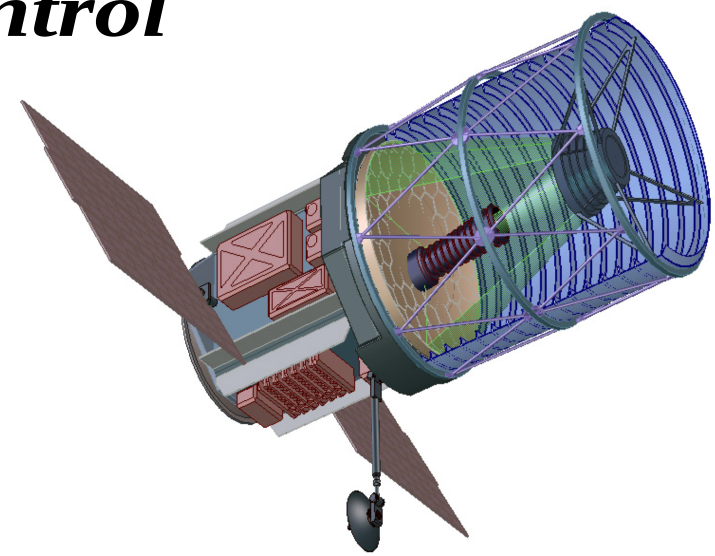
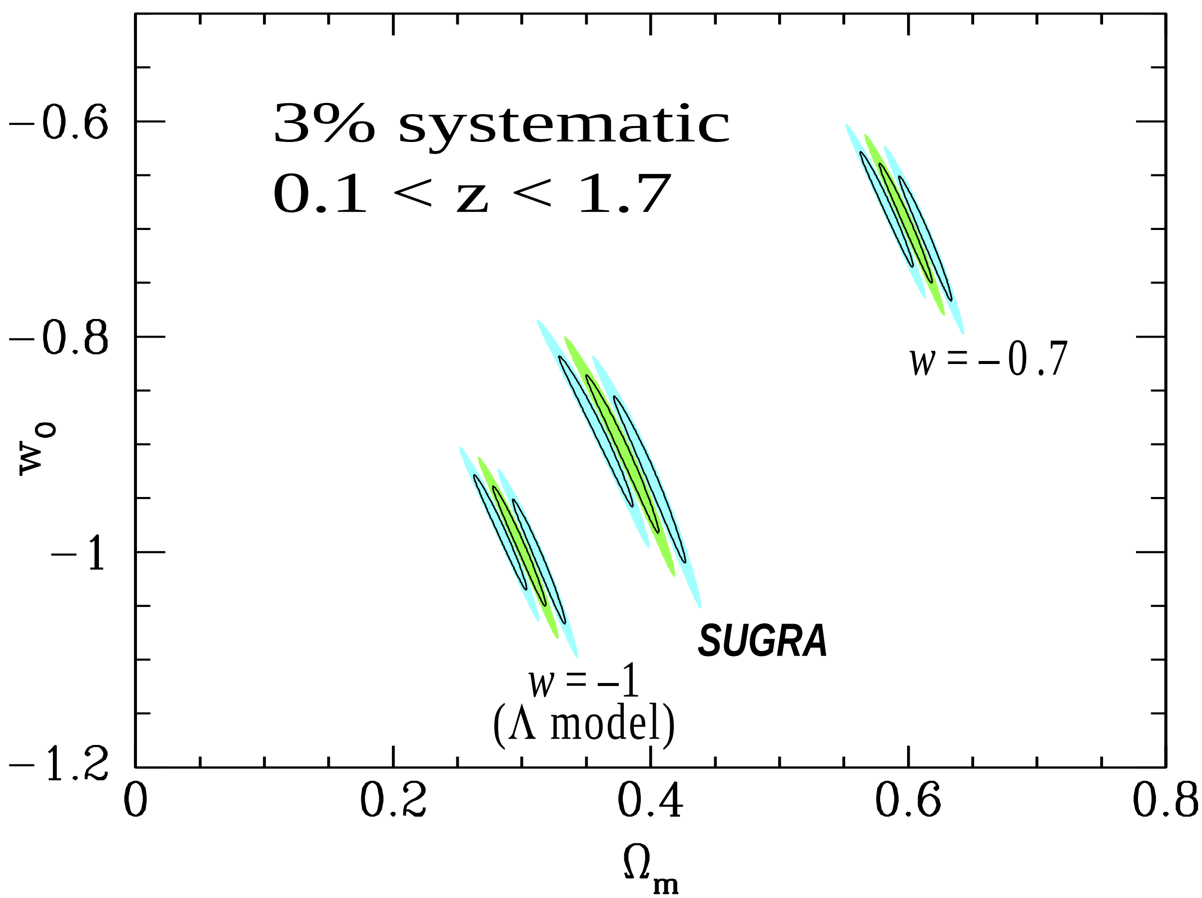
SNAP

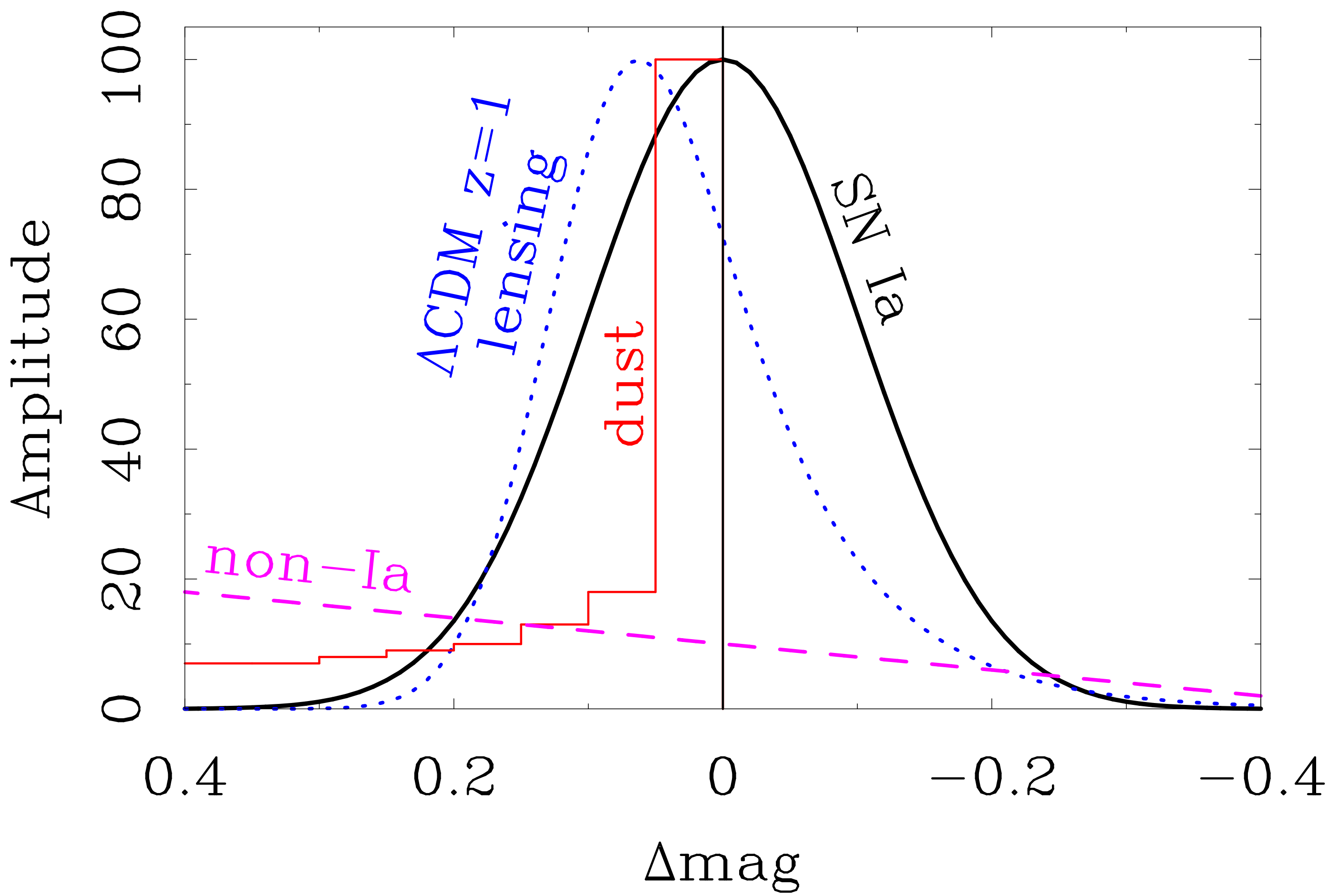
SNAP Systematics Control



- Introduction to cosmology/SN systematics
- On-going work to constrain systematics
- Derived requirements for SNAP systematics goals
- Comparison with other current & future facilities

Importance of Systematic Uncertainties for $m - z$ Test




Amplitude
0
20
40
60
80
100
0.4
0.2
0
−0.2
−0.4
Δmag
non−Ia
ΛCDM z=1
lensing
dust
SN Ia

What are the Systematics?

Known Systematics

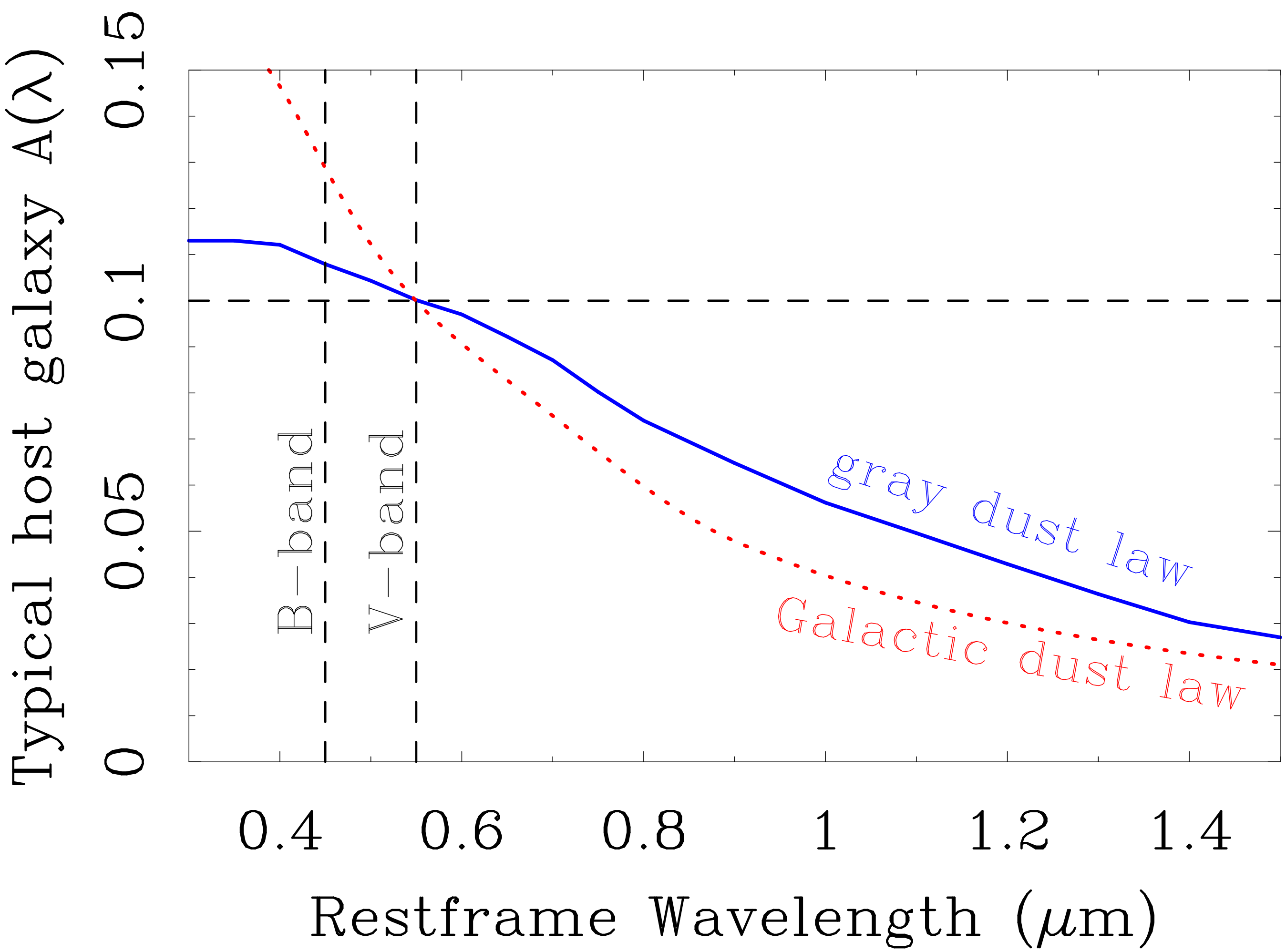
- Astrophysics
- Data Reduction
- Data Analysis

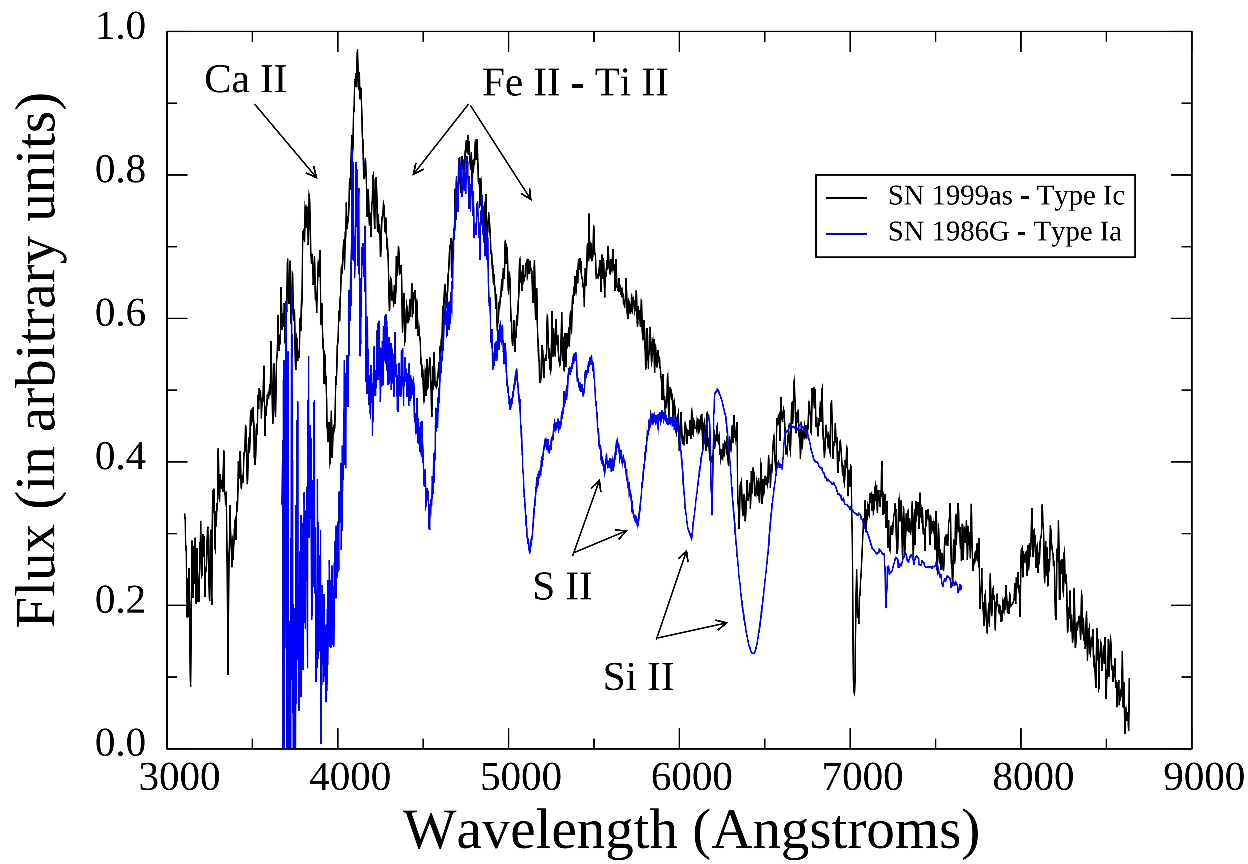
Possible Systematics

- Astrophysics
  - intergalactic dust
  - supernova “evolution”

Known Astrophysical Systematics

- Differing Host-Galaxy Extinction Laws
  - — host metallicty, star-formation history, hot gas
- Gravitational Lensing De/Amplification
  - — cosmology & structure formation; increases with redshift
- Contamination by non-Type Ia SNe
  - — star formation history; increases with redshift


Typical host galaxy A(λ)
0
0.05
0.1
0.15
B−band
V−band
gray dust law
Galactic dust law
0.4
0.6
0.8
1
1.2
1.4
Restframe Wavelength (μm)


Ca II
Fe II - Ti II
S II
Si II
SN 1999as - Type Ic
SN 1986G - Type Ia
Flux (in arbitrary units)
Wavelength (Angstroms)
0.0
0.2
0.4
0.6
0.8
1.0
3000
4000
5000
6000
7000
8000
9000

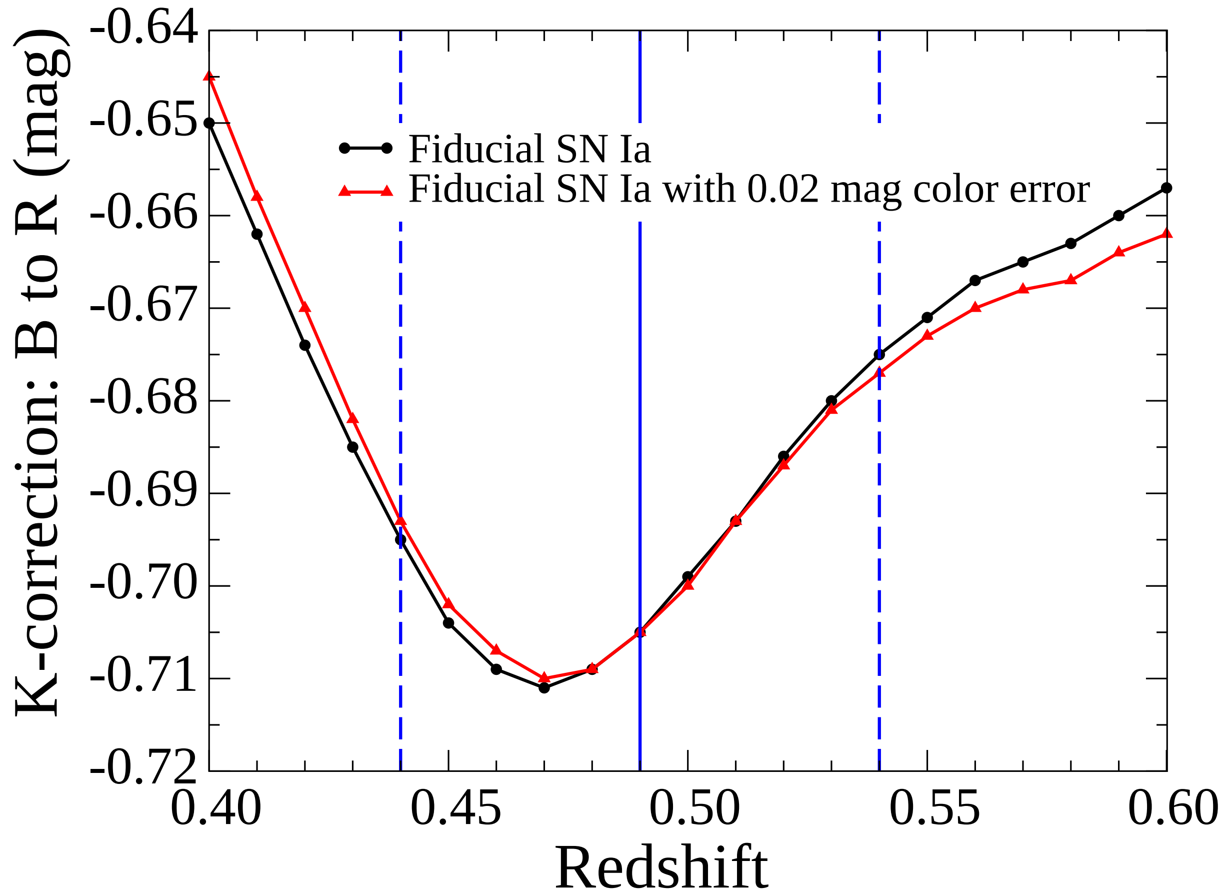
Data Reduction Systematics

- Flat-Fielding
  - — color dependence, scattered light, fringing
- Cross-Wavelength Flux Calibration
  - — dependent on spectrophotometric standard stars
- Variable Image Quality (Point-Spread-Function)
  - — temporal & spatial stability & uniformity
- Flux Linearity
  - — detector linearity, flux weighting, sky & galaxy subtraction
- Photometric Fidelity
  - — CTE, pixel MTF, sampling, dithering pattern

Data Analysis Systematics

- Malmquist Bias for Flux-Limited Sample
  - — scales as covariance between discovery and peak
  - — large for near-peak discovery (2% - 10%)
  - — volume-limit ideal, but thwarted by extinction;
  - — therefore, find SNe well before peak to reduce covariance
- Cross-Filter K-corrections
  - — dominated by spectral slope — SN features minor
  - — redshift-matched filters w/ overlap reduce interpolation
  - — spectral time series as templates
- Correlated Parameters & Correlated Uncertainties
  - — e.g. observed peak brightness & stretch can be correlated
  - — scales with N_{SNe}^2, and as power of # parameters

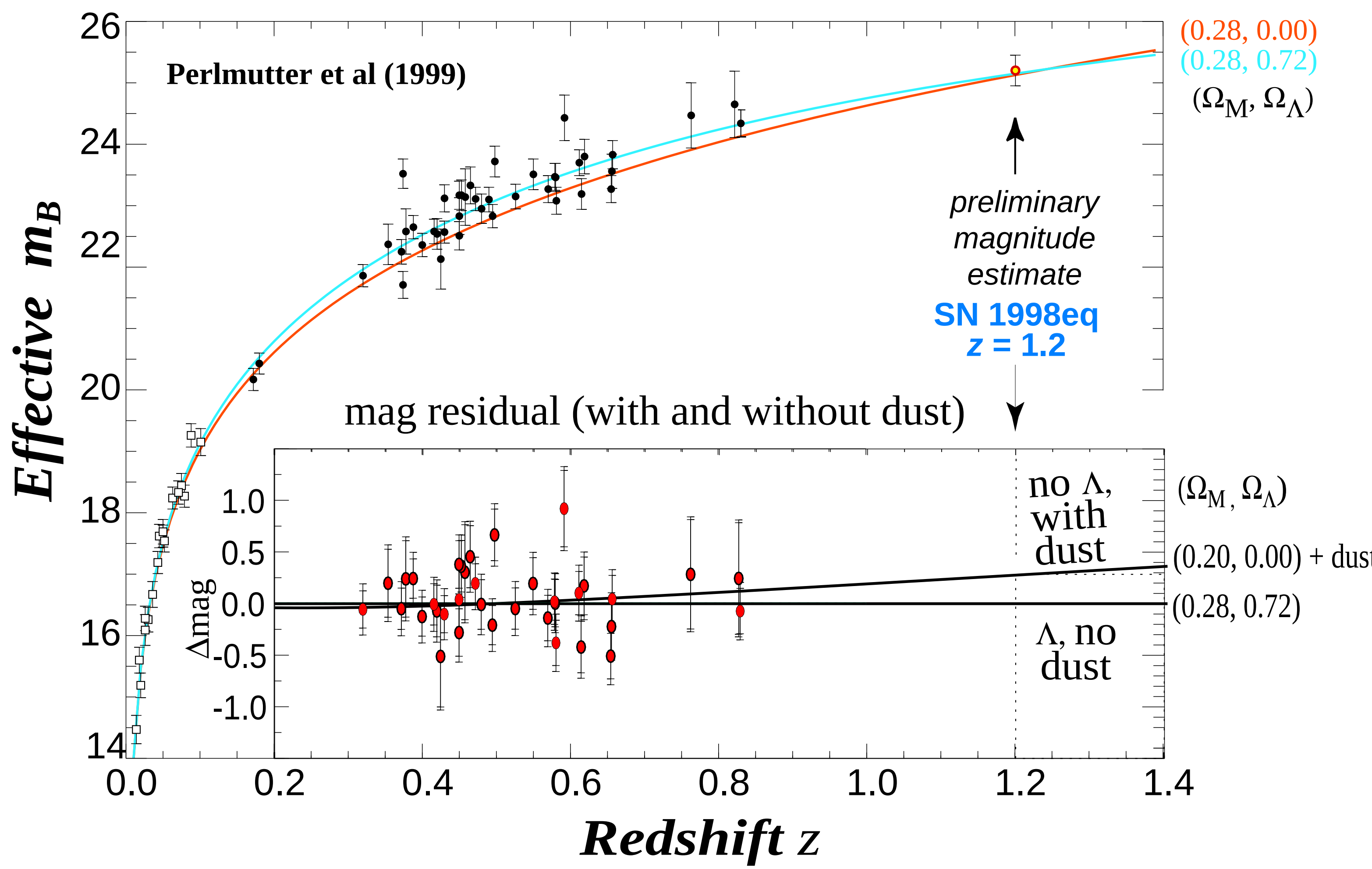
$B(z)$ filters w/ $\Delta z \sim 0.1$ bound K-correction errors



Past & On-going Work on (Gray) Dust Extinction

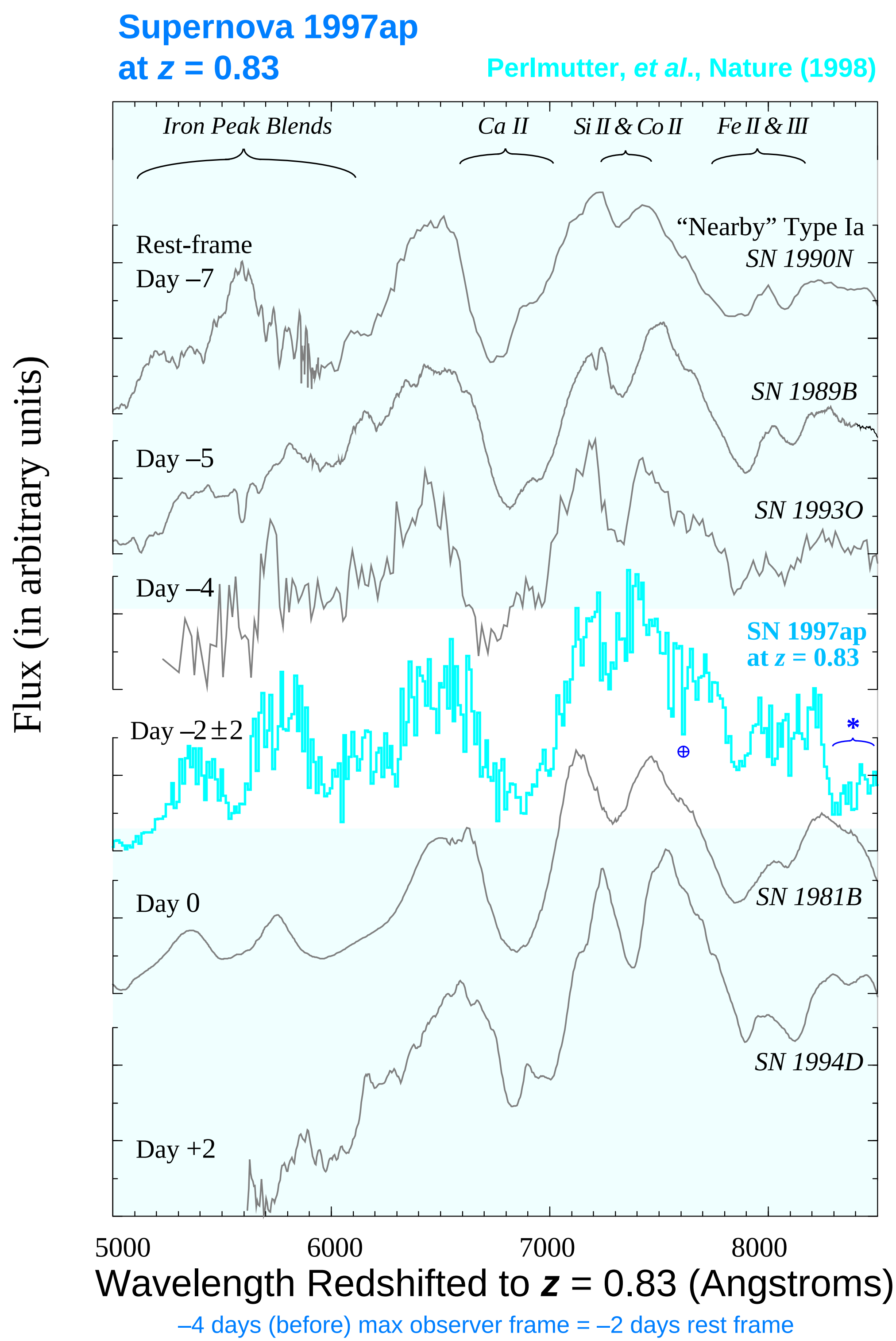
- $z = 1.2$ SN Ia prefers no intergalactic-dust cosmology
- Restframe $B - I$ color curve for $z = 0.5$ SN Ia
- Multiple QSO images seen through lensing galaxies
- Resolve far-infrared background into sources (*dust glows*)
- Nearby Supernova Factory / SCP high-z (*Ia & II*)

High-Redshift SN probes Cosmology vs. Dust/Evolution

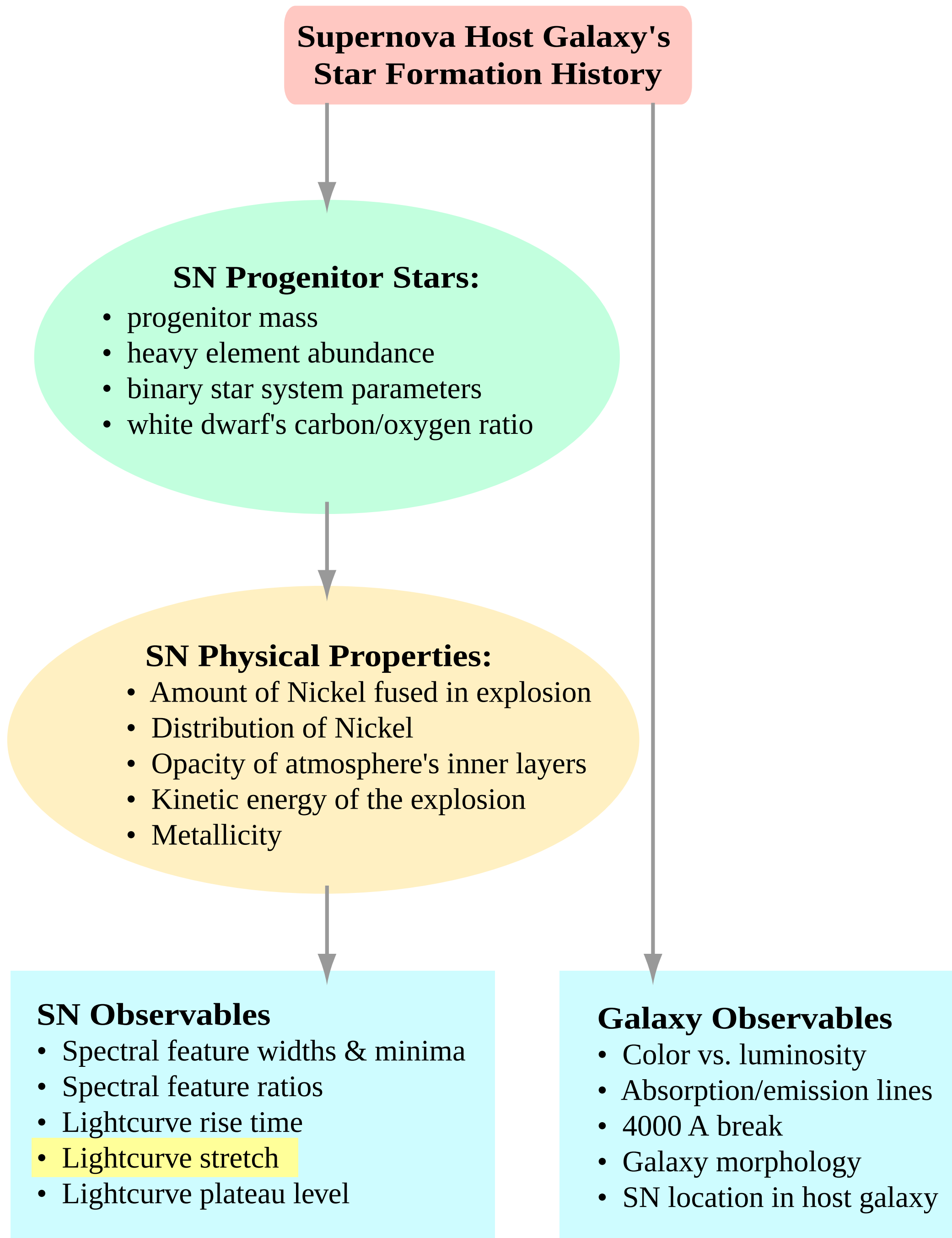


Past & On-going Work on "Evolution"

- Risetime comparison (high-z & low-z consistent)
- Spectral comparisons
- SCP nearby SNe
  (18 Ia w/ multi-color lightcurves & spectral time series)
- Nearby Supernova Factory
  (emphasis on wide range of environments/parameters)
- SCP (STIS spectroscopy) & High-Z high-z SNe


Supernova 1997ap
at z = 0.83
Perlmutter, et al., Nature (1998)
Iron Peak Blends
Ca II
Si II & Co II
Fe II & III
Rest-frame
Day –7
"Nearby" Type Ia
SN 1990N
SN 1989B
Day –5
SN 1993O
Day –4
SN 1997ap
at z = 0.83
Day –2 ± 2
*
⊕
Day 0
SN 1981B
SN 1994D
Day +2
Flux (in arbitrary units)
5000
6000
7000
8000
Wavelength Redshifted to z = 0.83 (Angstroms)
–4 days (before) max observer frame = –2 days rest frame

Control of Evolution Systematics:
Matching Supernovae



SNAP

Spectrum & Lightcurve Reveal Explosion Initial Conditions

Observables	^{56}Ni Mass	^{56}Ni Distribution	Kinetic Energy	Opacity	Metal-licity
Spectral feature minima	○	—	●	○	●
Spectral feature widths	○	—	●	○	●
Spectral feature Ratios	●	—	○	○	●
Lightcurve Stretch	●	○	○	●	—
Lightcurve Rise Time	●	●	○	○	○
Lightcurve Peak/Tail	○	—	○	●	—

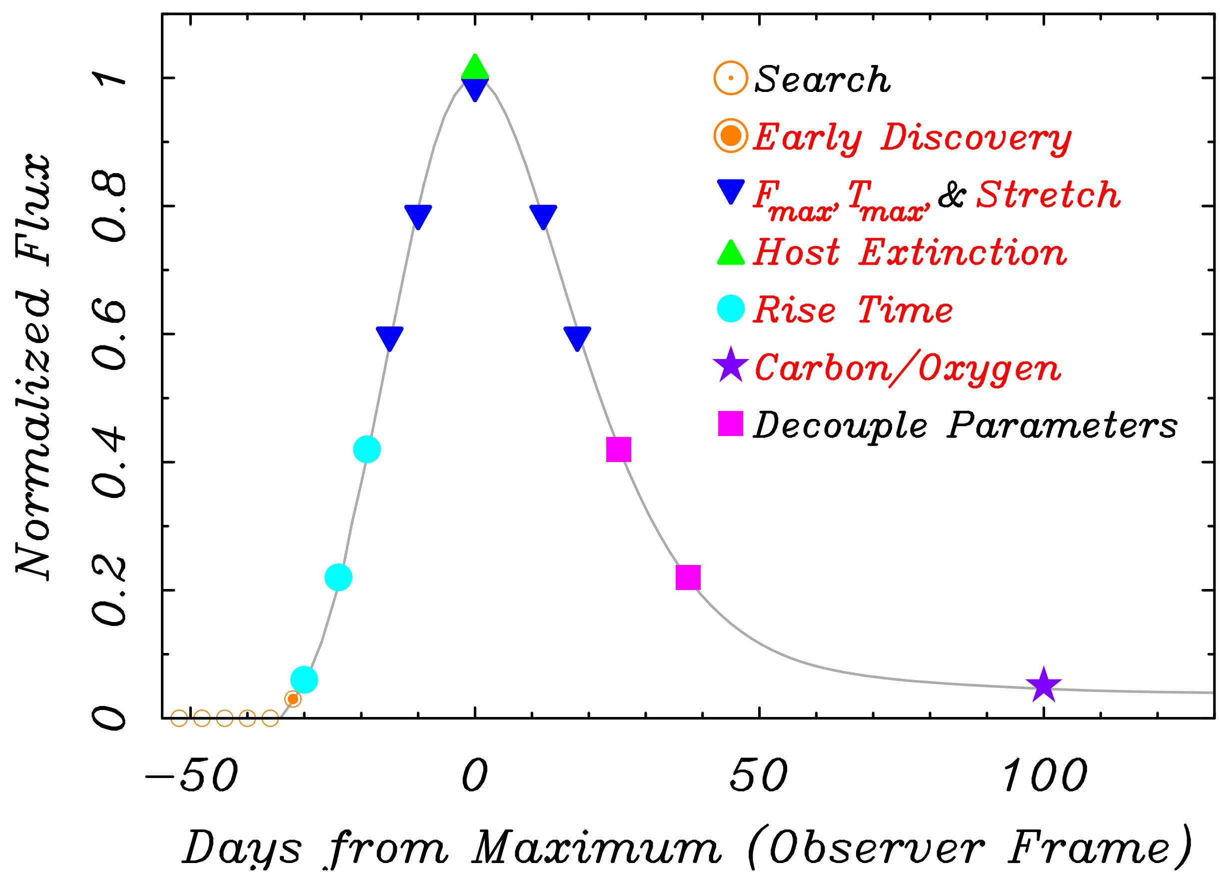
● = directly related to model parameter
○ = indirectly related to model parameter
— = slightly related to or no relation to the model parameter

SNAP will measure all of these Observables

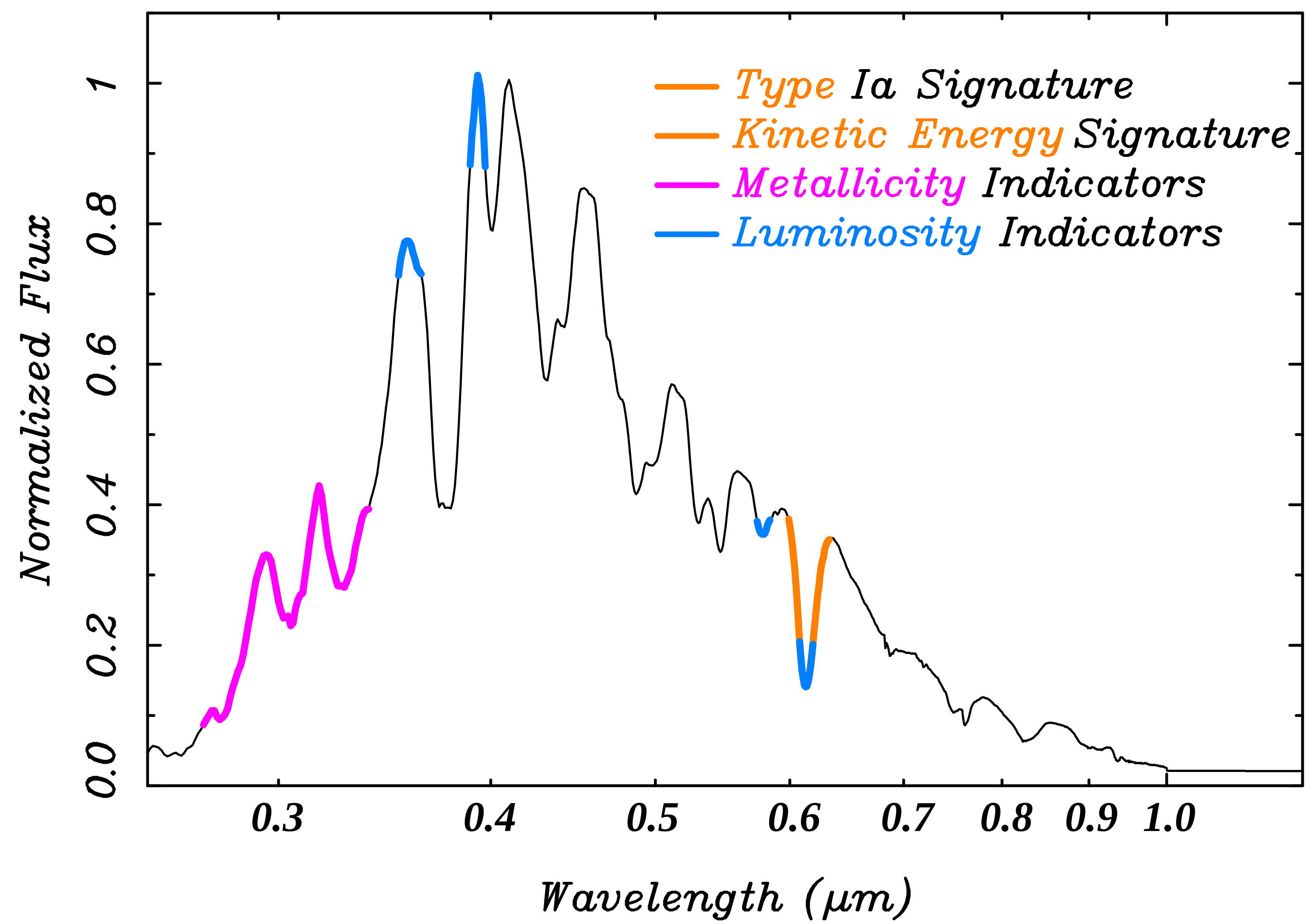
pre-cursor SNfactory will provide calibration

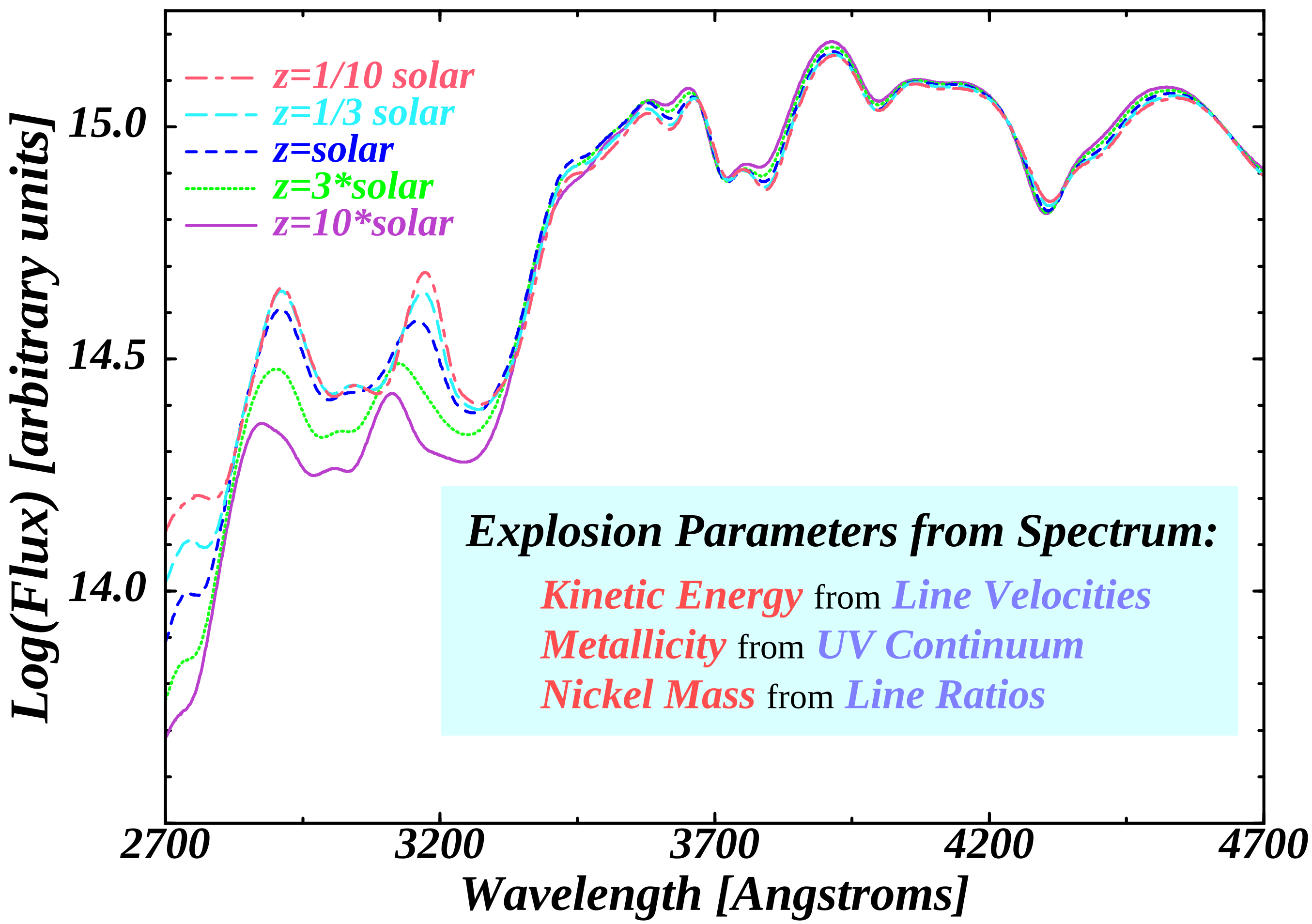
SNAP

B–band Lightcurve Photometry for $z = 0.8$ Type Ia



Type Ia Spectral Features




z=1/10 solar
z=1/3 solar
z=solar
z=3*solar
z=10*solar
Explosion Parameters from Spectrum:
Kinetic Energy from Line Velocities
Metallicity from UV Continuum
Nickel Mass from Line Ratios
Log(Flux) [arbitrary units]
15.0
14.5
14.0
2700
3200
3700
4200
4700
Wavelength [Angstroms]

Accuracy to Measure Explosion Initial Conditions

Spectrum Observables X	$\partial M_{peak}/\partial X$ (rest frame)	Requirement for $m_{sys} < 0.02$
Feature minima	0.04/500 km/s	250 km/s
Feature widths	0.03/1200 km/s	500 km/s
Feature Ratios	0.12 (@B), −0.75 (@$\lambda = 3000\mathring{A}$), 1.5 (@$\lambda = 6150\mathring{A}$)	5%

Light Curve Observables X	$\partial M_{peak}/\partial X$ (rest frame)	Requirement for $m_{sys} < 0.02$
Stretch	0.10/5%	1%
Rise Time	0.07/1 day	0.3 days
Peak to tail ratio	0.05/0.2 mag	0.05 mag

Derived Requirements to Control Systematic Uncertainties

First convert Systematic into Statistical Uncertainties

Systematic	Requirement to satisfy 2%
Data reduction	Common system; stable environment; built-in X-cal
Correlated errors	Accurate measurements; well-sampled lightcurves
Non-SN Ia Contam.	Peak spectrum covering Si II 6150Å
Malmquist bias	Early discovery at all redshifts
Cross-filter K-Corr.	Redshift-matched filters; Peak spectrum; in-situ templates
Milky Way extinction	SIRTF FIR + SNAP Galactic subdwarfs
Gravitational lensing	Average/model; large-N per Δz-bin, good precision
Host dust extinction	Long wavelength-baseline calibrated spectra
Supernova "Evolution"	Initial conditions from lightcurve & spectral features

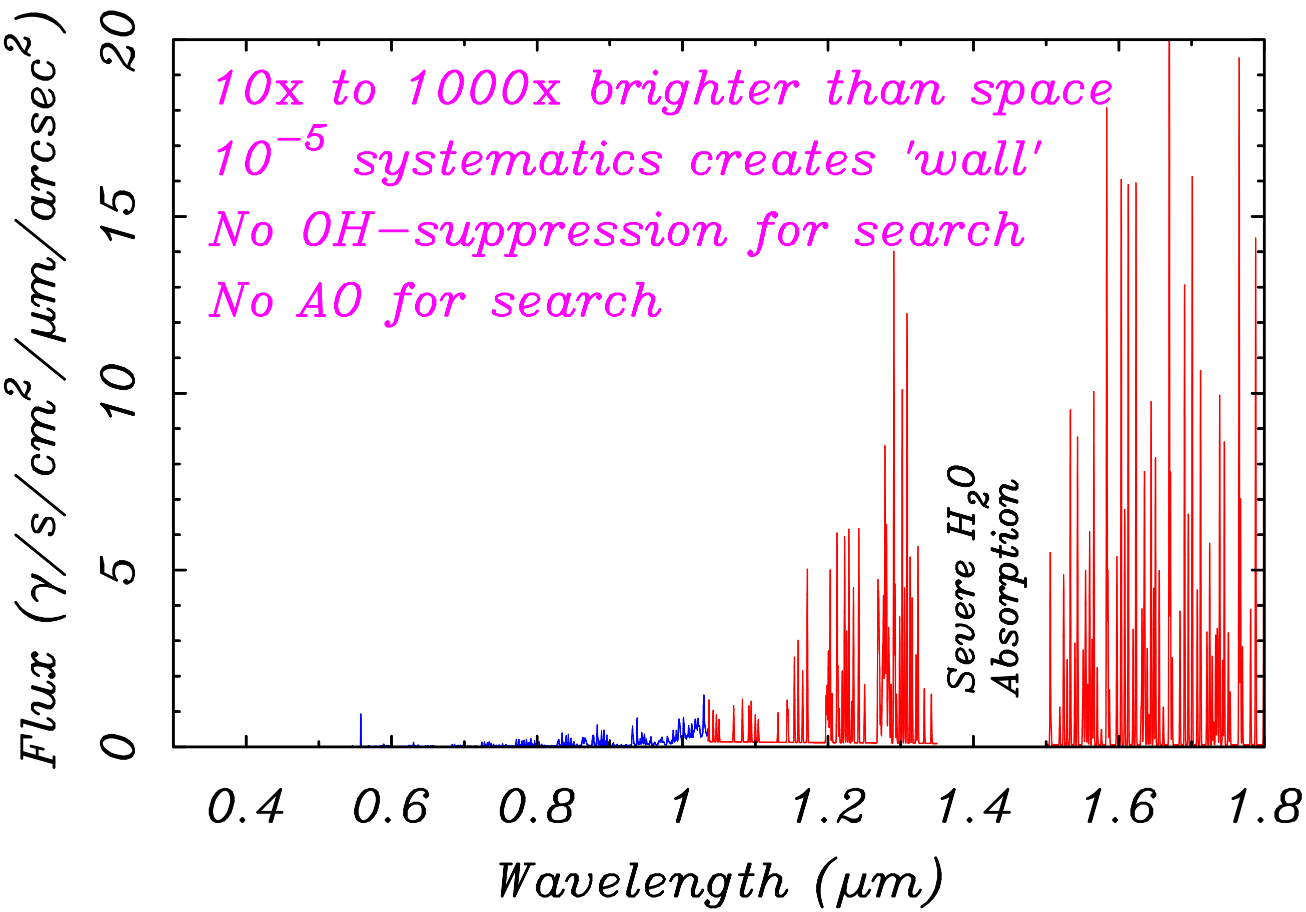
SNAP

Estimated Systematics Error Budget

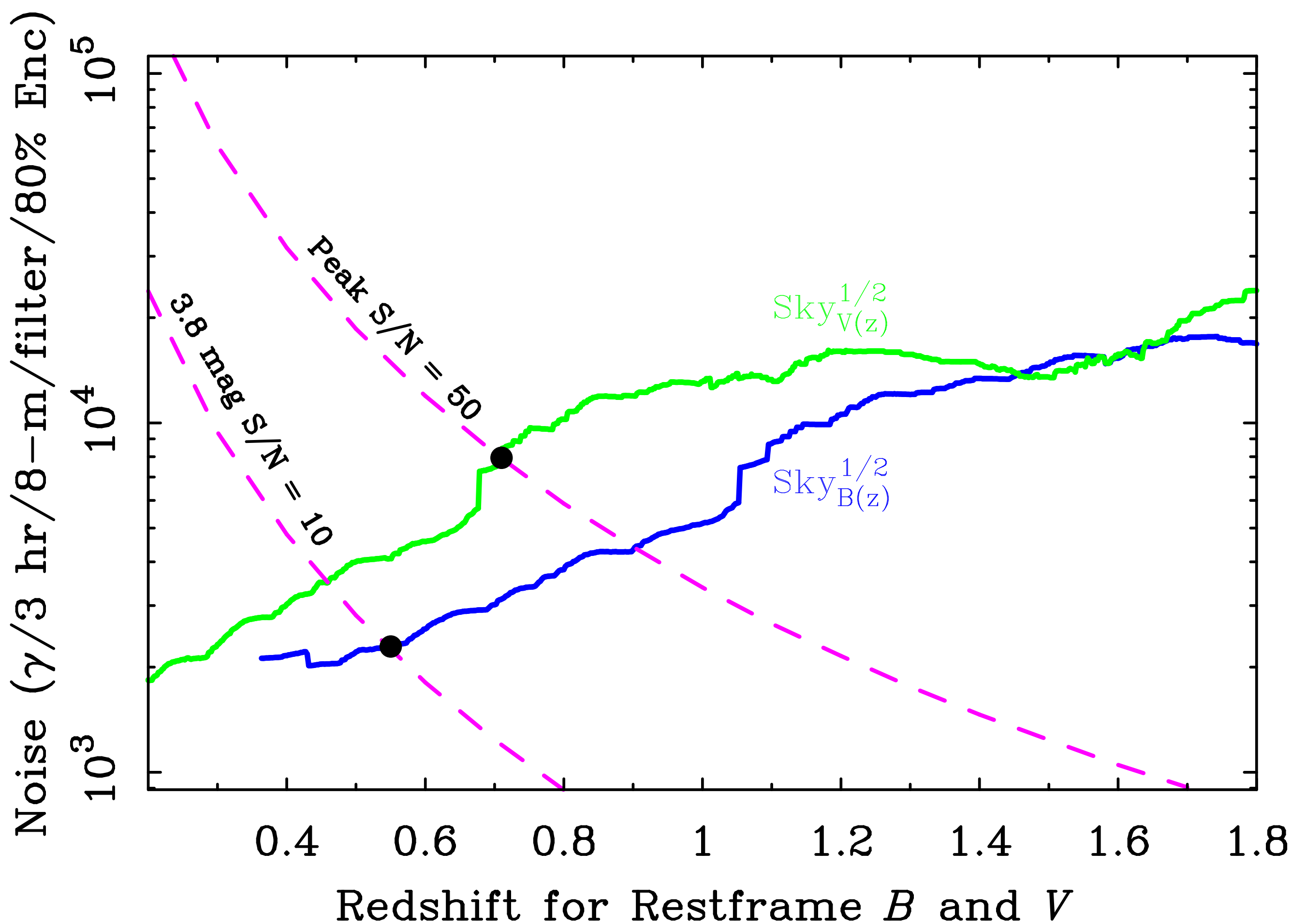
Goal: 2% per redshift bin over $0.1 < z < 1.7$;
<2% in adjacent redshift bins

Residual Systematic Source	Statistical	Estimated Residual
Data reduction	—	< 0.5%
Correlated errors	—	< 0.5%
Non-SN Ia Contamination	—	0.0%
Malmquist bias	—	< 0.5%
Cross-filter K-Correction	—	< 0.5%
Milky Way extinction	10–20%	0.5%
Gravitational lensing	1–10%	1%
Host dust extinction	1–20%	1%
Supernova "Evolution"	$\sim$ 10%	1%
Arithmetic Sum		3.5%
Quadrature Sum		2.1%

the Tremendous Sky Brightness compared to SNe



Sky Photon Noise: Ground 8−meter, 3 hr



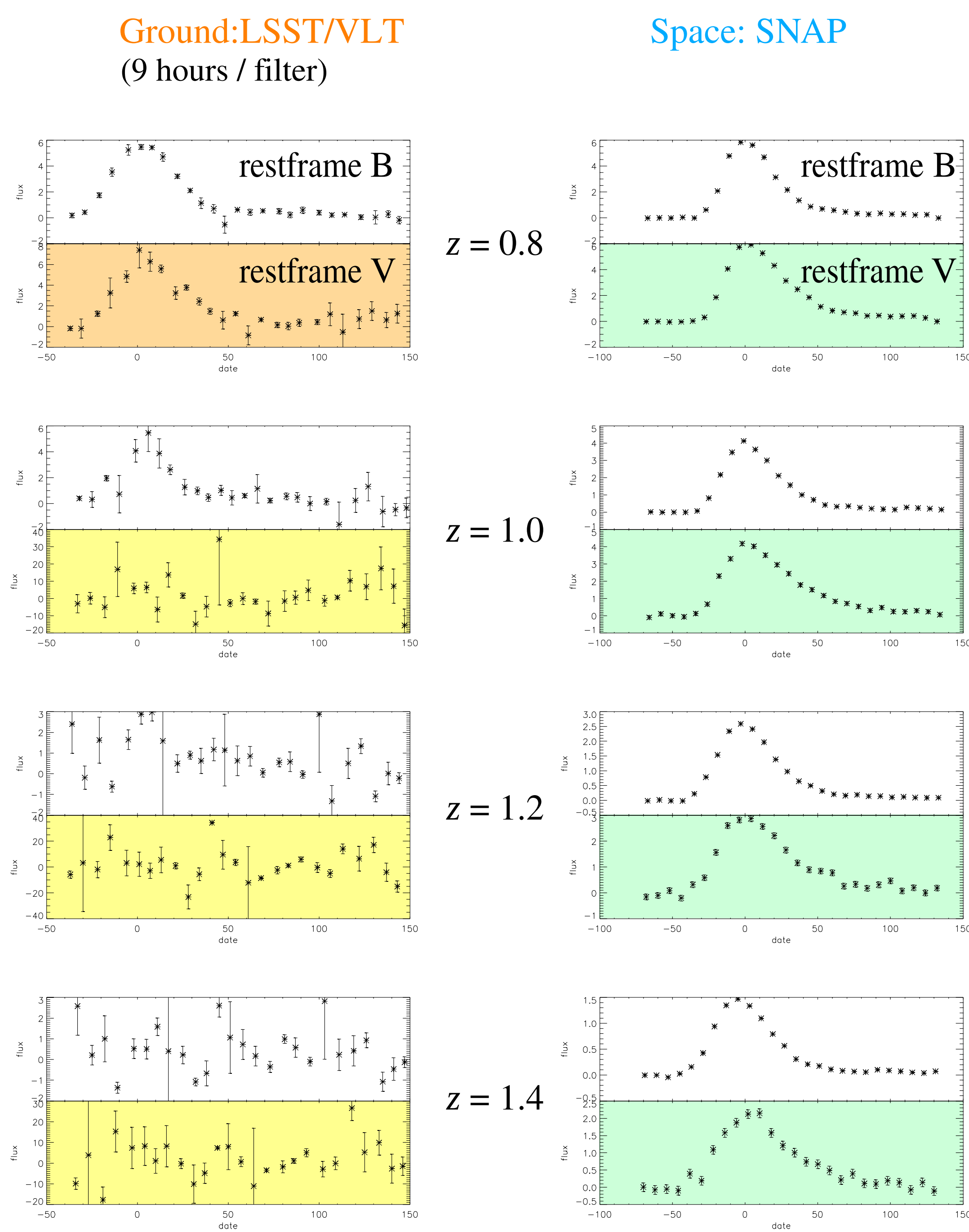
Ground and Space Simulations Inputs & Assumptions

Deep Lightcurve Photometry Simulation Parameters

Imaging Parameter	Ground	Space
Aperture	6.5-m effective	2-m w/ 5% obstruction
Image Quality	actual Paranal seeing distribution	diffraction $\otimes$ diffusion (5 μm) $\otimes$ pixel (10.5 μm)
Sky	observed Keck sky & OH line lists	HST/Ball zodiacal light at ecliptic poles
Host galaxy	average 22 mag/arcsec^2; $(1+z)^4$ dimming; Hubble deep field sizes	
Weather	78% photometric, 87% usable	clear!
Moonlight	Walker (NOAO) far-moon table	NA
Total throughput	60% optical; 30% NIR	60% optical; 30% NIR
Exposure	9 hrs total (full night)	set by SNAP requirements

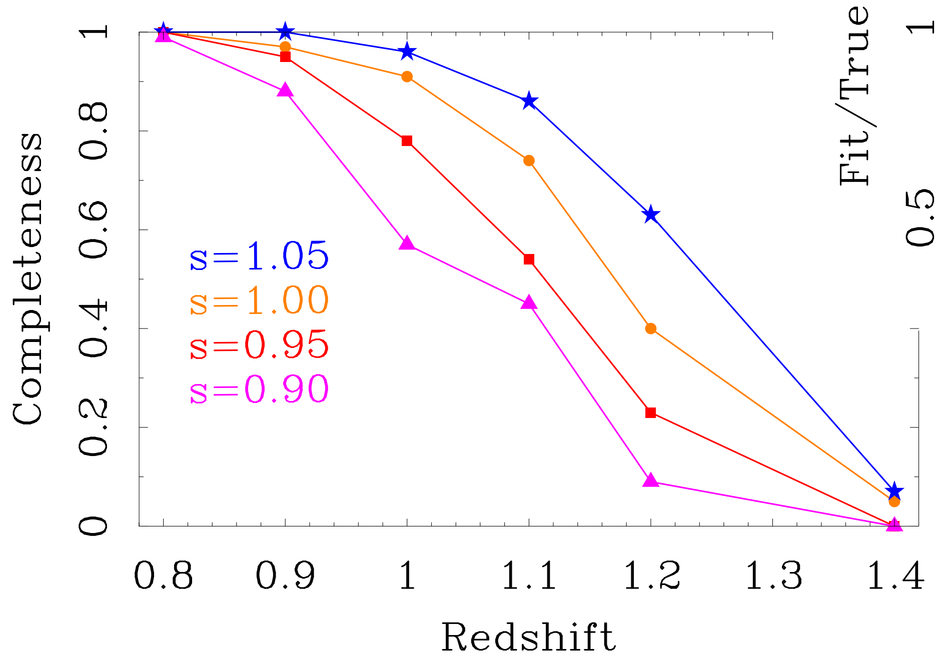
Spectroscopy Simulation Parameters

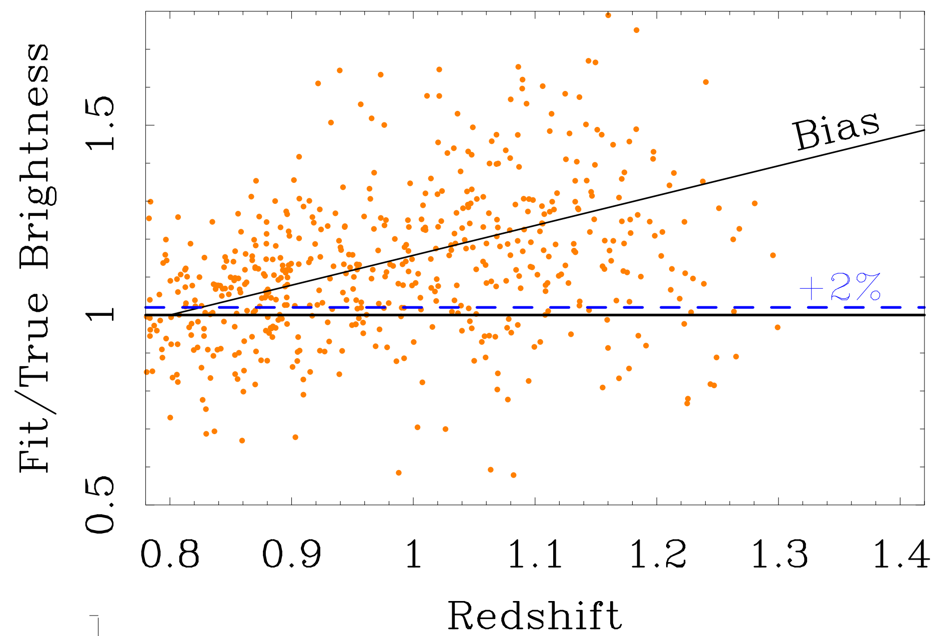
Spectroscopy Parameter	Ground	Ground+*AO*	Space
Aperture	8-m effective	8-m effective	2-m w/ 5% obstruction
Image Quality	median Paranal seeing	Strehl = 0.5	diffraction $\otimes$ diffusion $\otimes$ pixel
Total throughput	57% optical; 29% NIR	29% optical; 14% NIR	45% optical; 35% NIR
Readout noise (e^-/pix)	4 optical; 6 NIR	4 optical; 6 NIR	4 optical; 6 NIR
Dark current (e^-/pix/hr)	5 optical; 60 NIR	5 optical; 60 NIR	5 optical; 60 NIR
Exposure	9 hrs total (full night)	9 hrs total (full night)	set by SNAP requirements
Resolution	4000	4000	200
OH suppression	digital, and including grating & slit diffraction		NA



Ground:LSST/VLT
(9 hours / filter)
Space: SNAP
restframe B
restframe V
z = 0.8
z = 1.0
z = 1.2
z = 1.4
flux
date

LSST deep search Malmquist bias





Why not Wait and Use NGST?

- *SNAP* field of view is 225$\times$ that of *NGST*.
- *NGST* pointing time is ~ 20 minutes.
- Pointing time to cover $20\square^\circ$ is $\sim$ **31 days!**
- Pointing time for mininal follow-up of 2000 SNe is nearly a year!

$\therefore$ ***NGST* much too slow to keep up with discovery *or* follow-up.**

- NGST spectral response dead below 0.6 μm.

$\therefore$ ***NGST* misses CaII & UV flux for $z < 0.8$.**

Can Ground-Based AO do better than SNAP?

AO search & photometry w/ Big Ground-Based Telescope

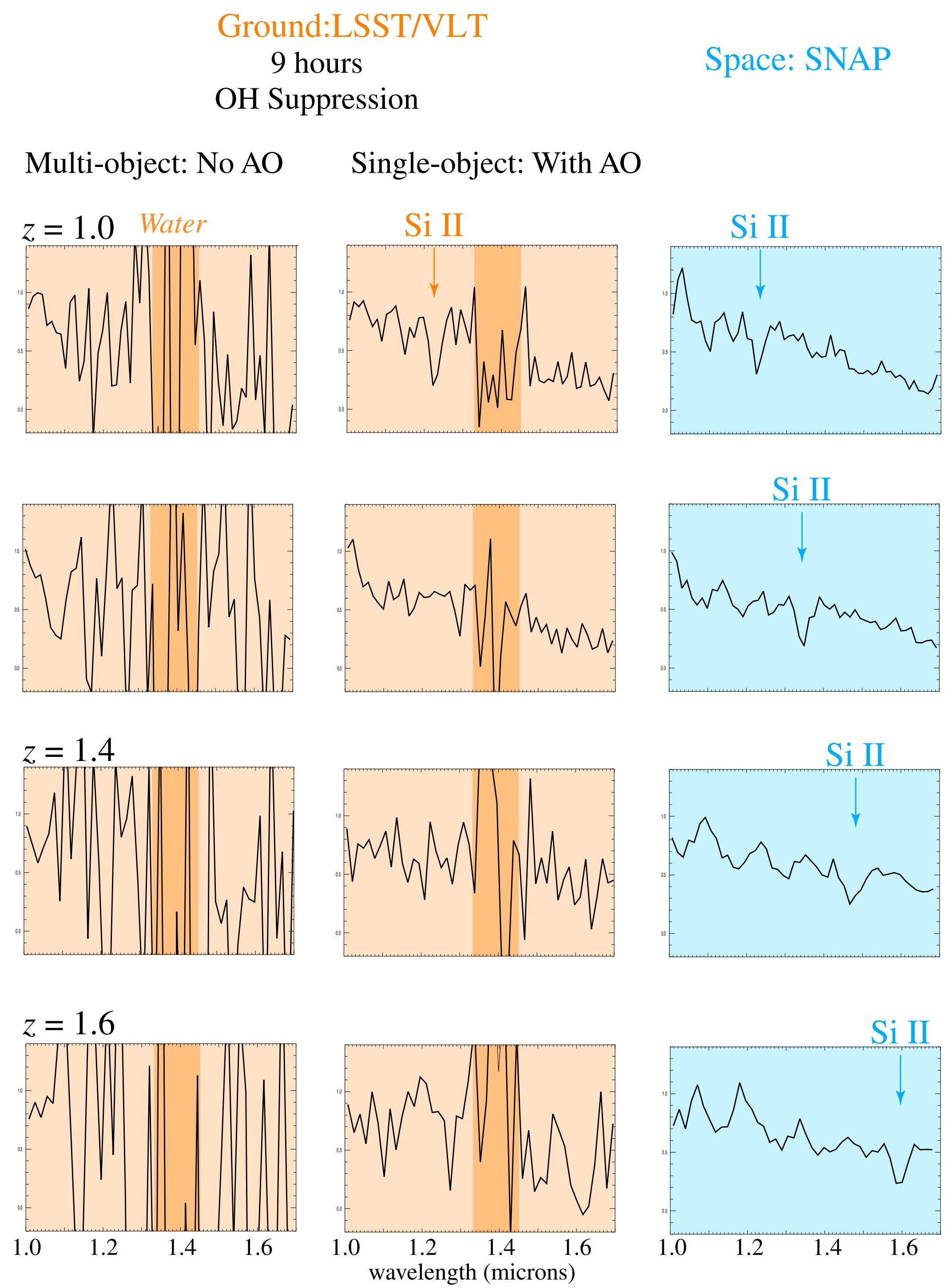
- AO can correct a very small region around SN (MCAO better, but not enough).
- *But, searching & lightcurve require wide field to obtain multiplex advantage.*
- *And, current AO photometry has serious systematics & no consistency/stability.*

AO search & photometry w/ Ground-Based Telescope Array

- Array of tip-tilt corrected 1-meter telescopes can improve large field.
- *But, large "skirt" of tip-tilt PSF negates advantage for accurate photometry.*
- *And, again there is no spatial or temporal consistency/stability.*

AO spectroscopy w/ Big Ground-Based Telescope

- 9 hrs on 8-m w/ OH-suppression & AO worse than SNAP.
- *1 hr on 30-m w/ OH-suppression & AO comparable to SNAP (@$z = 1.6$).*
- *Spectrum not photometric – lose dust correction & K-correction template.*



Ground:LSST/VLT
9 hours
OH Suppression
Space: SNAP
Multi-object: No AO
Single-object: With AO
z = 1.0
Water
Si II
Si II
Si II
z = 1.4
Si II
z = 1.6
Si II
1.0
1.2
1.4
1.6
wavelength (microns)

SNAP Internal Controls and Cross Checks

- Fit cosmology for spectrally matched subsamples
- Fit using galaxy morphology & radial subsamples
- Look for non-cosmological trends & increased scatter over wide redshift range
- Fit cosmology for SNe with best filter matches
- Use SNe II as independent check on SNe Ia
- Compare weak lensing Ω_M with SNe Ia asymptotic Ω_M at deceleration epoch

SNAP Systematics Control Summary

- Identified systematics become negligible or statistical
- Opt/NIR coverage enables correction for non-standard dust.
- Quality lightcurves & spectra check/correct for “evolution”
- “Sanity Checks” using subsamples & wide redshift range
- Cross-checks from SNe II & Weak Lensing
- Space facility offers superior systematics control

SNAP’s quality dataset keeps systematics under control