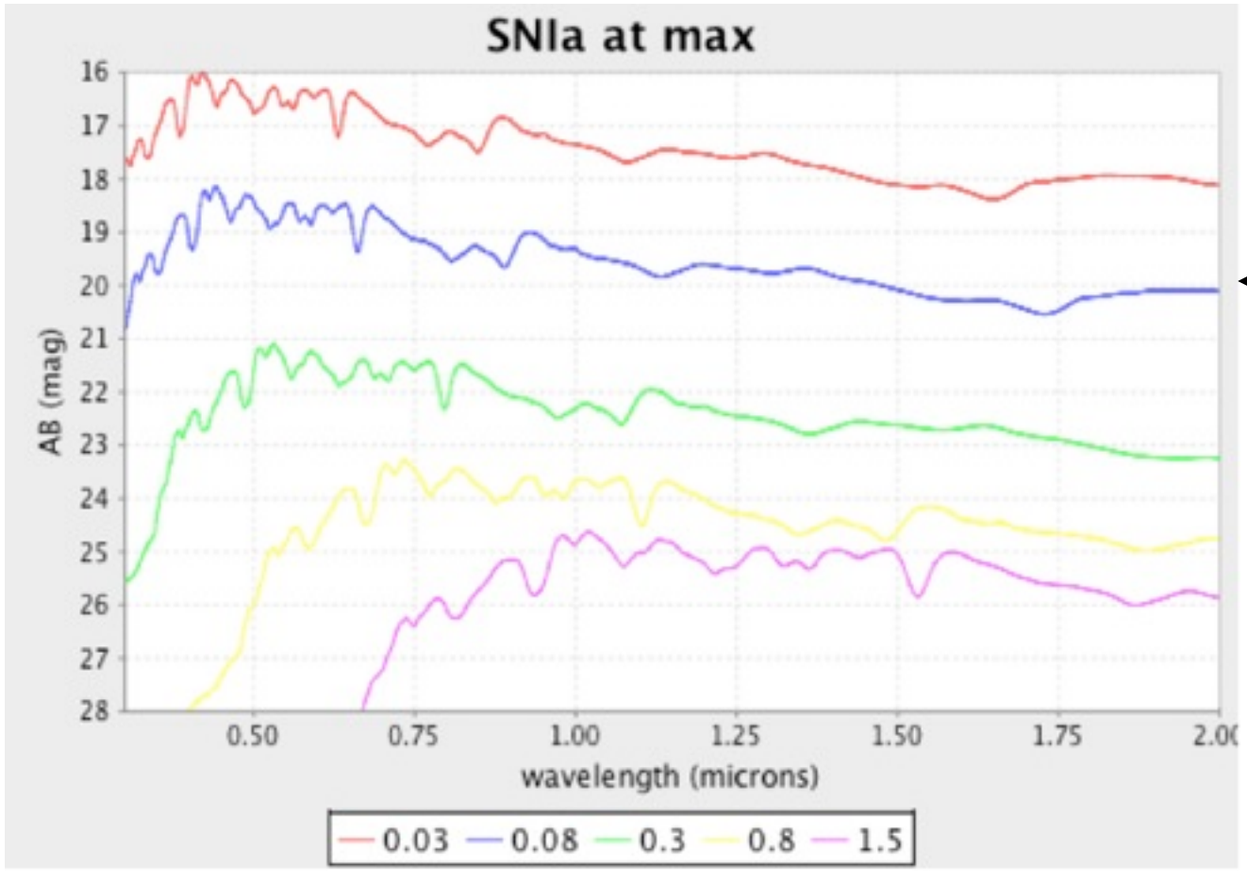


Sources of Systematic Uncertainty



Astrophysics in the line of sight affects flux

Sources of Systematic Uncertainty



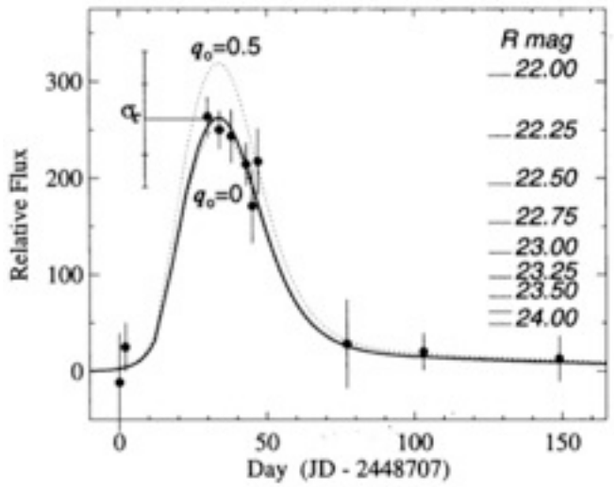
Inaccurate
SN flux model

Needs to Lower Systematic Uncertainties

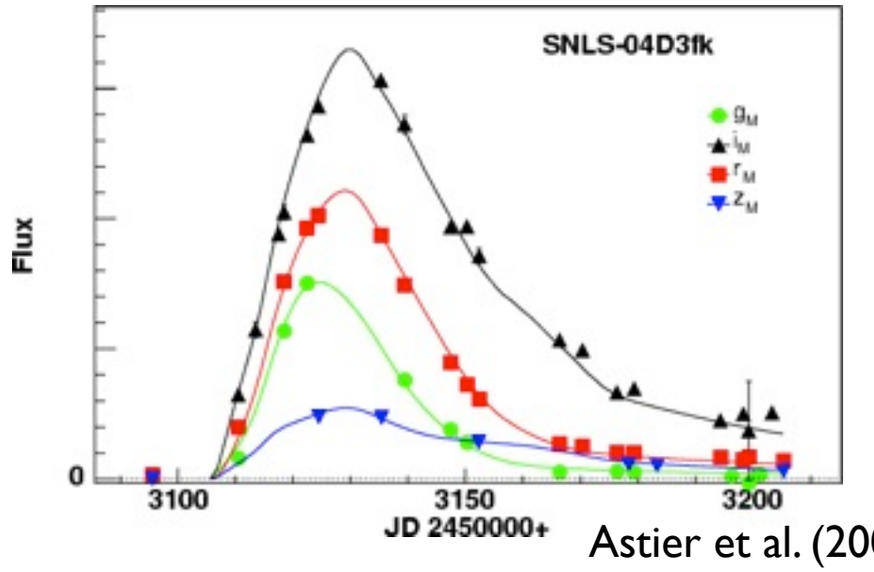
- Better data to get a more complete view of each supernova
  - New windows to exploit: Spectrophotometry, near-infrared
- Improve models used to determine SN Ia luminosity
  - Requires intensive study of nearby SNe
- Improve flux calibration
- Need spectroscopy to quantify biases from photometry-only analysis
- Better low-redshift sample
  - Use common SN-frame wavelengths to build Hubble Diagram
    - High-z searches rely on UV-B wavelengths where there is little low-z data
  - Leverage on dark energy parameters

Need a Modern SN Data Set: Reduces Standardization Systematics

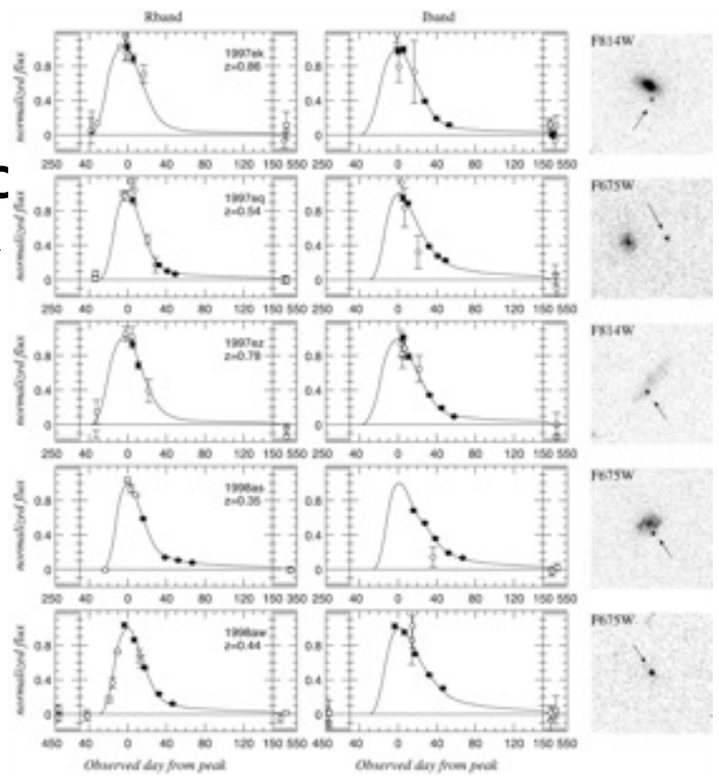
- With better quality data
  - Better quality distances
  - Estimate systematic errors with poorer quality data
- Supersedes previous SN data



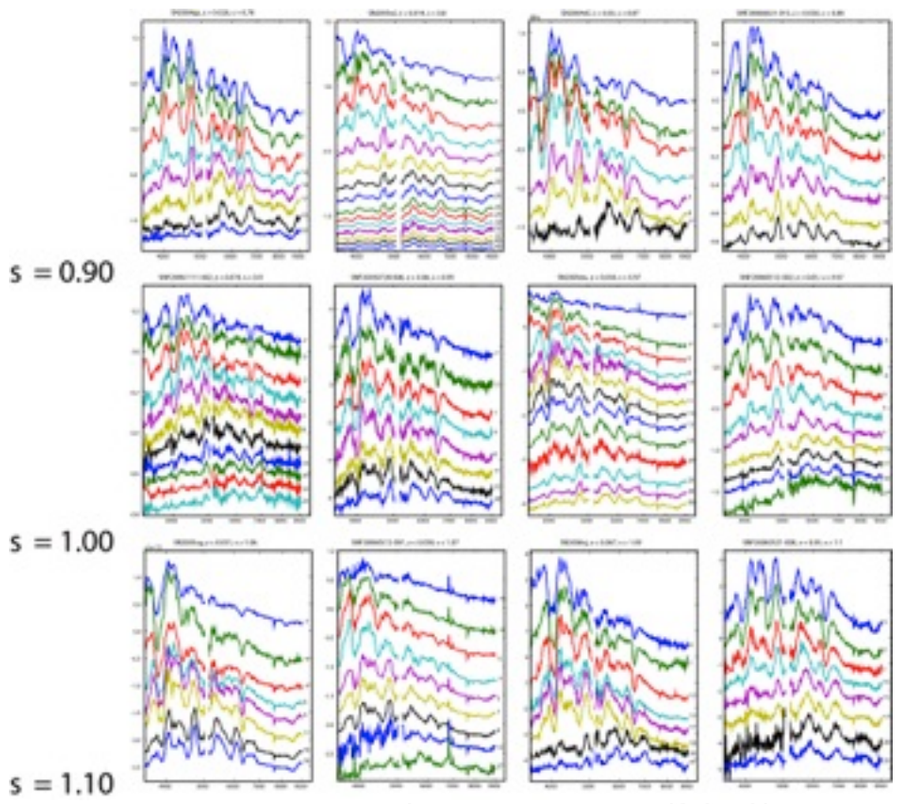
Perlmutter et al. (1995)



Astier et al. (2006)



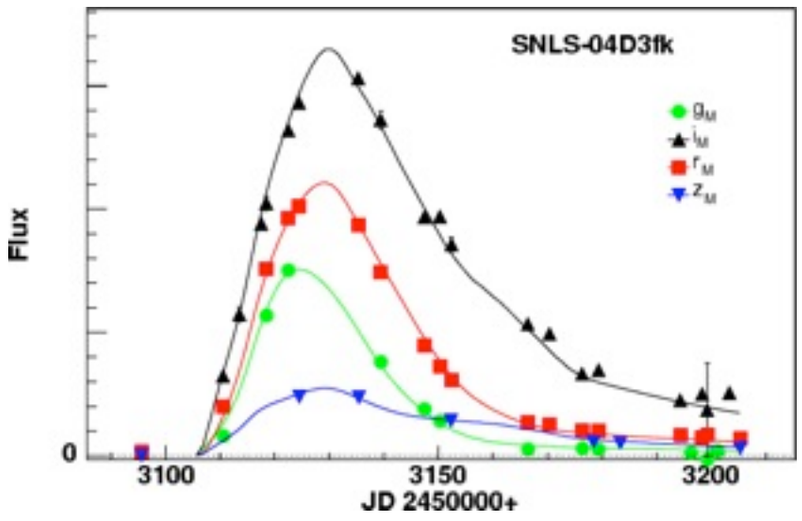
Knop et al. (2003)



Aldering et al. (2010)

Need Better SN Ia Model

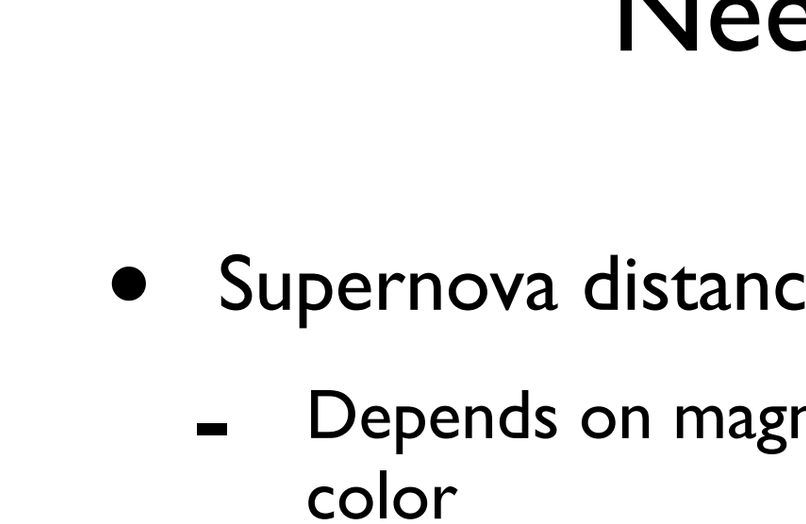
- Supernova distances determined from fits of multi-band light curves
  - Depends on magnitude at peak brightness, light-curve decline rate , and color

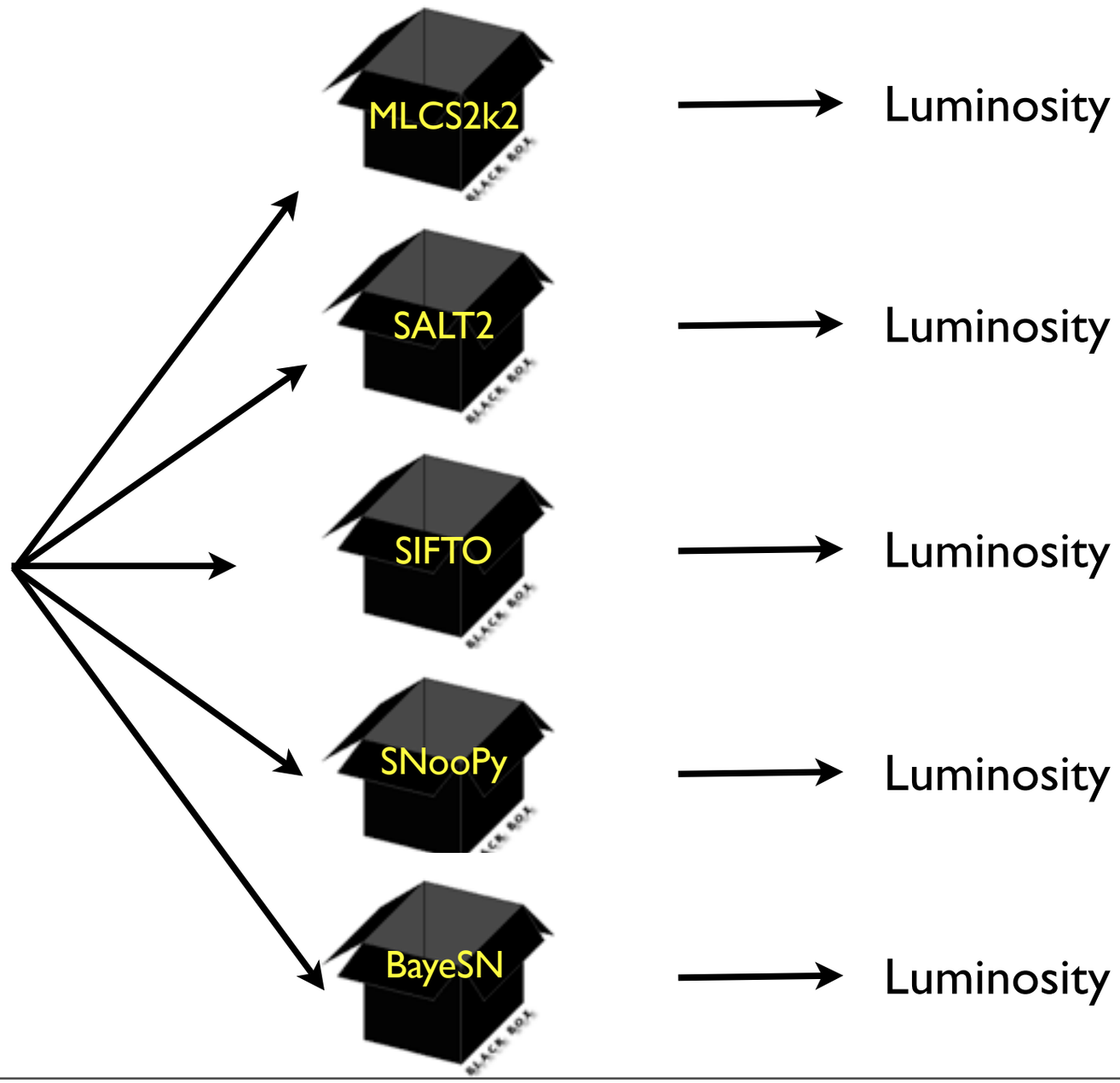


→ Luminosity

Need Better SN Ia Model

- Supernova distances determined from fits of multi-band light curves
  - Depends on magnitude at peak brightness, light-curve decline rate , and color

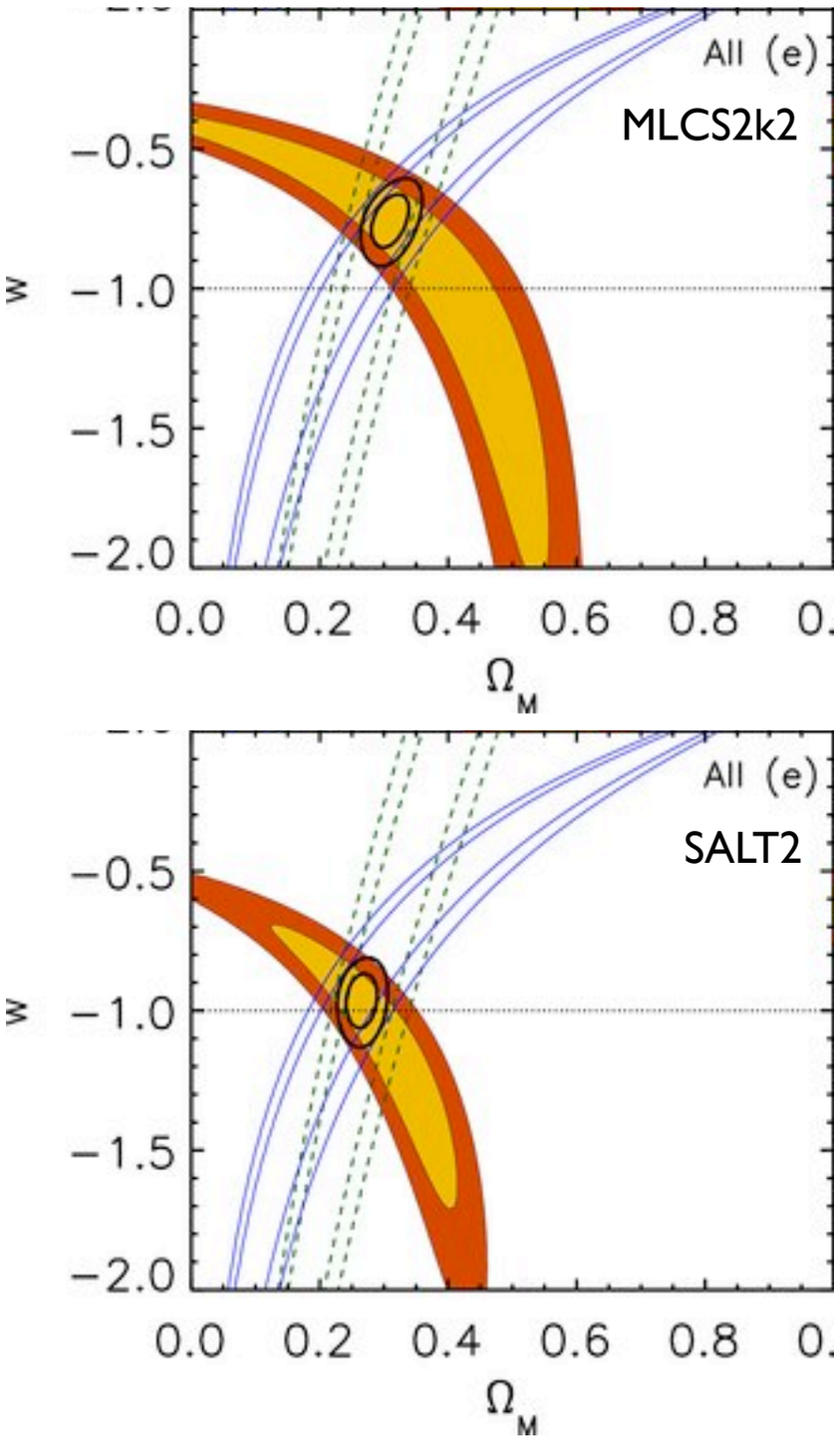




Uncertainty in SN Model Leads to Dark Energy Uncertainty

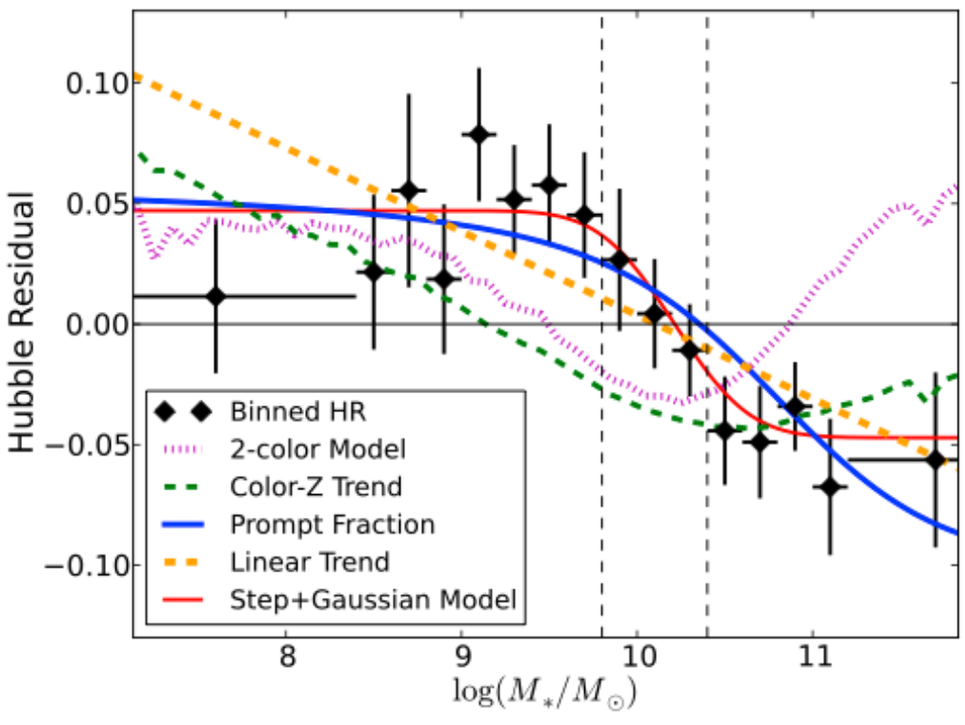
- Bulk of high-quality SN measurements in optical wavelengths and near peak
  - SNe less well understood in UV and NIR, well before and well after peak brightness
- Issue manifest in discrepancy of distances from different light-curve fitters
  - Inconsistent U-band templates
  - Different interpretation of color
  - Different priors

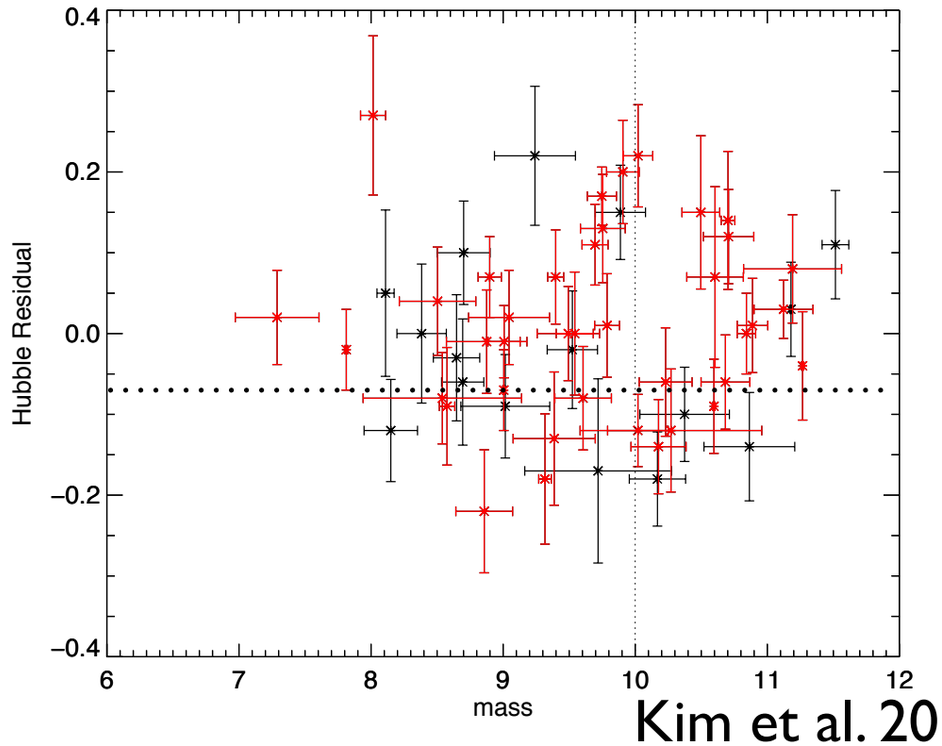
Kessler et al. (2009)



New Supernova Parametrization Lowers Statistical and Systematic Uncertainties

- Standardize to DES-filter light curves
- Absolute magnitude dispersion of new method (0.107 mag) better than other methods also using optical data (0.15 mag), and as well using optical+NIR data (0.105 mag)
- Hubble residual step between low- and high-mass hosts disappears

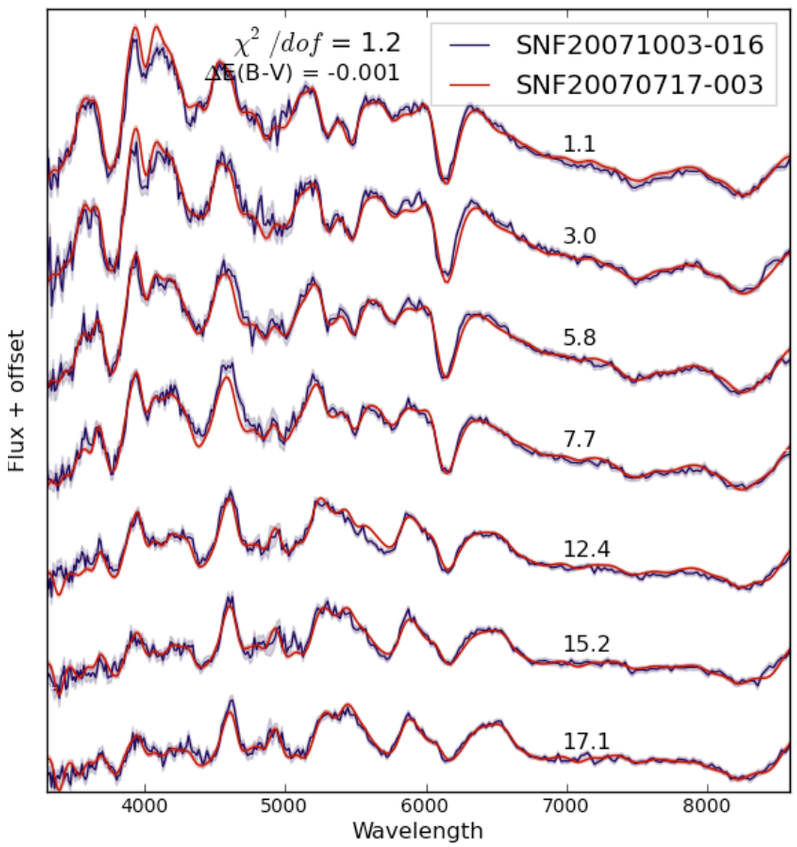


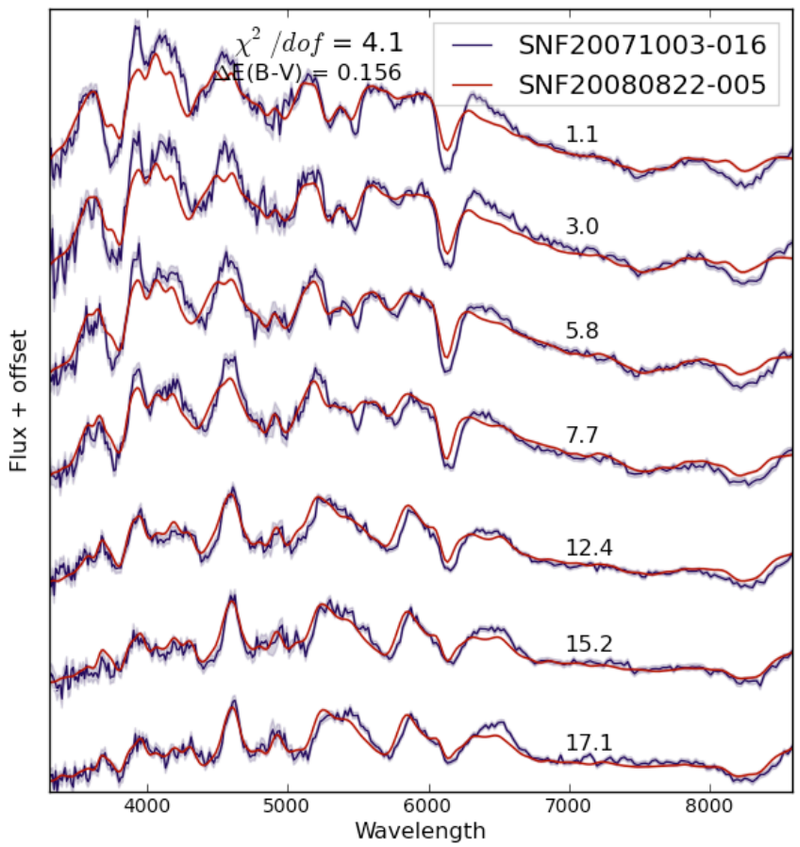


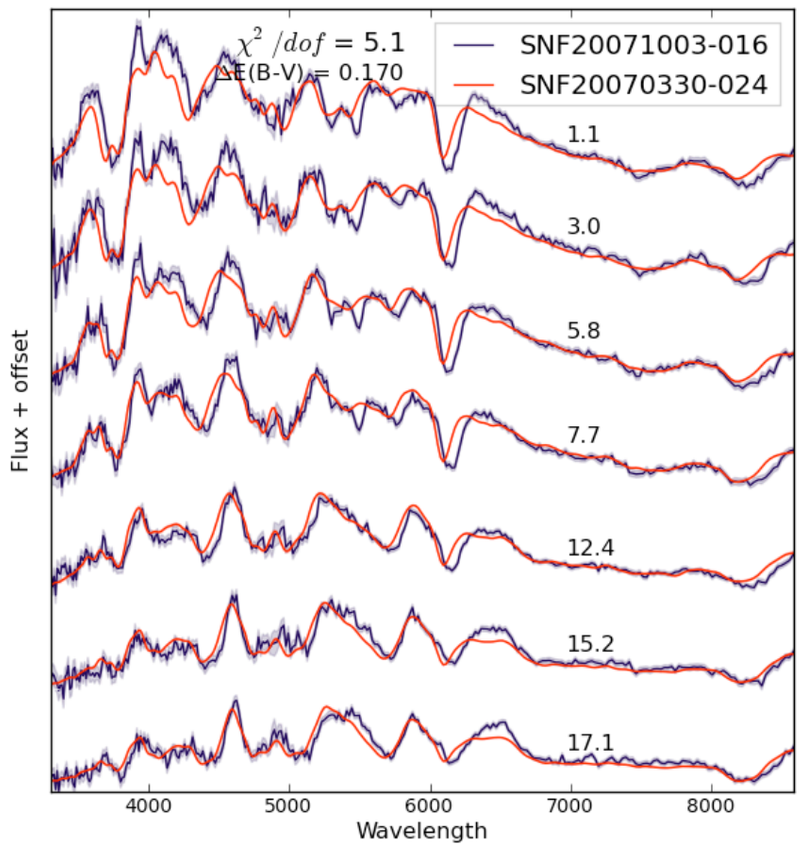
Kim et al. 2013
Kim et al. 2014

New Supernova Parametrization Lowers Statistical and Systematic Uncertainties

- SNe Ia exhibit heterogeneity in their spectra
- Regress to put different SNe on a common time grid
- Compare similarity of spectral time series







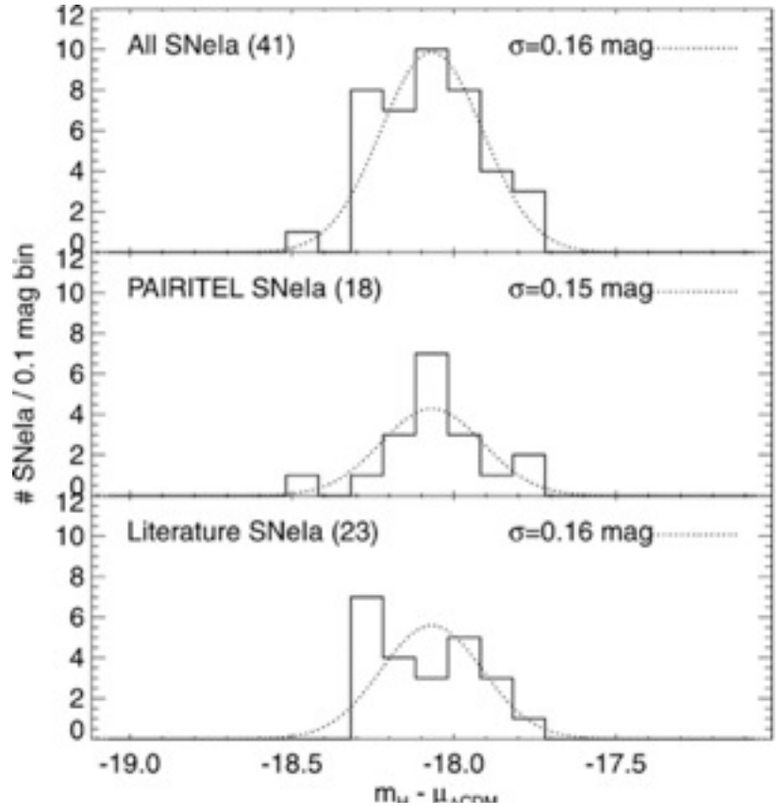
Twinny → Untwinny

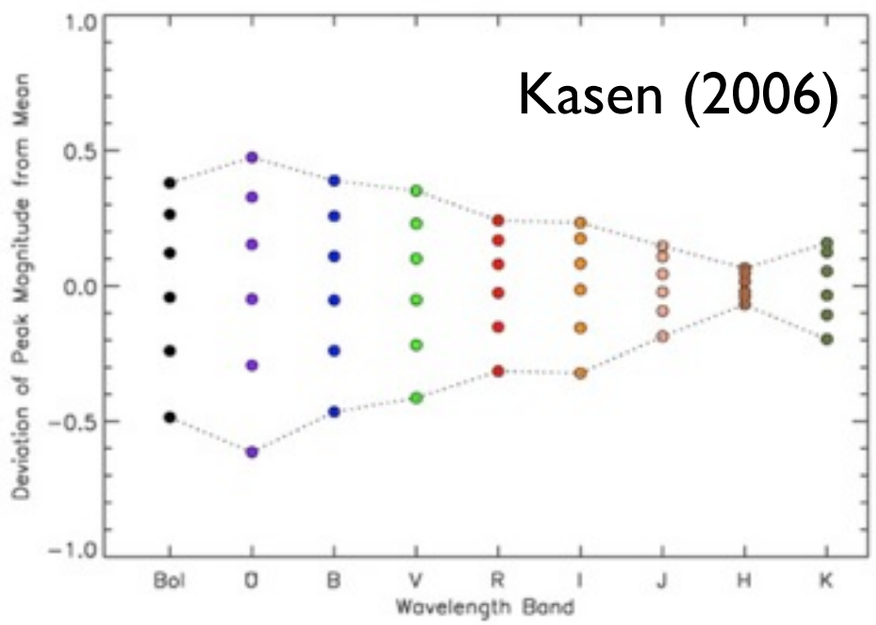
- Twin supernovae are good standard candles: 0.08 mag

Near-Infrared: Another Window Reduces Dust and Standardization Systematics

- SNe are observed to have ~0.15 absolute magnitude dispersion in the NIR with no light curve or dust corrections
- Less susceptible to dust extinction
- Small dispersion in the NIR also seen in SN explosion models

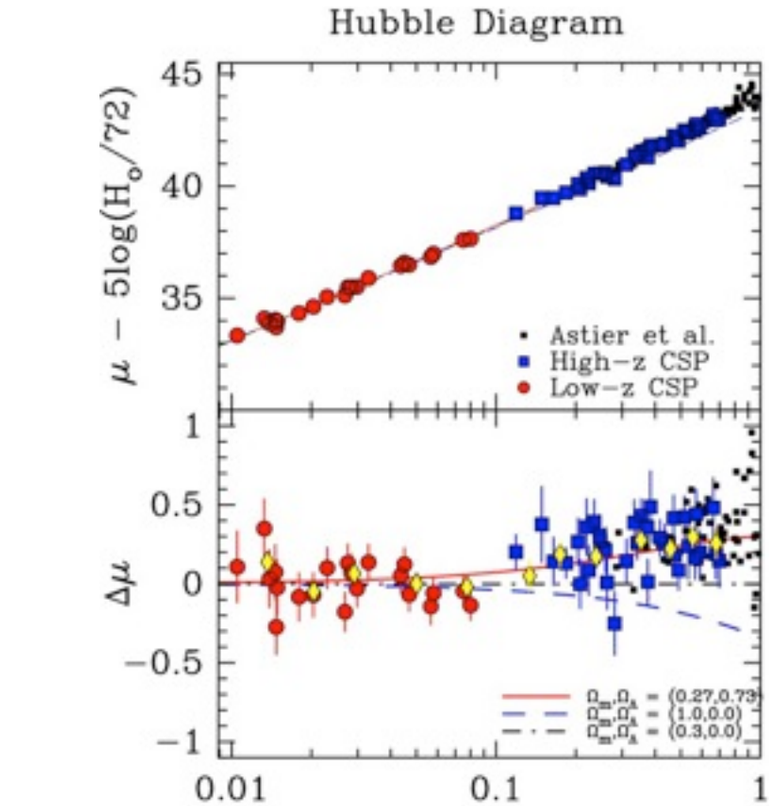
Wood-Vasey et al. (2008)

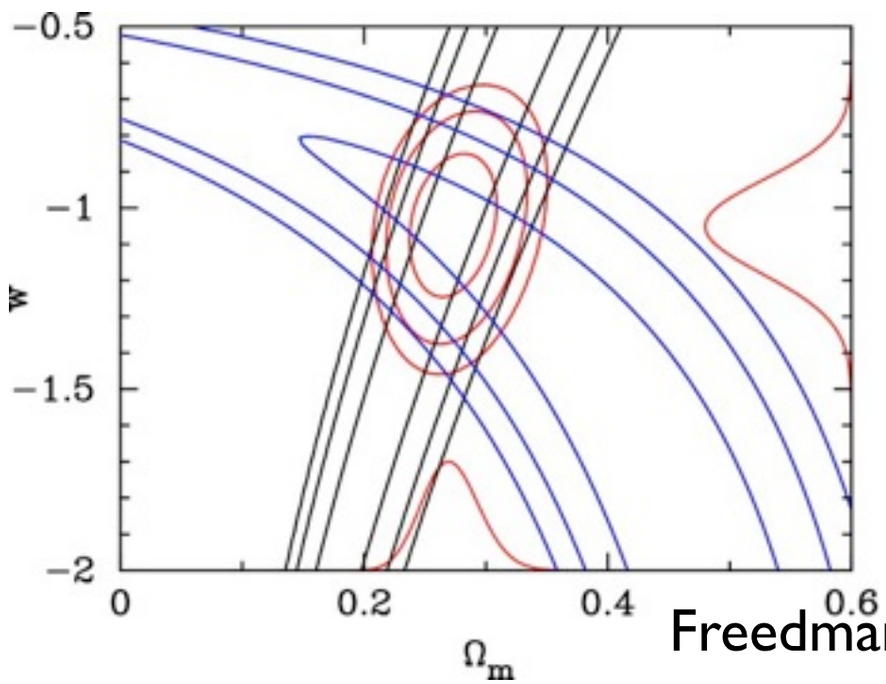




Near-Infrared: Another Window Reduces Dust and Standardization Systematics

- SNe are observed to have ~0.15 absolute magnitude dispersion in the NIR with no light curve or dust corrections
- Less susceptible to dust extinction
- Small dispersion in the NIR also seen in SN explosion models

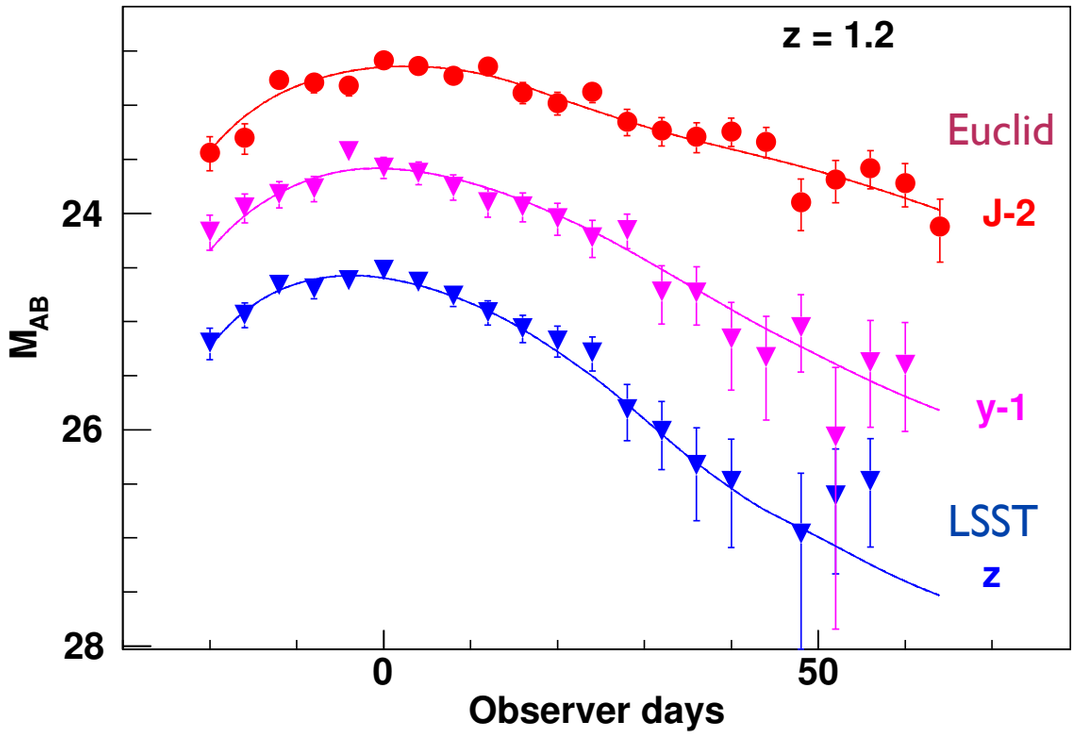




Freedman (2009)

LSST + Euclid

- Potential time for a Euclid Legacy Science
  - Supernova survey
- Combine LSST optical and Euclid infrared to extend restframe wavelength coverage and redshift range



	$\sigma(w_a)$	z_p	$\sigma(w_p)$	FoM
low-z + LSST-DDF + DESIRE	0.22	0.25	0.022	203.2
low-z + LSST-DDF	0.28	0.22	0.026	137.1
LSST-DDF + DESIRE	0.40	0.35	0.031	81.4

Astier et al. submitted

Need Better Photometric Calibration

- JLA (SDSS + SNLS) analysis provides most rigorous study of photometric calibration and SN cosmology to date

	$\sigma(Z)$ $(mmag)$	$\sigma(\lambda^{eff})$ (nm)
MEGACAM (SNLS)		
g	3	0.3
r	6	3.7
i	4	3.1
z	8	0.6
SDSS		
u	8	0.6
g	4	0.6
r	2	0.6
i	3	0.6
z	5	0.6

Zeropoint uncertainty dominated by ~3 mmag CALSPEC uncertainty

Betoule et al. , 2013, A&A, 552, A124
Betoule et al. , 2014, A&A, submitted

- For current data calibration still leading systematic but now comparable to statistical uncertainty
- Observatory calibration - planned for LSST
  - Star flats to calibrate relative PSF photometry at every position in the focal plane
  - Atmospheric monitoring and modeling
  - Tunable laser calibrates throughput of the telescope
- SNe are standard stars! Self-calibration

Process SNLS data with the LSST Photon Simulator: **(dkg 10/18/13)**

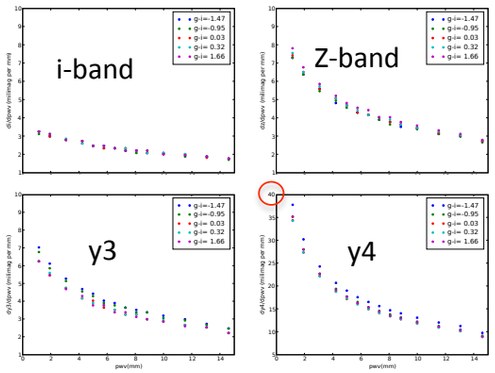
(A) Measure the telescope+filter+atmospheric transmissions from CFHTLS light curve data

(B) Compute synthetic magnitudes for a variety of spectral energy distributions from results of WD's in the field and compare to calculated (exact) transmission

(C) Run SNLS data through LSST PhoSim changing H_20 depth, Aerosol size/density and filter

Example: Applying different H_20 absorption w/errors in millimag/mm of H_20 w/ diff colors

H_20 - 1 mm induced errors on magnitudes (SNLS SN w/PhoSim)



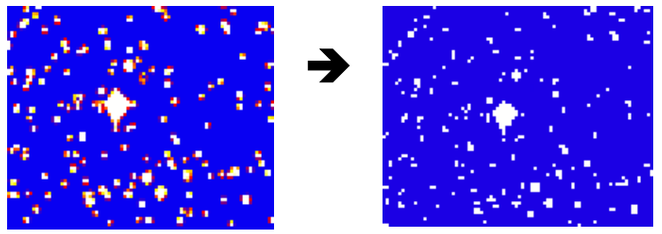
Flux from objects essential for photo-z and SN observations

Two distinct issues:

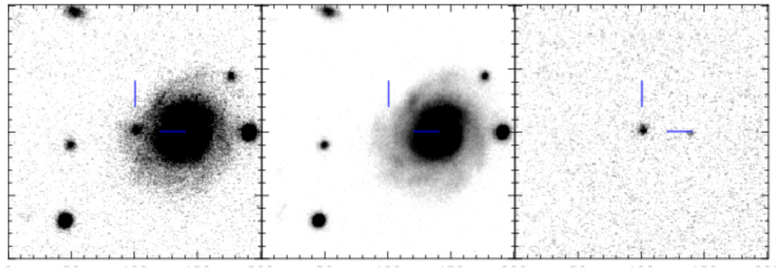
relative fluxes, in different passbands, for a single object

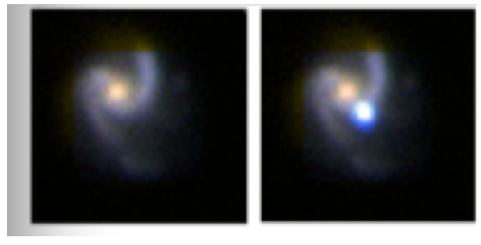
absolute flux calibrations, across the sky and wrt other cats

Accuracy of Simulated vs. Data	(PhoSim) vs. SNLS	
$\sigma\Delta z/(1+Z)$ for z <0.45	0.006	0.0019
Outlier rate	2.5%	3.1%



SNLS LSST PhoSim





Useful output or analysis from this effort will be:

Unreddened stellar locus

Galactic extinction coefficients as a function of E(B-V)

Stellar color transformations

Color terms in the LSST system

User input for characterizing the atmospheric transmission

Residual systematic errors

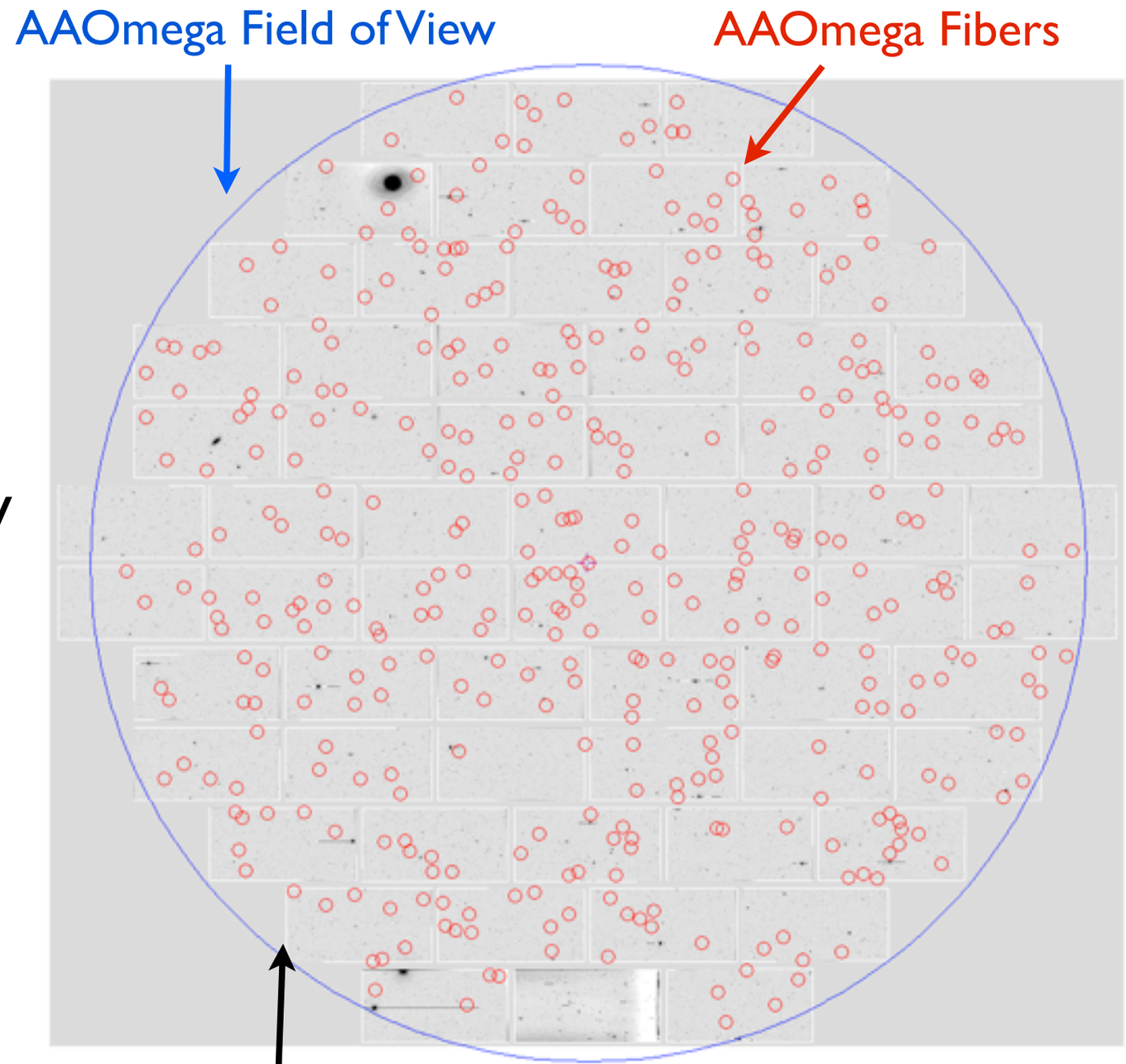
Overall instrumental sensitivity/systematics

Need Spectroscopy

- Redshift from host galaxy + SN photometric redshift inadequate for purposes of classification
  - Spectroscopic redshifts needed
  - No live-time requirement, can be done on host galaxy later
- Supernova spectral diversity informs absolute magnitude
- Calibrate and test photometric only analysis
  - Spectroscopic classification of an unbiased candidate subset
- Tom Matheson presentation

DES Redshifts and Classification - Spectroscopy

- AAT AAOmega-2df allows 392 fiber-fed optical spectroscopy
- 2 square degree closely matches 2.2 s.d. field of view of DECam
- 18 SN spectra from AAT, SALT, Keck, Gemini, GTC in Year 1
- Hard to get time for SN redshifts



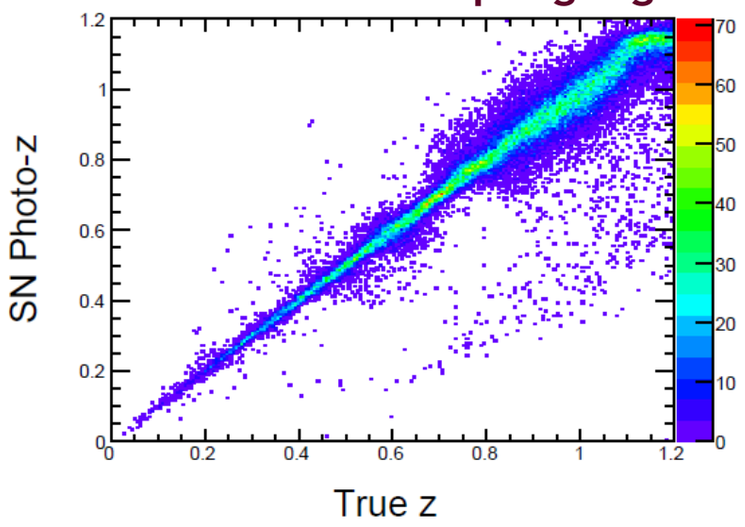
Photometric-Redshift Studies with Simulated SNe in LSST and DES

Eda Gjergo, Steve Kuhlmann, Eve Kovacs, Kyle Barbary, Rahul Biswas, Ravi Gupta
Argonne National Laboratory

Rick Kessler
KICP, Univ. Chicago

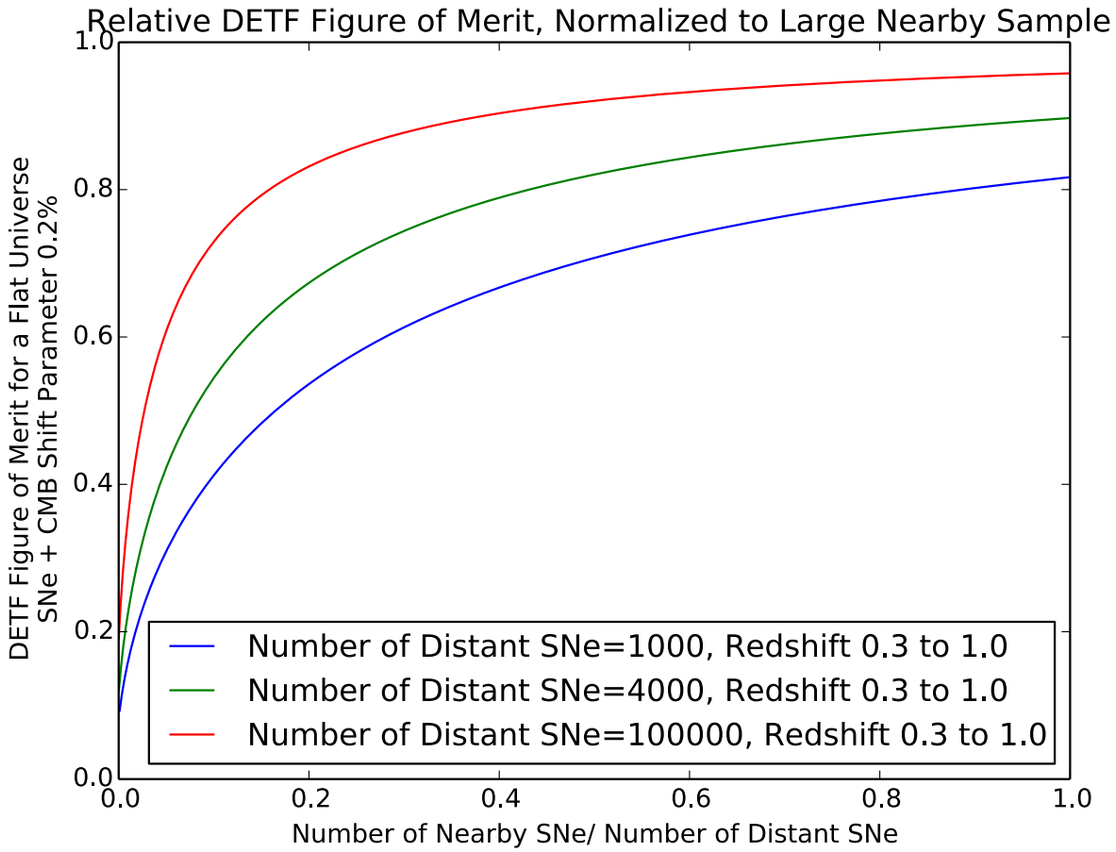
- **Multiple Photo-z algorithms tested**
- **With/Without Host Galaxy Information**
- **LSST Filter Vendor differences and their impact on photo-z performance studied**
- **2-3% "outliers" with (Photo-z - True z)/(1+True z) > 0.1**

LSST Simulated SNe Photo-z with SNCosmo Nested Sampling Algorithm

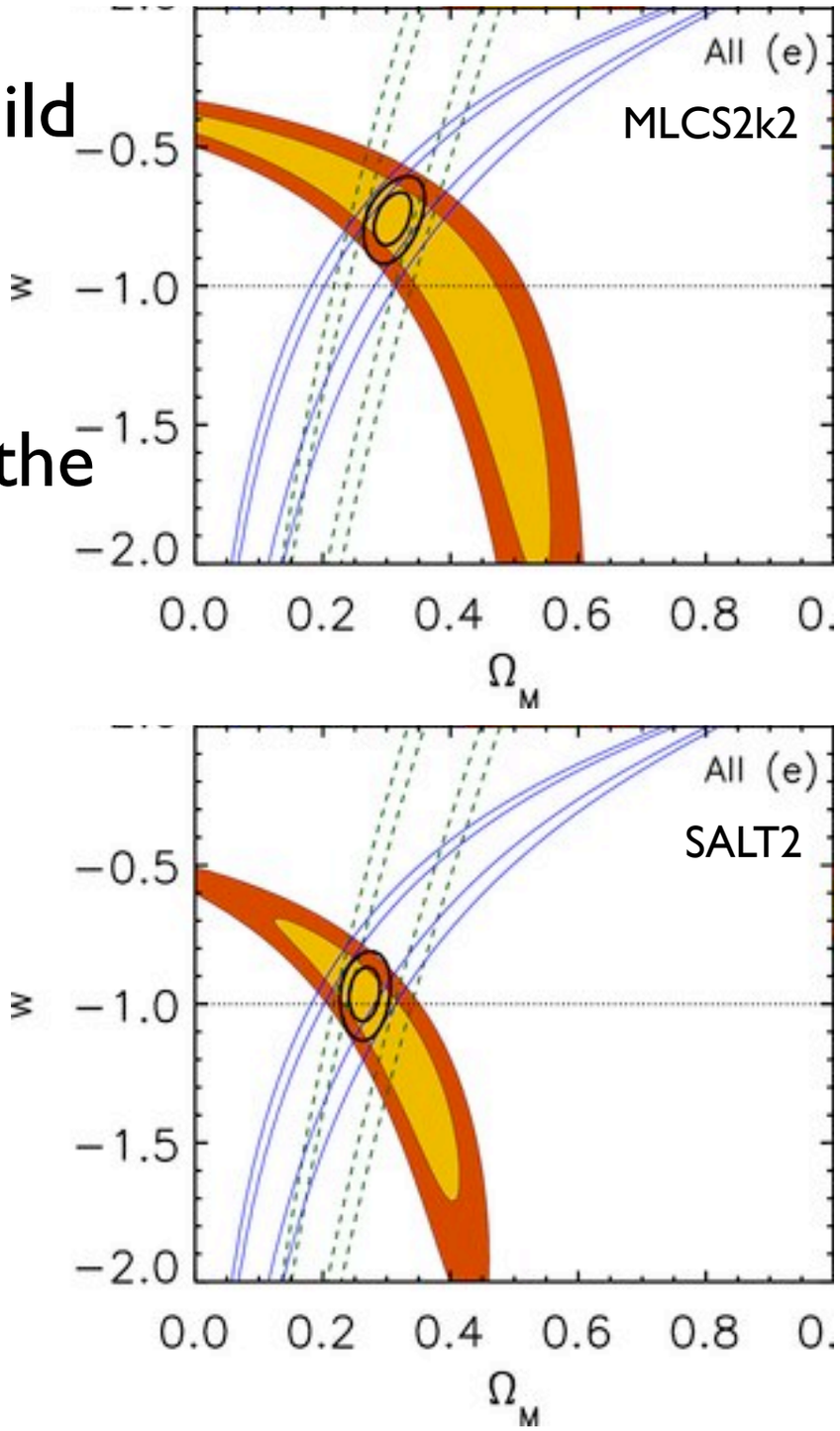


Need Low-z to Anchor Hubble Diagram

- Use common SN-frame wavelengths to build Hubble Diagram
  - Increase the sample with near-UV coverage
- Low-z SNe provide important leverage in the DE FOM



Kessler et al. (2009)



Need Blind Analysis: Reduces Scientist Bias

- Blind analysis is any method to hide some aspect of the data or result to prevent experimenter's bias
  - Dark energy parameters honing in on a Cosmological Constant - a special value preconceived to be good
- Blind analysis techniques for SN cosmology
  - Pre-define statistics used to measure exclusion of cosmological constant
  - Pre-defined blinding analysis rules
  - Blind information that can bias humans
    - Best-fit dark energy values, analysis algorithms, calibration offsets
  - Analysis procedure addressing ALL systematics and tests that would be done if data were inconsistent with cosmological constant
- DES SN WG Blinding Document

Conclusions

- As the tool used to discover the accelerating expansion of the universe and the leading probe of dark energy, the systematic error budget has been carefully scrutinized
- Current results are limited by systematic uncertainty
- There is a path forward to reduce current limiting systematics
  - Requires carefully planned low-redshift and cosmological surveys
  - Robust experimental design (space)
  - Advanced theoretical and empirical SN modeling