Defining the Issues: Supernovae

Saul Perlmutter
Berkeley

Premise #1:

Dark Energy, after 10 years, is still…

Premise #1:
Dark Energy, after 10 years, is still...

"Right now, not only for cosmology but for elementary particle theory, this is the bone in our throat." — *Steven Weinberg*

"Maybe the most fundamentally mysterious thing in basic science." — *Frank Wilczek*

"Would be Number 1 on my list of things to figure out." — *Edward Witten*

"This is the biggest embarrassment in theoretical physics." — *Michael Turner*

Premise #2:
After 10 years...

supernova measurements still provide the best developed and tested technique,
and yield the best constraints to date on the Hubble diagram and the dark energy equation-of-state.

...And these measurements can be taken much further in precision and redshift.

(Other days this week we will discuss the crucial need for, and strengths of, the other measurement methods, but for today's discussion we will be working to carry through on this bedrock method.)

For this meeting's SN working sessions:

Describe and discuss the missing elements for the next big step in SN precision: measurements, instrumentation, empirical and theoretical understanding, and analysis tools.

What does this imply for the space-based and ground-based planning?

For this meeting's SN working sessions:

1. What are factual elements that we can agree on that set the parameters of these programs? What calculations or compilations can be performed to establish them?

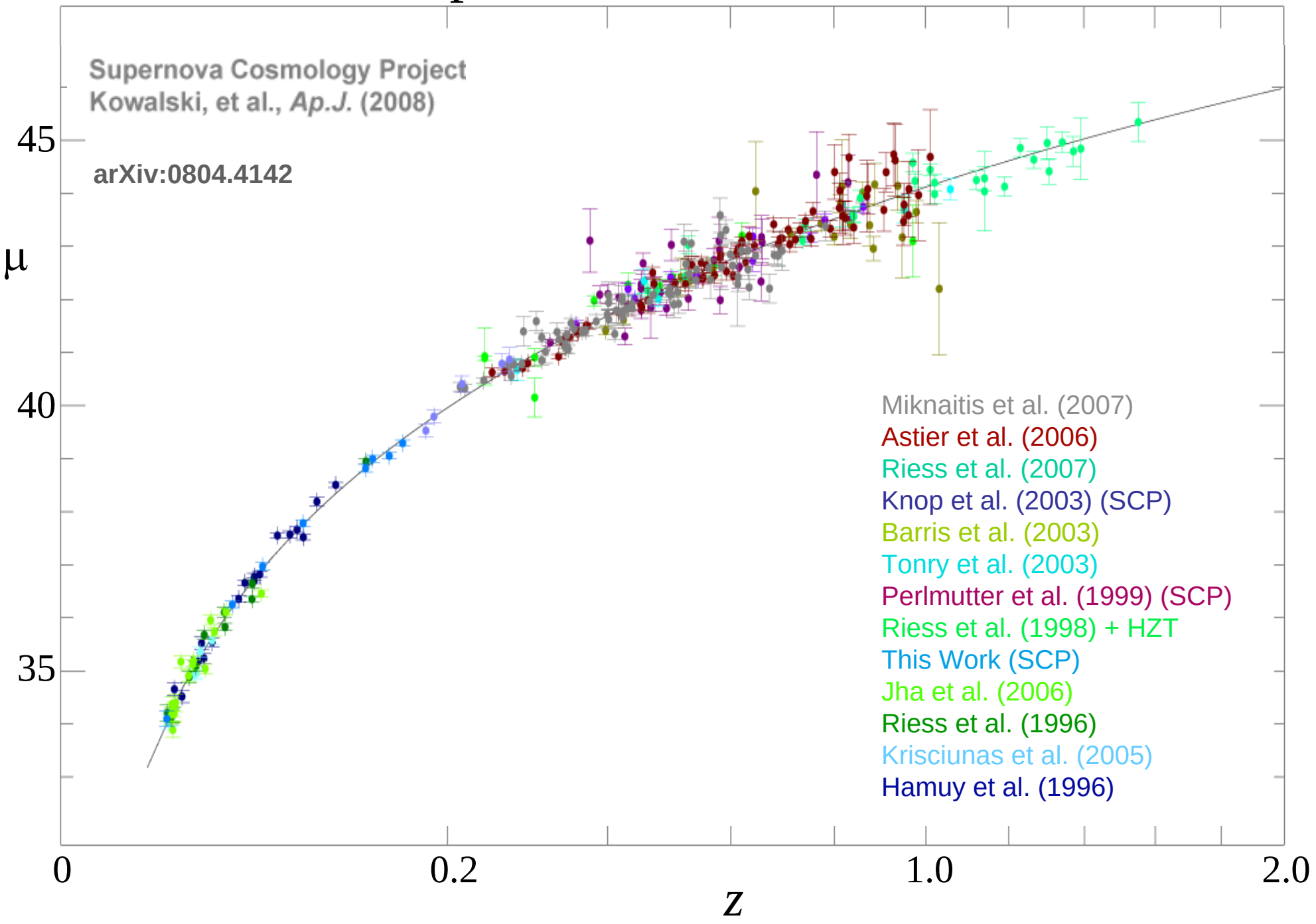
2. What are the decisions in defining these programs that must be based on science "taste"? Are there any changes in circumstances or data that would influence these preferences?

For this meeting's SN working sessions:

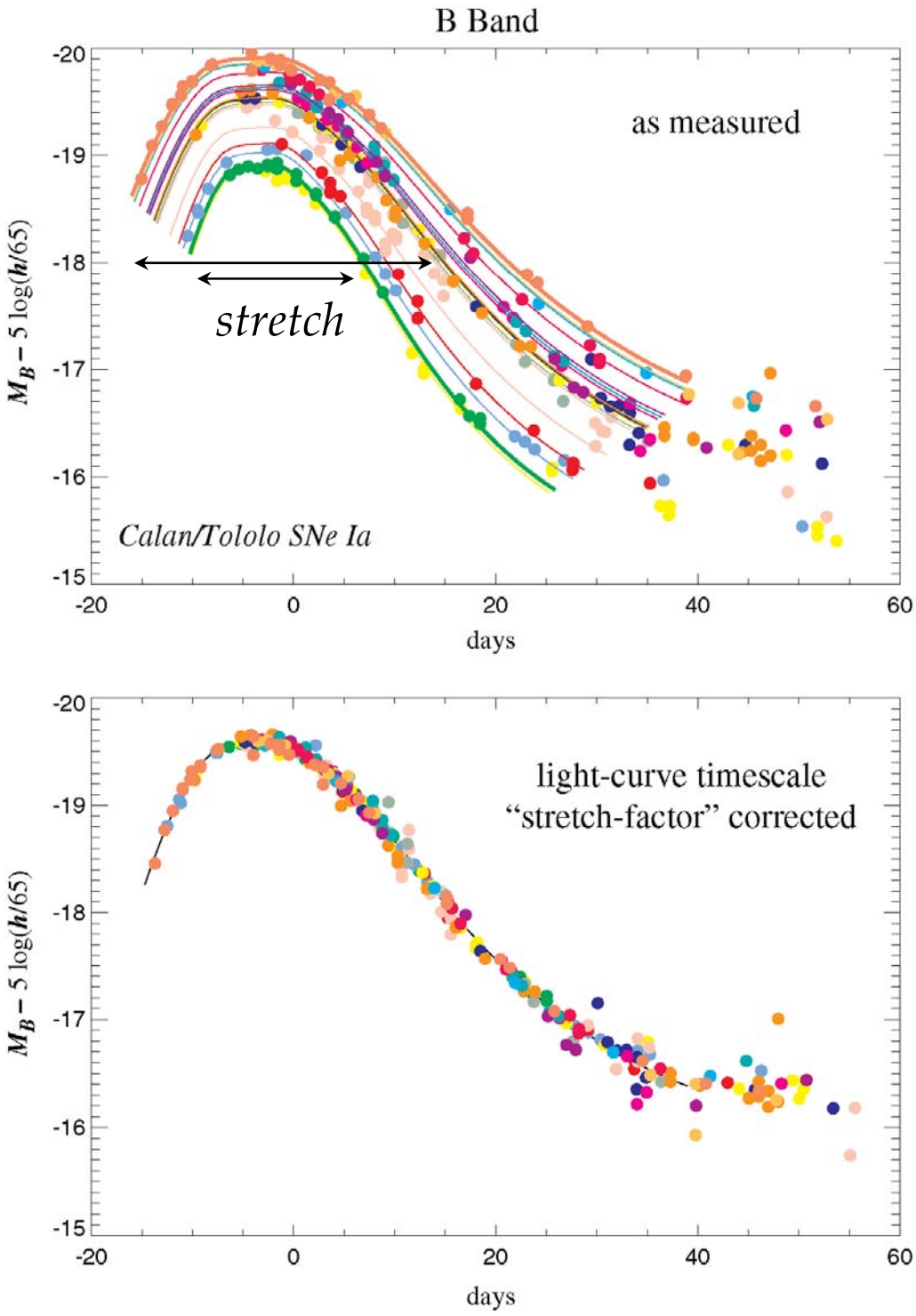
1. What are factual elements that we can agree on that set the parameters of these programs? What calculations or compilations can be performed to establish them?

If we can begin to compile these questions, and come to agreement on these factual issues/calculations over the next months, the field will be ready to work together — particularly if/when there is an opportunity for a joint Europe–U.S. mission.

The Union Compilation of SNe Ia – the world's data set so far

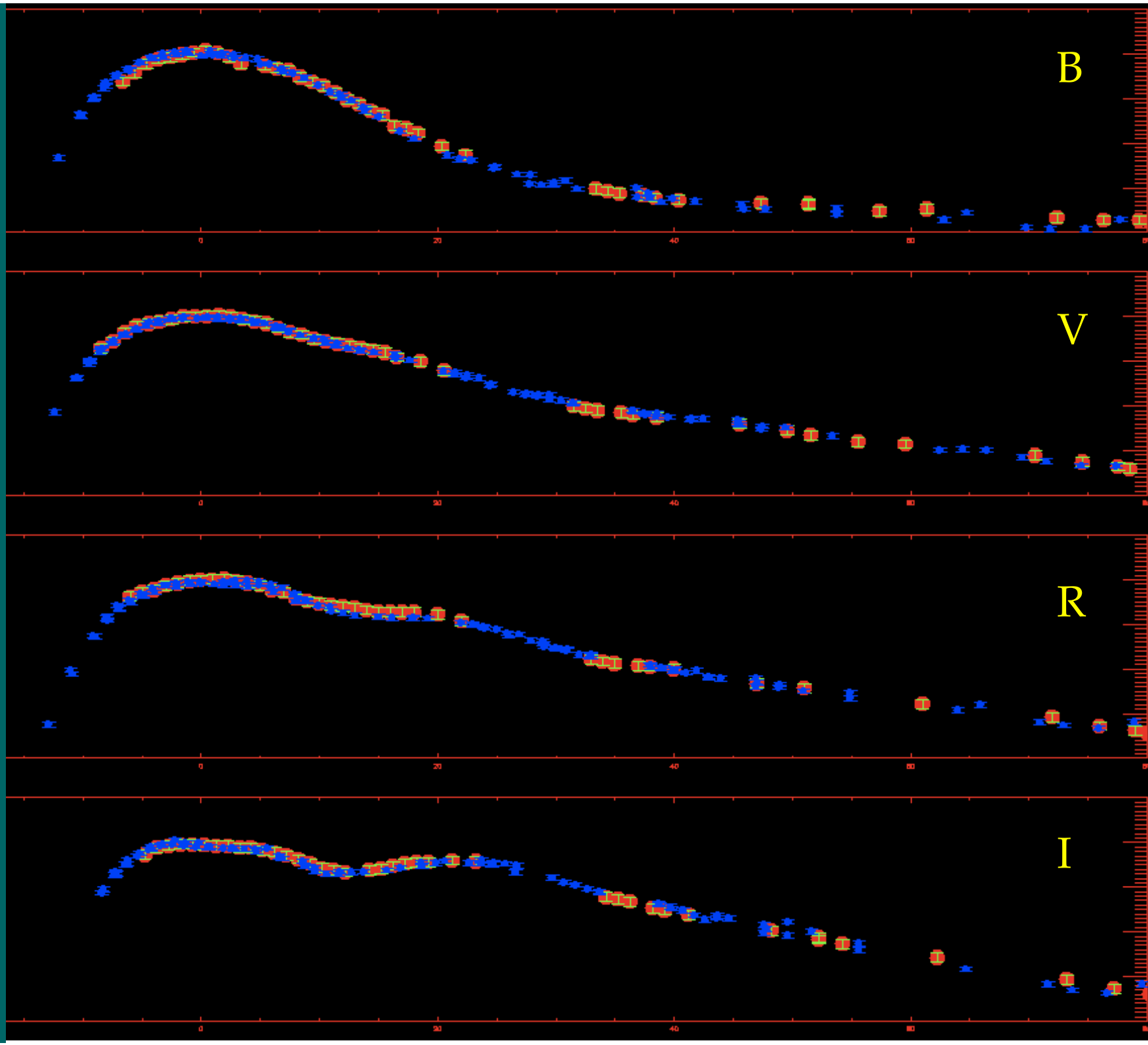


We can go beyond the indicators of SN diversity we currently use to calibrate SN luminosity.



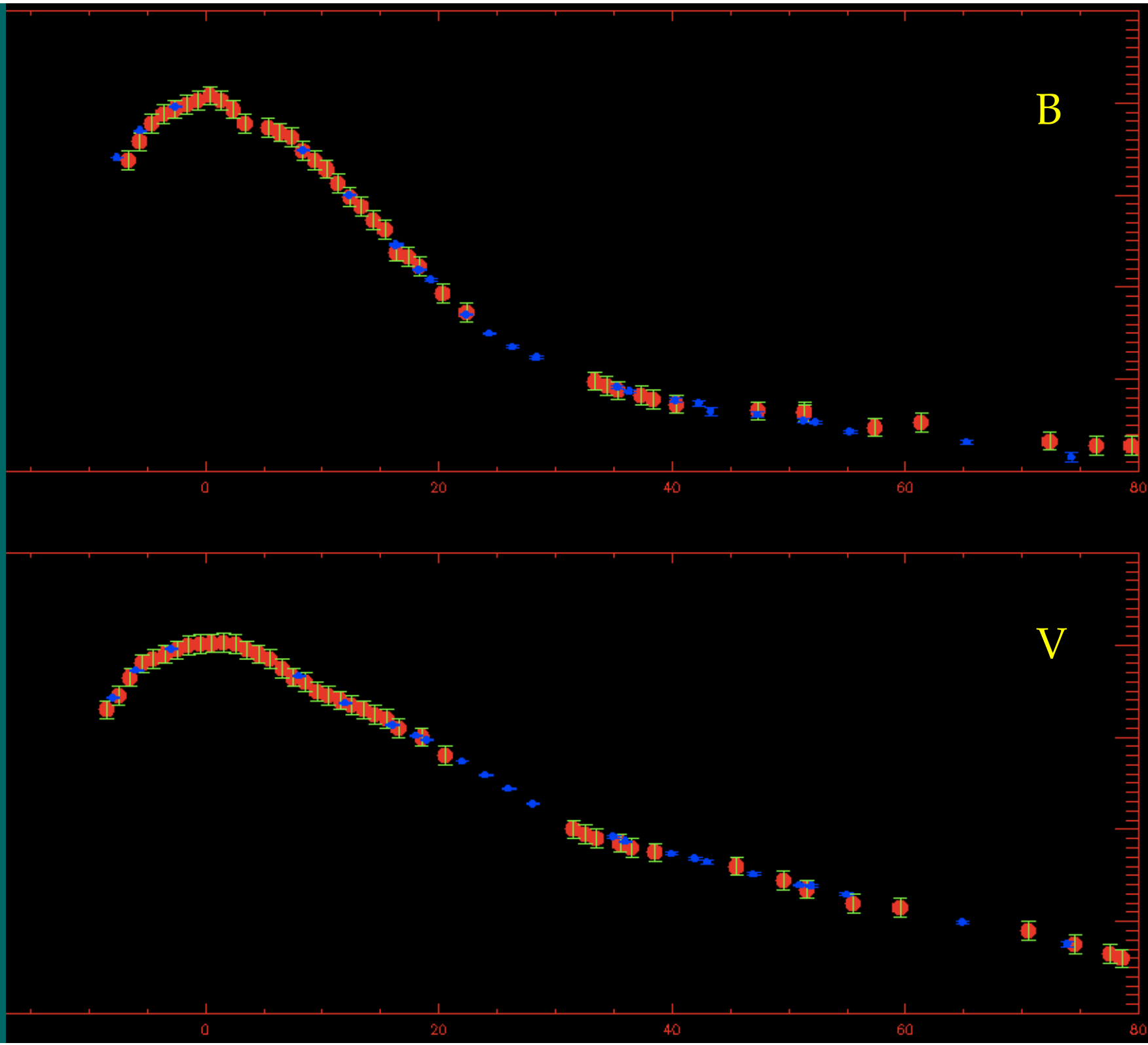
SNe Ia are not "all over the map":

There are lightcurve "twins"

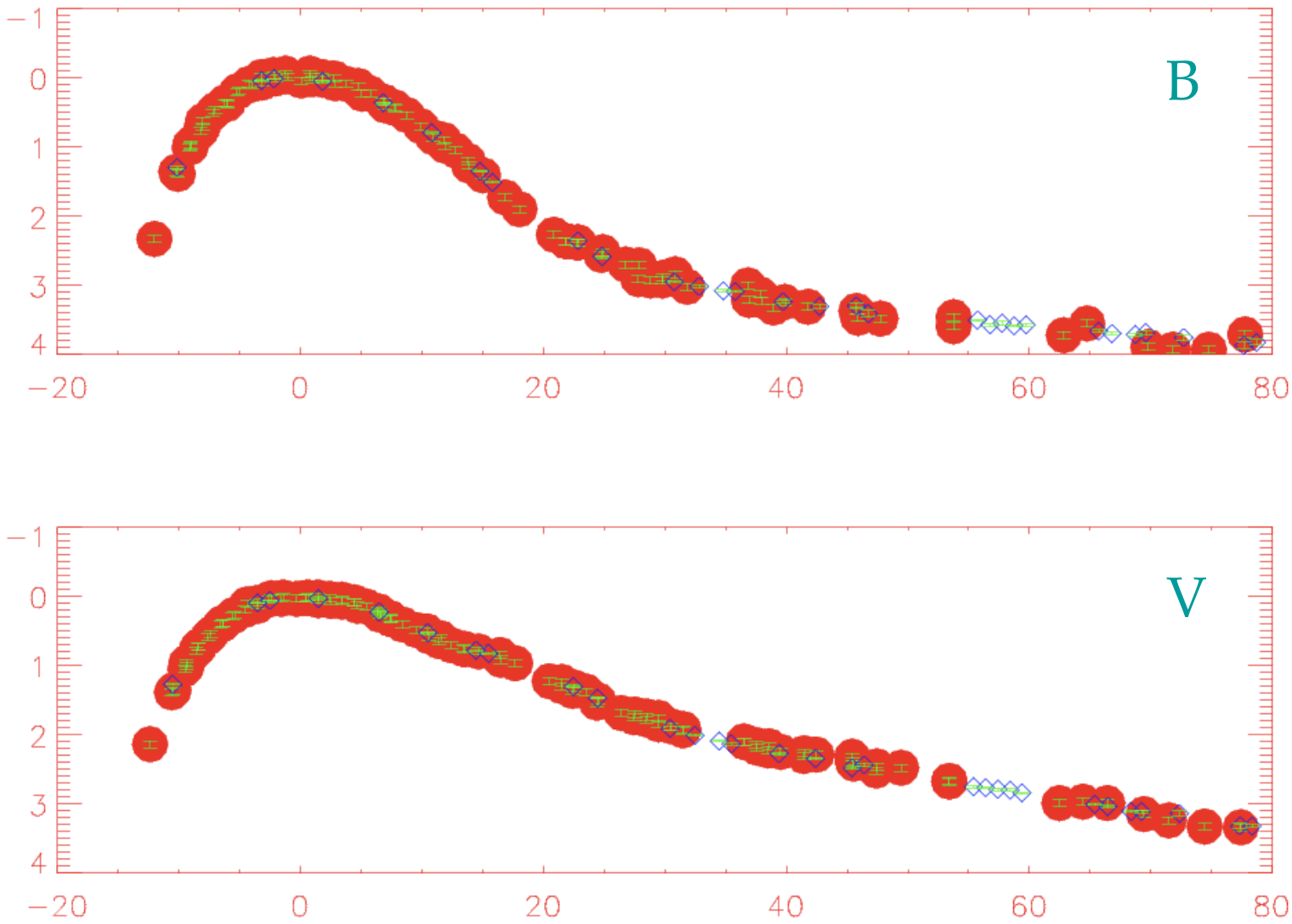


SNe Ia are not "all over the map":

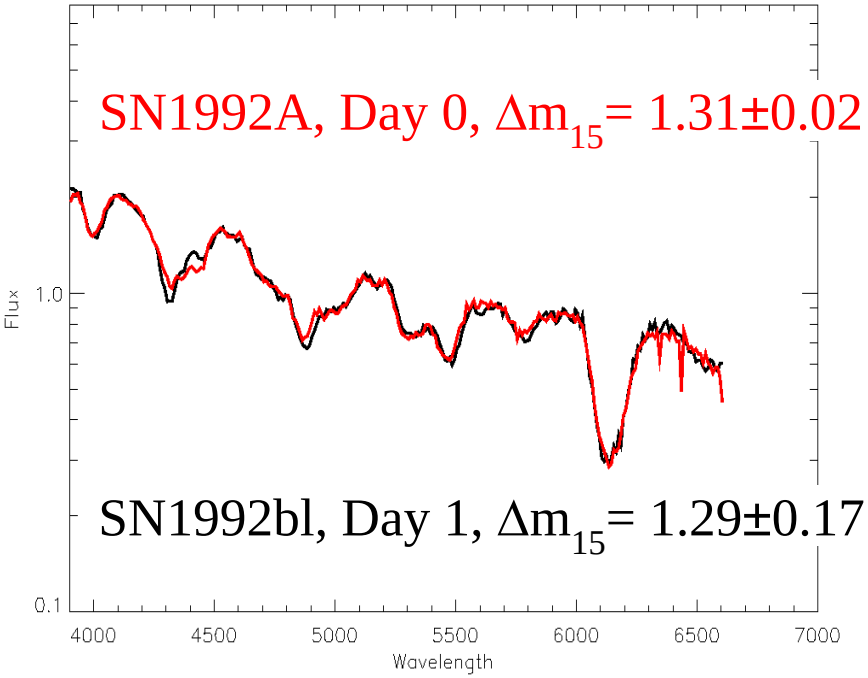
There are lightcurve "twins"

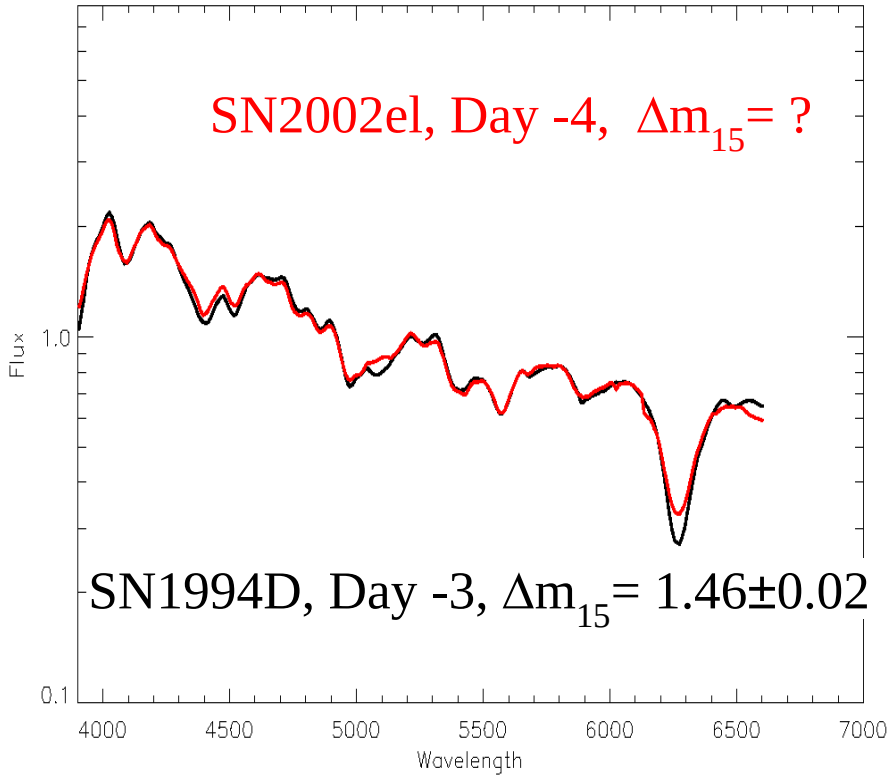


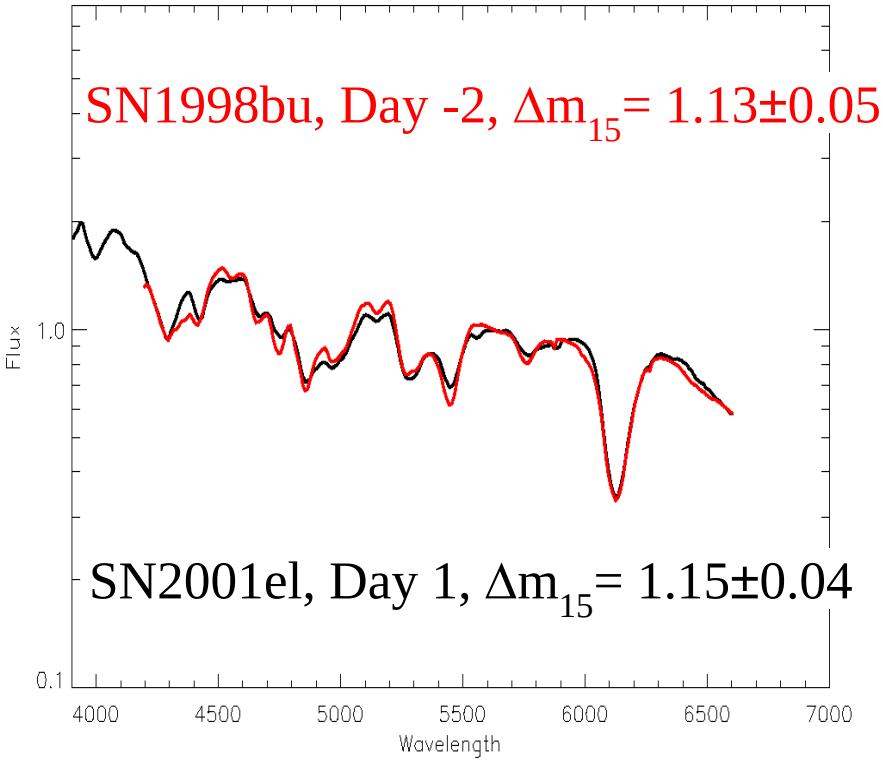
The twins are not rare. The 6 examples of lightcurve twins shown on this and the preceding slides were drawn from a sample of 35 SNe.



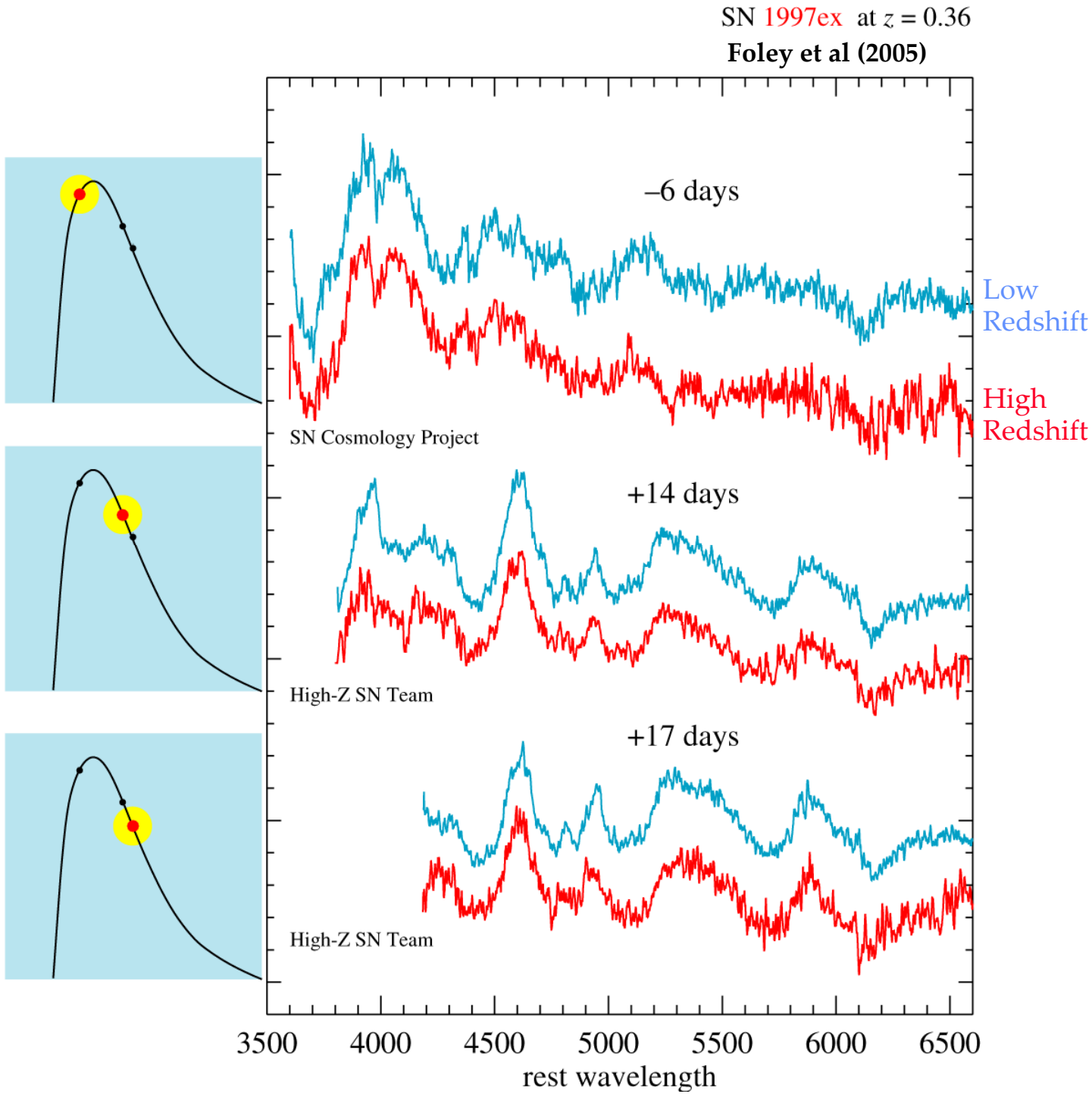
Similarly there are many spectroscopic "twins"







Moreover, spectra can be matched from low-redshift to high-redshift and over different epochs on the lightcurve.



So it should not surprise us that we can use further lightcurve and spectroscopy indicators to show both diversity and consistency (and thus calibrate).

but:

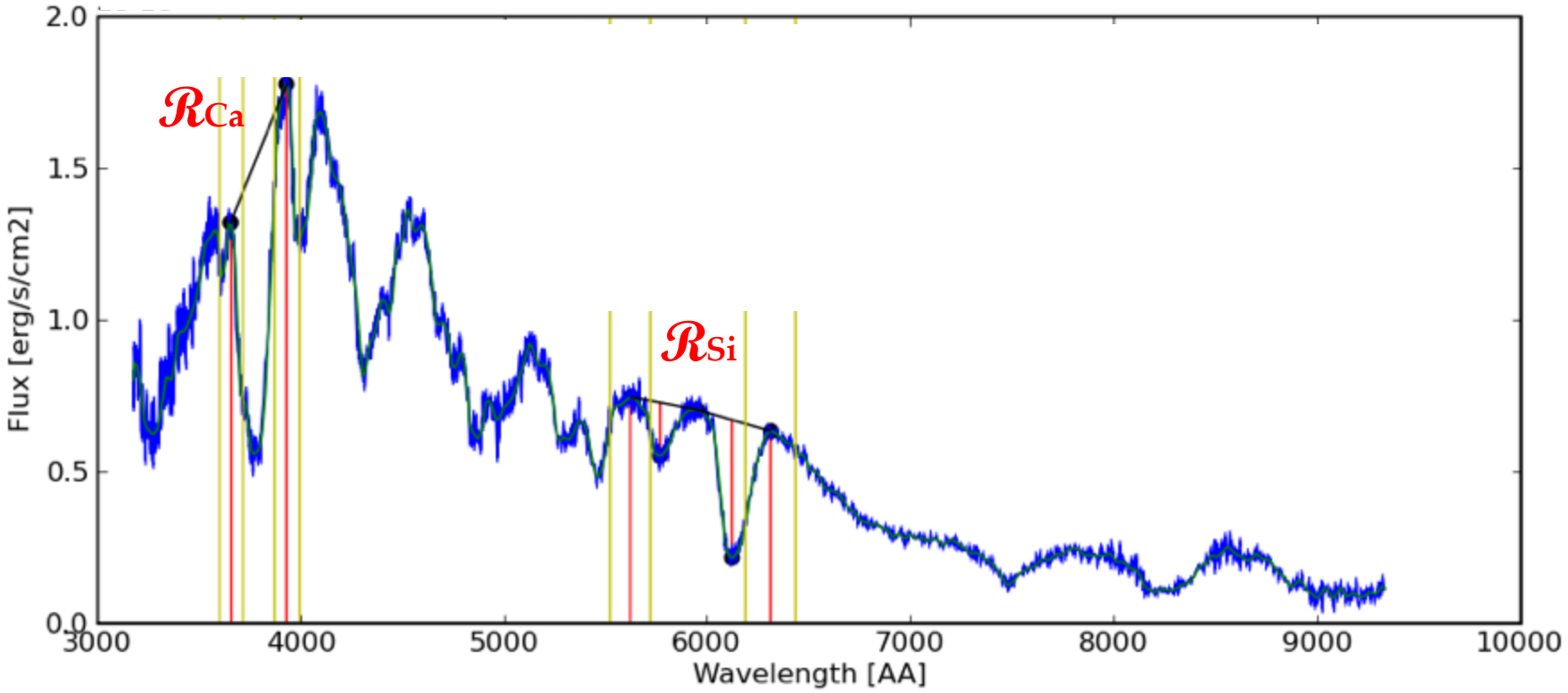
Generally these are based on studies of just nearby SNe so

1) cannot yet use these indicators to improve cosmology measurement, and

2) until recently (with SNfactory providing nearby Hubble-flow SNe), no relative luminosity calibration was possible because of peculiar velocity.

limitation from ground

Spectral indicators: line ratios

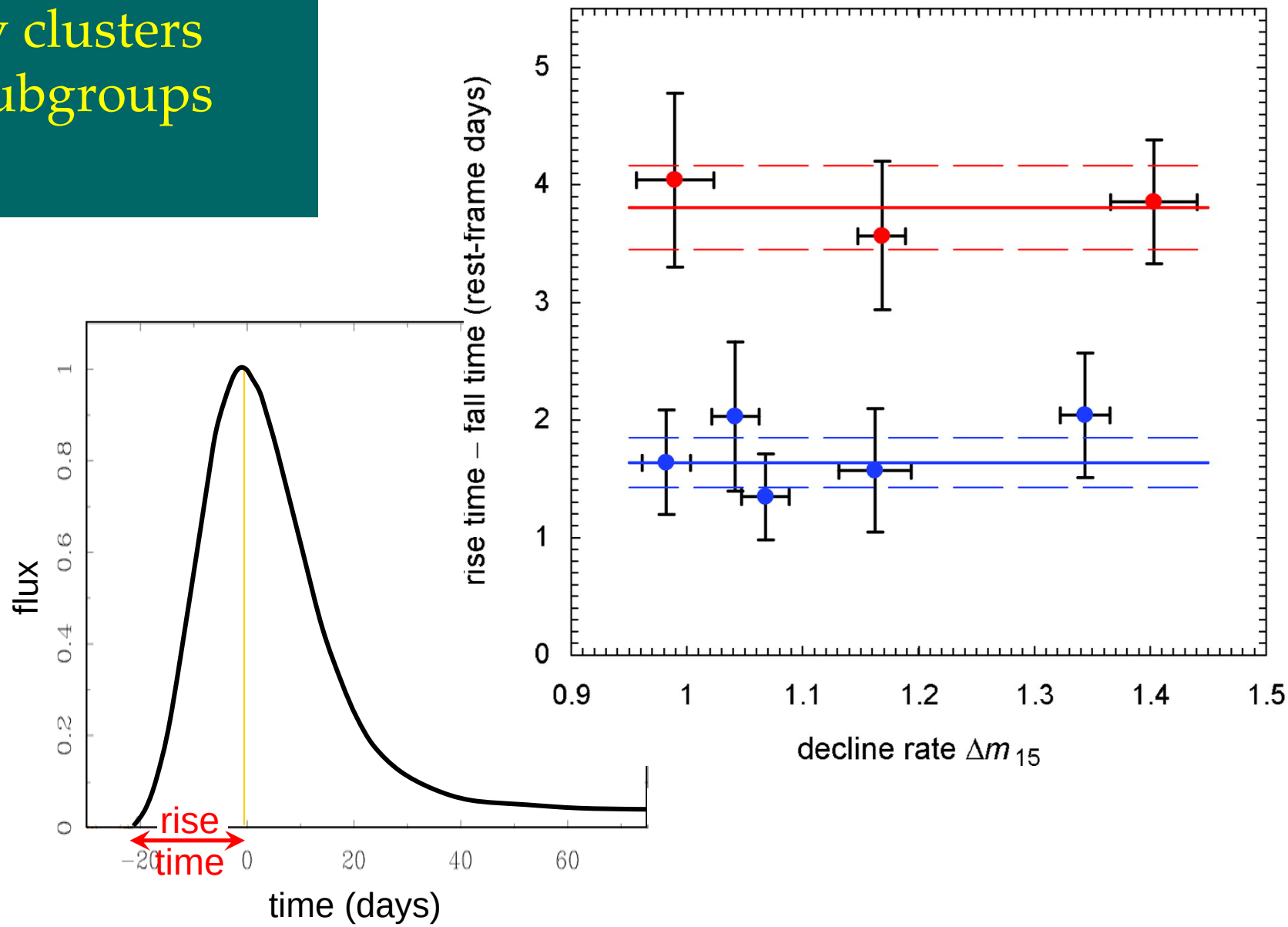


Lightcurve indicator:
rise time

apparently clusters
into two subgroups

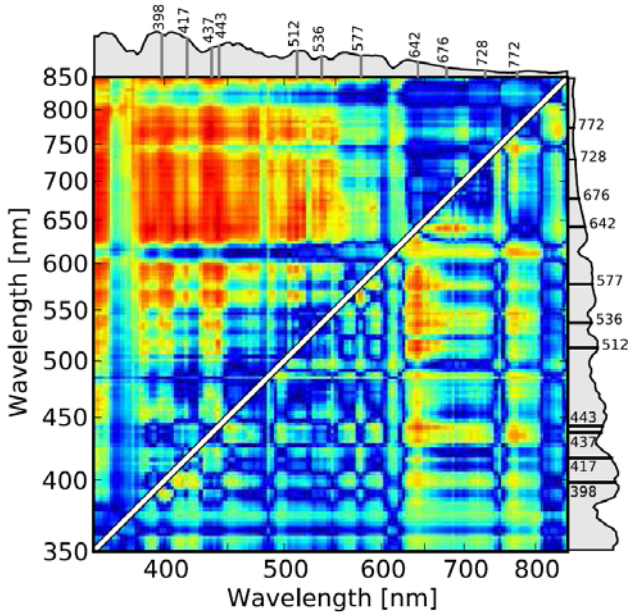
These subgroups also seen in preliminary SDSS data with larger sample.

Strovink (2007)

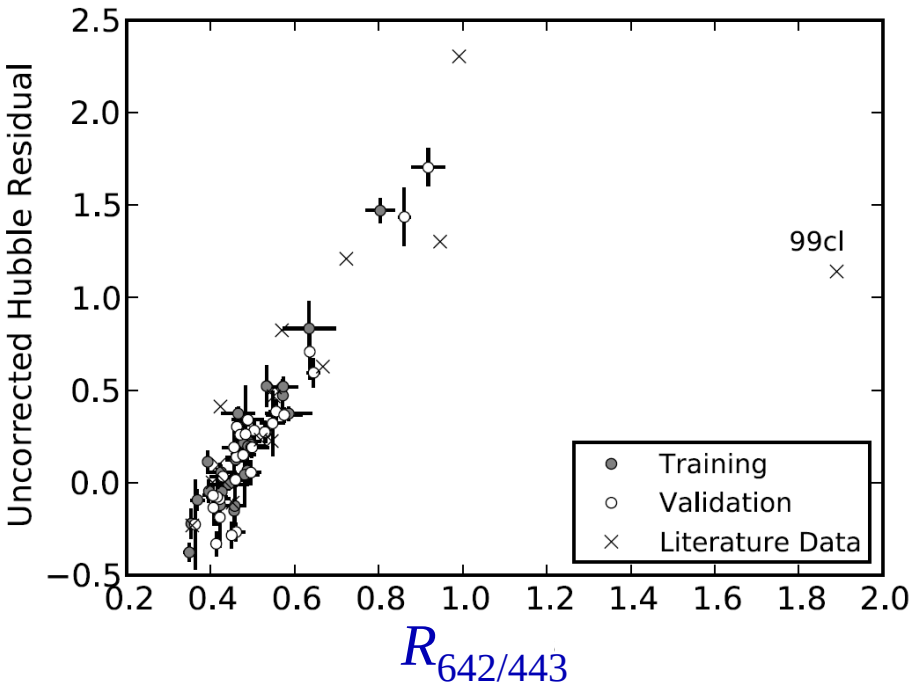


Nearby SN Factory: Spectroscopic Standardization

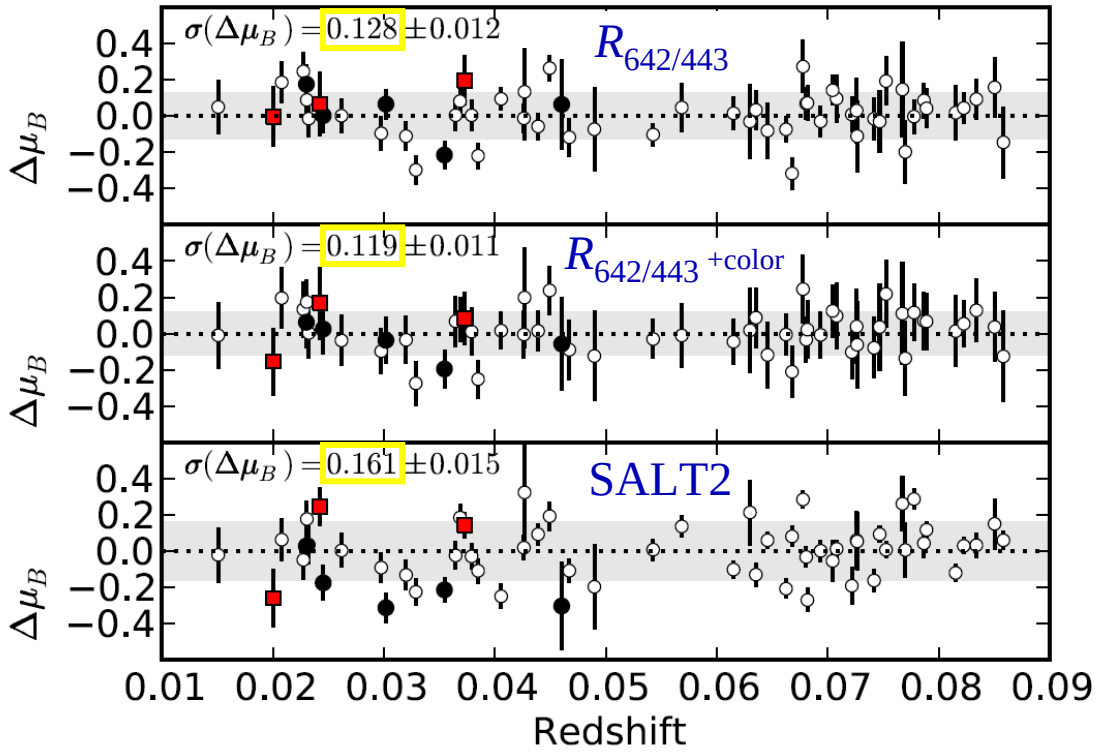
Bailey et al, arXiv:0905.0340
Accepted for publication



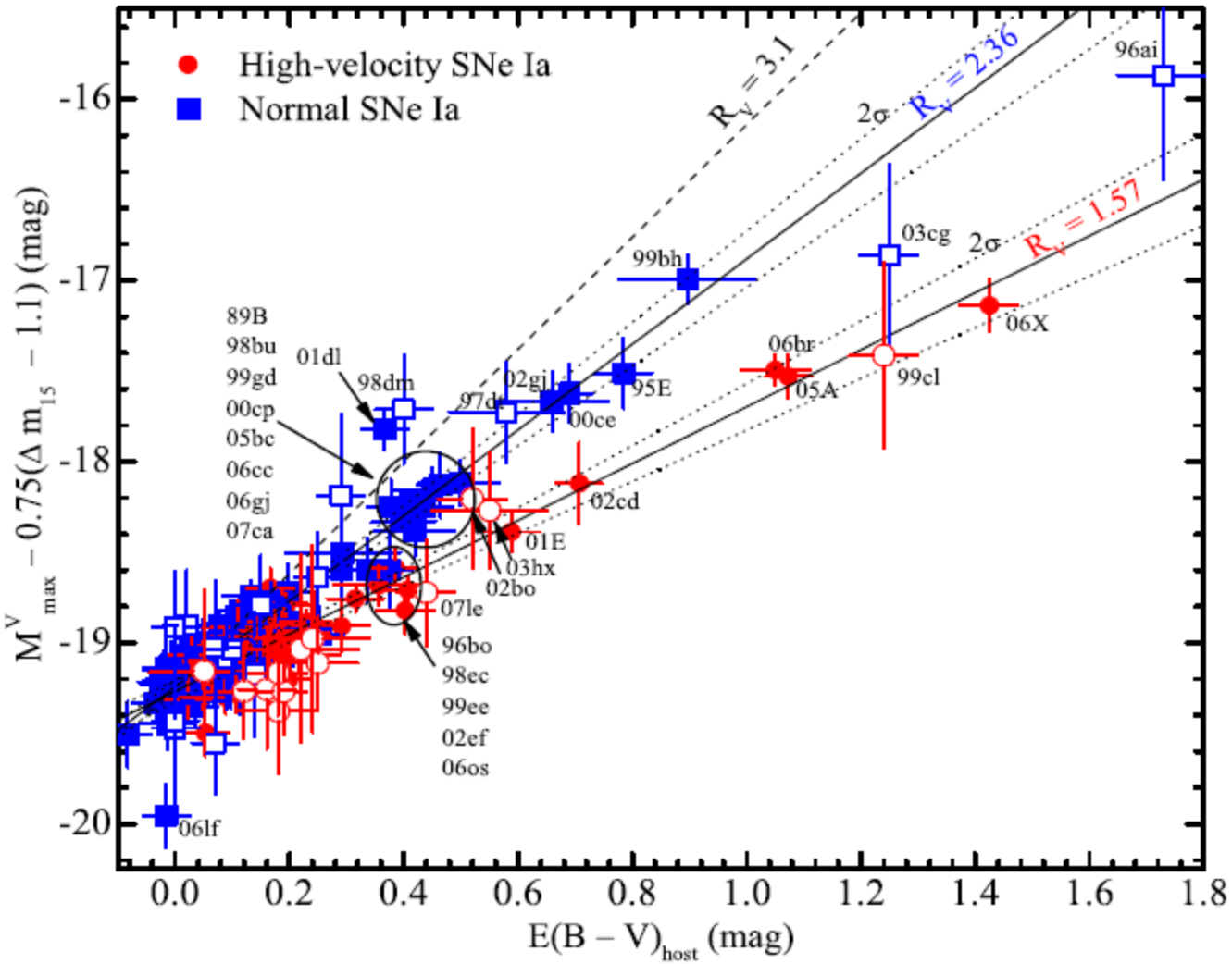
6% distance accuracy
from a single spectrum



Hubble Residuals



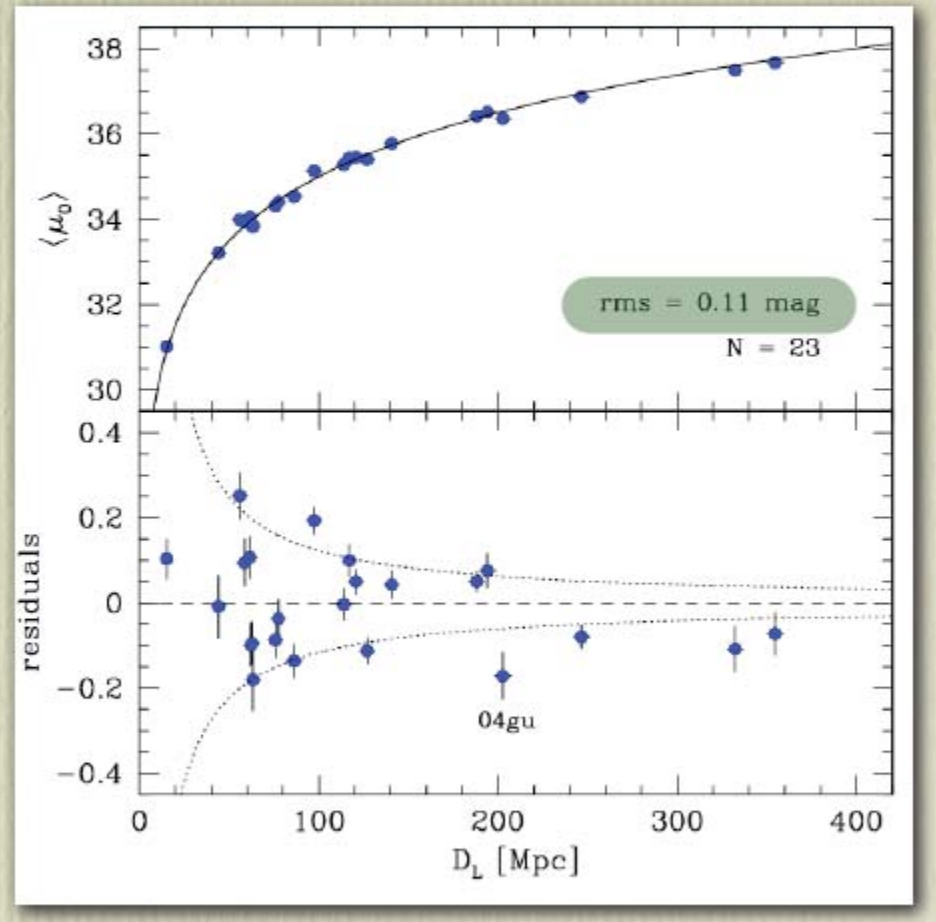
Wang et al (2009): Spectroscopic Feature Identification of "Dust" R_V



Mark Phillips (Santa Barbara, 2009):

SNe Ia as Precision Standard Candles

Filter	σ (mag)
u	0.13
g	0.14
r	0.13
i	0.14
B	0.14
V	0.14
Y	0.15
J	0.12
H	0.16



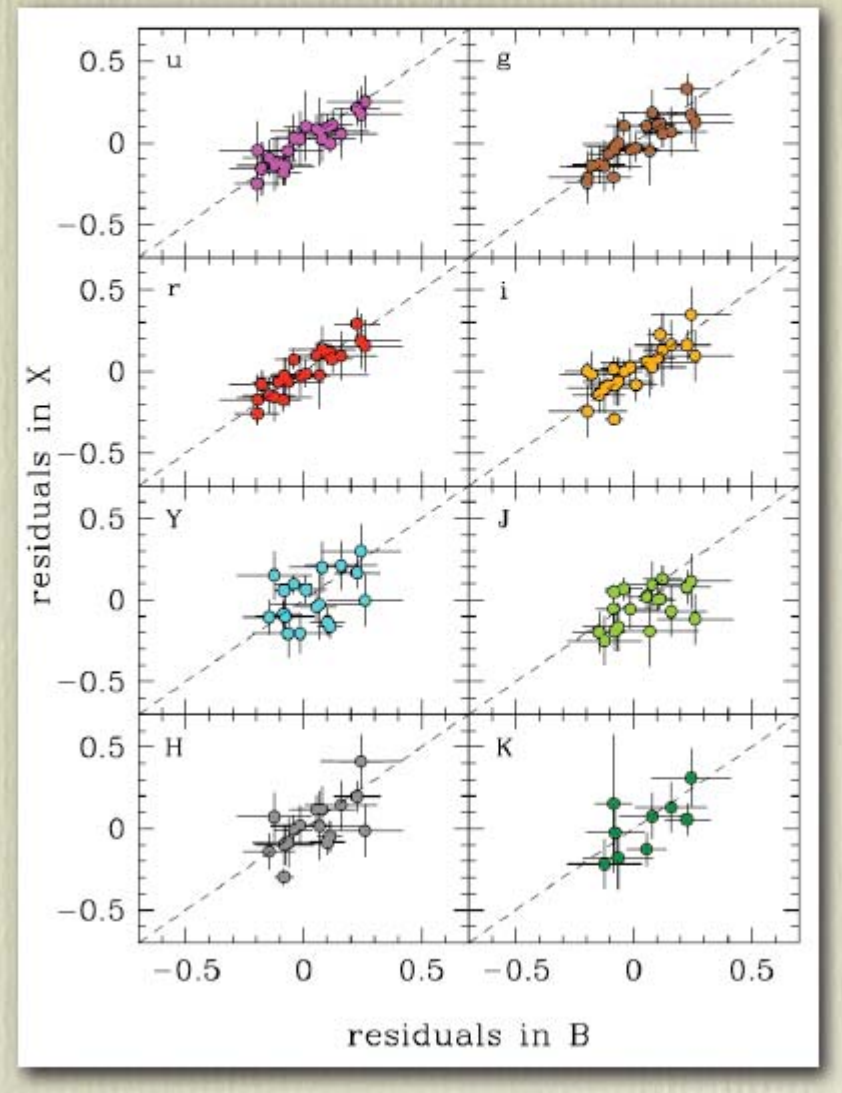
Combining Hubble diagrams in different bands does not yield a significant improvement in the observed dispersion

Mark Phillips (Santa Barbara, 2009):

SNe Ia as Precision Standard Candles

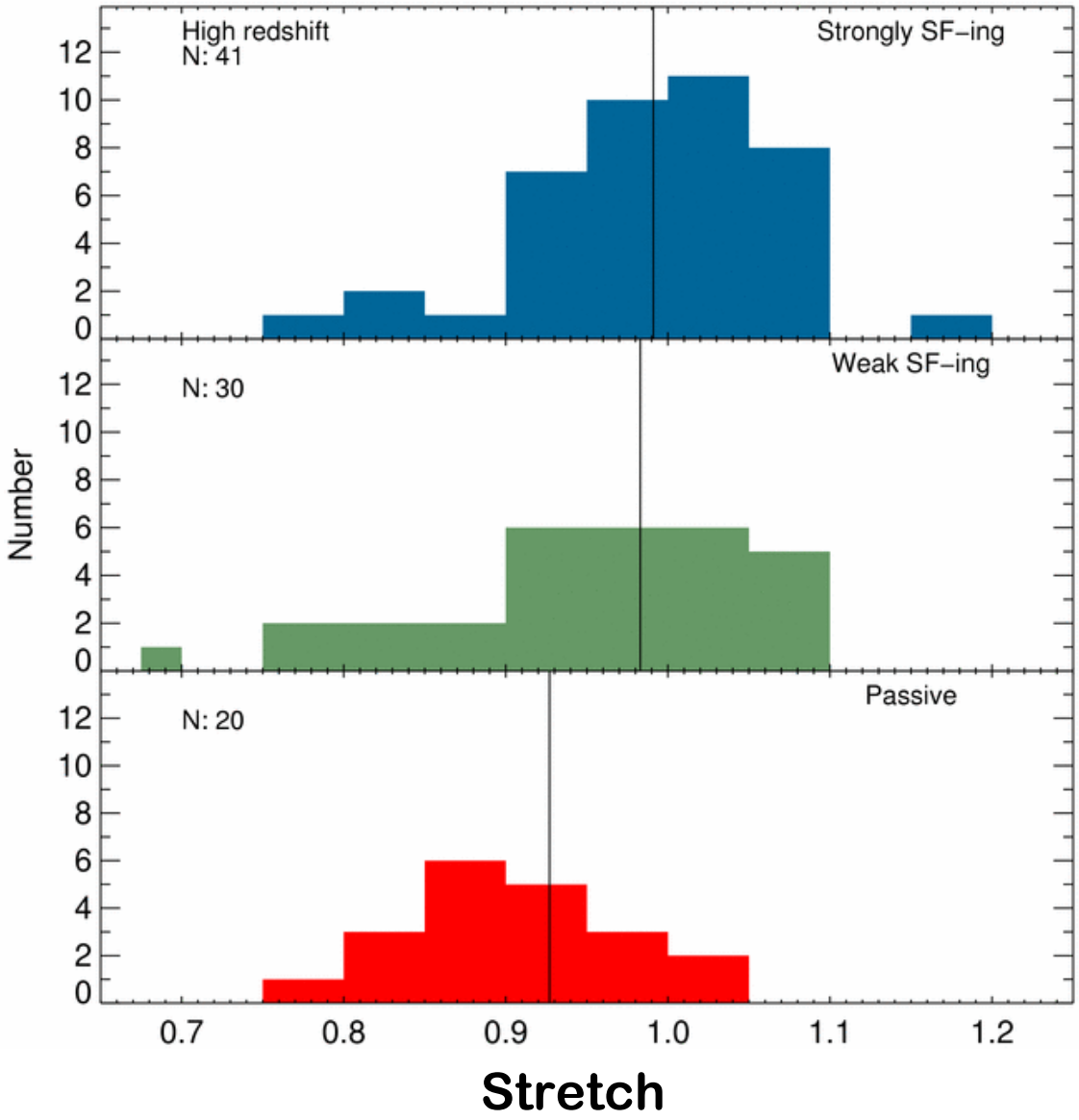
This is because the residuals in each color are highly correlated, presumably due to peculiar velocities

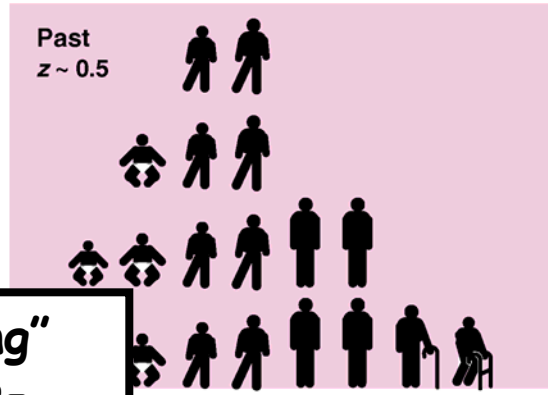
The implication is that we are actually measuring distances to a precision of 3-4%



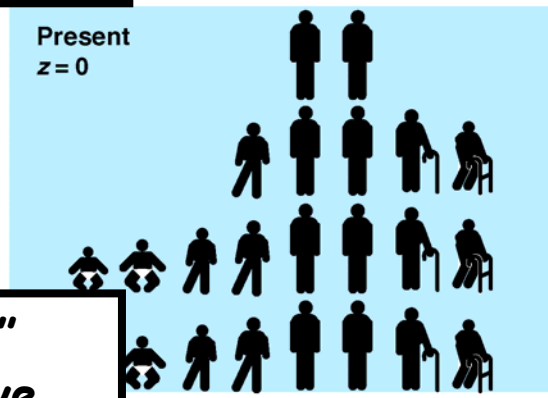
And we can even correlate with the host galaxy environment.

Sullivan et al. (2006)





"Young" Star-forming galaxies



"Old" Passive galaxies

←Fainter/faster SNe Brighter/slower SNe →

It appears that we can greatly improve statistical uncertainty, and the constraints on systematics such as evolution

but:

Most of these indicators require measurements than we cannot obtain from the ground at even moderately high redshifts.

limitation from ground

"Dust" is currently one of the most challenging aspects of the measurement.

Scare quotes around "dust" because it appears that using color we are probably calibrating something more intrinsic to the SNe than the usual dust.

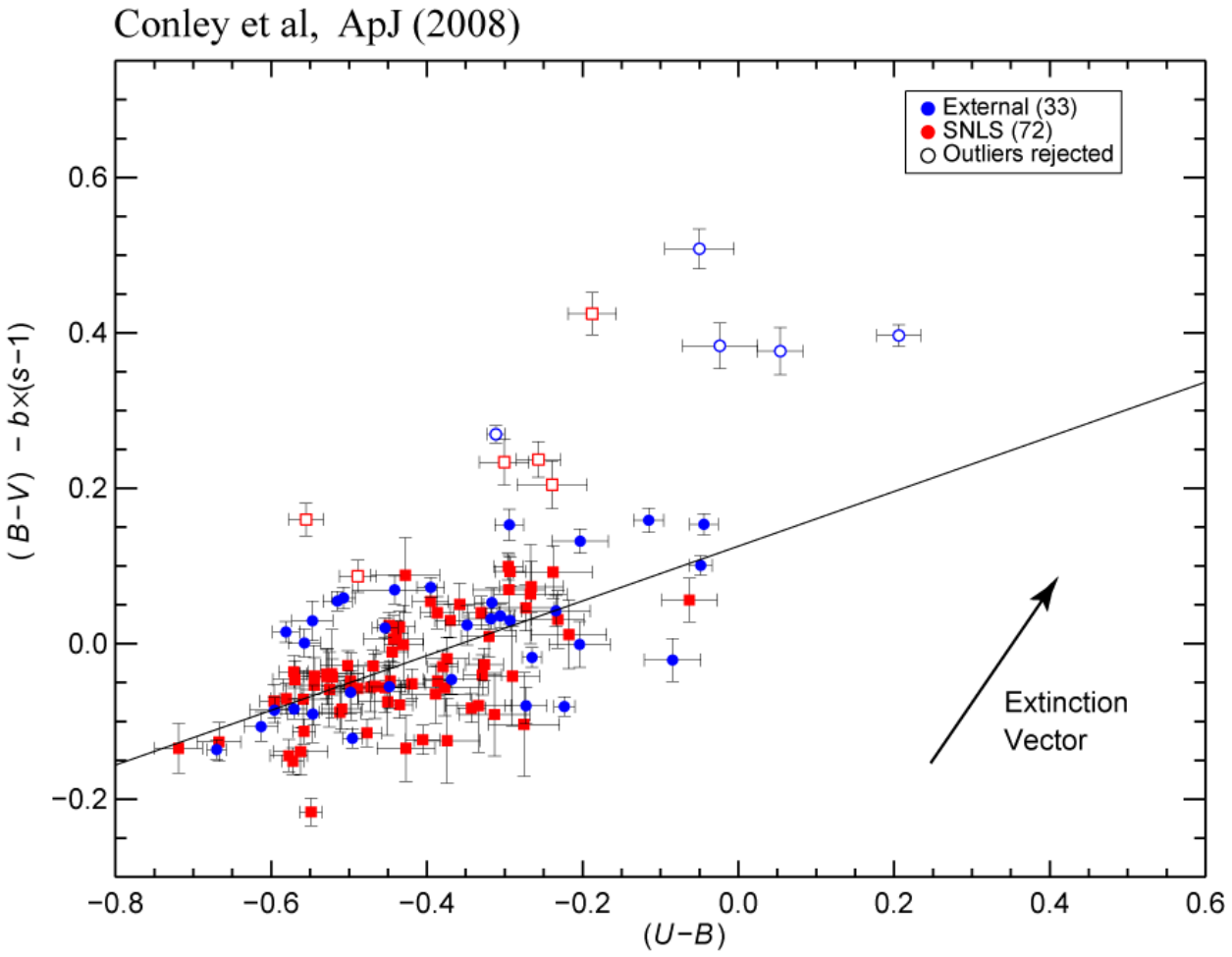
"Dust" is currently one of the most challenging aspects of the measurement, because:

We do not have good constraints on the intrinsic color of each SN.

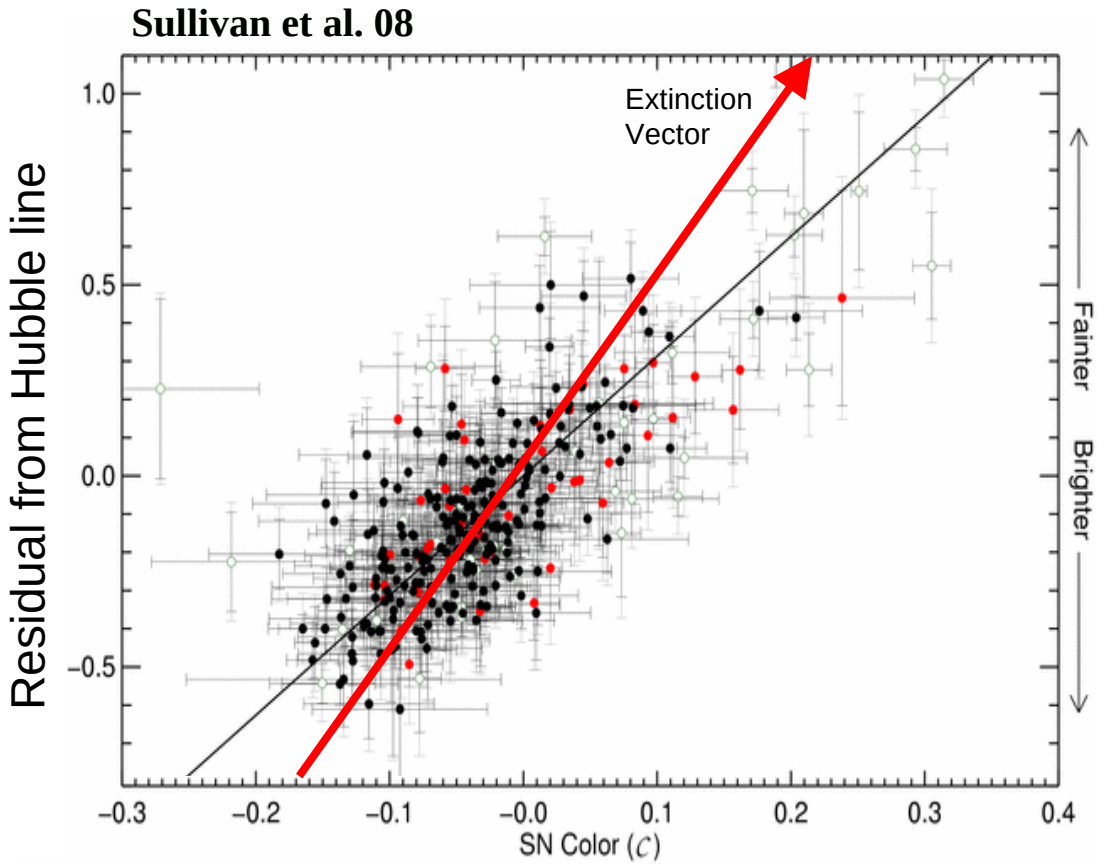
We do not have high-precision color measurements over a wide wavelength range. limitation from ground

With second, bluer color, $U-B$, the SNe show a color-color locus that does not follow a CCM dust law (for a wide range of R_B).

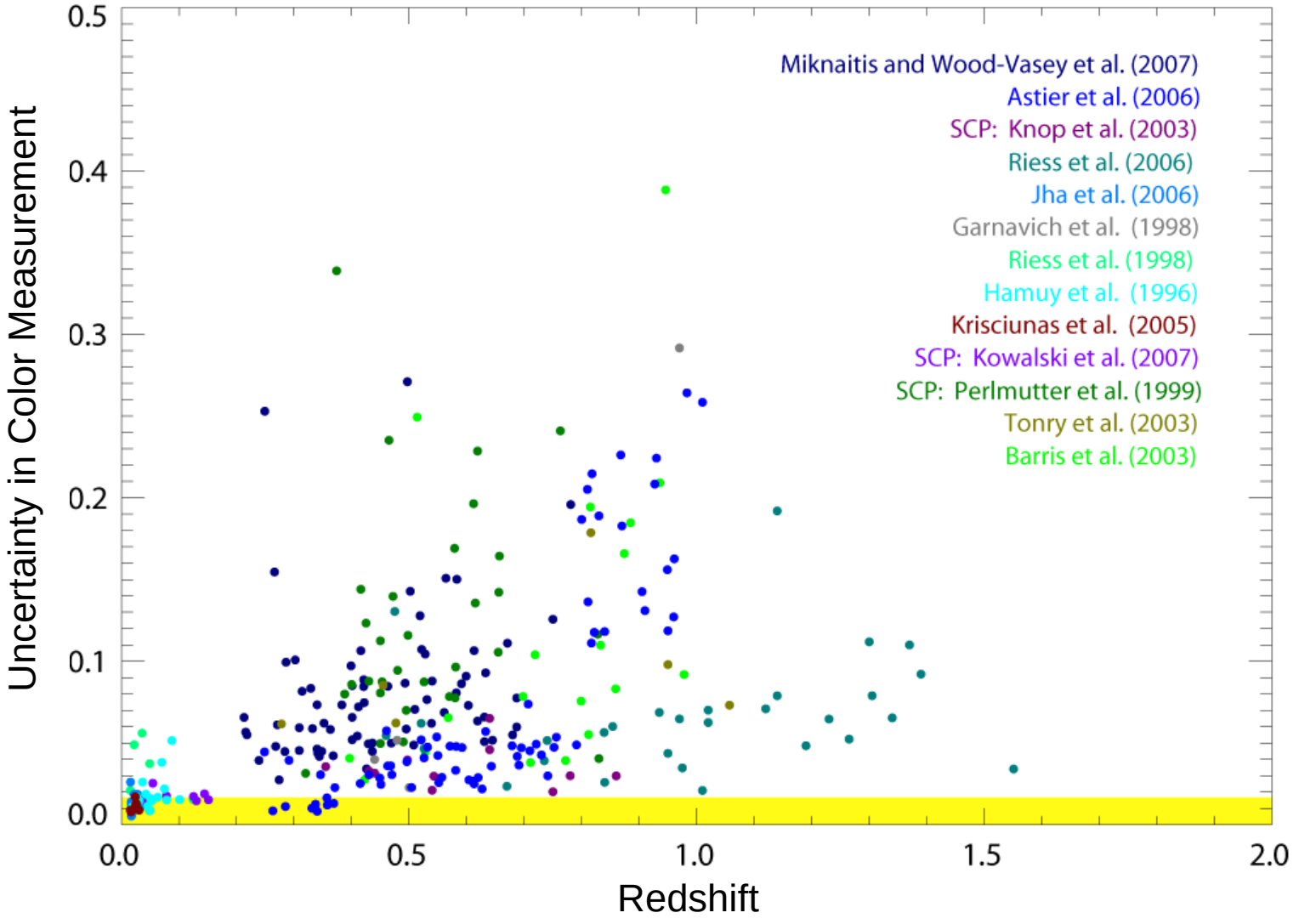
This indicates that intrinsic color is another parameter.



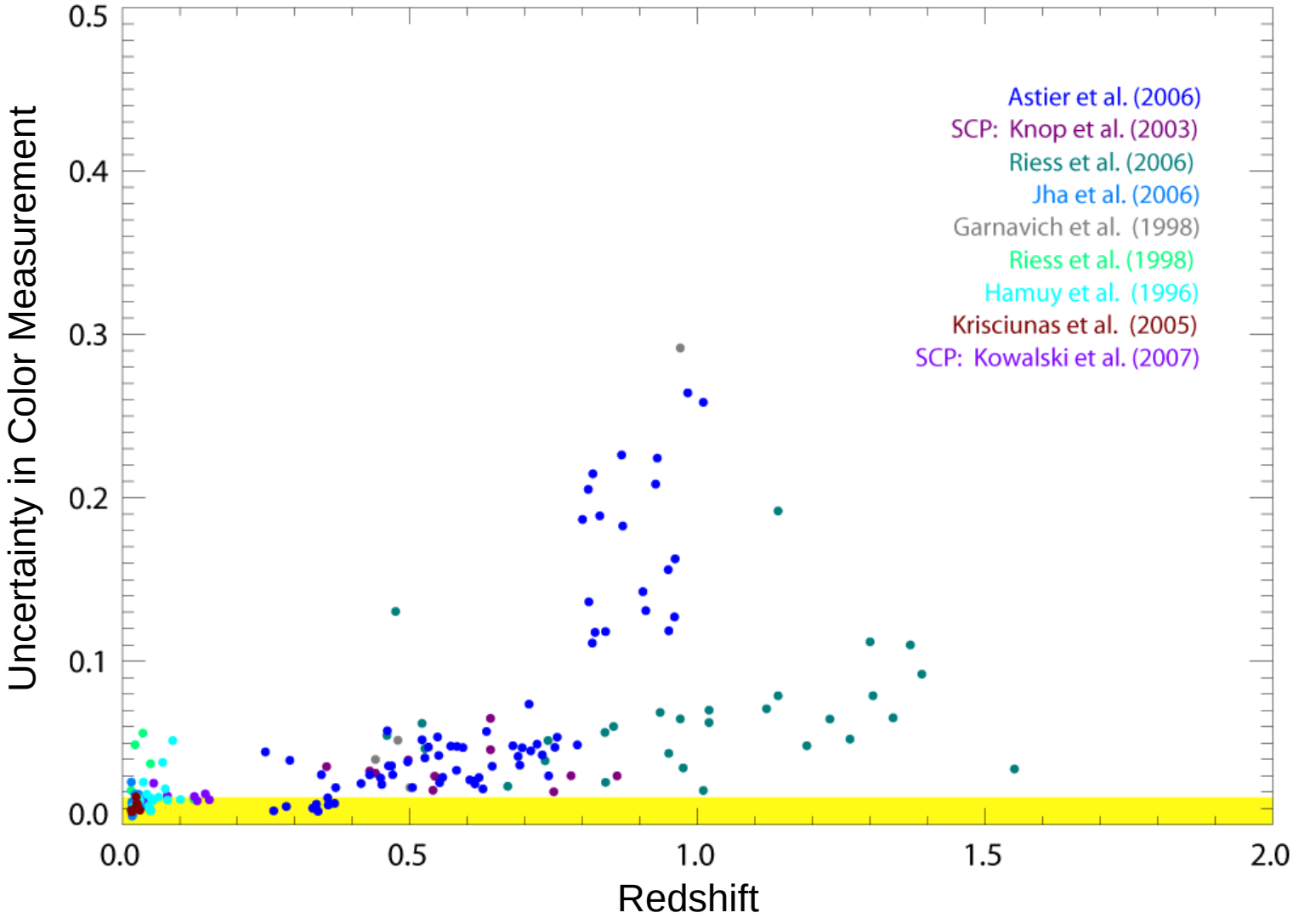
The color vs. Hubble-residual plot similarly indicates that the SNe are not following just a CCM dust law.



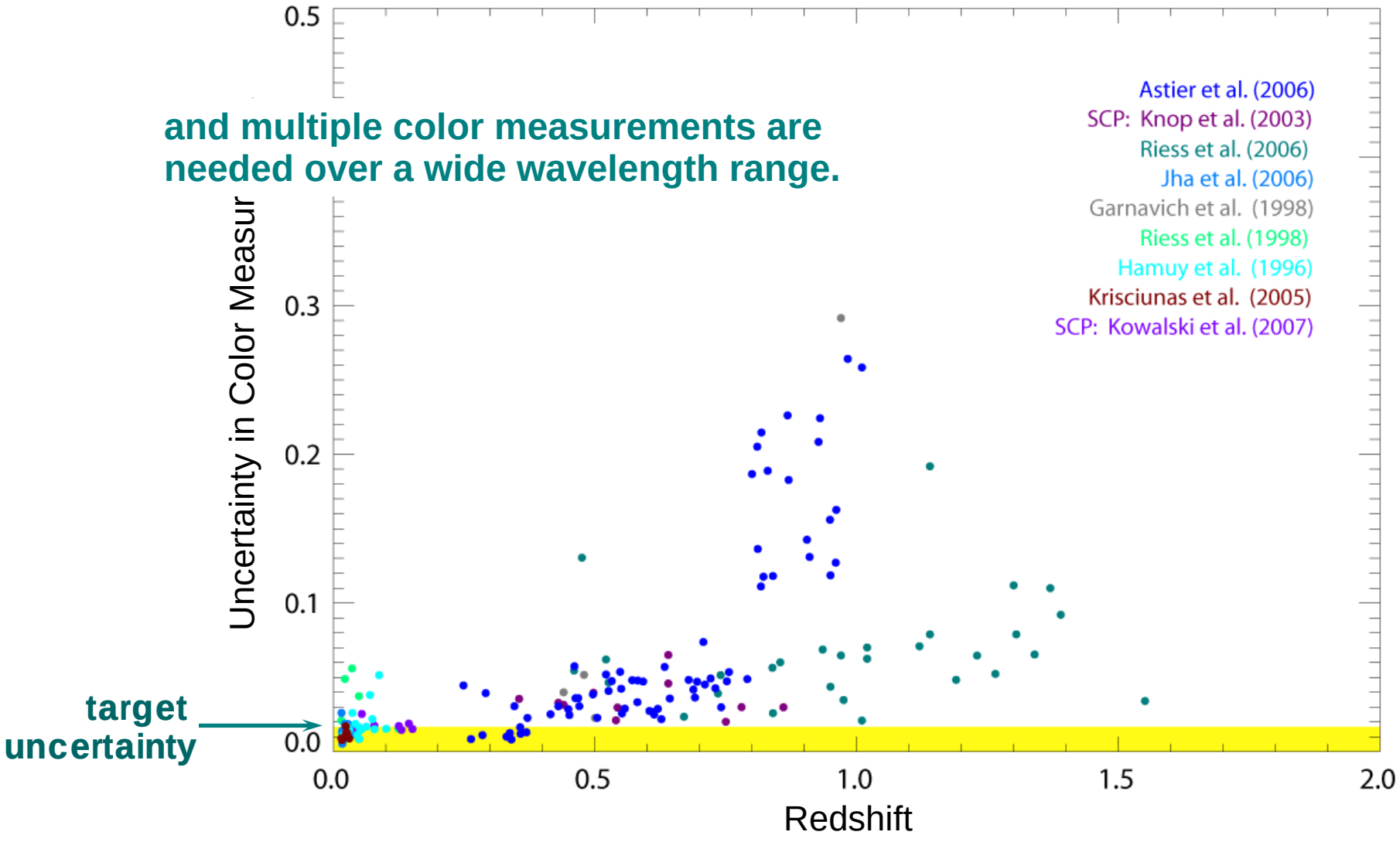
Even if one has identified the intrinsic colors of the supernovae the current color measurements are insufficient to constrain the "dust."



Even if one has identified the intrinsic colors of the supernovae the current color measurements are insufficient to constrain the "dust."



Even if one has identified the intrinsic colors of the supernovae the current color measurements are insufficient to constrain the "dust."



A definitive SN experiment must obtain the same set of measurements at every redshift.

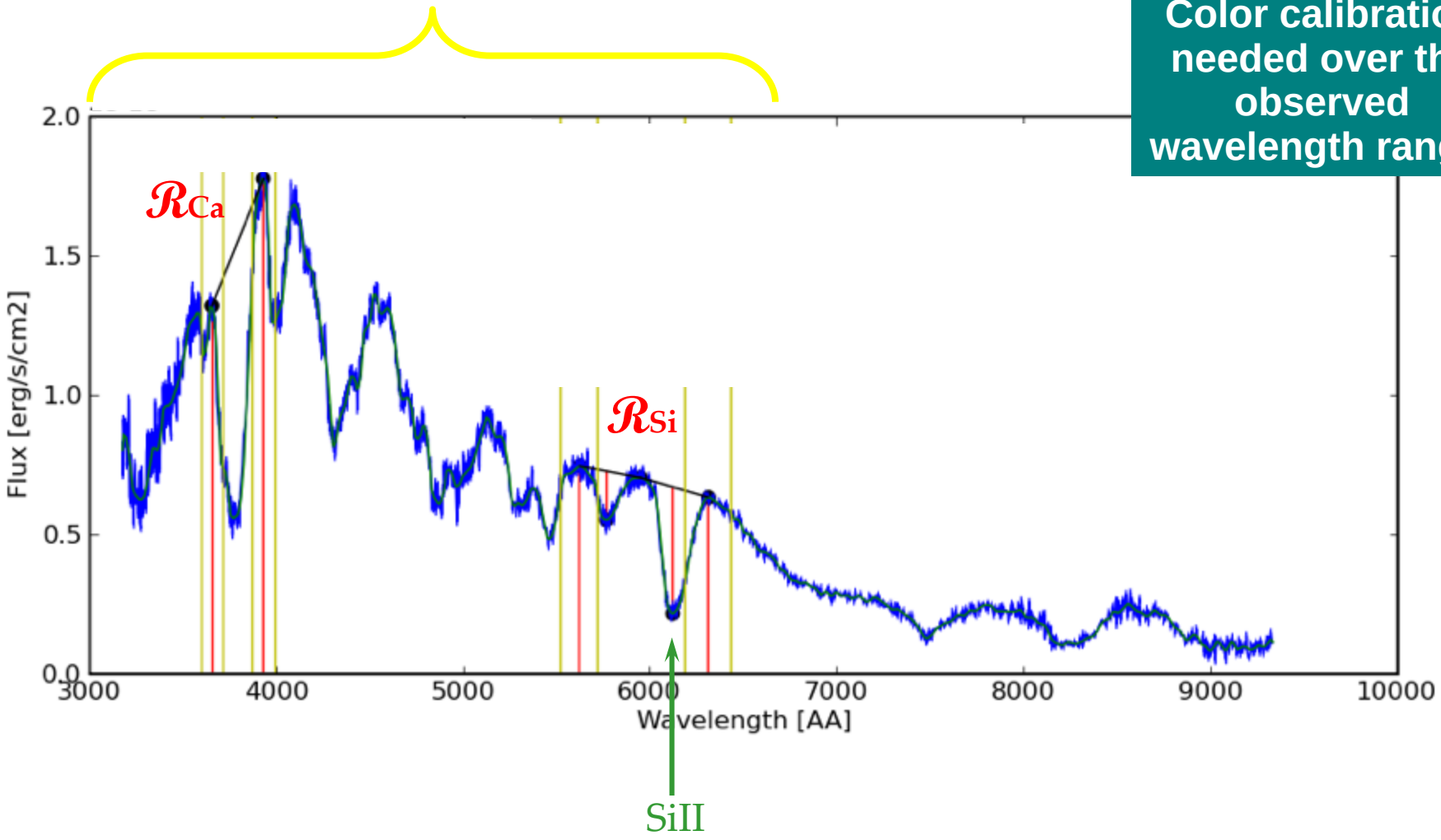
A definitive SN experiment must obtain the same set of measurements of SN and host galaxy at every redshift

i.e., a homogeneous dataset

…i.e., the same restframe wavelengths at every redshift

For example, to use these spectral feature indicators every SN must be observed over these restframe wavelengths.

Color calibration needed over the observed wavelength range.

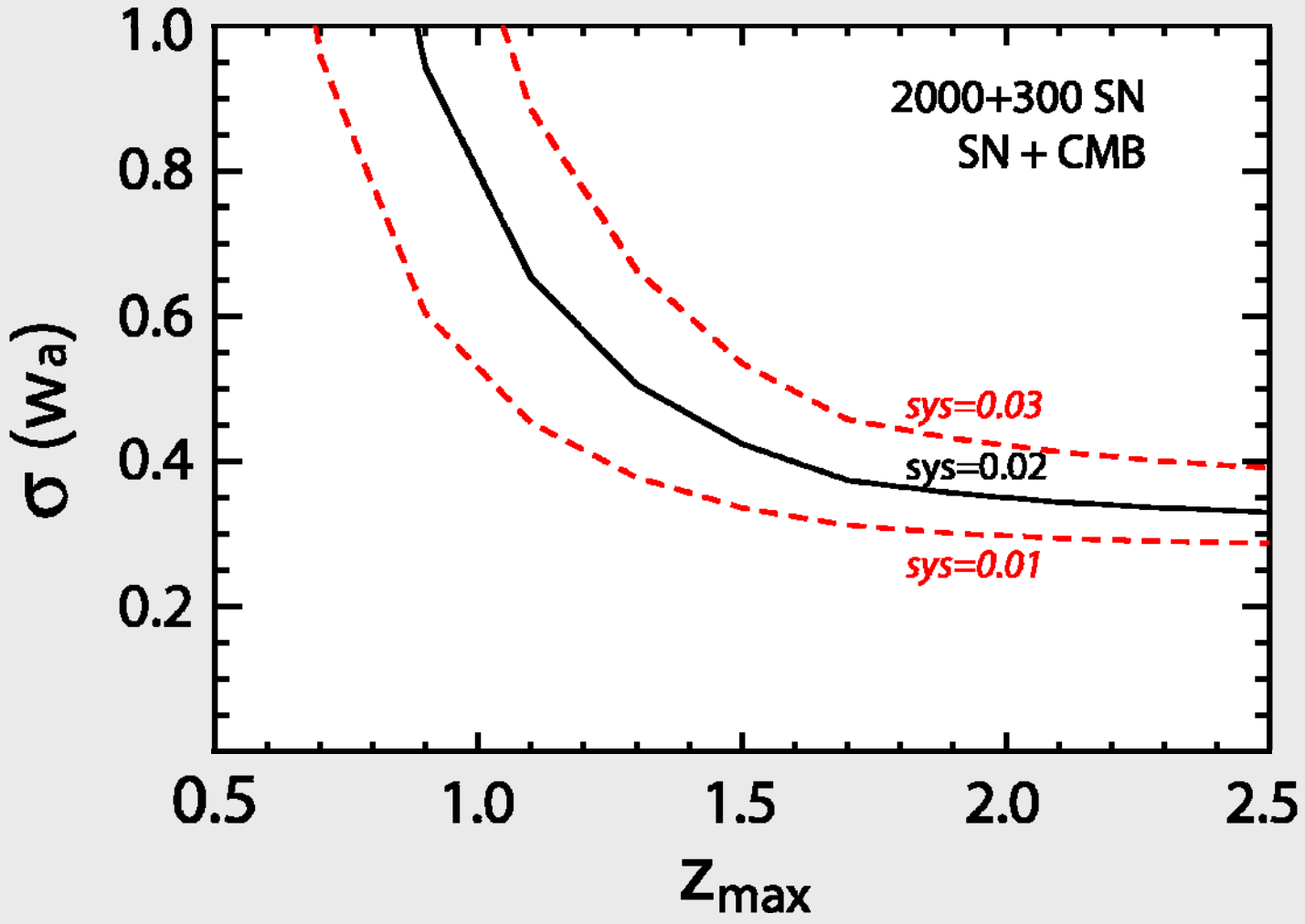


Same set of SN measurements over *what* redshift range?

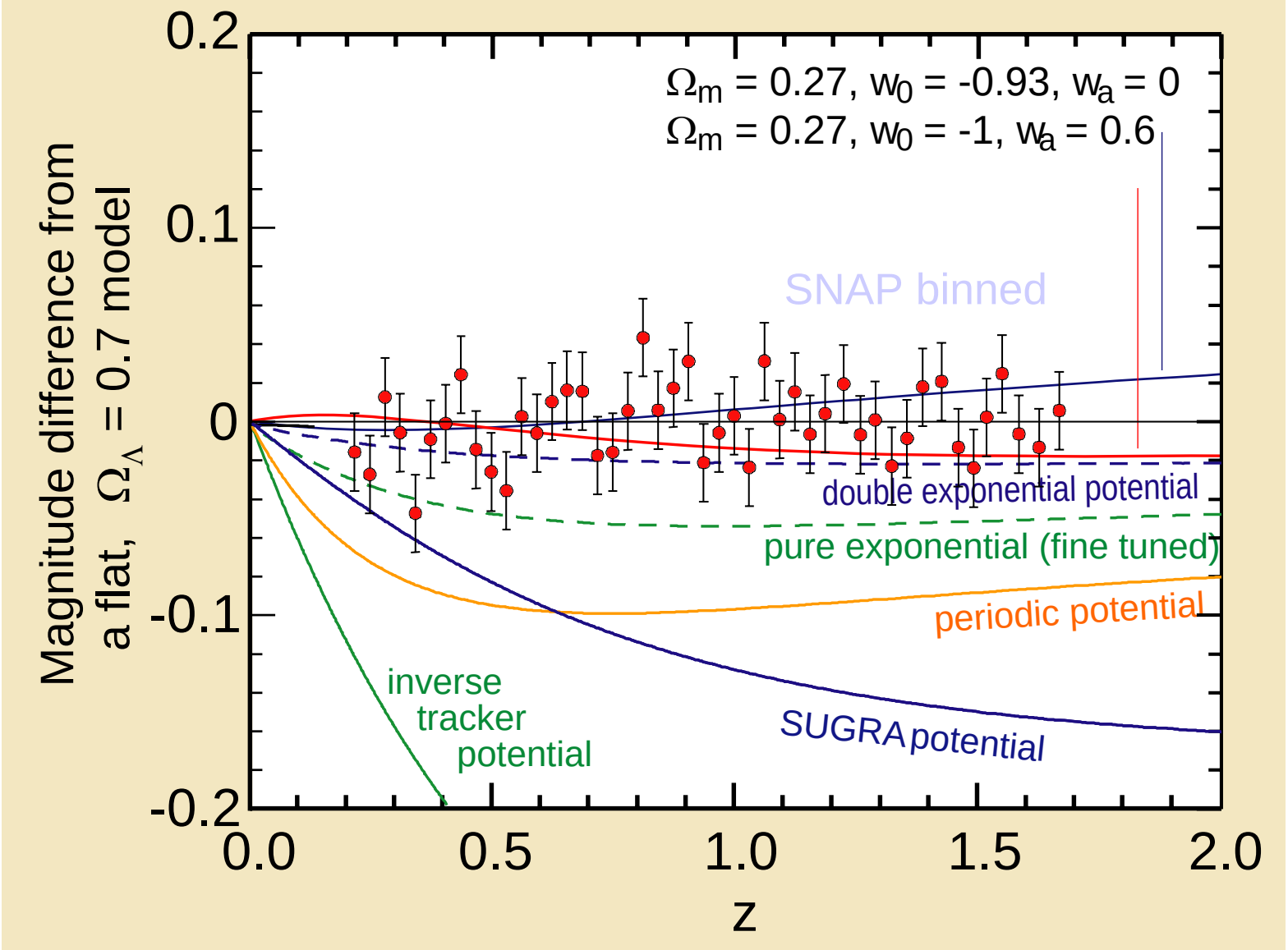
From first principles:

Measure expansion history out to the redshifts at which dark energy is no longer *expected* to be a significant component.

Redshift range



Redshift range



(based on Weller, Albrecht 2001)

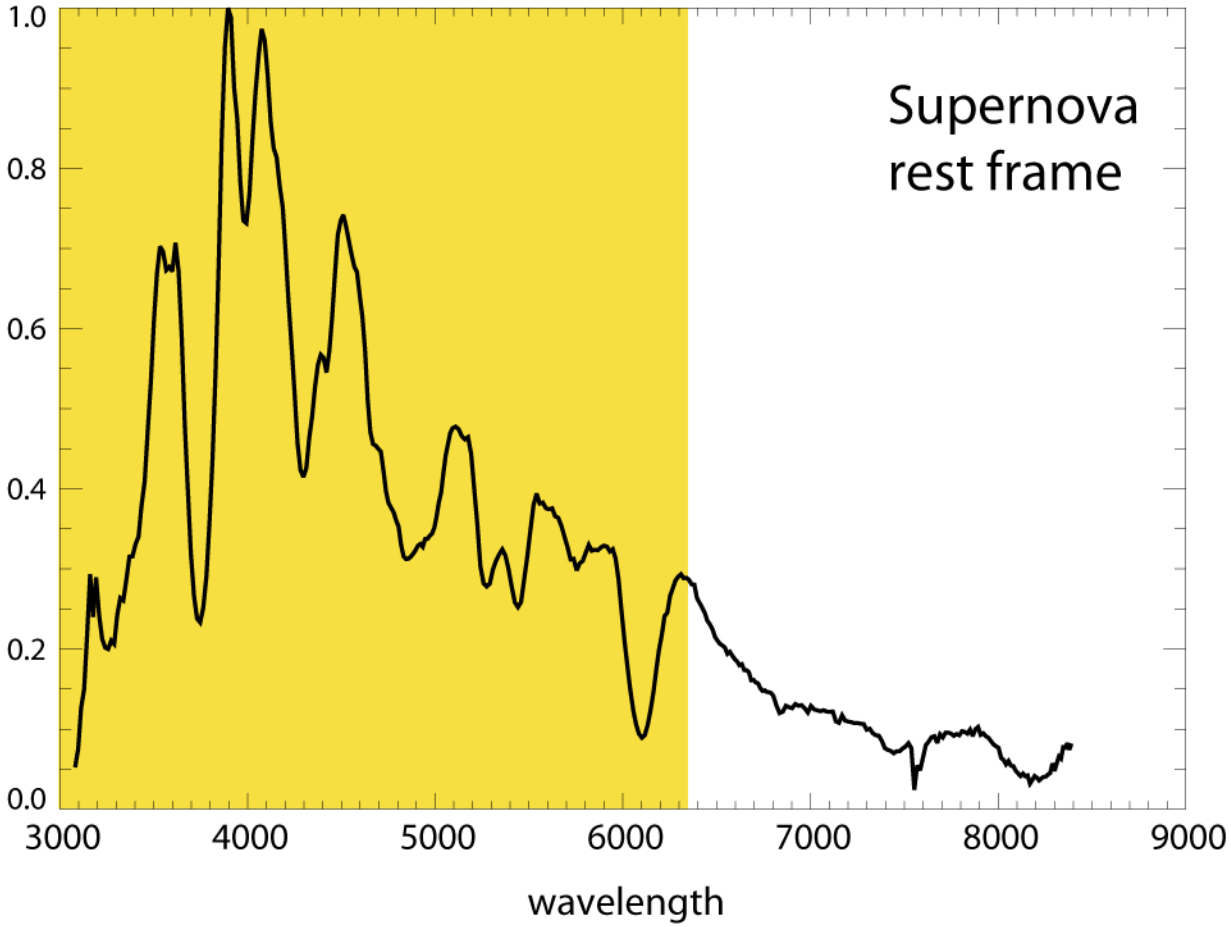
For this whole redshift range,
study every SN
in the same restframe wavelengths.

For this whole redshift range,
study every SN
in the same restframe wavelengths.

What restframe wavelengths?

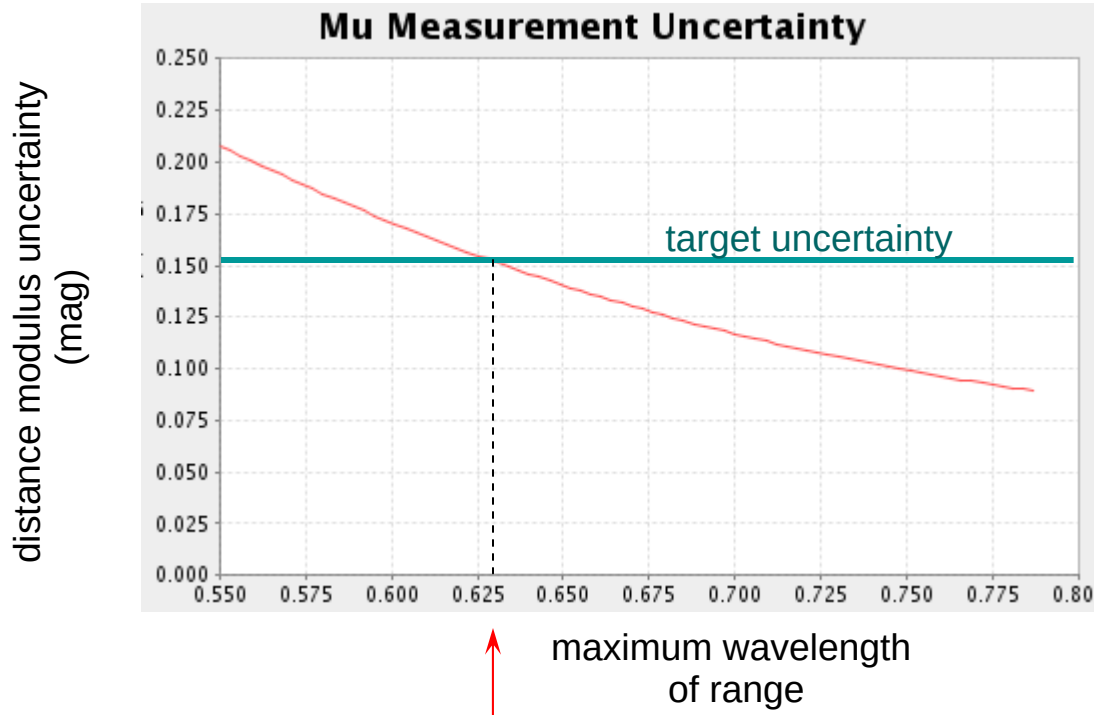
What restframe wavelengths?

0.3 to 0.63 microns includes over 90% of the SN light and is the wavelength range where SNe have primarily been studied.



What restframe wavelengths?

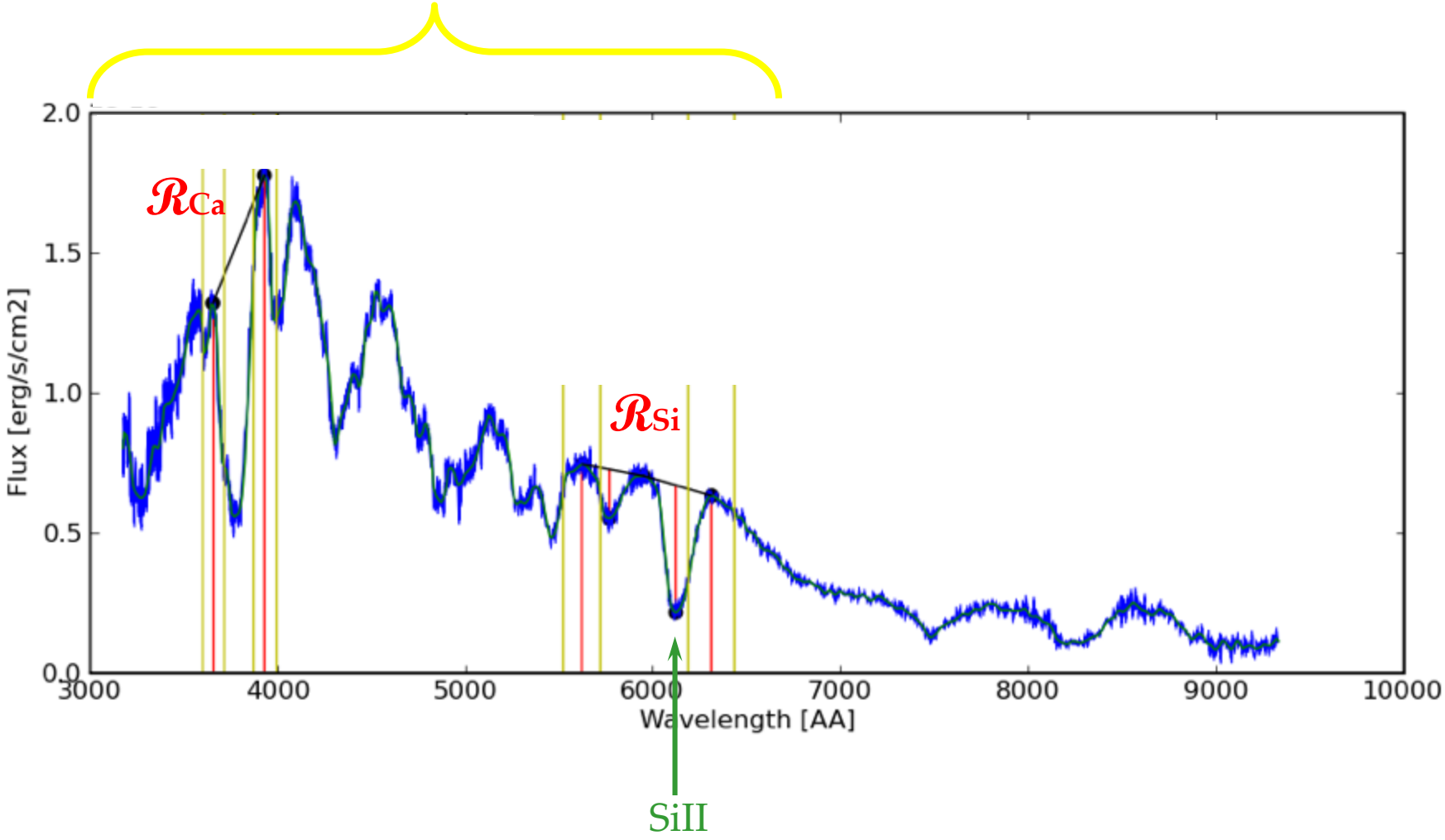
...This also corresponds to the wavelength range which gives a distance modulus fit at the 0.15 mag level, when we fit A_B and R_B to account for color.



Wavelength range:
from 0.3 microns to 0.63 microns

What restframe wavelengths?

...And this also corresponds to the wavelength range which captures the main spectral features that have been studied as absolute magnitude indicators.

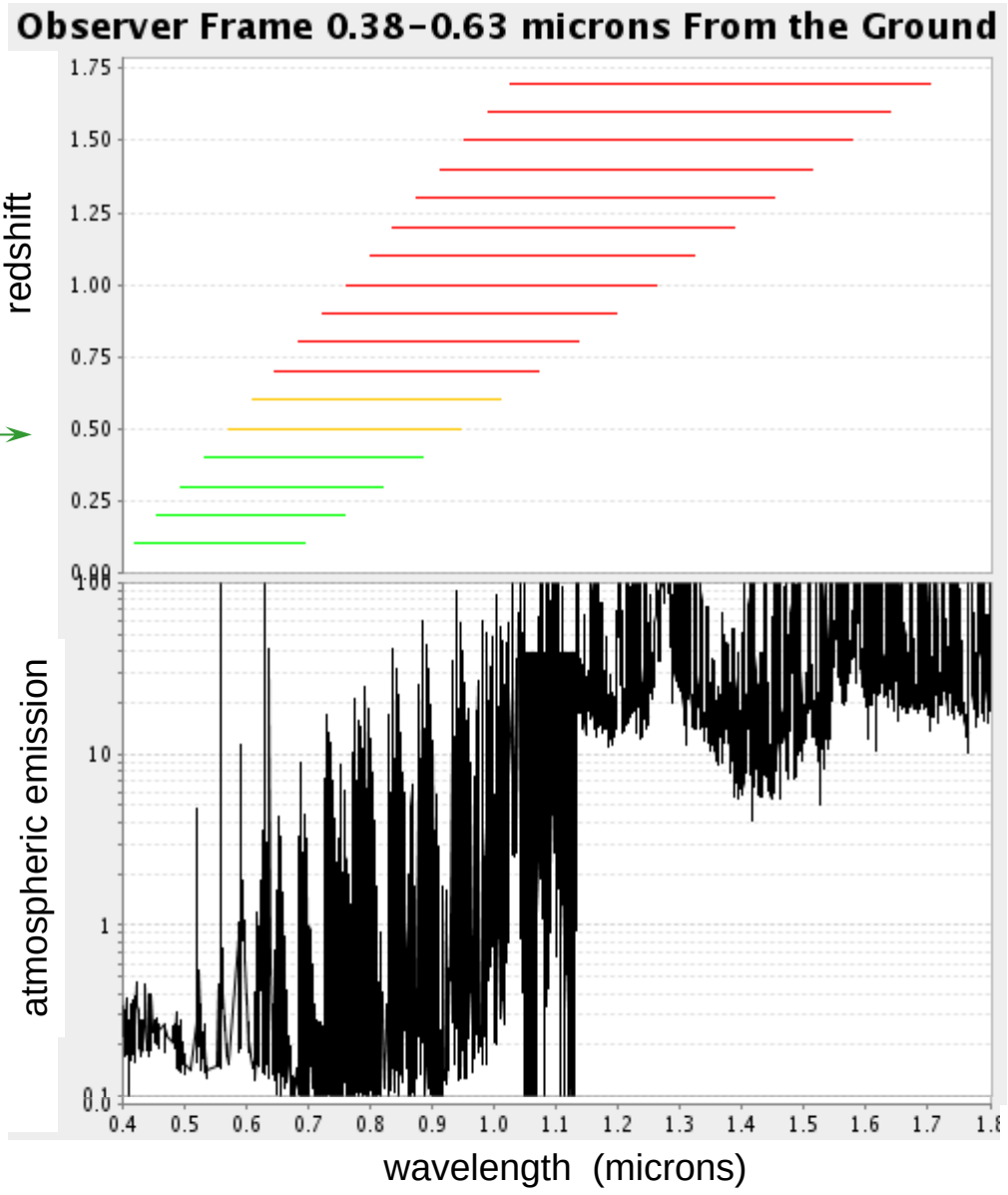


Do we need visible-wavelength detectors?

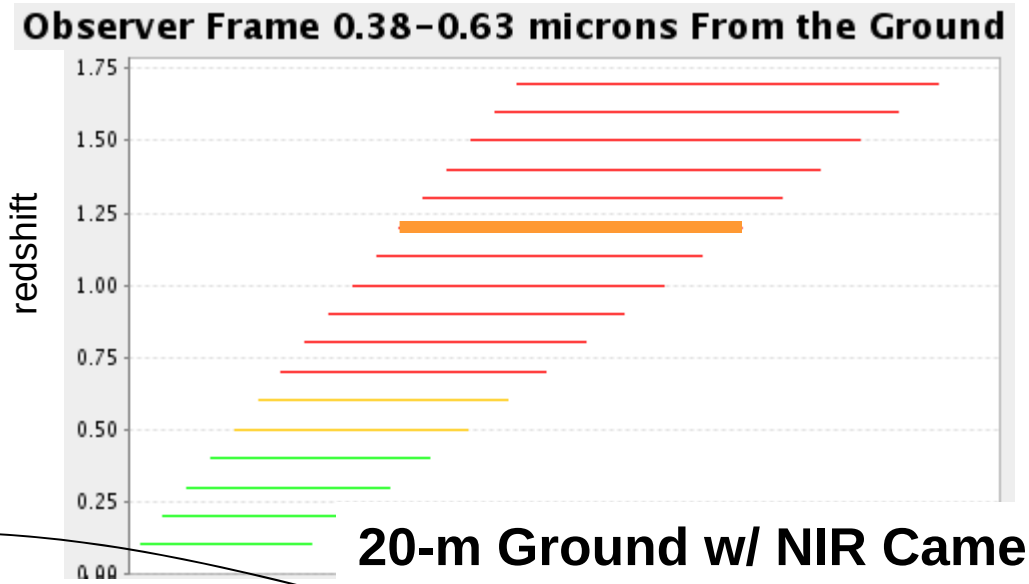
For what redshifts can these standard restframe wavelengths be studied from the ground?

At what redshifts can these wavelengths be studied from the ground?

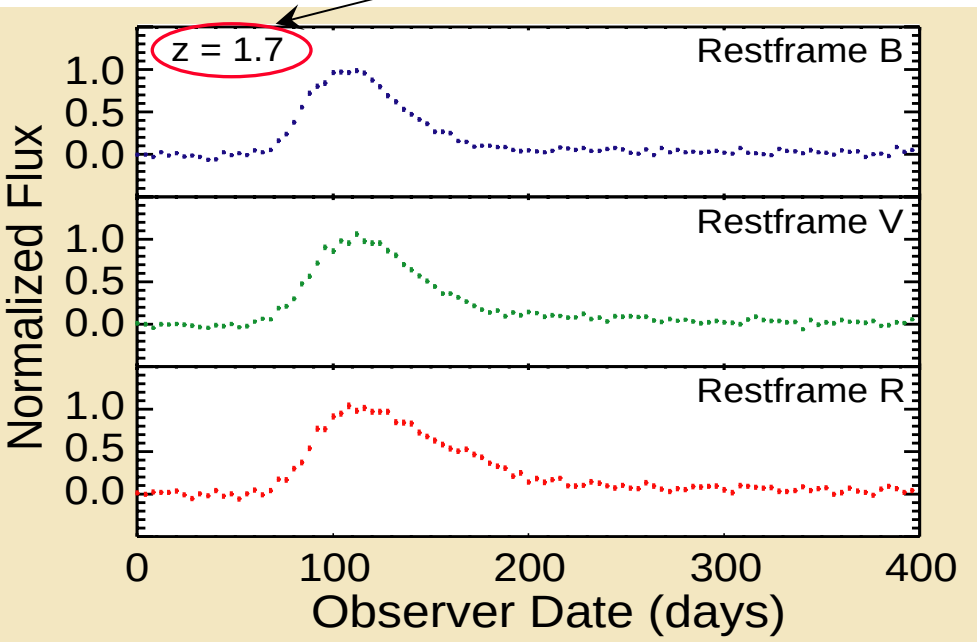
From the ground these wavelengths can only be studied up to z ~ 0.5 or 0.6



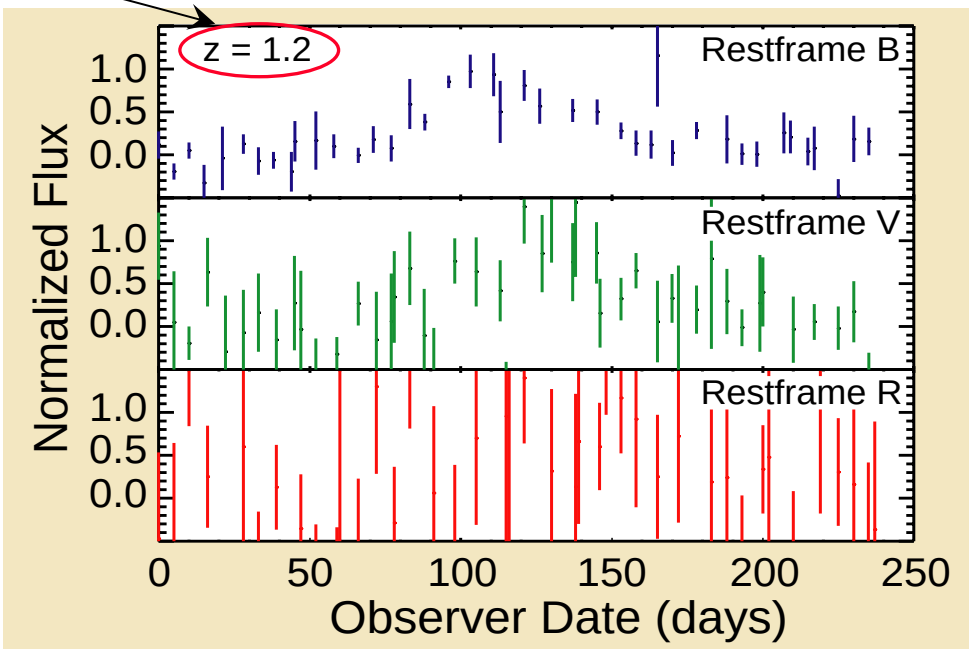
At what redshifts can these wavelengths be studied from the ground?



SNAP



20-m Ground w/ NIR Camera



We can begin to organize these topics with the two types of questions:

1. What are factual elements that we can agree on that set the parameters of these programs? What calculations or compilations can be performed to establish them?

2. What are the decisions in defining these programs that must be based on science "taste"? Are there any changes in circumstances or data that would influence these preferences?

1 What are factual elements that we can agree on that set the parameters of these programs? What calculations or compilations can be performed to establish them?

For various error models, what are figures of merit as a function of number of SNe and their redshift distribution?

What range of supernova absolute mag, stretch, color do we need to be able to study? What range of host galaxy environments?

What are the best estimates of SN rate versus redshift? How many SNe can be studied with instruments that achieve a give Aperture x Solid Angle x Time?

For various intrinsic color distributions and dust models, what color measurements (wavelength range and signal-to-noise) are needed to calibrate SNe?

For various spectral features, what wavelength range, resolution, and signal-to-noise is required to calibrate SNe and (perhaps equivalently) constrain evolution models?

Given these above measurement requirements, what can various specific instruments achieve over a given redshift range?

2 What are the decisions in defining these programs that must be based on science "taste"? Are there any changes in circumstances or data that would influence these preferences?

Emphasis on larger numbers of SNe versus more detailed measurements for each SN.

Emphasis on performing same restframe observations for the SNe at every redshift studied.

When you have to start to degrade your experiment from the ideal, what would you give up first?