SDSS-II Supernova Survey

Josh Frieman

SDSS Science Symposium

August 18, 2008

SNe from SDSS Southern stripe: an old idea

- Newberg, Munn, and Richmond ~1993
- Hogan and others: Southern Working group 1994

SUPERNOVAE

Bohdan Paczynski, June 26, 1994

I am in favour of establishing facts first. I think it should be possible to use the first southern strip season to determine the following:

1. The supernovae rate in galaxies and outside of galaxies.
2. How good standard candles SN Ia really are?

To answer these question it is sufficient and necessary to recognize all SN Ia brighter than 20 mag at maximum and to obtain their spectra. Note, that the so called "peak luminosity" is best determined with the whole light curve, the most critical region being the transition from the broad "bulge-like" maximum (which lasts about one month) to the quasi-exponential tail; the transition is about 3 mag below the peak (Press et al 1994).

The average peak magnitude of SN Ia is approximately given as

$$m_{B,max} \approx 19.1 + 5\log(z/0.1),$$

(Branch and Tammann 1992, and references therein). Supernovae of Type Ia form a one parameter family, with a very small scatter in the peak magnitude when the dependence on that phenomenological parameter is taken into account (Phillips 1993). According to Press et al. (1994) the residual scatter is no more than

From SDSS to STSS: Synoptic Time-Domain Survey Science

Craig J. Hogan on behalf of the Time Domain Team[1]

ABSTRACT

We describe two forefront time-domain survey projects where the SDSS 2.5m telescope and camera system can make critical contributions, namely 1) the detection and characterization of Solar System objects and 2) obtaining type Ia supernova light curves in the redshift range $0.05 < z < 0.35$. For the Solar System objects, we demand not only detection but characterization of orbits and compositions, and estimate the overall detection efficiency using detailed simulations. We show that the 2.5m is uniquely poised in the next five years to make an outstanding contribution to the NASA goal of detecting 90% of the potentially hazardous asteroids with diameters 1 km and larger. For the supernovae, we demand densely-sampled multiband light curves with much better photometric calibration and spectral coverage than are currently available, and estimate the sample quality and size using Monte Carlo simulations; we find that a realistic program would produce hundreds of light curves of unprecedented quality. The supernovae would fill an important gap in redshift space, providing unique new foundational knowledge of both intrinsic supernova properties and an important part of the Hubble diagram, including the best direct measurement ever made of the cosmic deceleration parameter q_0 and important constraints on the nature of dark energy. Both of these project simulations are reliably calibrated using actual SDSS time-domain data. Both proposed projects will make unique contributions, well beyond the capabilities of existing projects within a five year time frame, that are well aligned with key strategic priorities of the science community (as described in three recent NAS reports), major funding agencies (NSF, DOE, and NASA), and potential new partners.

2002-3: Study for SDSS-II

The Sloan Digital Sky Survey and Supernovae Ia

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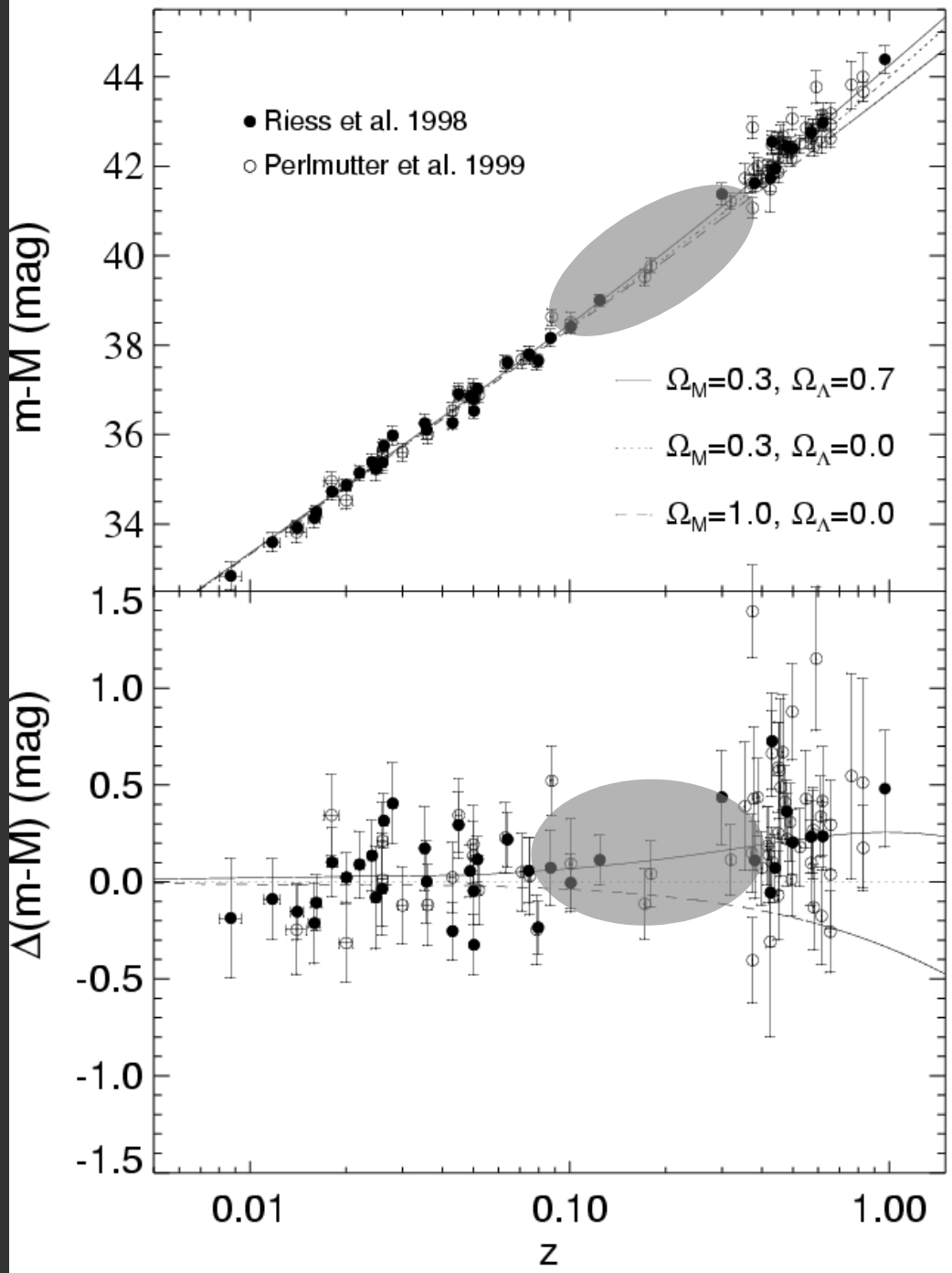
The Sloan Digital Sky Survey (SDSS) will produce a 3D map of the universe of galaxies over a volume $\sim 4 \times 10^7\ h^{-3}\ \mathrm{Mpc}^3$. Covering π sr centered on the north galactic cap, the SDSS will comprise a photometric (CCD) imaging survey of 10^8 objects in 5 wavebands, a magnitude-limited spectroscopic (redshift) survey of 10^6 galaxies and 10^5 quasars, and a nearly volume-limited redshift survey of 10^5 bright red galaxies. The less-well-known southern SDSS will include repeated imaging of a $\sim$ 225 sq. deg. region (to limiting magnitude $r' \sim 23$ per exposure) and should be useful for study of variable objects, including supernovae. This talk provides a brief overview of the SDSS and of its possible contributions to the study of Type Ia supernovae.

The Sloan Digital Sky Survey (SDSS) (York, etal. 1997) is a wide-area photometric and spectroscopic survey of the sky being carried out with a dedicated 2.5m telescope at Apache Point Observatory in southern New Mexico. While designed primarily to study galaxies, quasars, and their clustering properties in detail, the SDSS should prove a valuable tool for investigating a variety of variable phenomena in the sky, including supernovae. This short review provides an introduction to and status report on the SDSS, followed by some thoughts on detecting Type Ia SNe in the course of the survey.

1999

Cosmic Acceleration Discovery from High-redshift SNe Ia

SNe at z~0.5 are ~0.25 mag fainter than in an open Universe with same value of $_m$



= 0.7

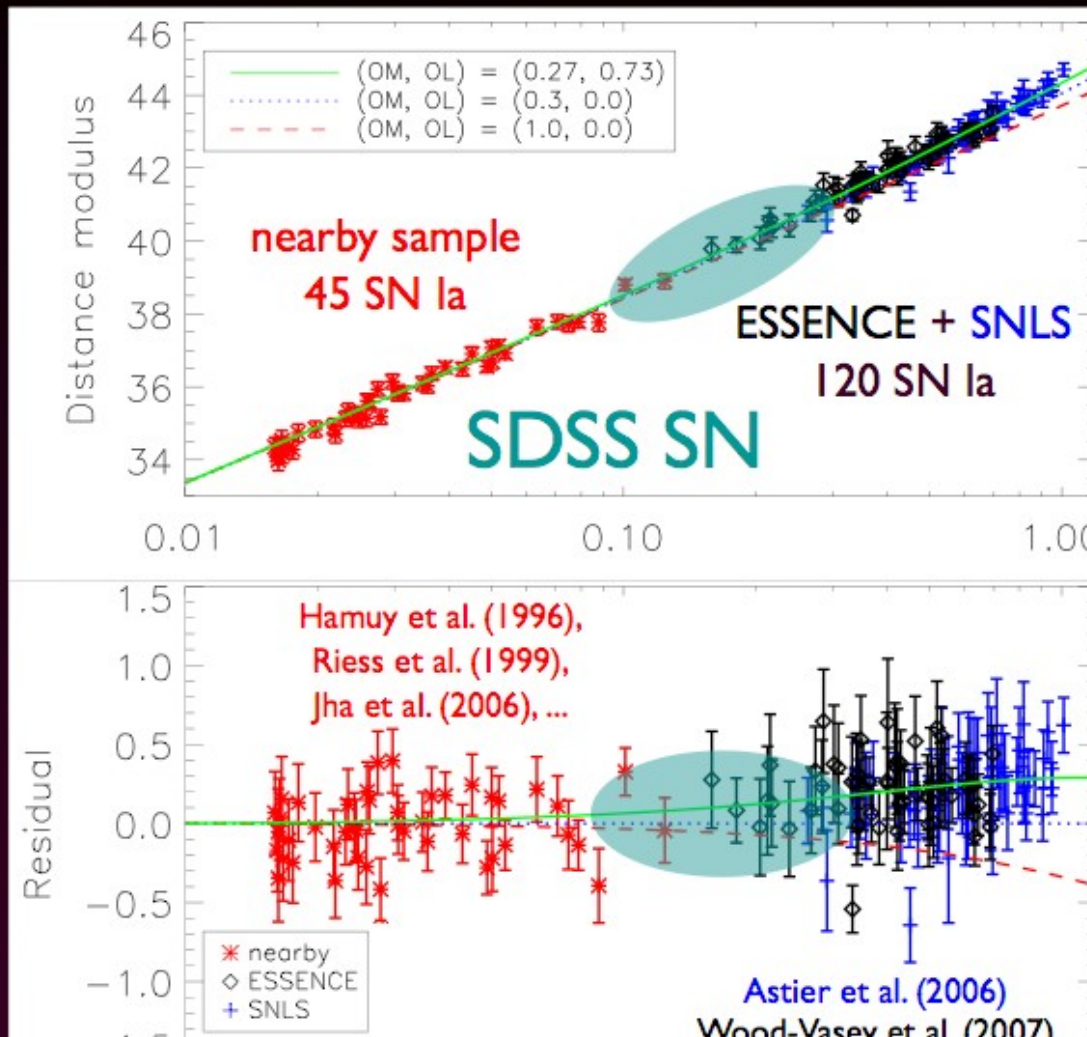
= 0.

$_m$ = 1.

SN Ia Hubble Diagram

- goal of the SDSS SN survey: fill in SN Ia Hubble diagram at redshifts $0.1 \lesssim z \lesssim 0.3$
  - connect low-z with high-z
  - test the concordance cosmology
- challenges
  - peak magnitude $m \simeq 20\text{-}22$
  - must search hundreds of square degrees of sky

→ SDSS 2.5m telescope + imager



http://sdssdp47.fnal.gov/sdsssn/sdsssn.html

Jha

SDSS II Supernova Survey Goals

- Obtain few hundred *high-quality* SNe Ia light curves in the `redshift desert' z~0.05-0.35 for continuous Hubble diagram
- Detailed spectroscopic follow-up, including some with multiple epochs, to study evolution and diversity of SN features
- Probe Dark Energy in *z* regime complementary to other surveys
- Well-observed sample to anchor Hubble diagram & train light-curve fitters
- Rolling search: determine SN/SF rates/properties vs. *z*, environment
- Rest-frame *u*-band templates for z >1 surveys
- Large survey volume: rare & peculiar SNe, probe outliers of population
- Enable time-domain science both in real time* & after the fact**

*candidates immediately on the web+IAU circulars+VOEventNet

**SN images & object catalogs all available publicly

SDSS-II SN Survey Team

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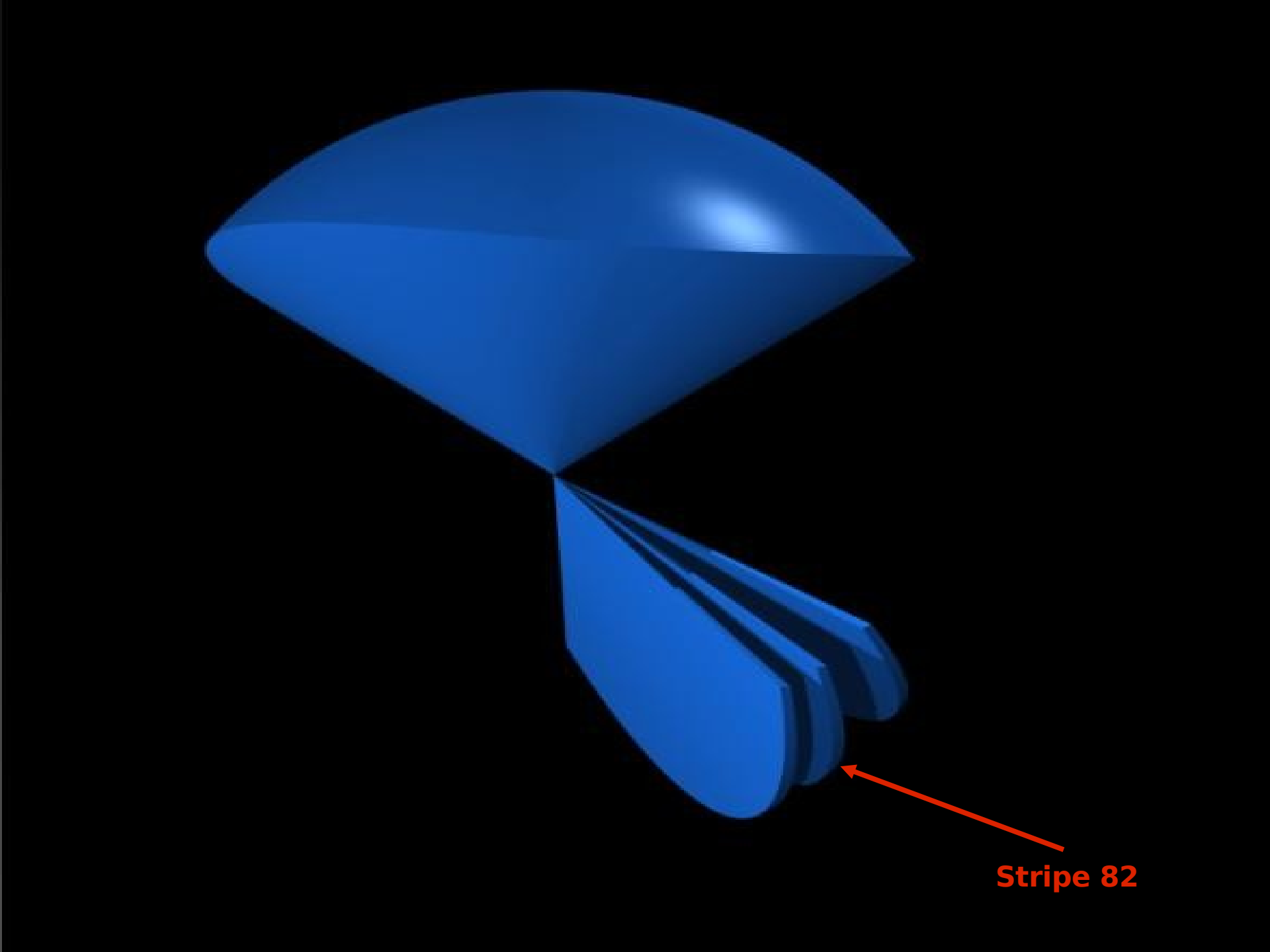
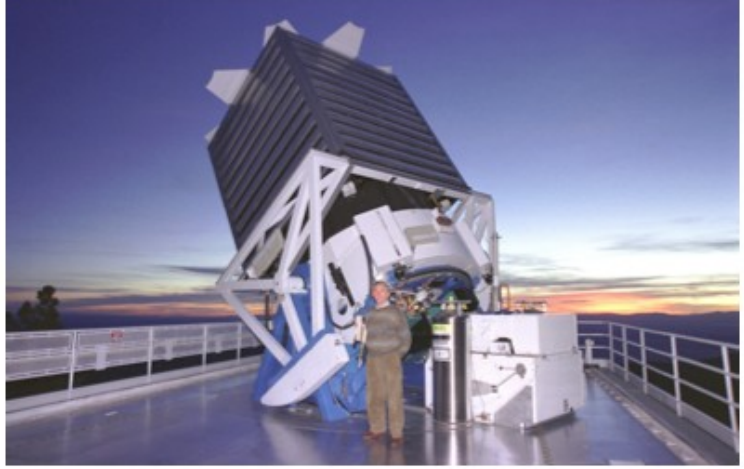
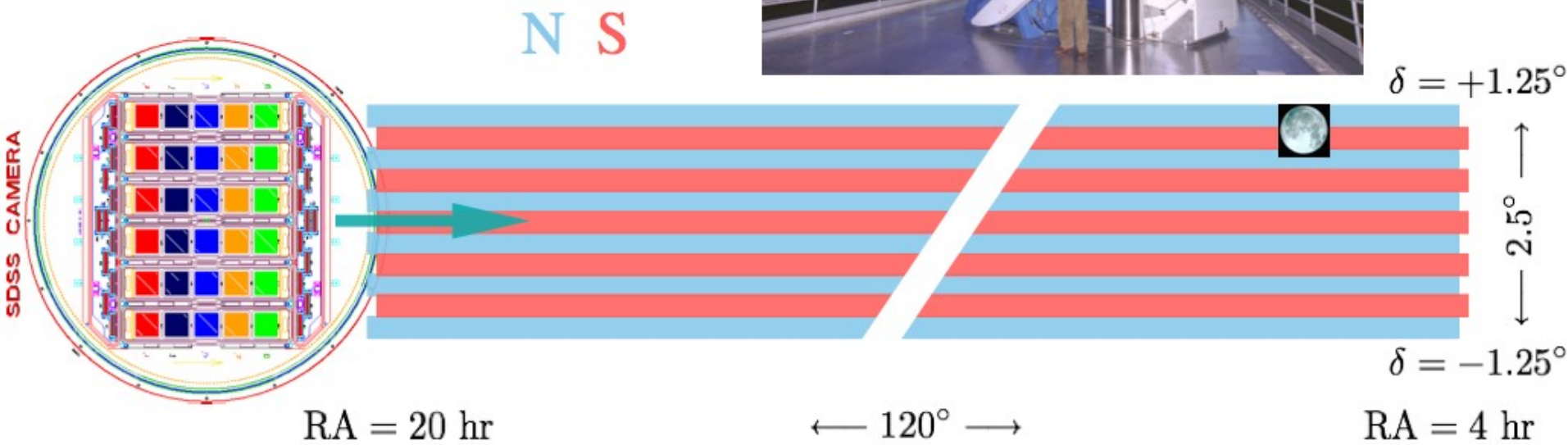
Subaru team	Y. Ihara
KPNO team	M. Florack, A. Hirschauer, D. O'Connor
Keck team	R. Foley, A. Filippenko

Spectroscopic follow-up telescopes


Stripe 82

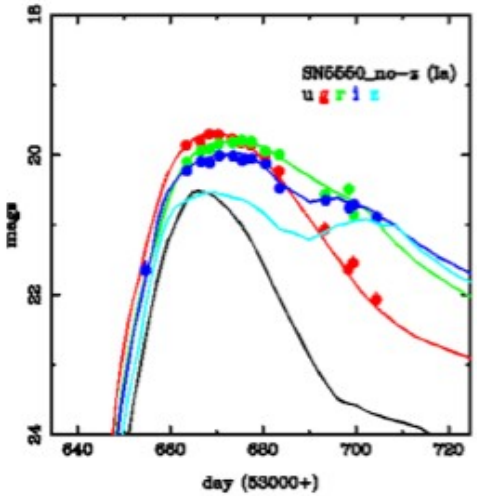
SDSS-II SN Survey





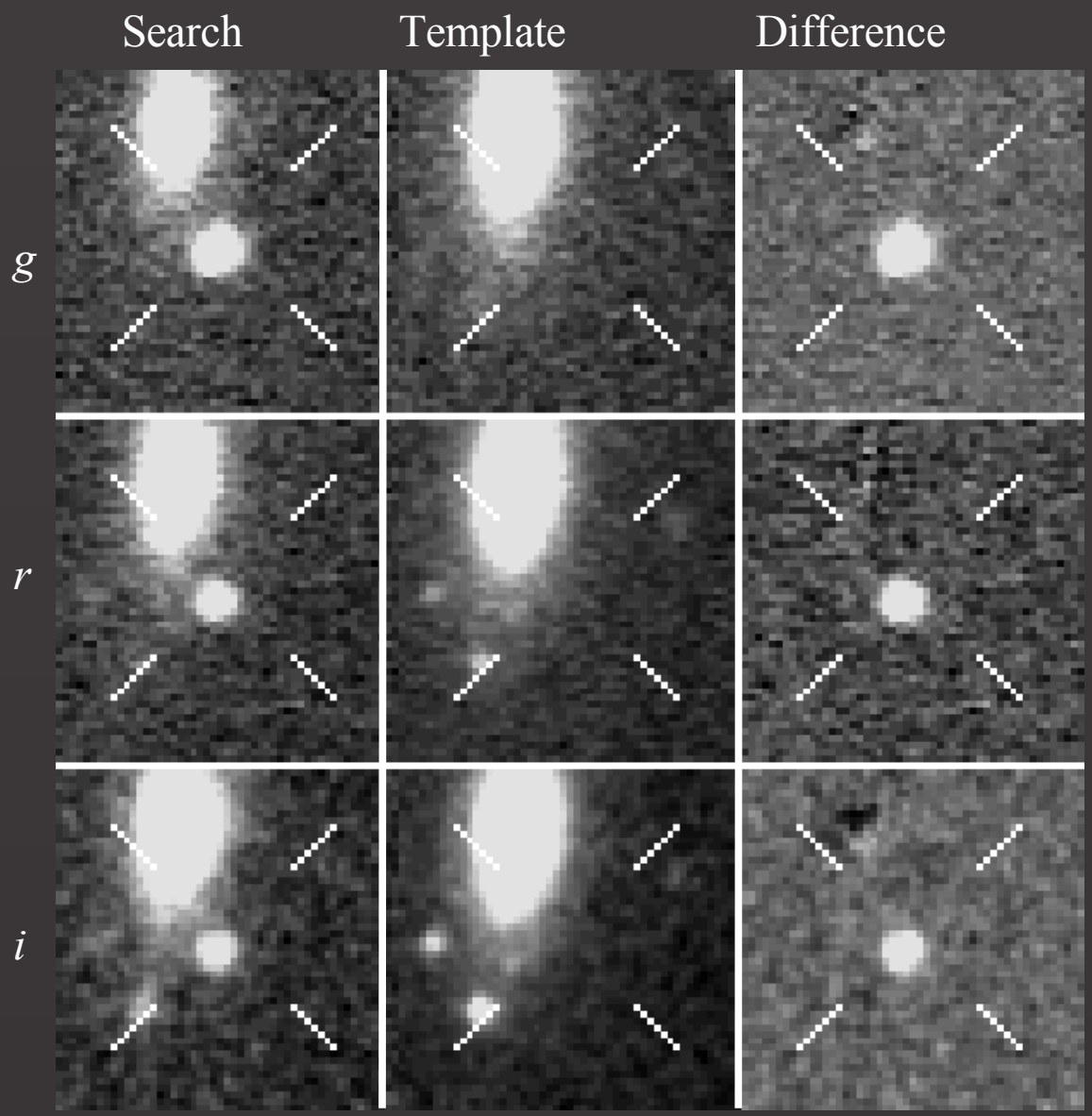
Use the SDSS 2.5m telescope

- September 1 - November 30 of 2005-2007
- Scan 300 square degrees every 2 days
- Obtain densely sampled multi-color light curves



Frieman, et al (2008); Sako, et al (2008)

Searching For Supernovae

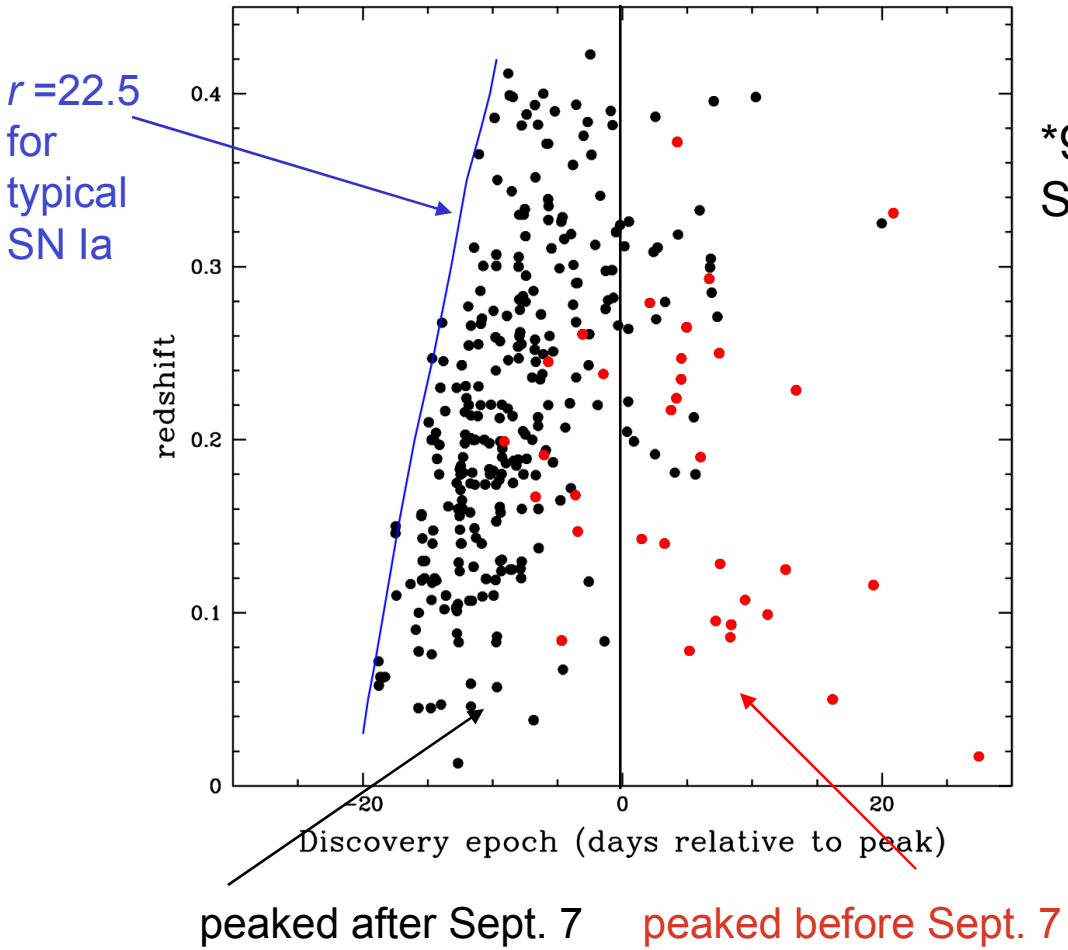


- 2005
  -
  -
  -

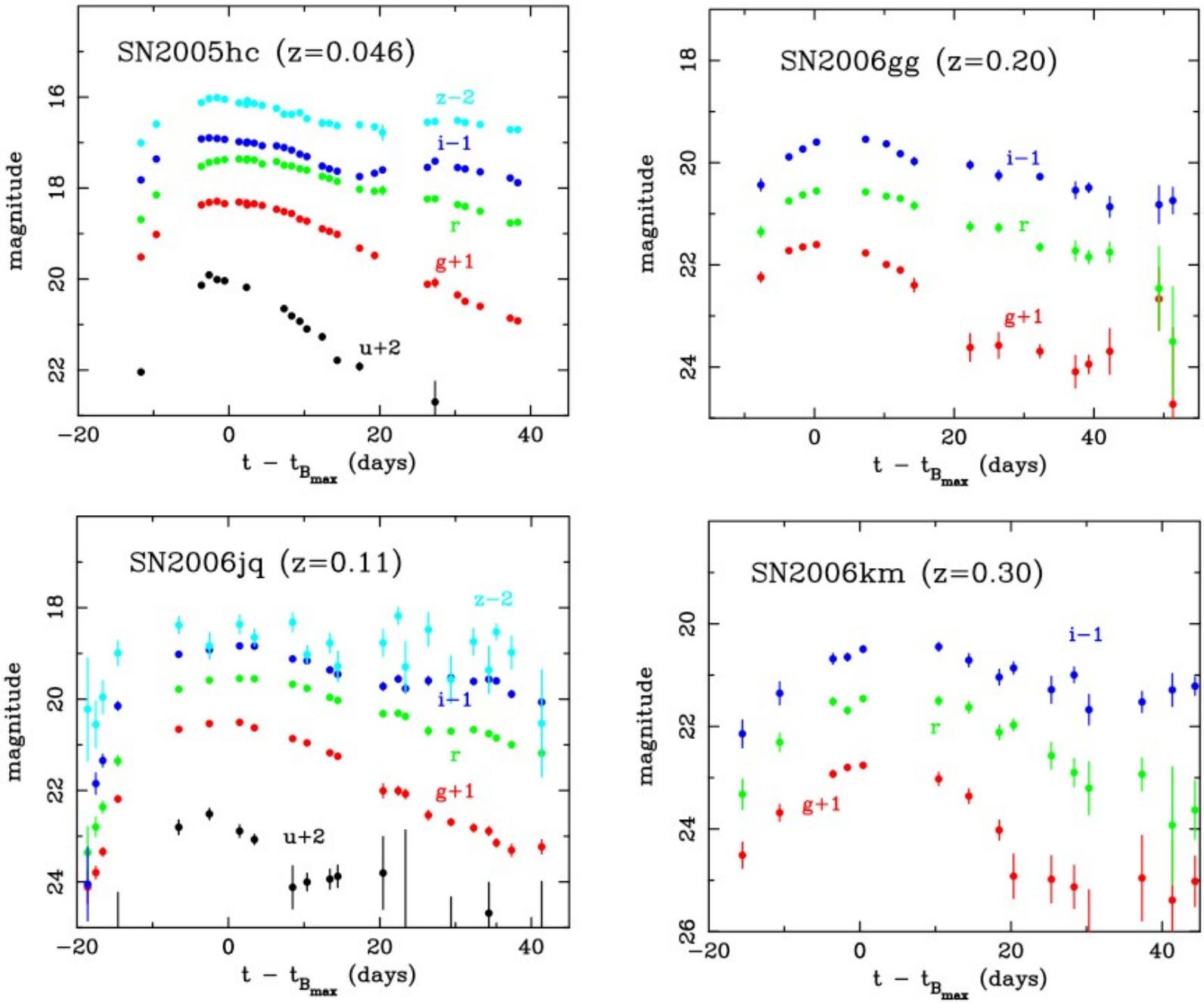
- 2006
  - 14,441 scanned
  - 3,694 candidates
  - 193 confirmed Ia
- 2007
  - 175 confirmed Ia

•Positional match to remove movers
•Insert fake SNe to monitor efficiency

Rolling survey leads to well-sampled*, well-constrained light curves



*9 epochs of imaging per SN (median)



SDSS SN Photometry: Holtzman et al. (2008) in press ``Scene modeling”

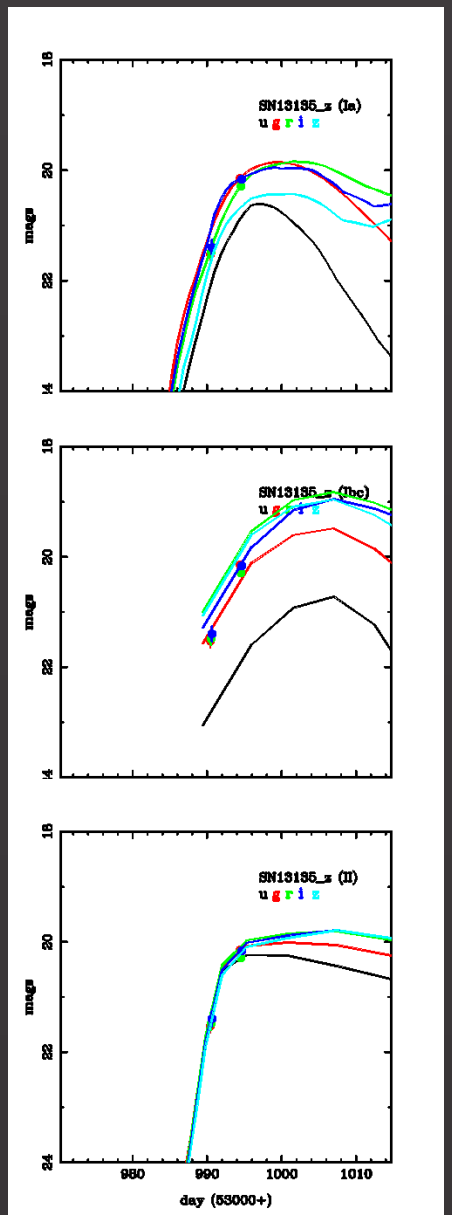
Spectroscopic Target Selection

2 Epochs

SN Ia Fit

SN Ibc Fit

SN II Fit



Sako etal 2008

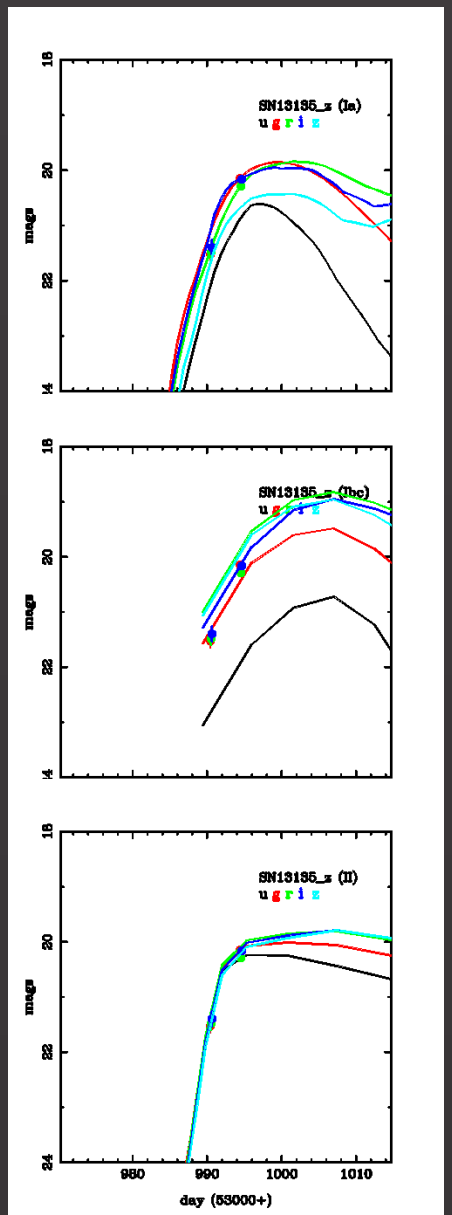
Spectroscopic Target Selection

2 Epochs

SN Ia Fit

SN Ibc Fit

SN II Fit

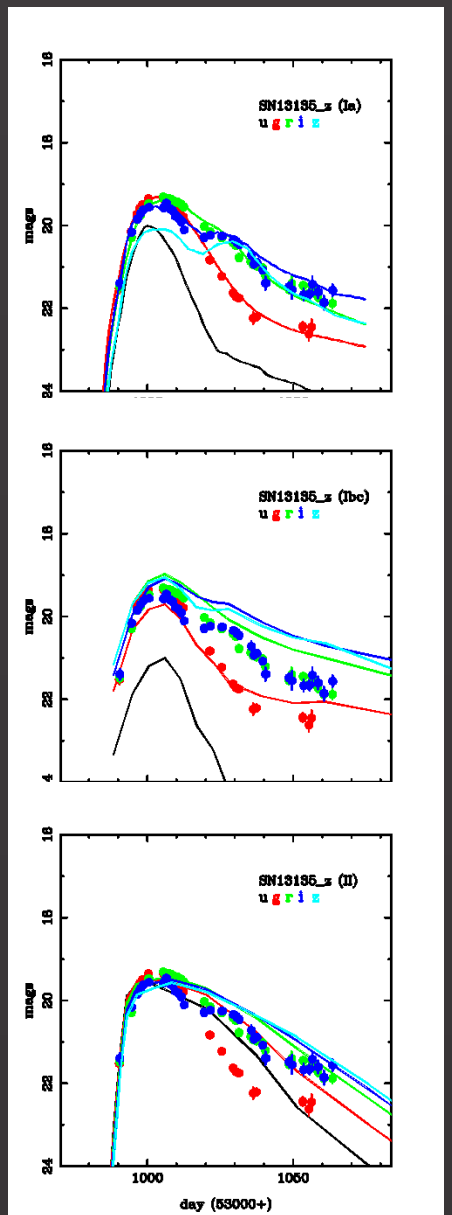


31 Epochs

SN Ia Fit

SN Ibc Fit

SN II Fit



Fit with template library

Classification >90% accurate after 2-3 epochs

Redshifts 5-10% accurate

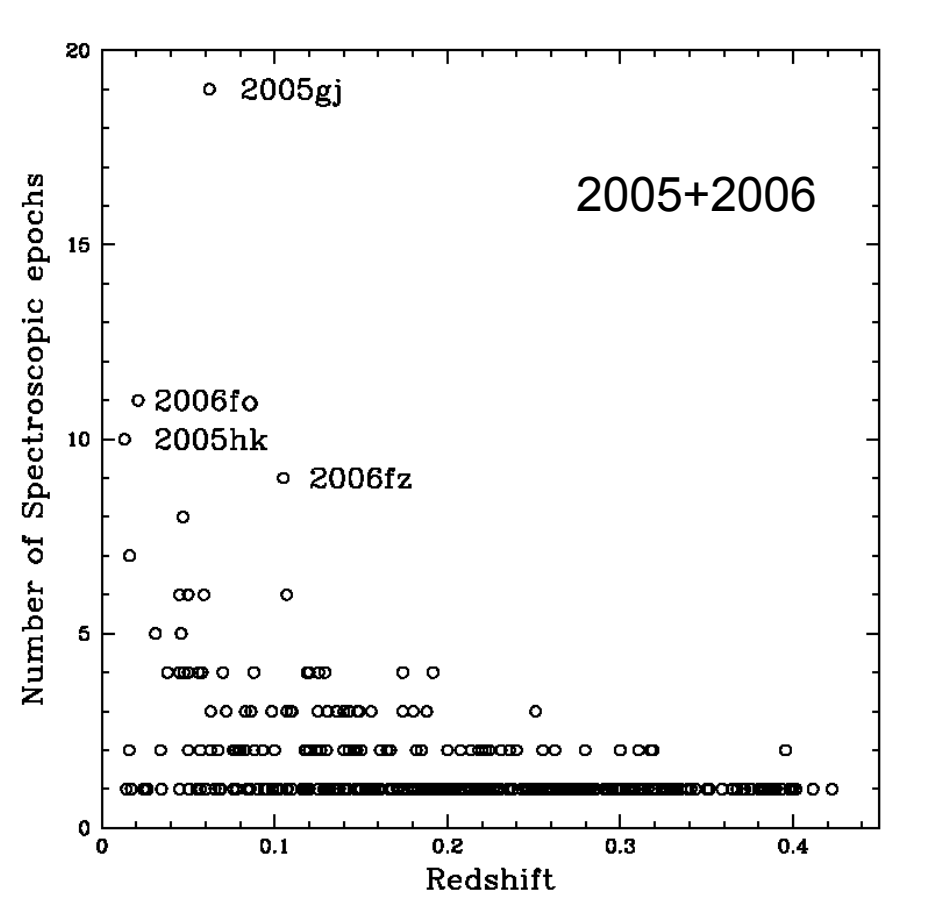
Sako etal 2008

SN and Host Spectroscopy

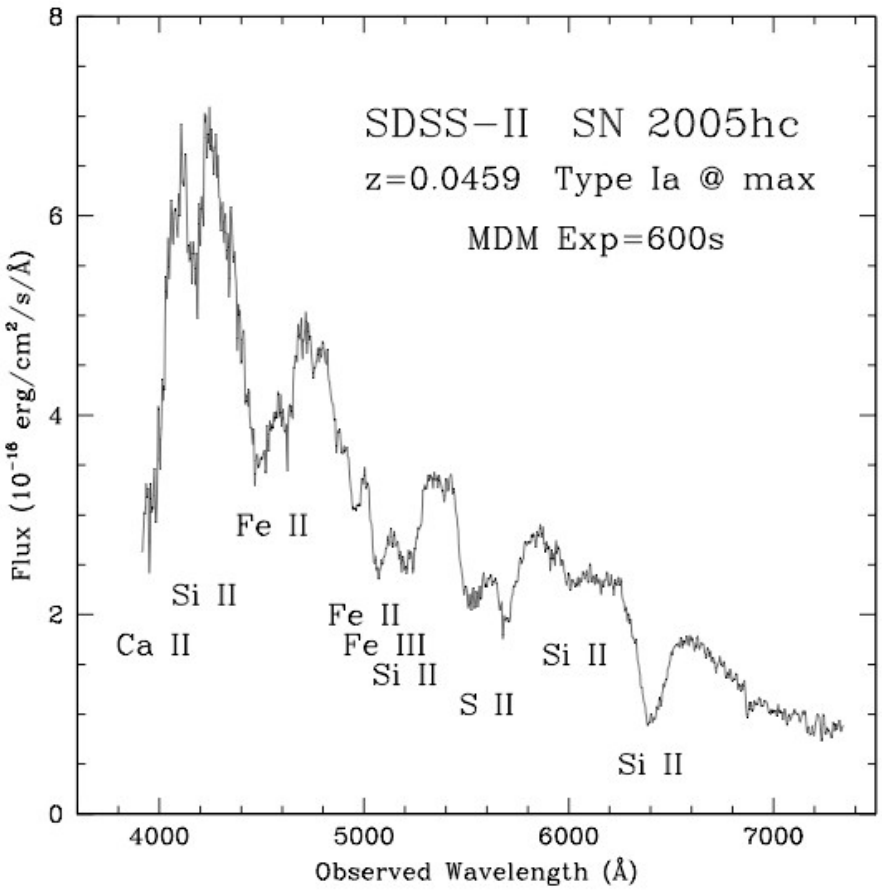


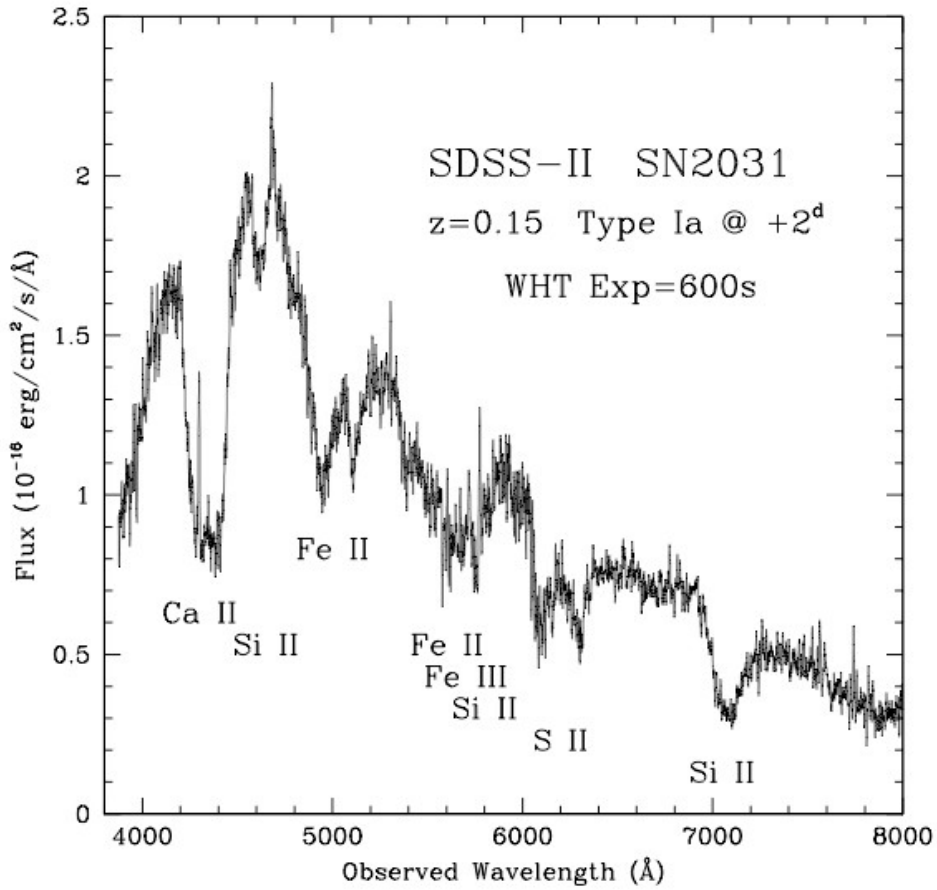


MDM 2.4m
NOT 2.6m
APO 3.5m
NTT 3.6m
KPNO 4m
WHT 4.2m
Subaru 8.2m
HET 9.2m
Keck 10m
Magellan 6m
TNG 3.5m
SALT 10m



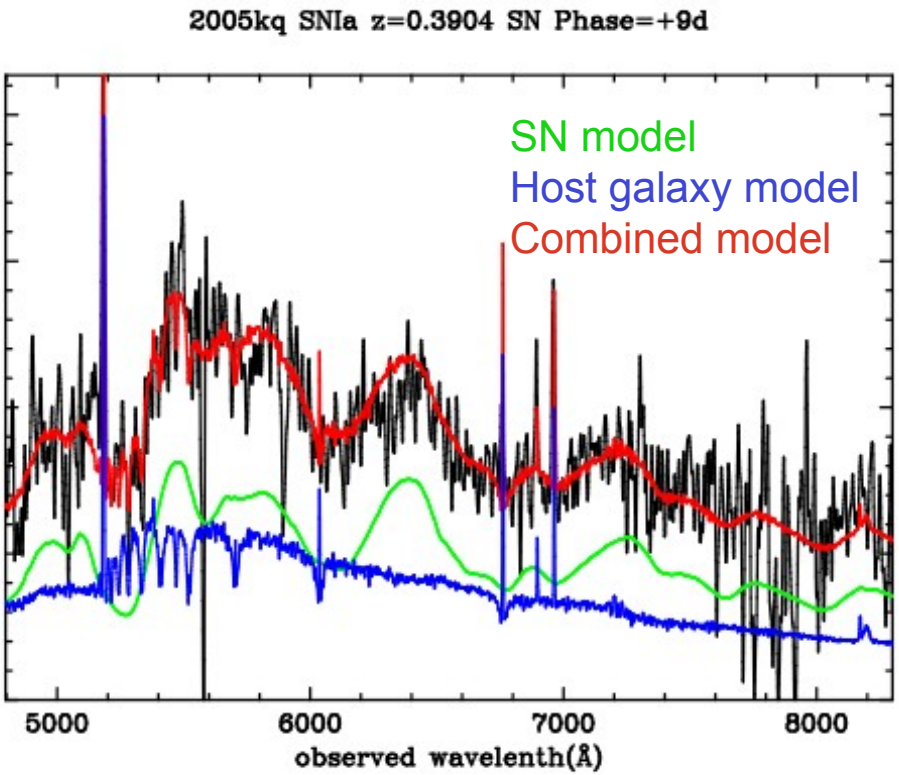
SN Ia Spectra

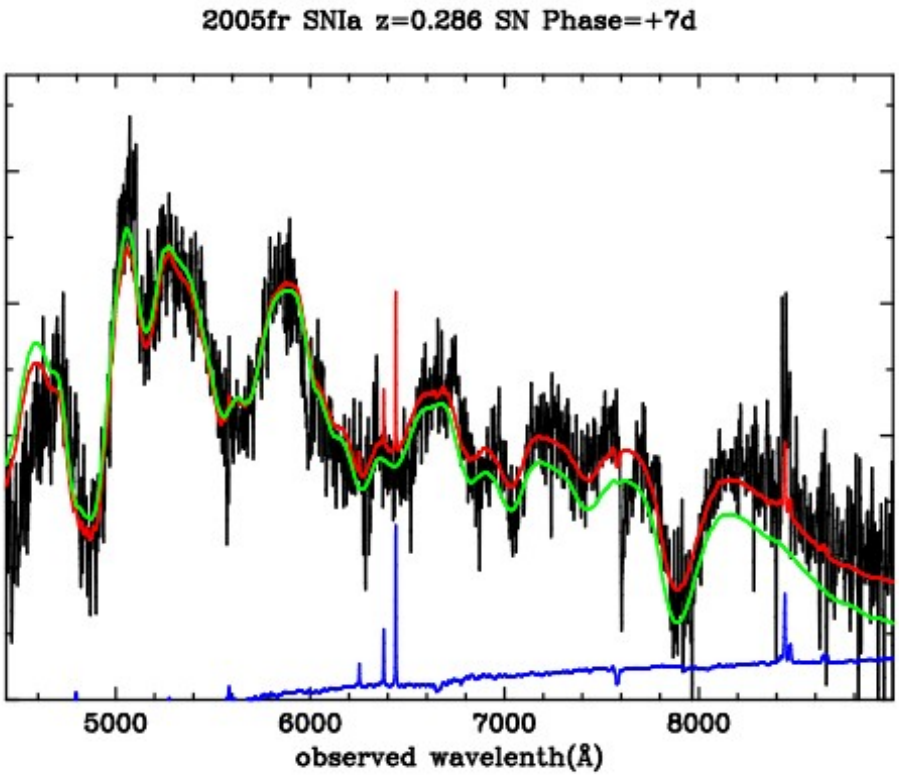




1325 spectra taken over 3 seasons

Spectroscopic Deconstruction



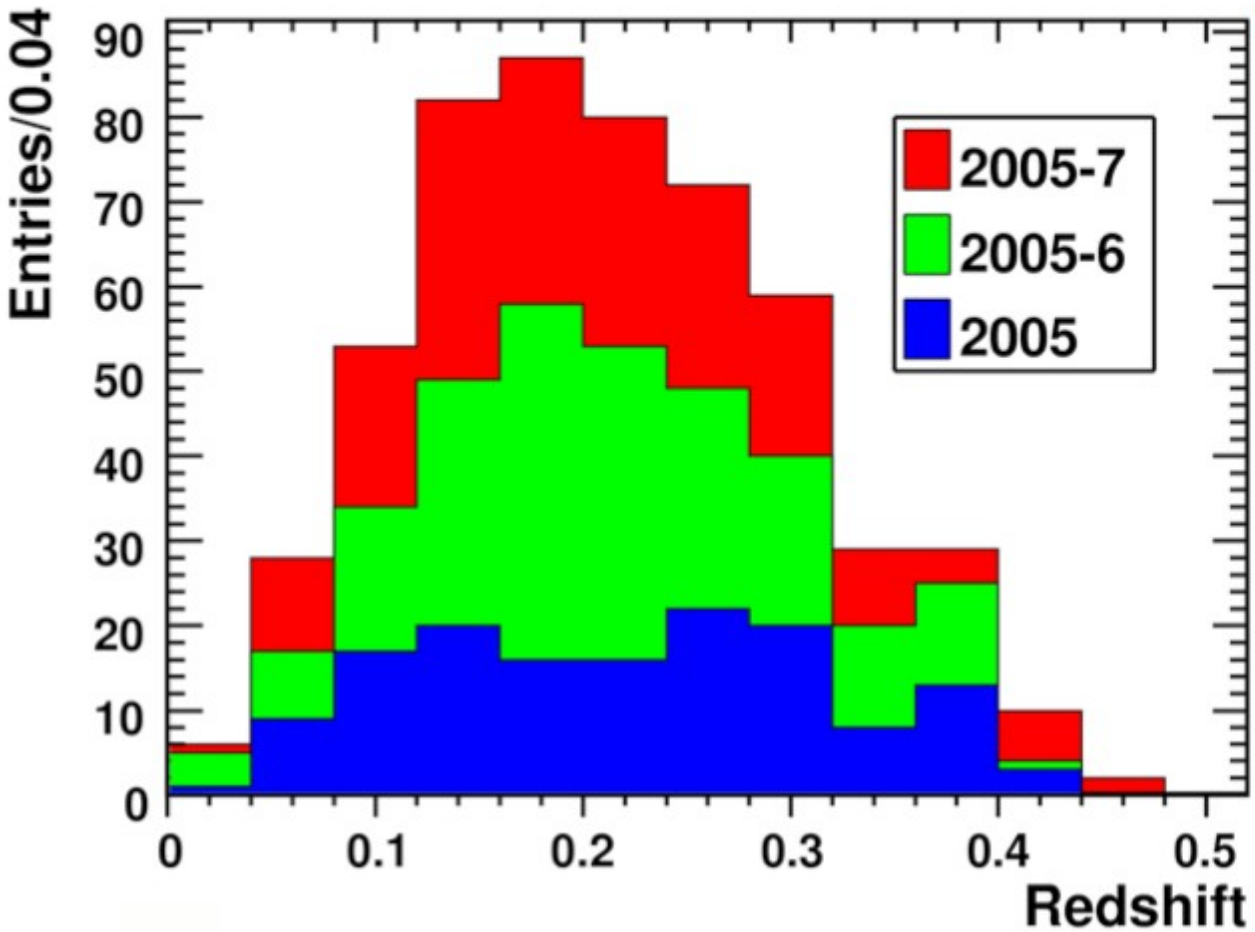


Zheng, et al (2008)

B. Dilday

484 confirmed SNe Ia with IAU designations

~500 spectroscopically confirmed SNe Ia



~50 spectroscopically probable SNe Ia

~20 SNe Ib/c

~60 SNe II

~200 photometric SNe Ia with host galaxy redshifts and counting

SDSS-II SN Science

"Peculiar SNe: 2005hk (Phillips et al 2007); 2005gj (Prieto et al 2007)

"SN Ia rate at low redshift (Dilday et al 2008)

"SN Ia rate vs. redshift; SN Ia rate in clusters (Dilday)

"SN Ia rate and properties vs. host-galaxy properties (Smith)

"UV evolution of SNe Ia (Foley)

"Hubble Diagram and Cosmology from 2005 season (Kessler, Becker, VanderPlas, Cinabro,&)

"BAO vs. SN distance scales (Lampeitl, Seo)

"Testing Exotic cosmologies (Sollerman, Davis)

"SN spectroscopic studies (Zheng; Konishi; Ostman, Nordin, Stanishev)

"SN Ia Rise and Fall time distributions (Hayden, Garnavich)

"Late-time properties of 2005hk (Jha)

"Light-curve studies with multi-band stretch method (Takanashi)

"Luminosity functions of SNe Ia and their hosts (Yasuda)

"Core-collapse SN Rate (Taylor)

"Cross-calibration of SDSS and CSP (Mosher)

"NIR SN observations (Goobar)

"Study of SN colors (Paech)

"Follow-up studies of SN host galaxies (Sako, Garnavich, Nichol, Marriner&)

"Type II, IIn, IIp studies (Tokita; Ihara; D Andrea)

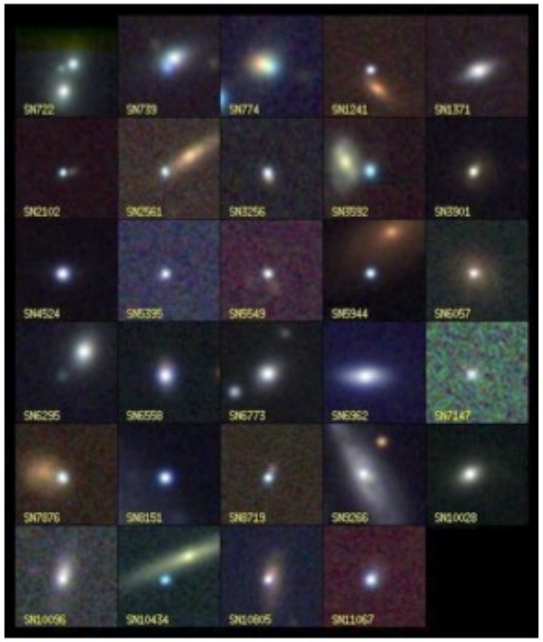
"SN Cosmology with photo-z s (Bassett)

Low-redshift ($z<0.12$) SN Ia Rate (2005 data)

29 confirmed SNe Ia before cuts

- 1 outside range of calibration star catalog
- 3 are peculiar (including 2005hk and 2005gj)
- 4 SNe have no observations at $t < -2$ days
- 5 SNe have no observations at $t > 10$ days

16 confirmed SNe Ia after cuts



Dilday

Low-redshift ($z<0.12$*) SN Ia Rate (2005)

+1 photometric SN & extinction distribution

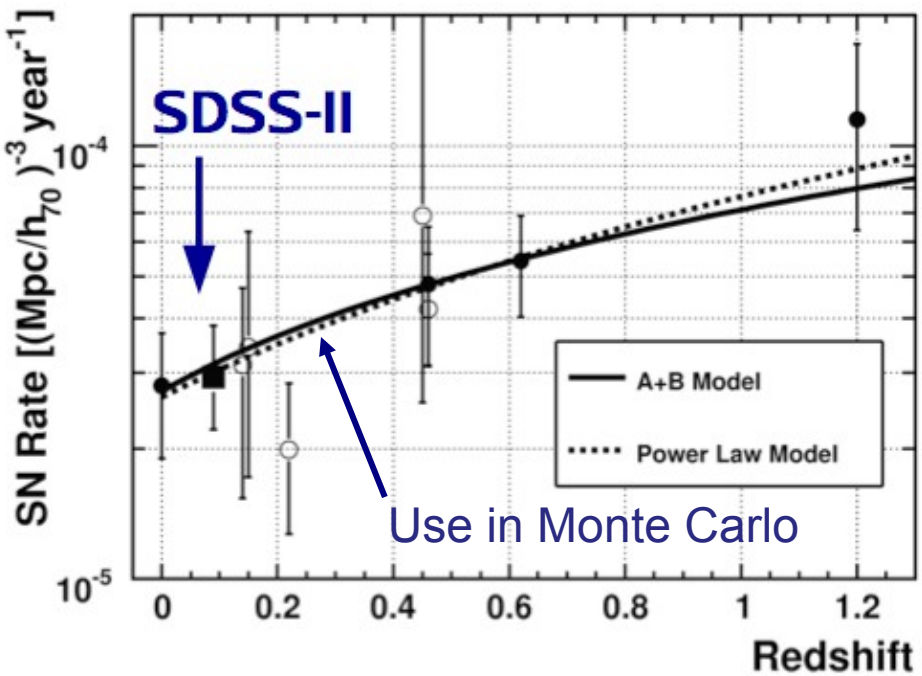
Statistical error

$$\text{Rate} = \left(2.9^{+0.2}_{-0.04} \pm 0.7\right) x\, 10^{-5} \ (\text{Mpc}/h_{70})^{-3}\ \text{year}^{-1}$$

Extinction distribution

Volumetric rate at mean z =0.09

Compilation of rate measurements



Dilday, et al

*spectroscopically complete

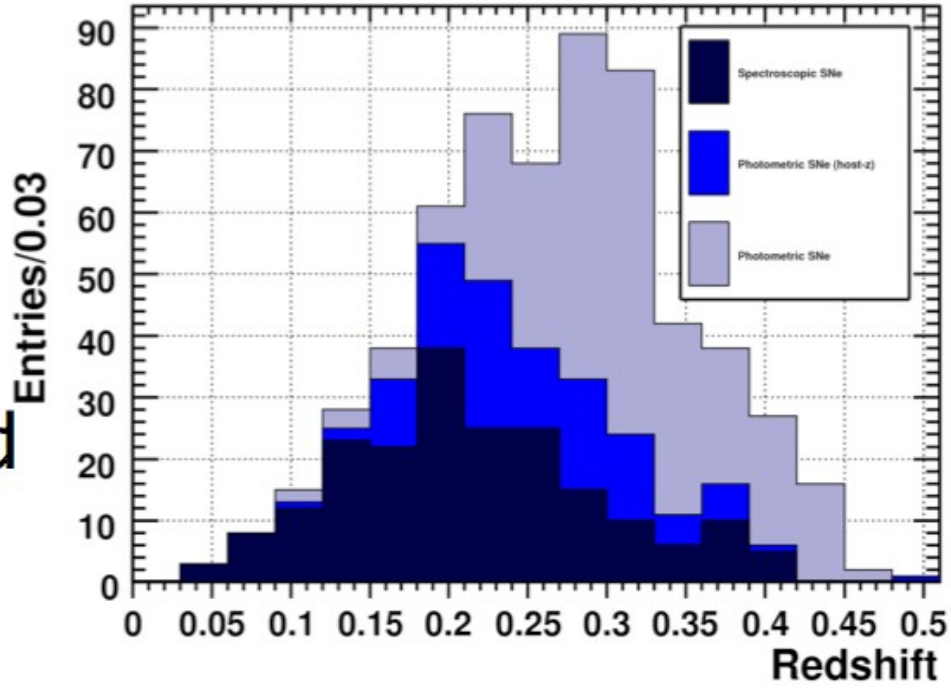
SN Ia Rate vs. Redshift (2005+6)

SN Selection

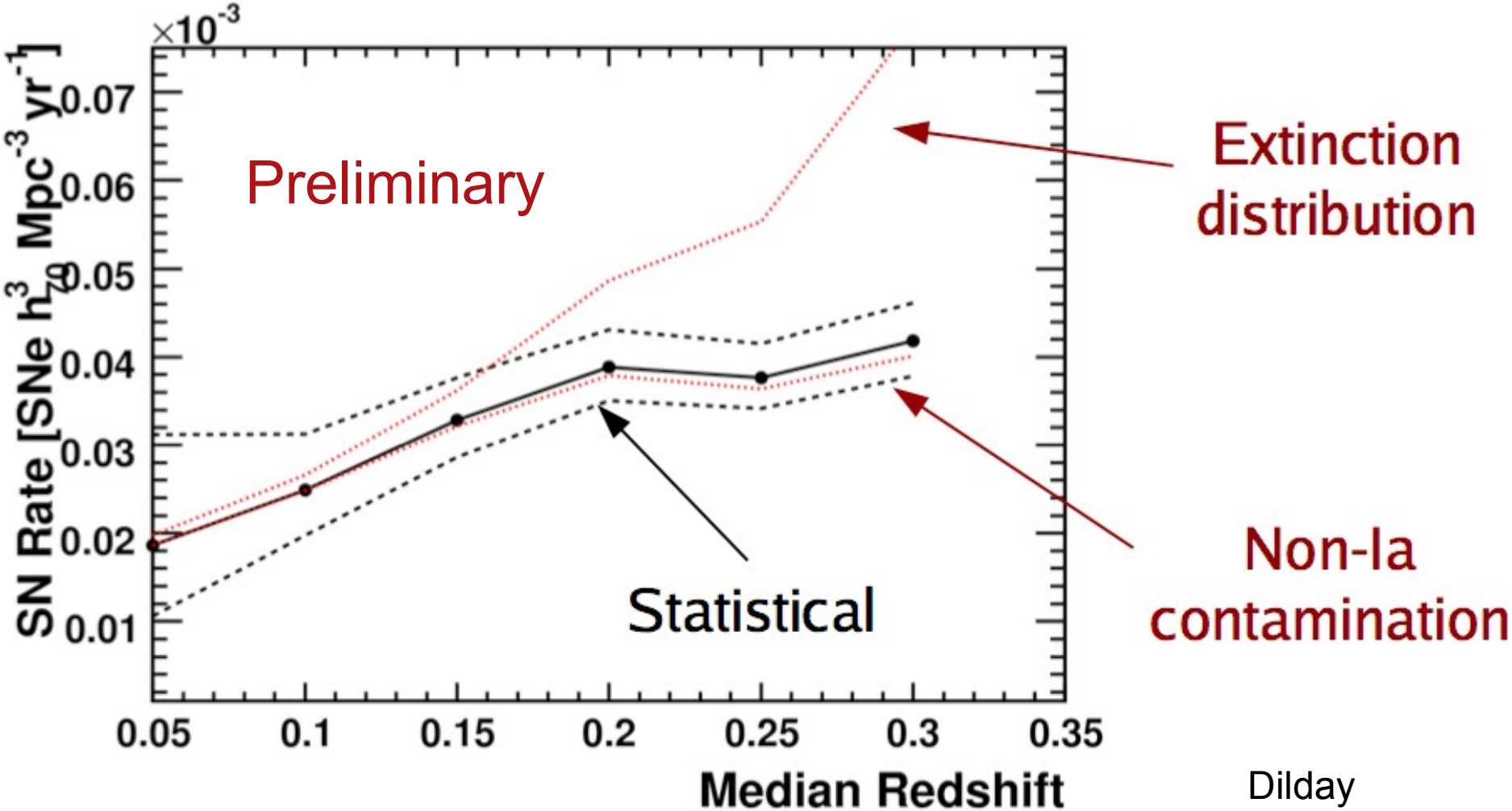
Z < 0.20
132 SNe
68% spec. confirmed
88% with redshifts

Z < 0.25
248 SNe
54% spec. confirmed
74% with redshifts

562 total SNe candidates with z < ~0.45



SN Ia Rate

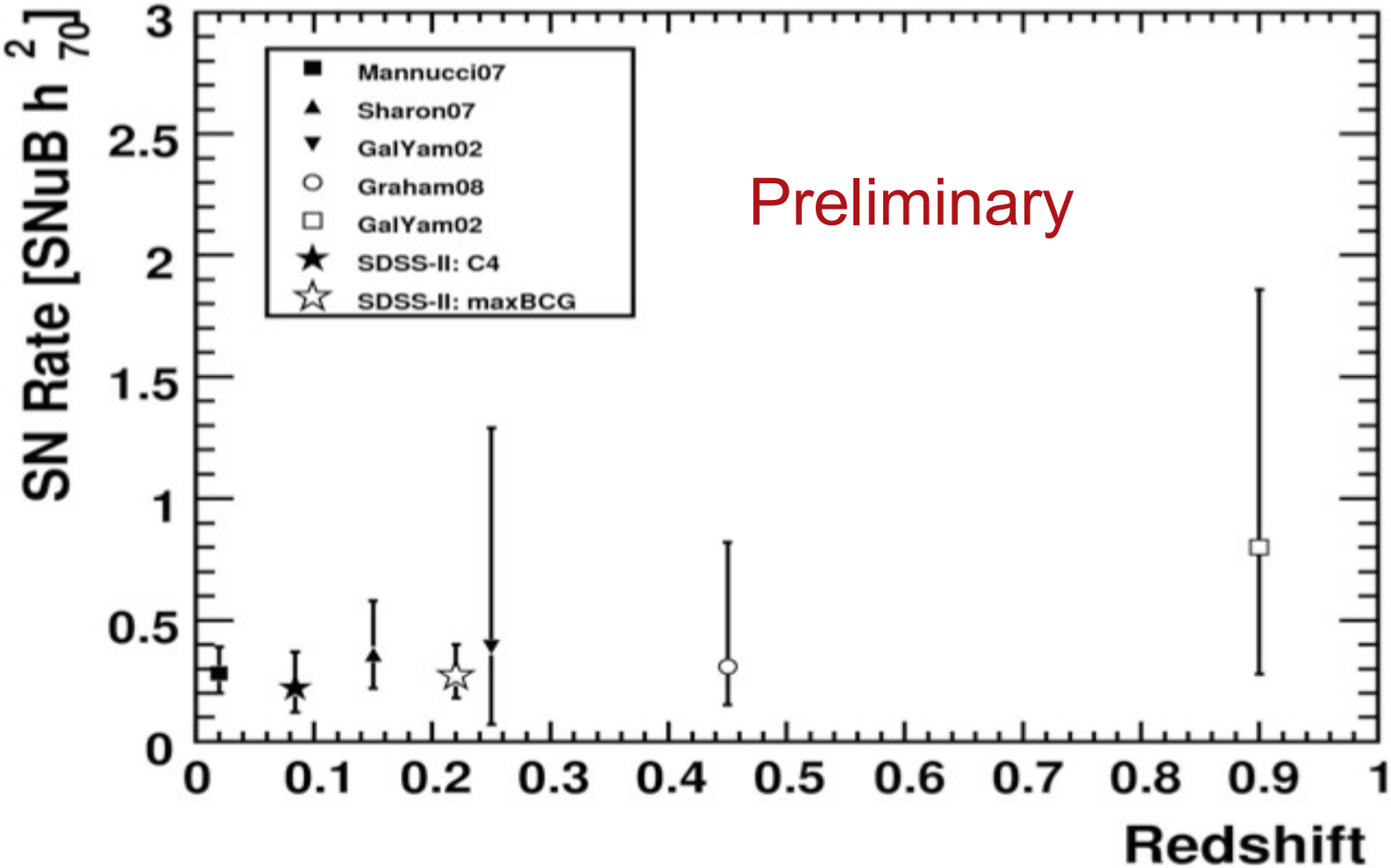


Dilday

Rate vs redshift slope for $0.1 < z < 0.2$:

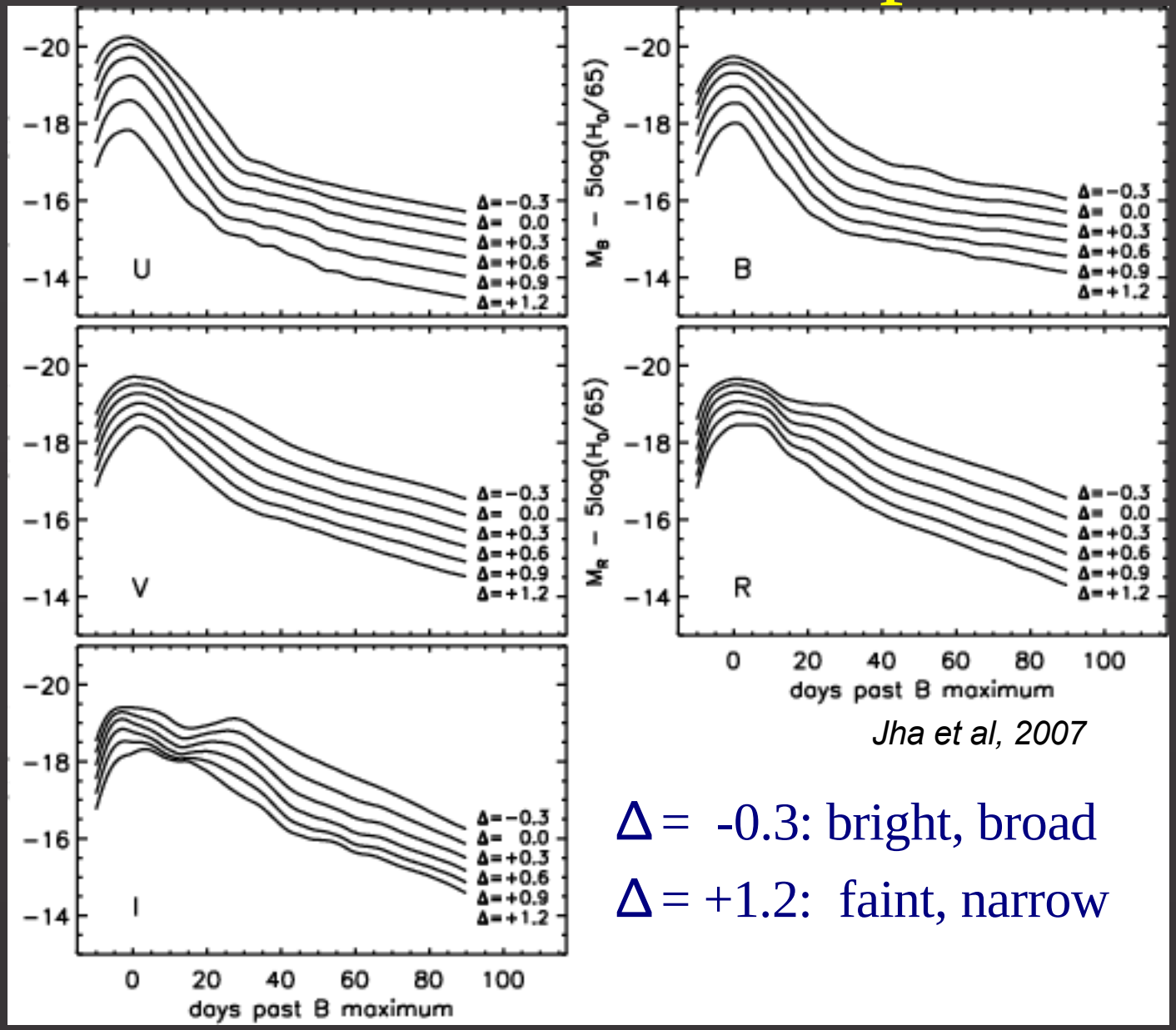
$dr/dz = (1.37 +- 0.69) \times 10^{-4}$ SNe yr^{-1} Mpc^{-3} h_{70}^{3}

SN Cluster Rate vs. Redshift



Consistent with a constant rate as a function of redshift

MLCS2k2 model templates

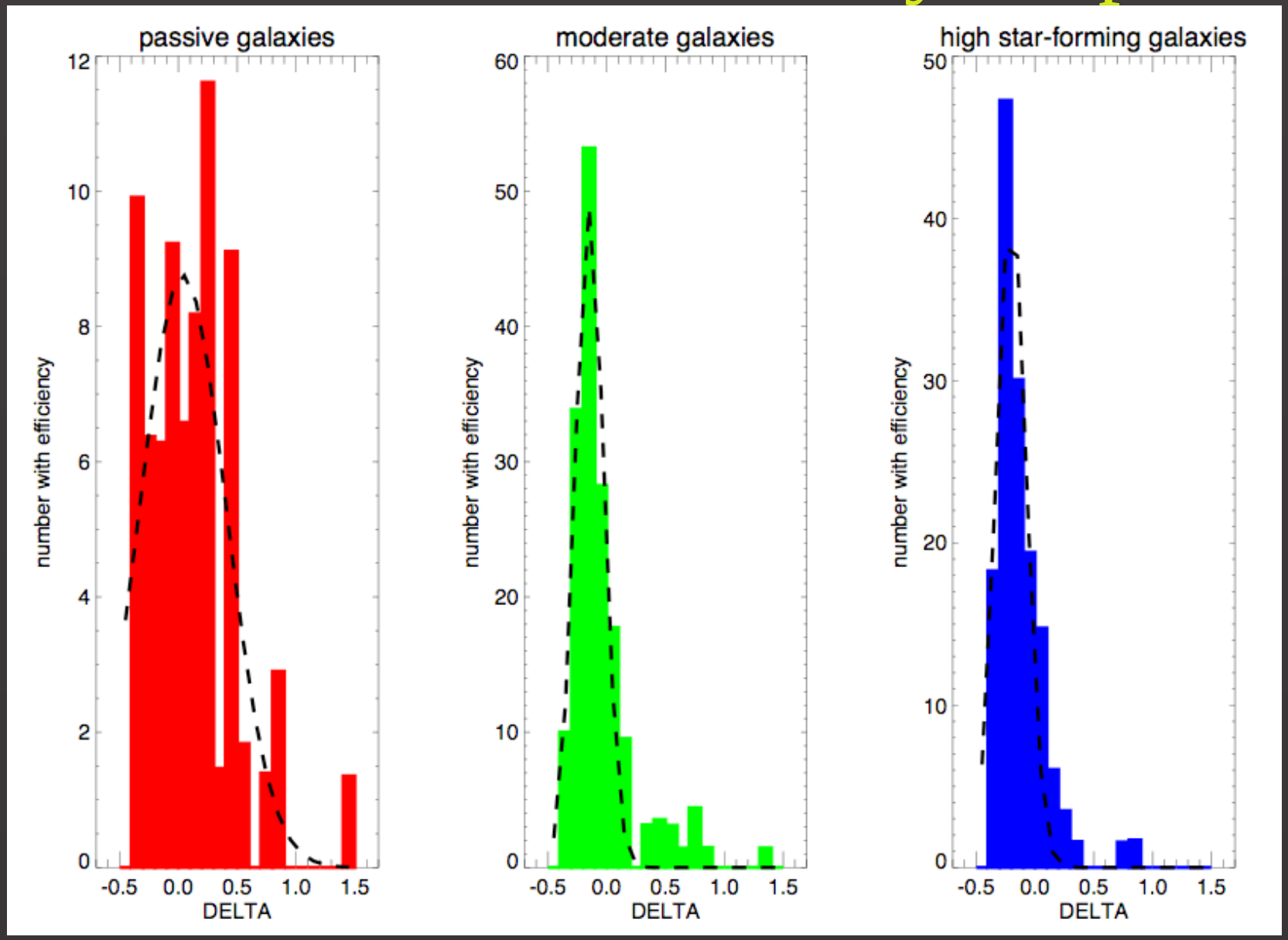


Jha et al, 2007

Δ = -0.3: bright, broad

Δ = +1.2: faint, narrow

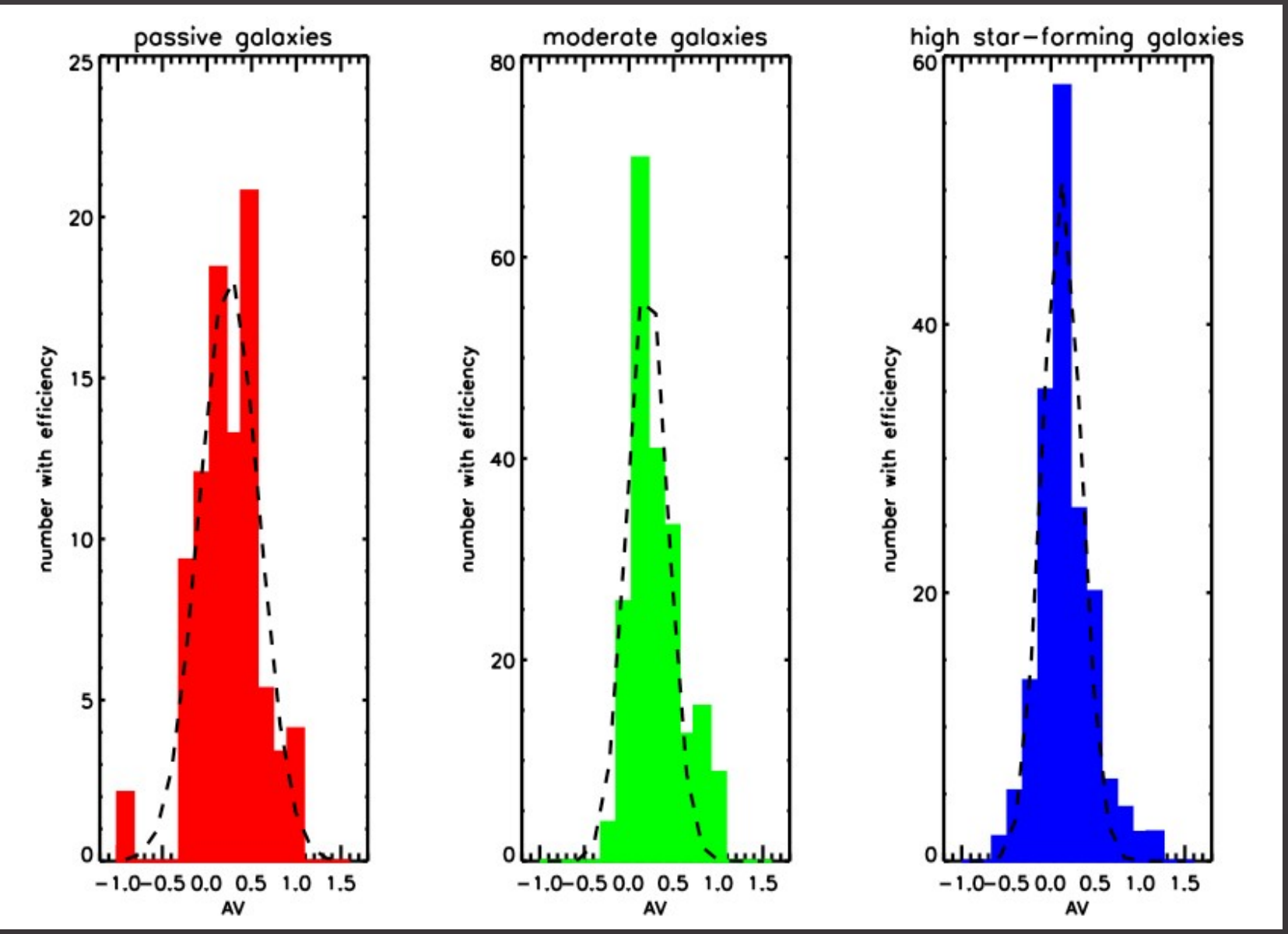
SN Ia vs. Host Galaxy Properties



Luminosity

Smith et al

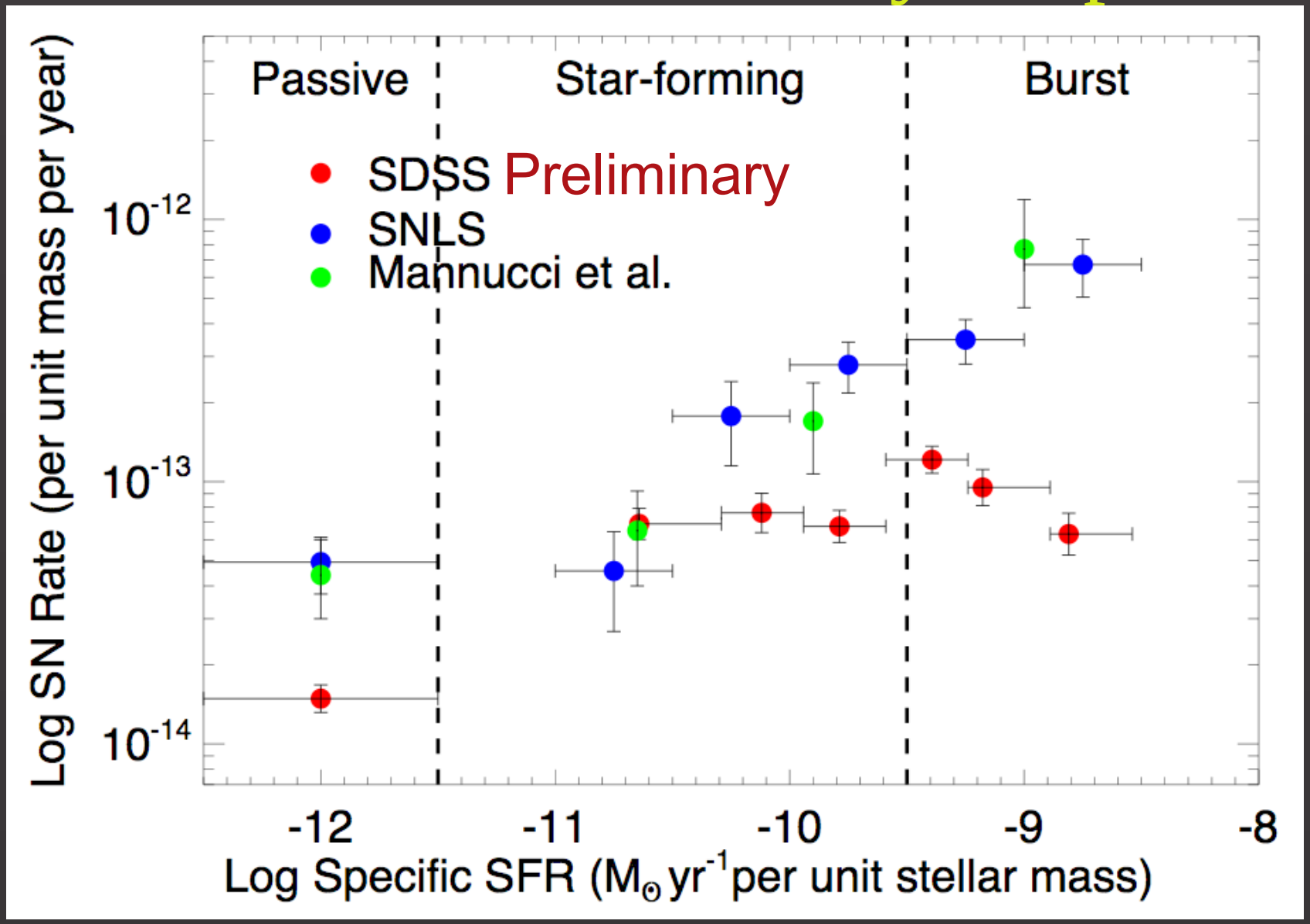
SN Ia vs. Host Galaxy Properties



Reddening/ color

Smith et al

SN Ia vs. Host Galaxy Properties



Smith et al

Fitting SN light curves: MLCS2k2

- Multicolor Light Curve Shape *(Riess et al '98; Jha et al '07)*
- Model SN light curves as a single parameter family, trained on low-z UBVRI data from the literature *(Hamuy et al '96, Riess et al '98, Jha et al '07)*
- Assumes SN color variations are due to dust extinction, subject to prior $P(A_v)$
- Rewritten to fit in flux, not magnitude

time-dependent model "vectors"

$$\vec{m}_X(t - t_0) = \vec{M}_X^0 + \mu_0 + \vec{\zeta}_X(\alpha_X + \beta_X/R_V)A_V^0 + \vec{P}_X\Delta + \vec{Q}_X\Delta^2,$$

fit parameters

Time of maximum | distance modulus | dust law | extinction | stretch/decline rate

Guy et al

SALT II Light-curve Fits

" Fit each light curve using rest-frame *spectral* surfaces*:

$$\frac{dF_{\rm rest}}{d\lambda}(t,\lambda) = x_0 \times [M_0(t,\lambda) + x_1 \times M_1(t,\lambda)] \times \exp[c \times CL(\lambda)]$$

light-curve shape

color term

" Transform to observer frame:

$$F^f_{\rm obs}(t) = \frac{1}{1+z}\int d\lambda' \left[\frac{dF_{\rm rest}}{d\lambda'}(t,\lambda') \times T^f(\lambda'\cdot(1+z))\right]$$

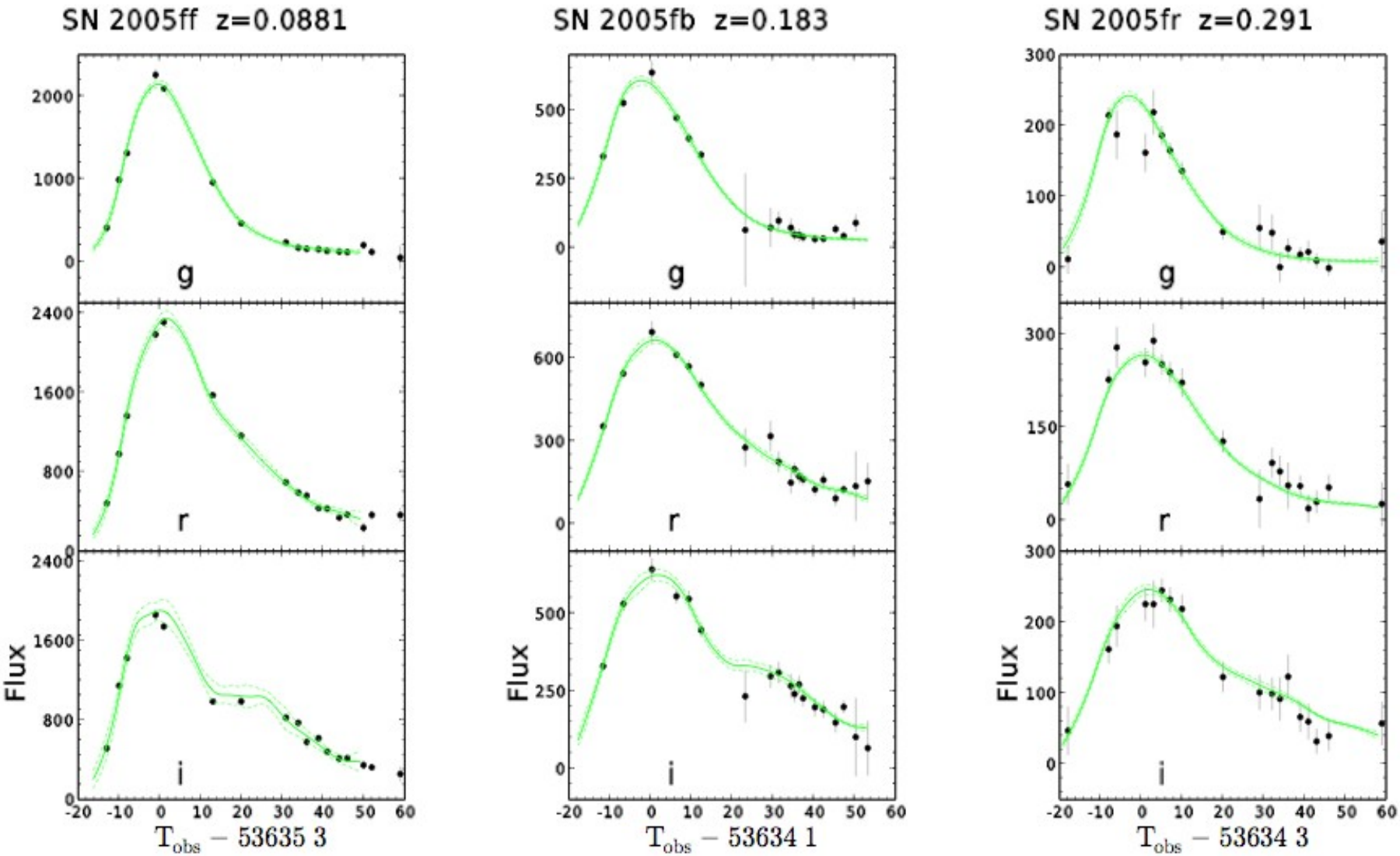
" Light curves fit individually, but distances only estimated globally:

$$\mu_i = m^*_{Bi} - M + \alpha \cdot x_{1,i} - \beta \cdot c_i$$

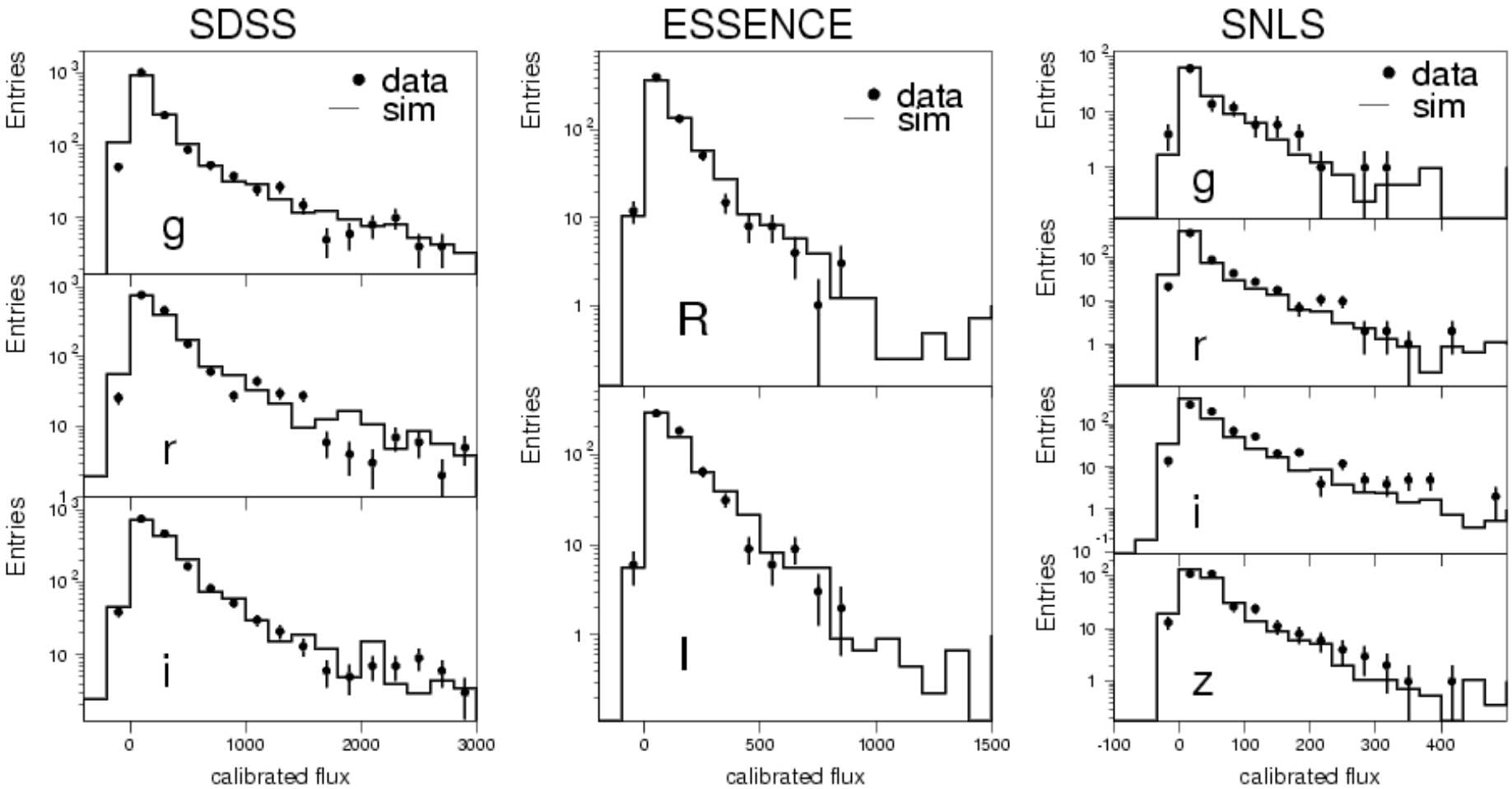
Global fit parameters, determined along with cosmological parameters

" *Not trained just on low-redshift data; distances are cosmology-dependent, flat priors on model parameters

Light Curve Fitting with MLCS2k2 and SALT-II

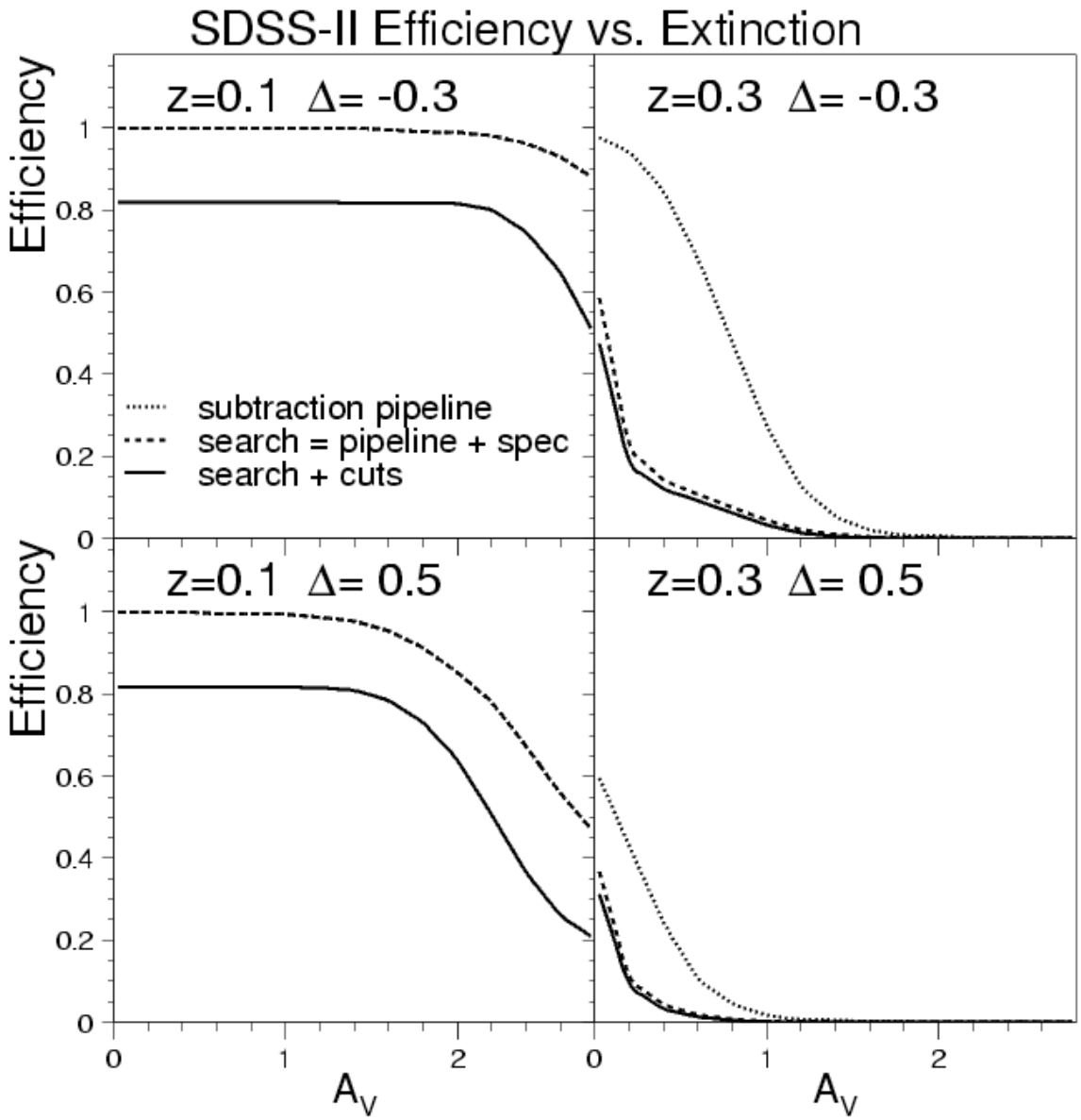


Monte Carlo Simulations match data distributions

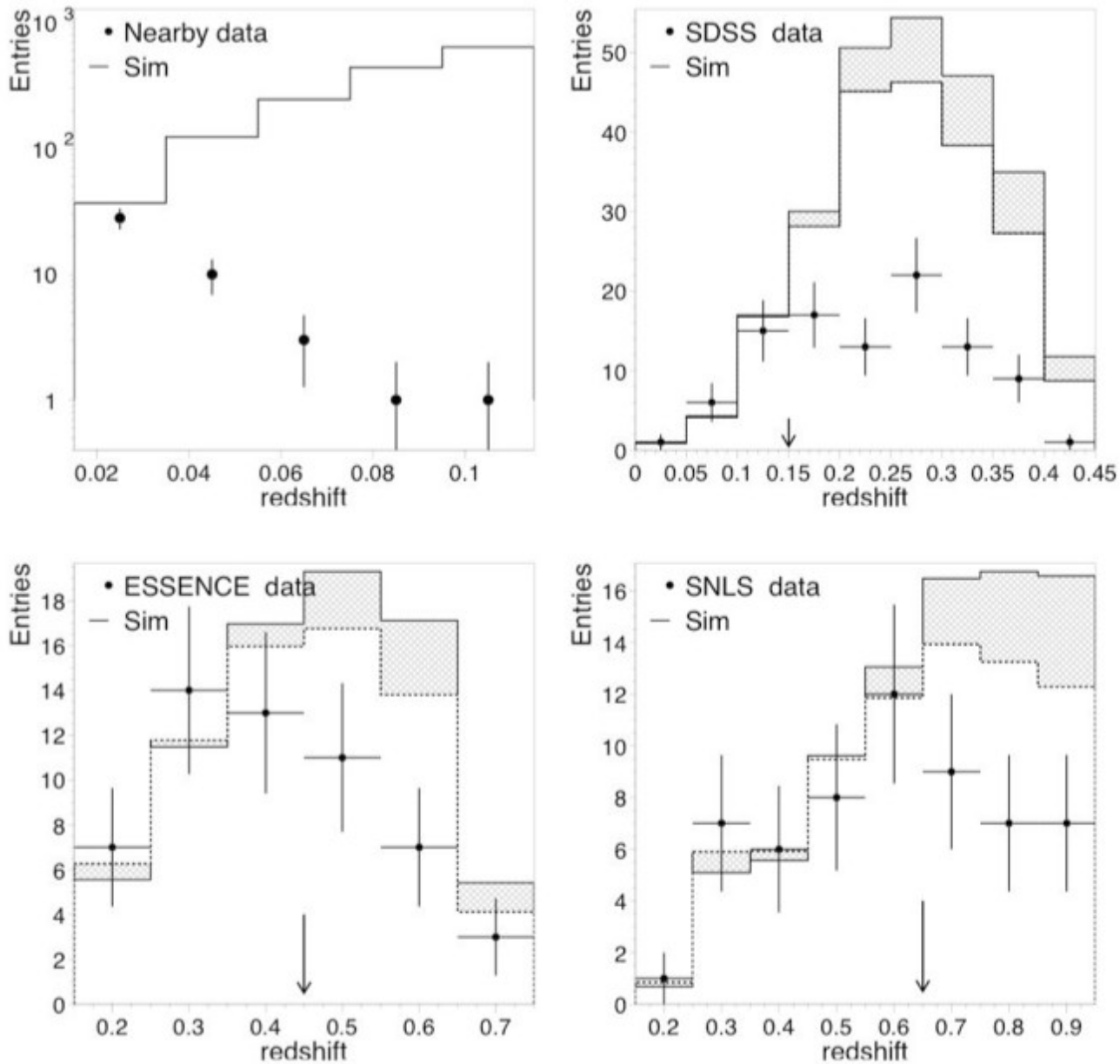


Use actual observing conditions (local sky, zero-points, PSF, etc)

Model Survey Efficiency



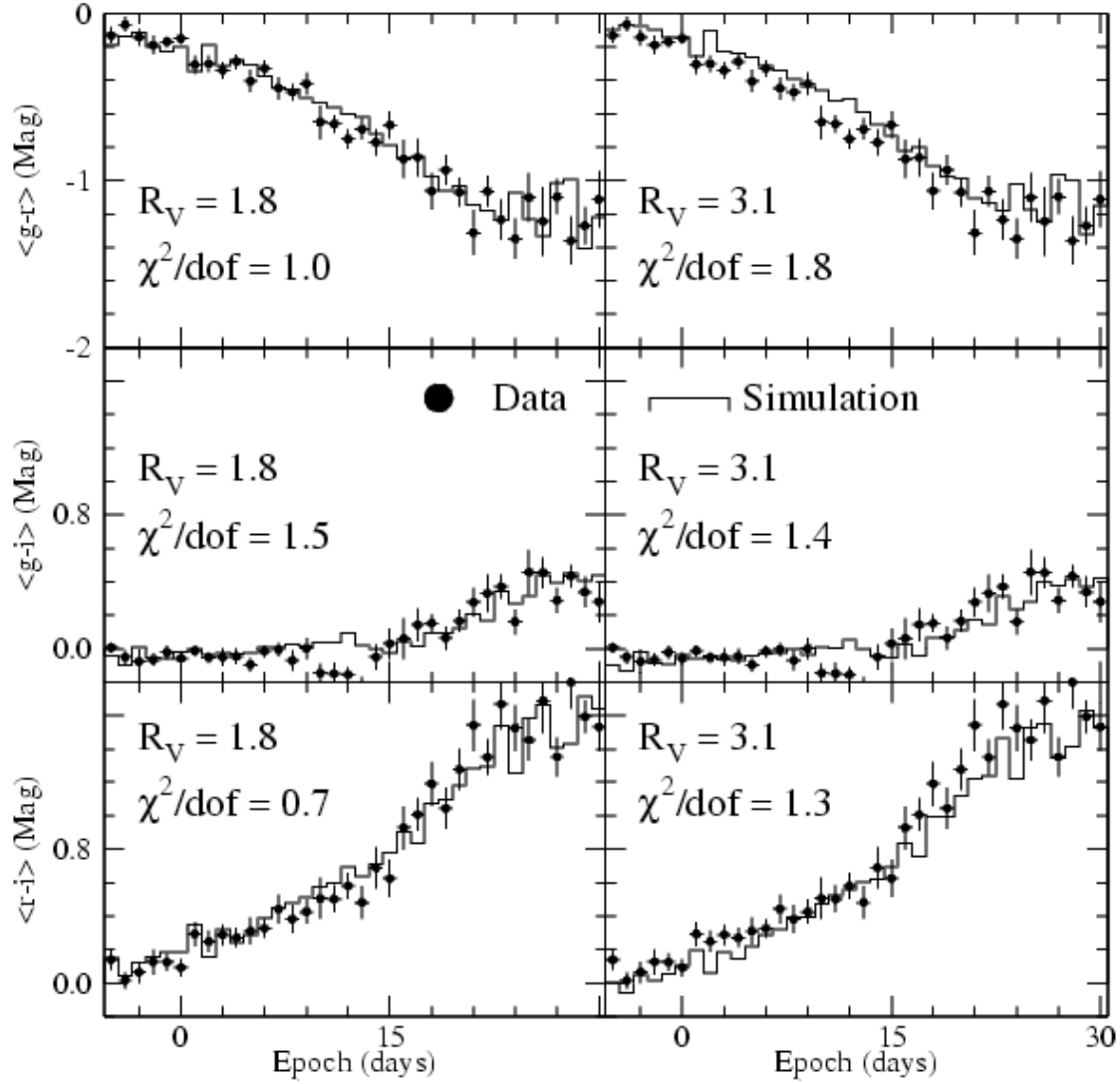
Model Spectroscopic & Photometric Efficiency



Extract R_V distribution from SDSS SN data

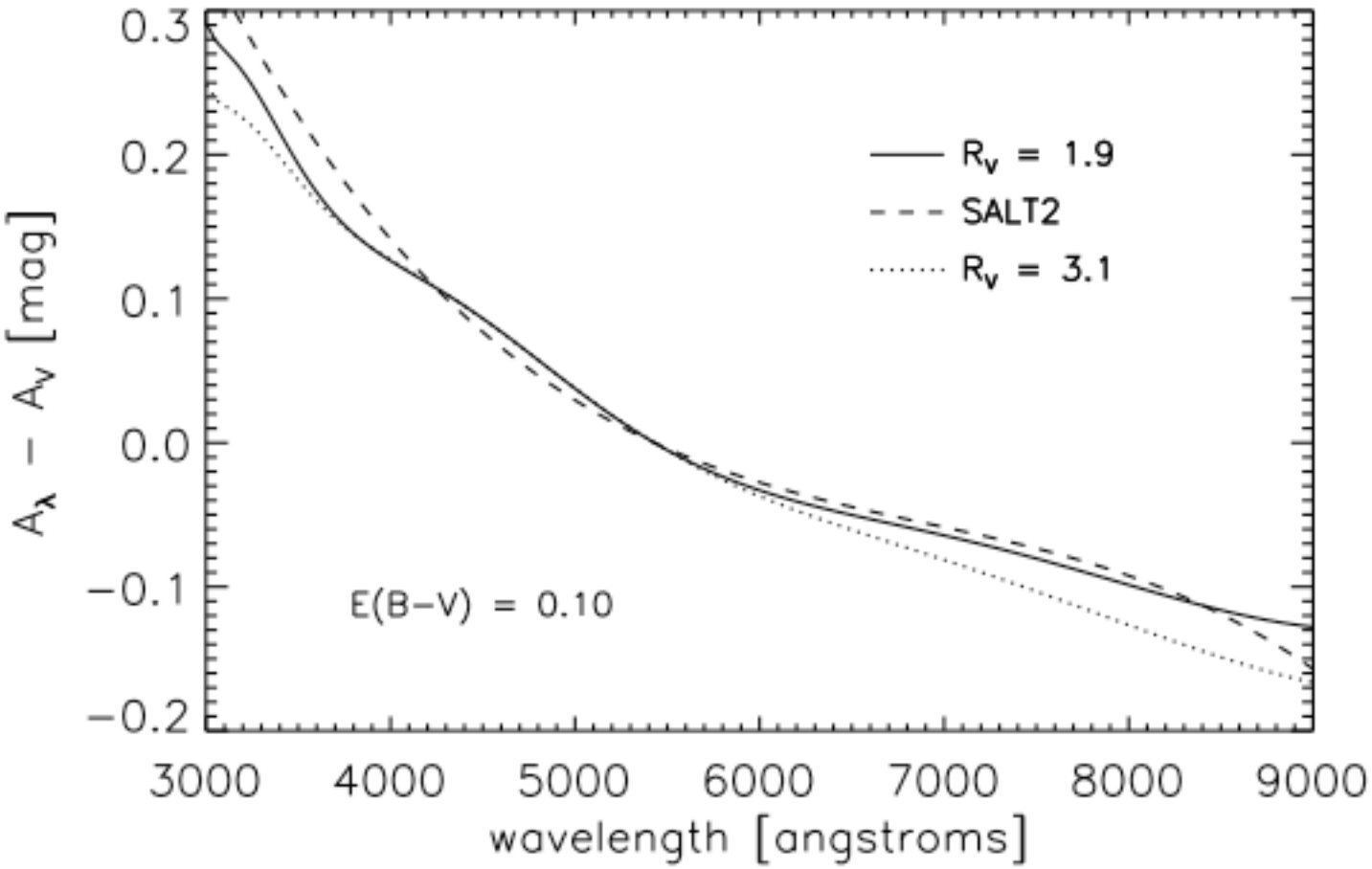
$$R_V = \frac{A_V}{E(B-V)} < 2$$

- MLCS previously used Milky Way avg R_V=3.1
- Lower R_V more consistent with SALT color law



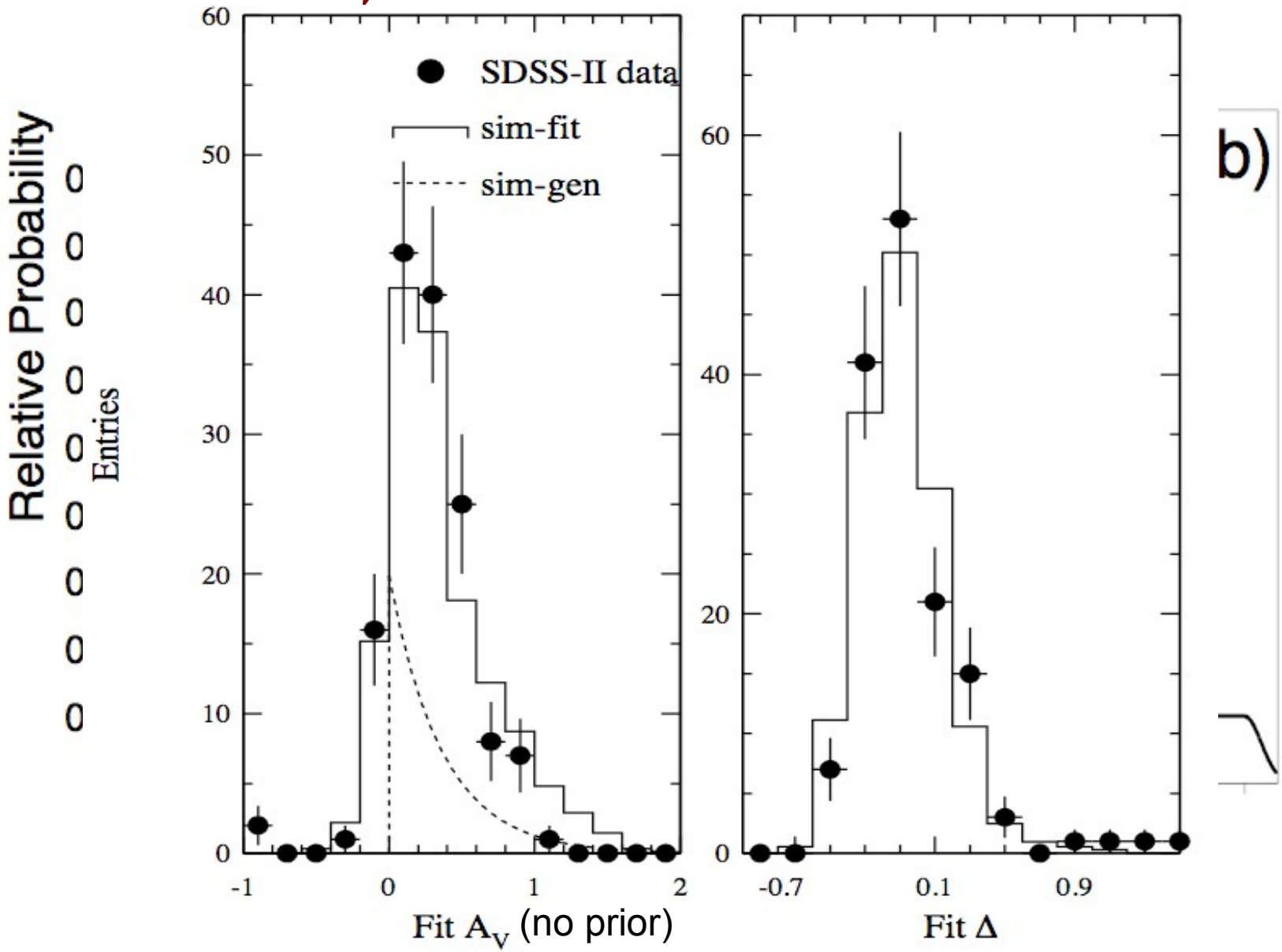
D. Cinabro

MLCS Extinction vs. SALT Color

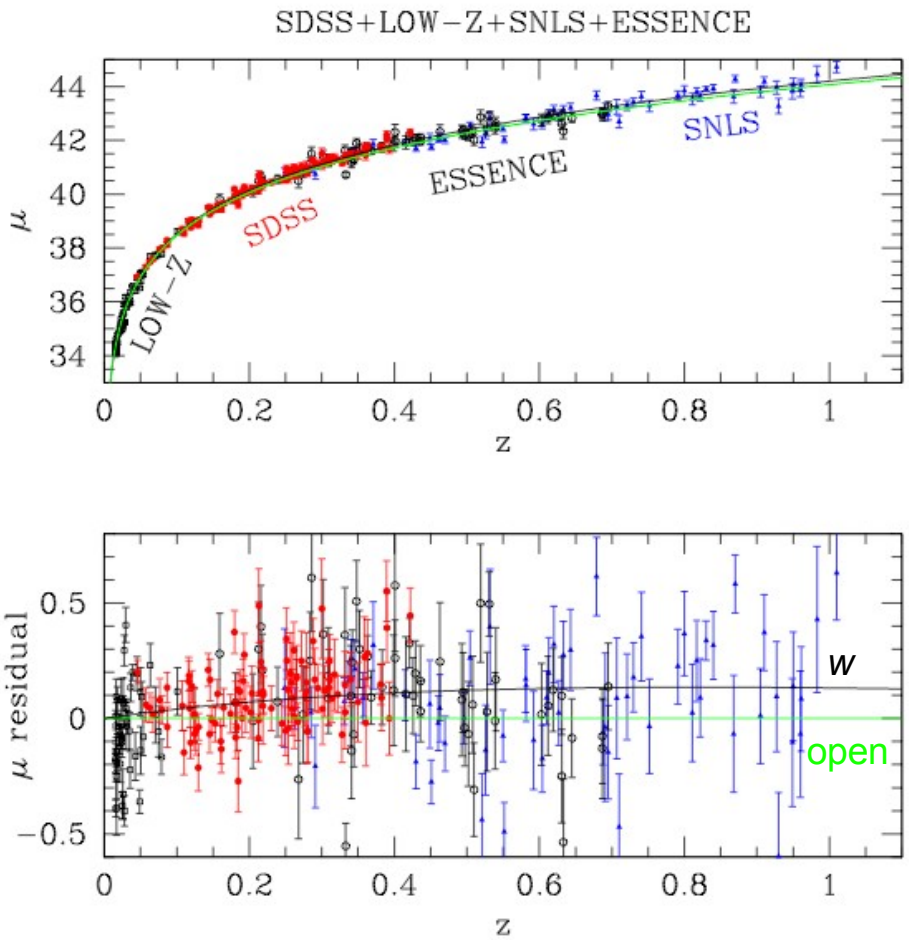


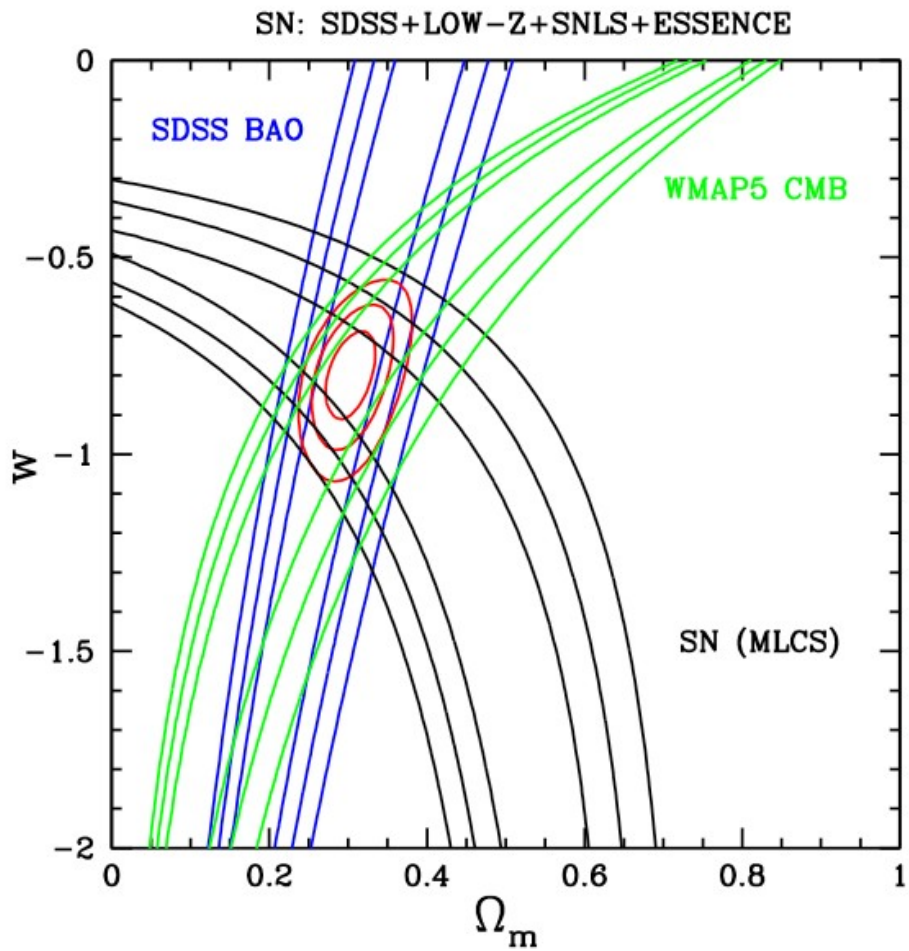
Jha

Extract A_V Distribution from SDSS



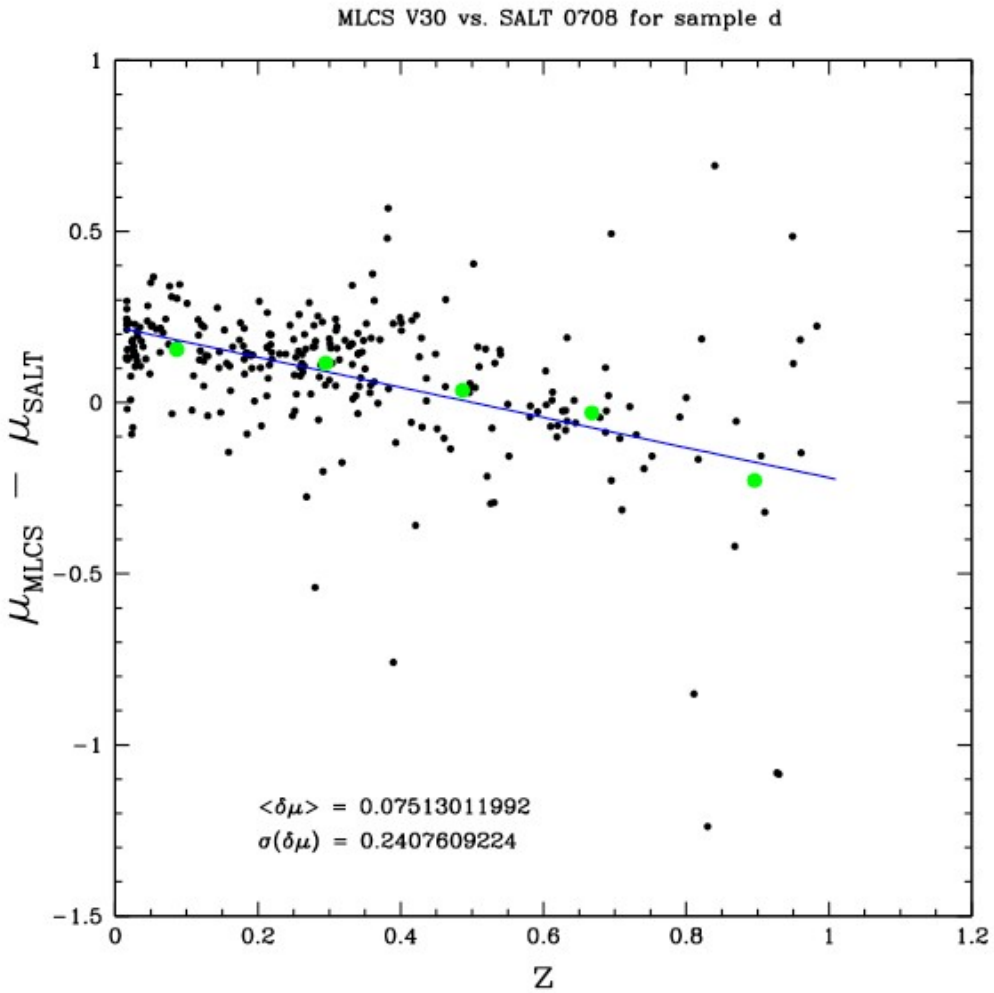
Preliminary Cosmology Results



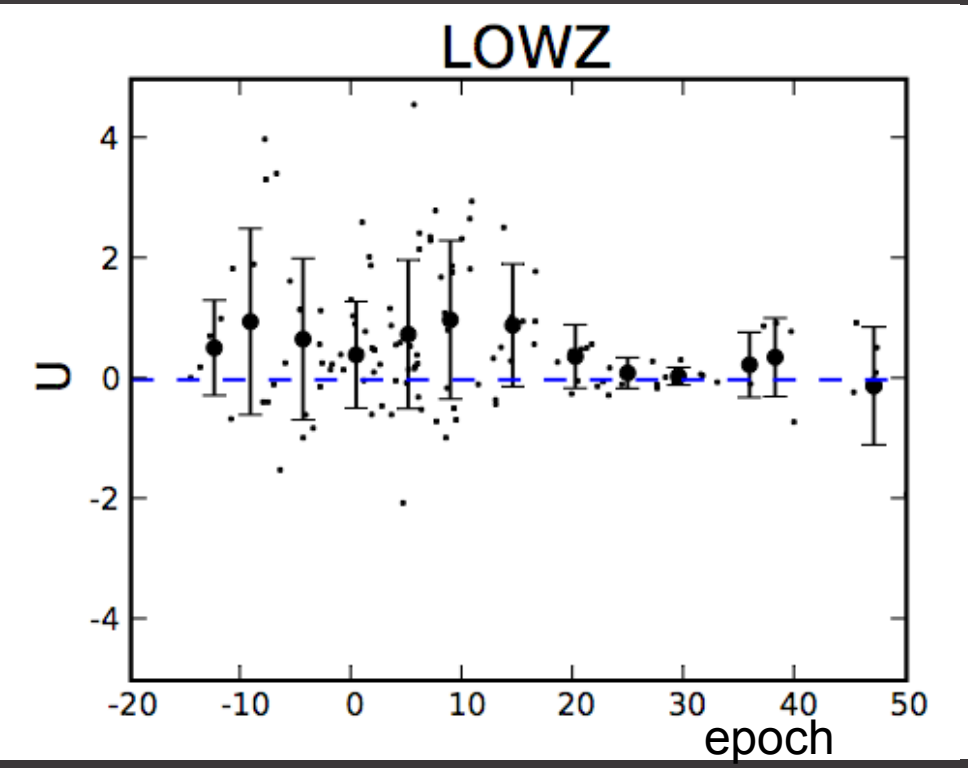


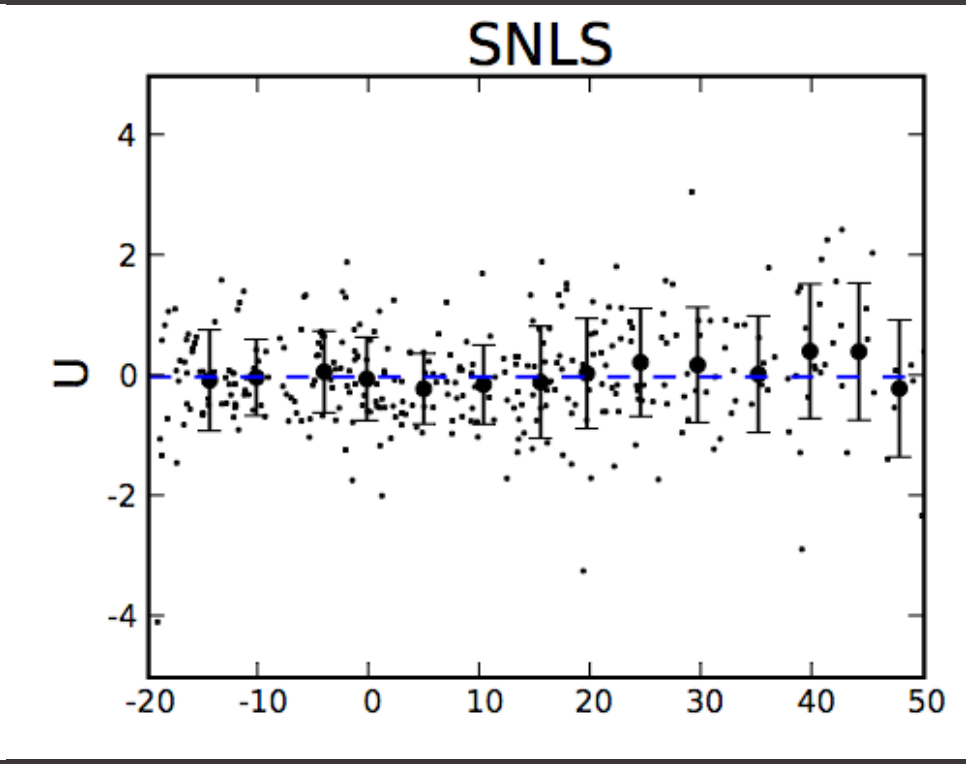
Kessler, Becker, et al. 2008

Comparative Hubble Diagram



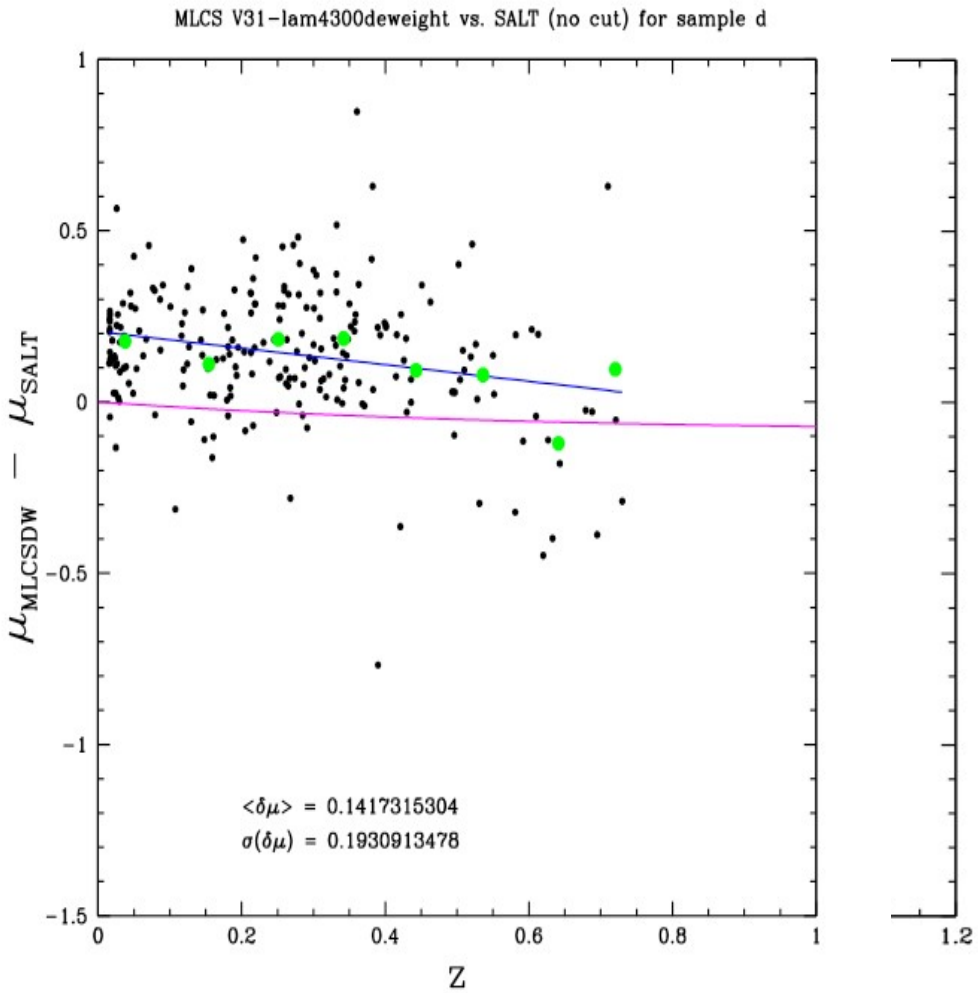
Issues with rest-frame U band



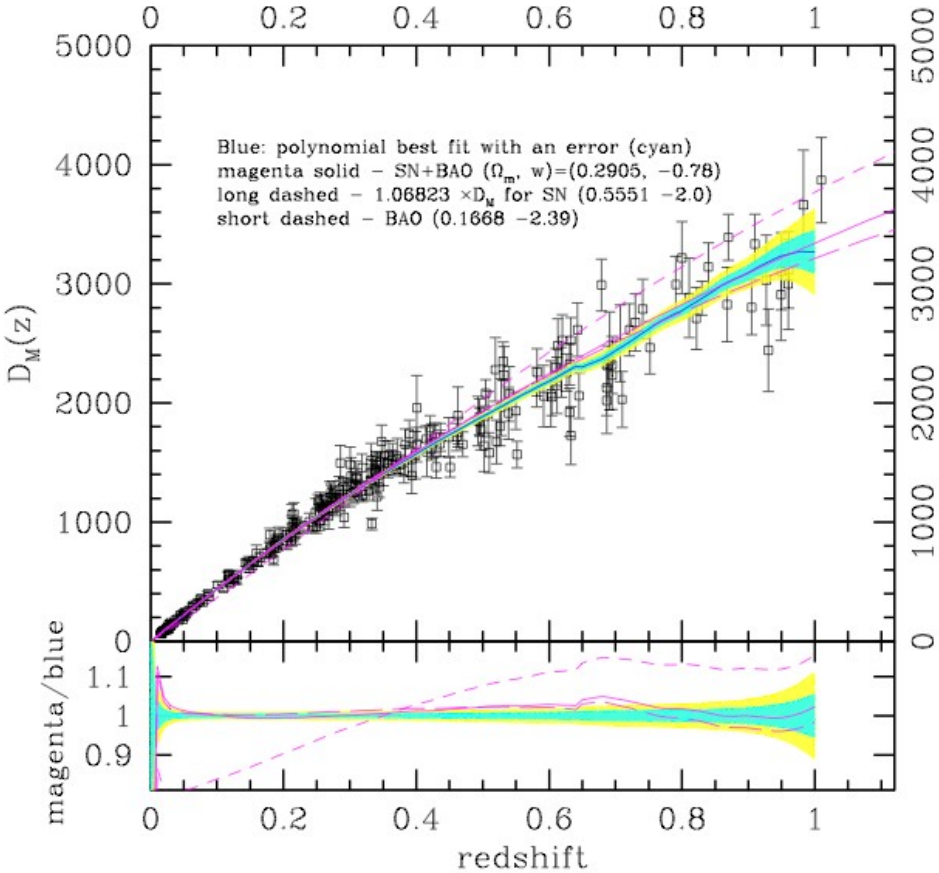


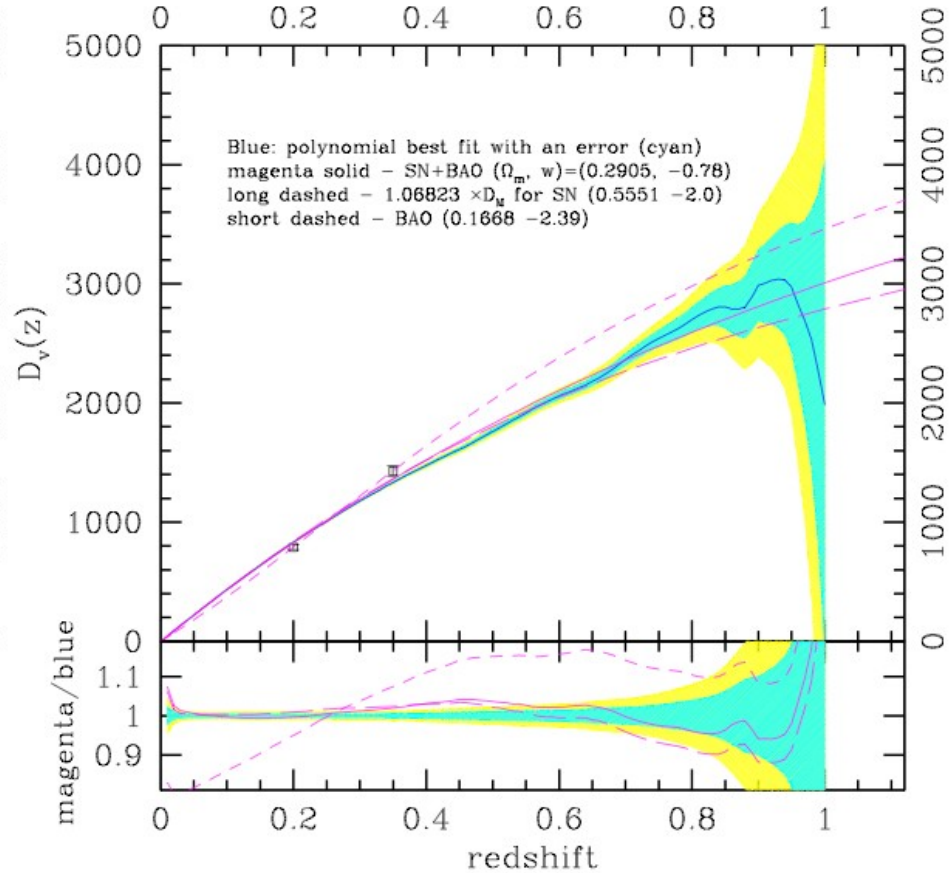
- Data vs. SALT Model Residuals
- ESSENCE, SDSS similar to SNLS
- Similar Low-z vs. High-z discrepancy seen in MLCS
- MLCS trained only on Low-z, SALT model dominated by High-z
- Similar differences seen in rest-frame UV spectra (Foley et al)

Rest-frame U band differences



SN vs BAO Distances

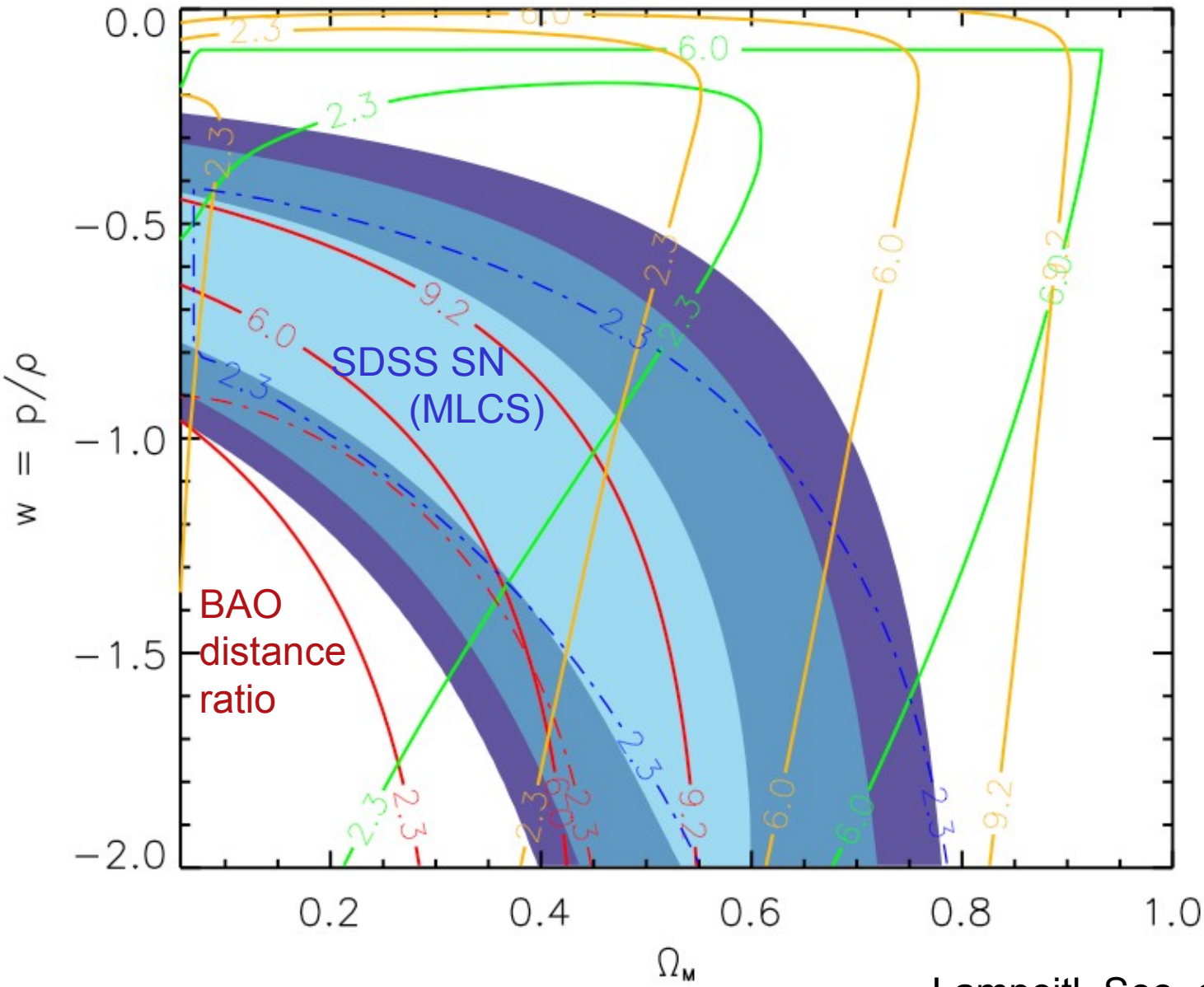




SNe: $D_L = (1+z)D_M = (1+z)\,f(z)$

BAO: $D_V = (D_M^2 zc/H(z))^{1/3} = (zf^2 f\,T)^{1/3}$

Lampeitl, Seo, et al



Lampeitl, Seo, et al

Future: Improved SN Ia Distances