Defining the Issues: Multiband Observations

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Oskar Klein Center

- **Funded by the Swedish Research Council for 10 years (~10 M$)**
  Director: L.Bergström
- **Main topics:**

  Dark Matter
  Dark Energy
  Evolution of structure in the Universe
  Physics of extreme objects: supernovae, neutrons stars, black holes
  Connections with fundamental theory

- **10 post-docs just hired (4 women, 3 US) + 1 just announced**
- **Longer appointments forseen for next years**
- **Profits from relocation of NORDITA to Stockholm (several workshops/yr); among these *"The Return of de Sitter", 28* Feb-25 Mar, 2011.**
- **Guest research program: come to visit us!**

Multiband Observations: key areas for DE include...

Spectroscopy

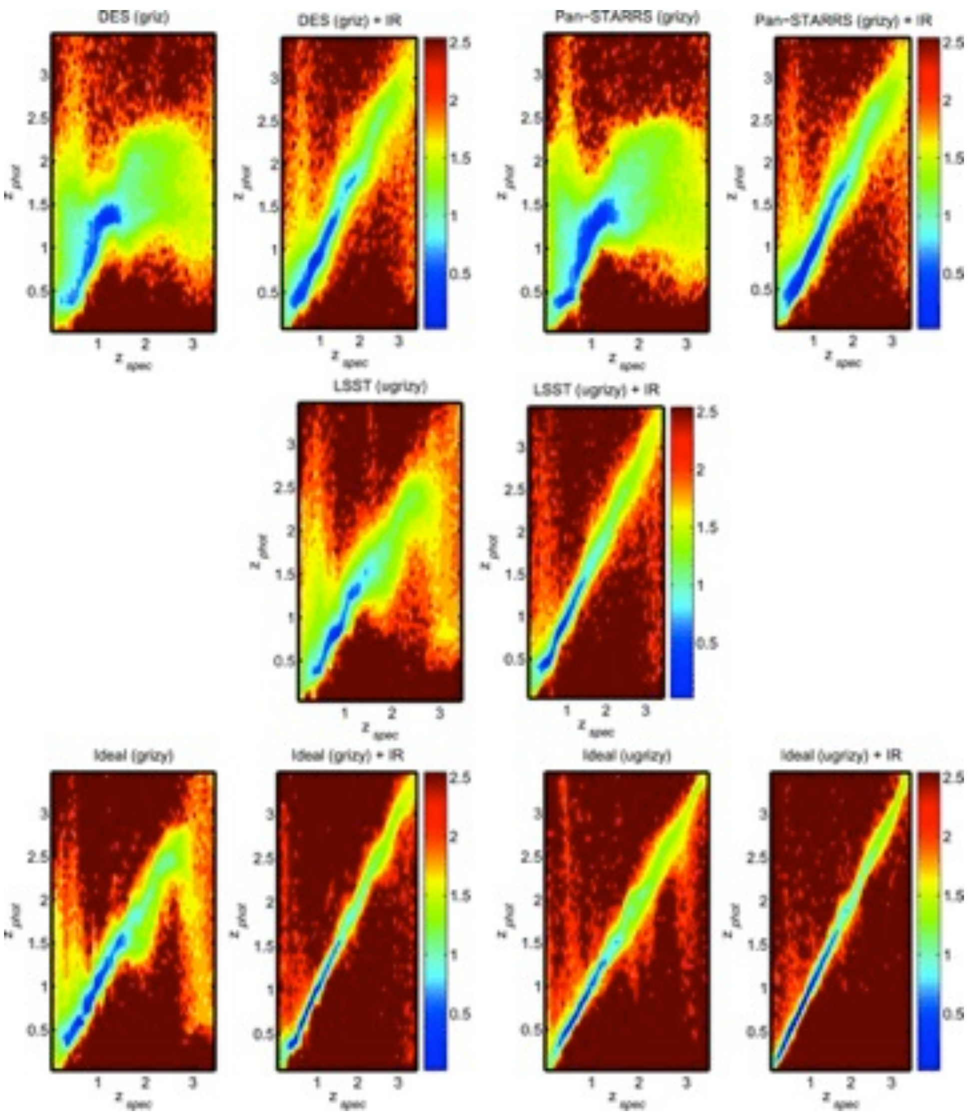
- Accurate redshifts over wide range
- Calibration of photo-z's (~1% of galaxies)
- Supernova typing
- SNIa subclassification: velocities, line ratios, pEW's, host galaxy environment, etc

Talks following this one + Anne's discussion this afternoon on technological trade-offs.

Imaging

- SNIa: accurate lightcurves, colors for calibration and reddening corrections
- Photo-BAO , cluster counts & WL: photo-redshifts
- Galaxy clusters: X-ray – optical/NIR – mm

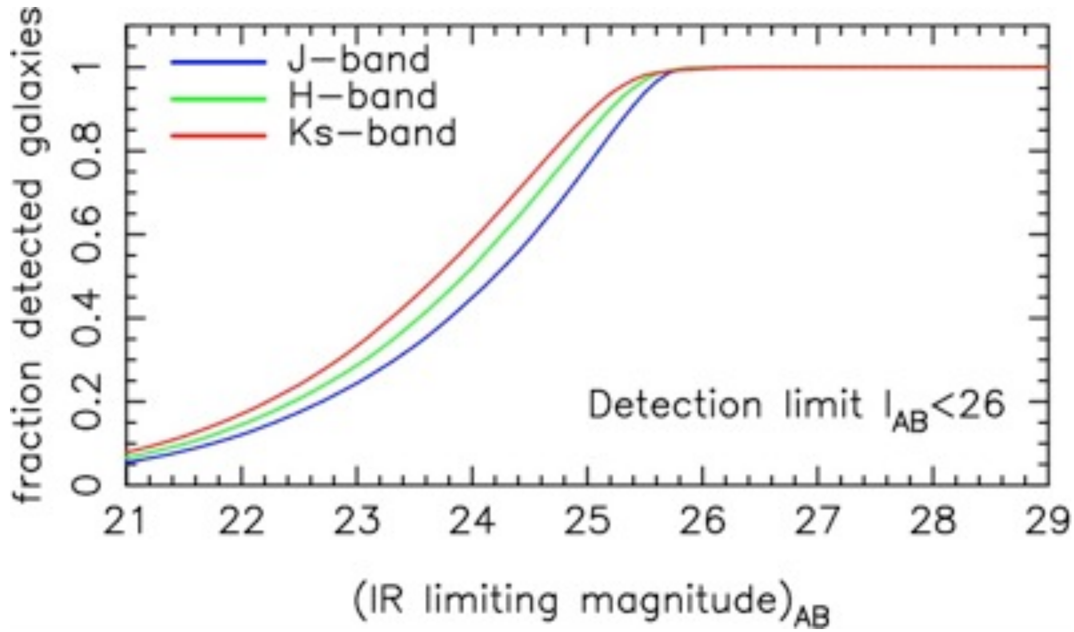
Photo-z's & multiband

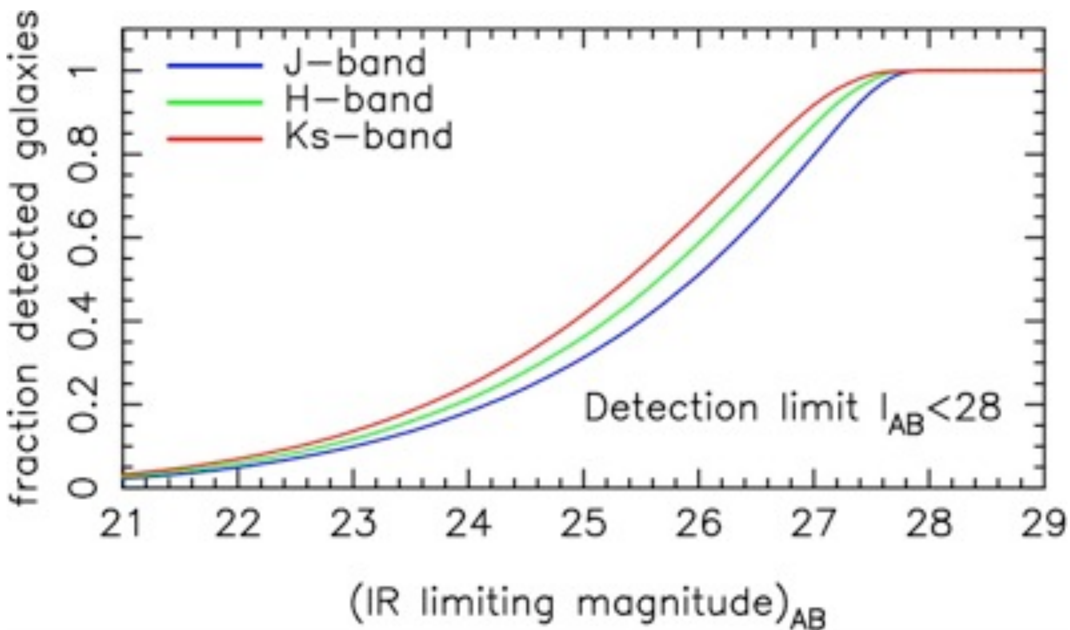


- The addition of *J+H* to *griz+RIZ* dramatically reduces the scatter in individual photo-*z*, in particular for the shallow *griz* surveys.
- The *u*-band filter is effective in removing outliers and can play the same role as the IR filters but only if the *RIZ* depth is significantly larger than the depth of the lensing survey chosen

Abdalla et al, 2008

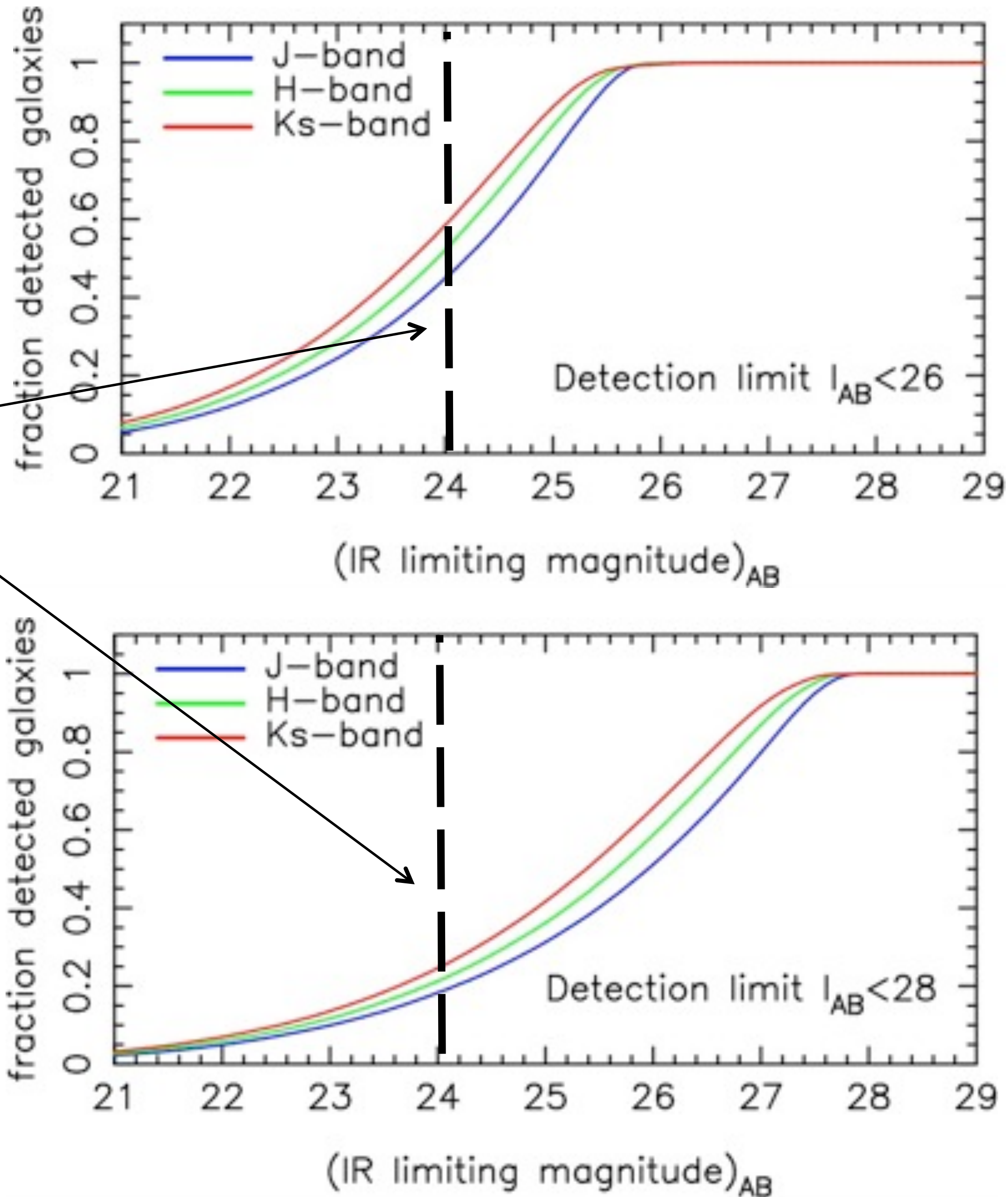
Galaxy photo-z's and near-IR





Courtesy of T.Dahlén

Galaxy photo-z's and near-IR



H-band:
~10 nights/sq.deg with ground based telescopes in good seeing.

Courtesy of T.Dahlén

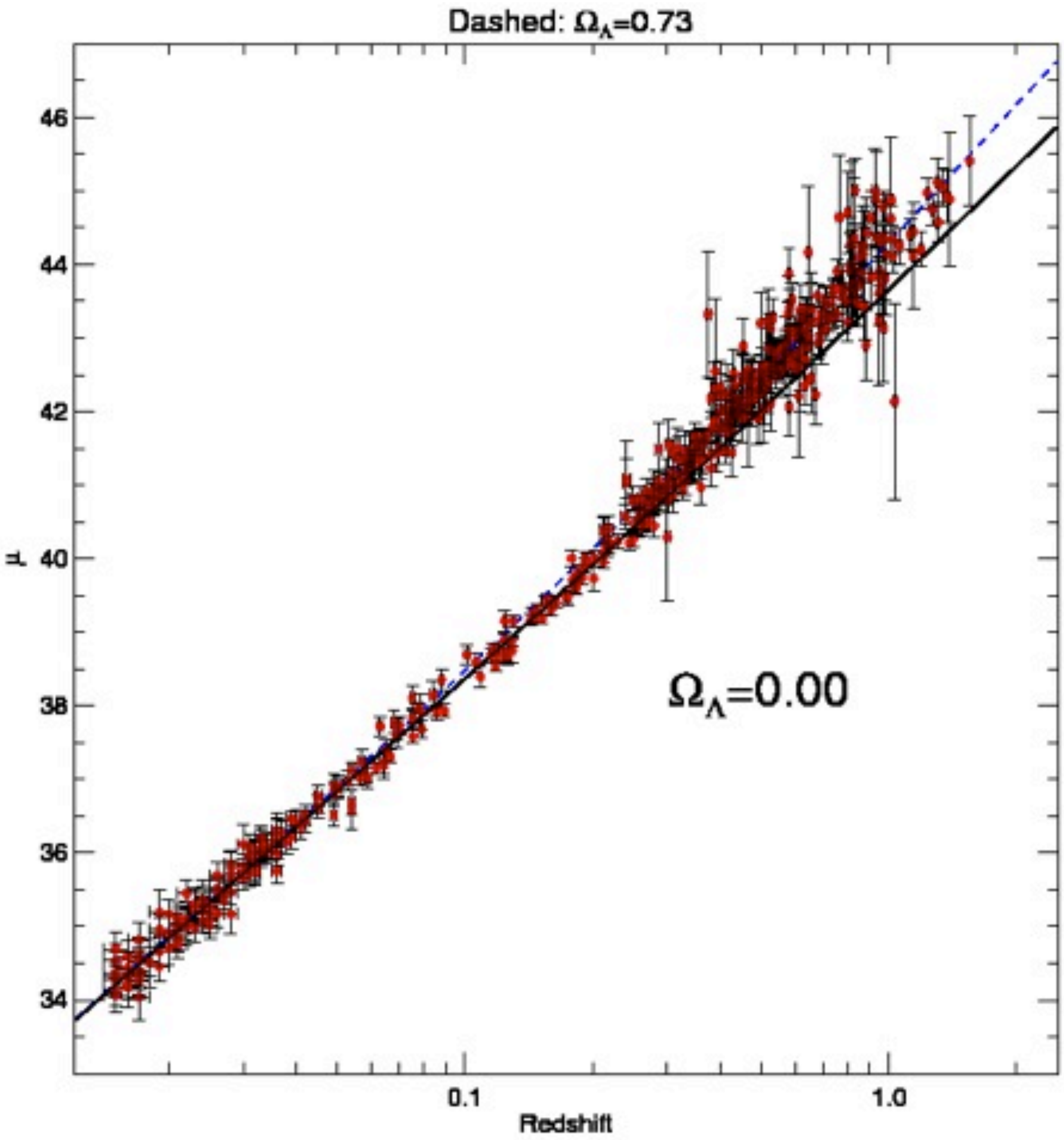
Multiwavelength & SNIa

- Empirical method: increased precission on DE requires redundant data sets, including wide range wavelength imaging and spectroscopic measurements
- Key element for cosmological parameter fitting: wide redshift lever arm in SNIa Hubble diagram, wide wavelength range needed to probe same restframe window
- Color-brightness relation requires multiple filters
- Exctinction by dust:
  - Fitting extinction law works best with UV-to near-IR
  - Smallest correction uncertainty in restframe near-IR
- Theoretical model (Kasen) suggests narrower intrinsic brightness dispersion in near-IR
- Second parameters (after ”stretch”): line ratios, line velocities, pEW, etc
- Probes for evolution:
  - UV flux sensitive to progenitor metallicity
  - Spectroscopic features

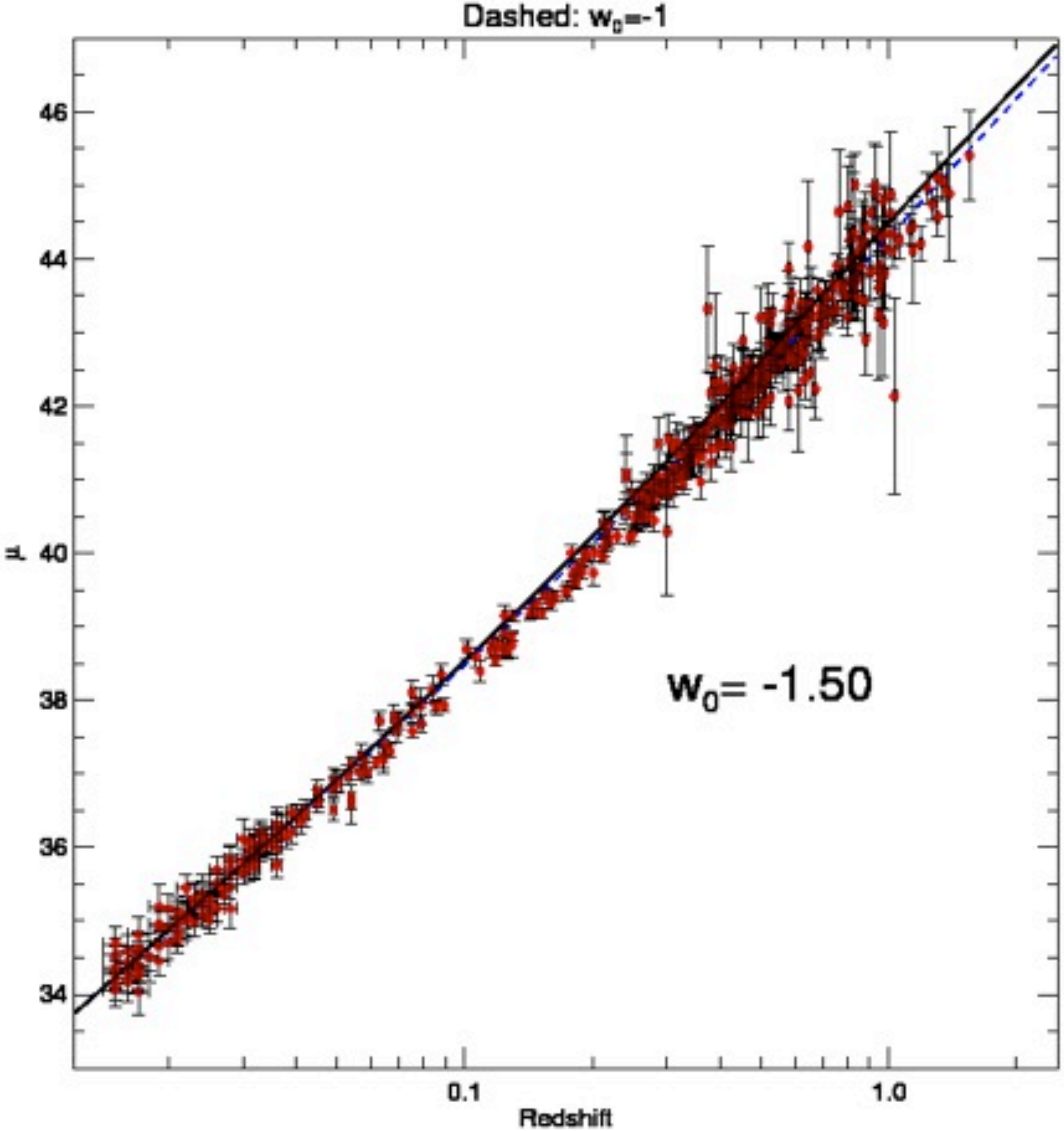
A partial list of open issues for SN-cosmology

- Optimal redshift range/wavelength coverage and adequate instrumentation and calibration
- Understanding/measuring the reddening law
- How do we best check that the candle is ”standard” over a wider redshift range. Drifting parameters?
- What can we do w/w.o spectroscopy
- Lightcurve fitters, whom do you trust? For which bands?
- Selection effects?

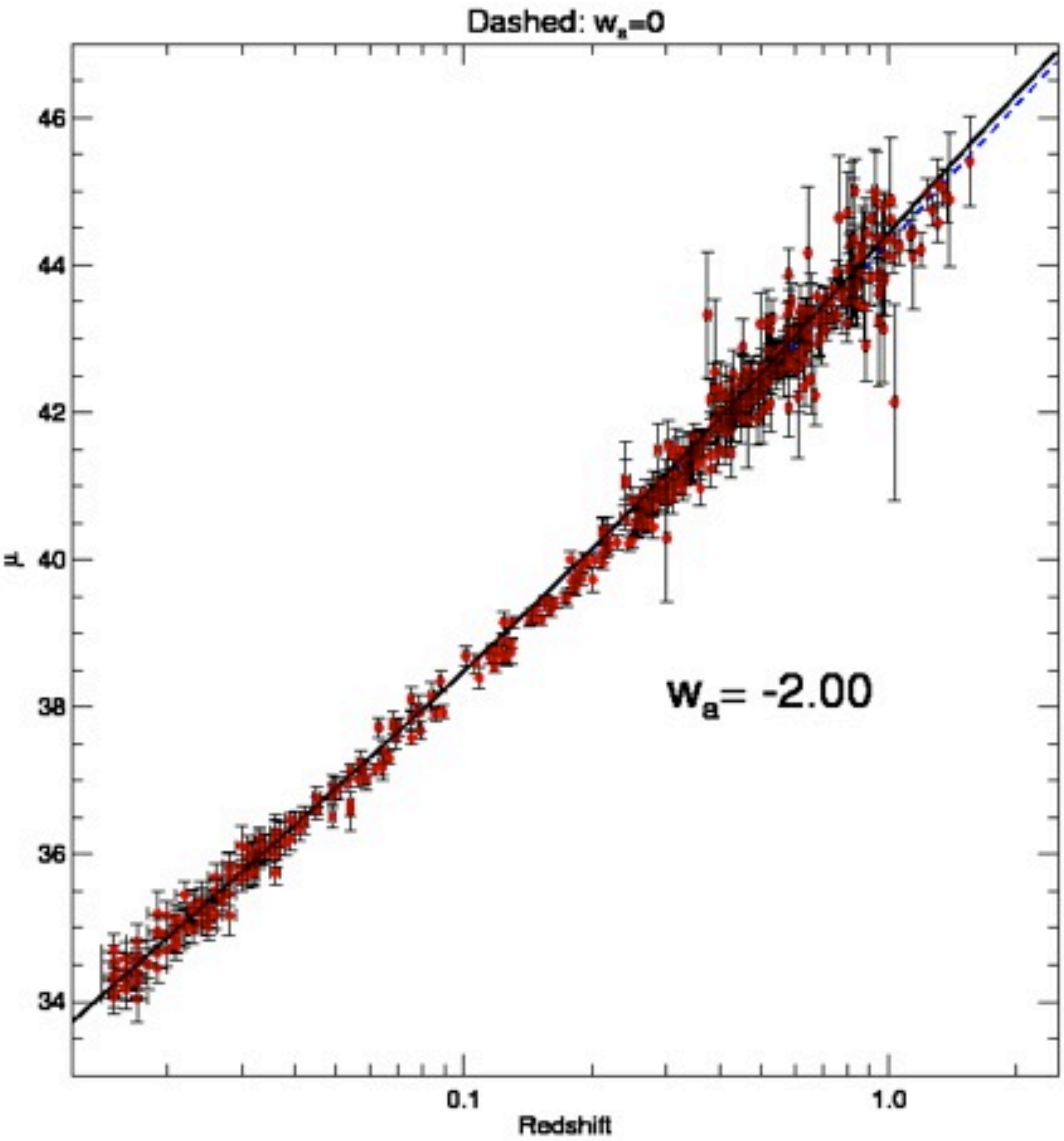
500 SNIa and counting!



This is what we are up against…

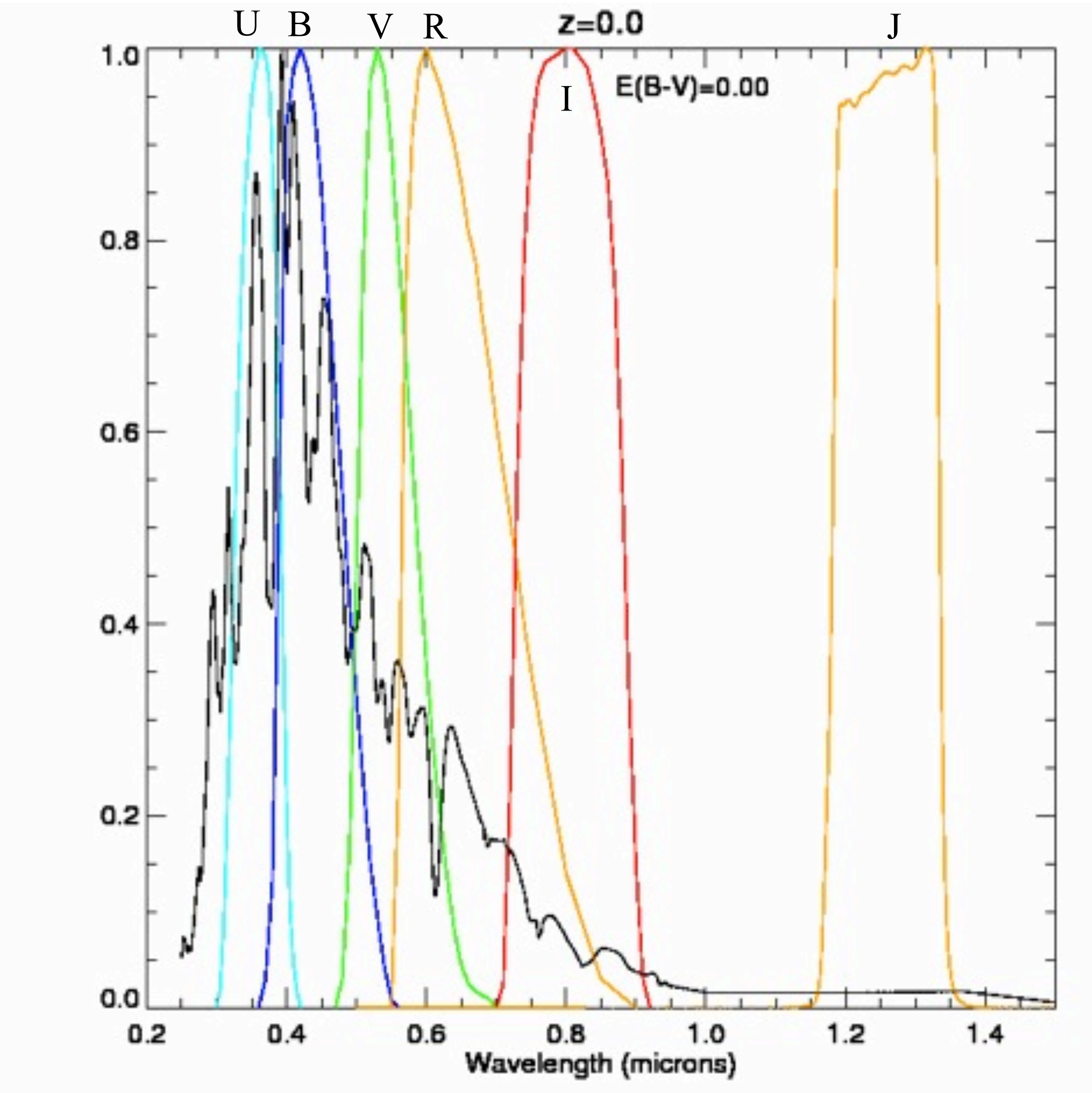


…and for the next generation!



Future missions to have same redshift range: need a lot better data!

Open issue (I): target redshift range for



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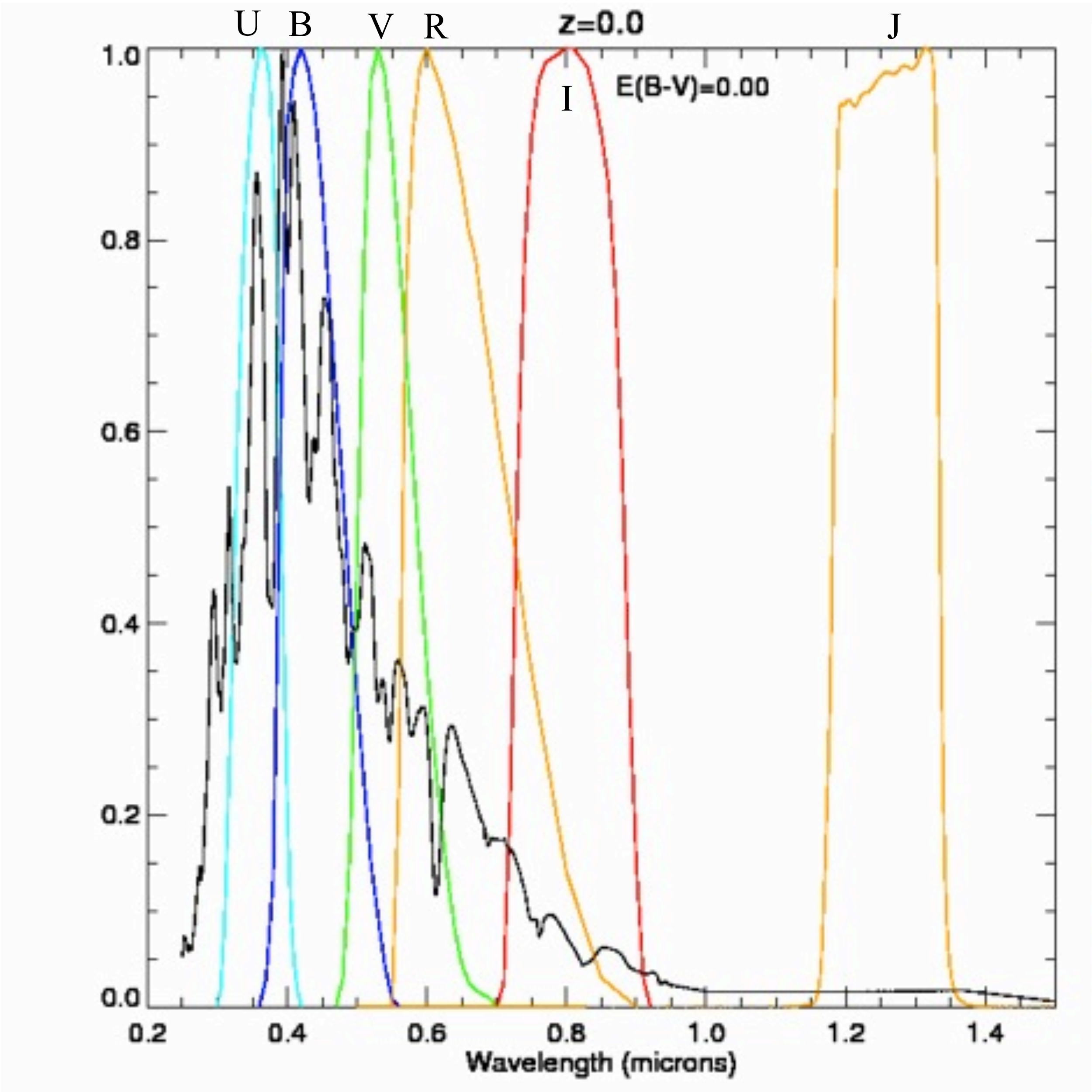
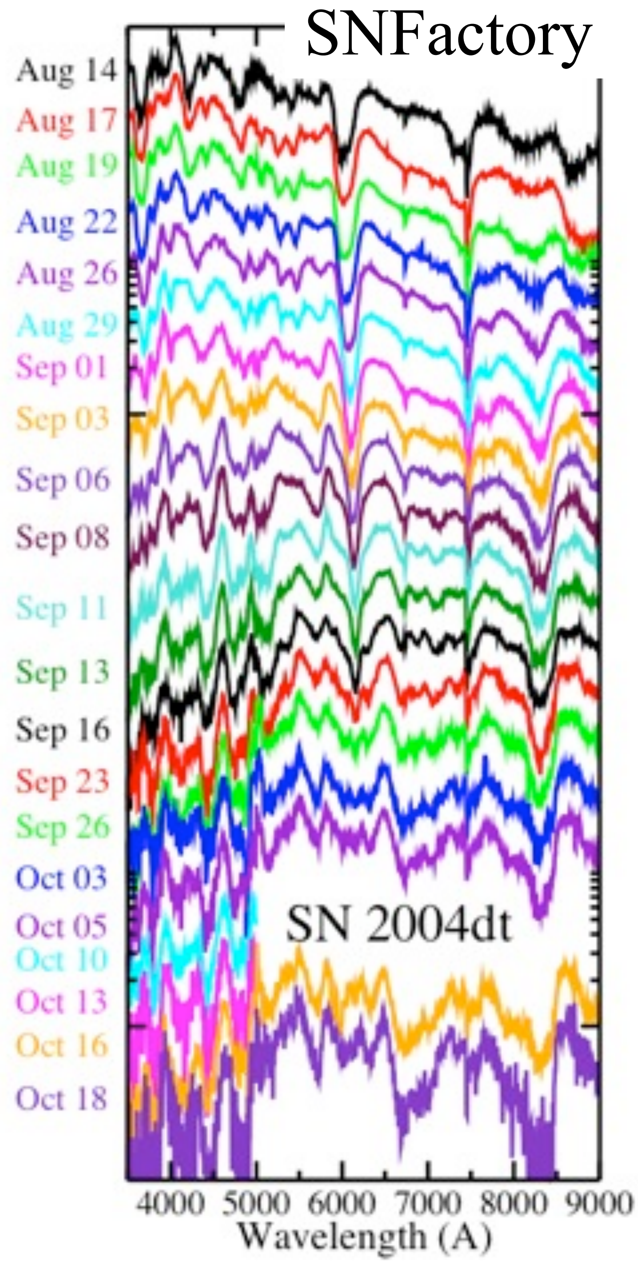
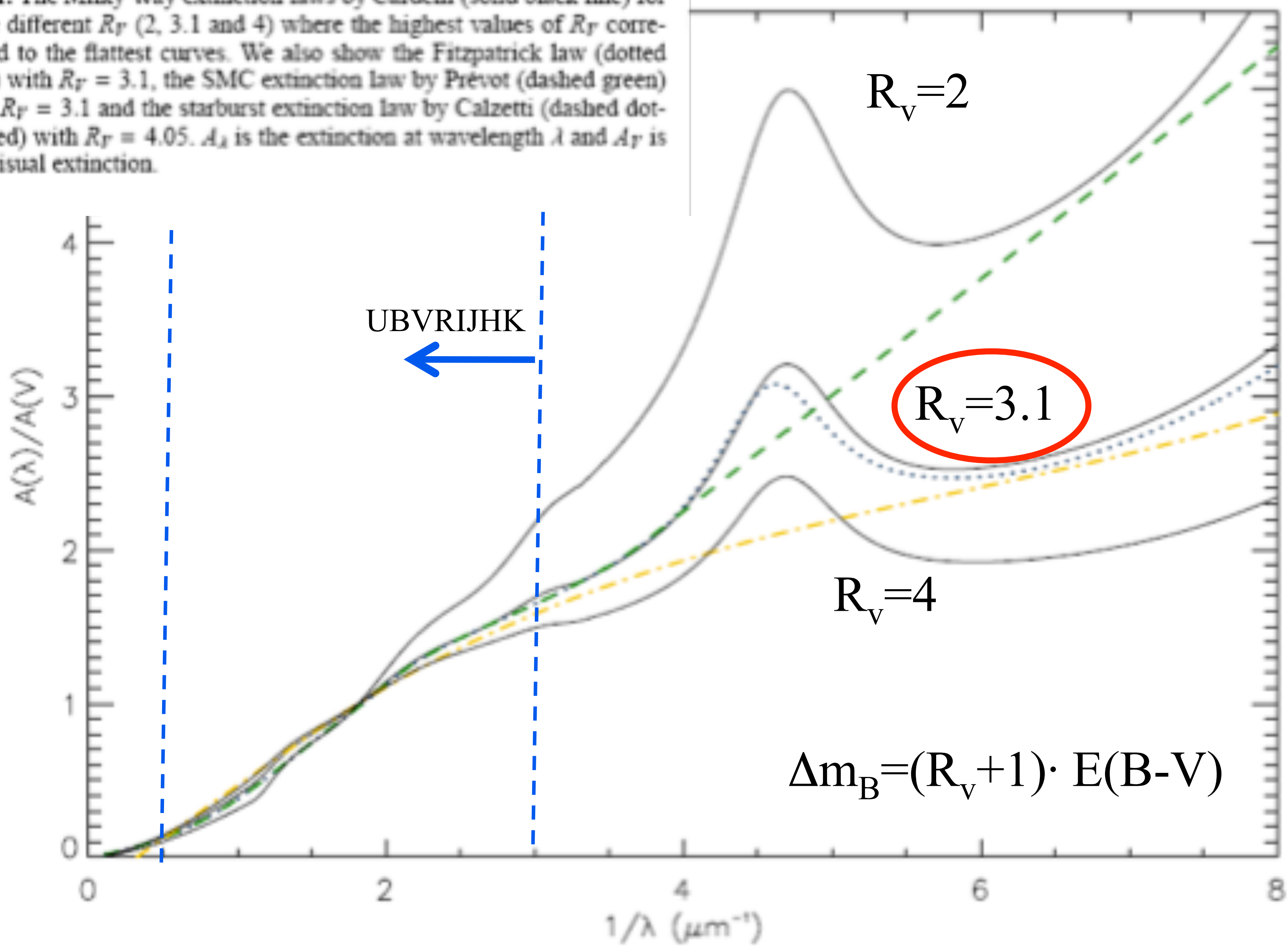


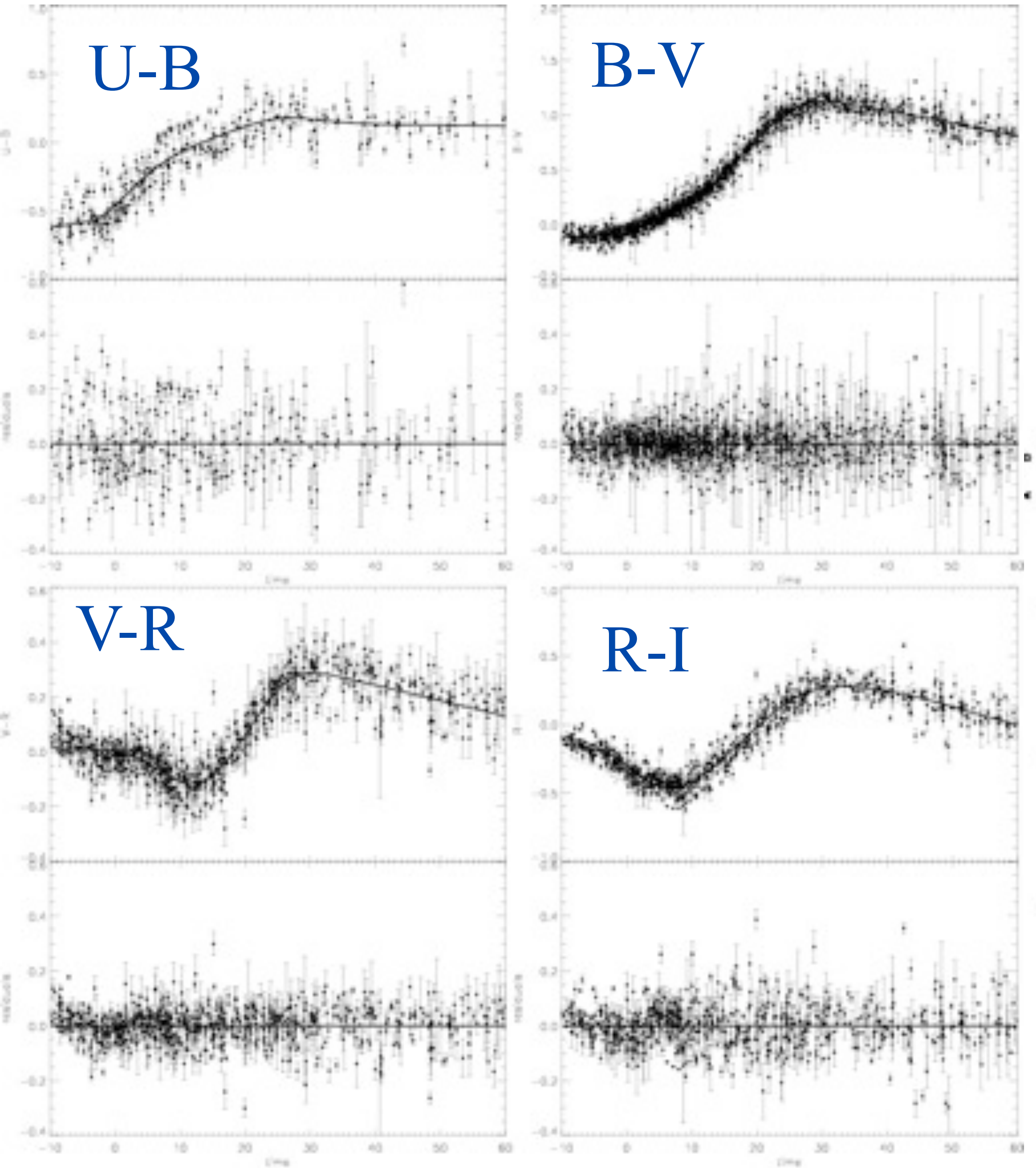


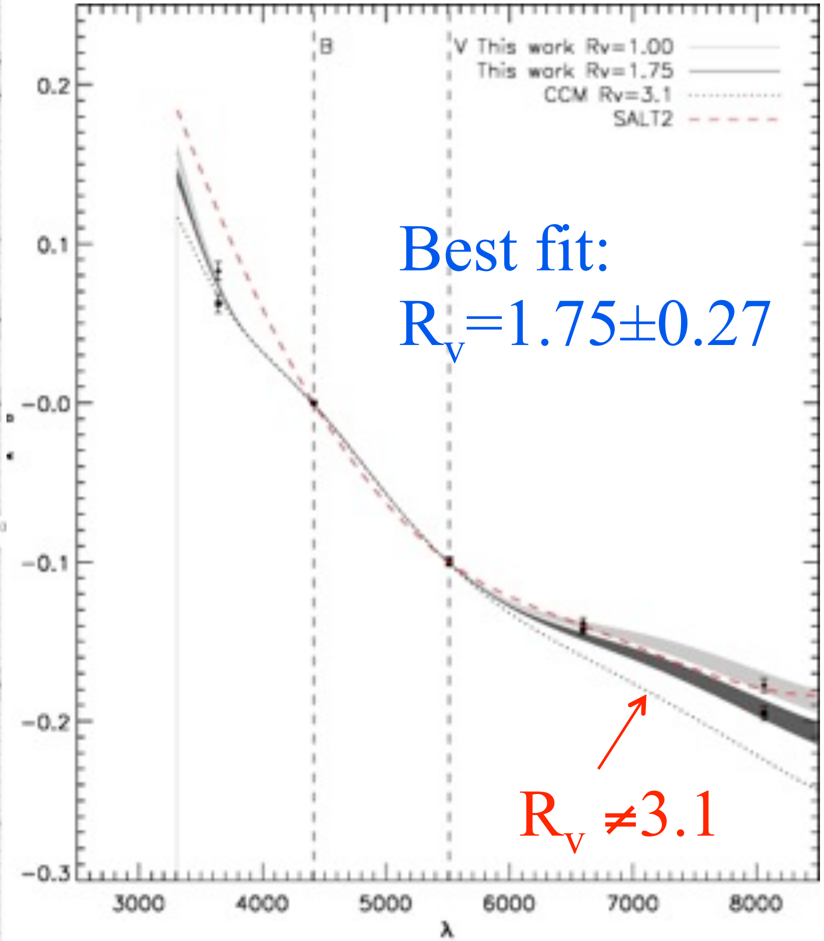
Open issue (II): reddening laws

Fig. 1. The Milky Way extinction laws by Cardelli (solid black line) for three different R_V (2, 3.1 and 4) where the highest values of R_V correspond to the flattest curves. We also show the Fitzpatrick law (dotted blue) with R_V = 3.1, the SMC extinction law by Prévot (dashed green) with R_V = 3.1 and the starburst extinction law by Calzetti (dashed dotted red) with R_V = 4.05. A_λ is the extinction at wavelength λ and A_V is the visual extinction.



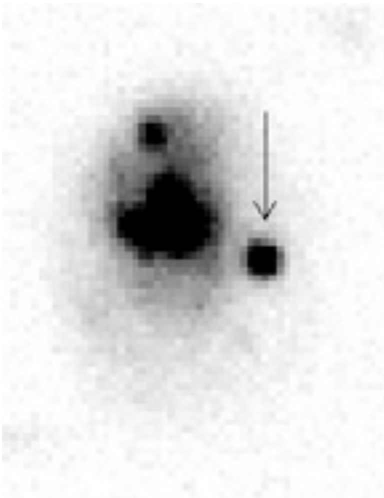
Global fit to minimize color dispersion in

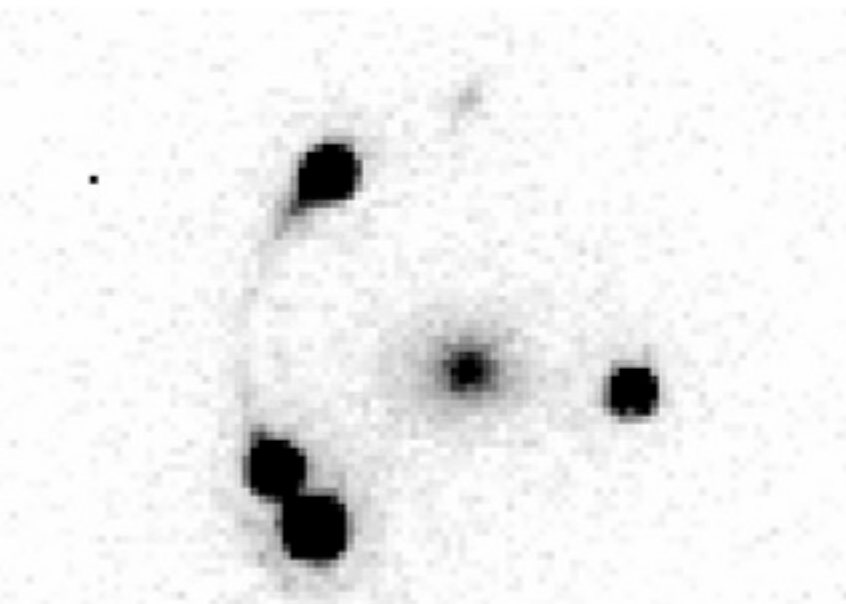


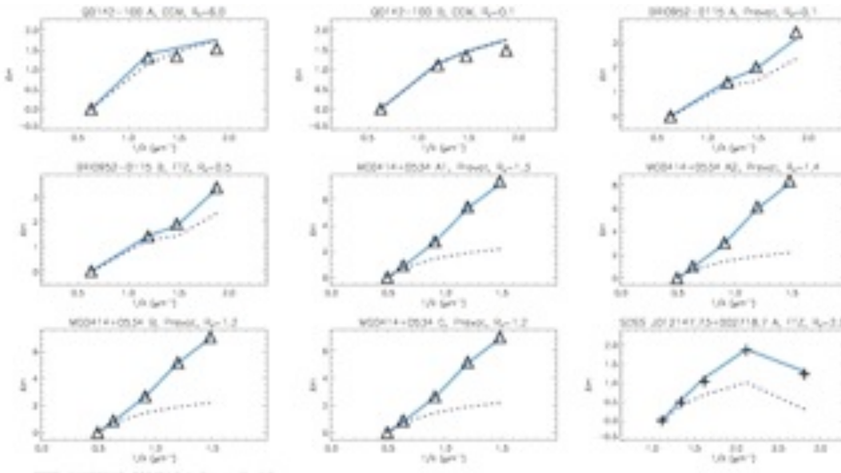


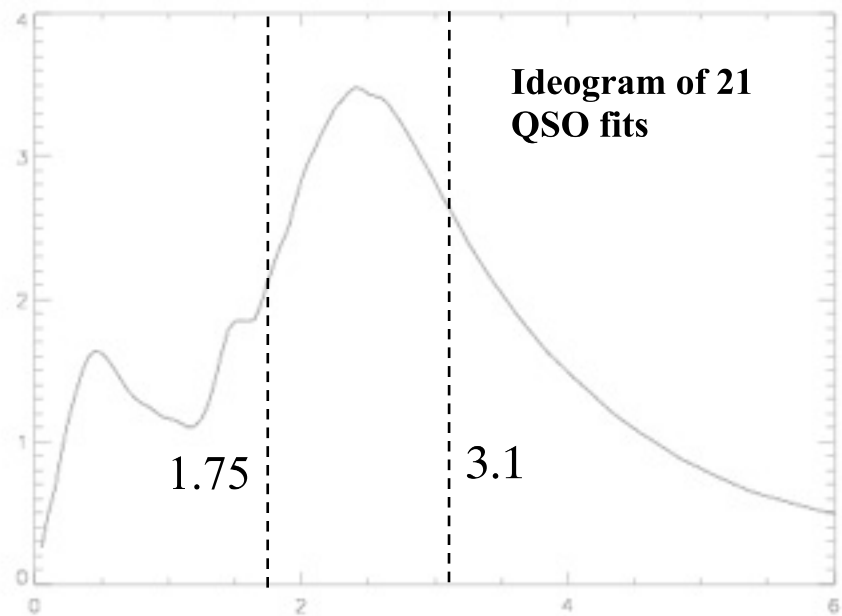
Nobili & AG, 2008, A&A

QSO shining through galaxies: 21 systems





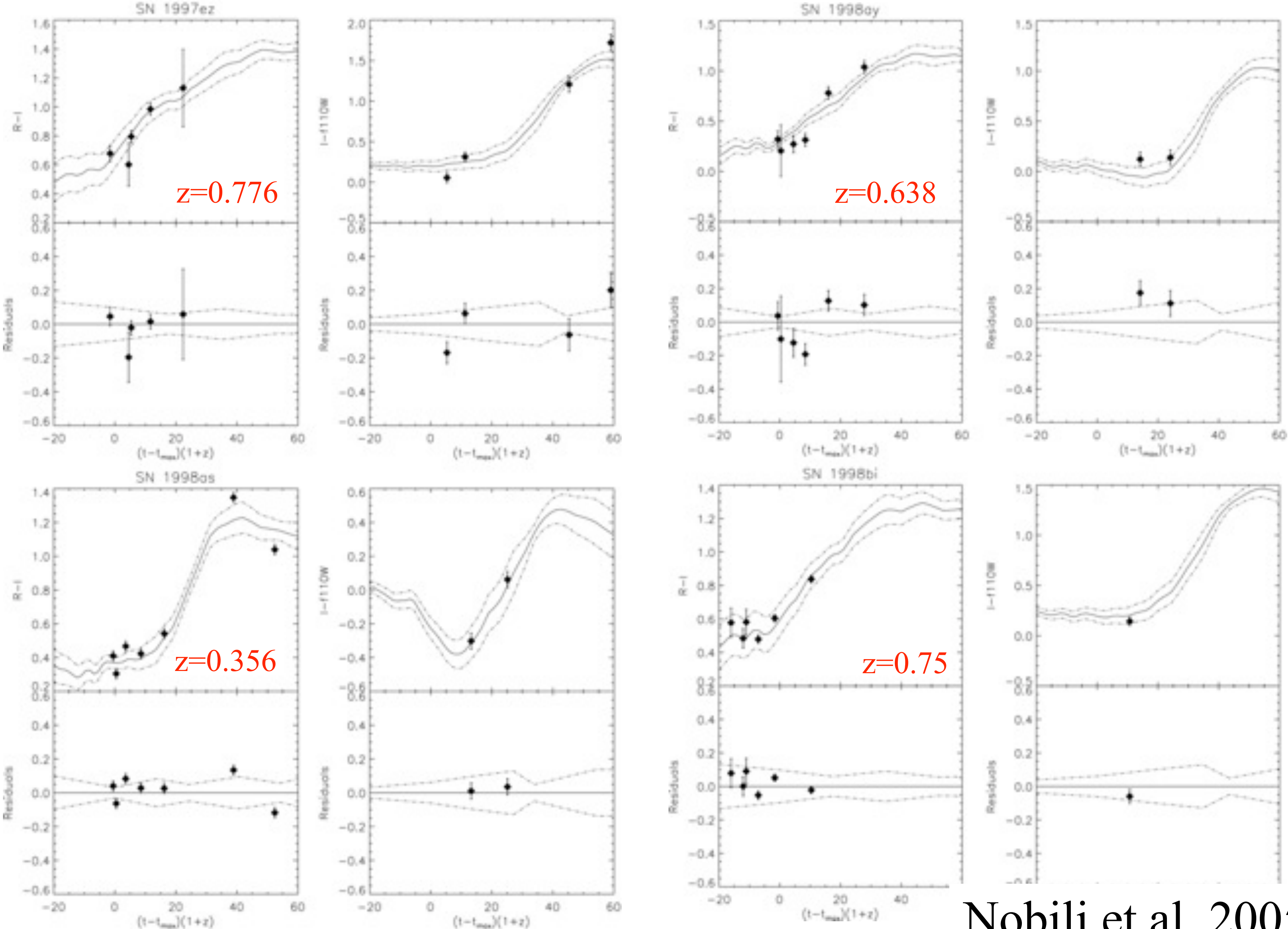




LSST will resolve higher-z foreground galaxies

Östman,AG,Mörtsell, 06' and 08'

SCP: high-z colors including restframe B to I

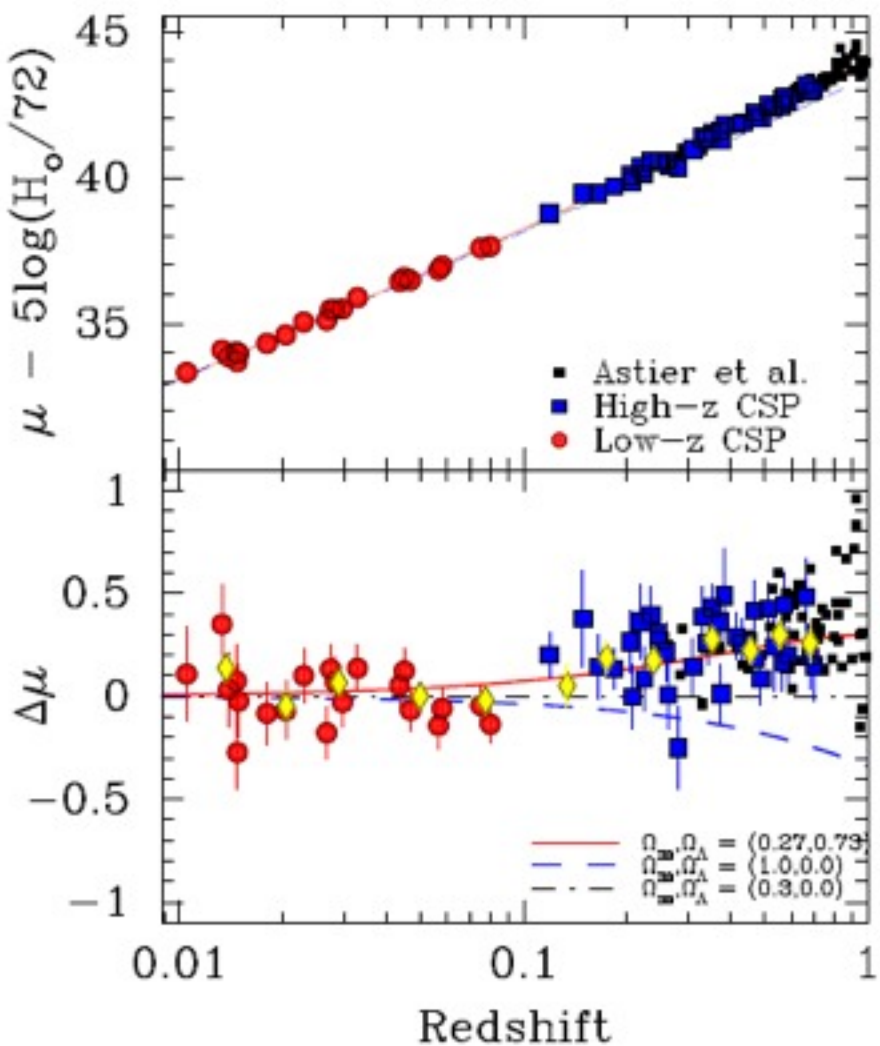


Nobili et al, 2005,09

THE CARNEGIE SUPERNOVA PROJECT: FIRST NEAR-INFRARED HUBBLE DIAGRAM TO Z~0.7*

third

Wendy L. Freedman[1], Christopher R. Burns[1], M. M. Phillips[2], Pamela Wyatt[1], S. E. Persson[1], Barry F. Madore[1], Carlos Contreras[2], Gaston Folatelli[2,3], E Sergio Gonzalez[2], Mario Hamuy[3], Eric Hsiao[4], Daniel D. Kelson[1], Nidia Morrell[2], D. C. Murphy[1], Miguel Roth[2], Maximilian Stritzinger[2], Laura Sturch[1], Nick B. Suntzeff[21] P. Astier[6], C. Balland[6,7], Bruce Bassett[8], Luis Boldt[2], R. G. Carlberg[9], Alexander J. Conley[9], Joshua A. Frieman[10,11,12], Peter M. Garnavich[13], J. Guy[6], D. Hardin[6], D. Andrew Howell[14,15], Richard Kessler[16,11], Hubert Lampeitl[5], John Marriner[10], R. Pain[6], Kathy Perrett[9], N. Regnault[6], Adam G. Riess[17], Masao Sako[16,18], Donald P. Schneider[19], Mark Sullivan[20], and Michael Wood-Vasey[22]



$R_v = 1.74 \pm 0.27$

Open issue (3): Lightcurve fitting in I-band

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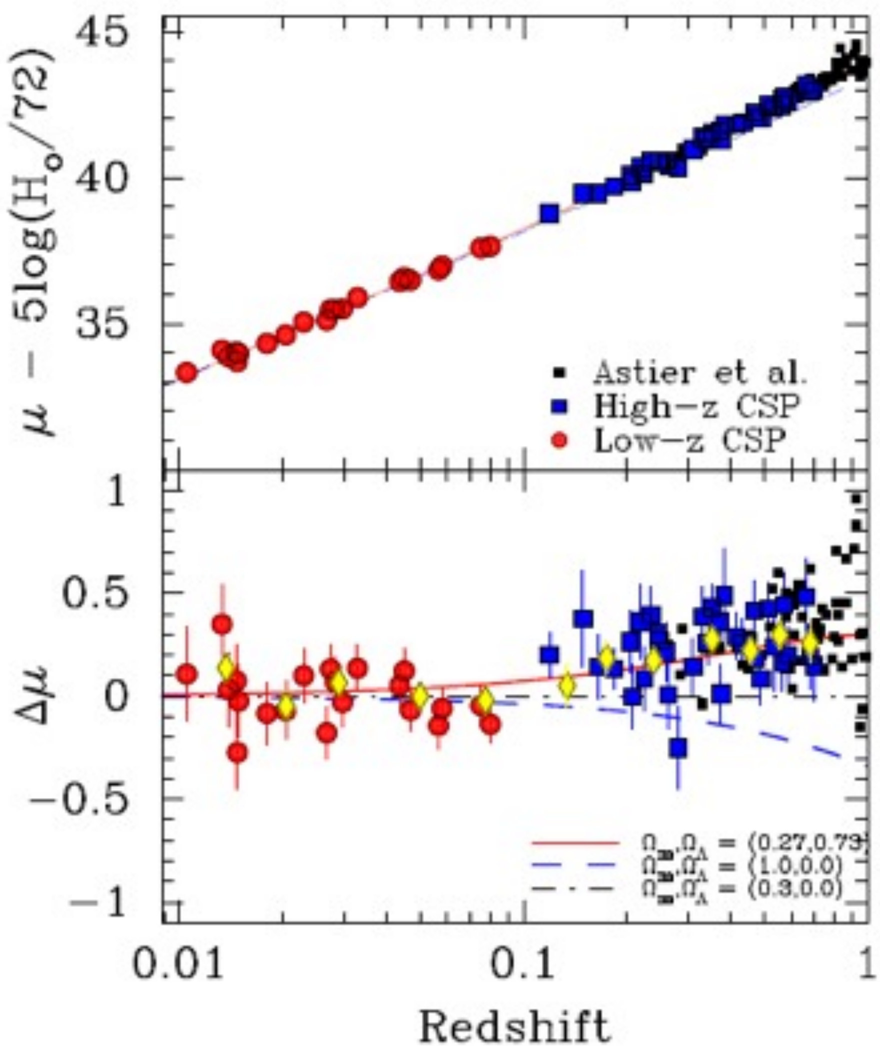

R_V=1.74±0.27

Freedman et al.

TABLE 7
COSMOLOGICAL RESULTS

R_V	Band	Ω_m	w	rms
1.74	$W^{i'}_{BV}$	0.27 ± 0.02	-1.05 ± 0.13	0.13
	W^{B}_{BV}	0.27 ± 0.02	-1.08 ± 0.14	0.15
3.1	$W^{i'}_{BV}$	0.26 ± 0.02	-1.20 ± 0.13	0.20
	W^{B}_{BV}	0.25 ± 0.03	-1.24 ± 0.16	0.24

Open issue (3): Lightcurve fitting in I-band

SDSS-II: first year

FIRST-YEAR SLOAN DIGITAL SKY SURVEY-II (SDSS-II) SUPERNOVA RESULTS: HUBBLE DIAGRAM AND COSMOLOGICAL PARAMETERS

Richard Kessler,[1,2] Andrew C. Becker,[3] David Cinabro,[4] Jake Vanderplas,[3] Joshua A. Frieman,[2,1,5] John Marriner,[5] Tamara M Davis,[6,7] Benjamin Dilday,[8] Jon Holtzman,[9] Saurabh W. Jha,[8] Hubert Lampeitl,[10] Masao Sako,[11] Mathew Smith,[10,12] Chen Zheng,[22] Robert C. Nichol,[10] Bruce Bassett,[12,13] Ralf Bender,[20] Darren L. Depoy,[14] Mamoru Doi,[15,16] Ed Elson,[12] Alexei V. Filippenko,[17] Ryan J. Foley,[17,18] Peter M. Garnavich,[19] Ulrich Hopp,[20] Yutaka Ihara,[15,21] William Ketzeback,[22] W. Kollatschny,[24] Kohki Konishi,[27] Jennifer L. Marshall,[14] Russet J. McMillan,[22] Gajus Miknaitis,[37,5] Tomoki Morokuma,[23] Edvard Mörtsell,[25] Kaike Pan,[22] Jose Luis Prieto,[26] Michael W. Richmond,[29] Adam G. Riess,[30,31] Roger Romani,[32] Donald P. Schneider,[33] Jesper Sollerman,[7,28] Naohiro Takanashi,[23] Kouichi Tokita,[15,21] Kurt van der Heyden,[35] J. C. Wheeler,[34] Naoki Yasuda,[27] and Donald York[1,36]

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ABSTRACT

We present measurements of the Hubble diagram for 103 Type Ia supernovae (SNe) with redshifts $0.04 < z < 0.42$, discovered during the first season (Fall 2005) of the Sloan Digital Sky Survey-II (SDSS-II) Supernova Survey. These data fill in the redshift "desert" between low- and high-redshift SN Ia surveys. Within the framework of the MLCS2K2 light-curve fitting method, we use the SDSS-II SN sample to infer the mean reddening parameter for host galaxies, $R_V = 2.18 \pm 0.14_{\rm stat} \pm 0.48_{\rm syst}$, and find that the intrinsic distribution of host-galaxy extinction is well fit by an exponential function, $P(A_V) = \exp(-A_V/\tau_V)$, with $\tau_V = 0.334 \pm 0.088$ mag. We combine the SDSS-II measurements with new distance estimates for published SN data from the ESSENCE survey, the Supernova Legacy Survey (SNLS), the Hubble Space Telescope (HST), and a compilation of nearby SN Ia measurements. A new feature in our analysis is the use of detailed Monte Carlo simulations of all surveys to account for selection biases, including those from spectroscopic targeting. Combining the SN Hubble diagram with measurements of baryon acoustic oscillations from the SDSS Luminous Red Galaxy sample and with cosmic microwave background temperature anisotropy measurements from WMAP, we estimate the cosmological parameters w and Ω_M, assuming a spatially flat cosmological model (FwCDM) with constant dark energy equation of state parameter, w. We also consider constraints upon Ω_M and Ω_Λ for a cosmological constant model (ΛCDM) with $w = -1$ and non-zero spatial curvature. For the FwCDM model and the combined sample of 288 SNe Ia, we find $w = -0.76 \pm 0.07({\rm stat}) \pm 0.11({\rm syst})$, $\Omega_M = 0.307 \pm 0.019({\rm stat}) \pm 0.023({\rm syst})$ using MLCS2K2 and $w = -0.96 \pm 0.06({\rm stat}) \pm 0.12({\rm syst})$, $\Omega_M = 0.265 \pm 0.016({\rm stat}) \pm 0.025({\rm syst})$ using the SALT–II fitter. We trace the discrepancy between these results to a difference in the rest-frame UV model combined with a different luminosity correction from color variations; these differences mostly affect the distance estimates for the SNLS and HST supernovae. We present detailed discussions of systematic errors for both light-curve methods and find that they both show data-model discrepancies in rest-frame U-band. For the SALT–II approach, we also see strong evidence for redshift-dependence of the color-luminosity parameter (β). Restricting the analysis to the 136 SNe Ia in the Nearby+SDSS-II samples, we find much better agreement between the two analysis methods but with larger uncertainties: $w = -0.92 \pm 0.13({\rm stat})\ ^{+0.10}_{-0.33}$ (syst) for MLCS2K2 and $w = -0.92 \pm 0.11({\rm stat})\ ^{+0.07}_{-0.15}$ (syst) for SALT–II.

Subject headings: supernova cosmology: cosmological parameters

Open Issue (4) SDSS-II paper:

The source of discrepancy

Rick's talk:

- MLCS & SALT-II assume different SEDs in the UV region, required for color corrections of high-z Sne
- MLCS prior: $A_v>0$
- MLCS assumes Milky-Way interstellar extinction law, although with lower value of R_v

- ❑ Evidence point to problem in restframe UV for z<0.1
- ❑ MLCS uses <u>only</u> nearby SNIa for training and is thus more sensitive. (SALT-II trained on both low and high-z).

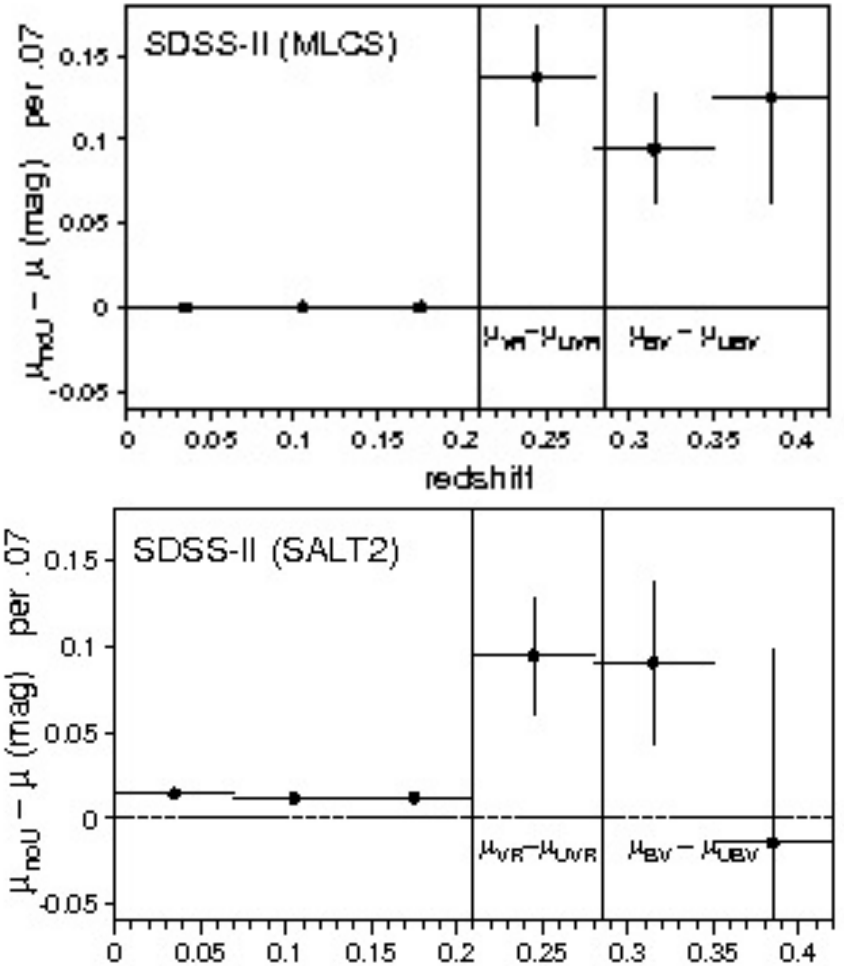
SMOCK simulation of "Constitution Set"

- **Discrepancy between fitters could fuel criticism from SNIa-skeptics**

SPECIAL EDITION

BEING CHARLES BENNETT

Open issues : restframe U-band (5) and Sample bias (6)



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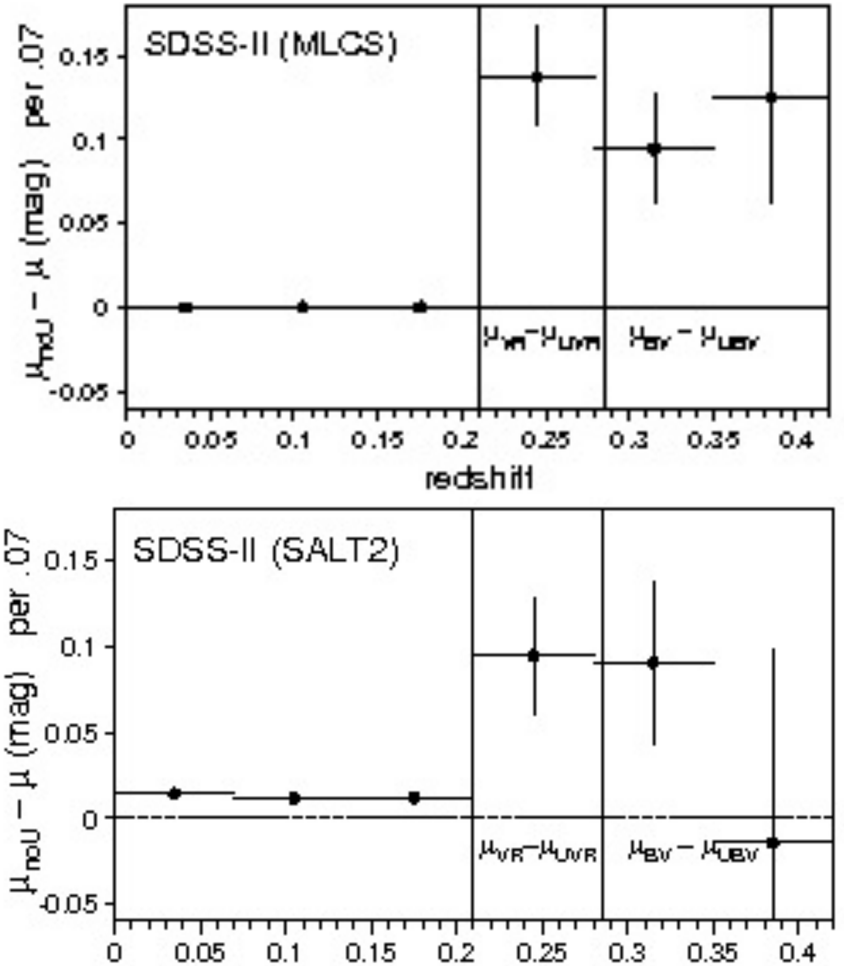
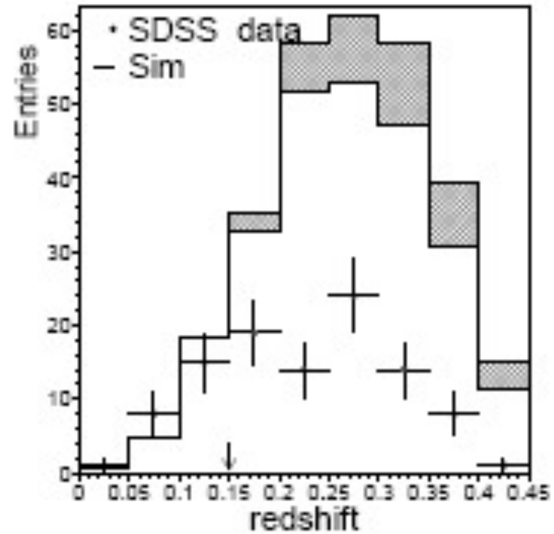
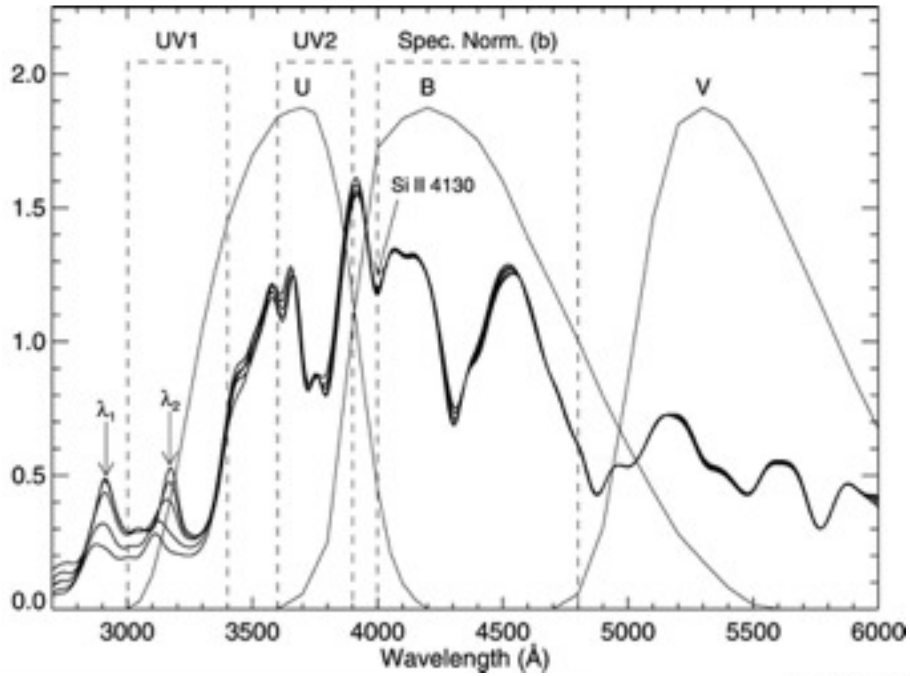
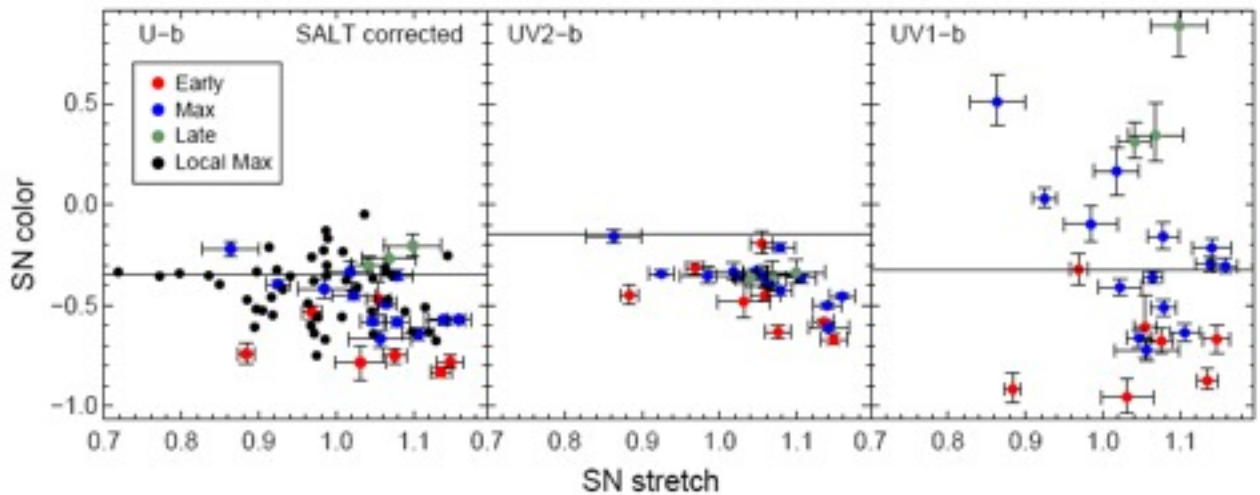




Related ?

SNLS@Keck: restframe UV





Ellis et al, 2008

FIG. 10.— Various SN Ia stretch-color relations, with colors measured directly from the SALT color law corrected Keck spe
colors shown are $U-b$, $UV1-b$ and $UV2-b$ – see Fig. 3 for filter definitions. SNe are color-coded according to the phase of the
as defined in Fig. 1. The black points in the $U-b$ distribution refers to the $U-b$ distribution of local SNe Ia at maximum light
SN surveys (e.g. Jha et al. 2006). The error-bars for the SNLS SNe include propagated uncertainties from host galaxy subtracti

Open Issue (7): Drifting properties? (we heard a partial response by Julien)

Kessler et al., 2009

MLCS2k2:
R_v=2.18±0.14±0.48

SALT-II:
β = 2.64±0.12±0.18

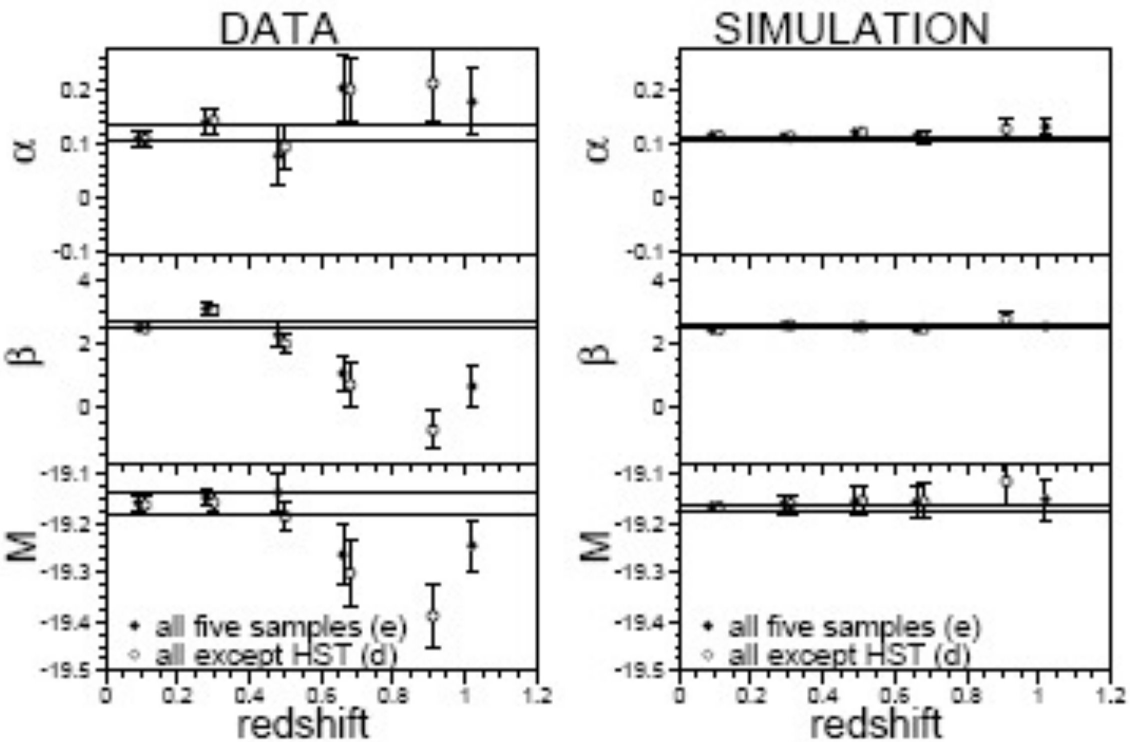


FIG. 39.— SALT–II fitted values and uncertainties for α, β, and M, evaluated independently in redshift bins for the Nearby+SDSS+ESSENCE+SNLS+HST sample combination (e) (solid dots) and for the Nearby+SDSS+ESSENCE+SNLS combination (d) (open circles). Left is for data; right is for a simulation with 10 times the number of SNe as in the data. For each redshift bin, the cosmological parameters w and Ω_M are fixed to the values from the global combination (d or e) fit. The redshift bins are $\Delta z = 0.2$ for $z < 0.8$; the highest-redshift bin includes all SNe Ia with $z > 0.8$. The dashed lines show the $\pm 1\sigma$ statistical error band based on the global fit to combination (e).

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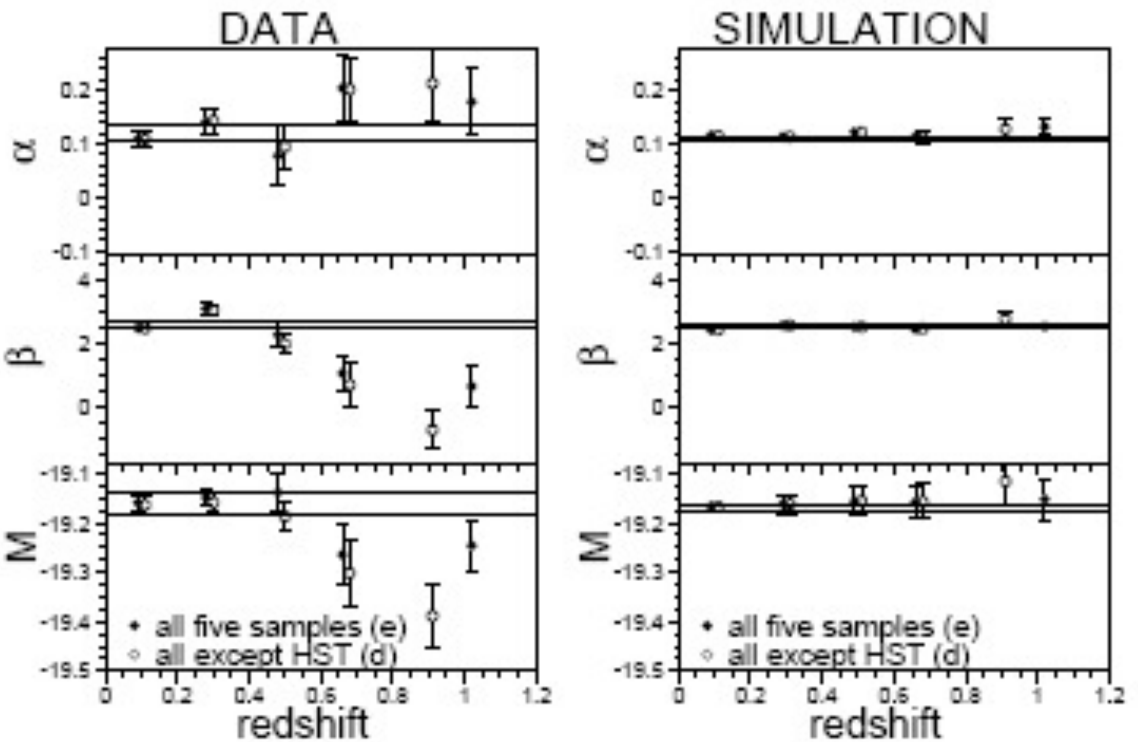
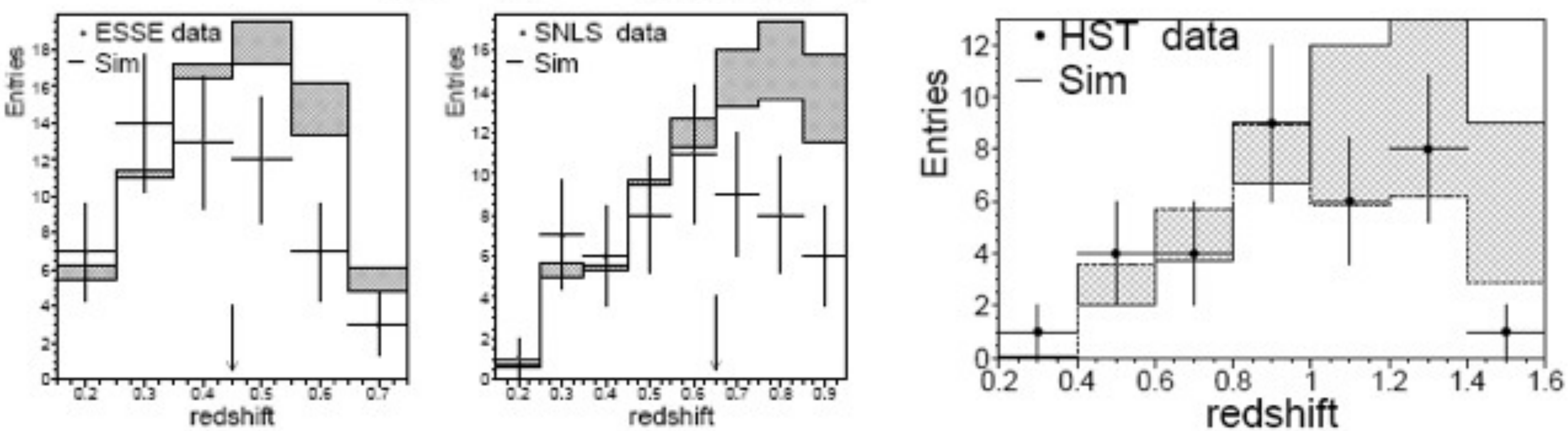
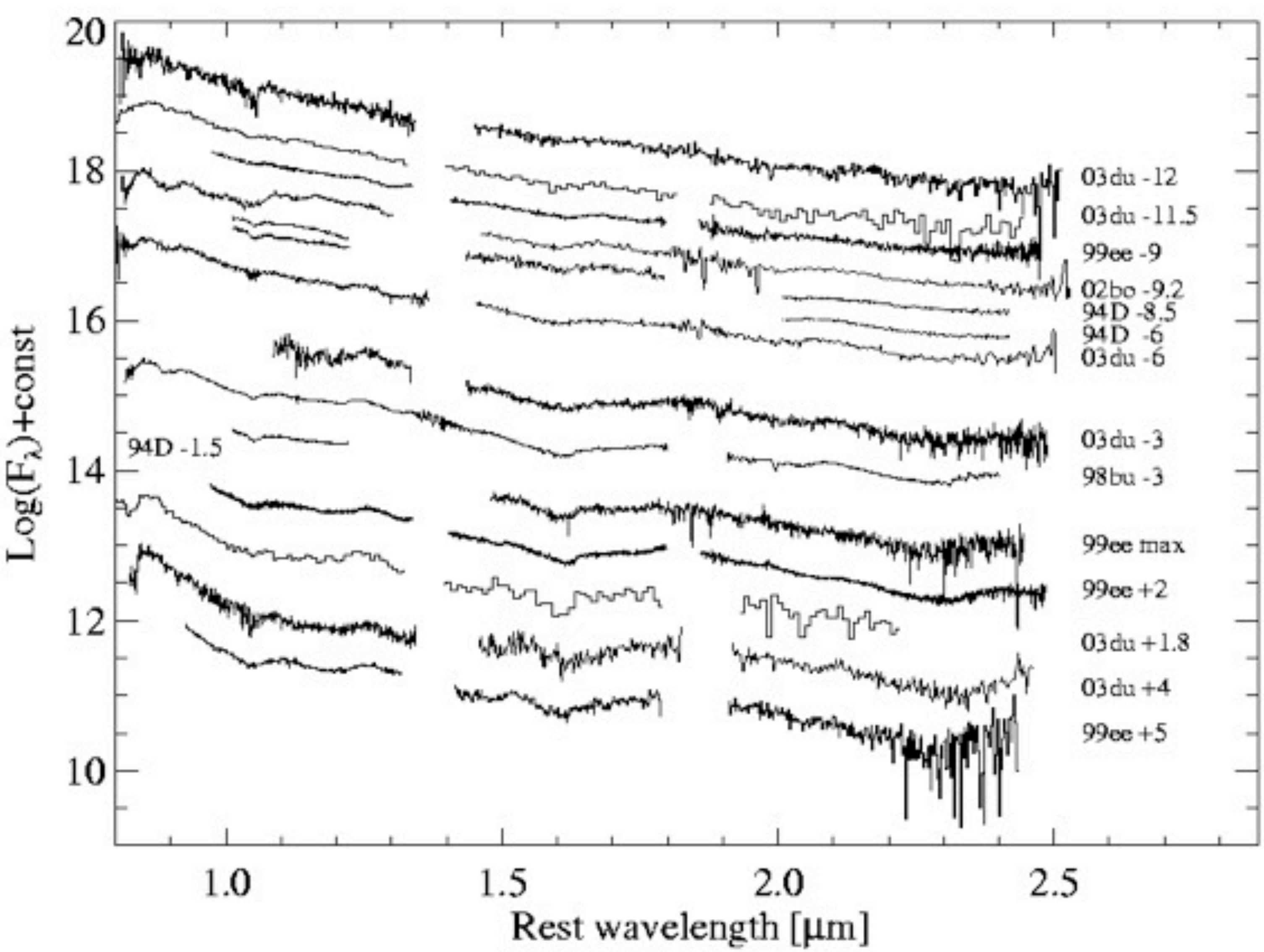




Open Issue (8):SNIa in the near-IR

We love it, but can we do it at high-z?

Featureless SED around LC max in NIR



Stanishev et al. 2007

Best standard candles in *restframe* NIR?

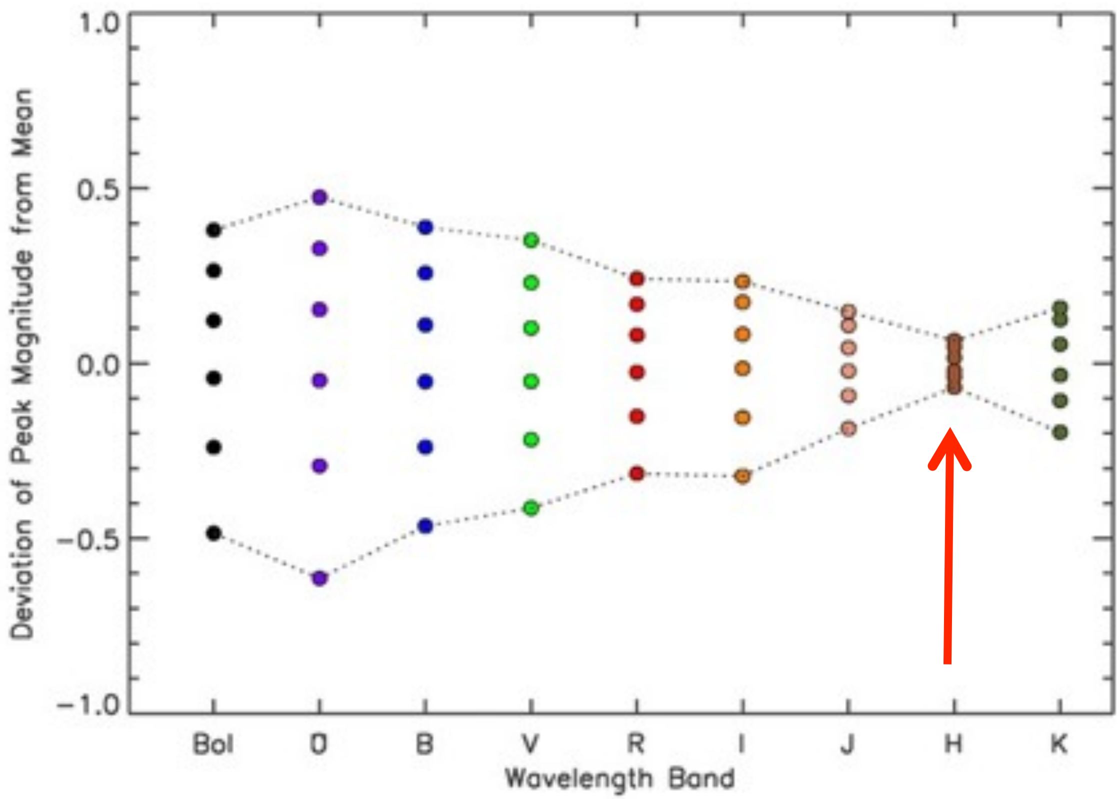


FIG. 15.—Dispersion in peak magnitude (measured at the first light curve maximum) as a function of wavelength band for the models of Fig. 10 with ^{56}Ni masses between 0.4 and 0.9 $M_{\odot}$. [*See the electronic edition of the Journal for a color version of this figure.*]

Takes into account SN modelling only – not extinction by dust

Kasen, 2006

Recent CfA results

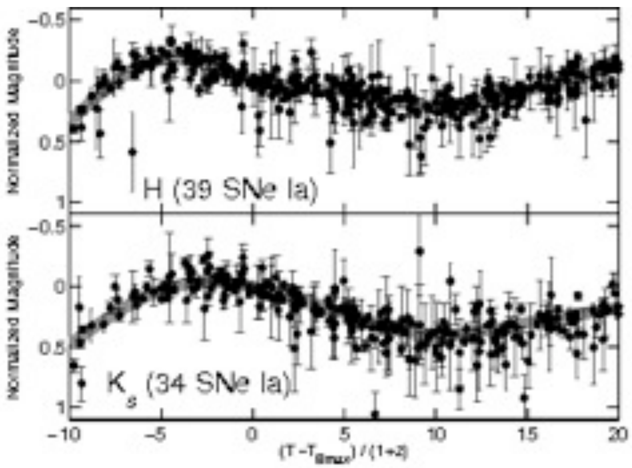
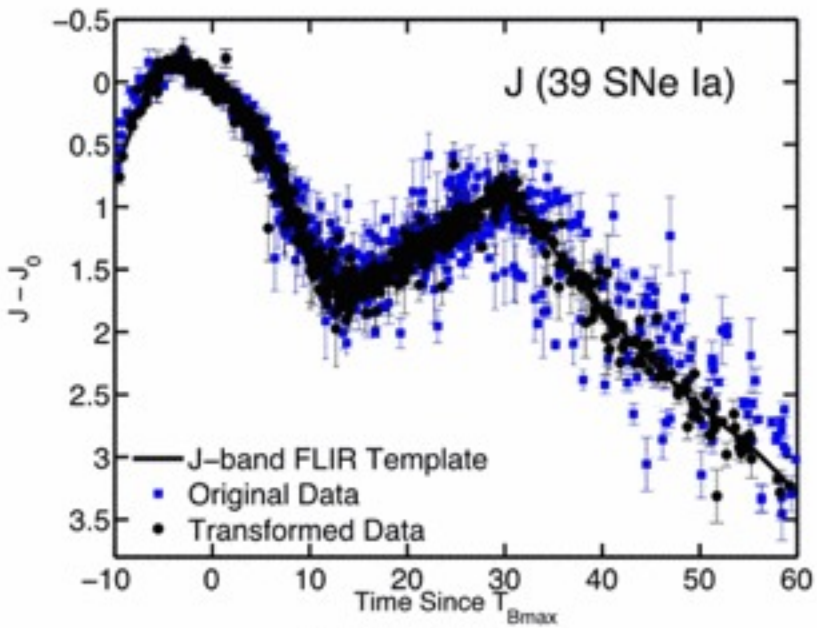
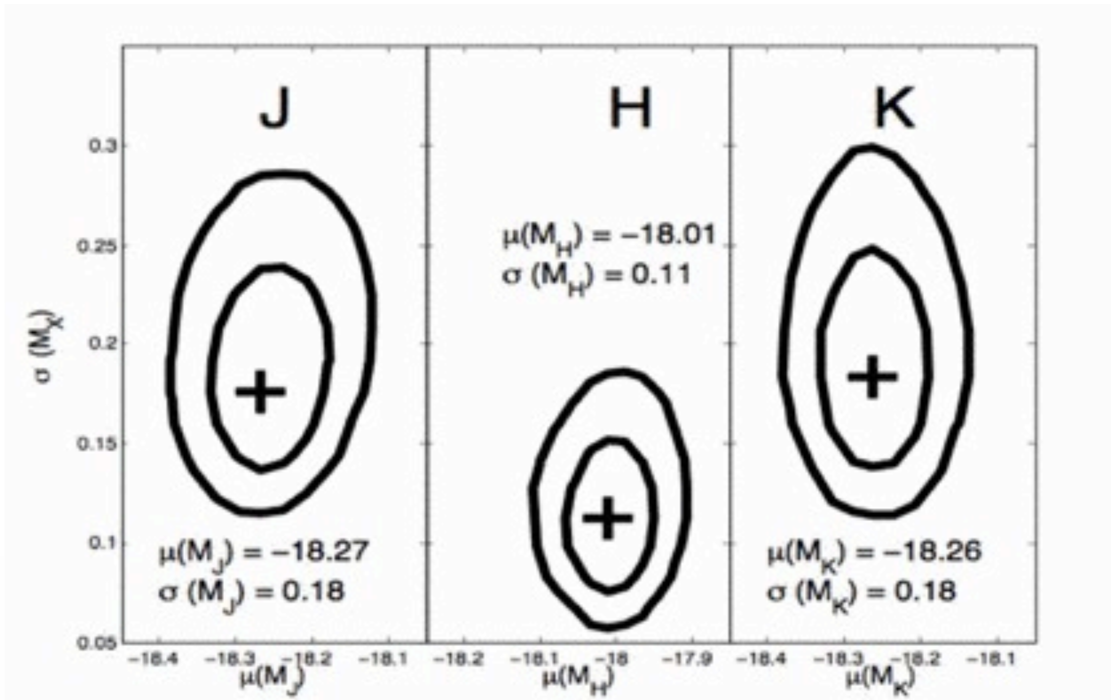


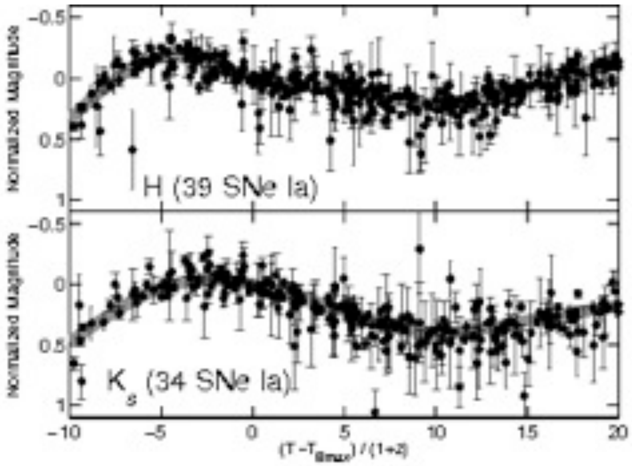
FIG. 3. Maximum likelihood templates (grey curves) with the H and K_s band data. The H and K_s normalized light curves of different SN are very similar between -10 and 20 days.





Mandel et al, 2009 (Talk following)

Recent CfA results



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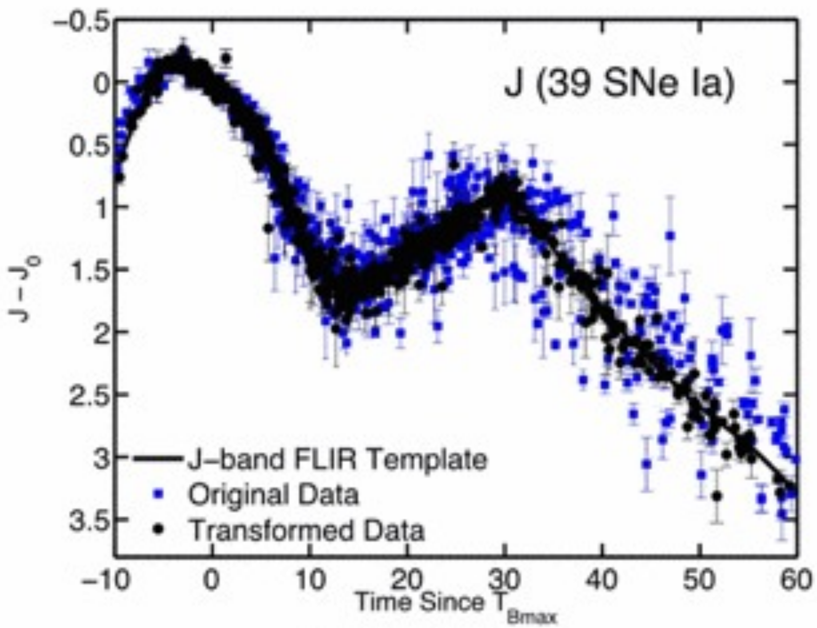
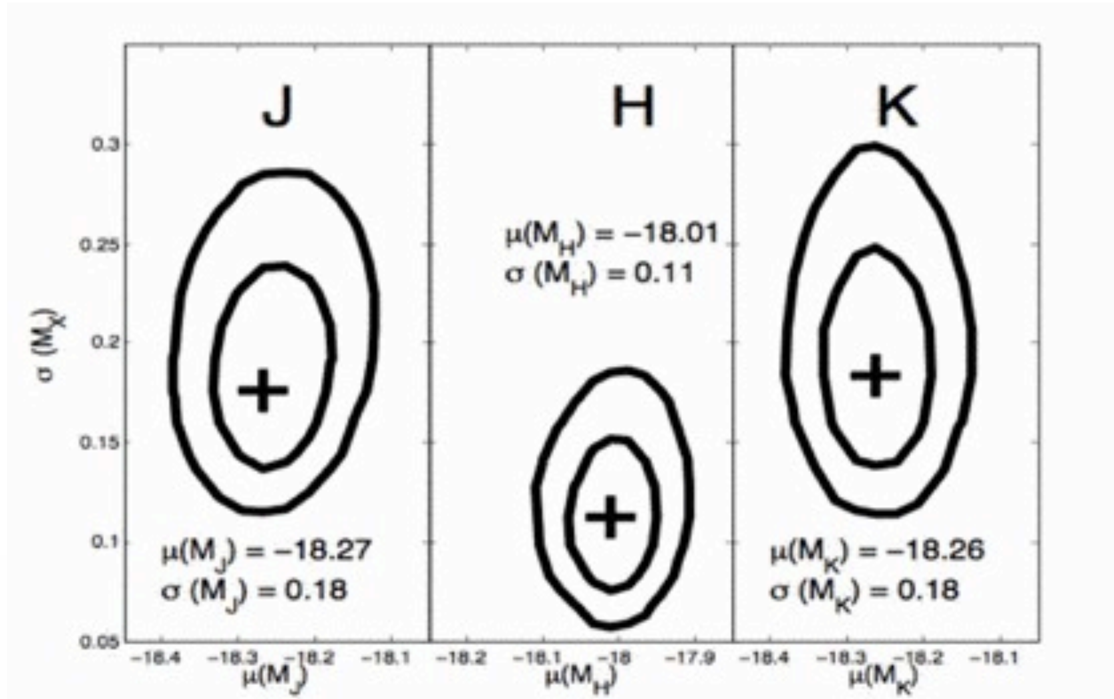
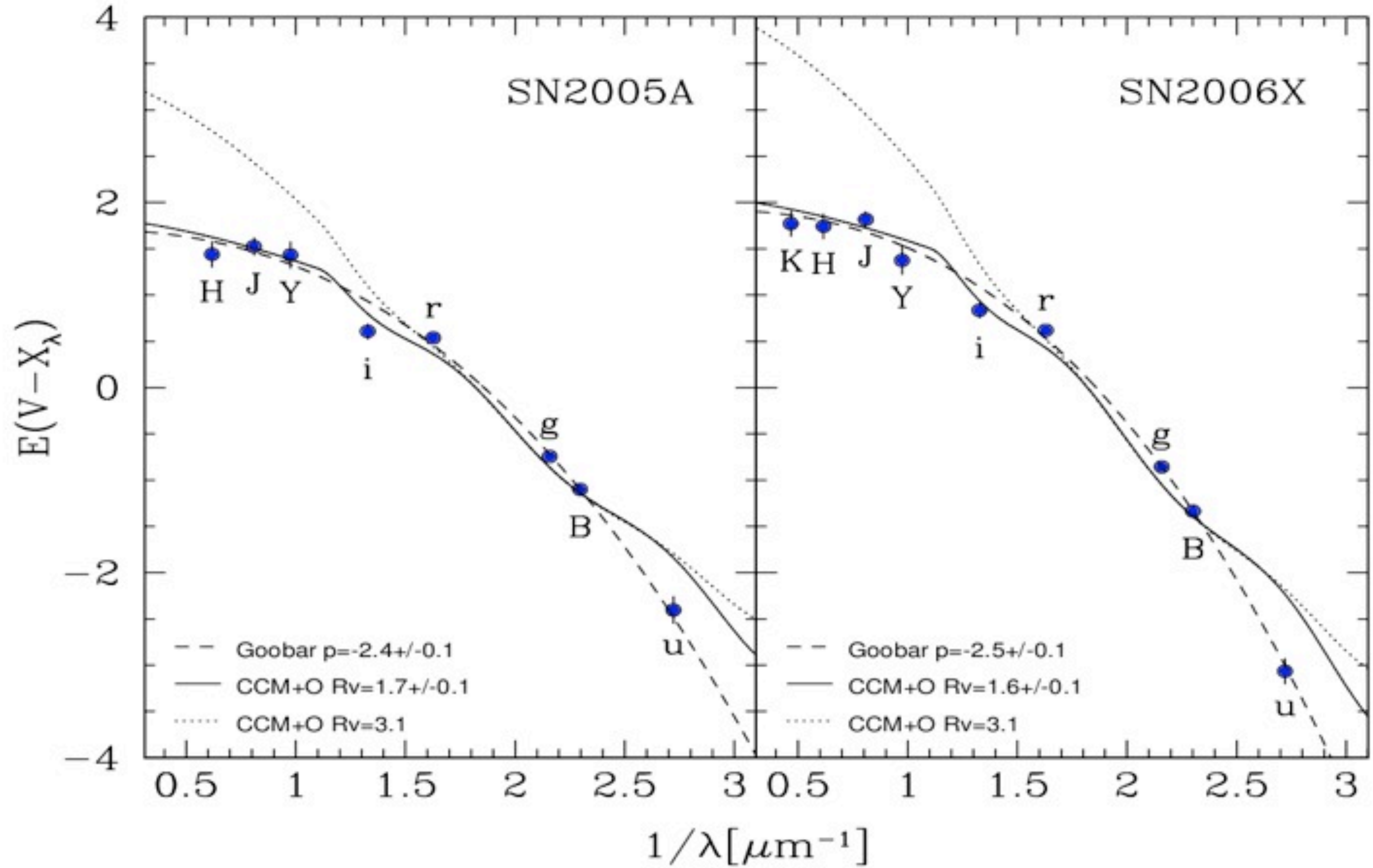




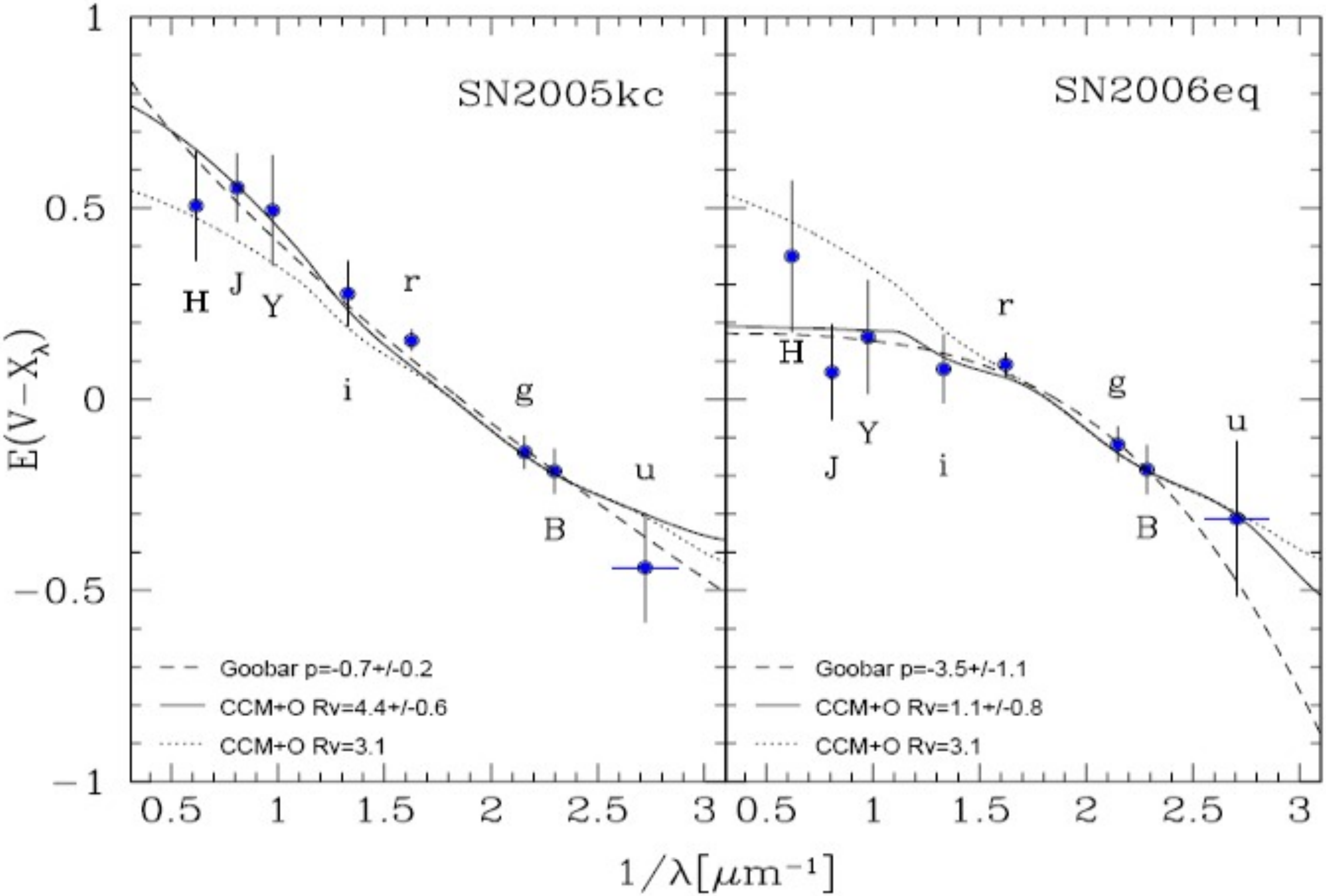
Mandel et al, 2009 (Talk following)

Problem: not easily observable at high-z!
JWST?

Carnegie Supernova Project: reddest SNIa (Folatelli et al, priv. com)

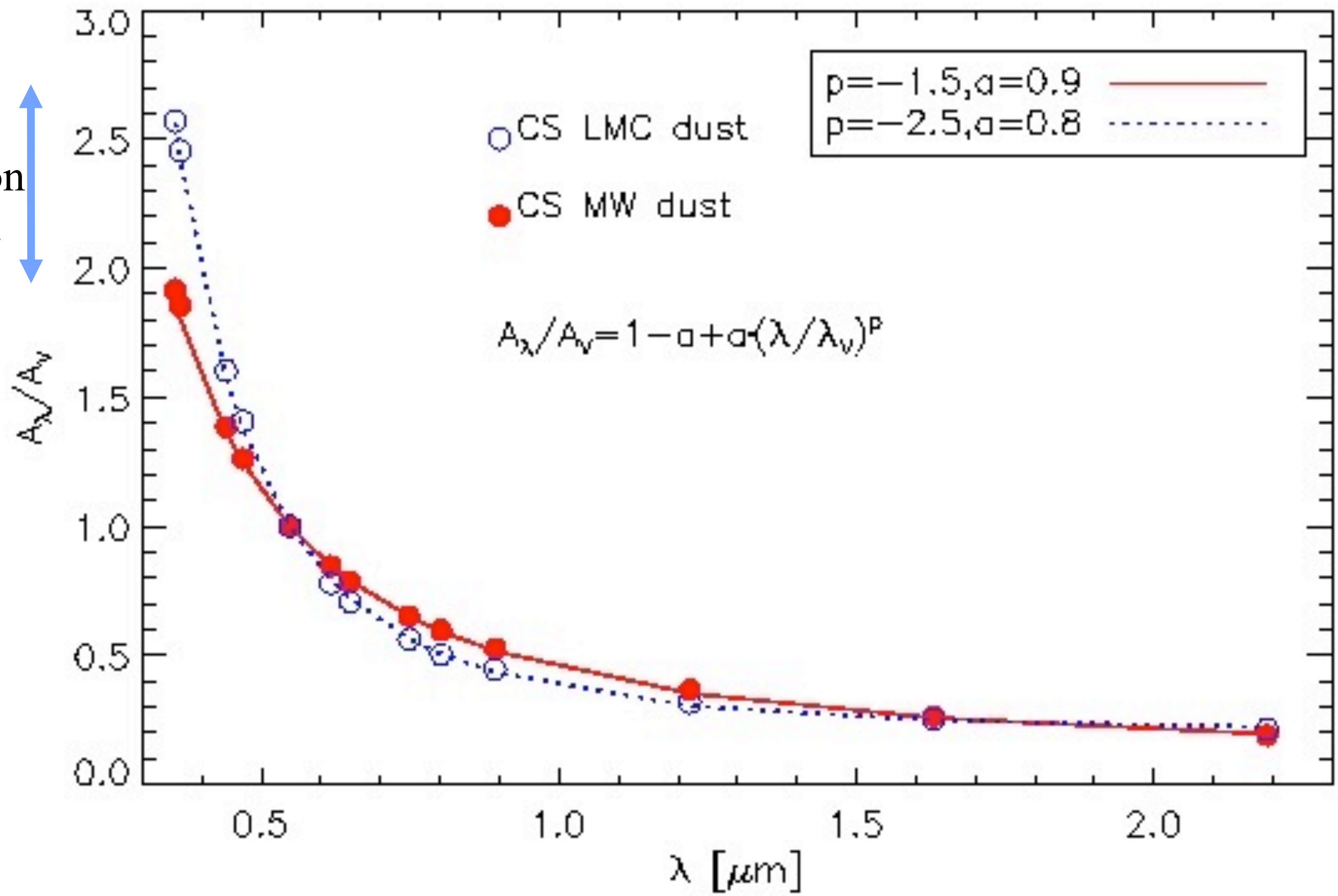


Not all quite the same...



CS dust? Power-law extinction

Large dispersion expected




”Color is my day-long obsession, joy
and torment”
-Claude Monet

Open Issue (9): Spectroscopic follow-up of SNIa

We love it, and may be necessary to test for evolution, but will we ever have the resources to do it for z~1.5?

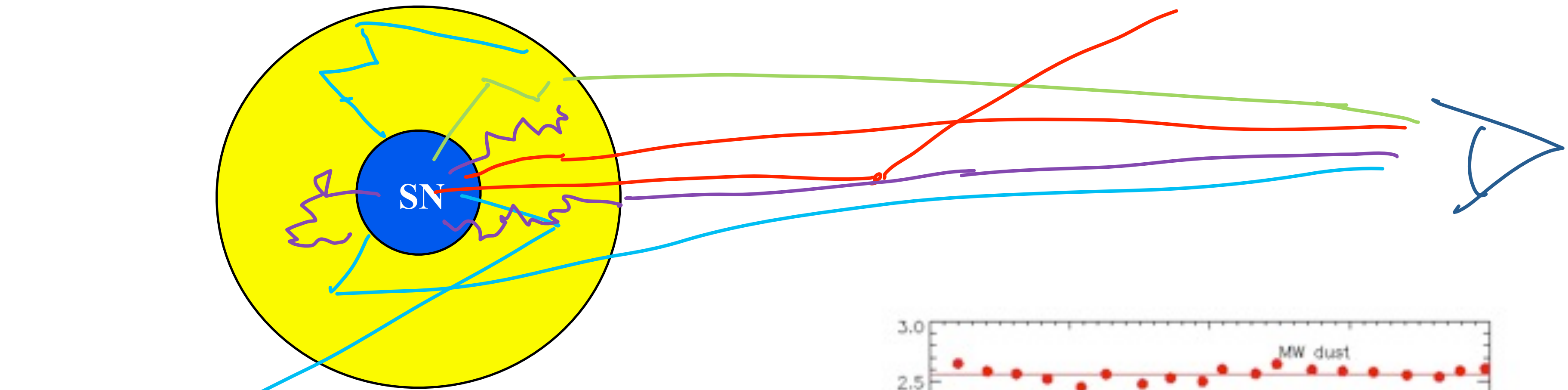
Talks following!

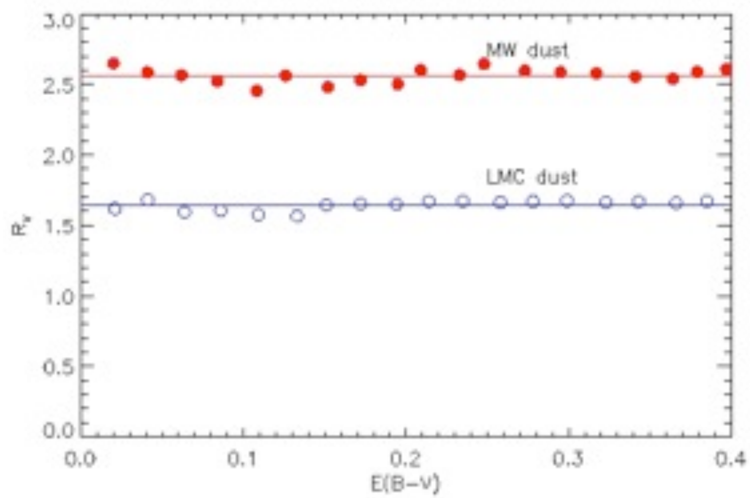
The Last Slide

- Infrared observations are key to sucess for most DE probes
- Requires space mission – Combined with ground obs?
- Planned projects may stop short of probing the entire interesting spectroscopic and photometric wavelength region for SNIa – Combined with JWST?
- Progenitors and reddening of SNIa remain key unknowns
- UV @ SNIa: don’t want cosmological fits to rely on it, but it is an important element to trace evolution and color-brightness relation
- Legacy of Cfa, CSP, SDSS, SNLS, SNFactory extremely rich
- The strengths and weaknesses of LC fitters are clearer now
- New *low-z* projects have huge potential, thanks to earlier experience: massive spectroscopic and multiband follow-up would be key, including U-band and NIR. Will this happen?

Multiple scattering in circumstellar

Observed colors after the semi-diffusive shell will depend on:
-Wavelength dependent : cross-section, albedo and scattering angle
-Dust density and shell volume





AG, ApJ 2008

see also Wang 05

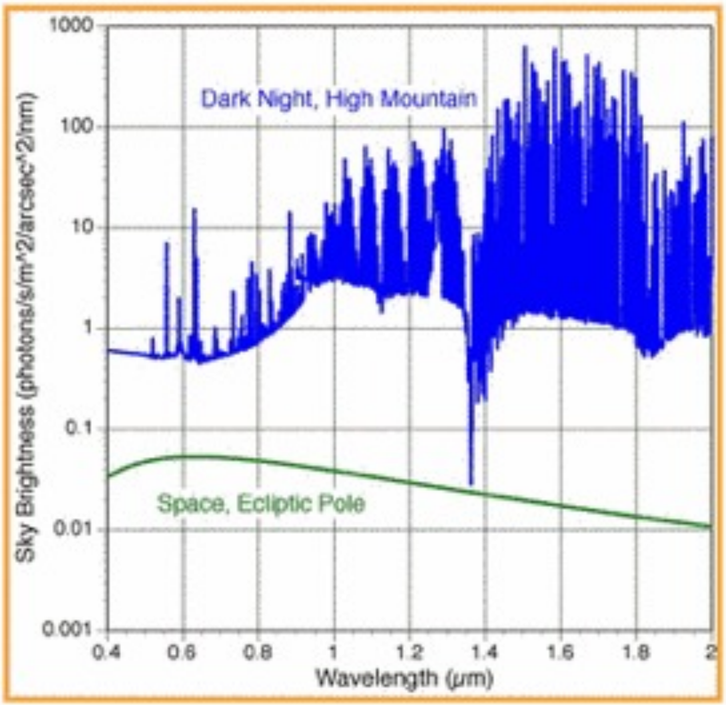
Only in space!

Rest frame IR measurements of z~1 supernovae are not possible from the ground (CSP was aiming at I-band, and this was very difficult)

Go as far into the IR as technically feasible!

Sky is very bright in NIR: >100x brighter than in space

Sky is not transparent in NIR: absorption due to water is very strong and extremely variable



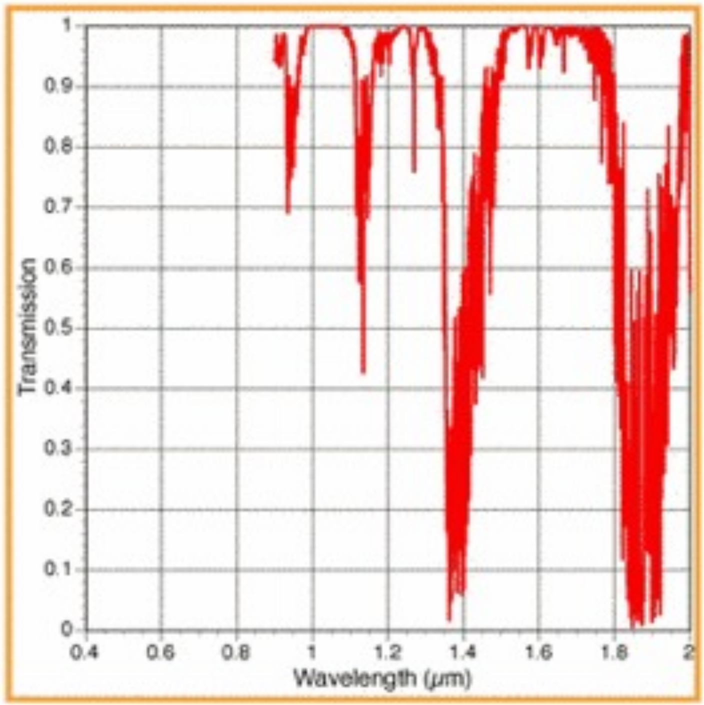
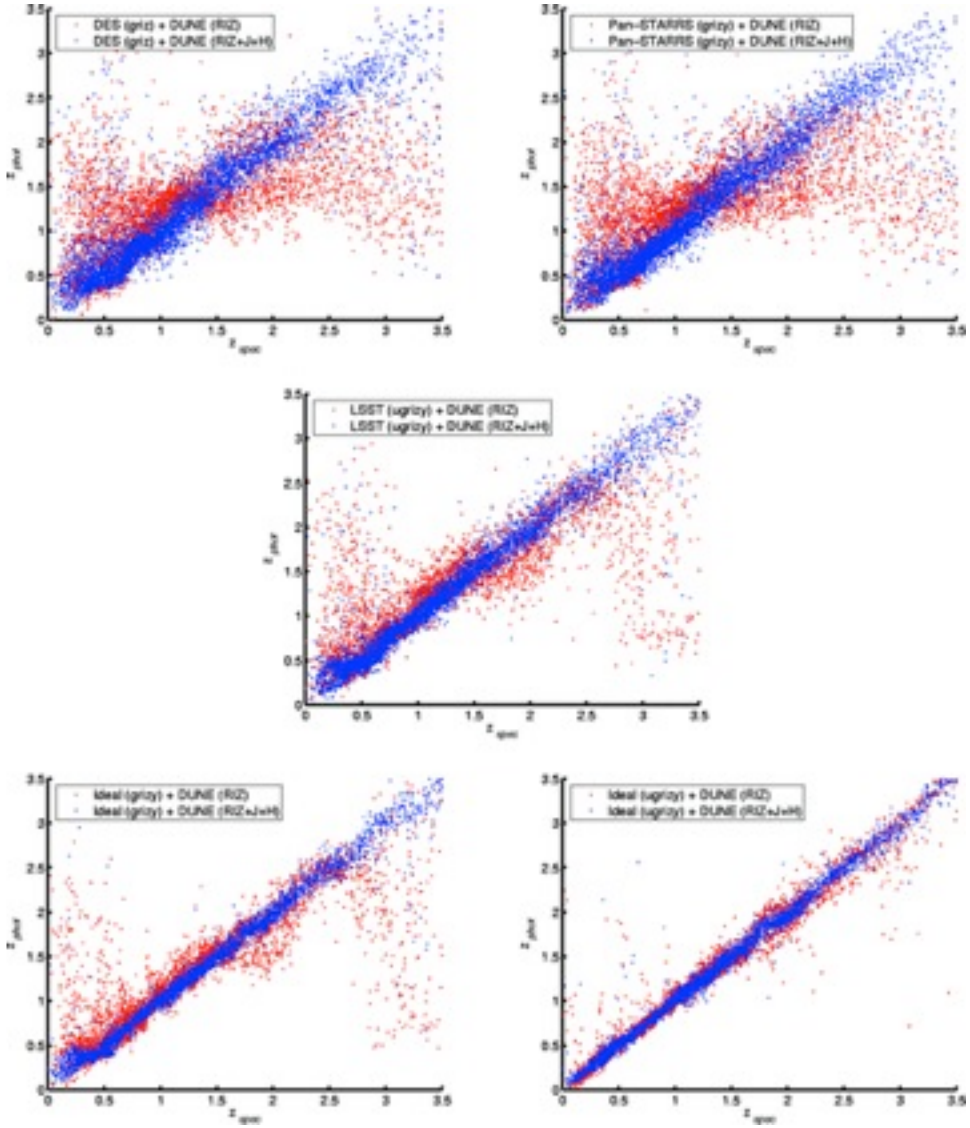
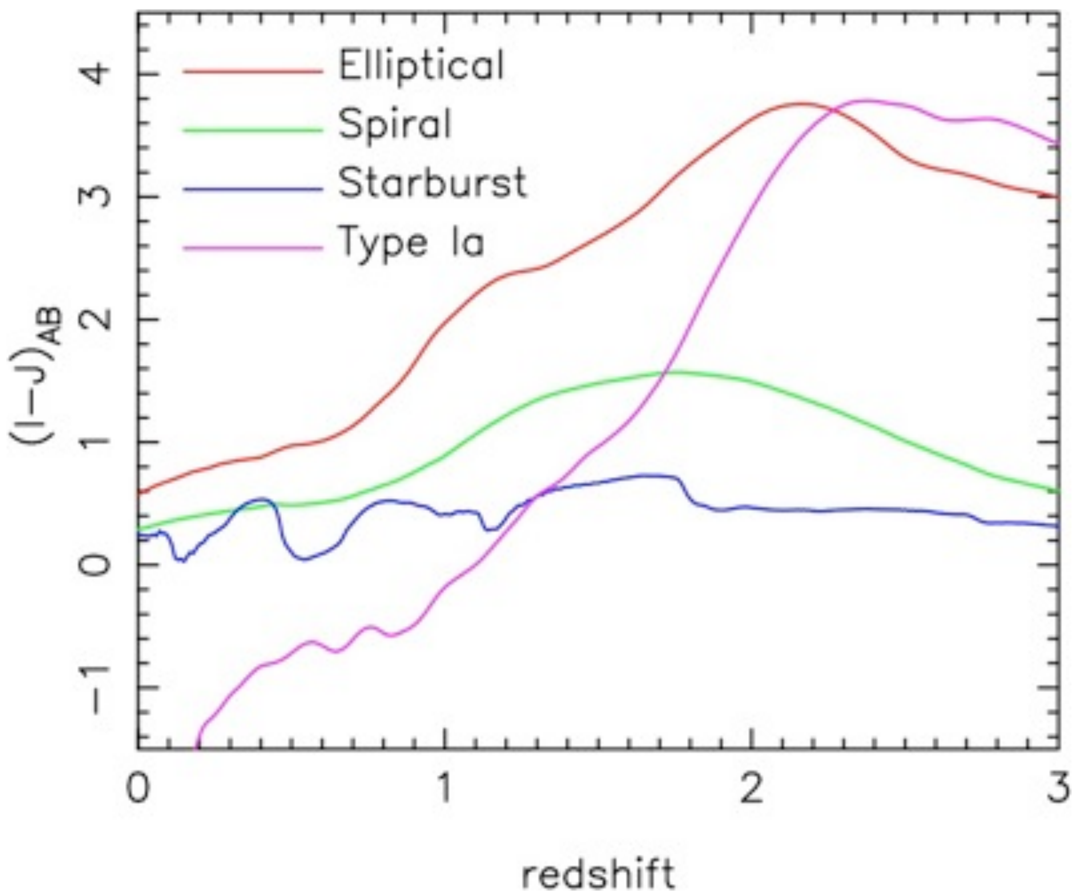


Photo-z's & near-IR



Abdalla et al, 2008



Elliptical
Spiral
Starburst
Type Ia
(I−J)AB
redshift
4
3
2
1
0
−1
0
1
2
3