Observational cosmology and Type Ia Supernovae, Part II

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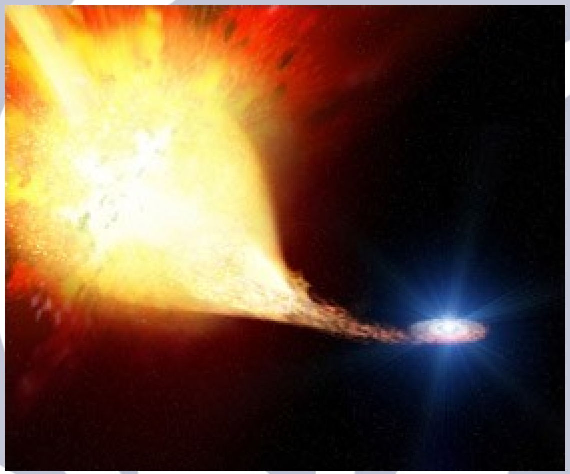
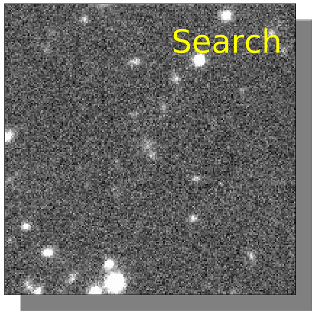
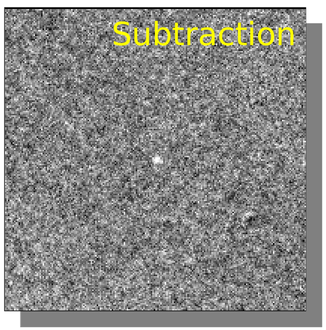
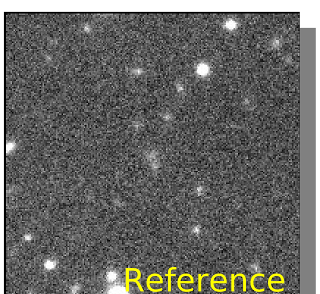


rahman@fysik.su.se

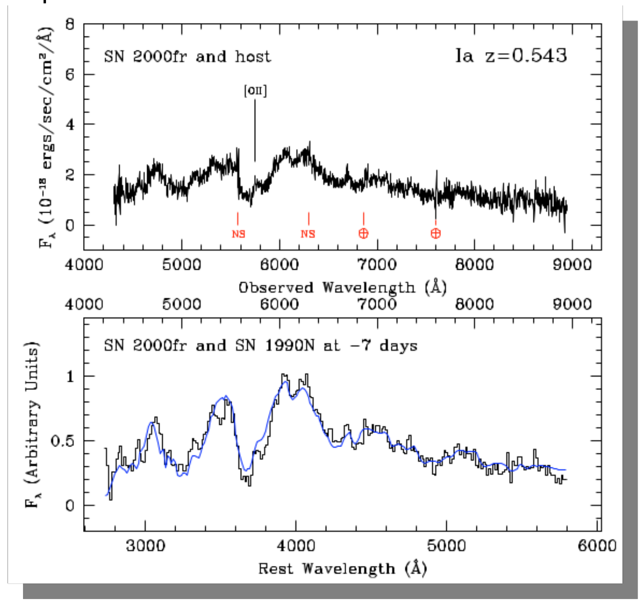
SN Ia cosmology tutorial



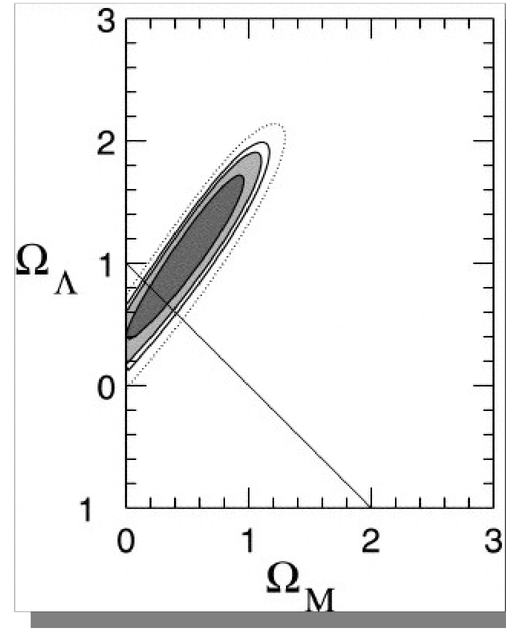




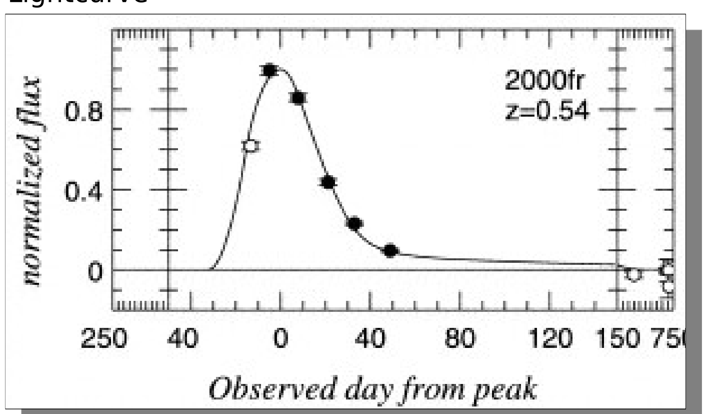
Spectrum



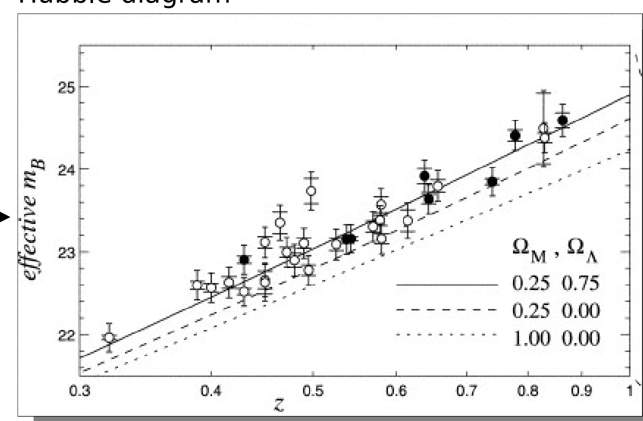
Cosmology fits



Lightcurve



Hubble diagram



Recap of yesterday

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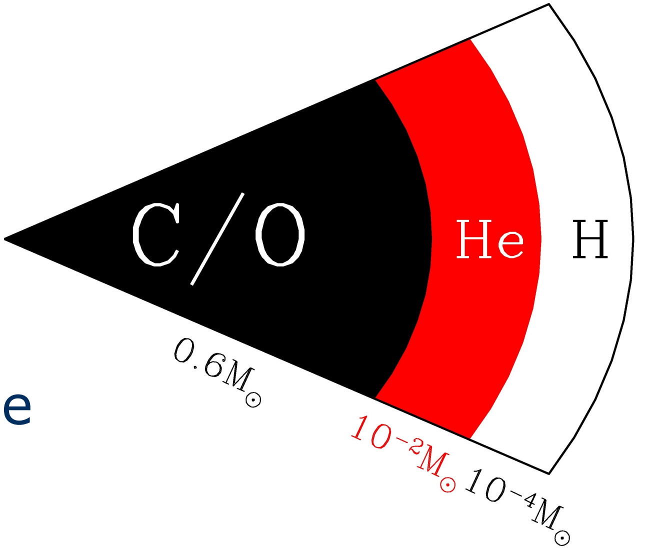
Astrophysics Cosmology

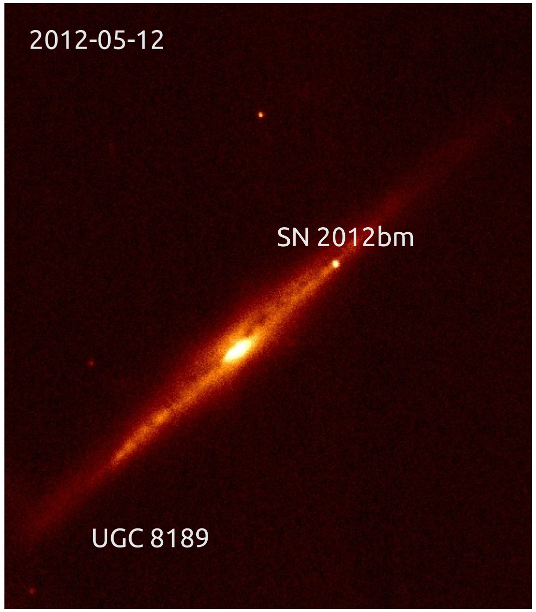
$$m - M = 5\log_{10}\left((1+z)\int_0^z \frac{dz'}{H(z')}\right) \quad \text{for} \quad k = 0$$

$$H(z)^2 = H_0^2\left[\Omega_M(1+z)^3 + \Omega_K(1+z)^2 + \Omega_\Lambda\right]$$

Type Ia Supernovae

- Degenerate white dwarf
- Thermonuclear explosion of a CO white dwarf that has reached the Chandrasekhar mass ~ 1.4 M_{sun}
- Outshines entire host galaxy (for a short time).
- Standard candles ~10-15% scatter in brightness.
- Spectrum: Silicon, but unlike other SN types, no H or He.





NOTCam / Tanja Petrushevska

$M \sim -19.3$

SN Ia lightcurve

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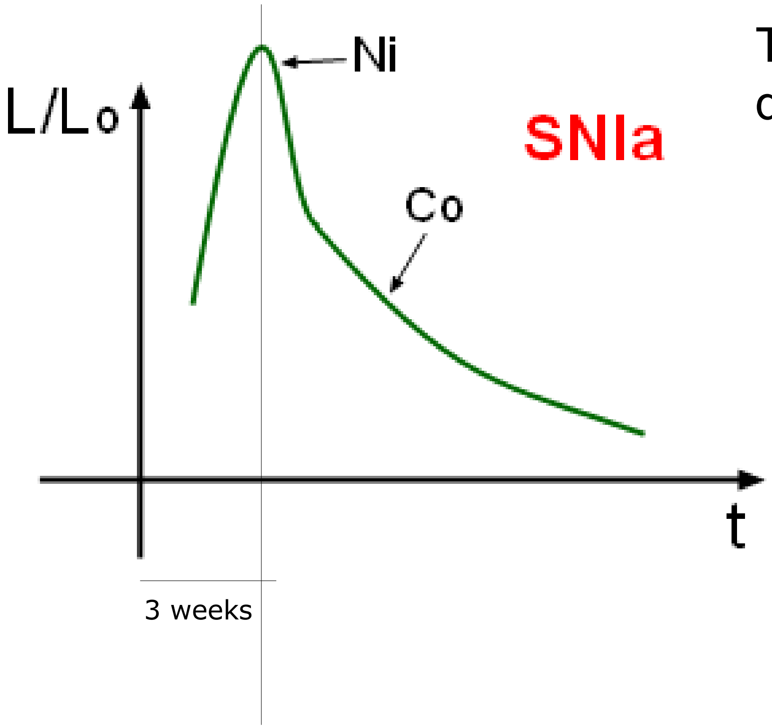
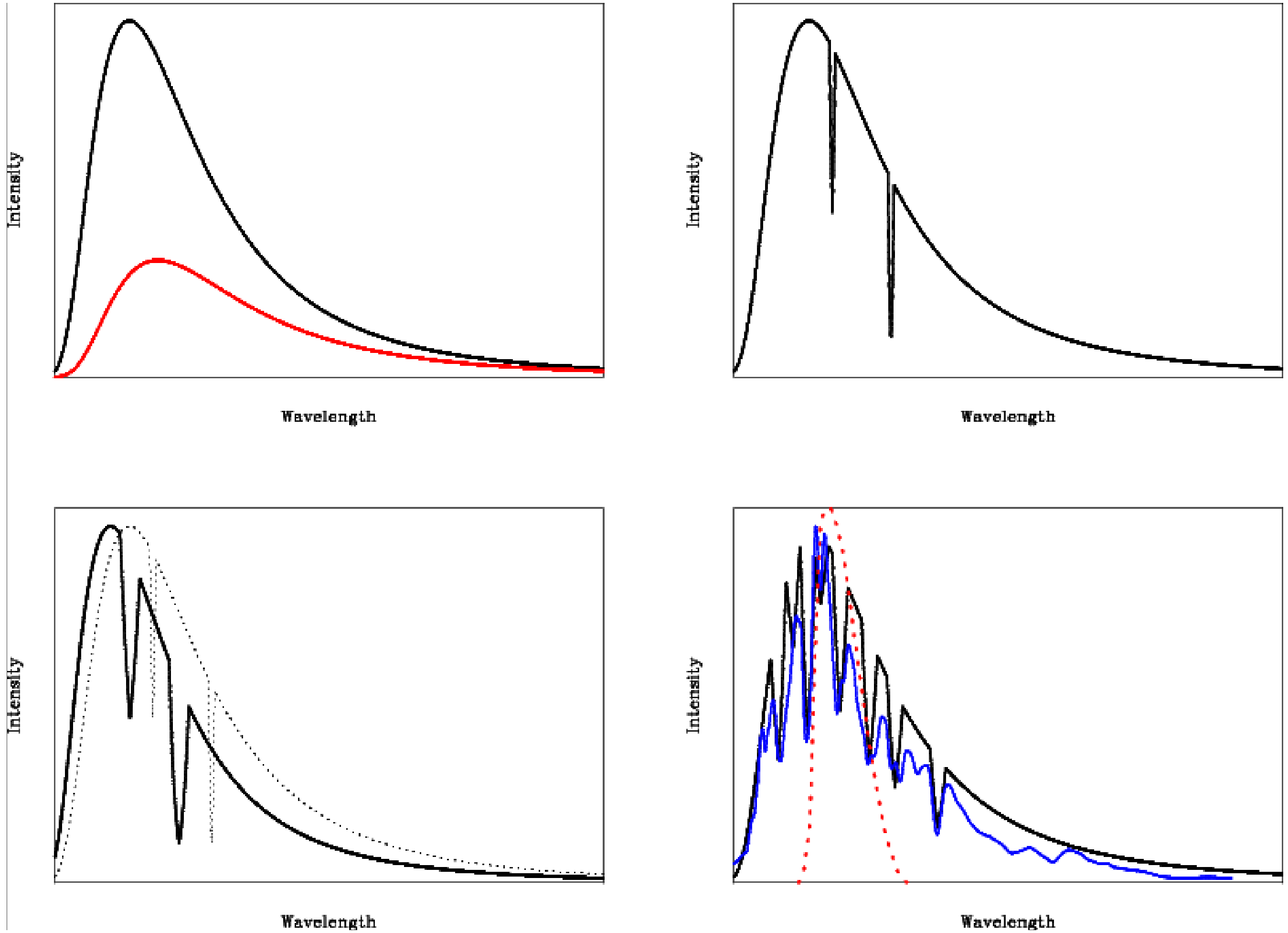


The SN lightcurve is powered by radioactive decay of $^{56}Ni \rightarrow {}^{56}Co \rightarrow {}^{56}Fe$

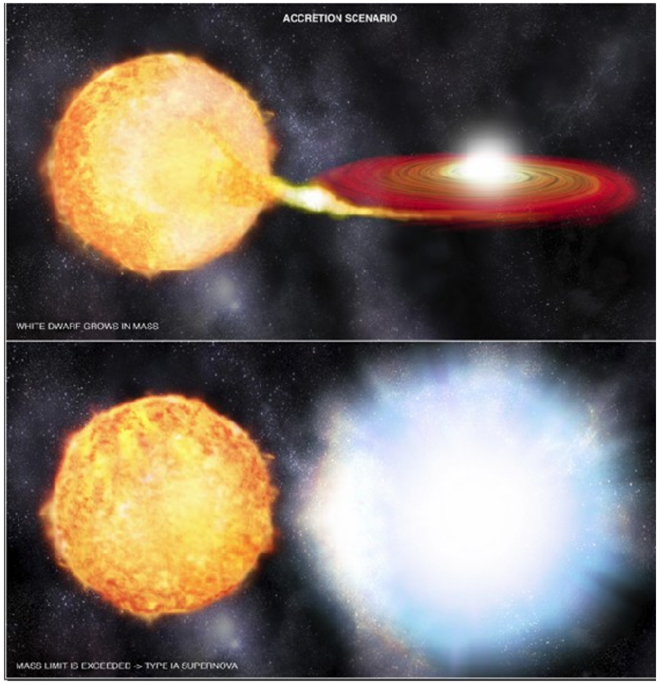
SN Ia spectrum



(courtesy of Jakob Nordin)

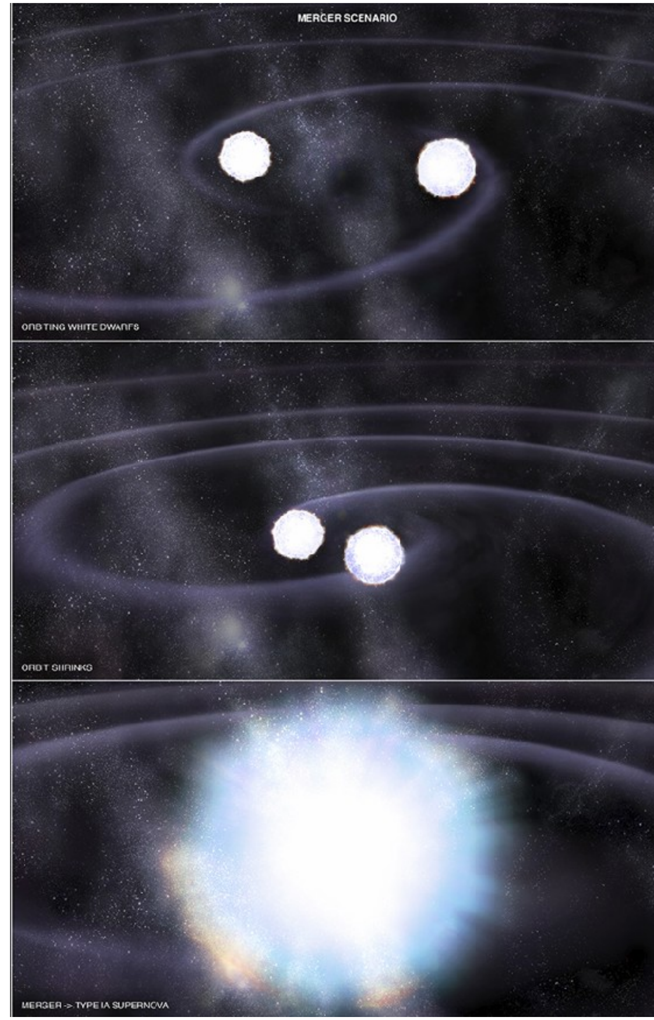
Explosion scenario

Single degenerate



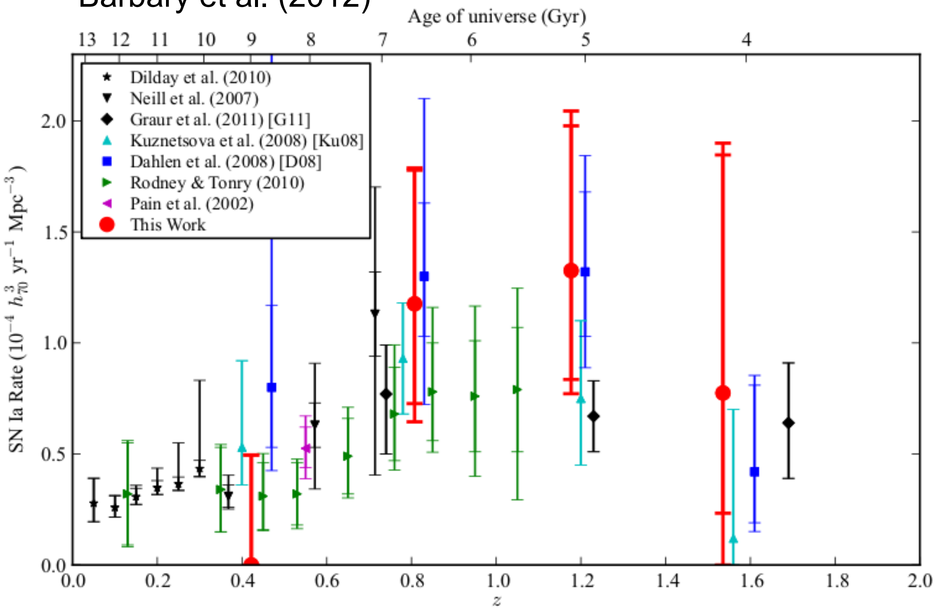
- Chemical composition – spectroscopy
- Delay-time distribution
- SN rate vs environment

Double degenerate



Delay time and rates

Supernova Cosmology Project
Barbary et al. (2012)



Try to catch SNe Ia as early as possible!

Kankare et al. (2008)

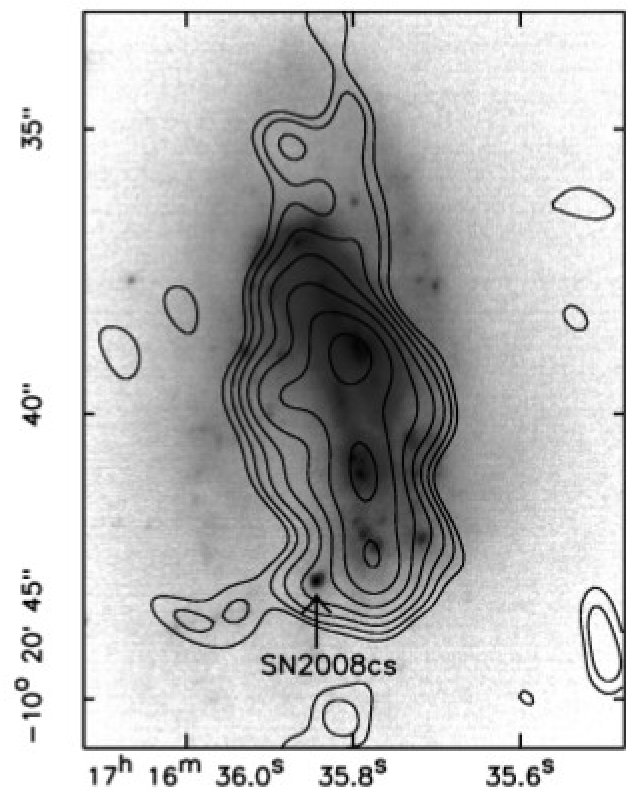
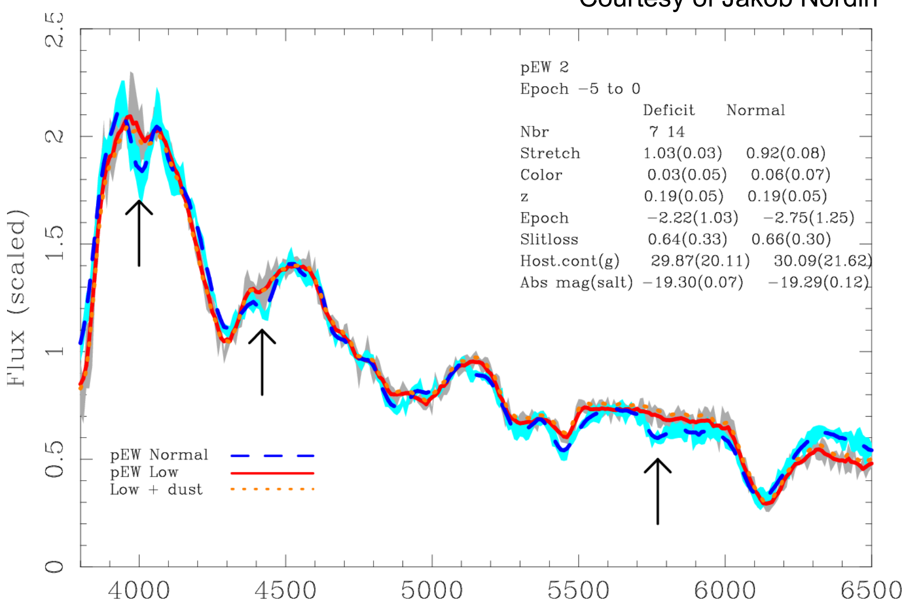
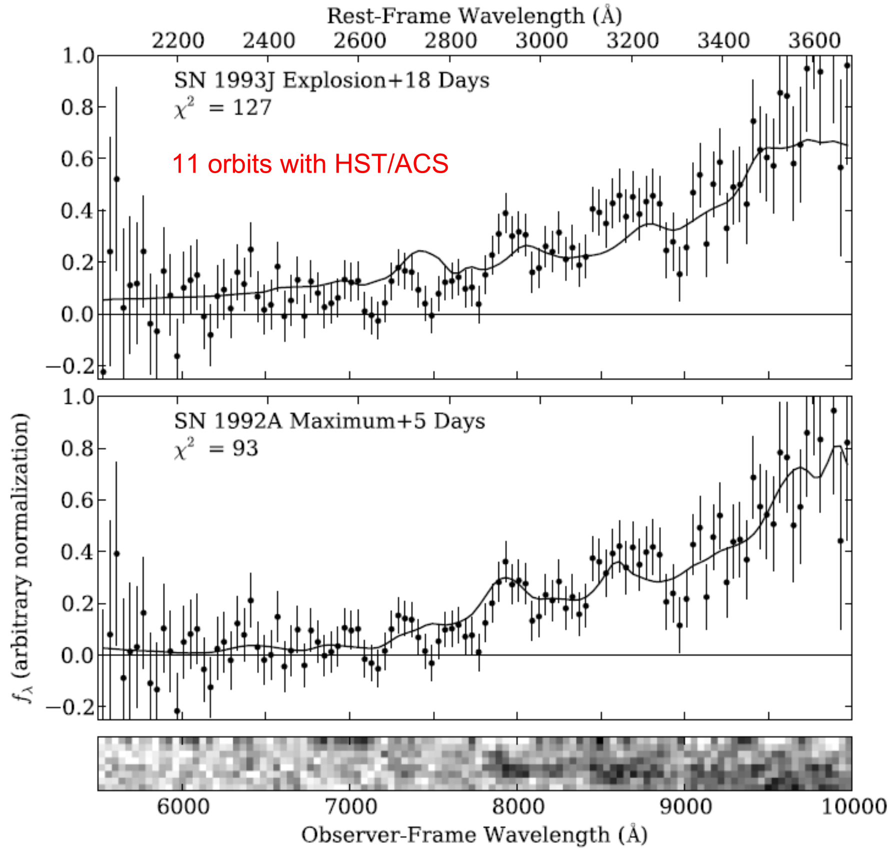


FIG. 4.—*K*-band Gemini ALTAIR/NIRI image from 2008 June 25 with 22.4 GHz VLA-C contours from 2008 May 19 overlaid. [*See the electronic edition of the Journal for a color version of this figure.*]

Evolution?

Courtesy of Jakob Nordin

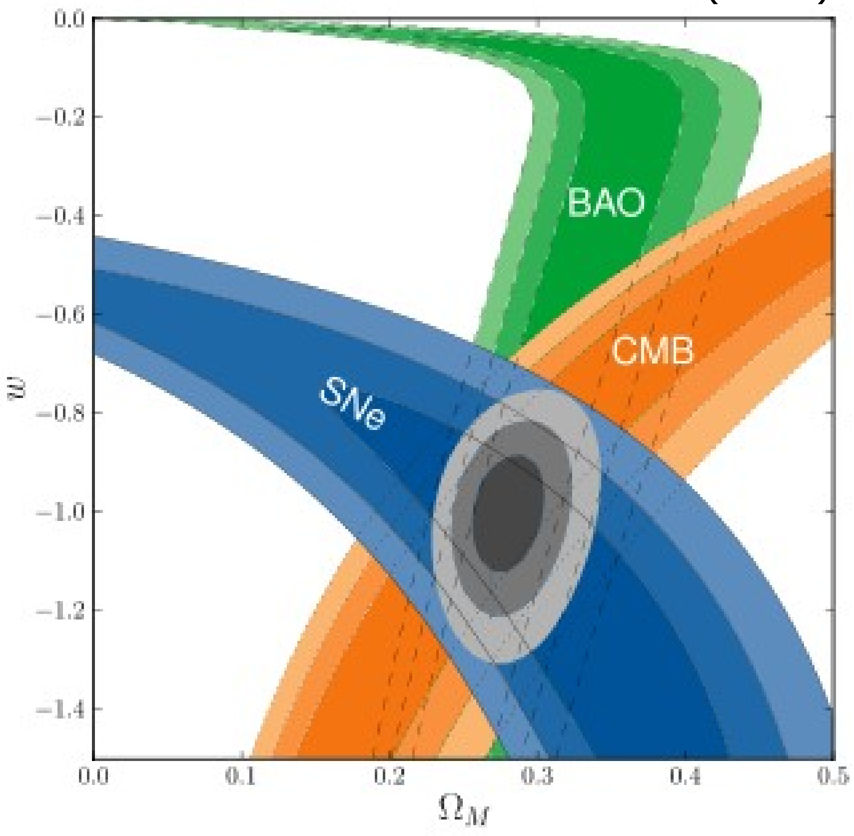




Rubin et al. (in prep.) SN SCP-0401 @ z = 1.72

Constraints on dark energy

Amanullah et al. (2010)



Assuming a time-independent *w* and a flat Universe.

$$w = -0.977^{+0.050(+0.077)}_{-0.054(-0.082)}$$

Pros and cons of SN cosmology

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Pros:

- Probes expansion rate directly
- Most mature technique today
- Up to now simple and cheap: acceleration was discovered using 2.5 – 4 m telescopes

Cons:

- Astrophysical uncertainties:
  - Brightness evolution
  - Dimming along the line of sight
- Future will require high instrumental accuracy

Systematics for the Union2 sample

Table 9

Effect on w Errorbar (including BAO and CMB constraints) for Each of the Systematic Errors Included

Source	Error on w
Zero point	0.037
Vega	0.042
Galactic extinction normalization	0.012
Rest-frame U-band	0.010
Contamination	0.021
Malmquist bias	0.026
Intergalactic extinction	0.012
Light-curve shape	0.009
Color correction	0.026
Quadrature sum (not used)	0.073
Summed in covariance matrix	0.063

Notes. The proper way to sum systematic errors is to include each error in a covariance matrix.

What do we mean by “magnitude”?

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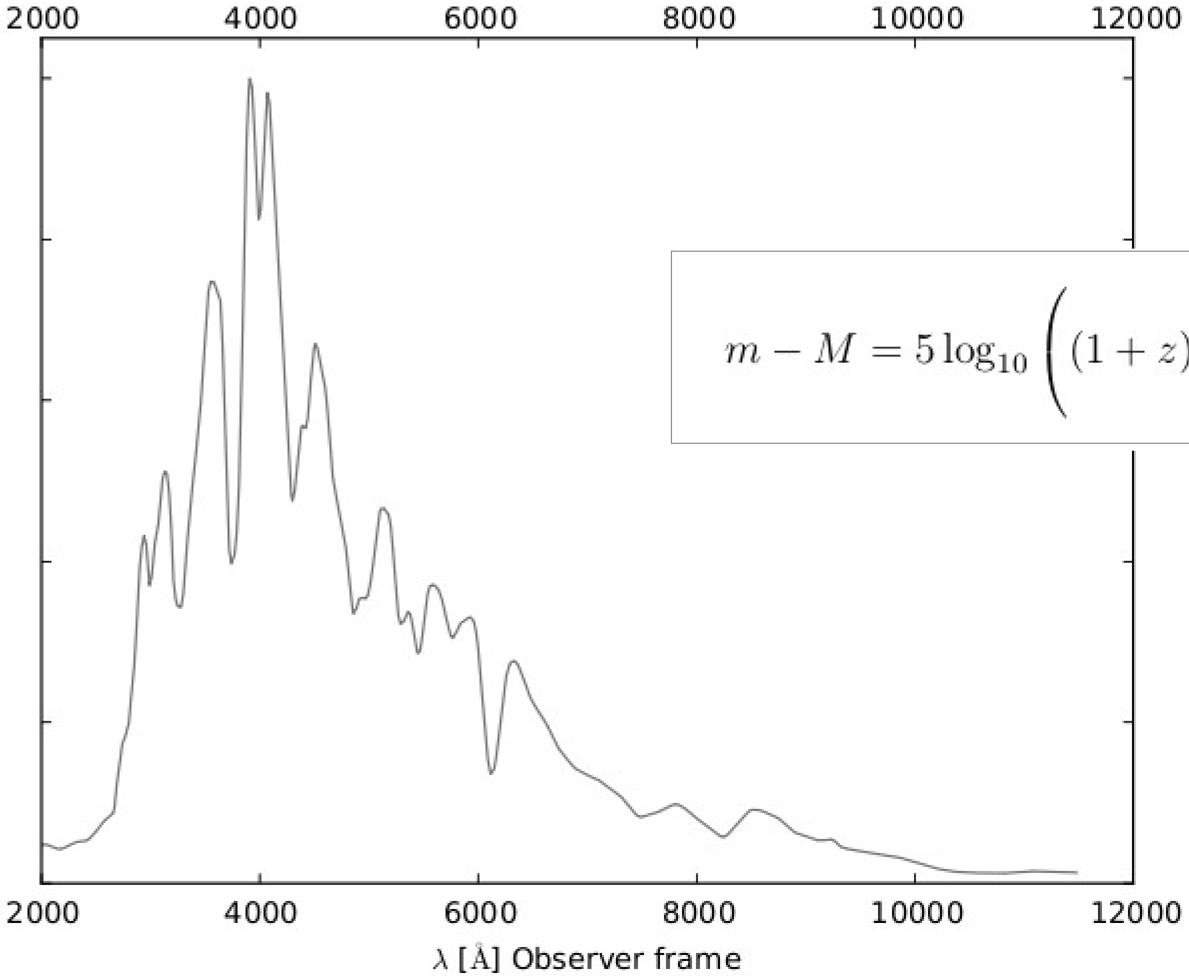
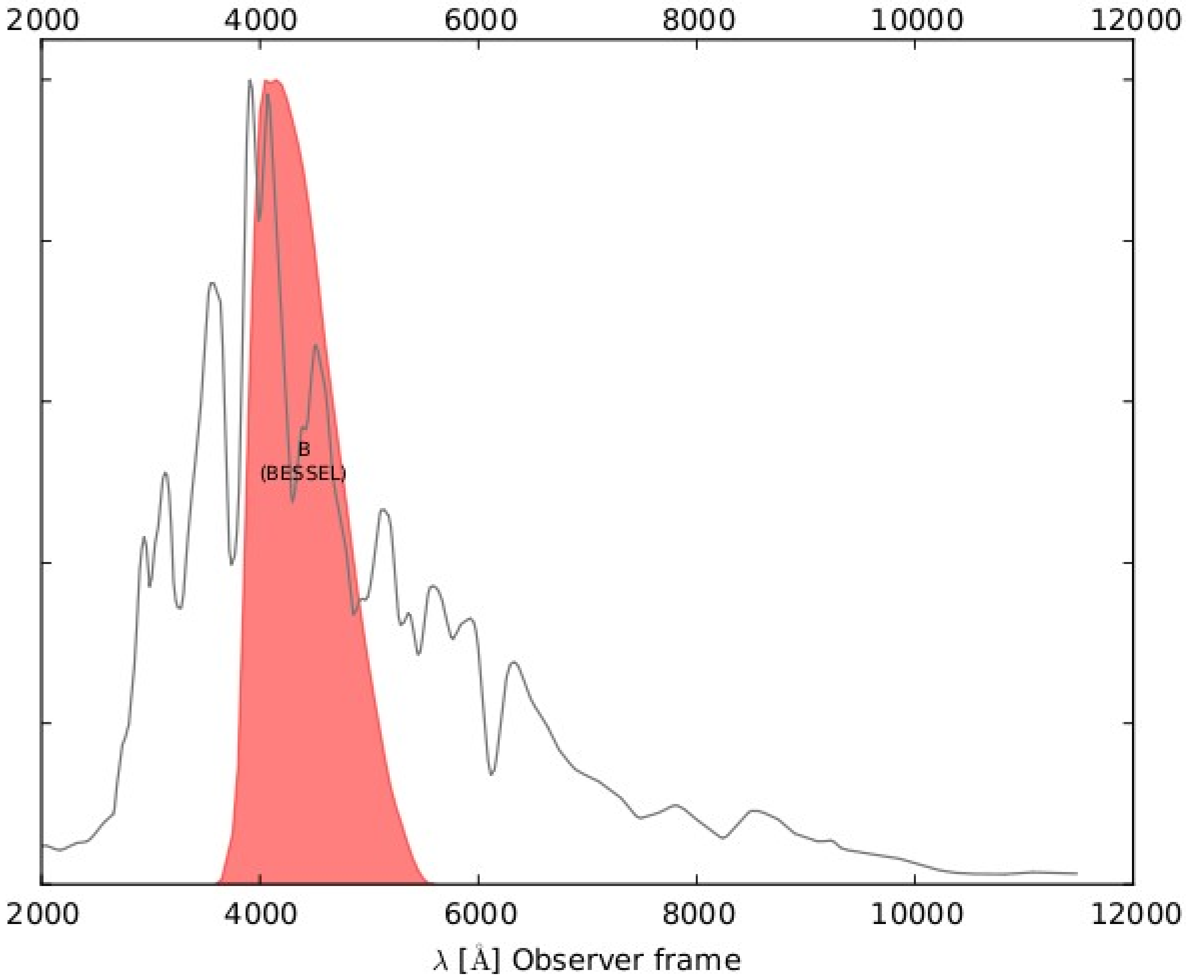
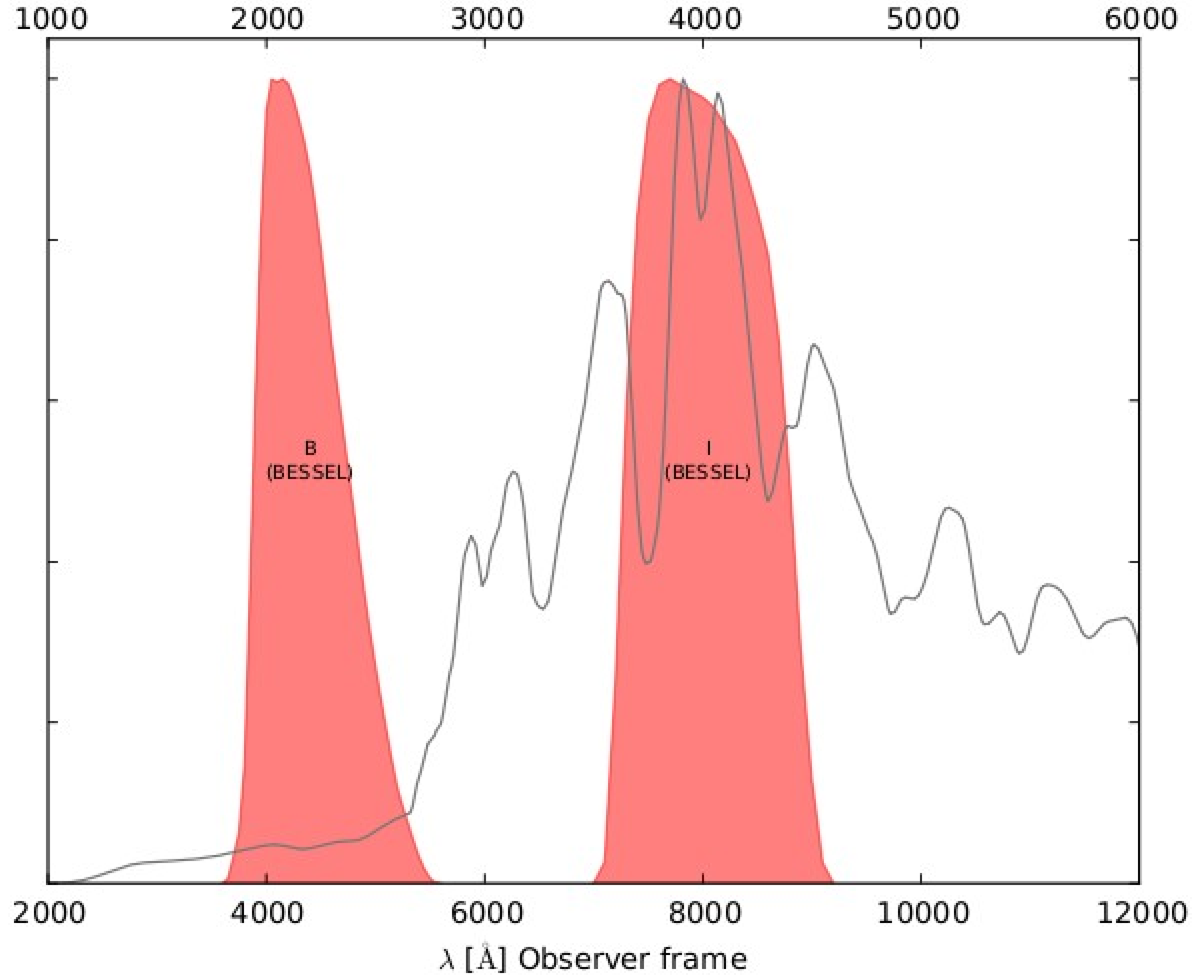


$$m - M = 5\log_{10}\left((1+z)\int_0^z \frac{dz'}{H(z')}\right) \quad \text{for} \quad k = 0$$

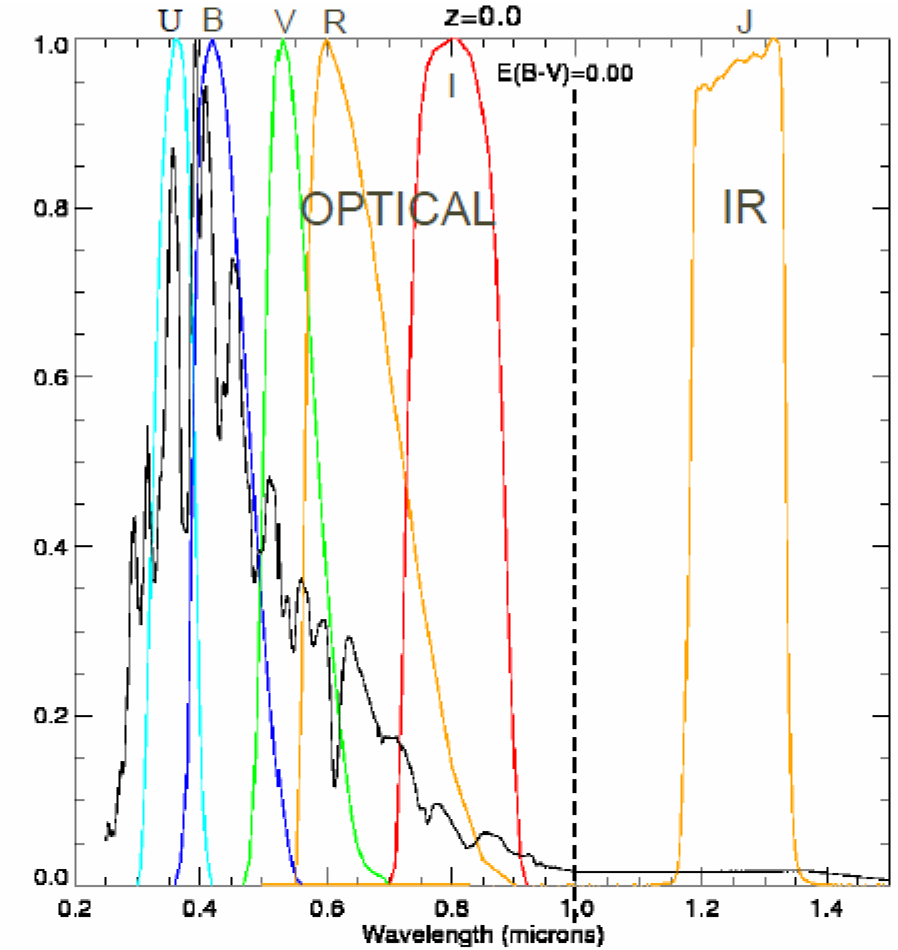
SN Ia at z = 0



SN Ia at z = 1


1000
2000
3000
4000
5000
6000
B
(BESSEL)
I
(BESSEL)
2000
4000
6000
8000
10000
12000
λ [Å] Observer frame

K-corrections



K-corrections are needed for comparing SNe observed at different redshifts.

•Assumption of the spectrum is needed
•Need to correct for dimming

SNe Ia are standard candles... sort of...

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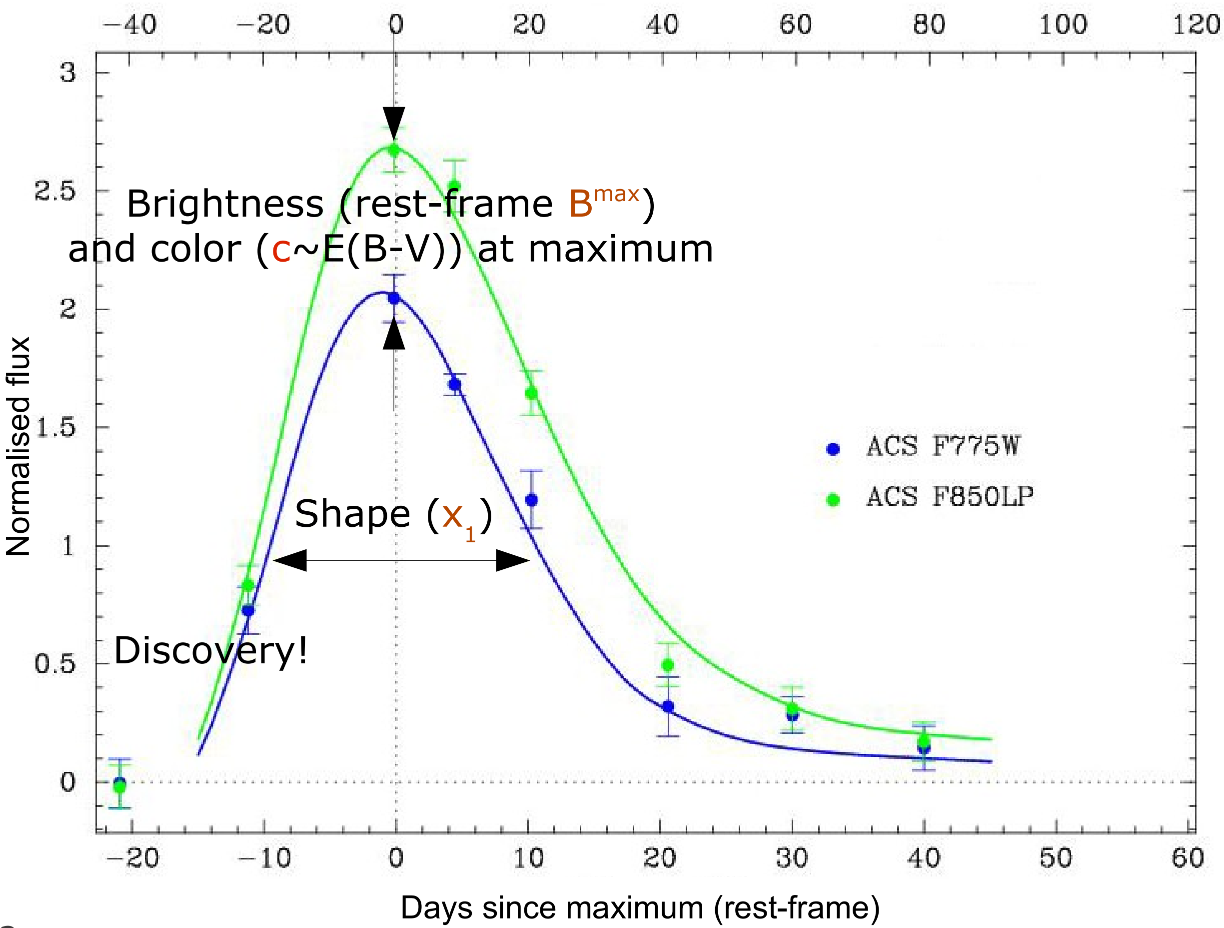
SN distance modulus	Cosmology

$$B^{\max} - \beta \cdot c + \alpha \cdot x_1 - M_B = 5\log_{10} d_L(\Omega_M, \Omega_X, w; z)$$



Measured SN properties

Fitted parameters

Fitted peak brightness can be color and light-curve shape corrected to form a standard candle that can be used for measuring relative cosmological distances.

Stretch and color

Phillips (1993)

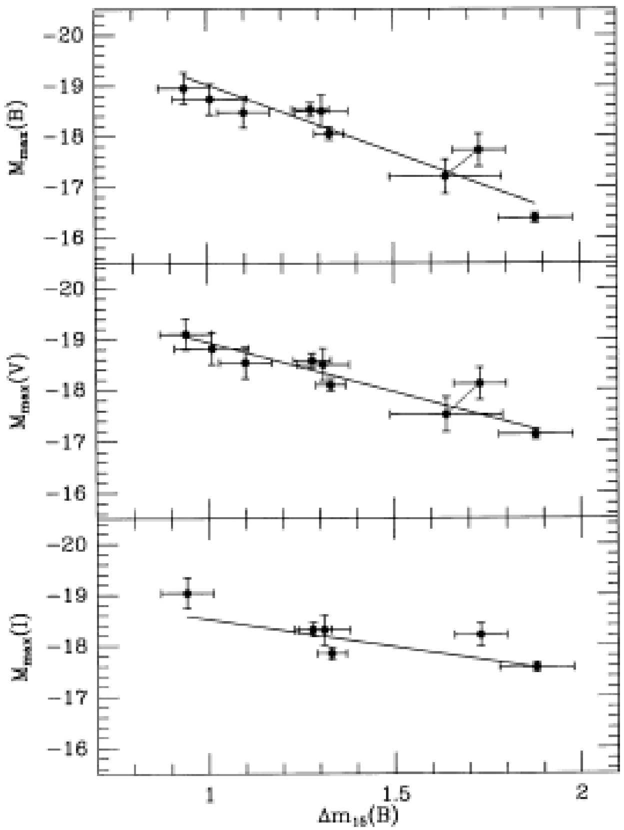
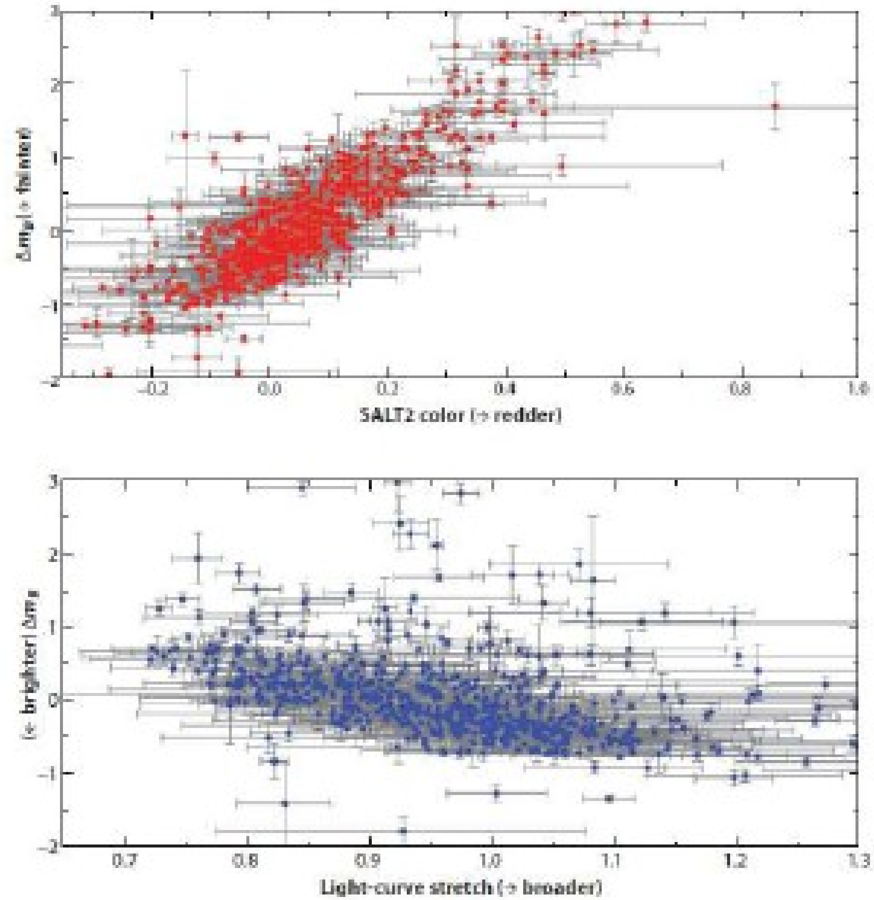


FIG. 1.—Decline rate–peak luminosity relation for the nine best-observed SN Ia's. Absolute magnitudes in B, V, and I are plotted vs. $\Delta m_{15}(B)$, which measures the amount in magnitudes that the B light curve drops during the first 15 days following maximum.



Goobar & Leibundgut (2011)

Selection effects

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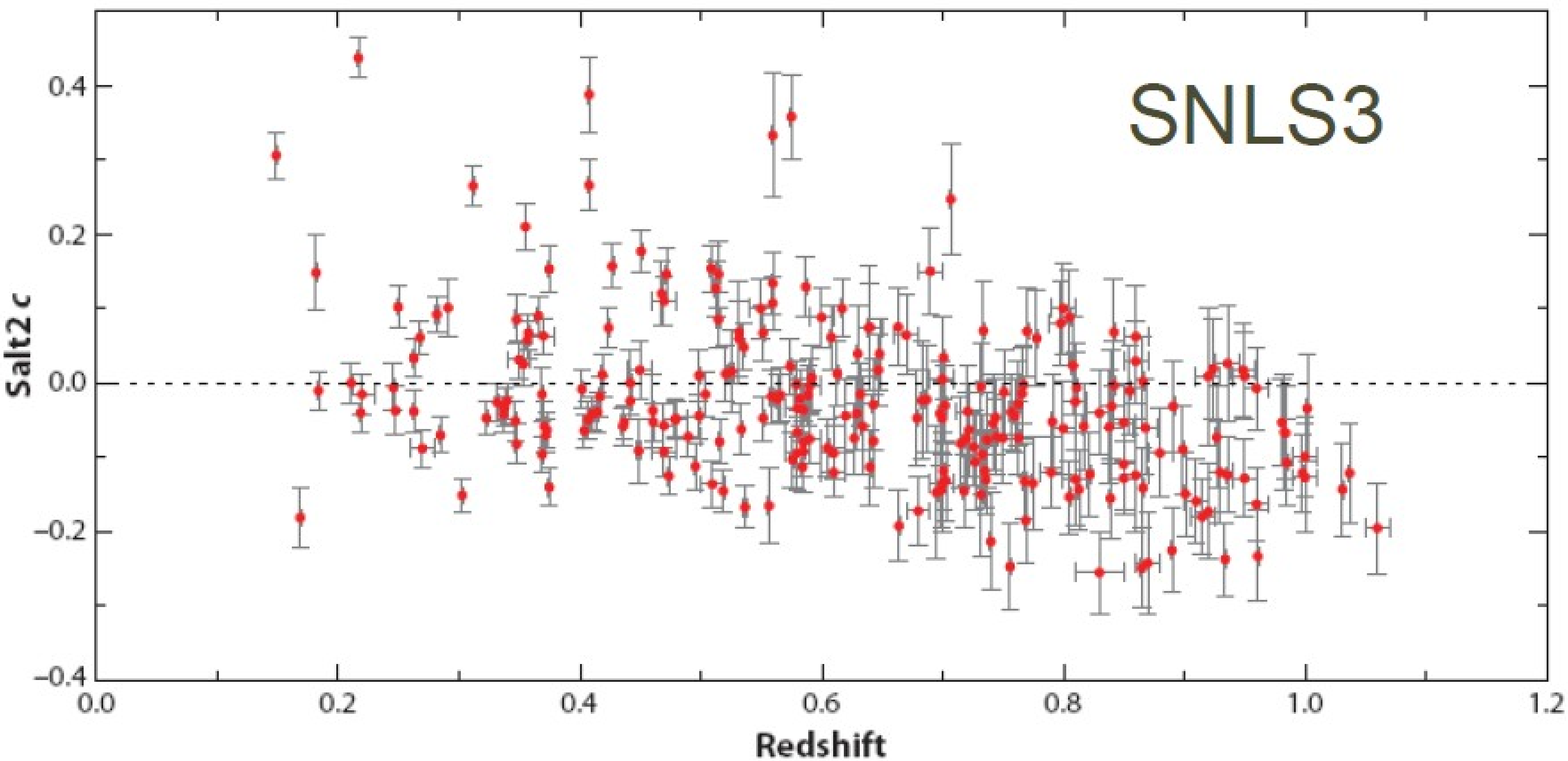
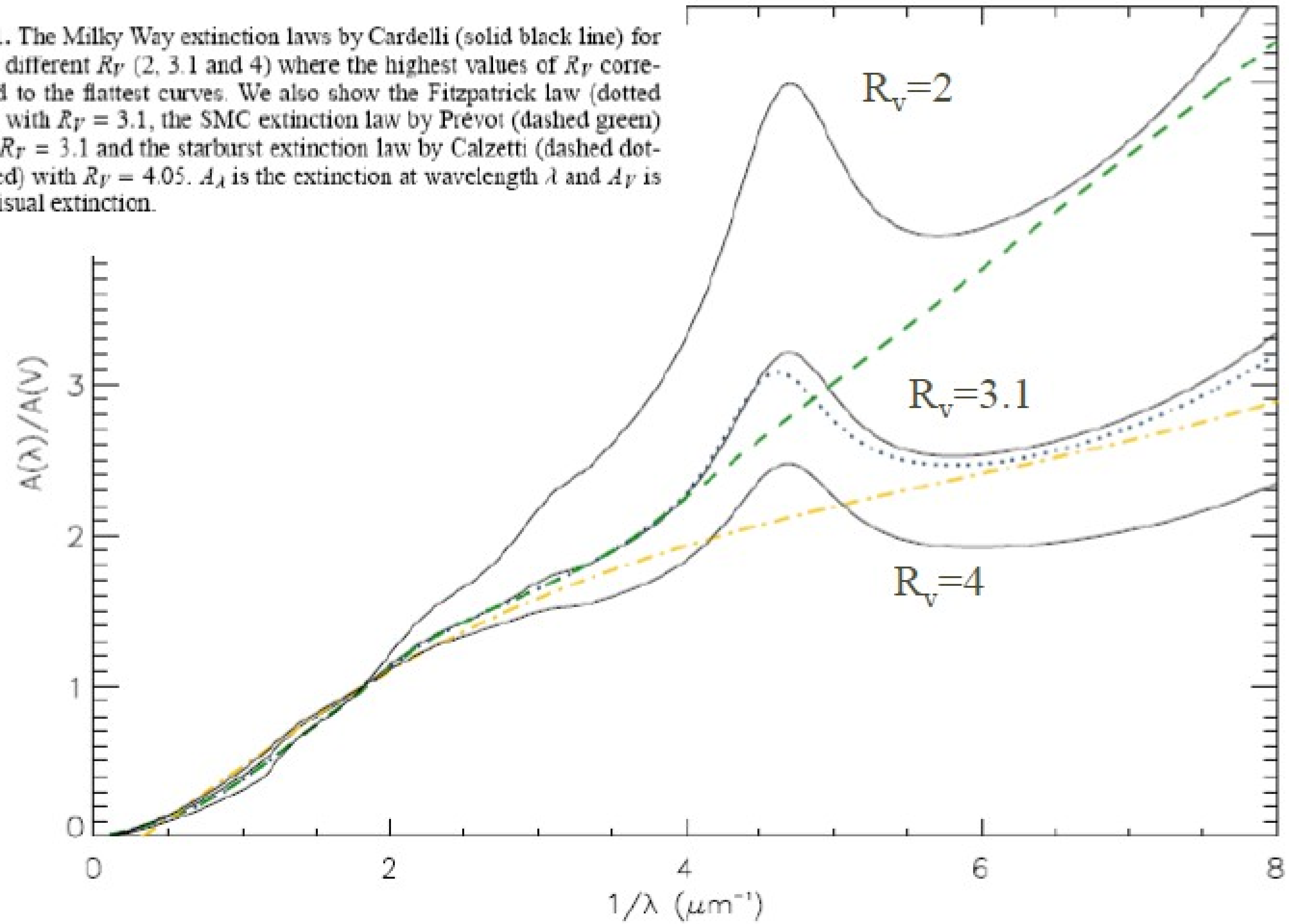
Goobar & Leibundgut (2011)



Extinction laws $R_V \sim \beta - 1$

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.



What is causing the reddening?

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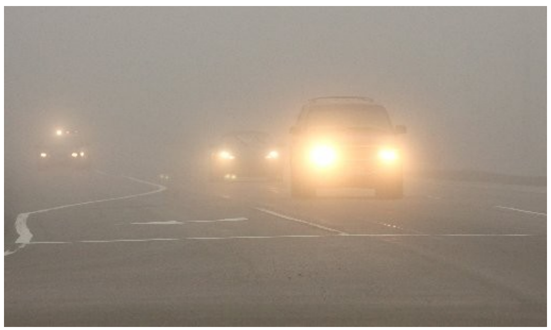
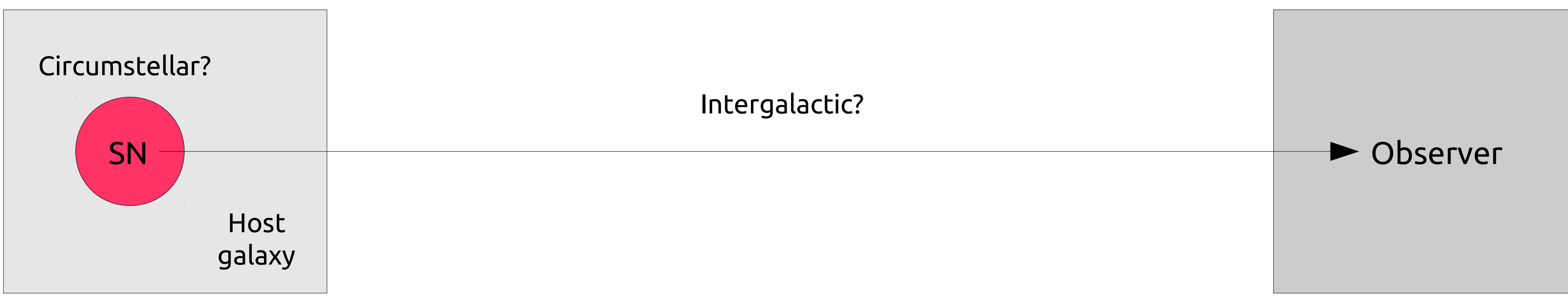
Extinction?	Intrinsic variations?	Perhaps it is a Combination of both...?





Different sources of reddening?

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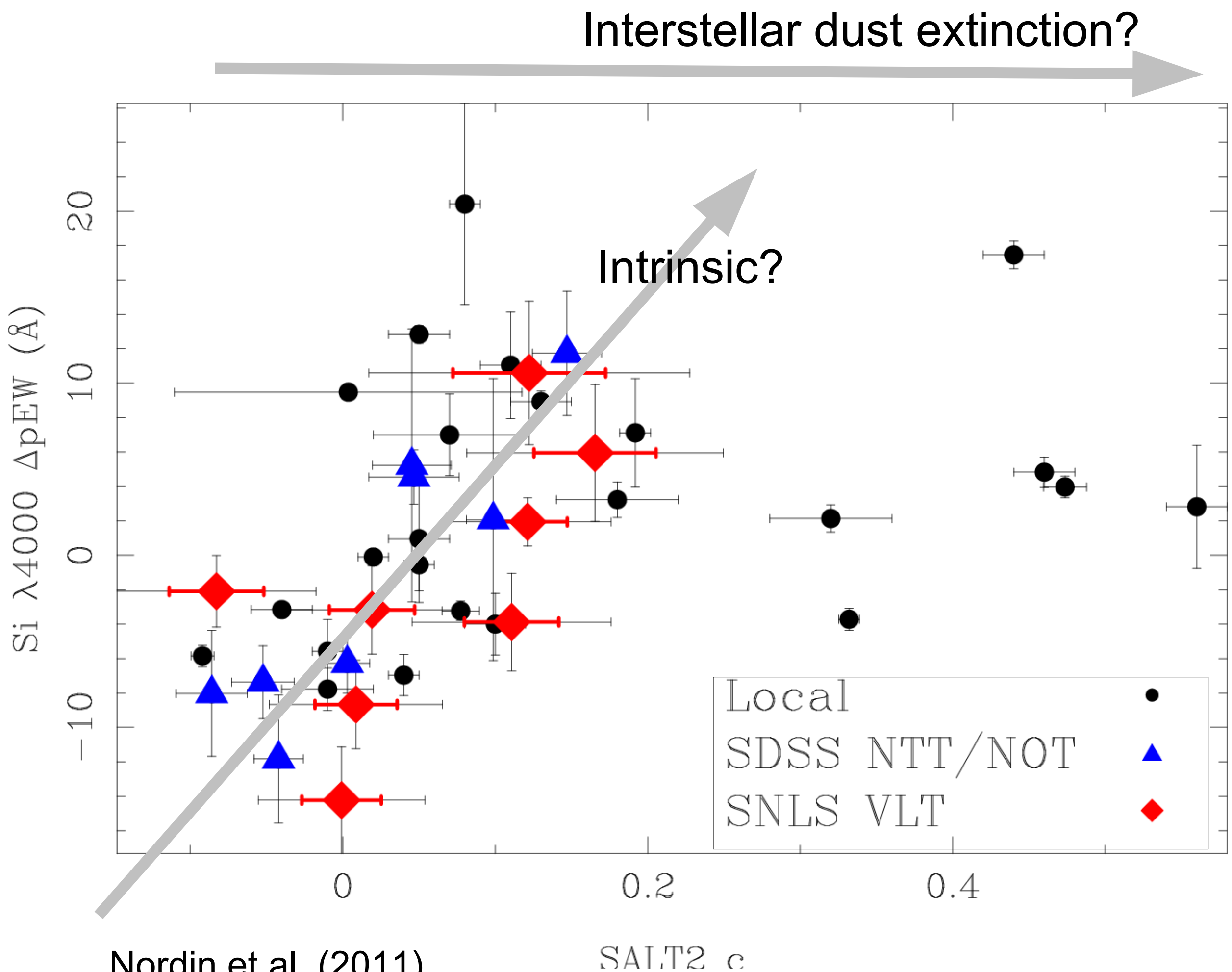
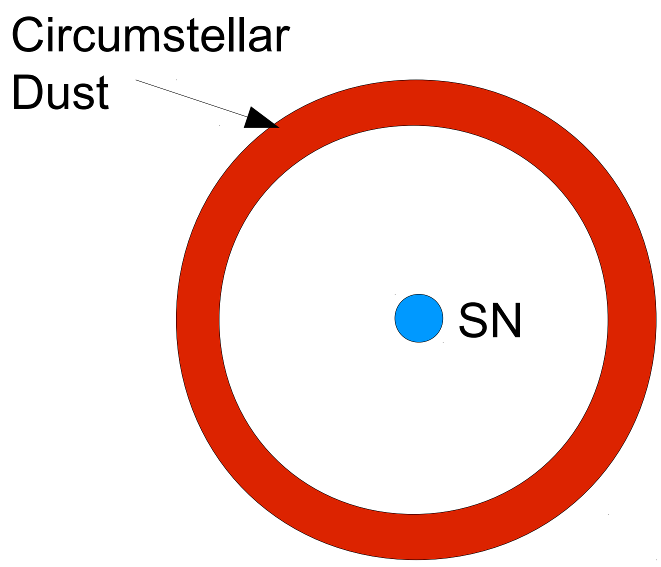


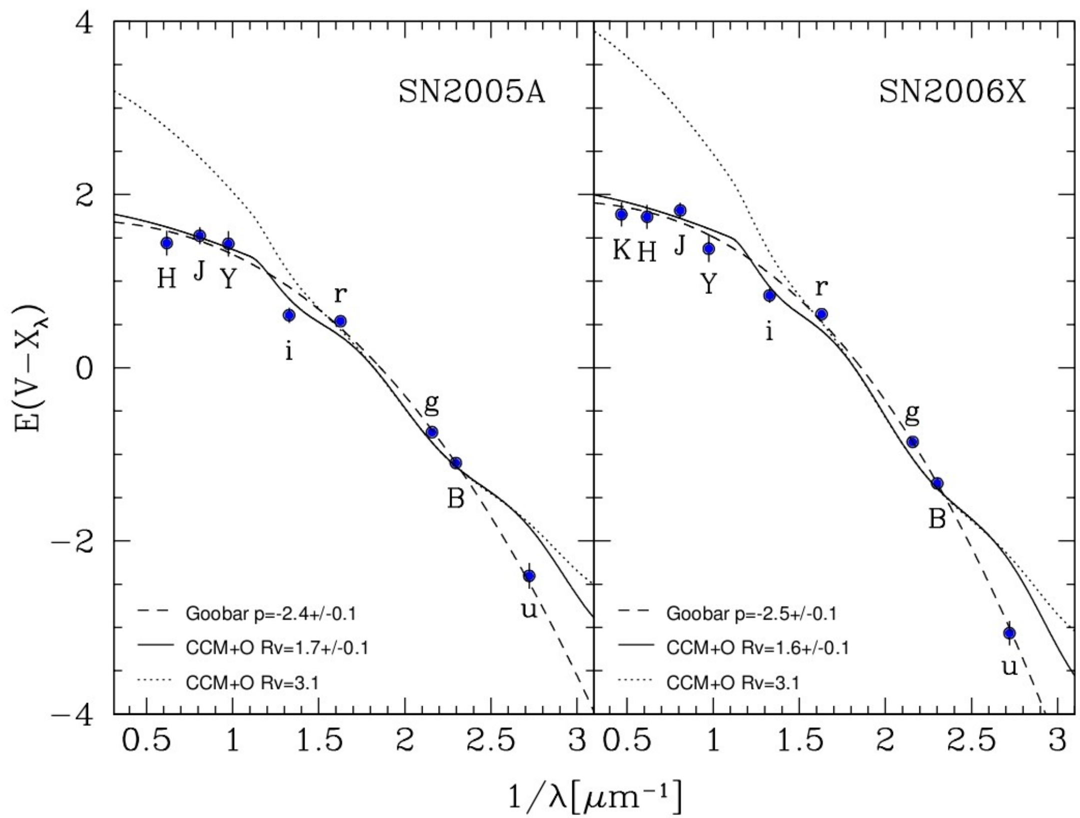
Nordin et al. (2011)

Circumstellar Dust

Could CS dust explain SN colours (Wang 2005, Goobar, 2008)?



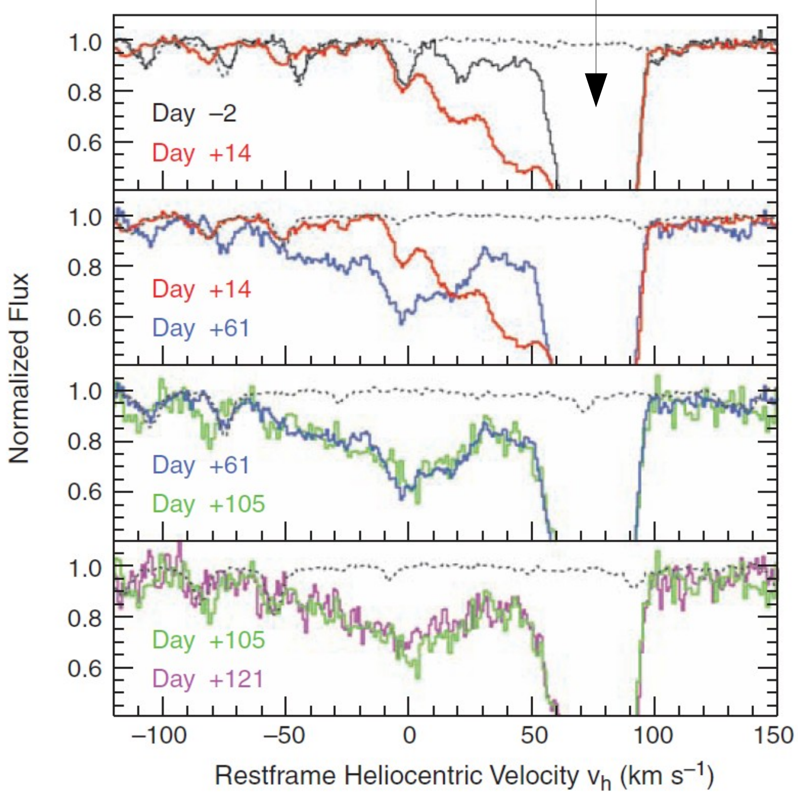
Folatelli et al. (2010)



Na I D in 2006X

Host

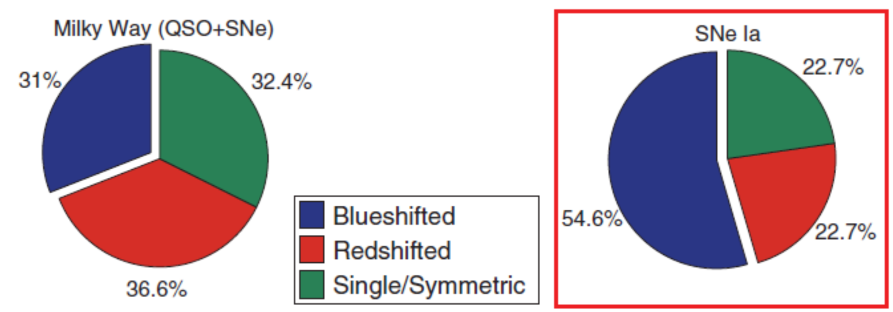
Patat et al. (2008)



Sternberg et al. (2011)

Table 1. Classification of absorption features.

Sample	Blueshifted	Redshifted	Single/Symmetric	Total
SNe Ia	12 [16]	5 [6]	5 [6]	22 [28]
CC SNe	4 [8]	3 [5]	2 [3]	9 [16]
MW (SNe)	12 [13]	13 [16]	17 [22]	42 [51]
MW (QSO)	10	13	6	29
MW (QSO+SNe)	22 [23]	26 [29]	23 [28]	71 [80]



Reddening vs ejecta velocity?

Wang et al. (2009)

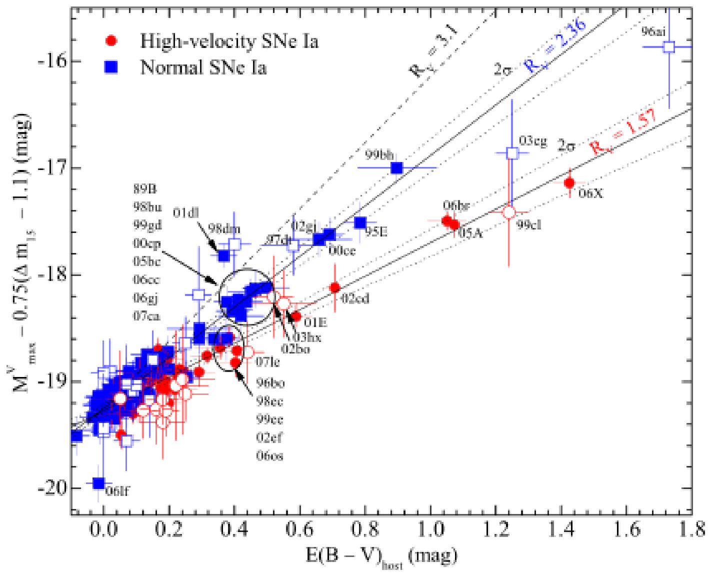
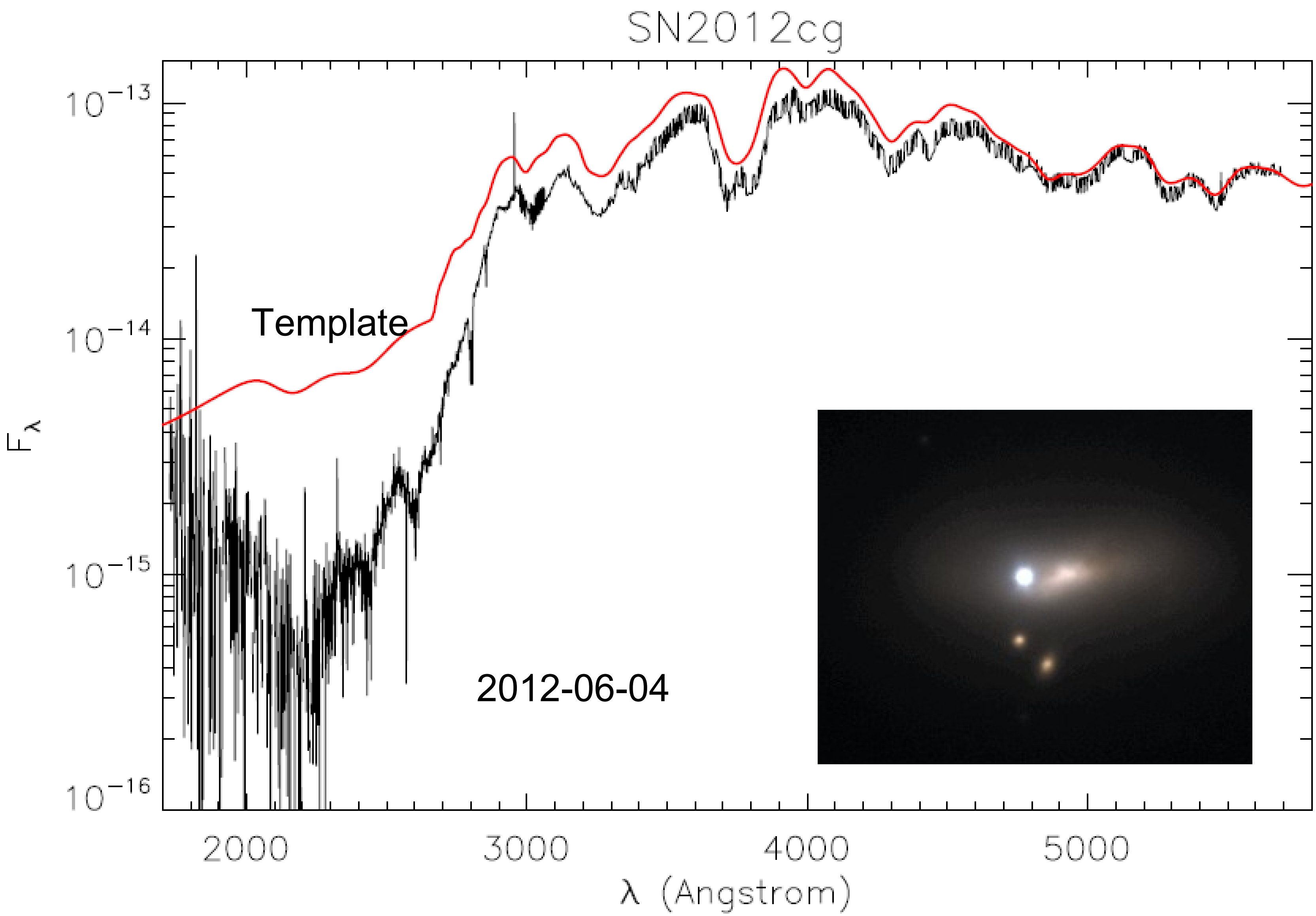


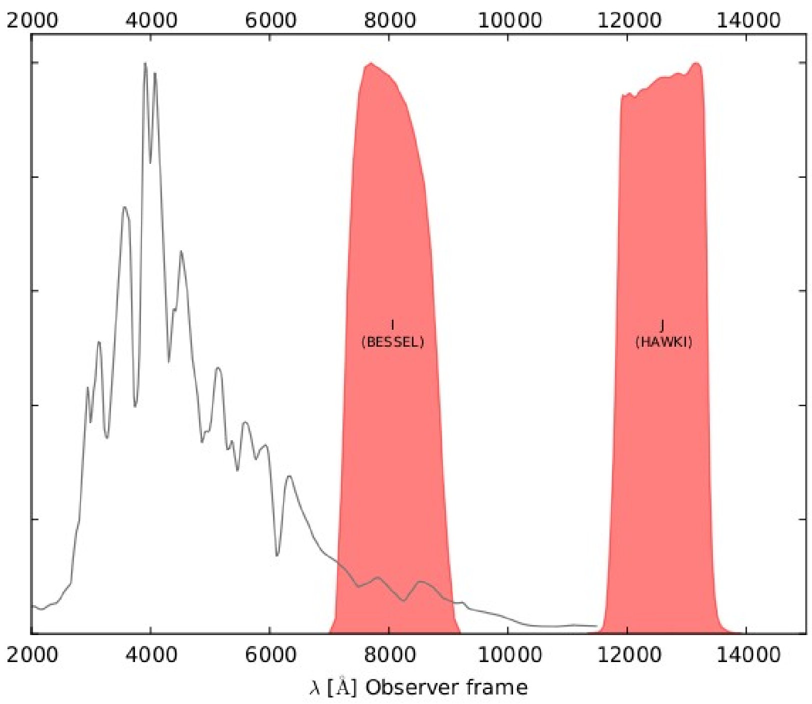
Figure 4. Δm_{15}-corrected absolute V mag at maximum brightness vs. the host-galaxy reddening. The filled symbols are SNe with $z \gtrsim 0.01$ or Cepheid-based distances, and the open symbols are nearby objects that were not included in the fit. The two solid lines show the best-fit R_V for SNe in the HV and Normal groups, with dotted lines indicating 2σ uncertainties. The dashed line represents the Milky Way reddening law.

How do we solve this mystery?



UV – NIR data are called for!

Can we circumvent the problem?



Freedman et al. (2009)

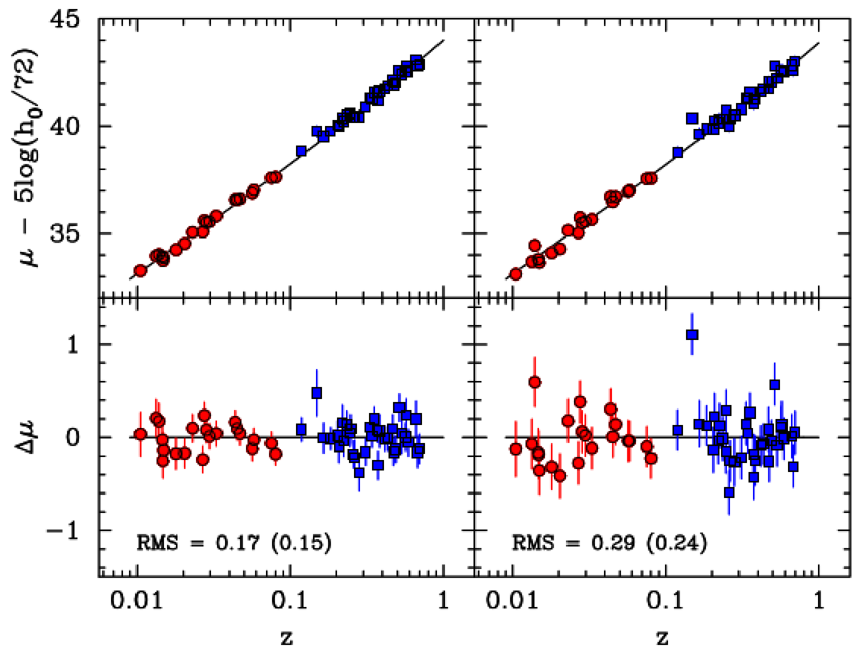
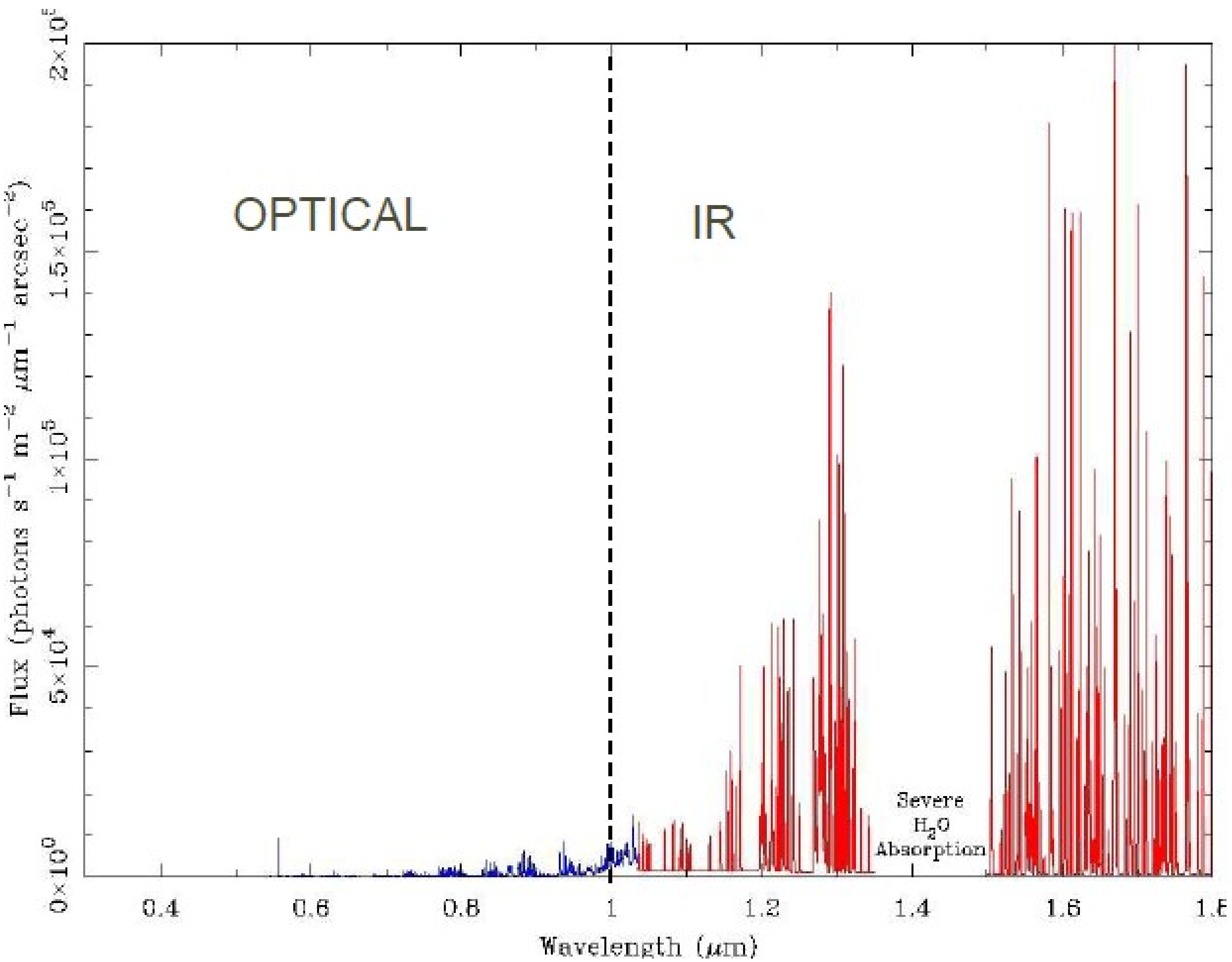


Figure 14. Top panel: *i*- and *B*-band Hubble diagrams for 21 low-redshift and 35 high-redshift SNe Ia from the CSP, *uncorrected for reddening*. Bottom panel: the residuals about the best fit to these data. The values for rms scatter about the best fit to these data are labeled. The rms value in brackets excludes the most discrepant (highly reddened) SNLS 05D1hn.

(A color version of this figure is available in the online journal.)

Atmospheric emission



SN properties vs host properties

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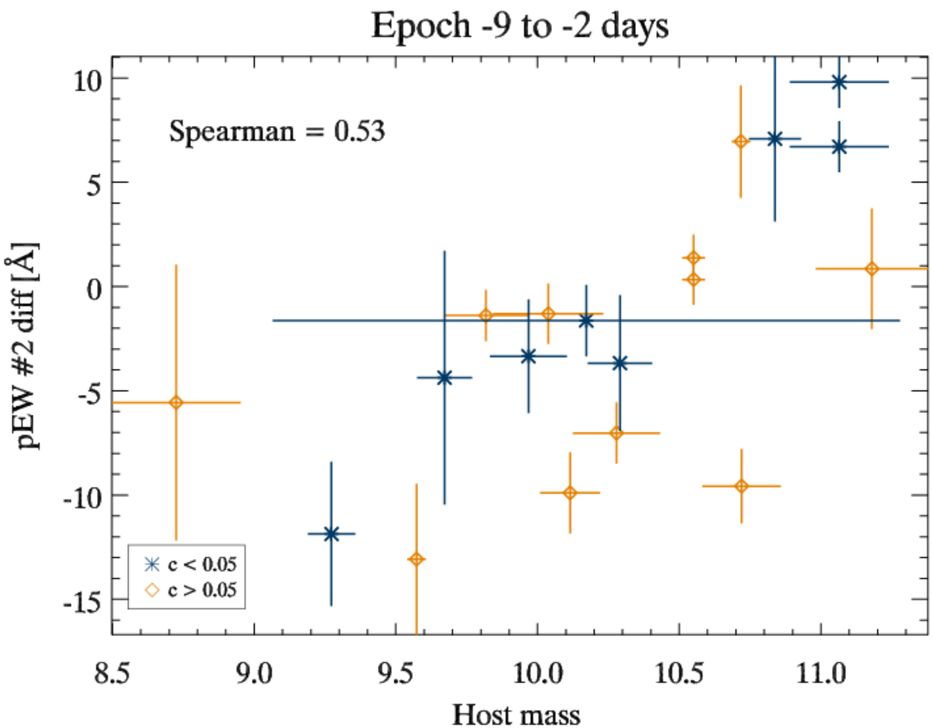
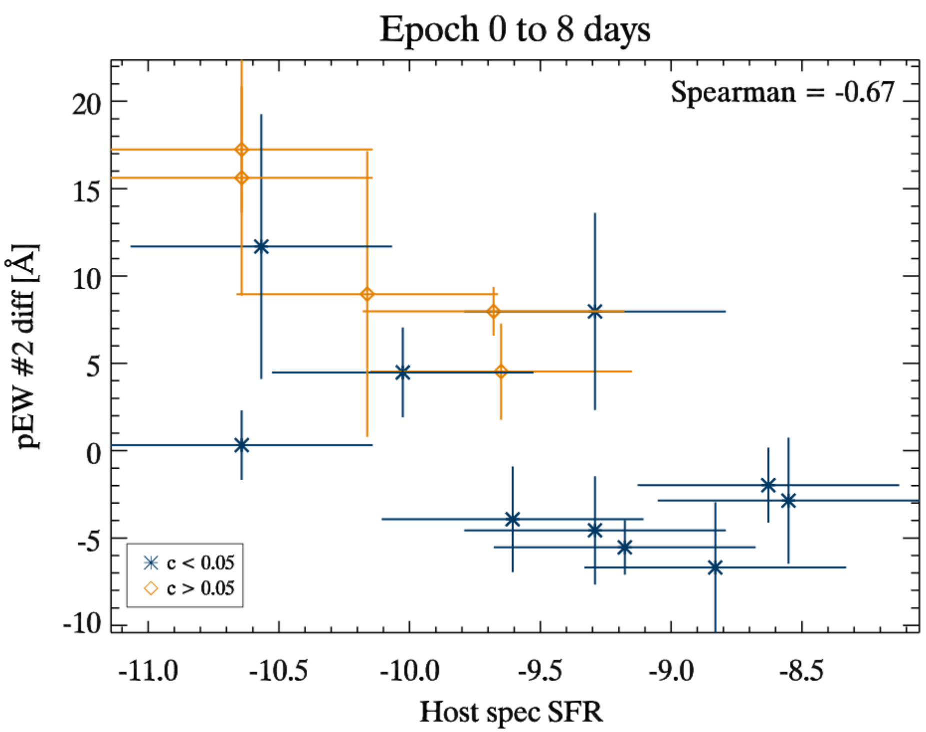




Nordin et al. (2011)

Host evolution

SN brightness depends on the host galaxy mass!
Kelly et al. (2010), Sullivan et al. (2010), Lampeitl et al. (2010)

Higher host mass – brighter SN

The low-z sample has a are hosted by more massive galaxies than the high-z data

But now we are correcting for this (Conley et al., 2011 and Suzuki et al., 2012)

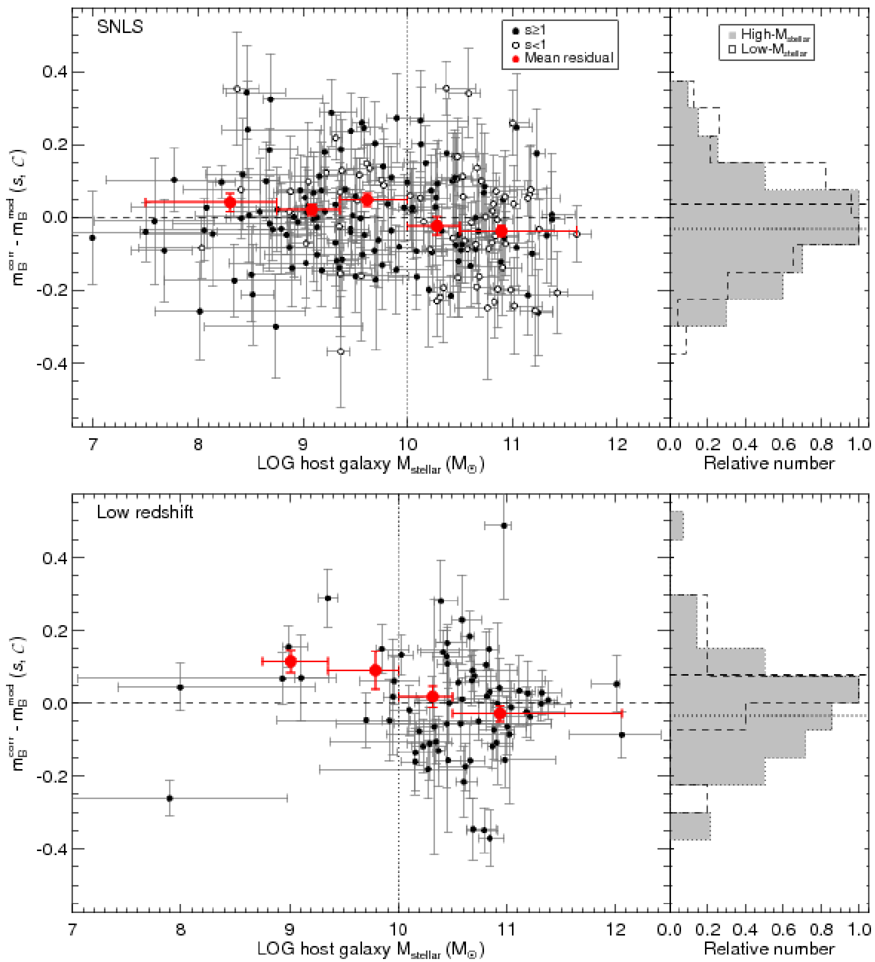


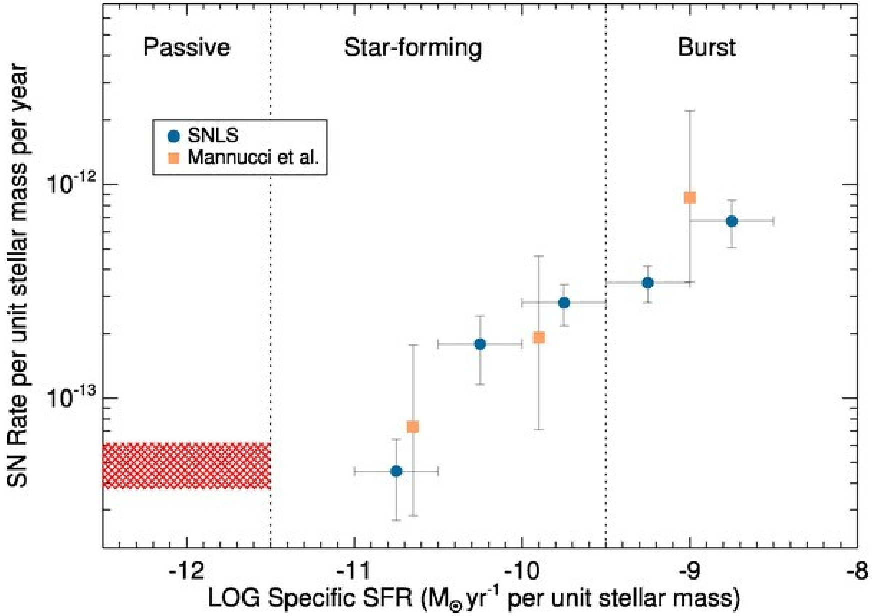
Figure 4. As Fig.3, but for $M_{\rm stellar}$ instead of sSFR.

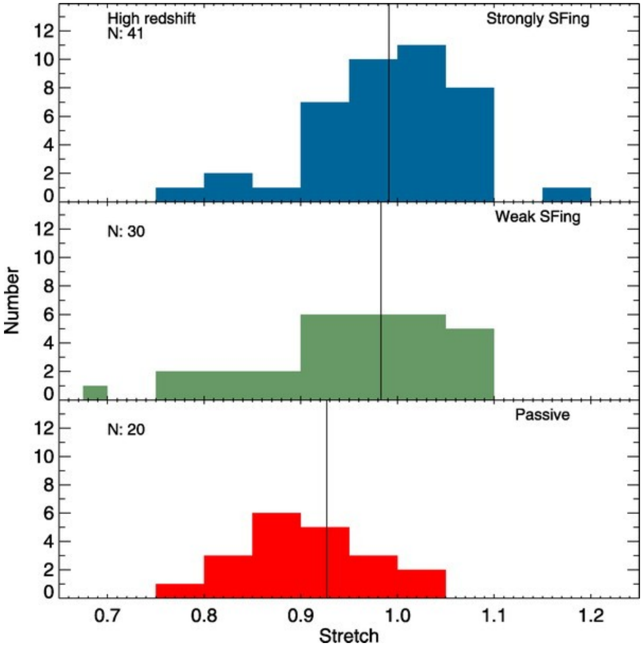
Sullivan et al. (2010)

The SN Ia host environment

Red vs blue galaxies

Sullivan et al. (2006)





Choose a special environment!

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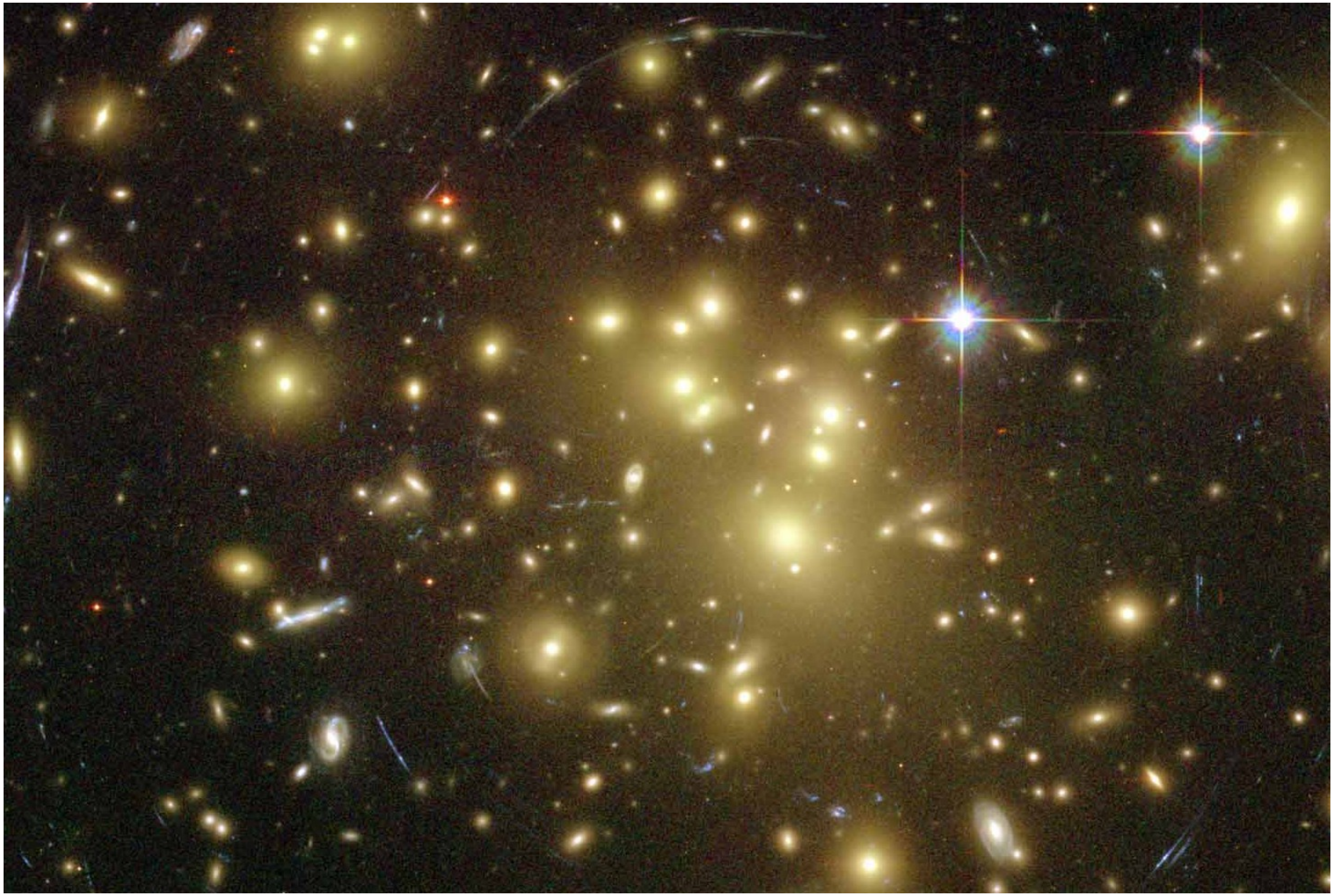

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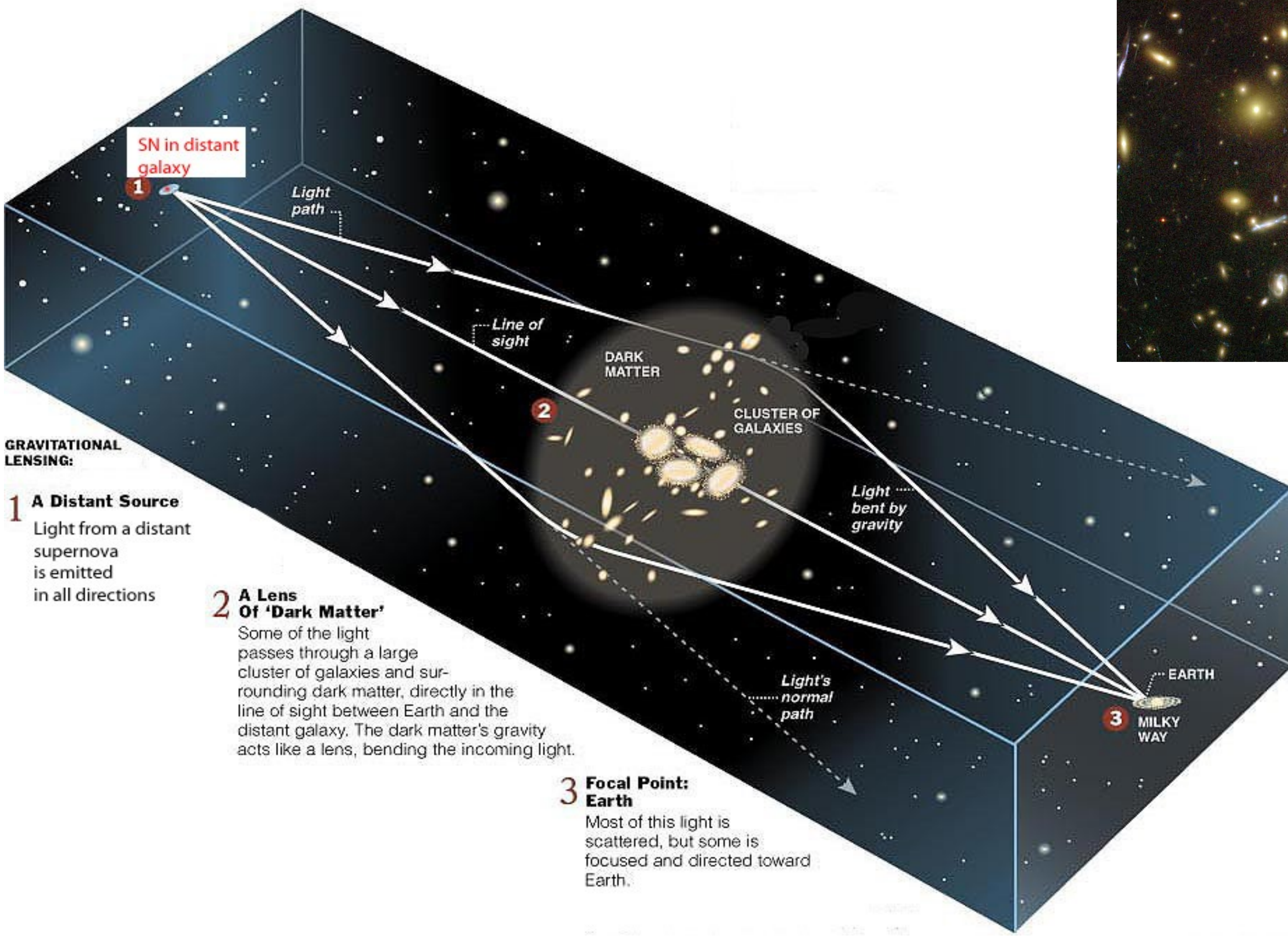
Observing the unobservable

Observer

Lens

Object

Using massive galaxy clusters as natural telescopes



The Refsdal method (MNRAS, 1966)

Primarily the Hubble constant, but also DE!

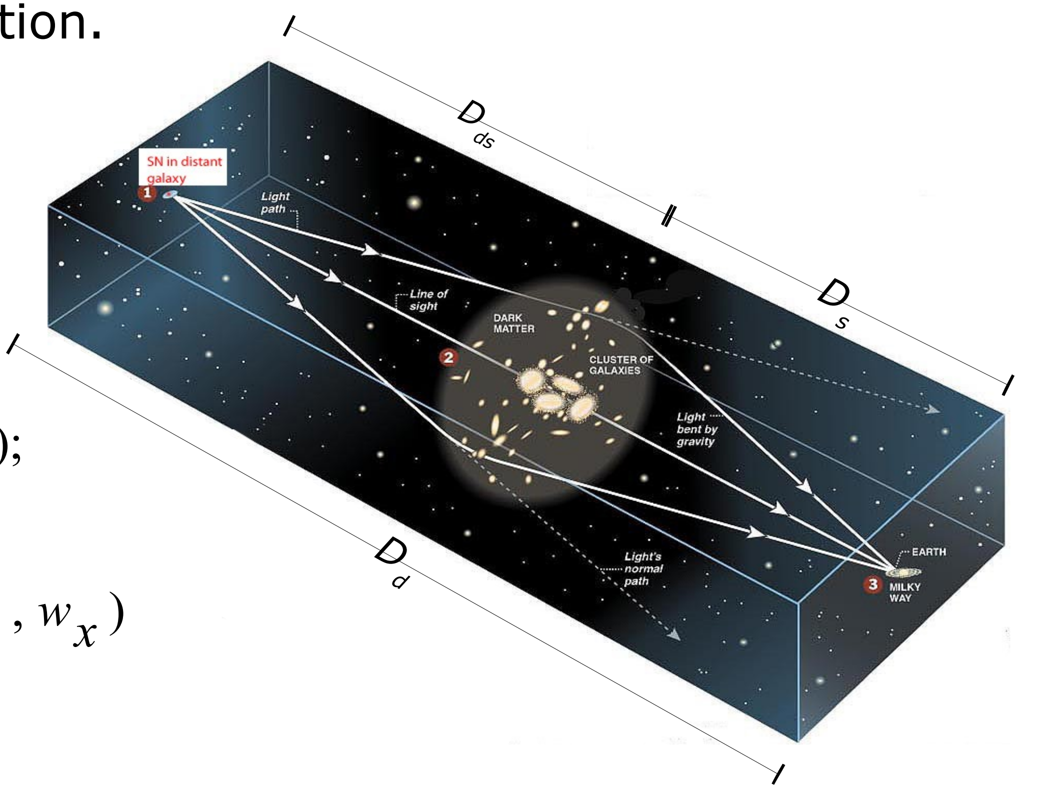
or... cluster mass distribution.

In the event of a strongly multiply lensed SN.

Measure!

$$\Delta t = \frac{\Delta\theta^2}{2} \frac{D_d D_s}{D_{ds}} \left(1+z_d\right) f(r_{flux});$$

$$D_{ij} = D_{ij}(z_i, z_j; H_0, \Omega_M, \Omega_X, w_x)$$



Future surveys

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Ground (optical)

PanSTARRS (2010-2015) 4 x 1.8-meter/ 3 sq.deg; ~5000 SN z<1

DES (2012-2016): 4-meter/ 3 sq.deg; ~3000 SN z<1

LSST (2020?): 8-meter/ 9 sq.deg; ~250000 SN z<1 /yr (!)

Limited spectroscopic follow-up

+ Low-z surveys: SNFactory, PTF, CSP; SkyMapper,...

+ Next generation of 30-40 m telescopes for spectroscopic follow-up

Space (2018+?)

JWST (6.5-meter / 4 sq.arcmin, i.e not really wide field)

WFIRST? (NASA), EUCLID (ESA):1.2 - 1.5-meter class telescopes,

Currently porposed SN survey in Euclid not suitable for DE.

Learn more

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Ariel Goobar and Bruno Leibundgut

Supernova Cosmology: Legacy and Future

Annual Review of Nuclear and Particle Science

Vol. 61: 251-279 (Volume publication date November 2011) DOI: 10.1146

Good luck with SN2012cg!