A Survey of SN Ia Near-Infrared Surveys

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SN Ia NIR workshop
U. Pittsburgh
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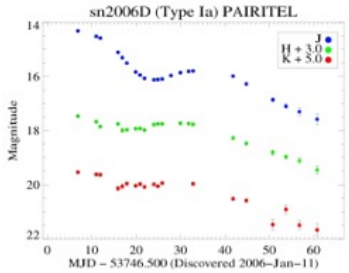
Outline

- CfAIR2 (Andy Friedman+2015):
  - low-z SN Ia NIR (JHK_s) sample with PAIRITEL
  - optical LCs in CfA3/4 (Hicken+2009,2012).
- RAISIN = RAISIN1 (GO-13046) + RAISIN2 (GO-14216):
  - high-z NIR (rest-frame YJ) with Hubble Space Telescope
  - optical from ground (Pan-STARRS & DES)
- VEILS: VISTA (4m) Extragalactic Infrared Legacy Survey
  - new UK-led ESO Public Survey, 1st unbiased extragalactic transient survey in the NIR.



CFAIR2: 94 INFRARED LIGHT CURVES OF TYPE IA SUPERNOVAE FROM PAIRITEL

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UCSD CASS Massachusetts Institute of Technology VERITAS CfA Harvard-Smithsonian Center for Astrophysics

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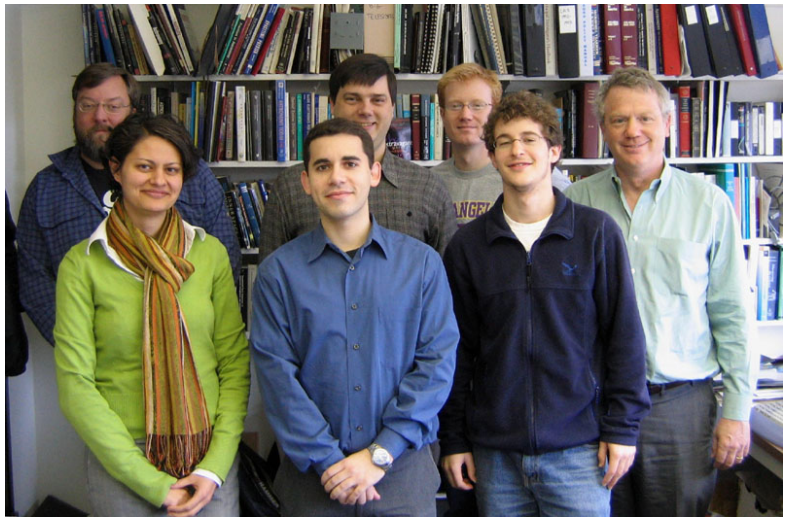
COLLABORATORS



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UCSD CASS Massachusetts Institute of Technology VE RI TAS NSF NASA PAIRITEL PETERS AUTOMATED INFRARED IMAGING TELESCOPE

PAIRITEL SN PROJECT

- Study NIR properties of large, homogeneous, ground-based, low-z, bright SN Ia data set
- NIR+Optical→ more accurate & precise distances
- Understand dust in other galaxies
- Training: High-z cosmology (RAISIN, WFIRST)

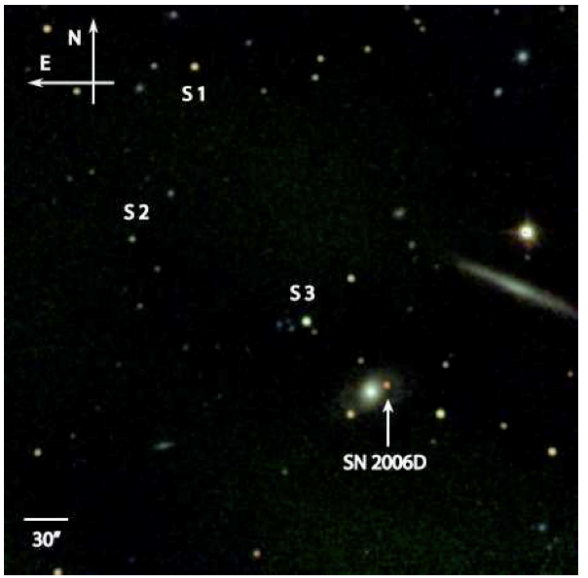
Peters Automated InfraRed Imaging TELescope

- **PAIRITEL 1.3m: 2MASS telescope**
- **Roboticized in 2004: (Bloom+06)**
- **Autonomous queue scheduled obs.**
- **20+ science projects + SN follow-up**

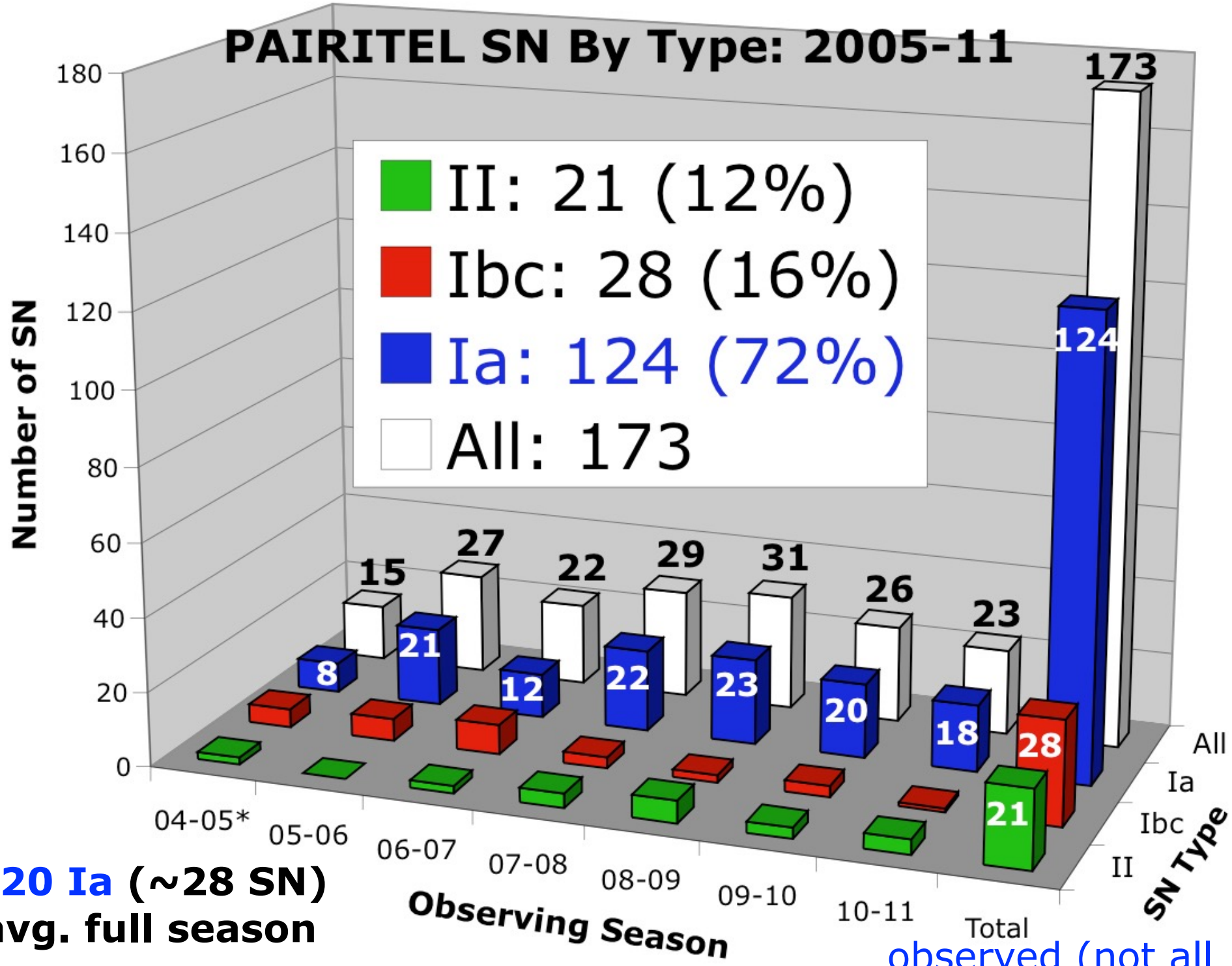
PAIRITEL END OF LIFE 2013 (RIP)

PAIRITEL SN Project

- **~30% time on telescope 2005-11 (12)**
- **Homogeneous data set, tested camera**
- **Simultaneous JHK, ~nightly cadence**
- **Photometric calibration → 2MASS**
- **Optical Phot., Spectra (1.2m, 1.5m)**



PAIRITEL JHKs: SN2006D
WV08 FIG 1



~20 Ia (~28 SN)
avg. full season

observed (not all published)

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CFAIR2: NEAR-INFRARED LIGHT CURVES OF 94 TYPE Ia SUPERNOVAE

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94 Ia
(4 Iax)

ABSTRACT

CfAIR2 is a large, homogeneously reduced set of near-infrared (NIR) light curves (LCs) for Type Ia supernovae (SNe Ia) obtained with the 1.3 m Peters Automated InfraRed Imaging TELescope. This data set includes 4637 measurements of 94 SNe Ia and 4 additional SNe Iax observed from 2005 to 2011 at the Fred Lawrence Whipple Observatory on Mount Hopkins, Arizona. CfAIR2 includes JHK_s photometric measurements for 88 normal and 6 spectroscopically peculiar SN Ia in the nearby universe, with a median redshift of $z \sim 0.021$ for the normal SN Ia. CfAIR2 data span the range from −13 days to +127 days from B-band maximum. More than half of the LCs begin before the time of maximum, and the coverage typically contains ∼13–18 epochs of observation, depending on the filter. We present extensive tests that verify the fidelity of the CfAIR2 data pipeline, including comparison to the excellent data of the Carnegie Supernova Project. CfAIR2 contributes to a firm local anchor for SN cosmology studies in the NIR. Because SN Ia are more nearly standard candles in the NIR and are less vulnerable to the vexing problems of extinction by dust, CfAIR2 will help the SN cosmology community develop more precise and accurate extragalactic distance probes to improve our knowledge of cosmological parameters, including dark energy and its potential time variation.

Key words: cosmology: observations – distance scale – infrared: stars – supernovae: general – techniques: image processing – techniques: photometric

CFAIR2: NEAR-INFRARED LIGHT CURVES OF 94 TYPE IA SUPERNOVAE

Friedman+2015

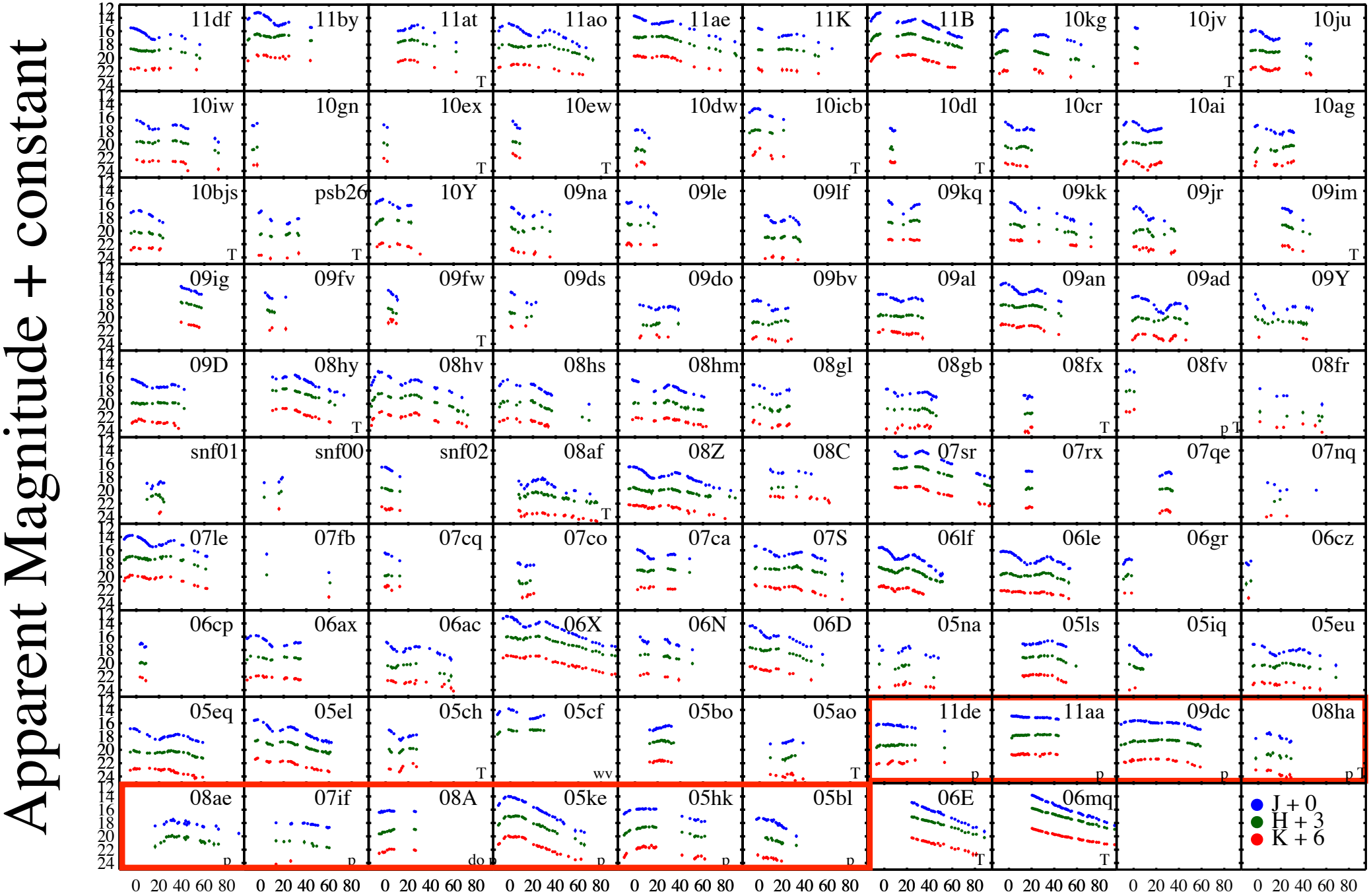
- **Improved photometry: redo 20/21 Wood-Vasey, Friedman+2008 LCs**
- **p3: More data, better sky sub, noise maps**
- **Better understanding of Errors**
- **NN2 vs. NNT galaxy subtraction**
- **Compare CSP/PAIRITEL LCs (~18 overlap objects)**

CfAIR2: Near-Infrared Light Curves of 94 Type Ia Supernovae

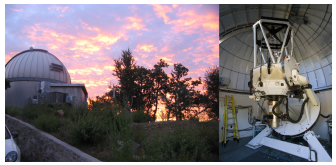
Friedman+2015

- CfAIR2 was largest homogeneous NIR SN Ia sample (94 CfA , 70 CSP1/2). Now CSP3 (114 Ia)
- +73 new normal NIR SN Ia LCs (109 → 182) (superseding WV08)
- +14 normal NIR SN Ia also observed by CSP
- Nearly doubled # of obs (4637 CfA , 2434 CSP1/2)
- CSP1/2: fewer LC pts, but excellent data, smaller errors

98 LCs: 94 Ia, 4 Iax. 88/98 normal Ia. 10/98 Ia pec or Iax



CfAIR2 **(F15)**



CFAIR2 vs. CSP1/2

18 overlap SN Ia		Individual Photometric Observations				Phot. Errors brightest pt.
	SN Ia	**Y**	**J**	**H**	**K**	**σ_{mag}**
CfAIR2	**98**	0	**1733**	**1636**	**1268**	~0.02-0.05
CSP1/2	73	**829**	776	705	124	**~0.01-0.03**

	Telescope	**Pixel size ["]**	**Image FWHM ["]**	**Under-sampled**
CfAIR2	PAIRITEL 1.3m *2MASS South Camera*	2	~2.5-3.0	Yes
CSP	Swope 1.0m *RetroCam*	**0.201**	**~1.0-2.0**	**No**
	duPont 2.5m *WIRC*	**0.196**	**~1.0-2.0**	

CfAIR2: Near-Infrared Light Curves of 94 Type Ia Supernovae

Friedman+2015

- **PAIRITEL & CSP: Complementary Data Sets**
  Quantity vs. Quality, Different objects

- **PAIRITEL / CSP (18 Overlap SN Ia)**

- **CfAIR2/CSP3 comparison in progress…**

- **Benchmark low-z data sets. Training to learn properties of NIR Ia sample, host galaxy dust, for high-z cosmology (HST RAISIN, WFIRST)**

RAISIN

Current State of Play

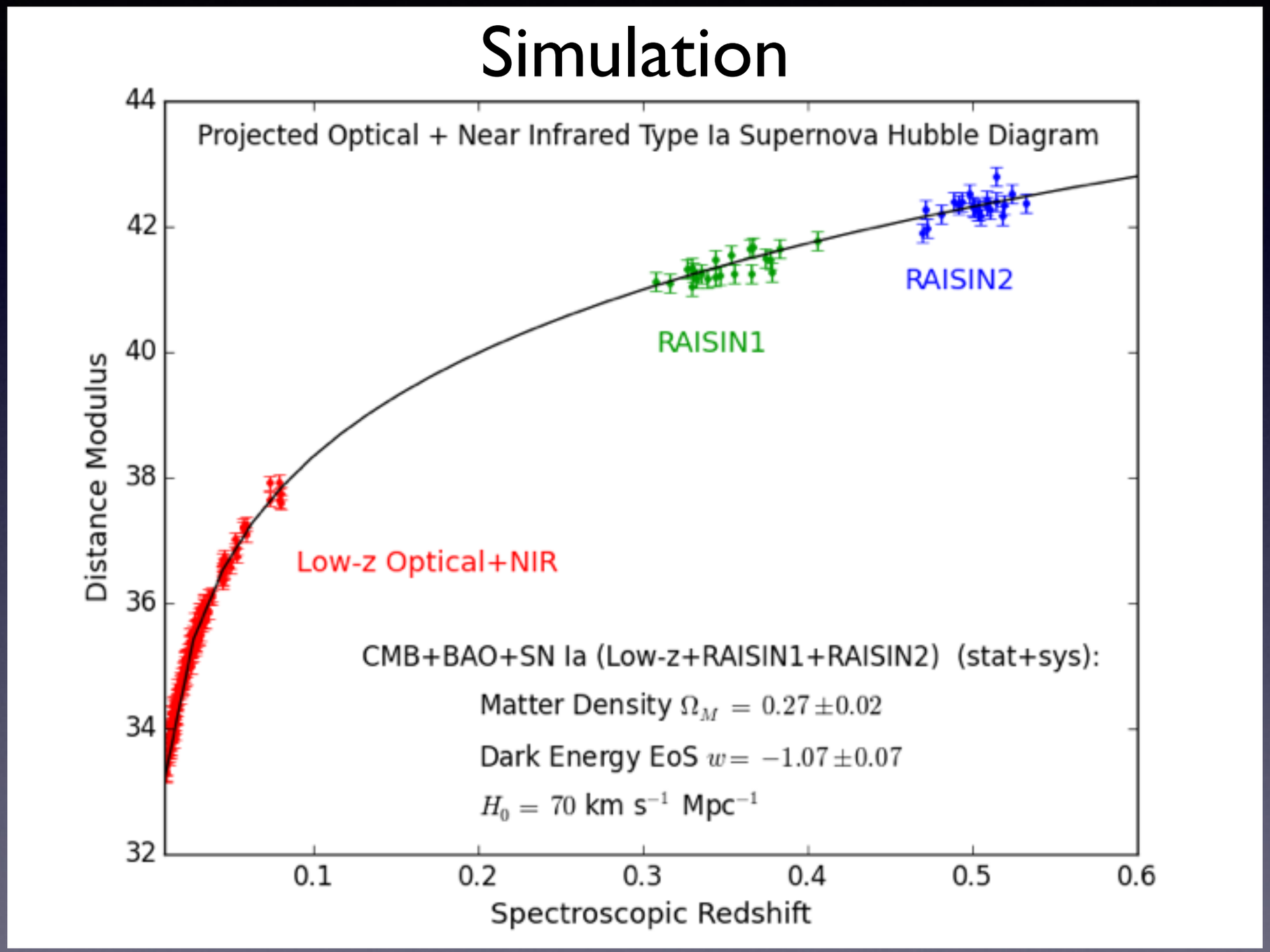
- Current optical surveys are now limited by systematic uncertainties rather than “statistical” (number of supernovae).
- Standard analysis method does not distinguish between intrinsic SN variations and extrinsic effects of host galaxy dust and reddening
- Scolnic et al. 2014 : a different statistical modelling color/mag interpretation of the data results in a 4% systematic shift in w, comparable to total uncertainty
- Mitigating systematic error due to host galaxy dust effects is important for accurate cosmological constraints

Strategy: Go to the infrared!

- Dust extinction is significantly diminished (by ~4x) in the rest-frame NIR (i.e. YJHK) compared to optical
- SN Ia are excellent candles in the NIR (small variance in absolute magnitude)
- Wavelength Range of Optical+NIR data helps constrain dust absorption & reddening better
- CfA, CSP groups built up large samples of nearby SN Ia light curves in the NIR (CfAIR2 - Friedman+2015, CSP - Krisciunas+2017).
- RAISIN1+2: 200 HST orbits to observe ~50 SN Ia in the NIR at z = 0.2-0.6 discovered with Pan-STARRS and Dark Energy Survey

Goal:
Cosmological Hubble Diagram of SN Ia in NIR

Simulation



(credit: Arturo Avelino)

How can we leverage the good NIR properties at high-z?

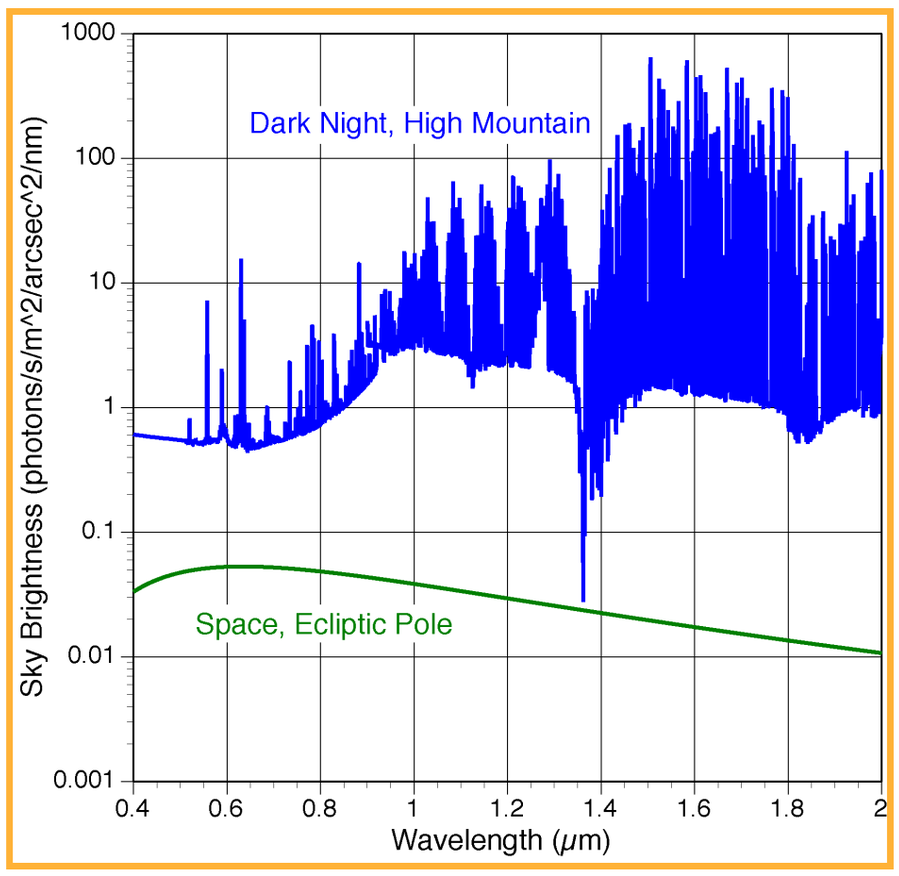
Only in space!

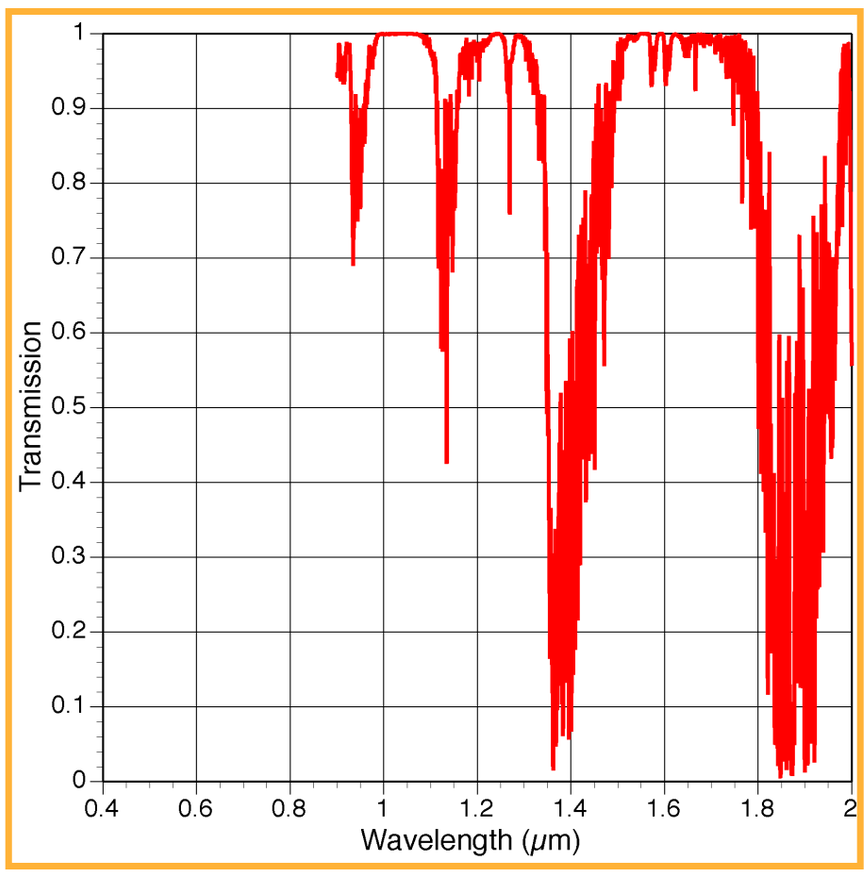
Rest frame IR measurements of z~1 supernovae are not possible from the ground

Go as far into the IR as technically feasible!

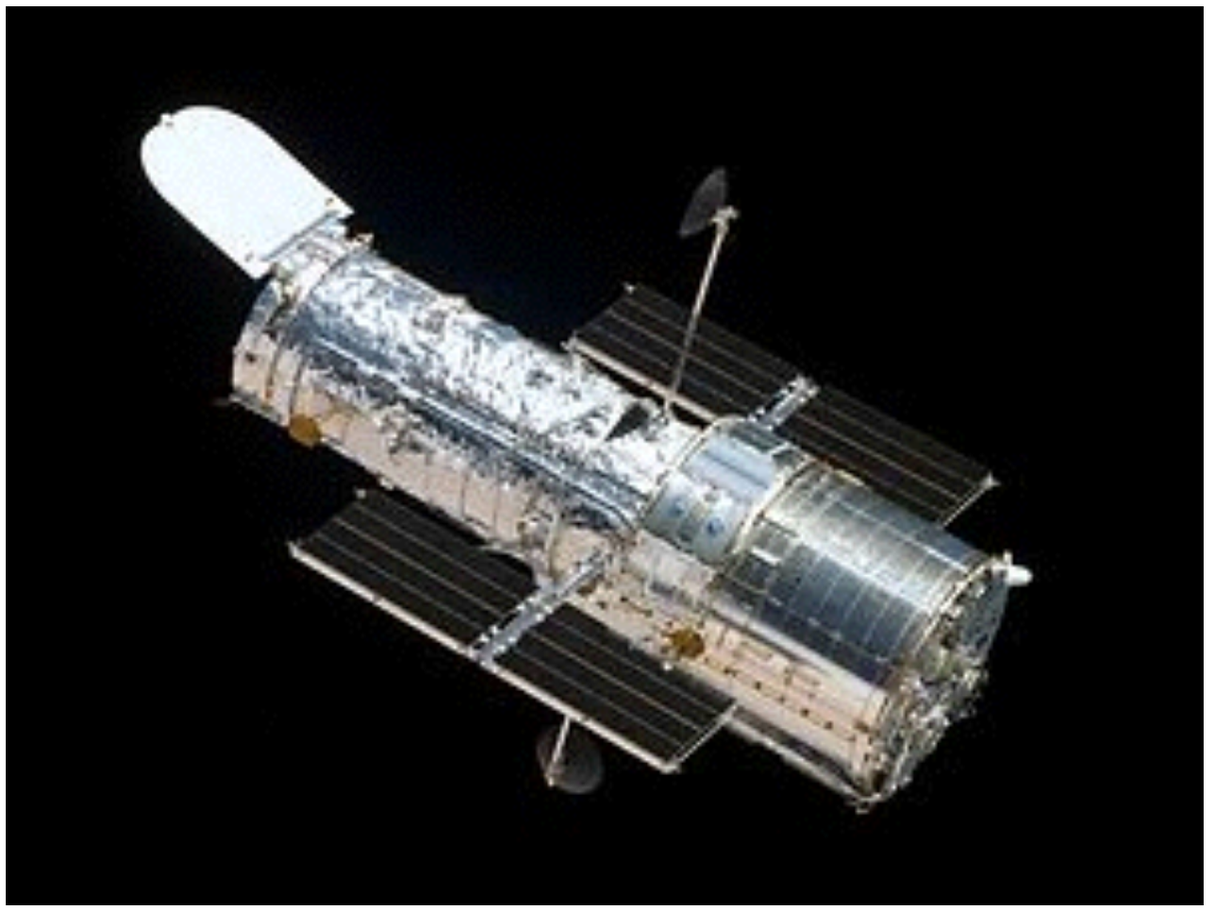
Sky is very bright in NIR: >100x brighter than in space

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





RAISIN1 (GO-13046):
Tracers of cosmic expansion with SN Ia in the IR
with the Hubble Space Telescope (HST)



Large HST program executed 2012-14 with 100 orbits to observe ~23 SN Ia at z ~ 0.35 discovered by Pan-STARRS

R. Kirshner, P. Challis, A. Avelino, D. Jones, G. Narayan, K. Mandel et al.
+ some of you!

Idea: Combining NIR HST observations with (ground-based) Optical improves statistical precision by ~2x
Reduces systematic sensitivity to dust error

PanSTARRS: A Supernova Discovery Machine

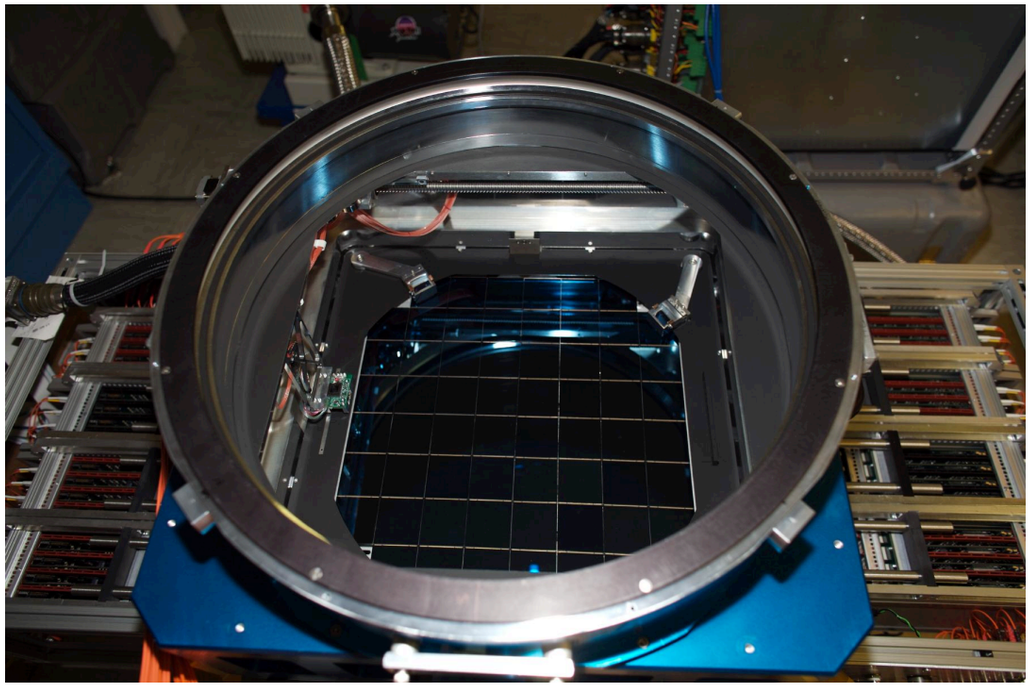
Medium-Deep Fields

Good light curves at z~0.4

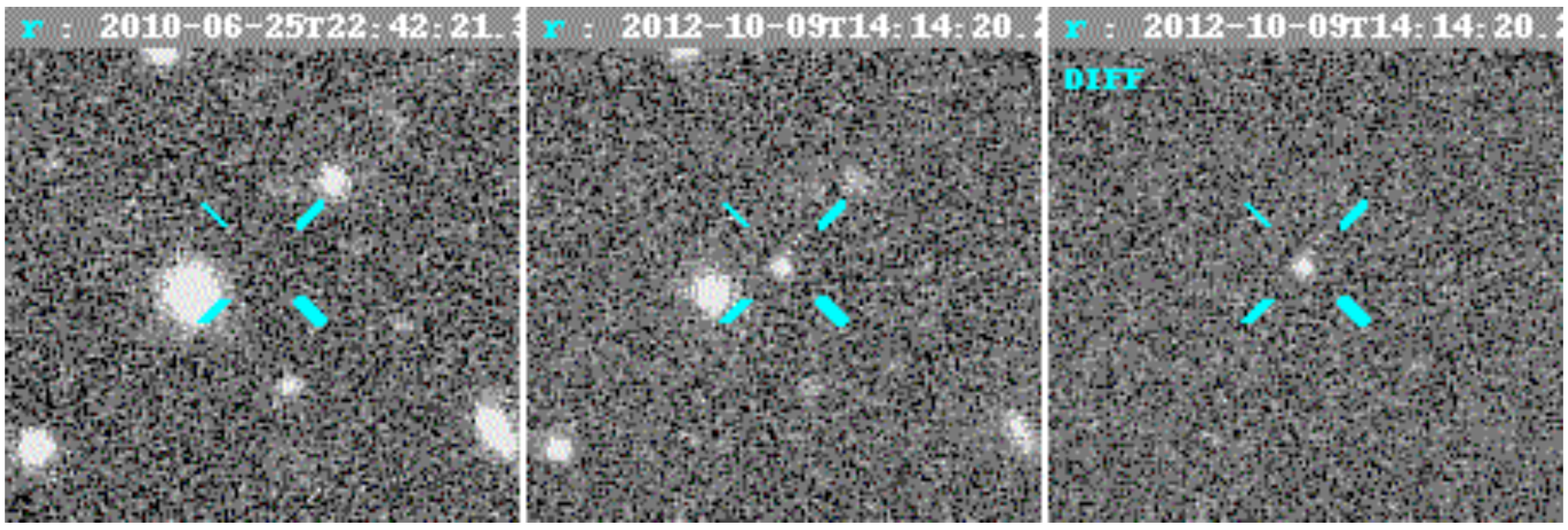
Every 4 days griz

7 square degrees 0.26”/pixel

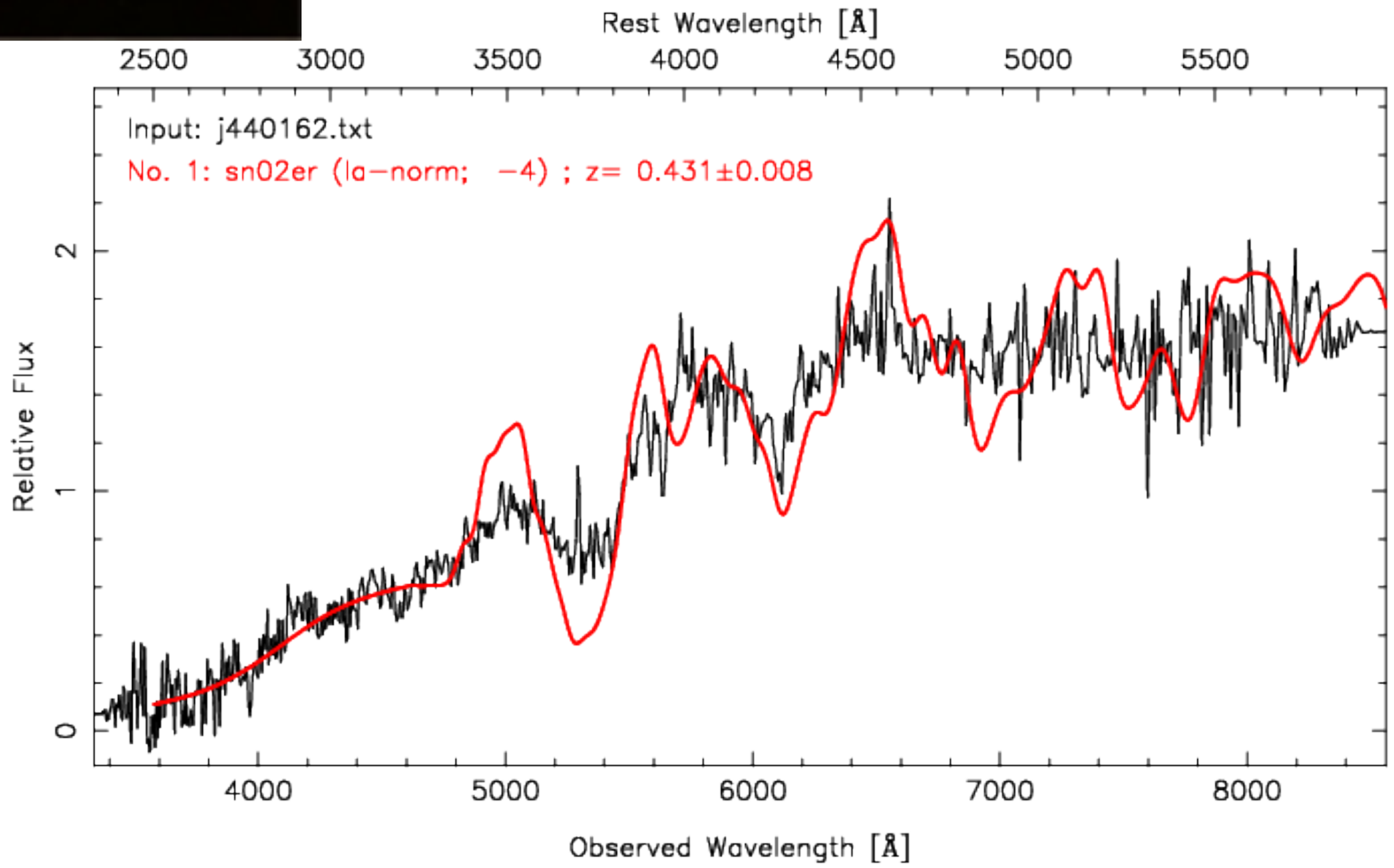
Dozens of supernova candidates every month!



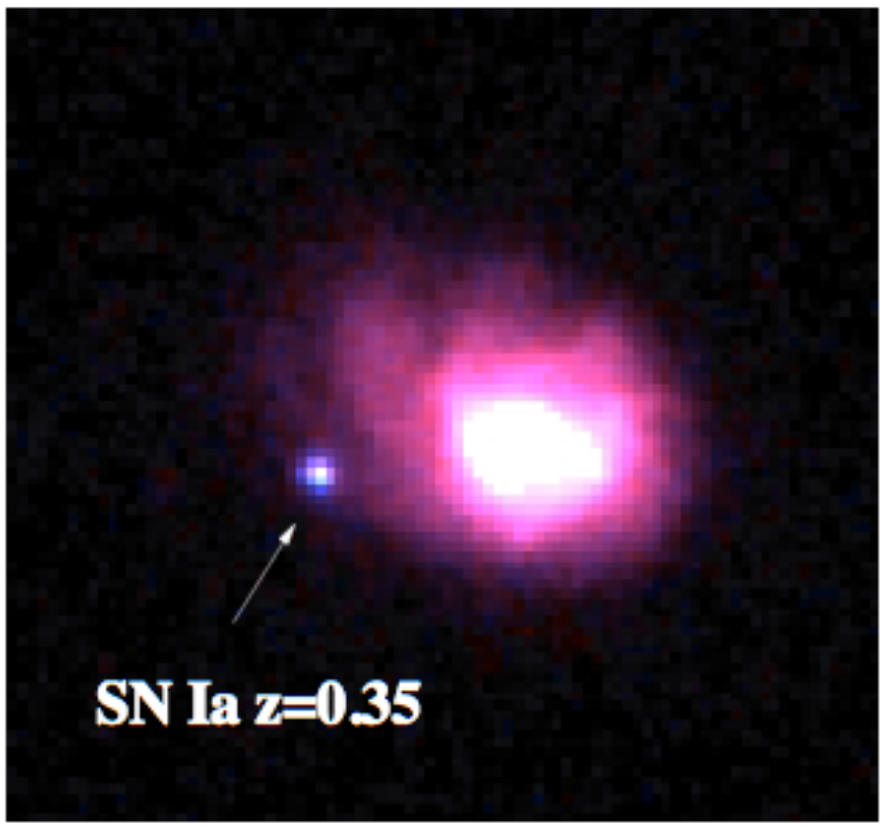
Discover Supernovae with Pan-STARRS and Difference Imaging

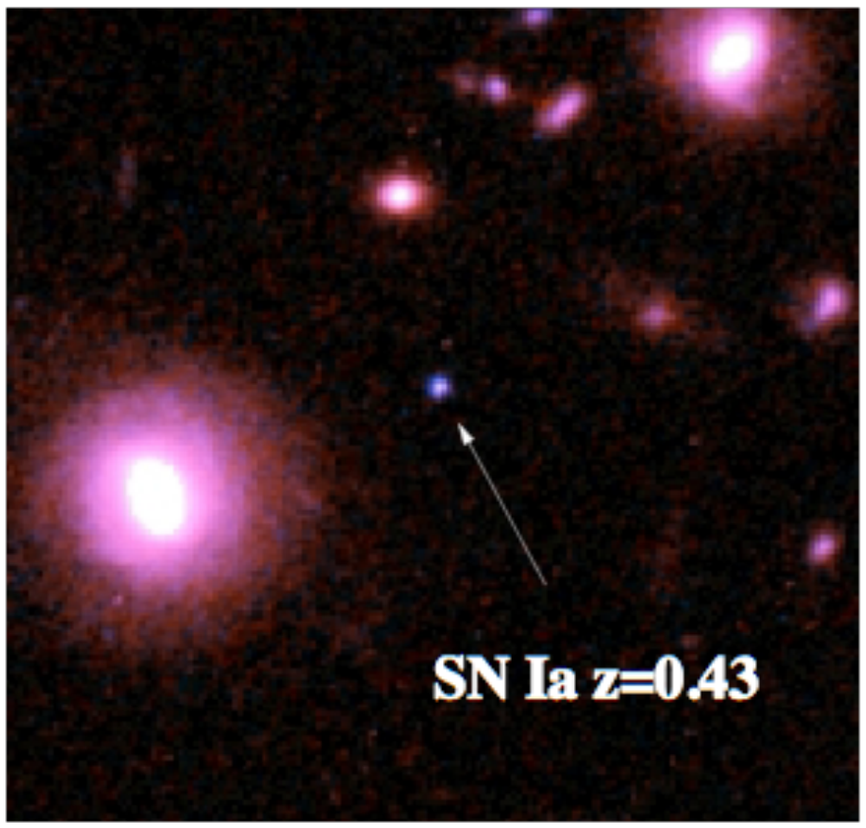


Get spectrum with MMT (or Magellan, Gemini or Keck) 358 Spectroscopic SN Ia



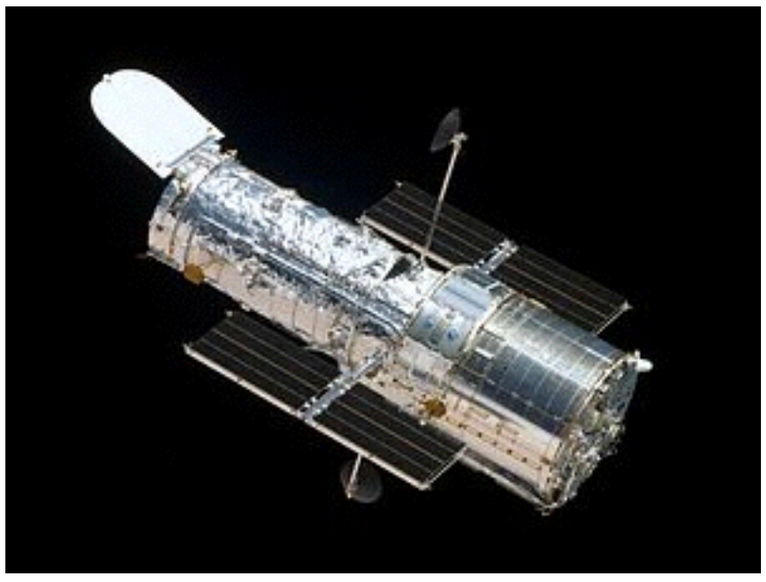
Trigger ToO HST observations



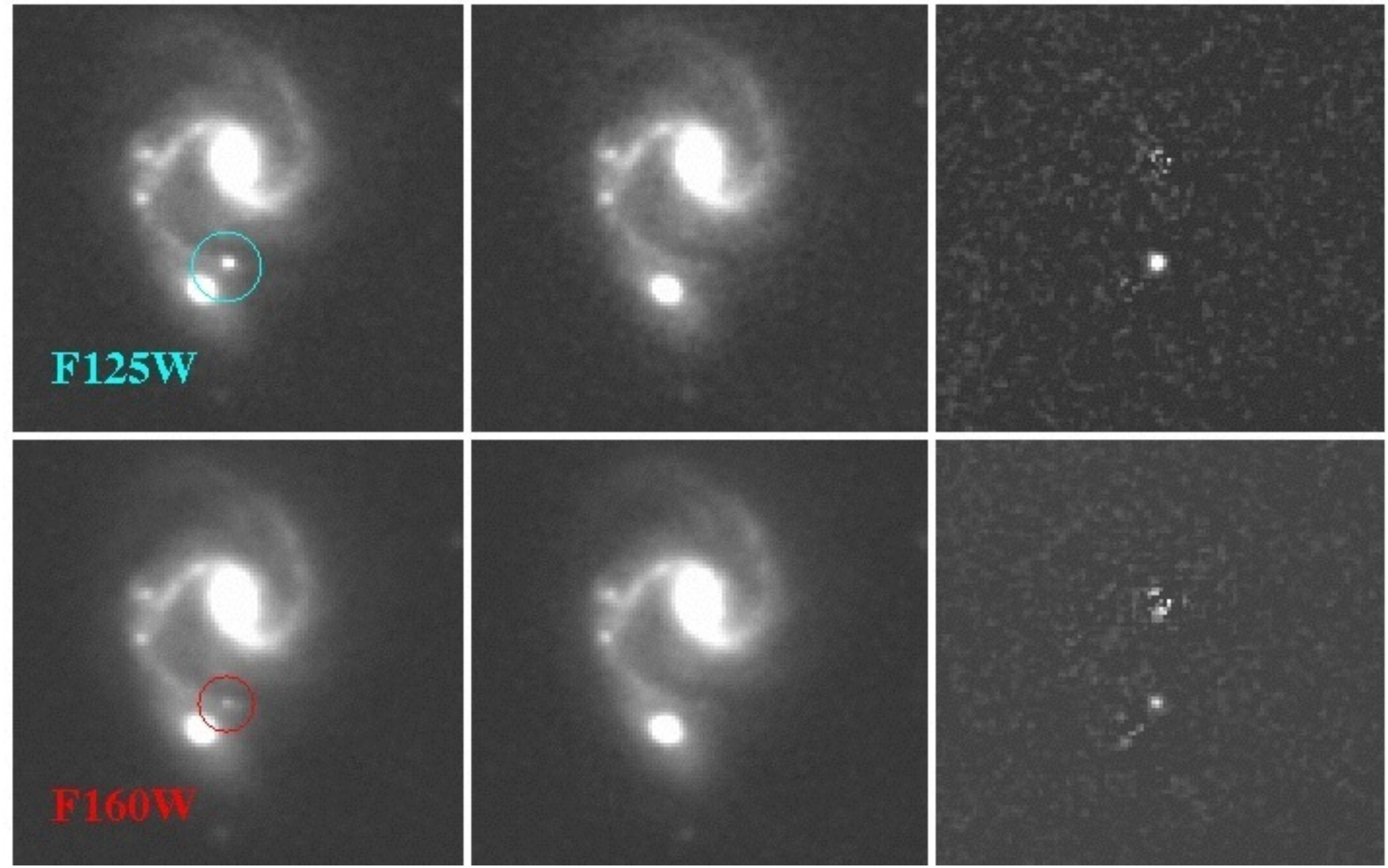


Observed through F125W (1.25 μm) and F160W (1.60 μm) on WFC3/IR

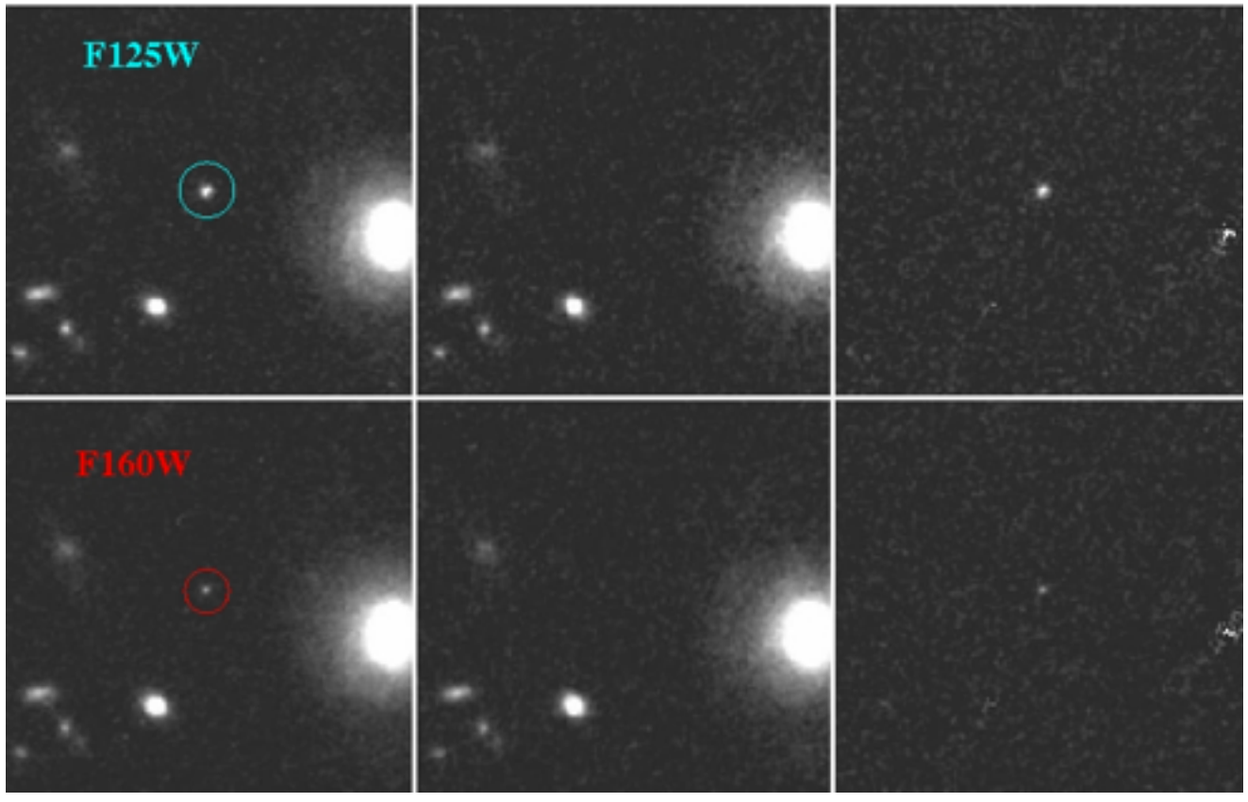
Usually need to return much later to get image for galaxy subtraction



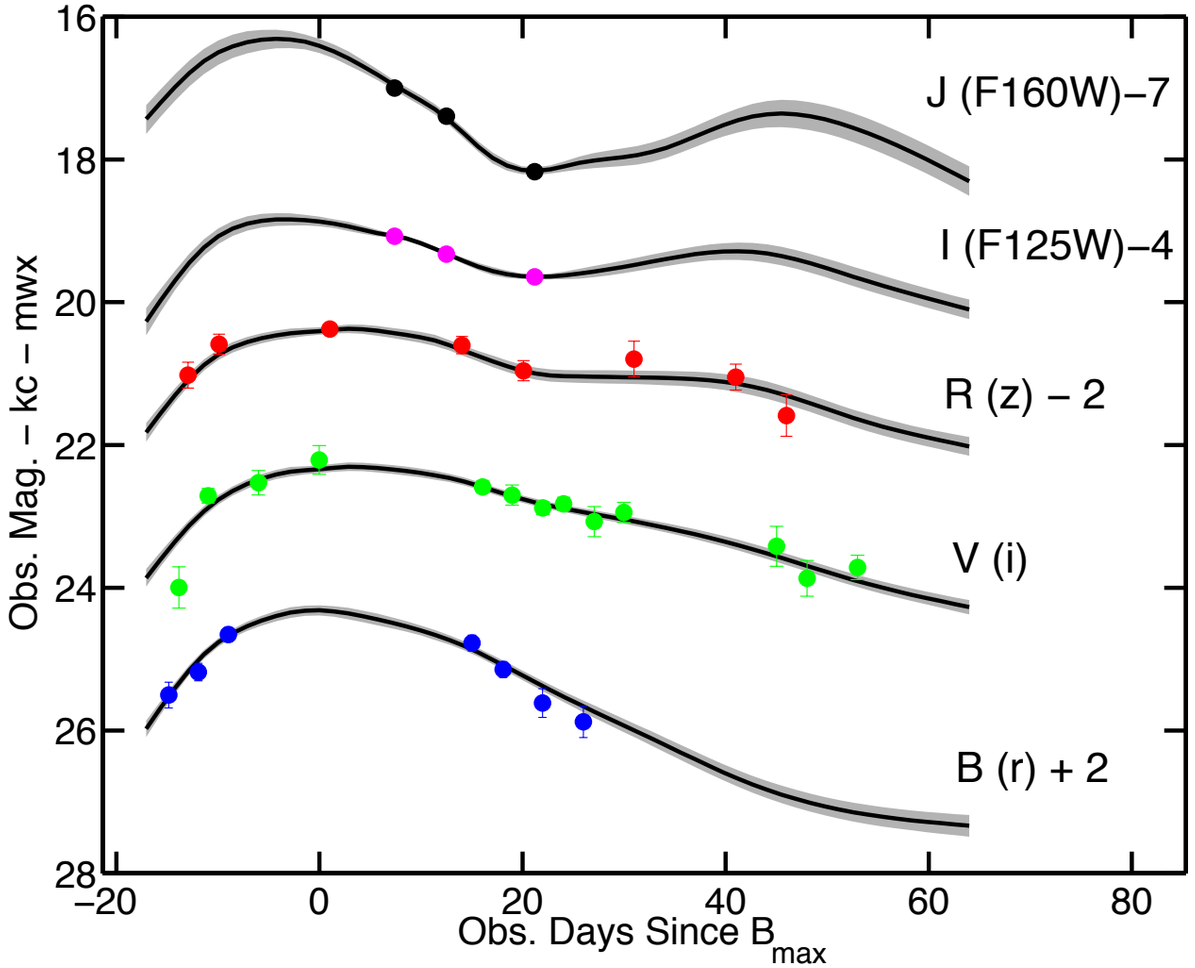
Template subtraction works well



Pan-STARRS + RAISIN1 data



RAISIN–PS1–490037 : z=0.422

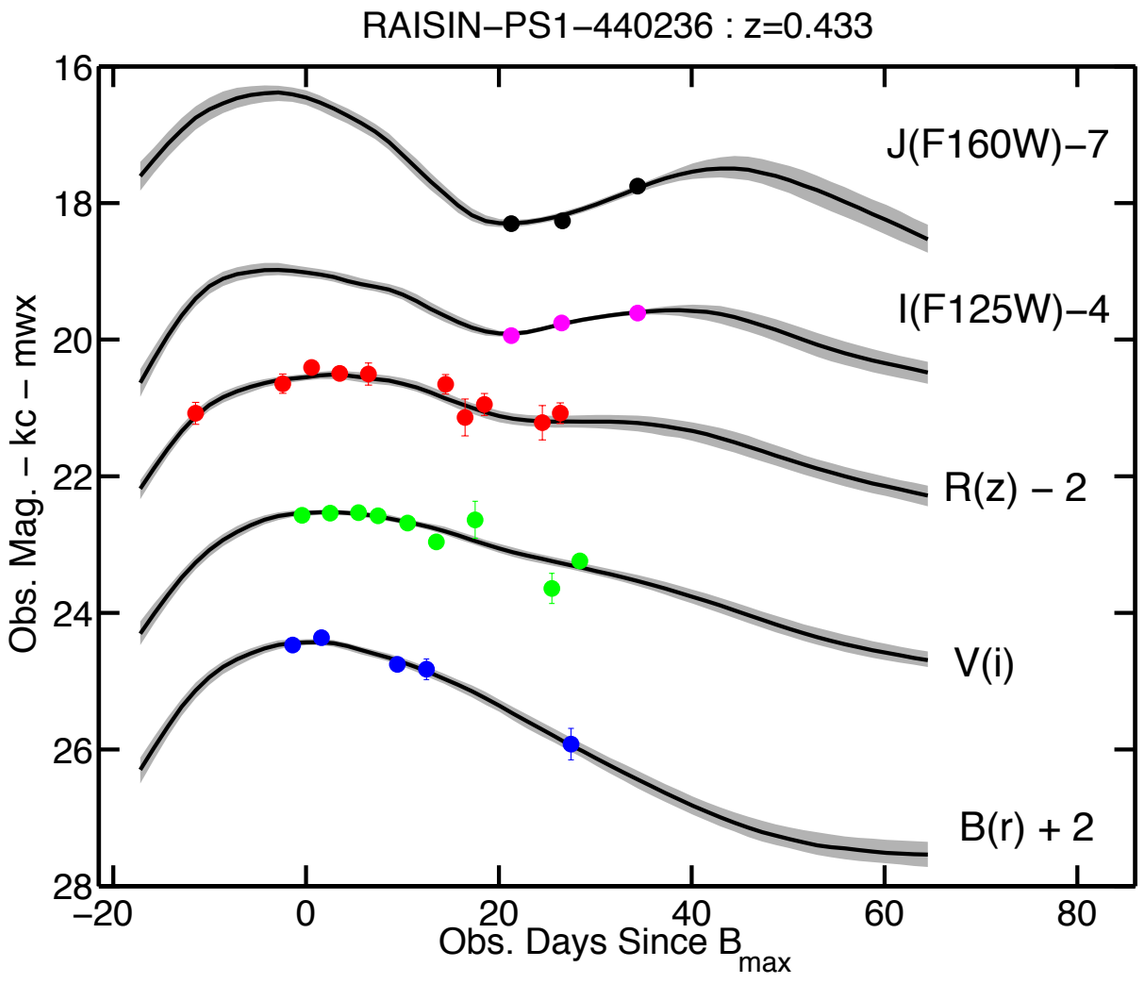


HST/WFC3 NIR
J & H bands

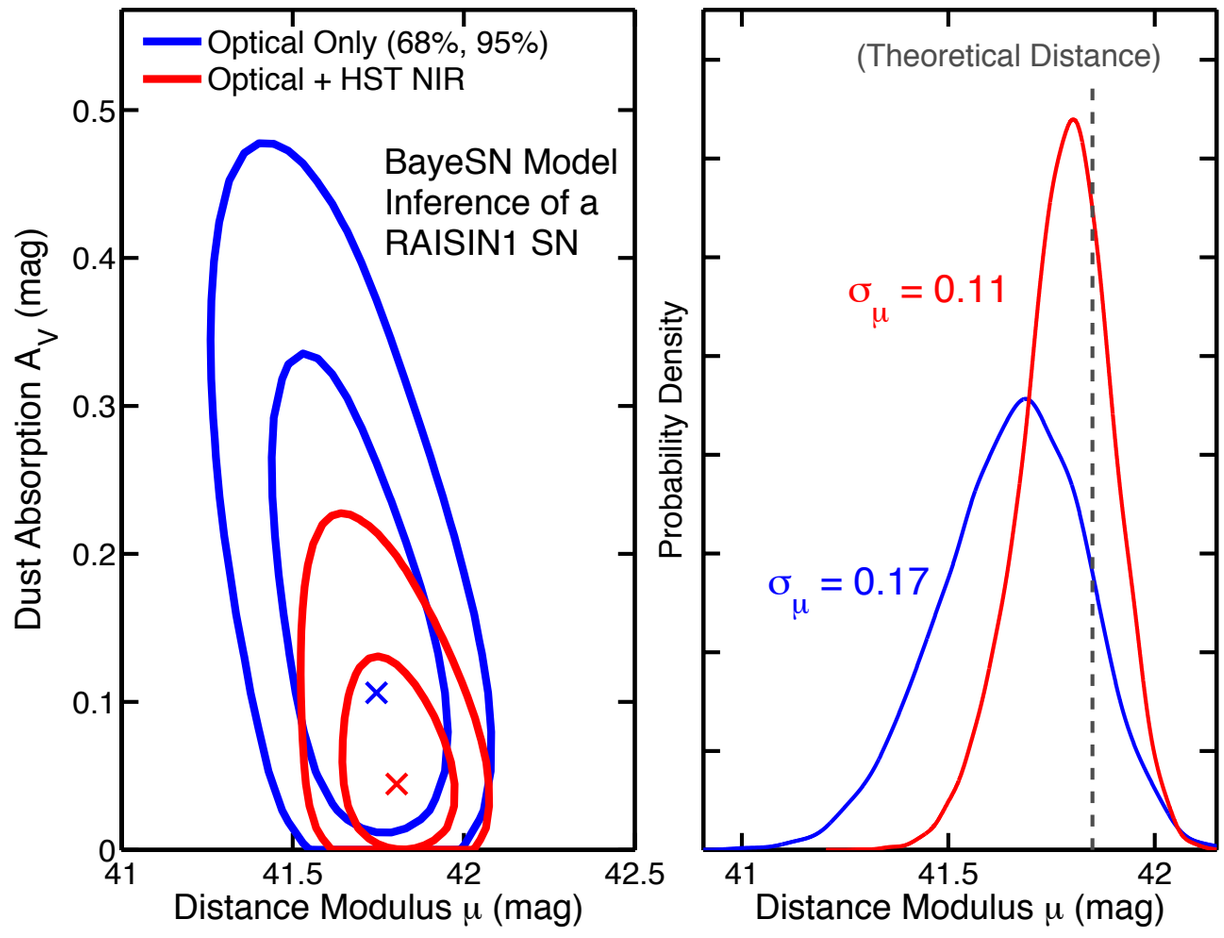
Pan-STARRS
Optical bands

(Preliminary)

Improving dust and distance estimates with HST/WFC3/IR and BayeSN

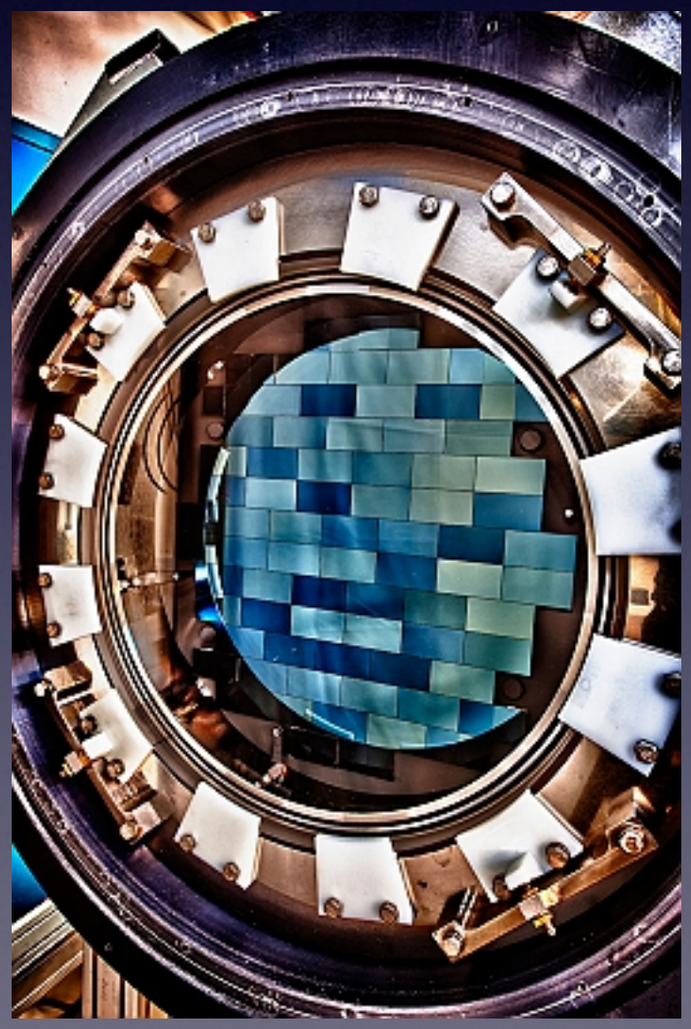


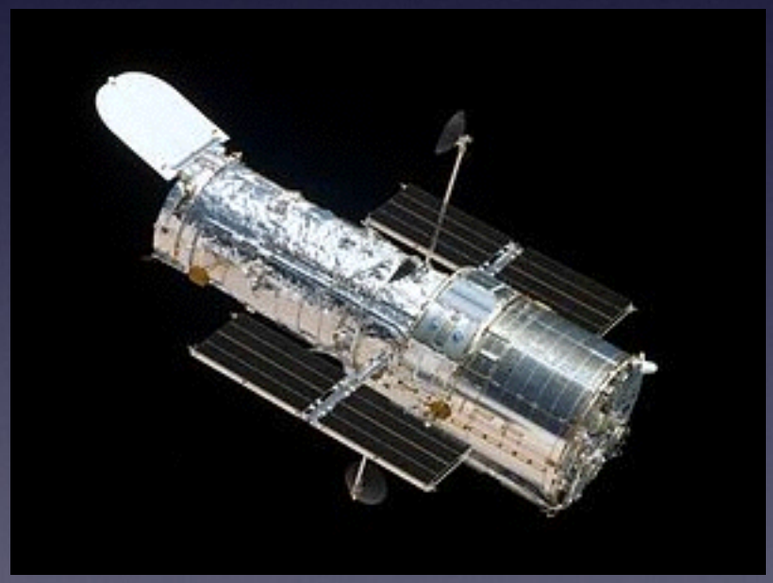
Optical (PS1) + NIR (HST) LC



Distance Precision improved by ~ $(0.183/0.116)^2$ = 2.5x using NIR

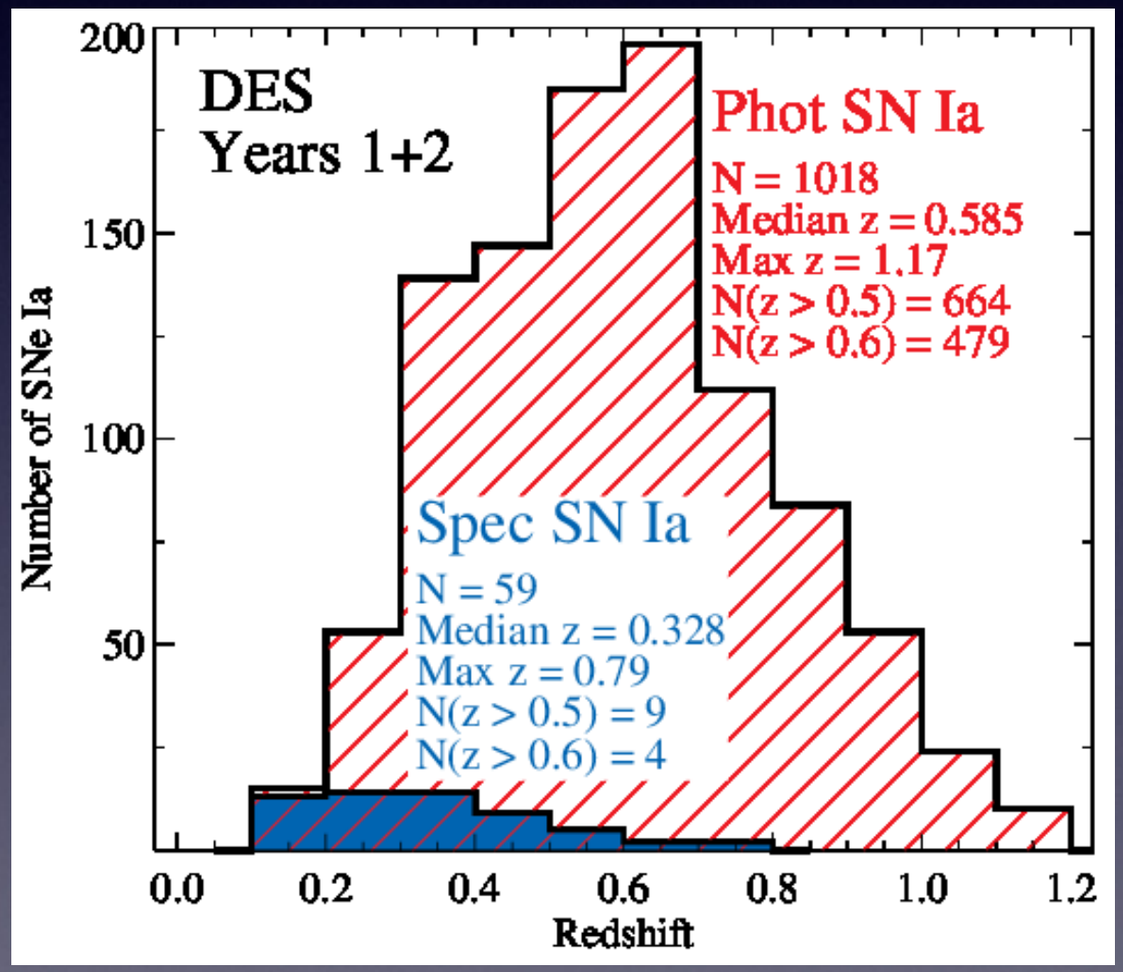
RAISIN2 (GO-14216) 2015-2017:
100 HST orbits for NIR observations of
z ~ 0.5 SN Ia
discovered by Dark Energy Survey (DES)

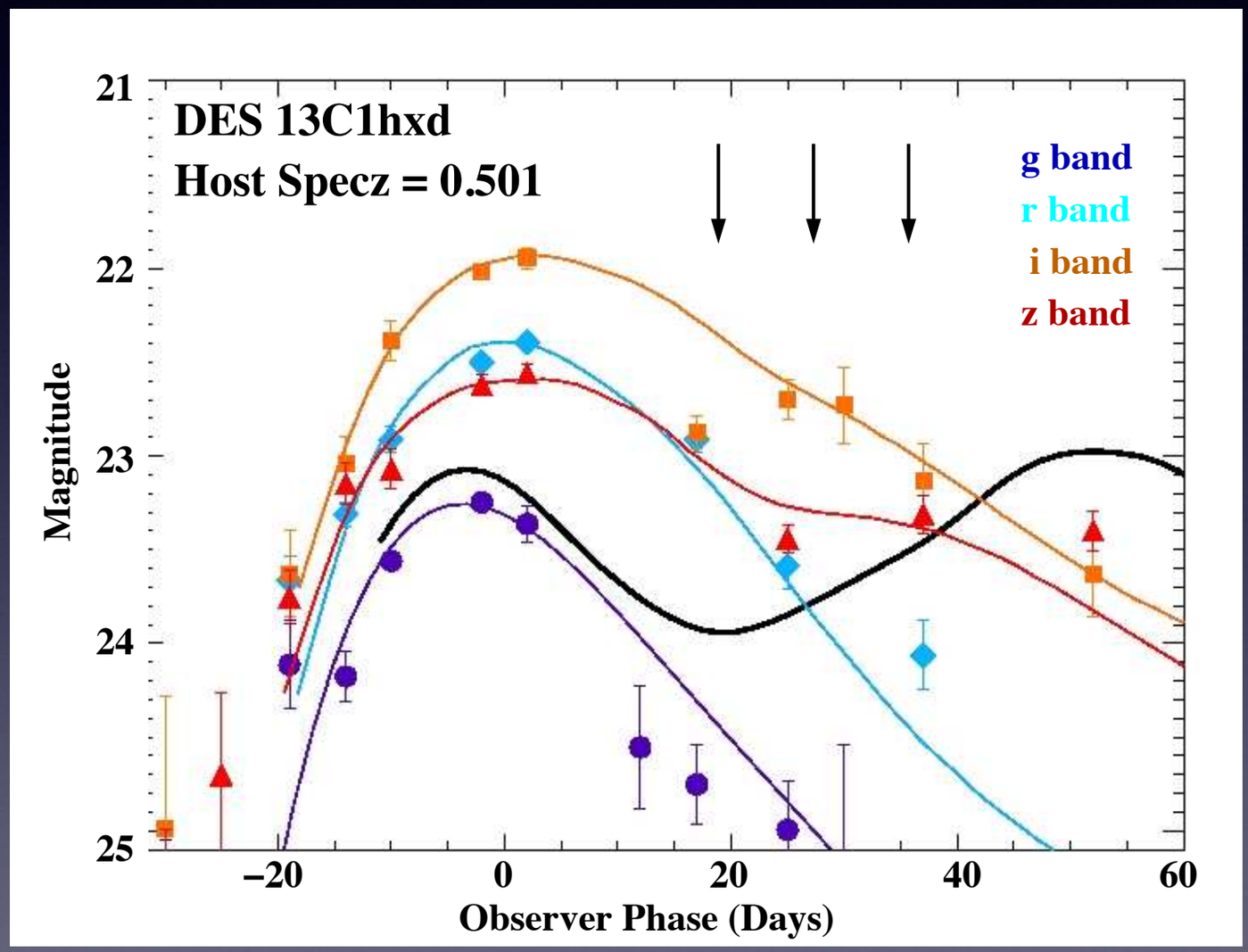




Dark Energy Survey (DES) Supernova Search

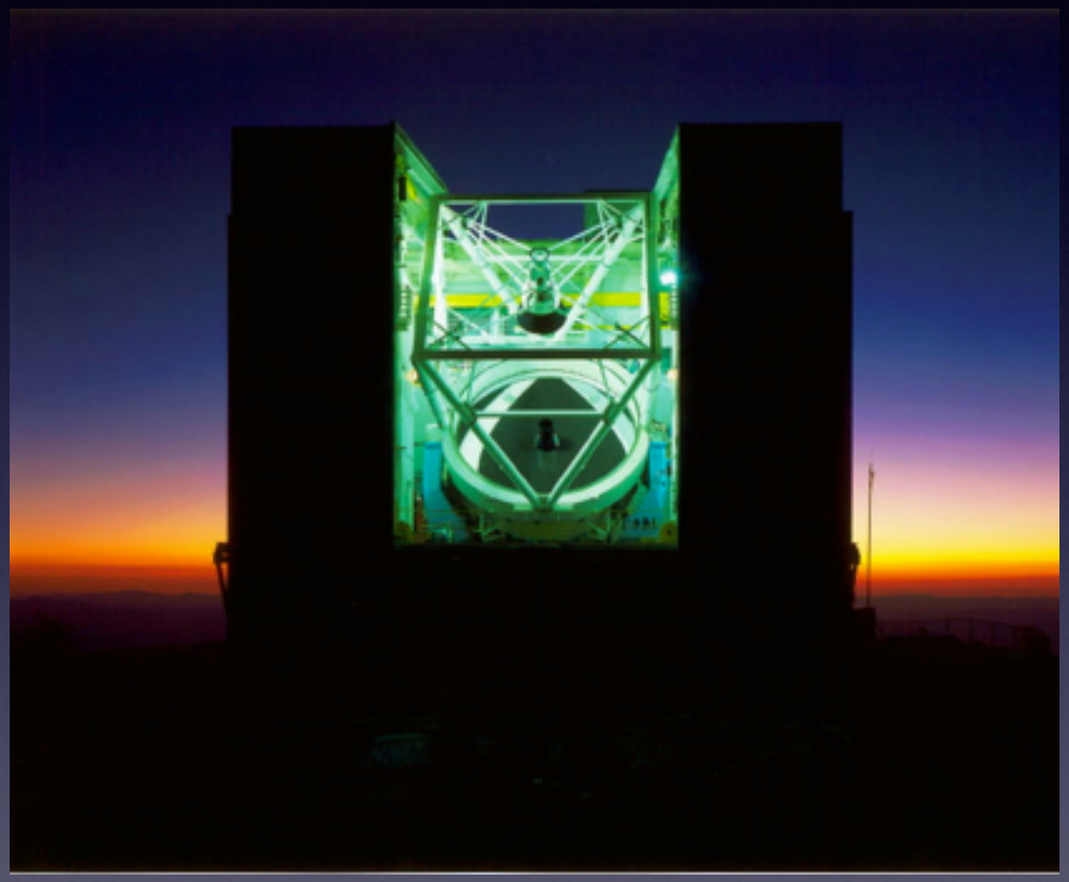
DES SN Ia discoveries



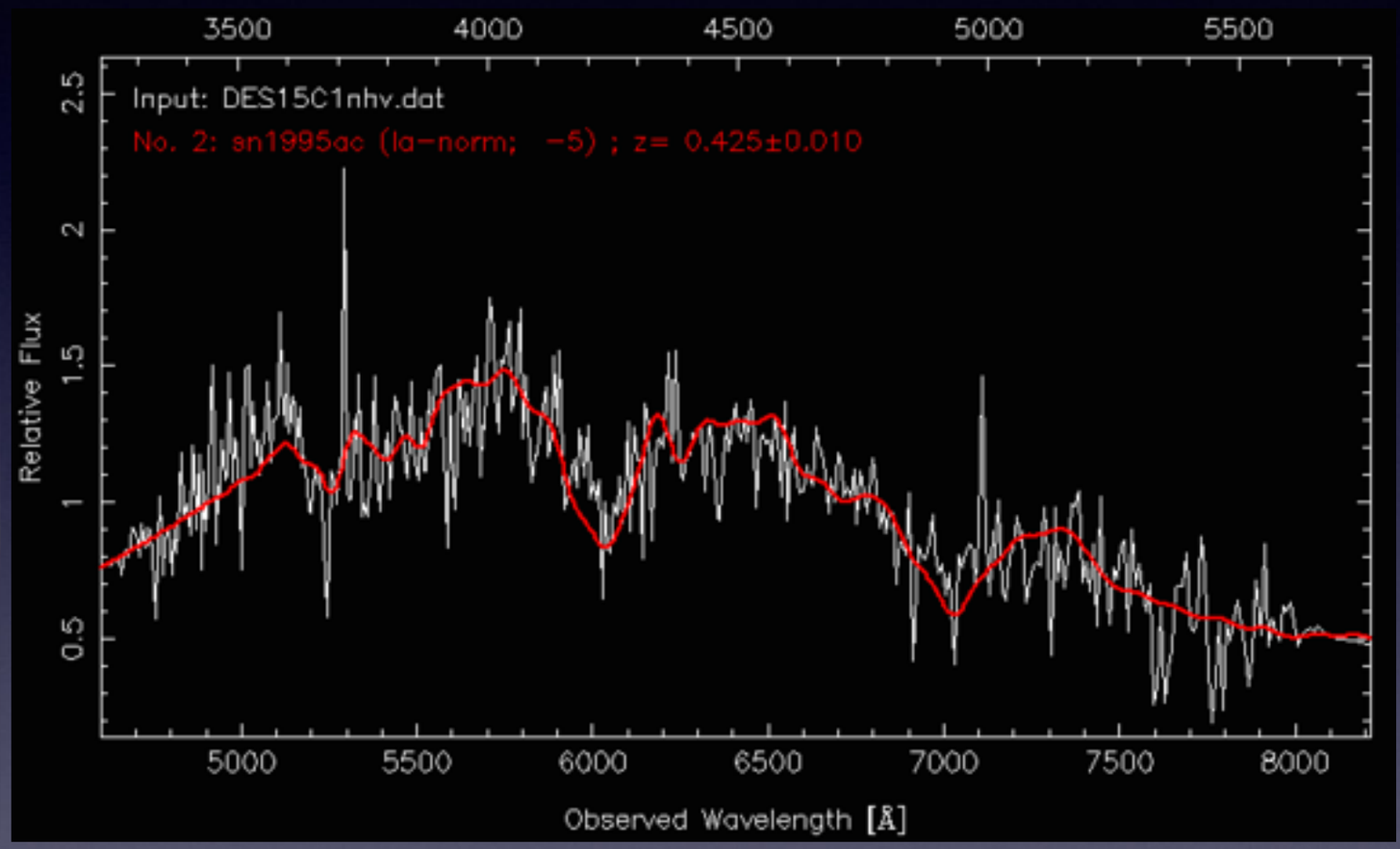


Example DES Optical Light Curve

RAISIN2 Collaboration with DES: Trade Spectra for Targets



MMT Telescope (Arizona)



(credit: Pete Challis)

Use Spectrum to Confirm Supernova and Measure Redshift

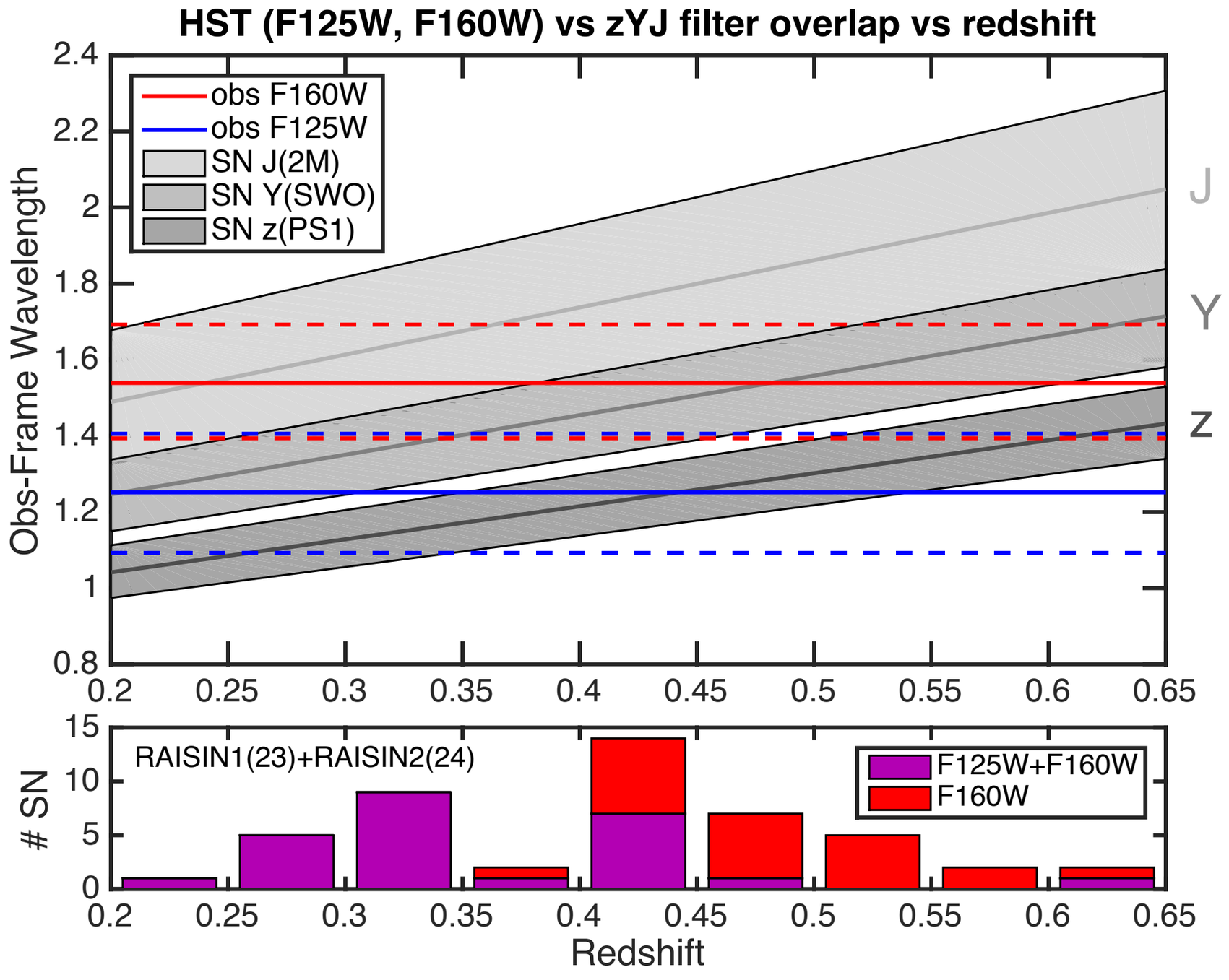
A RAISIN2 Hubble Image of DES Supernova at z = 0.43

(credit: Pete Challis)

Observational Status

- RAISIN2 template images completed (Dec 2017)
- Final sample:
  - RAISIN1: 23 SN Ia PS1 (Optical) + HST NIR
  - RAISIN2:
    - 23 SN Ia DES (Optical) + HST NIR
    - 1 SN Ia HST Optical (Rodney) + HST NIR
- HST NIR photometry nearing completion

Distribution of combined RAISIN1+RAISIN2 samples

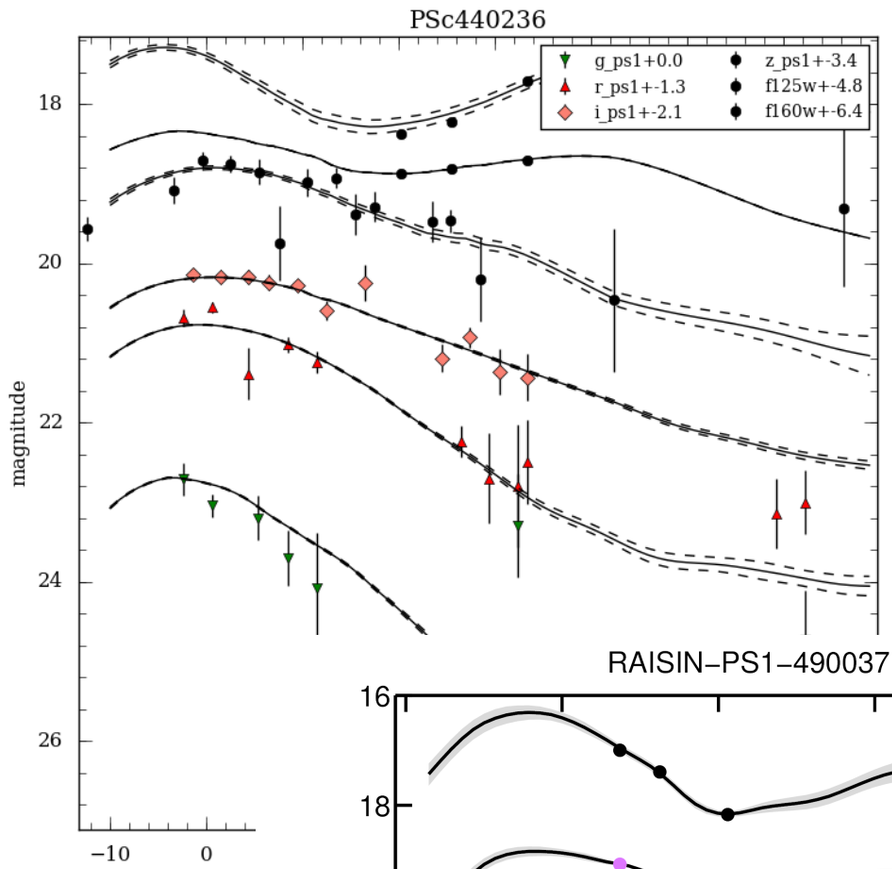


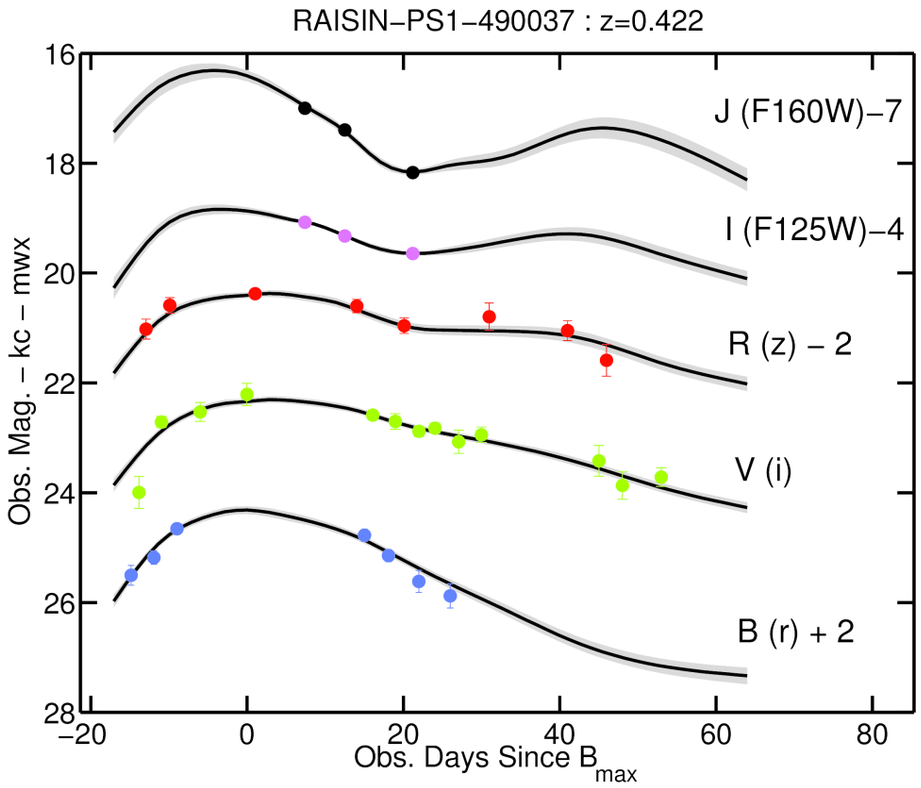
Preliminary RAISIN fitting

Arturo Avelino

Optical + NIR fitters

- SNooPy (Chris Burns et al.)
- SALT2nir (Steve Rodney et al. in preparation)
- BayeSN (Kaisey Mandel et al.)





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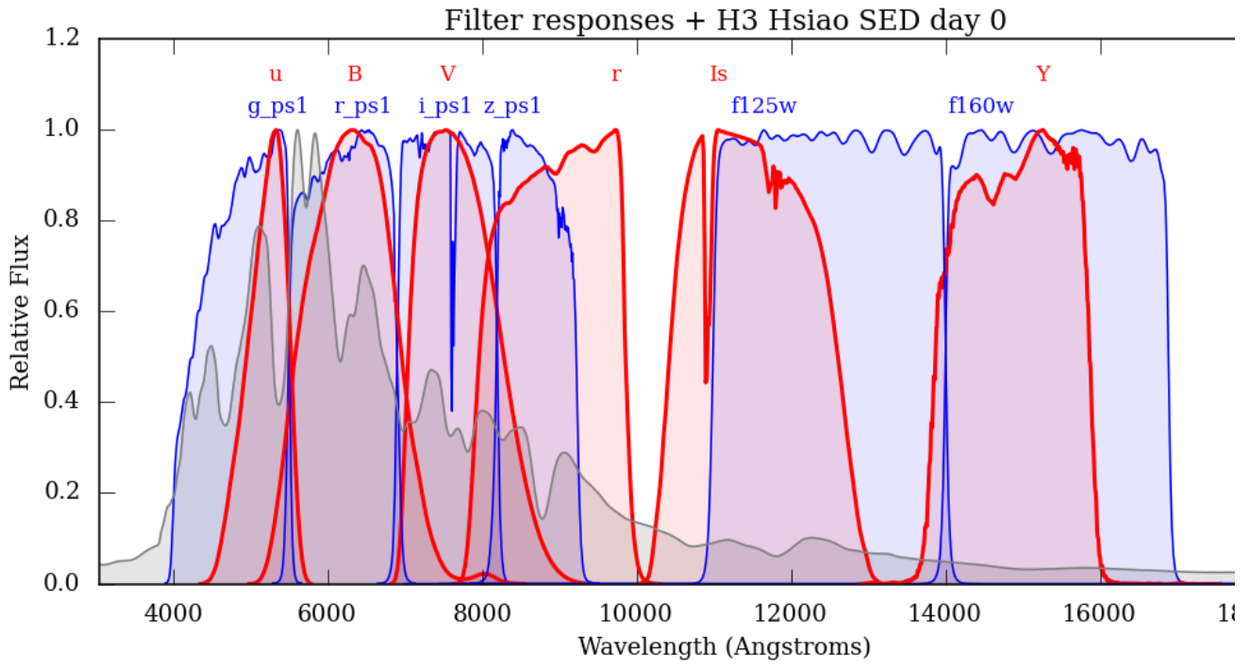
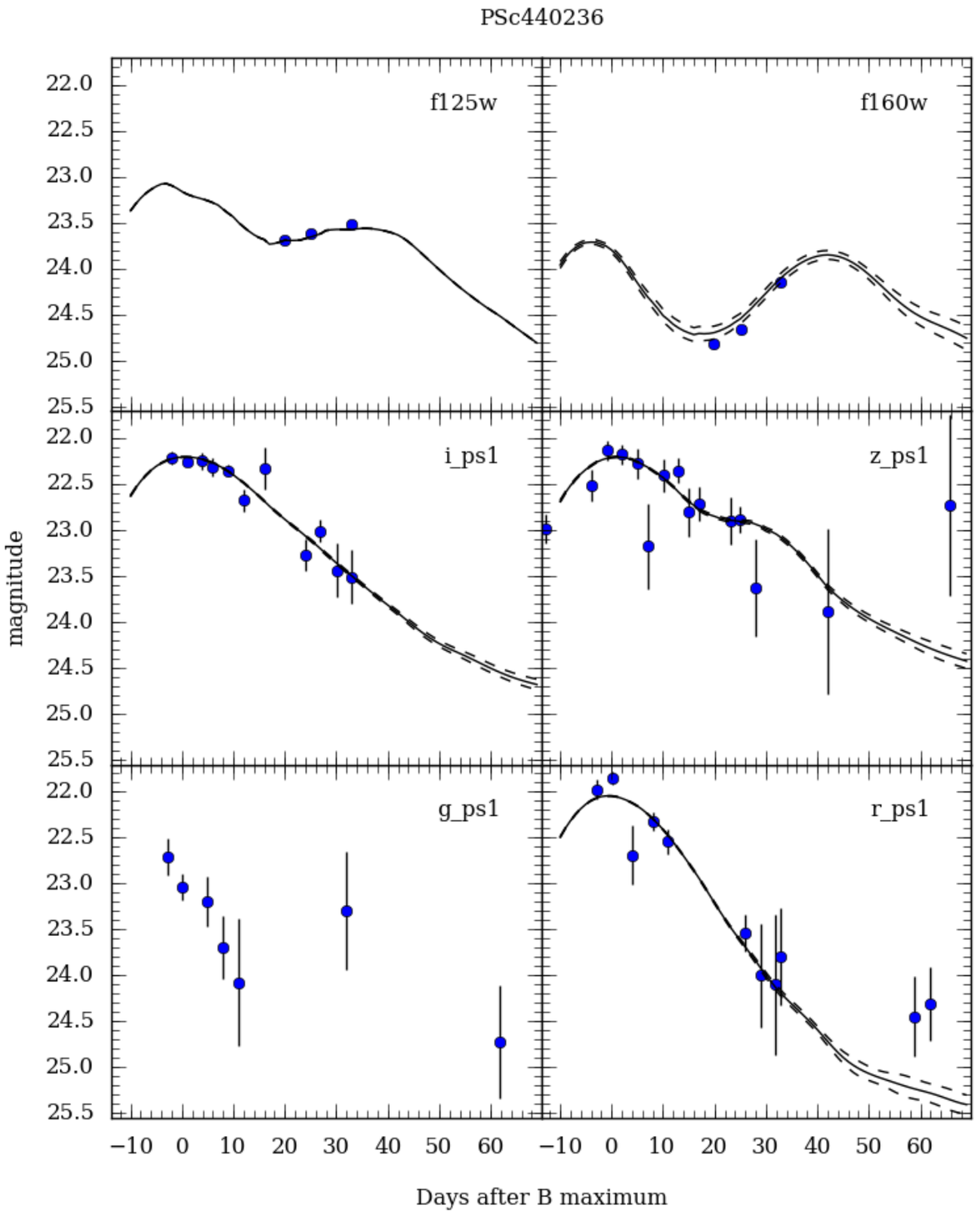
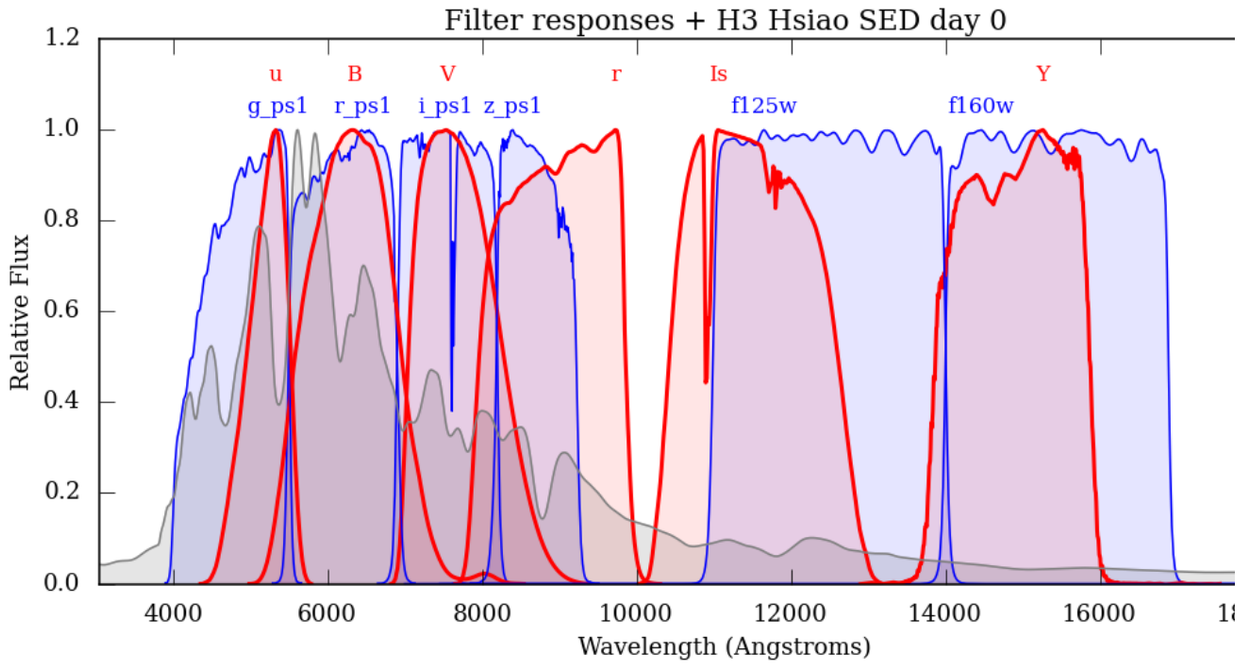
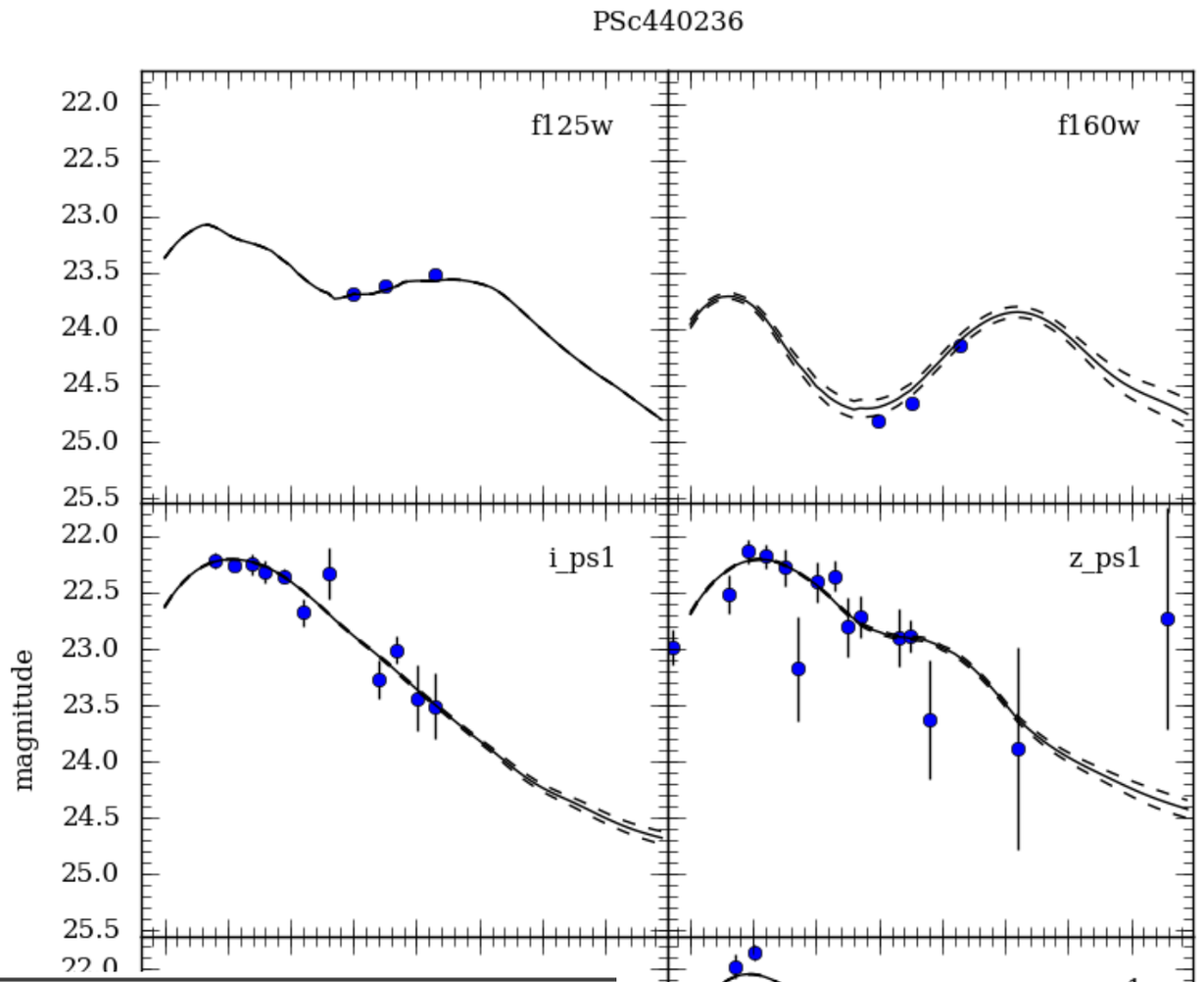


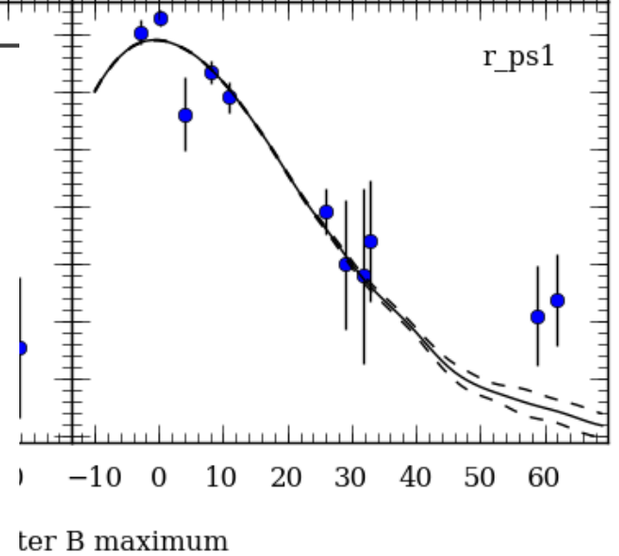


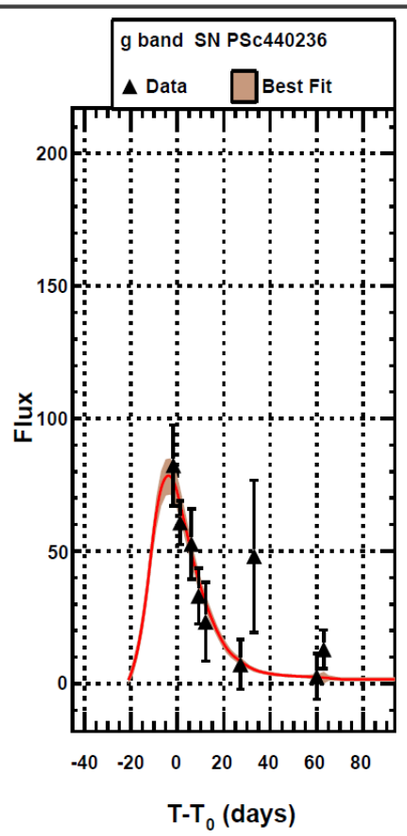
(Preliminary)

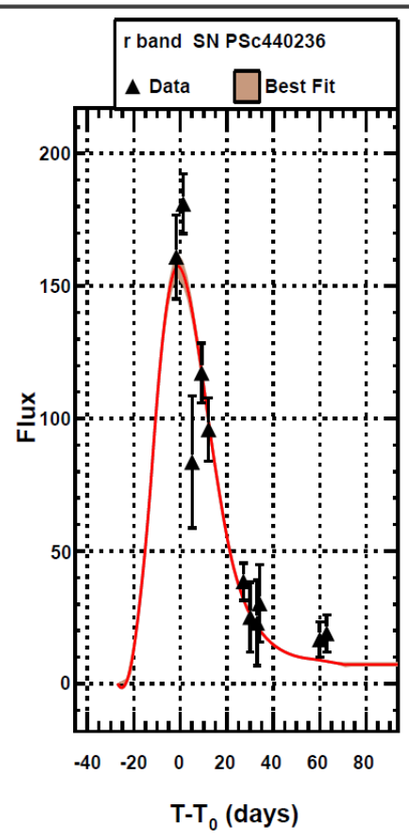
z_cmb = 0.432

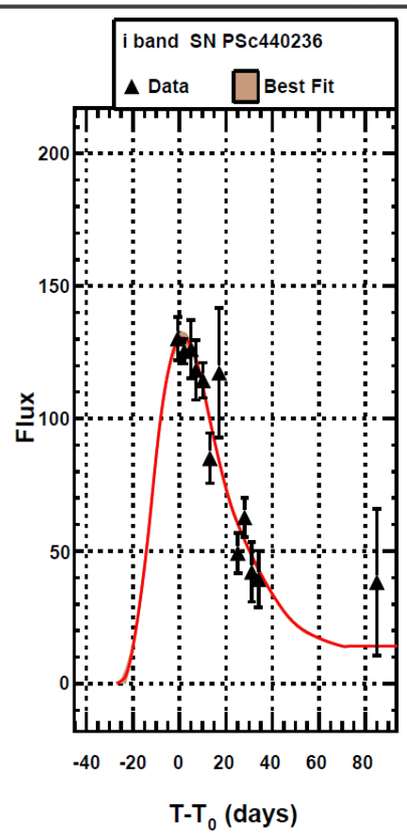


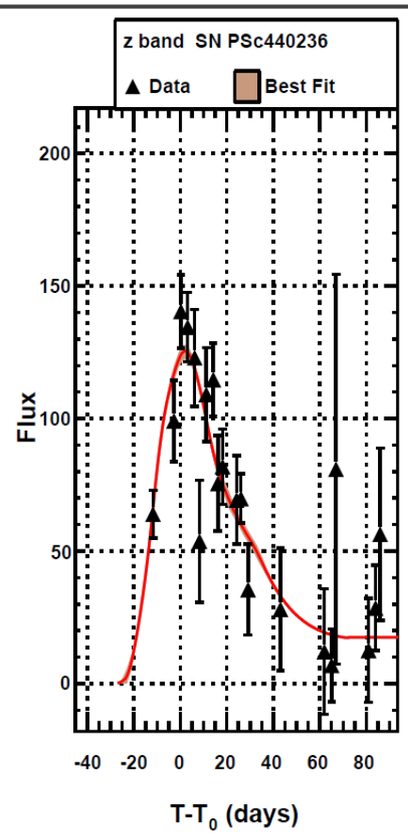




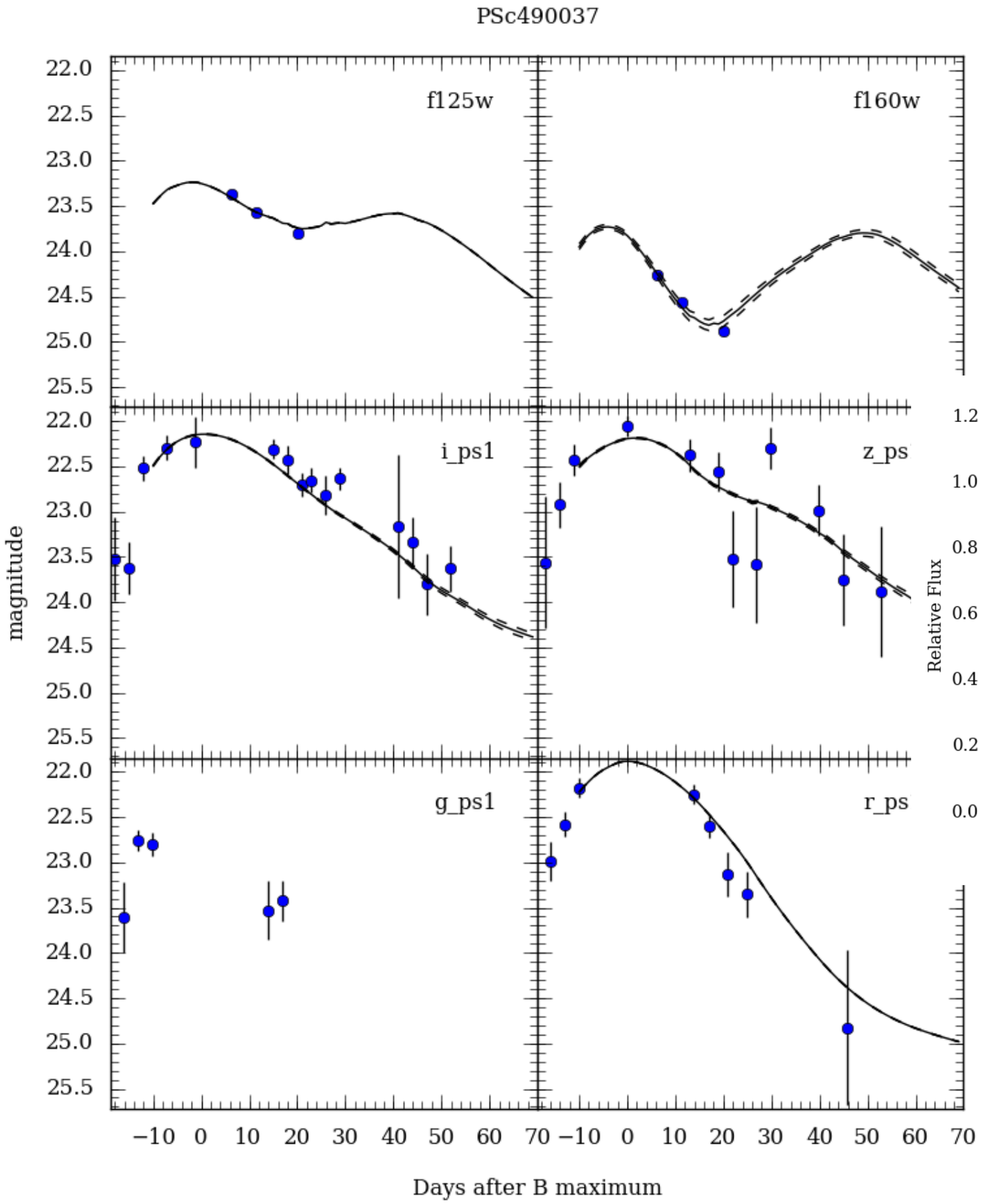




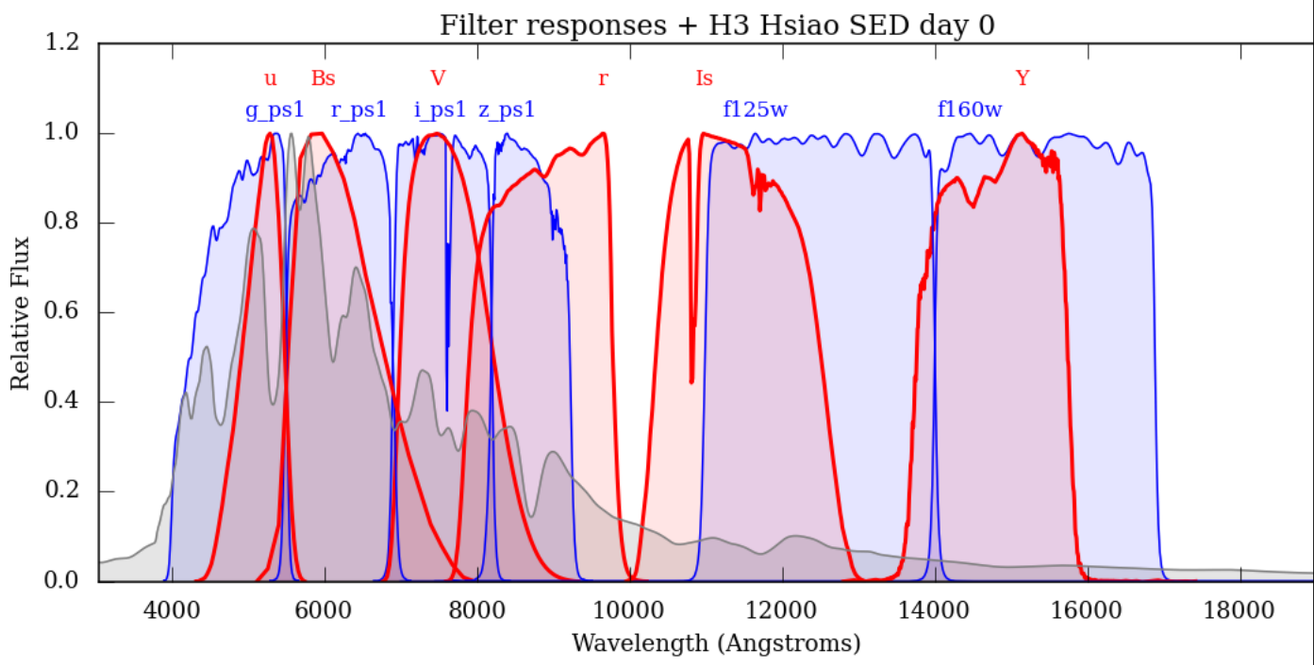




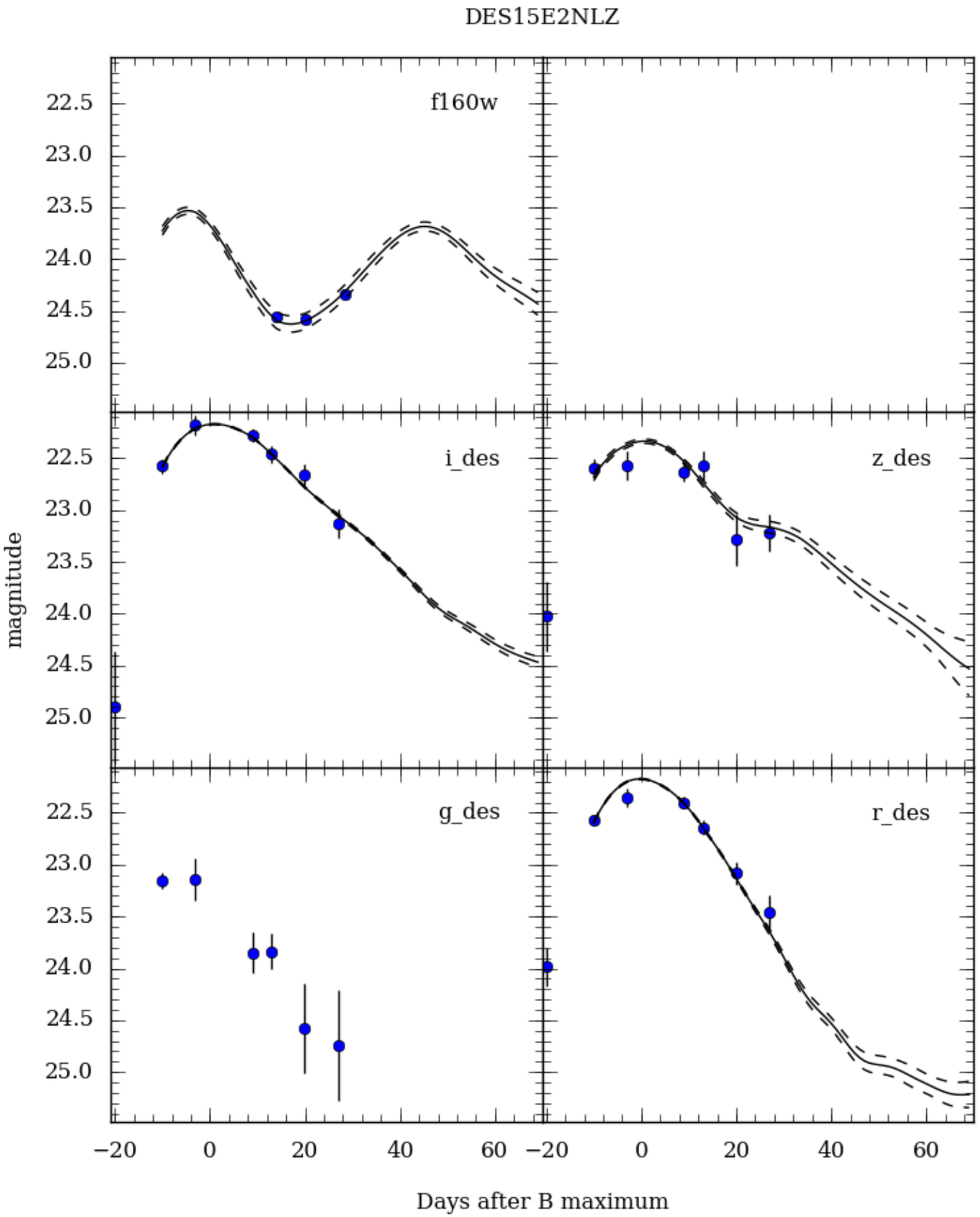
(Preliminary)



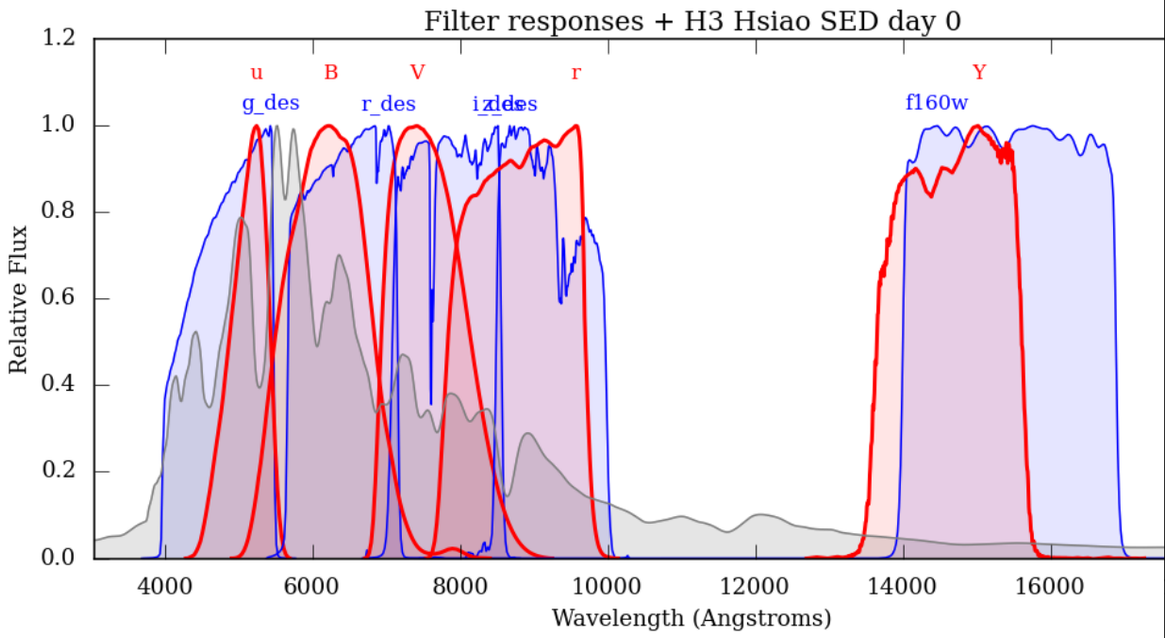
z_cmb = 0.423



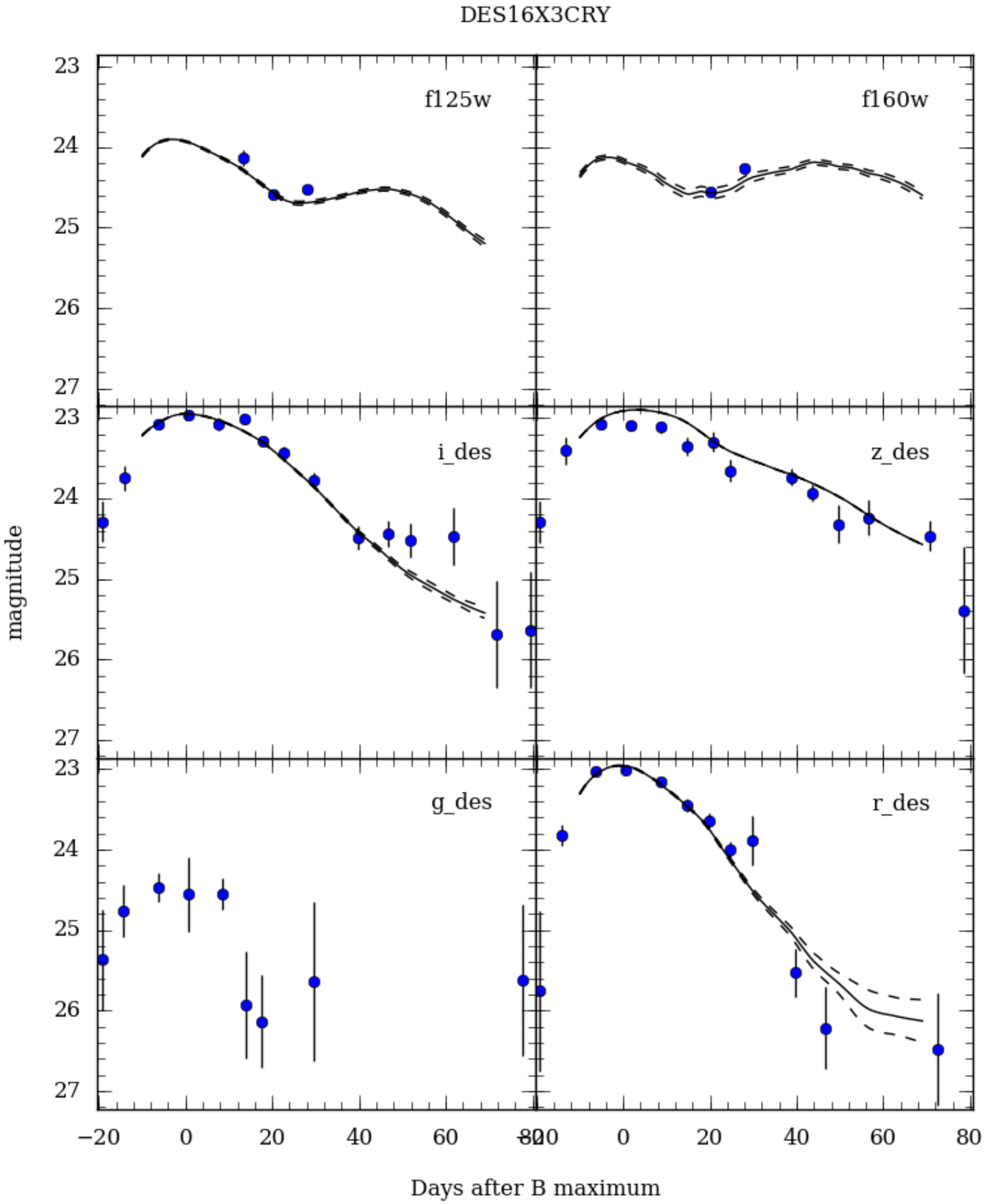
(Preliminary)



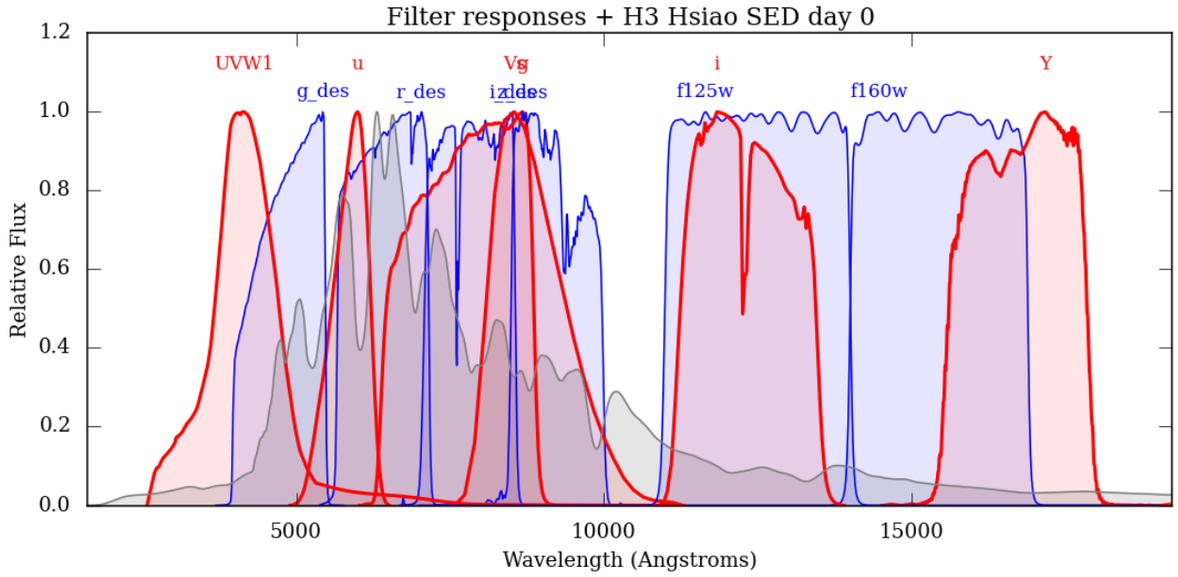
z_cmb = 0.41



(Preliminary)

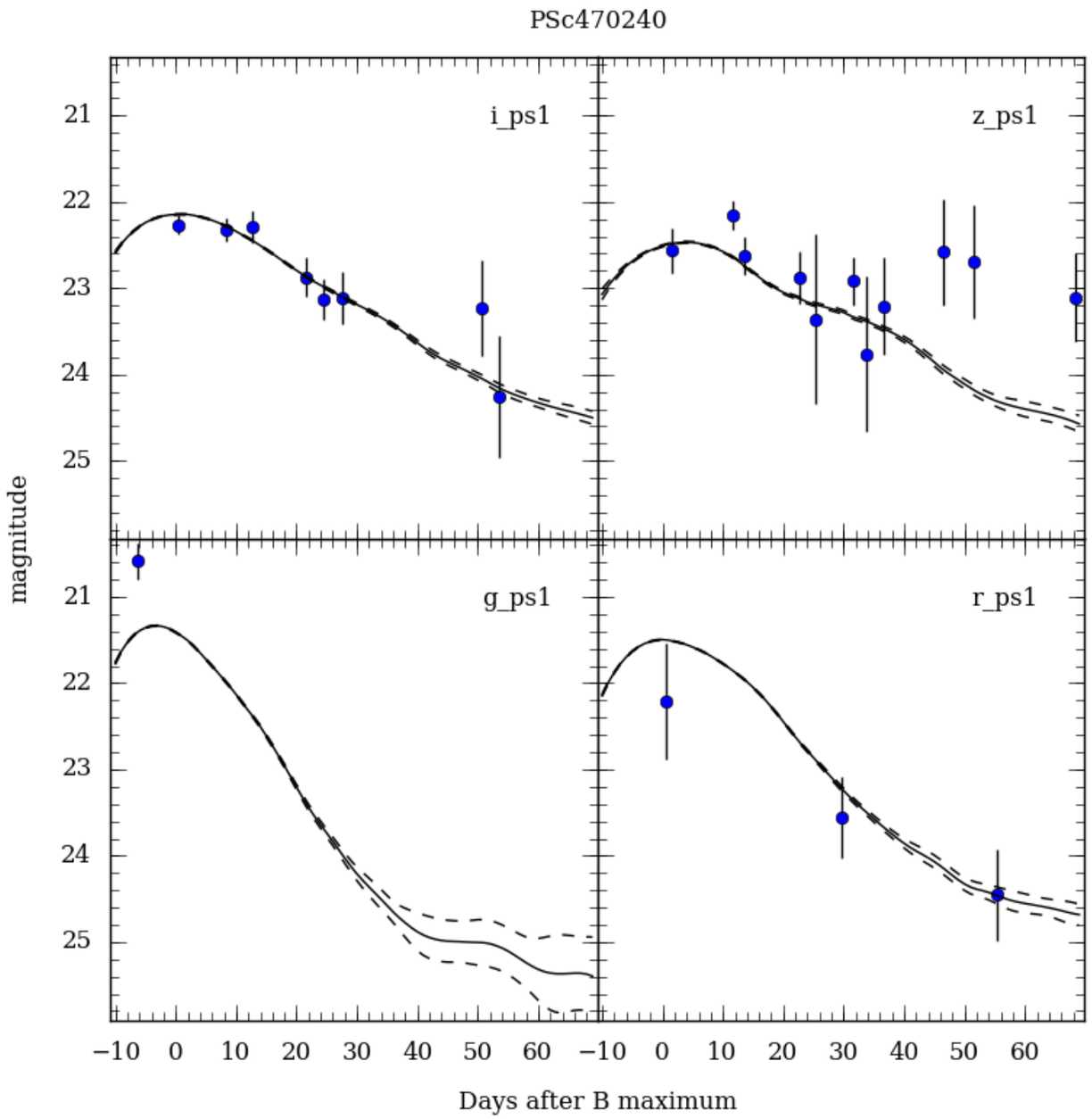


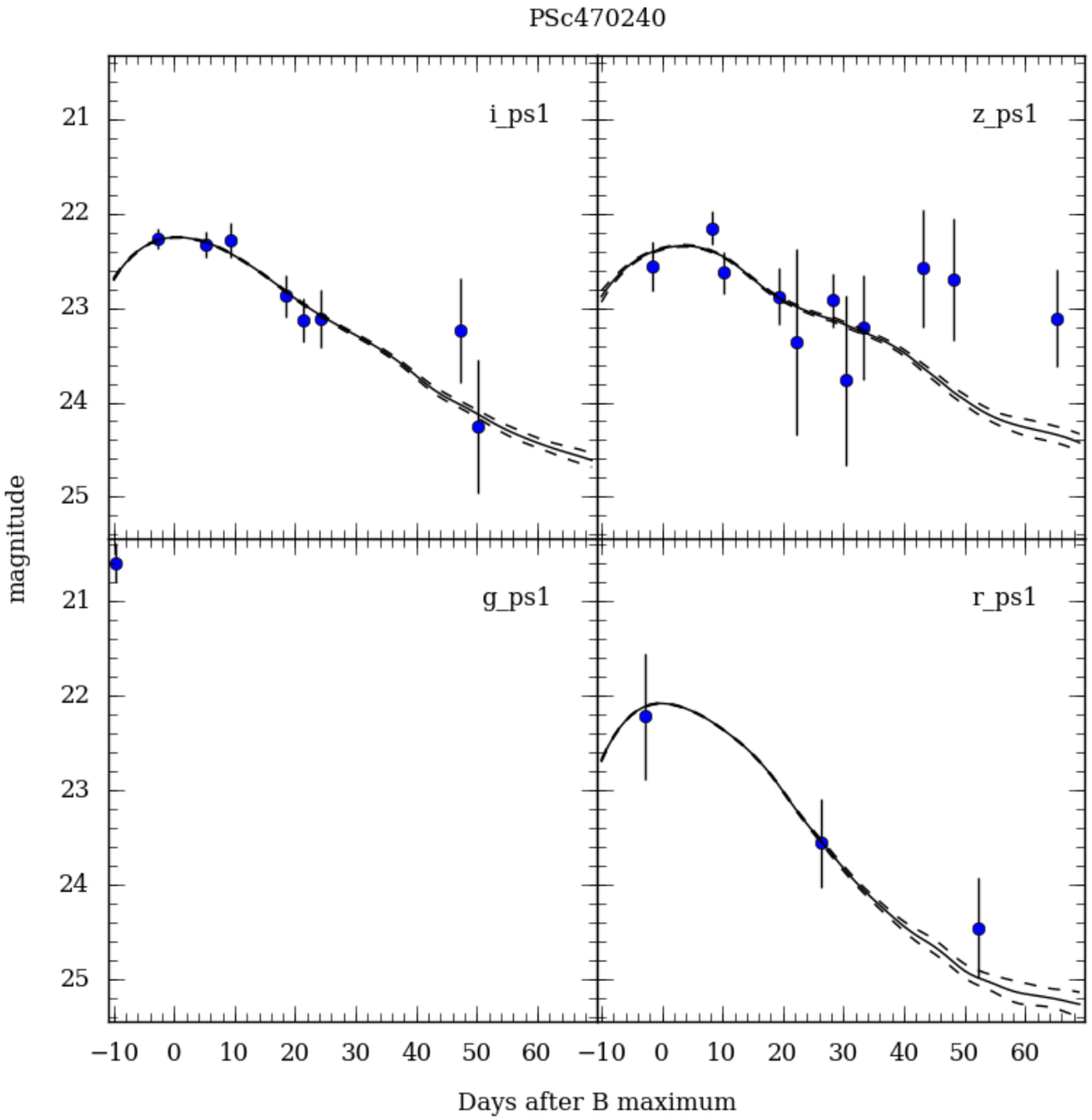
z_cmb = 0.612



(Preliminary)

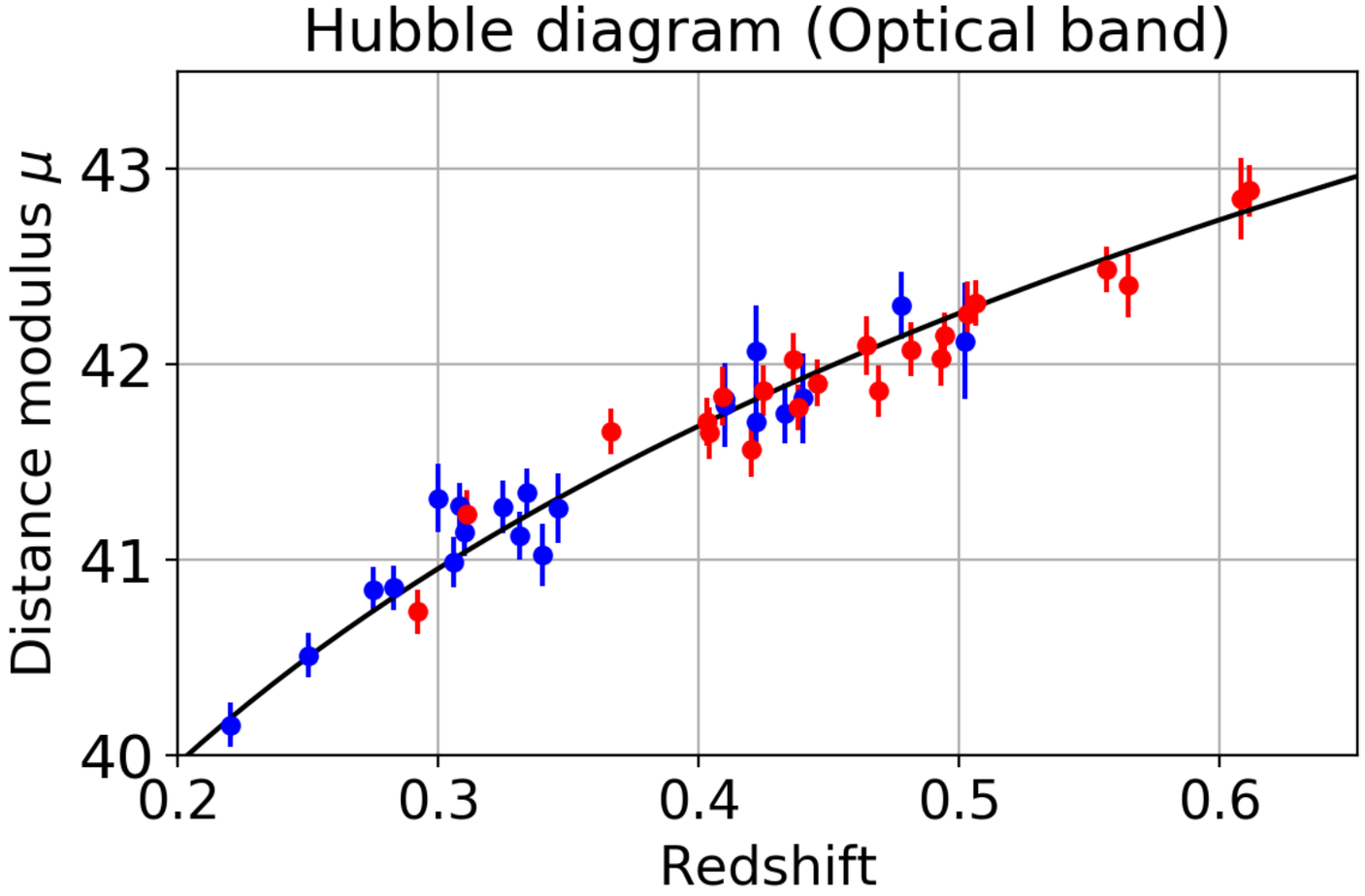
The effect of restframe U-band



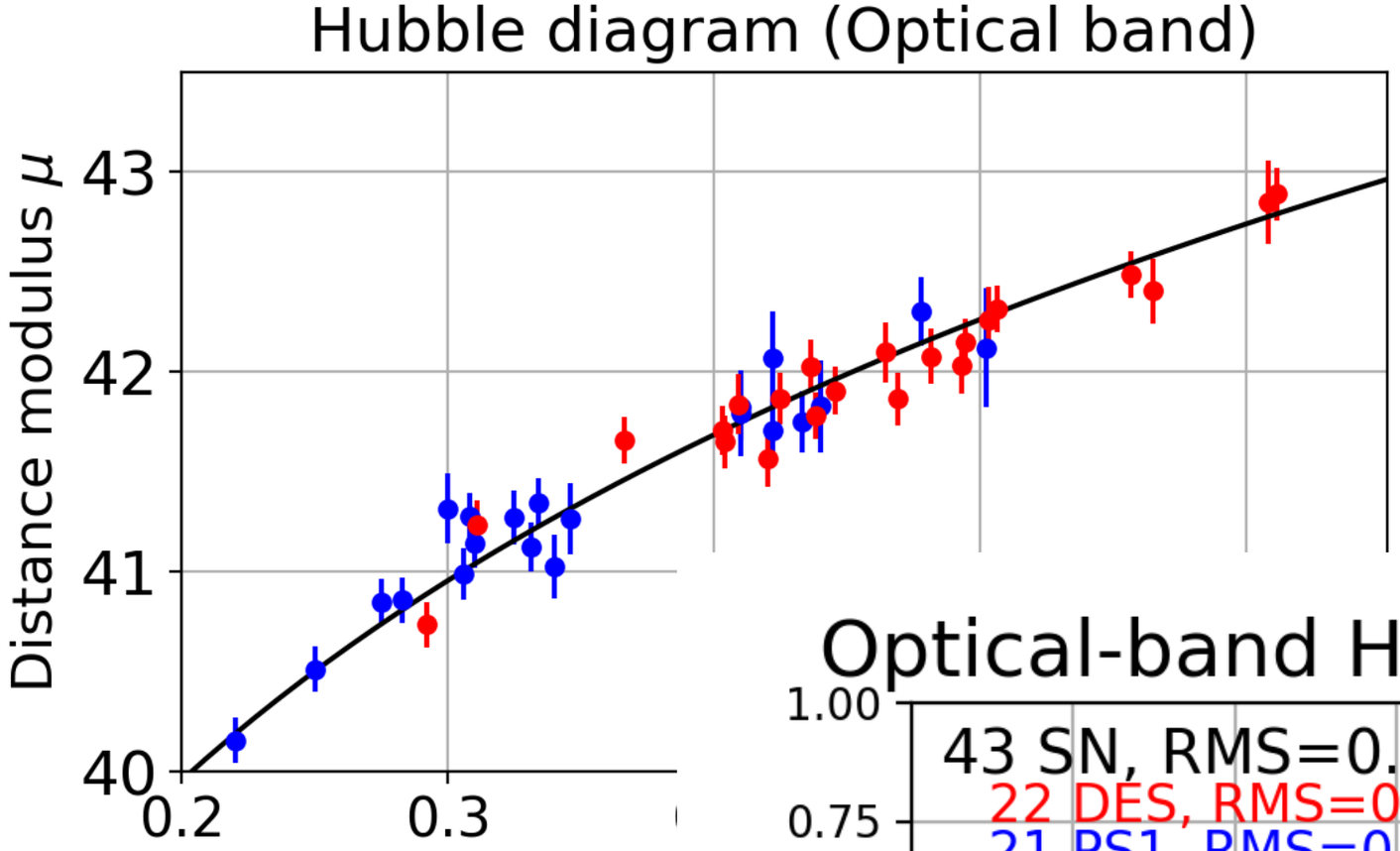


Preliminary Optical RAISIN Hubble diagram

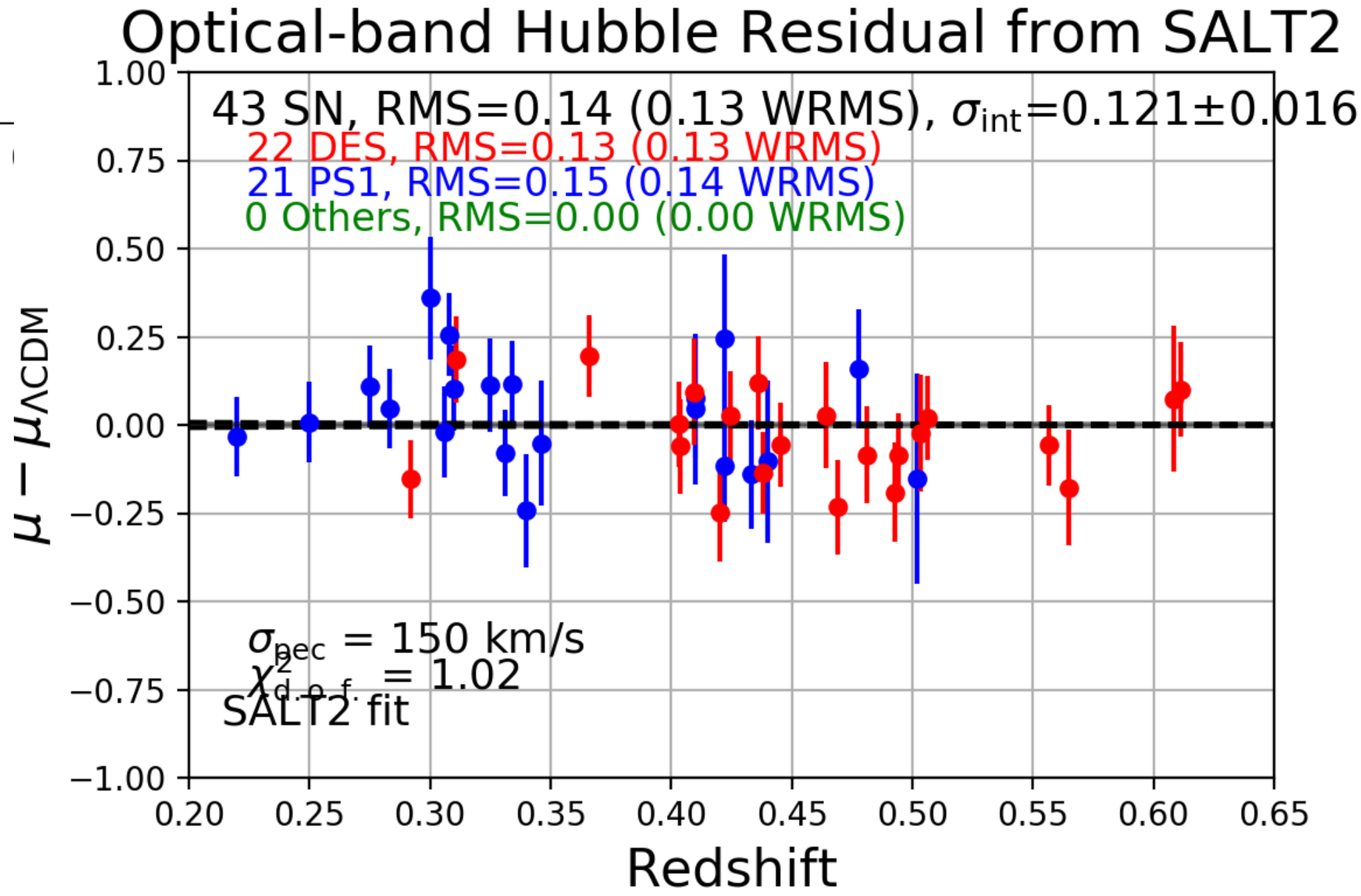
SALT2 fit to optical bands only



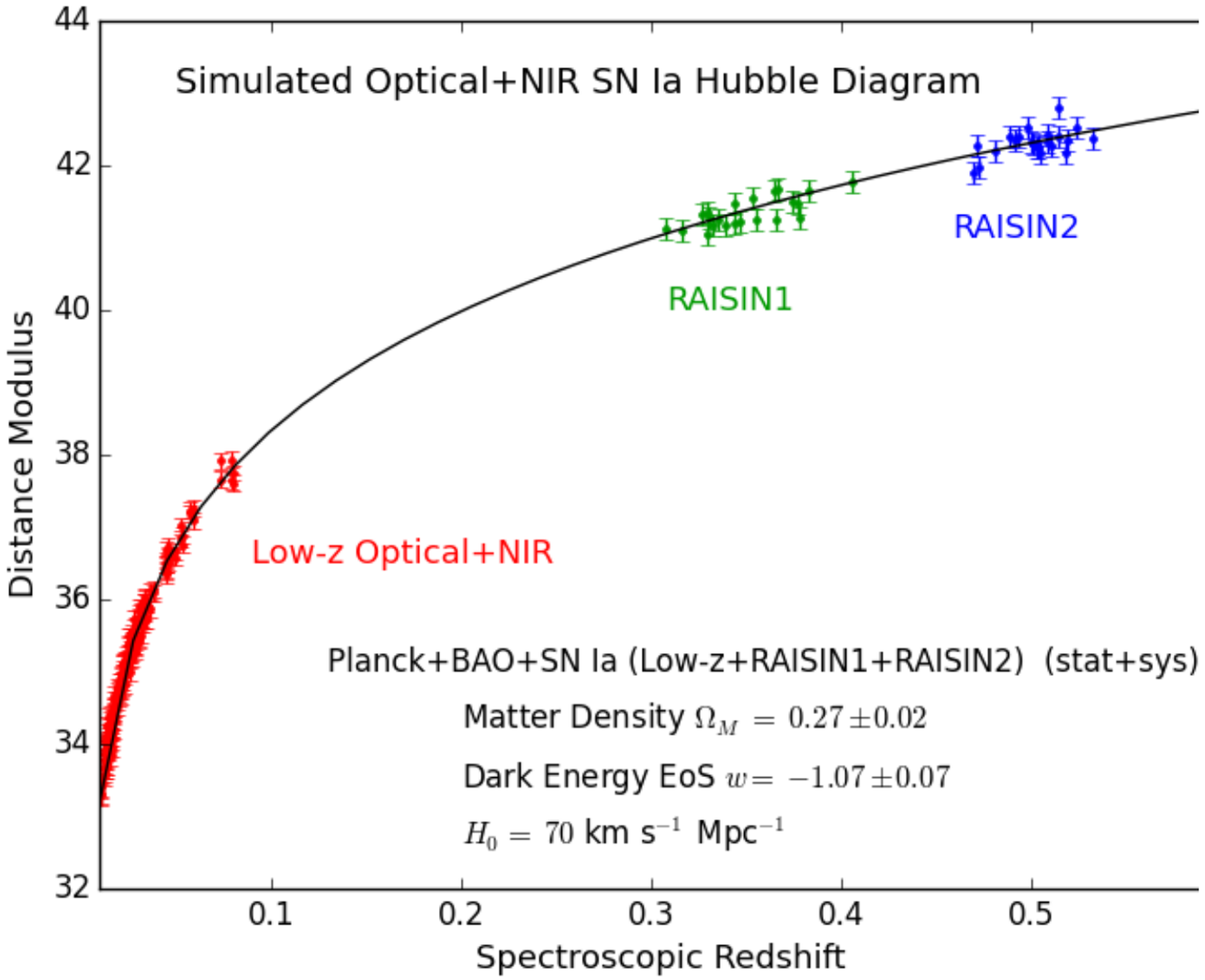
Ho = 70
Om = 0.3, flat
w = -1

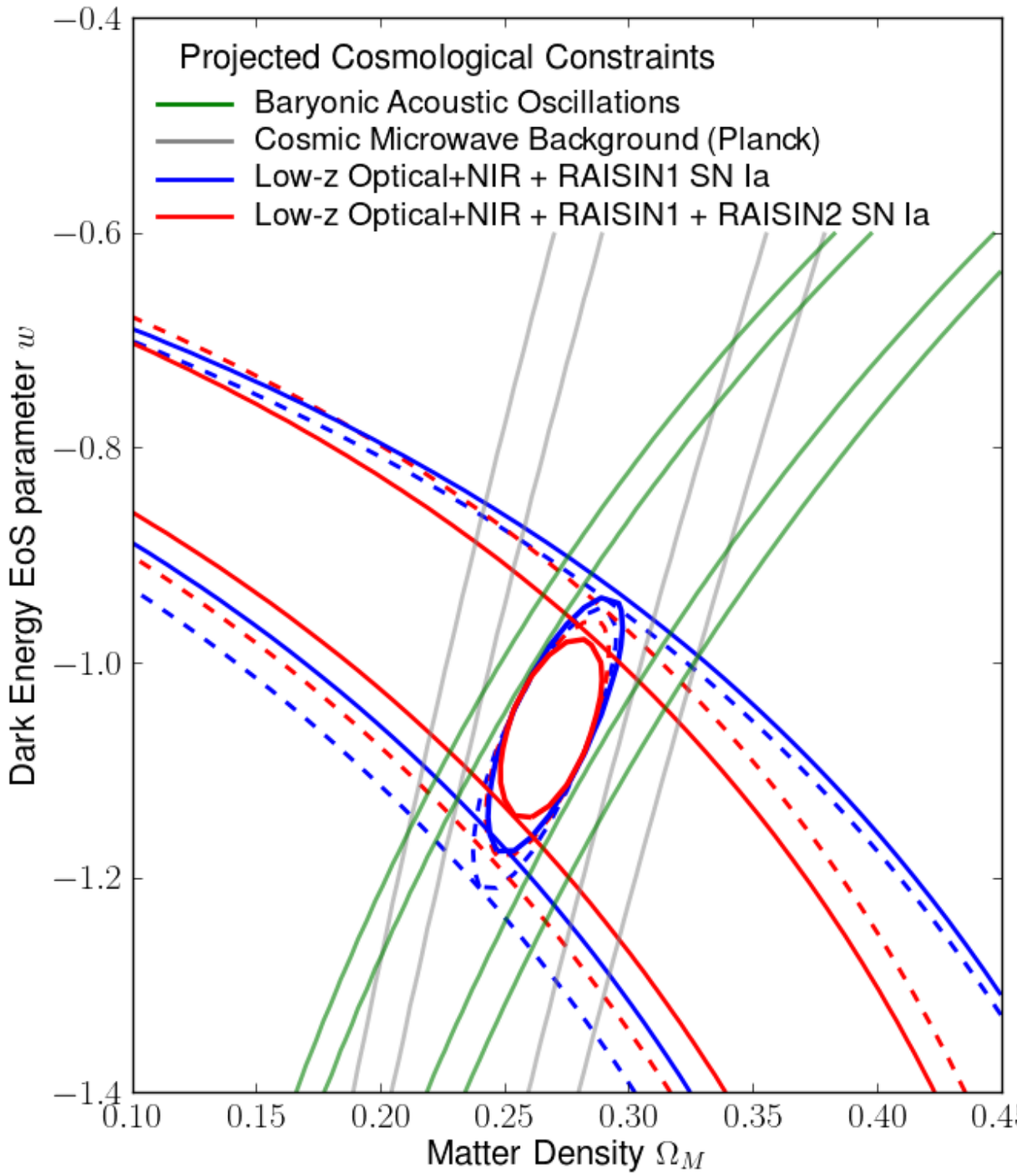


Ho = 70
Om = 0.3, flat
w = -1



Simulation of RAISINs





w = ??? +/- 0.07 (stat + syst)

VEILS:
VISTA Extragalactic Infrared Legacy Survey

- PIs: M. Banerji (Cam / Static), S. Hoenig (Soton / Transient)
- new UK-led ESO Public Survey, 1st unbiased extragalactic transient survey at NIR wavelengths.
- SN Science: Mark Sullivan, Mat Smith, Tomas Müller (Soton), KSM (Cam)
- Goal: 300 SN Ia to z = 0.1 ~ 0.6 with optical + NIR
- NIR from VISTA 4m (until 4MOST installed ~2021/2)
- Optical from DES (last year), VIOLETTE (VST, next 2 years)
- Spectra from WHT / VLT / Oz-DES ?

VEILS: observer frame J-band

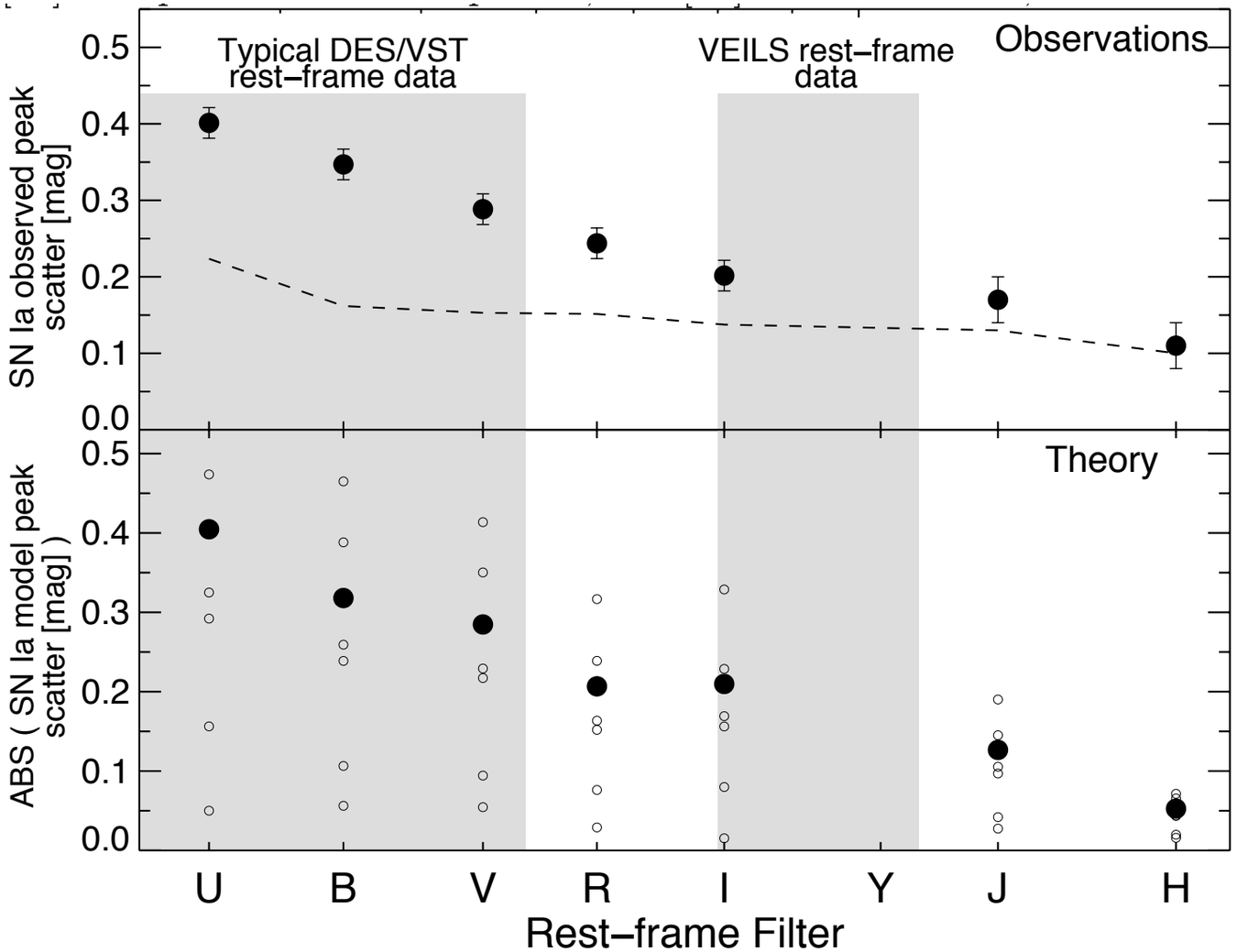


Fig. 1: The intrinsic rms scatter of SN Ia peak magnitudes as a function of wavelength from observations (top panel) and modelling (lower panel). Both show significantly smaller scatter at redder wavelengths, but most SN cosmology experiments (SNLS, PS1, DES) probe bluer wavelengths as observer-frame $griz$ data is redshifted into rest-frame UBV at high-redshift. VEILS, operating in the observer-frame NIR (J), will sample rest-frame I/Y data for the first time in a large sample of SNe Ia at high redshift.

credit: Mat Smith

VEILS: expected redshift distribution

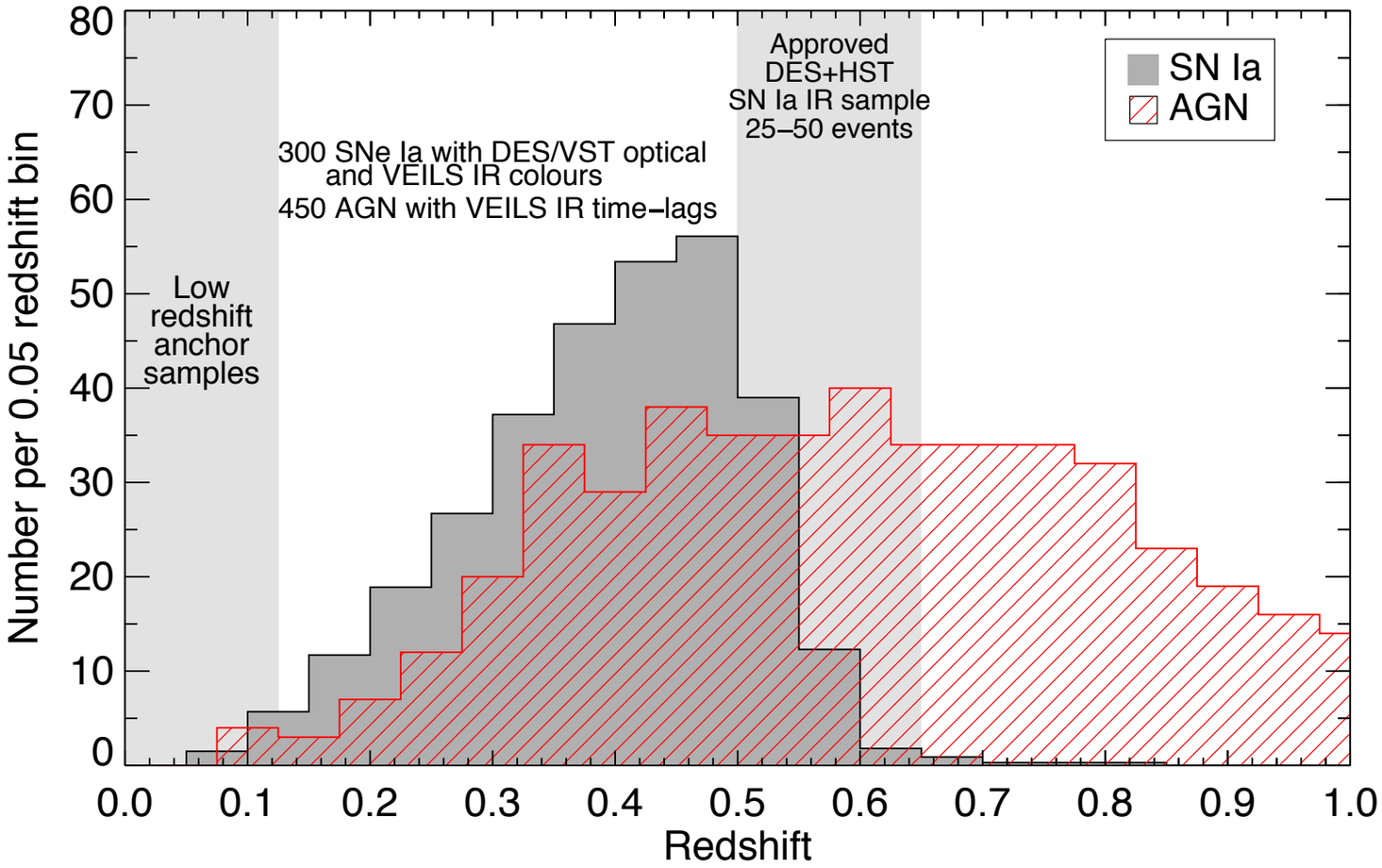


Fig. 2: The redshift histogram for the VEILS SN Ia and AGN samples after 3 years. For the SNe Ia, the redshift range of complementary local-anchor samples and higher-redshift *HST* samples are also shown as shaded grey regions. All the SNe Ia will have high-quality DES/VST optical and VEILS/VIRCAM J-band light curves. Here we propose to obtain a complete, unbiased sample of *all* SNe up to $z = 0.4$.

credit: Mat Smith

VEILS: optical + NIR LCs

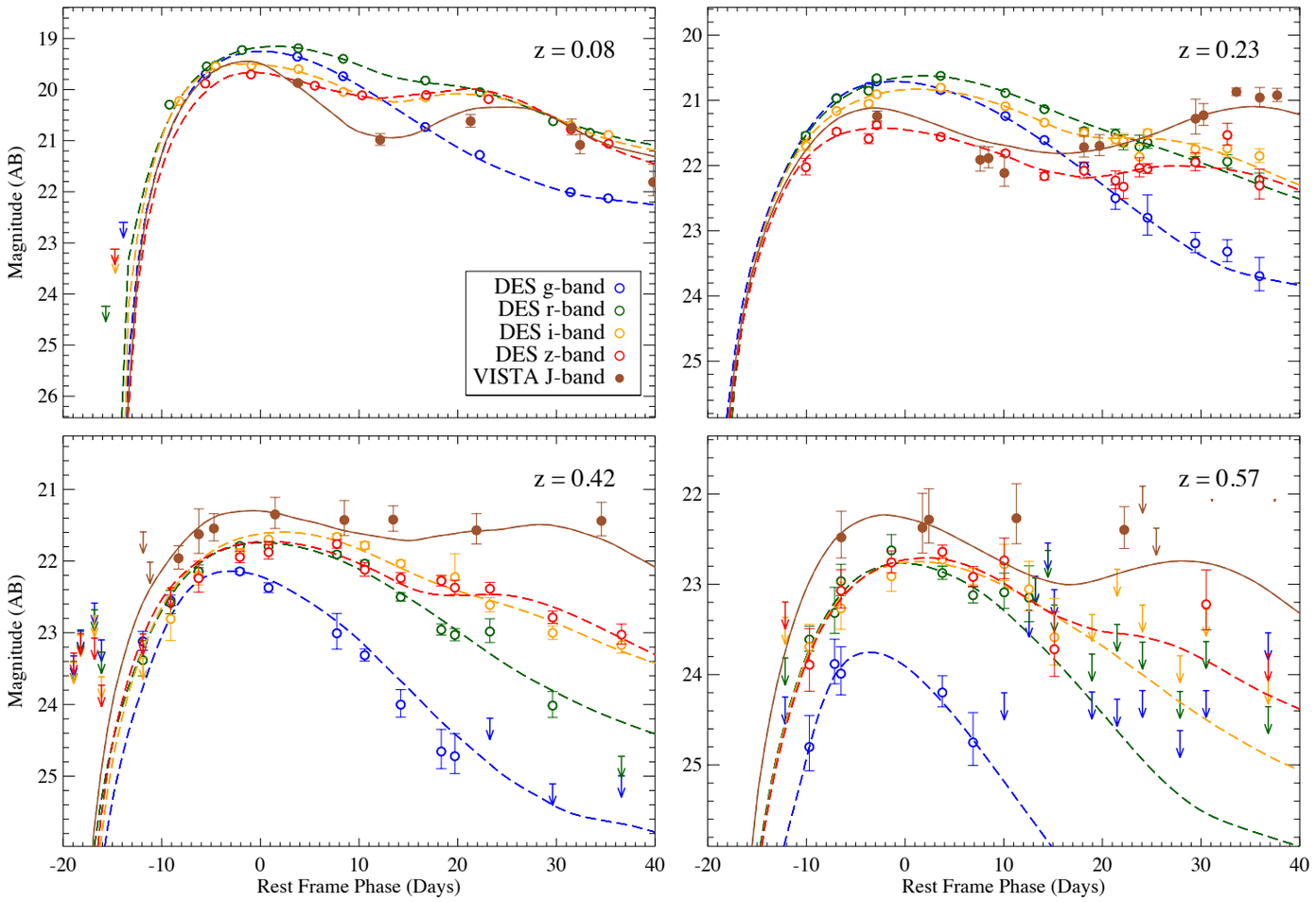


Fig. 3: Combined DES *griz* (open circles) and VISTA (filled circles) J-band light-curves for a sample of 4 SNe Ia from the first year of the VEILS survey. Template fits are over-plotted (dashed and solid lines) highlighting the near-infrared (NIR) secondary maximum, which is not observed in the bluer optical bands. Over 3 years, VEILS will produce a well sampled catalogue of 300 spectroscopically confirmed SNe Ia up to $z = 0.6$, with which to independently test the cosmological model.

credit: Mat Smith, Tomas Müller