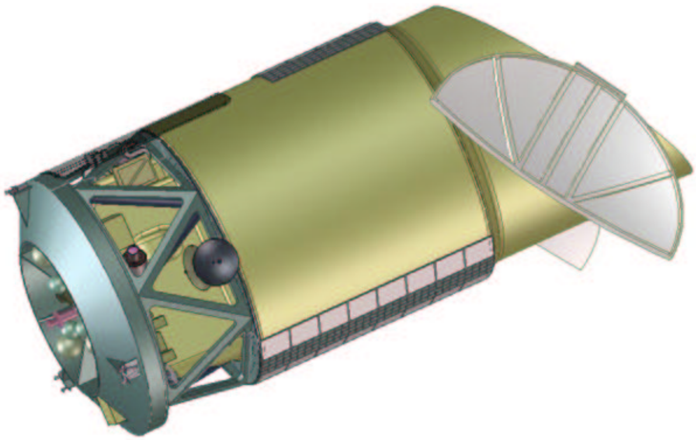
SNAP Systematics Control



- Introduction to cosmology/SN systematics
- On-going work to constrain systematics
- Derived requirements for SNAP systematics goals

SNAP Error Budget

Science Requirements

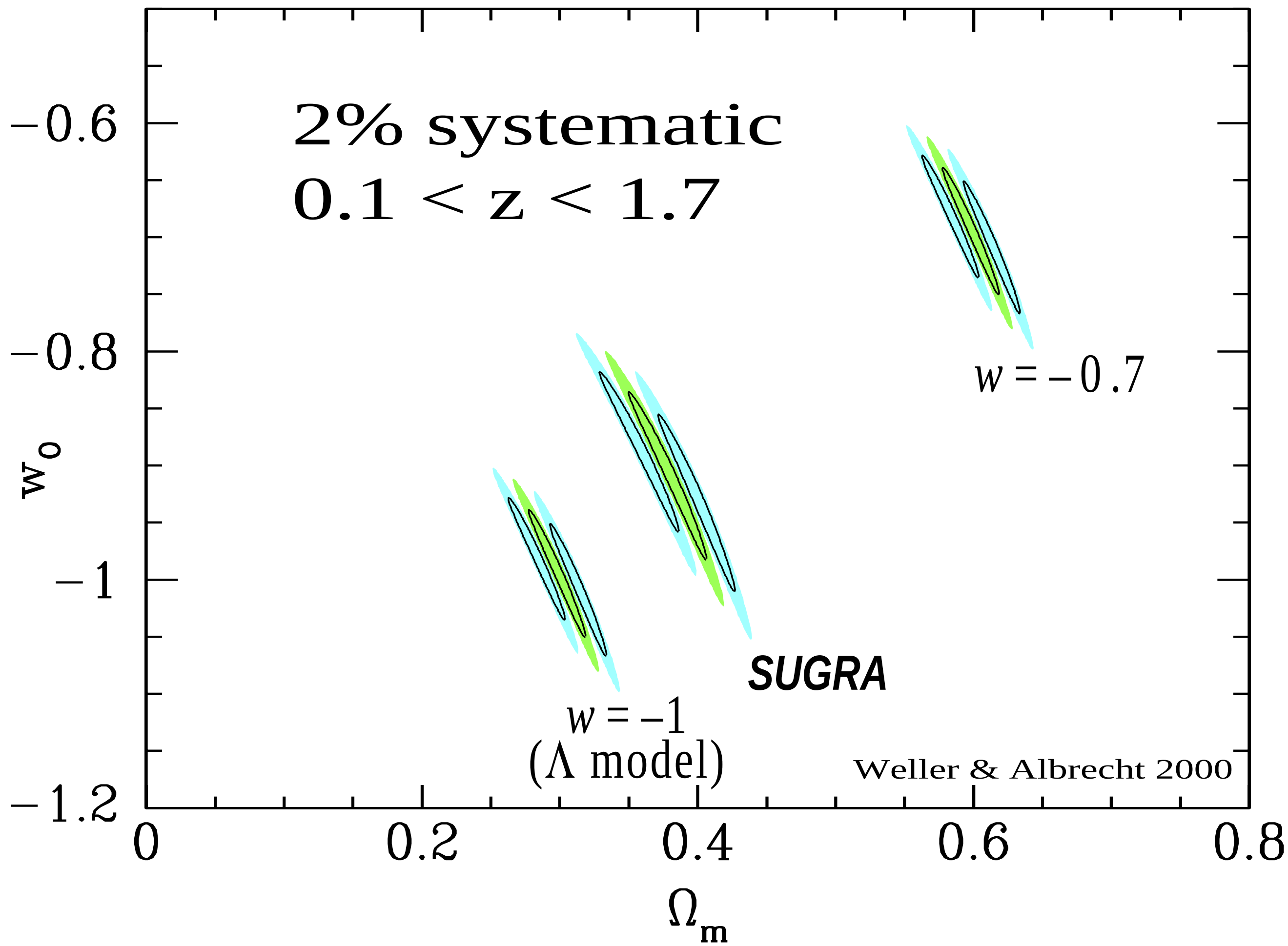
- Map expansion history, $a(t)$ vs. t, to 2%
- Examine Dark Energy
  - ◇ Measure w_0 to 0.05
  - ◇ Measure w_1 to 0.3

Derived Error Budget

- Statistical $\rightarrow$ 2000 SNe Ia over wide z range
- Systematic $\rightarrow < 2\%$ after statistical correction

SNAP

Importance of Systematics for $m - z$ Test



Estimated Systematics Error Budget

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

Residual Systematic Source	Statistical	Estimated Residual
Data reduction/correlations	—	$< 0.5\%$
Non-SN Ia Contamination	—	0.0%
Malmquist bias	—	$< 0.5\%$
Cross-filter K-Correction	—	$\sim 0.5\%$
Milky Way extinction	10–20%	$\sim 0.5\%$
Host dust extinction	1–20%	$\sim 1\%$
Gravitational lensing	1–10%	$\sim 0.5\%$
Supernova “Evolution”	$\sim 10\%$	$\sim 1\%$
Absolute color calibration	non-stat	$\sim 1\%$
Quadrature Sum		$\sim 1.9\%$

What are the Systematics?

Known Systematics

- Astrophysics
- Data Reduction/Analysis
- Absolute Color Calibration

Possible Systematics

- Astrophysics

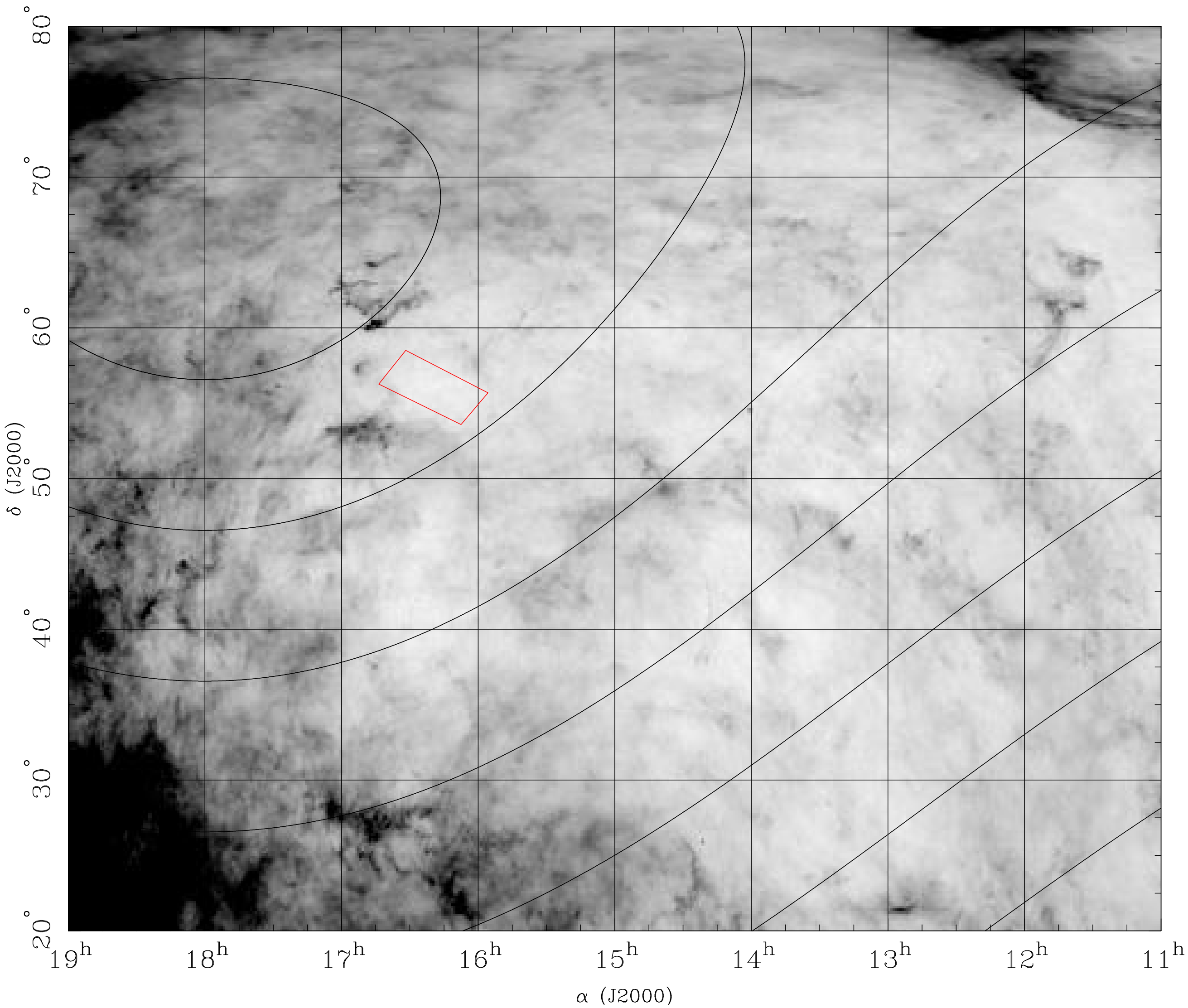
  — intergalactic dust

  — supernova "evolution"

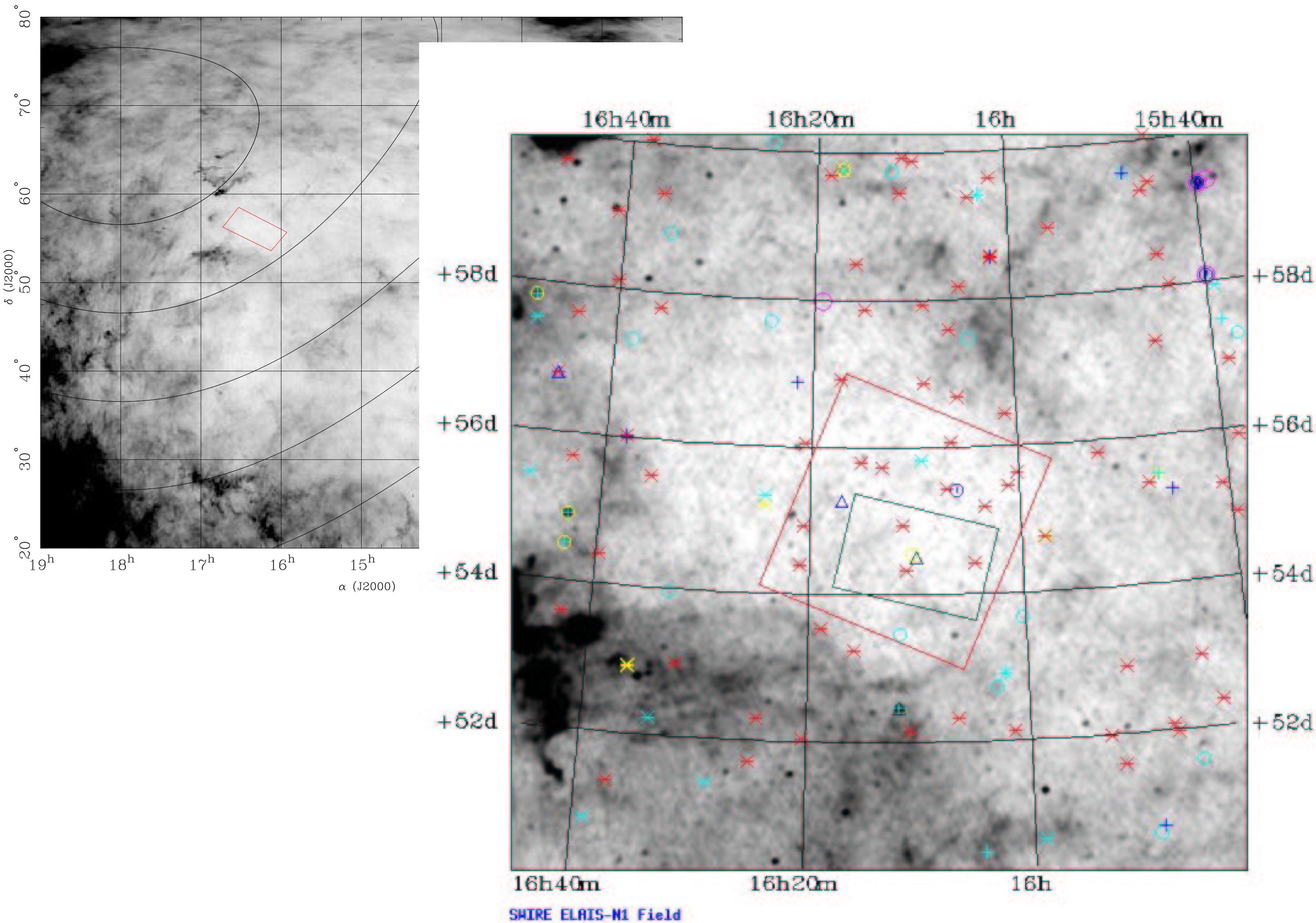
Known Astro-Systematics

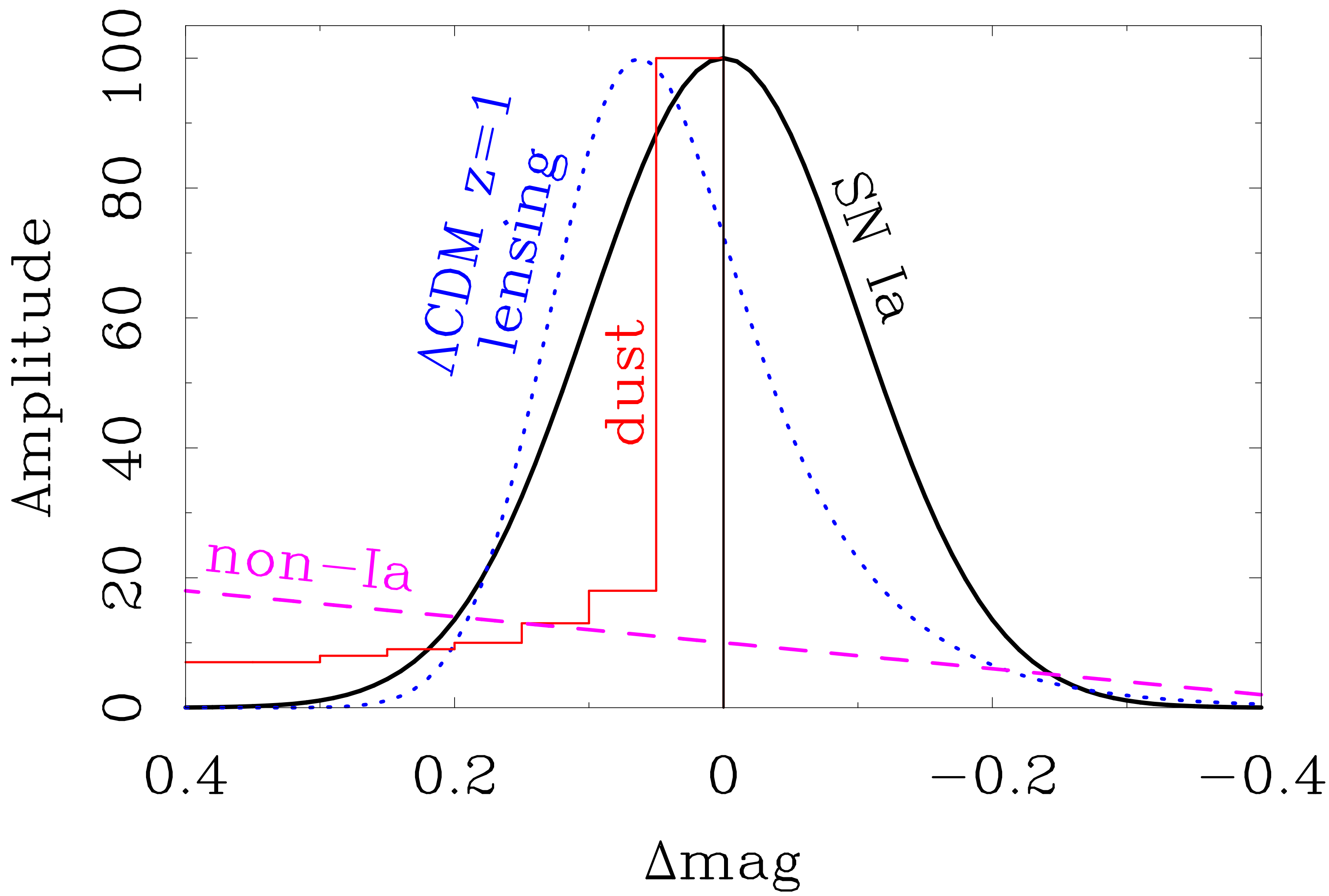
- Milky Way Dust Extinction
  - — structured across sky, variable properties
- Differing Host-Galaxy Extinction Laws
  - — host metallicty, star-formation history, hot gas
- Gravitational Lensing De/Amplification
  - — cosmology & structure formation; increases with redshift
- Contamination by non-Type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

North Ecliptic/Galactic Pole Dust Map

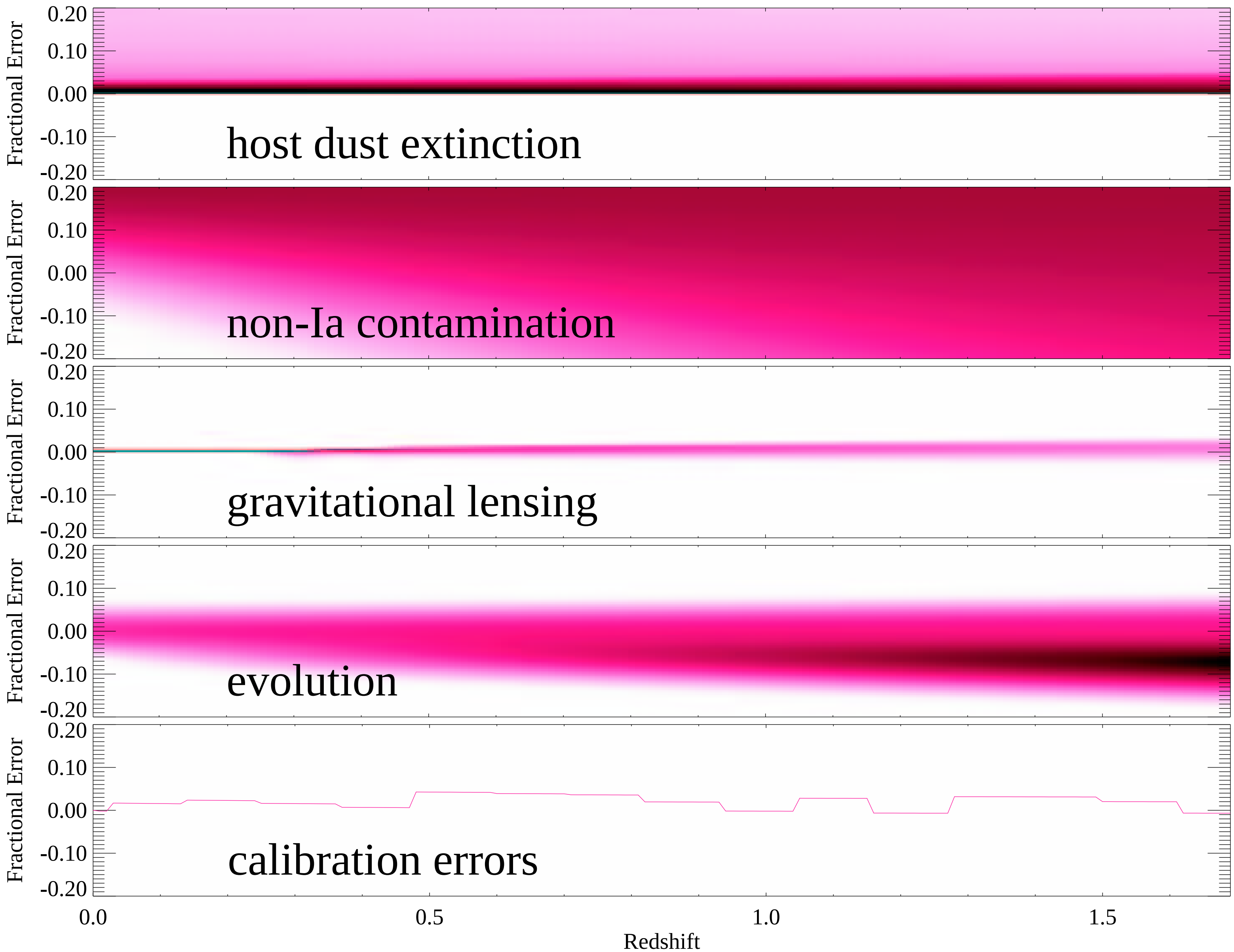


North Ecliptic/Galactic Pole Dust Map

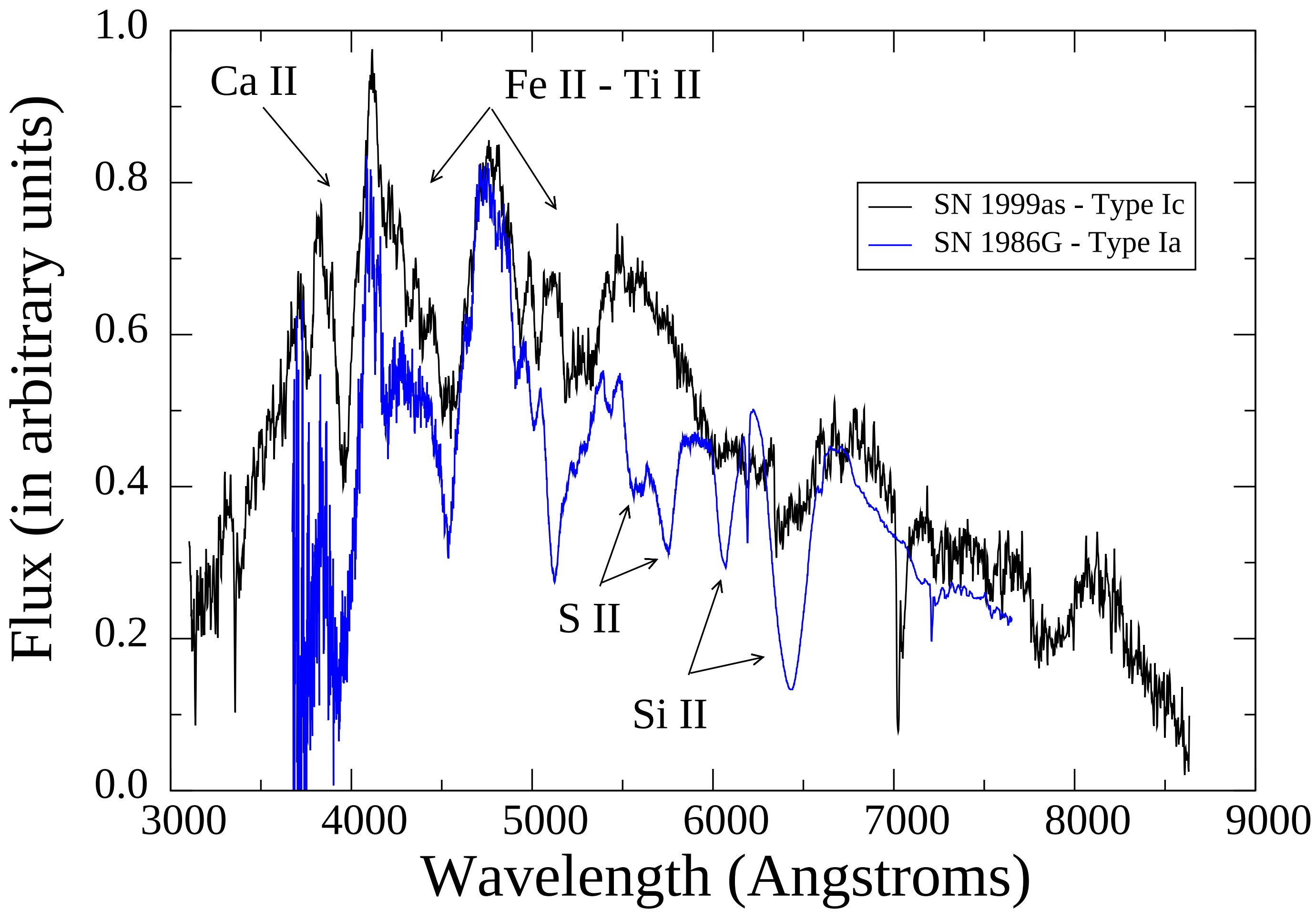


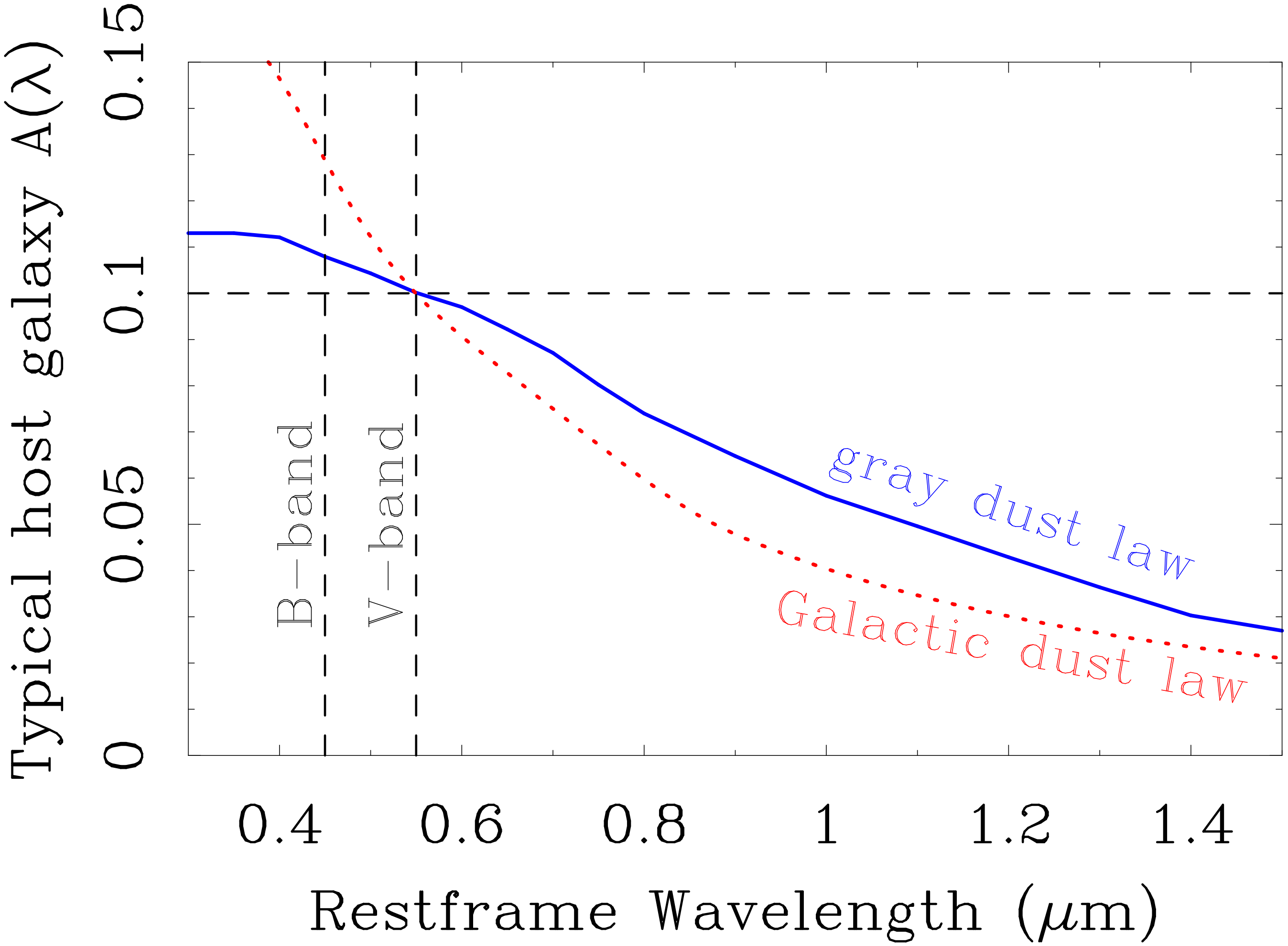


Amplitude
0
20
40
60
80
100
0.4
0.2
0
−0.2
−0.4
Δmag
ΛCDM z=1
lensing
dust
SN Ia
non−Ia


host dust extinction
non-Ia contamination
gravitational lensing
evolution
calibration errors
Fractional Error
0.20
0.10
0.00
-0.10
-0.20
0.0
0.5
1.0
1.5
Redshift

Si II Needed to Eliminate Contaminants

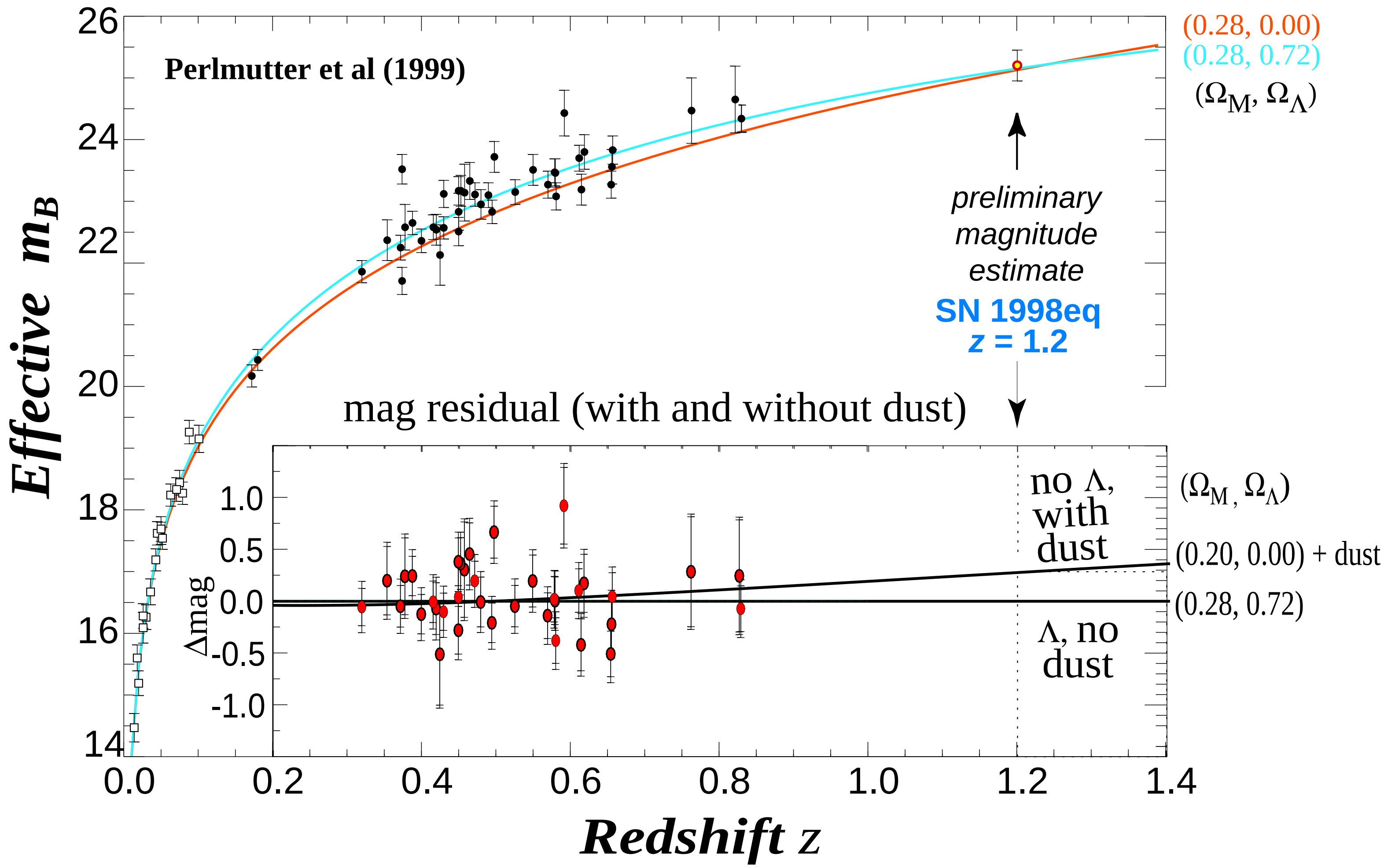



Typical host galaxy A(λ)
0
0.05
0.1
0.15
0.4
0.6
0.8
1
1.2
1.4
Restframe Wavelength (μm)
B−band
V−band
gray dust law
Galactic dust law

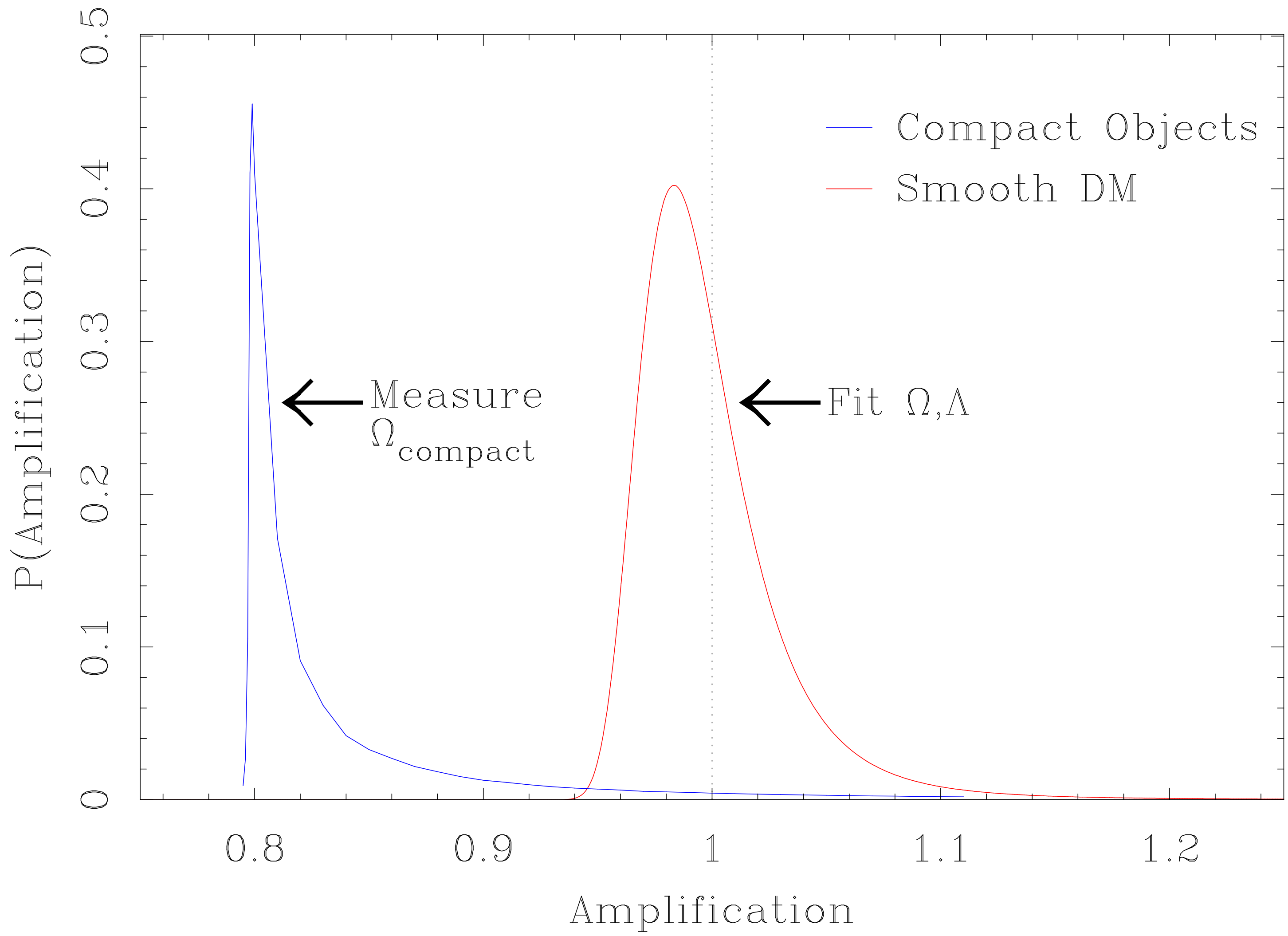
Past & On-going Work on (Gray) Dust Extinction

- $z = 1.2$ and 1.7 SNe Ia prefer 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*)

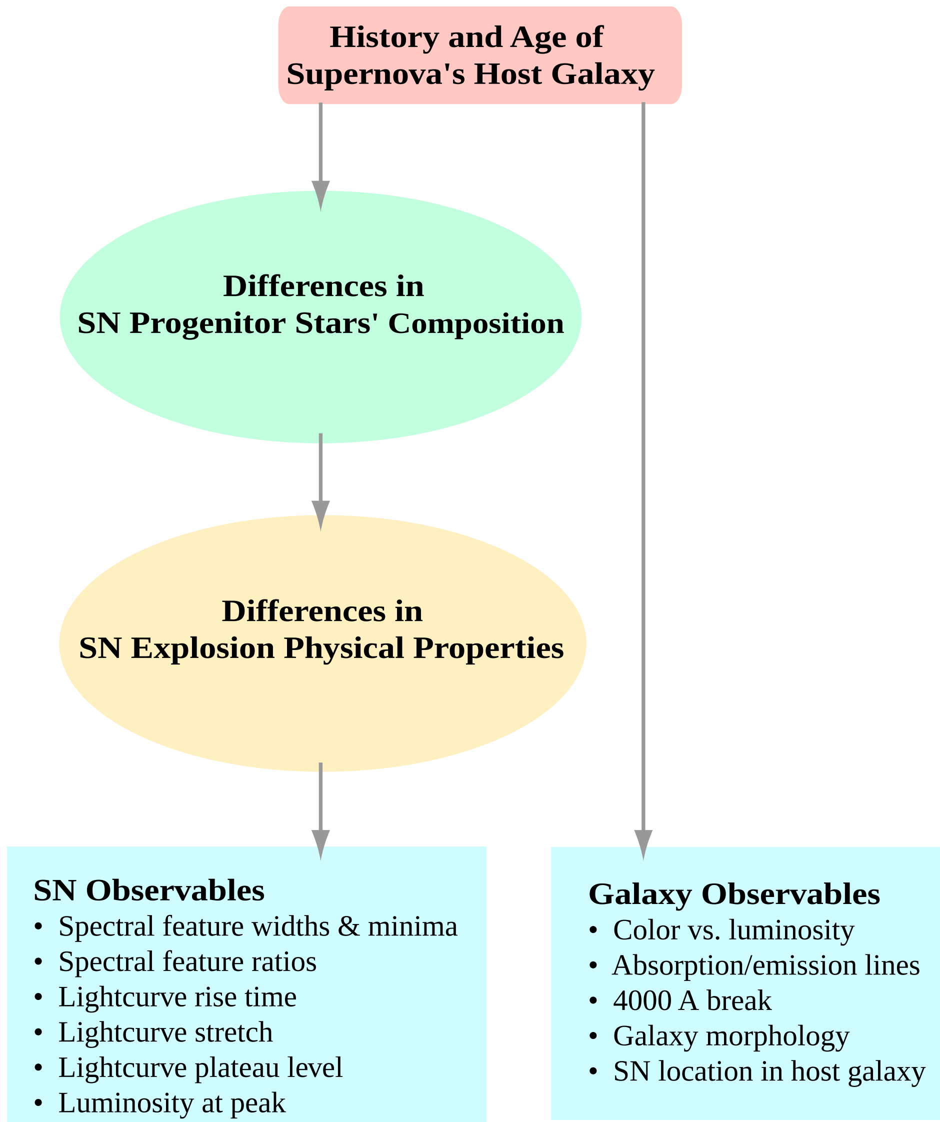
High-Redshift SNe probe Cosmology vs. Dust/Evolution



Gravitational Lensing: Average/Check with Model



Systematics Control - Matching SN Evolutionary States

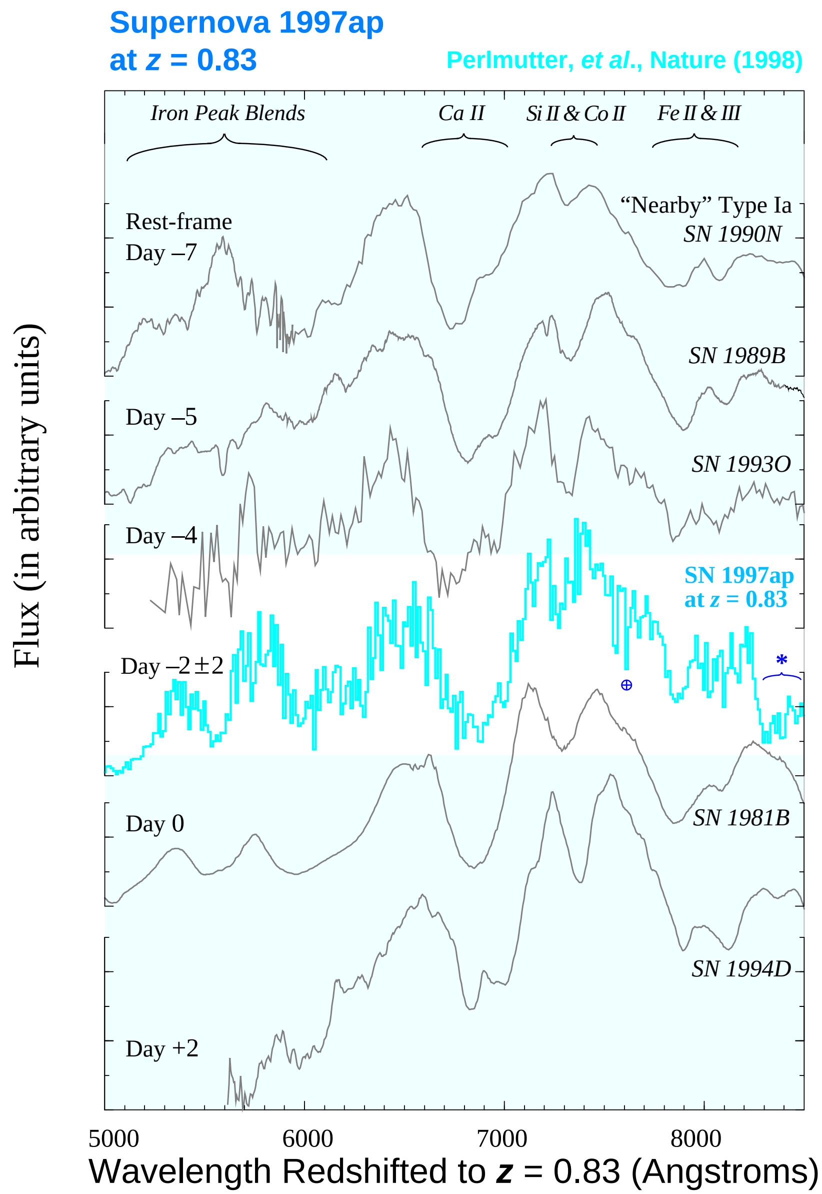


Past & On-going Work on "Evolution"

- 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
"Nearby" Type Ia
SN 1990N
Rest-frame
Day –7
SN 1989B
Day –5
SN 1993O
Day –4
SN 1997ap
at z = 0.83
Day –2±2
SN 1981B
Day 0
SN 1994D
Day +2
Flux (in arbitrary units)
5000
6000
7000
8000
Wavelength Redshifted to z = 0.83 (Angstroms)

SNAP

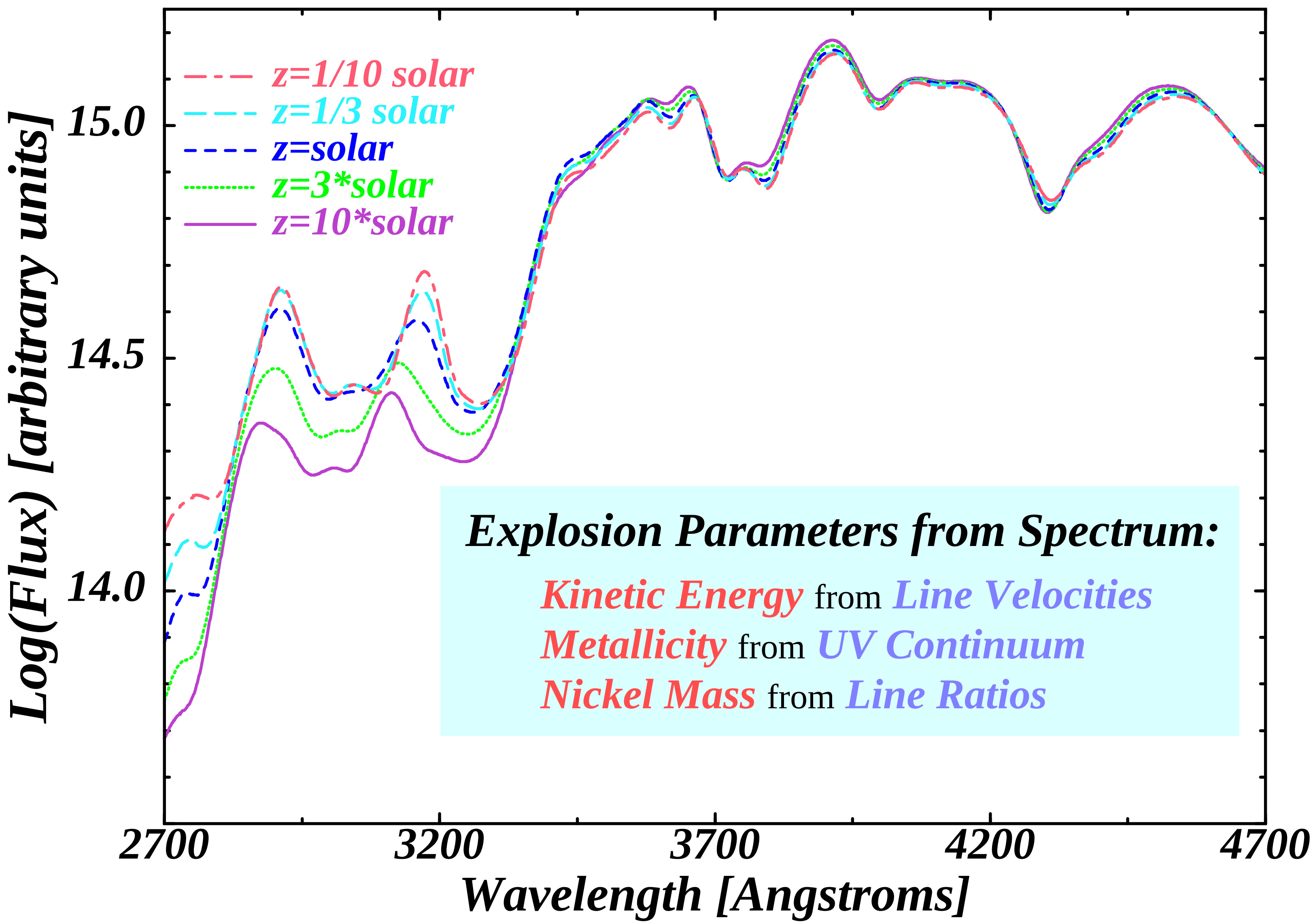
Spectrum & Lightcurve Reveal Explosion Initial Conditions

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

SNfactory will provide calibration


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	0.03/500 km/s	300 km/s
Feature widths	0.03/1200 km/s	800 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	0.10/1 day	0.2 days
Peak to tail ratio	0.20/0.2 mag	0.02 mag

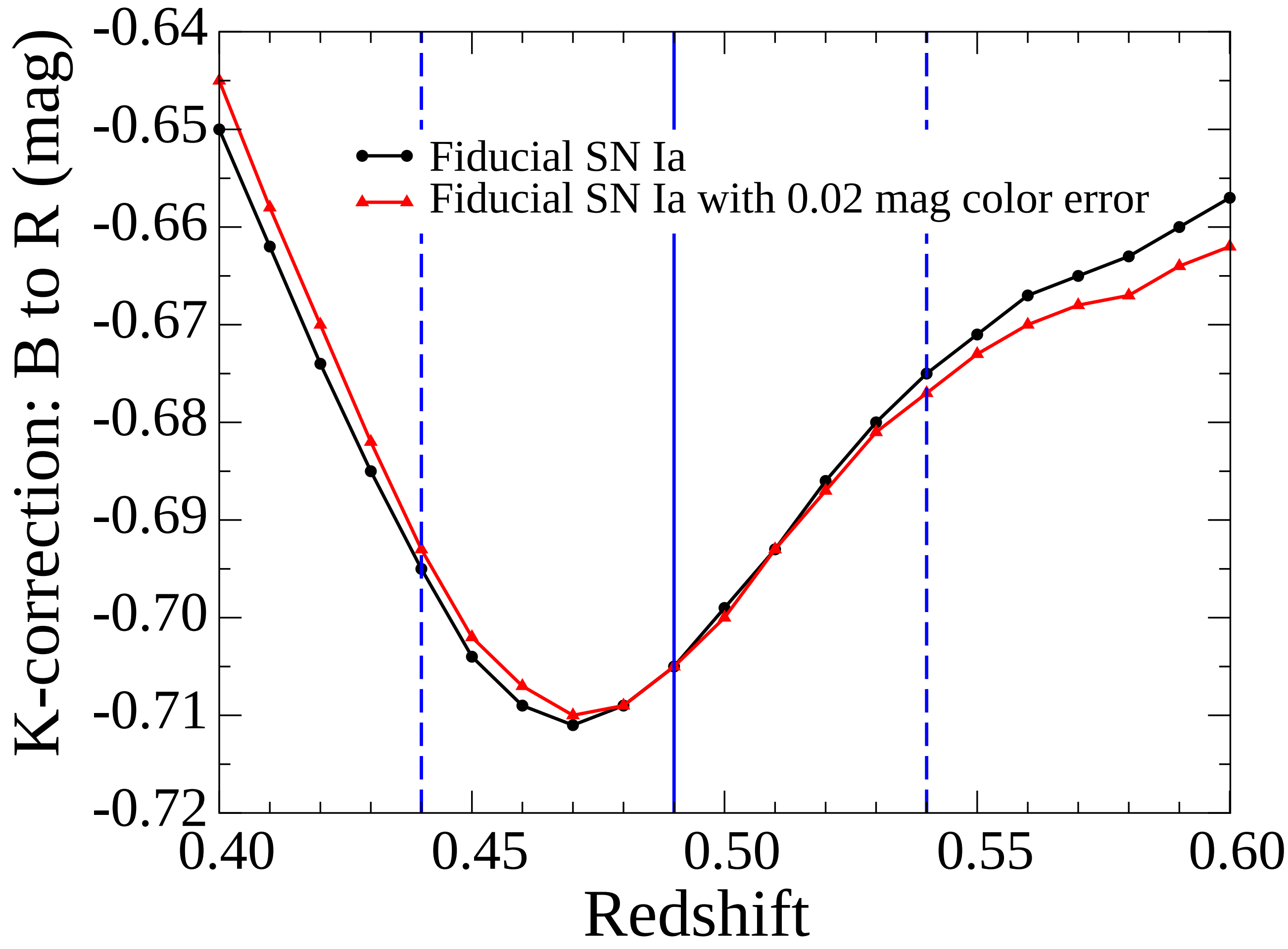
Data Reduction Systematics

- 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

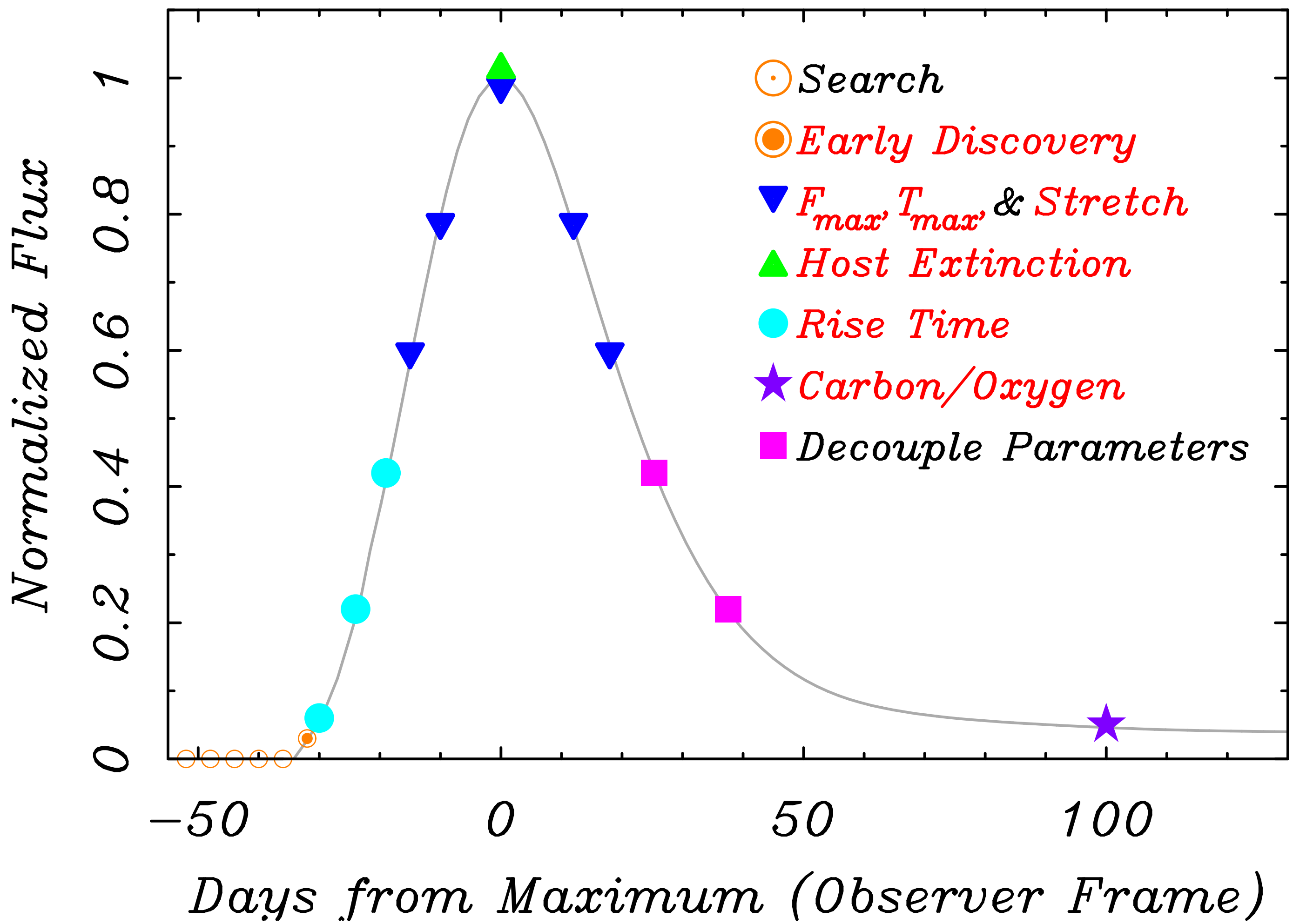
Data Analysis Systematics

- 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^2_{SNe}, and as power of # parameters

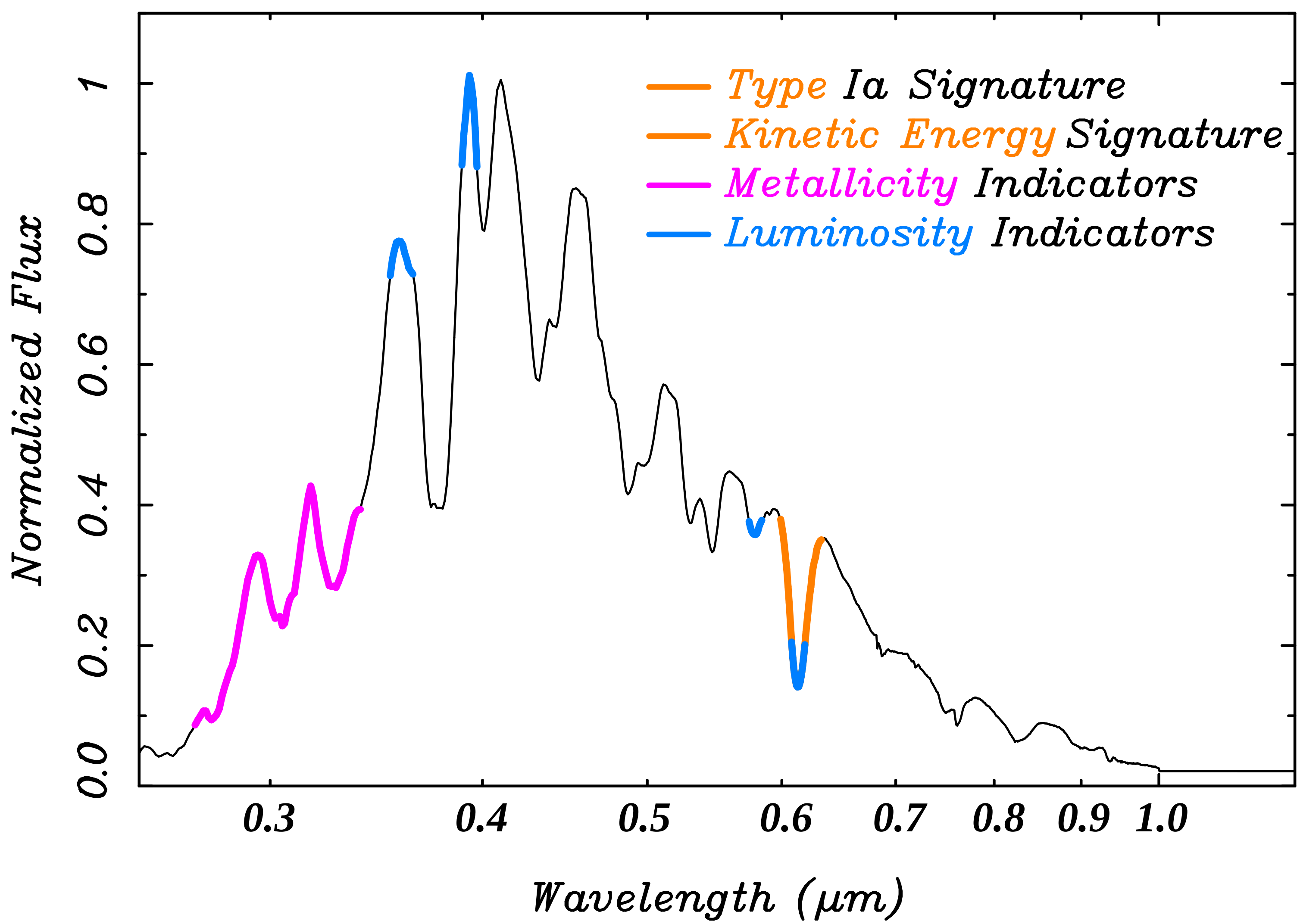
$B(z)$ filters w/ $\Delta z \sim 0.1$ bound K-correction errors



B−band Lightcurve Photometry for z = 0.8 Type Ia



Type Ia Spectral Features



Derived Requirements to Control Systematic Uncertainties

Systematics are Converted into Statistical Uncertainties

Systematic	Requirement
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/photometry
Supernova "Evolution"	Initial conditions from lightcurve & spectral features

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SNAP Internal Controls and Cross Checks

- Compare photometry with spectrophotometry
- 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