Addressing astrophysical systematics in SNe Ia cosmology: reddening and evolution

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The Oskar Klein Centre

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Cook's Branch Meeting on "Supernova Cosmology and Looking into the Future"


Stockholm this morning…

Reddening and dimming of SNe Ia

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a) Dust

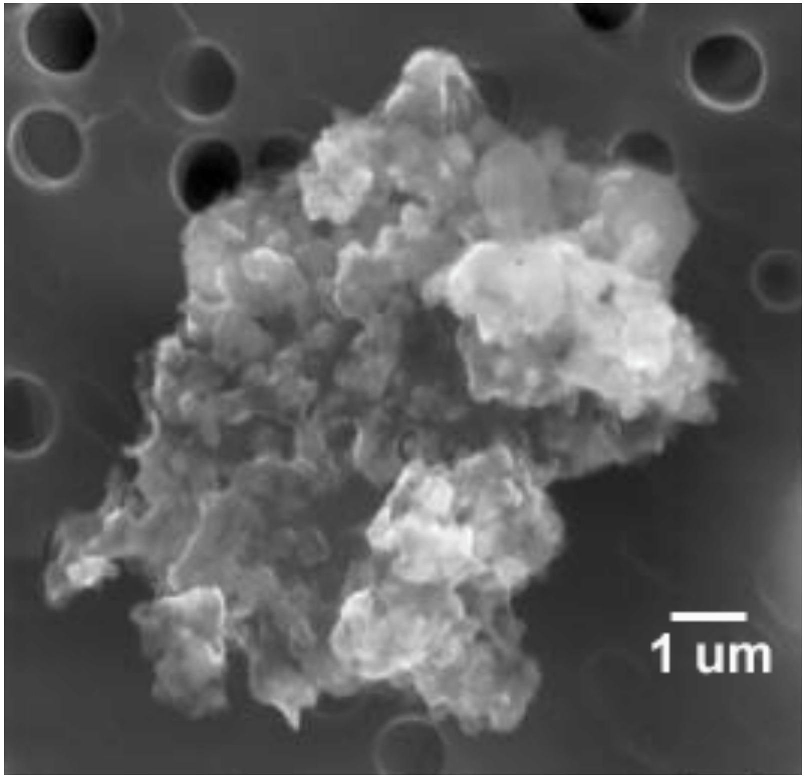
Milky Way ✓

This talk

Host galaxy interstellar medium

Intergalactic medium?

Circumstellar medium?

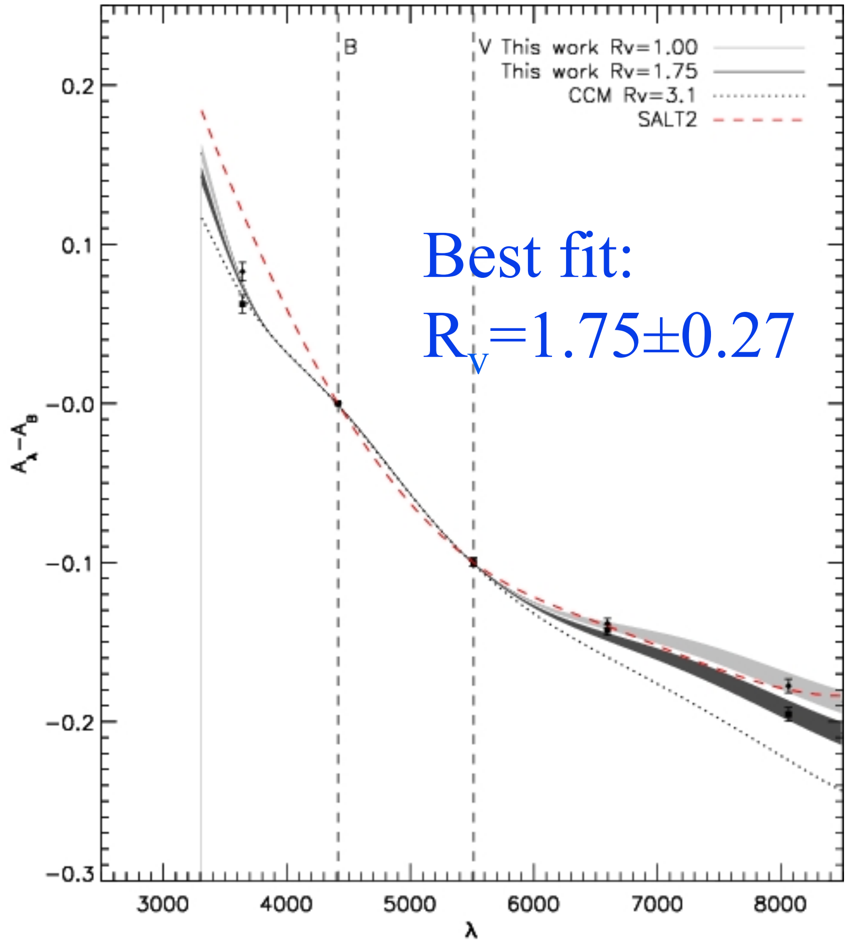


b) SN physics

Intrinsic color-brightness relation. Evidence in e.g. Wang et al 2009, Nordin et al 2011, Foley et al 2012,…

PS: Attenuation by excitation and ionization of atoms negligible in optical and NIR.

Low R_V no matter how you look…



Nobili & Goobar (2008)

Re-evaluated intrinsic colors of near-by SNe, e.g. dependence on stretch, and found that a consistent picture emerged for R_V~1.7

A few years earlier I had been to Berkeley and gave a talk showing that I could get a tighter Hubble diagram from the Riess 04 data with very low R_V . Schlegel: There is no such dust!

Dust in intergalactic medium

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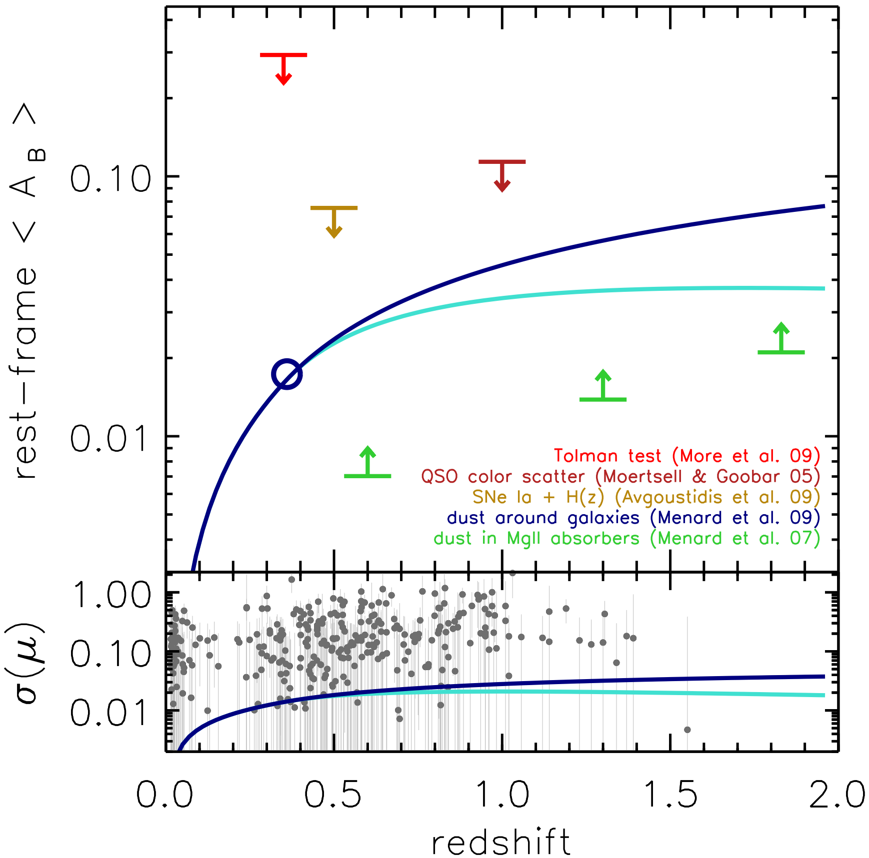

Issue for *high-precision* high-z cosmology

Negligible at low-z: not related to “low” R_v problem

Menard,Kilbinger & Scranton (2009)

Multiple scattering on dust around SNe?

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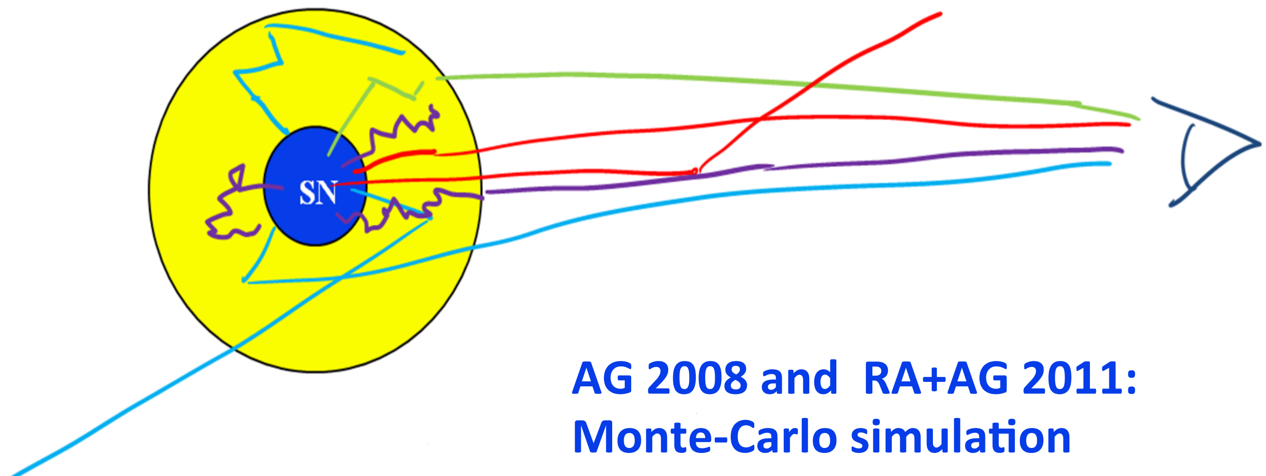
Observed colors after the semi-diffusive shell will depend on:

- **Wavelength dependent cross-sections, albedo and scattering angles**
- **Dust density and shell volume**

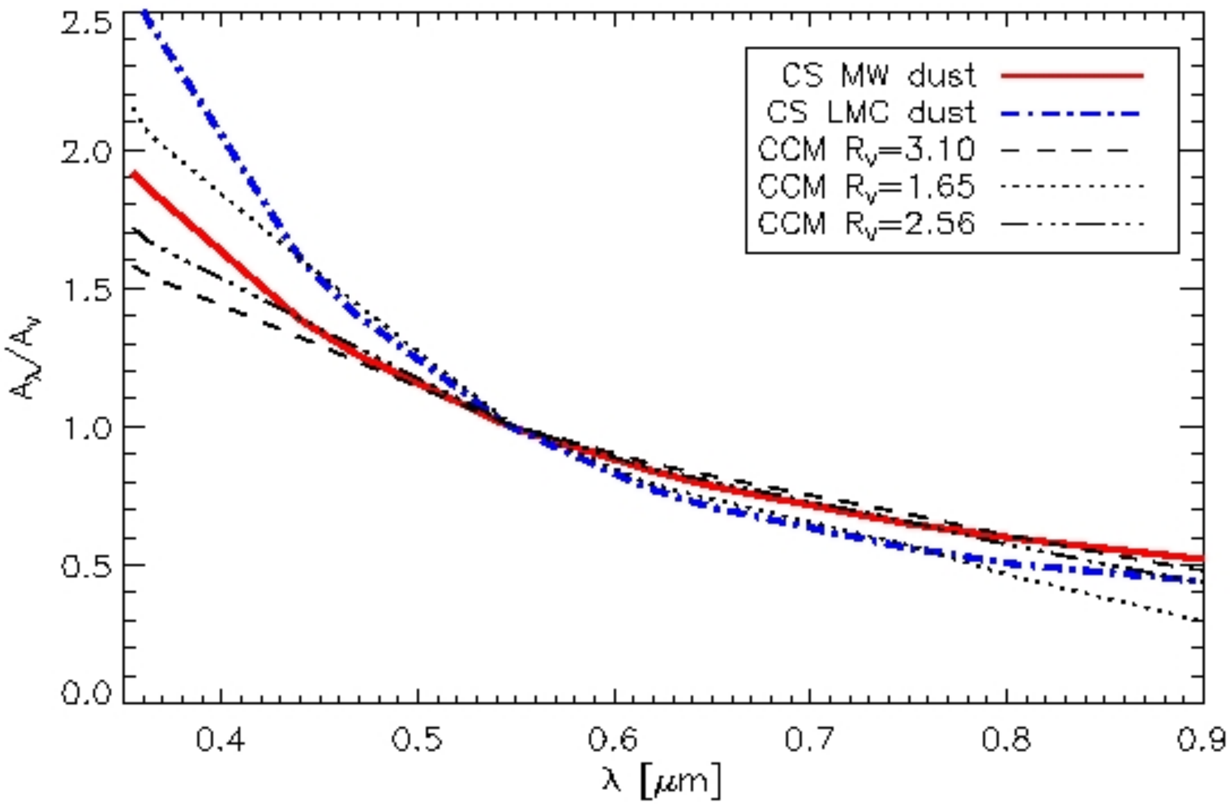


AG 2008 and RA+AG 2011:
Monte-Carlo simulation

Use dust parameters for MW and LMC by:
Draine ApJ 2003, Weingartner & Draine ApJ 2001
(also SMC dust , but mostly absorption, not scattering, at optical wavelengths)

L.Wang (2005)
A.Goobar (2008)
R.Amanullah & A. Goobar (2011)

Differential extinction law differs, especially towards UV



Cardelli law does not fit entire optical window, for any R_v

AG 2008

Power-law

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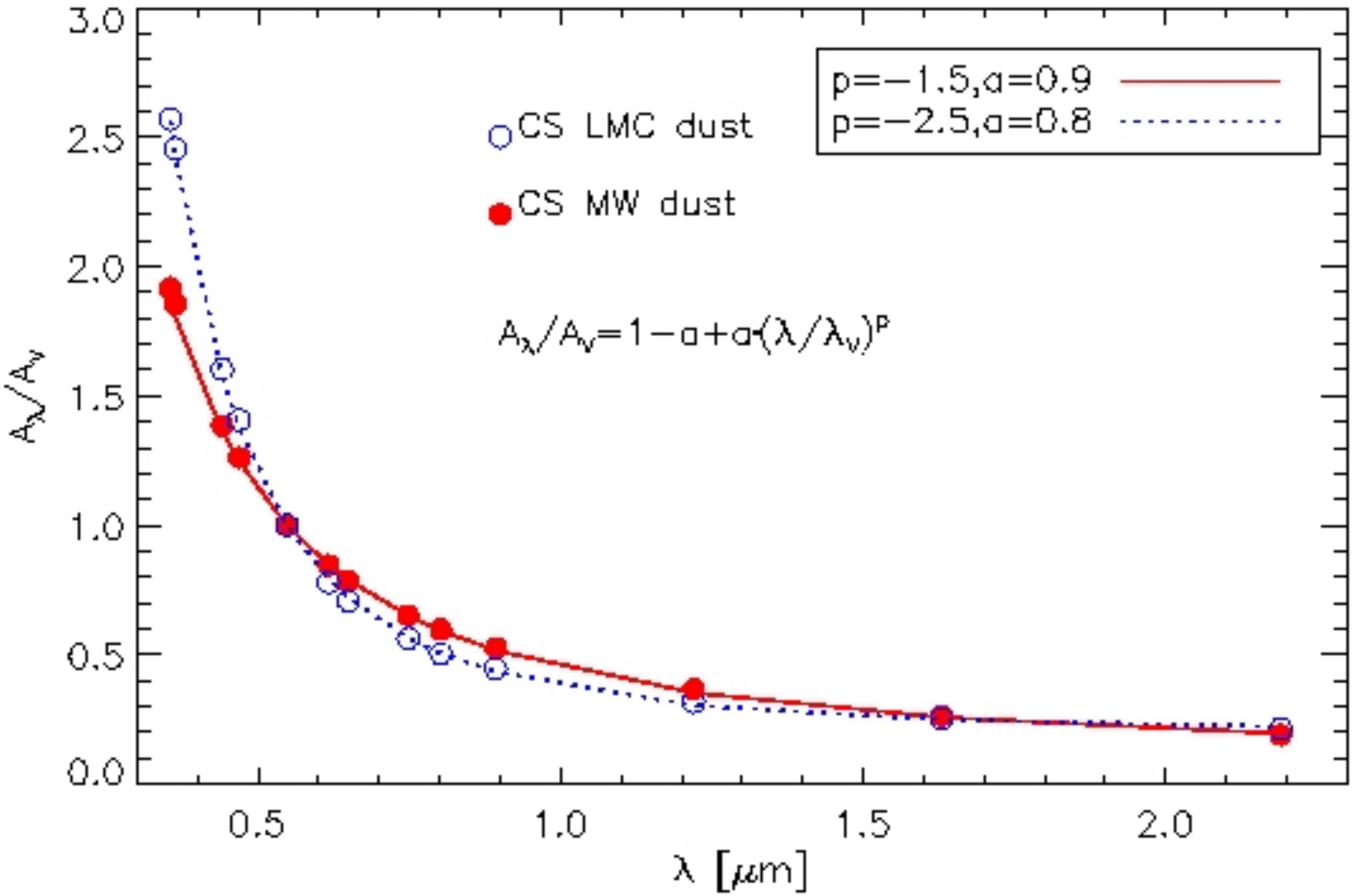
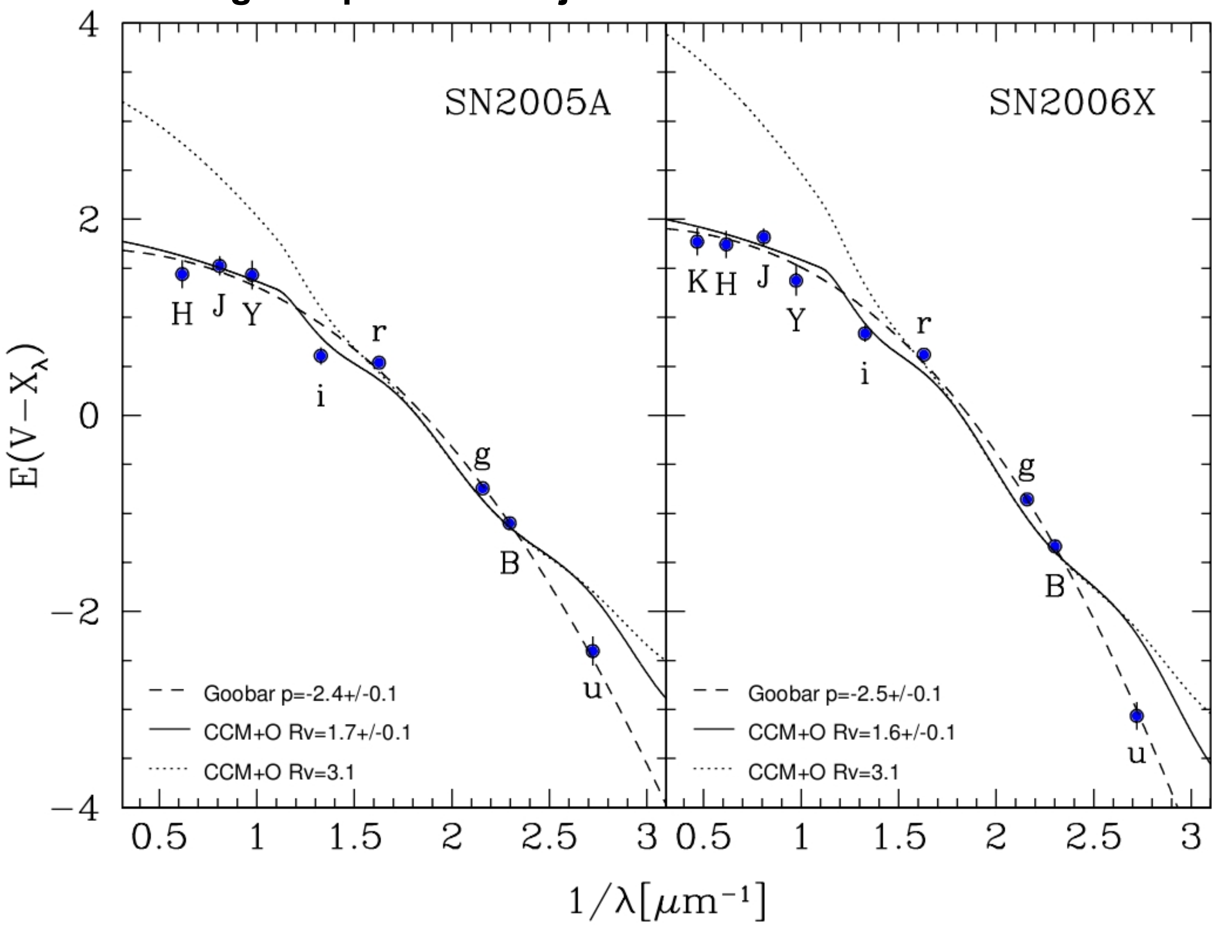
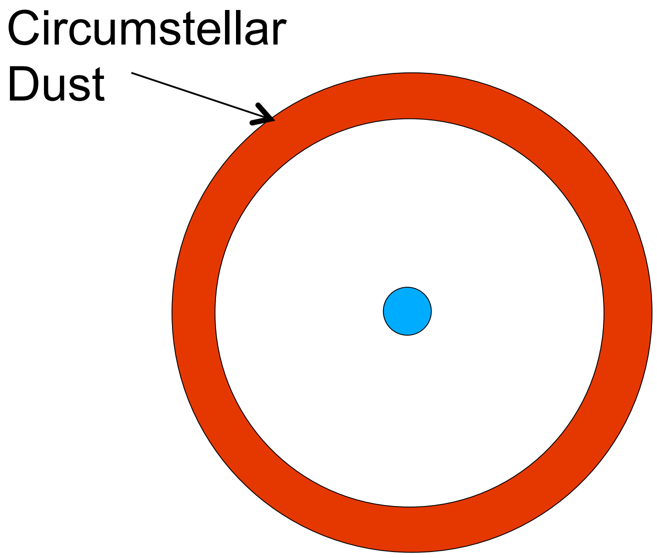


Reddening law from circumstellar dust provides a good fit for highly reddened SNe Ia

Folatelli, Phillips et al. (2010) – Carnegie Supernova Project



Dust in the CS Medium?

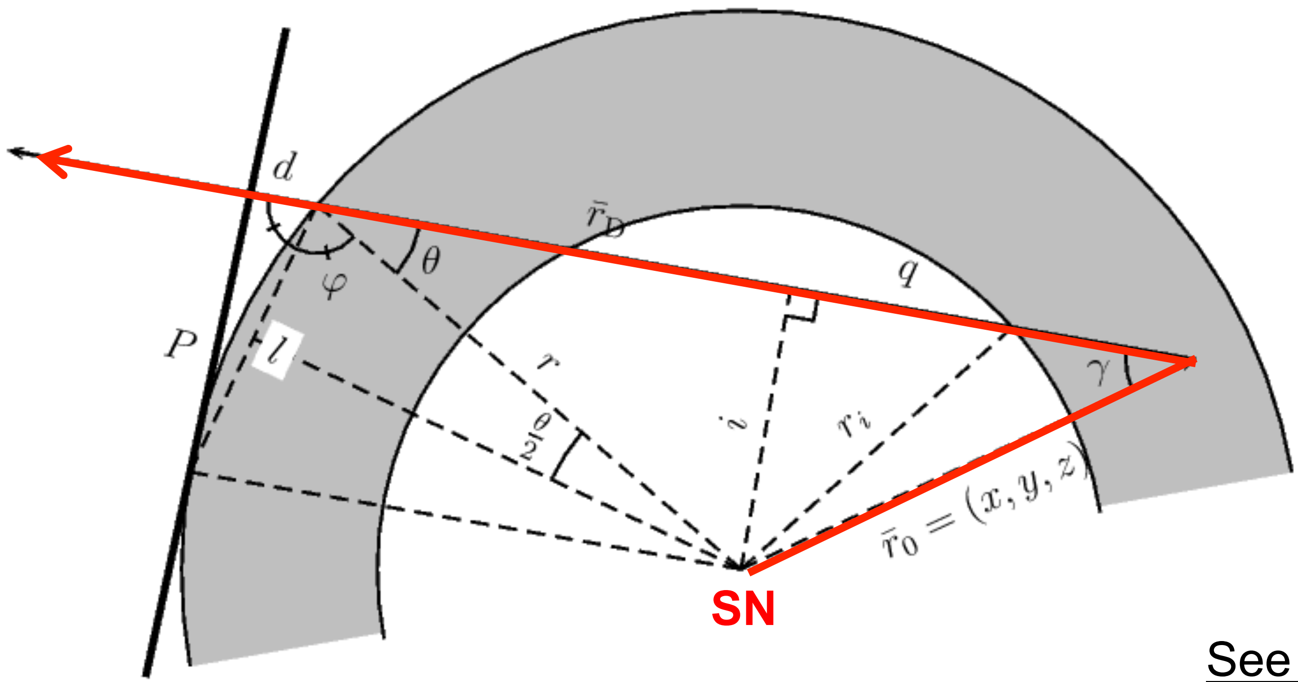


Evaporation radius ~10^{16} cm

What else should we see?
(I) Time delay of photons

Implications on SN Ia observables beyond the reddening law!

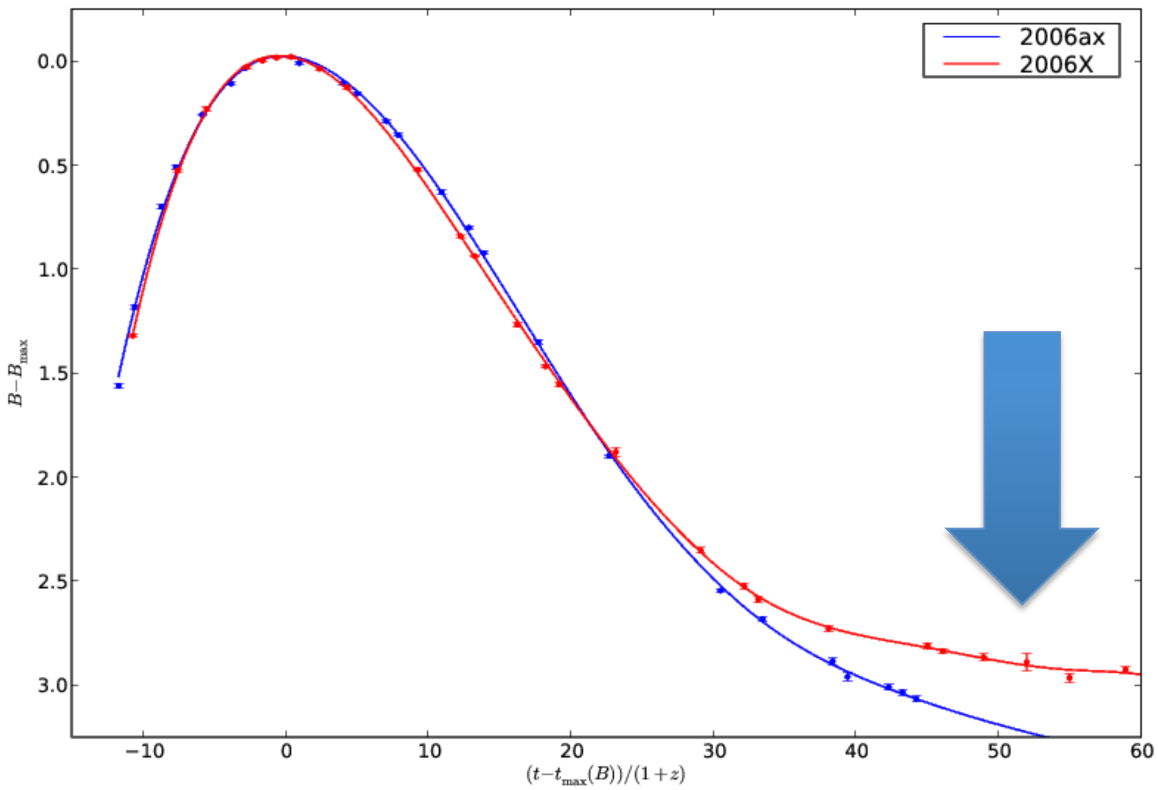
Amanullah & Goobar (2011)



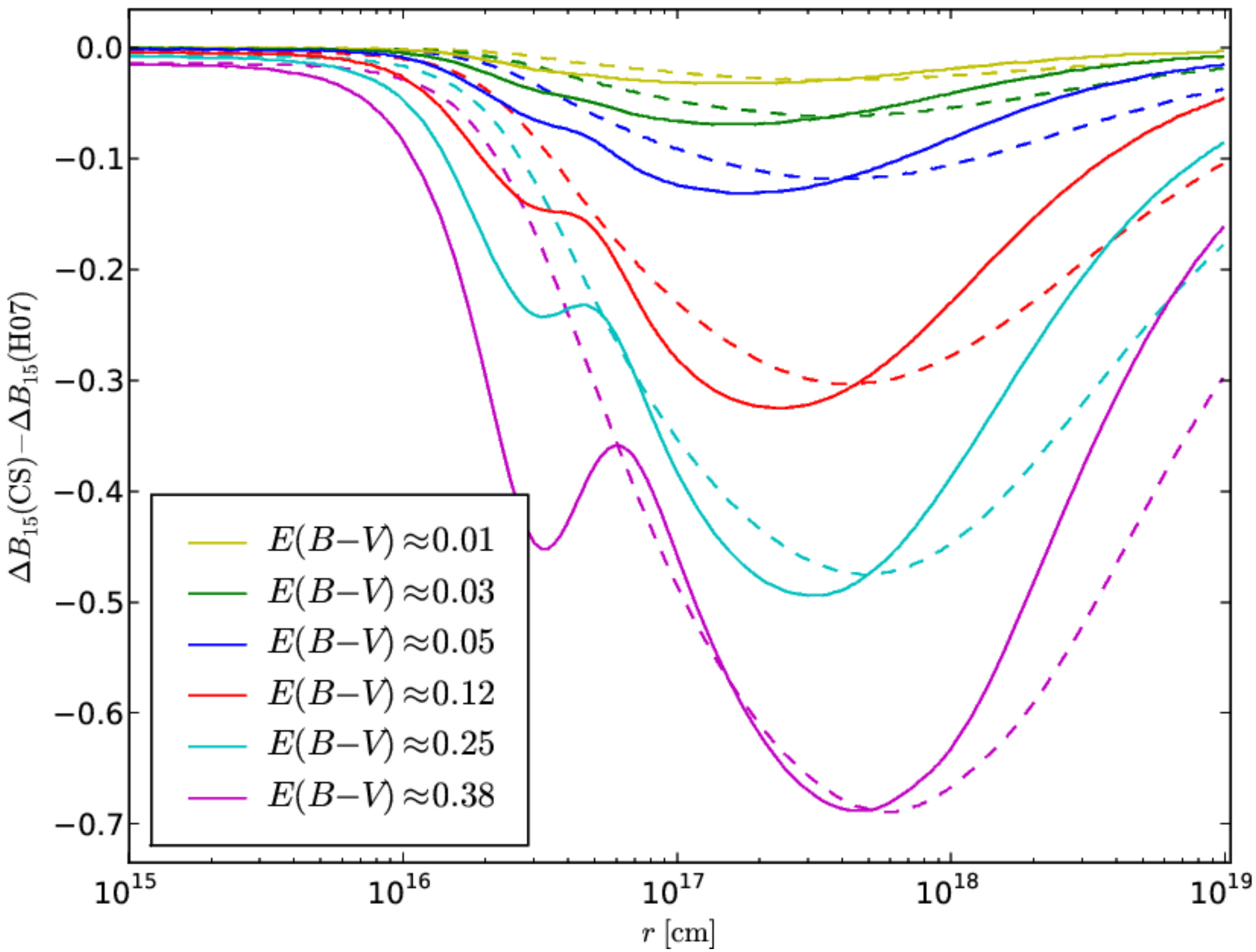
See also:
Patat (2005)
Patat et al. (2006)

Qualitative comparison with data

CSP data (looked at in Amanullah & AG)



Implications on lightcurve shape – LC width becomes a func of shell radius and width



Amanullah & AG

Time-dependent color excess: blue photons arrive later, SN gets bluer at late times

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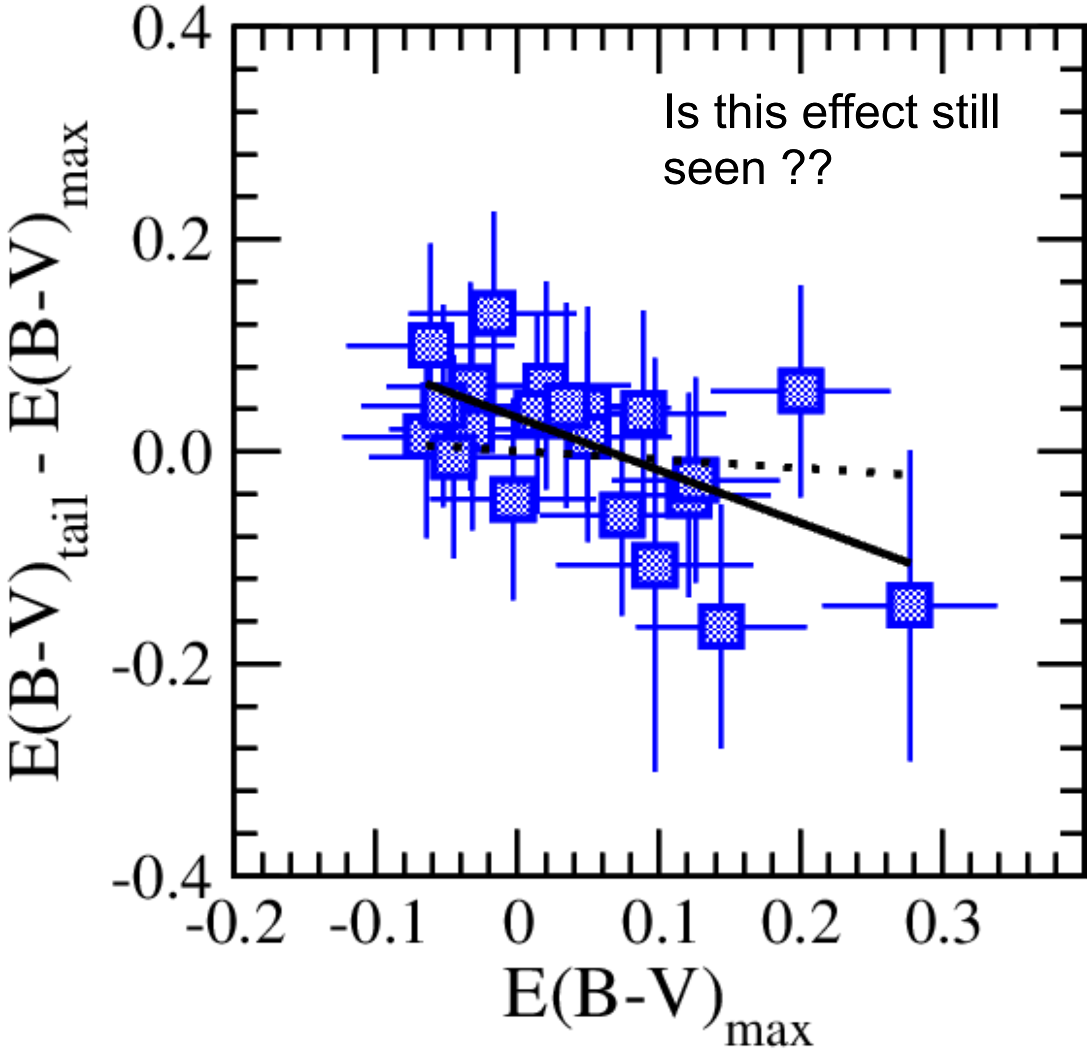
Folatelli et al. (2010)

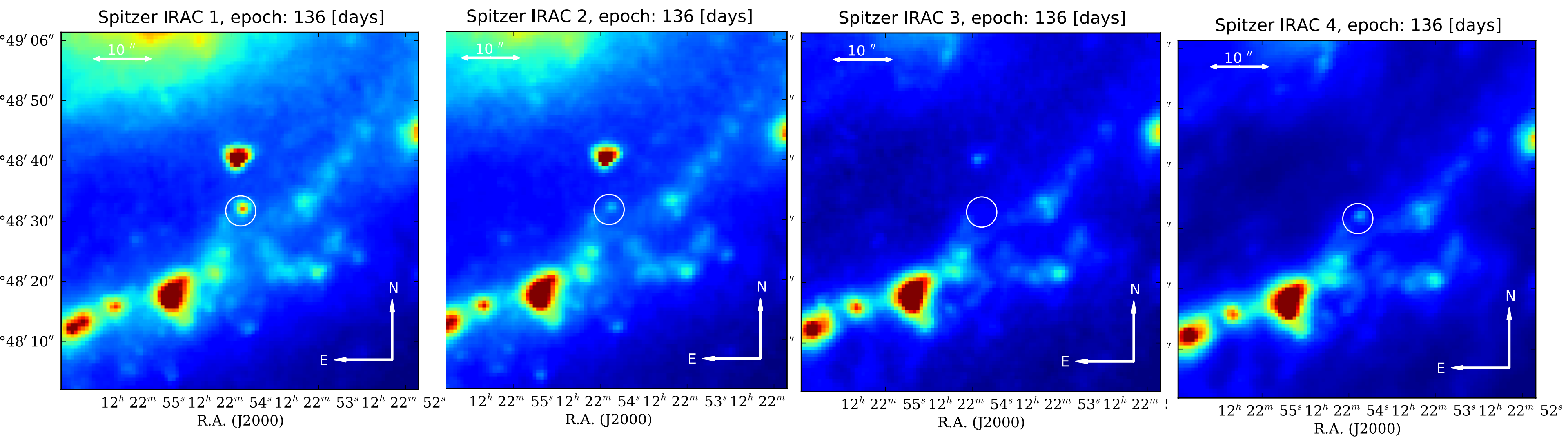


Prediction:

some perturbation of SN features, since we get to a mixture of epochs

Other observables: (II) Re-emission of dust at longer wavelengths?

SN2006X



3.6 μ | 4.5 μ | 5.8 μ | 8.0 μ

Data compatible with 10^{-2} $M_{\odot}$ dust at T~250 K

What else should we see?
(II) Re-emission of dust at longer wavelengths

SN2006X

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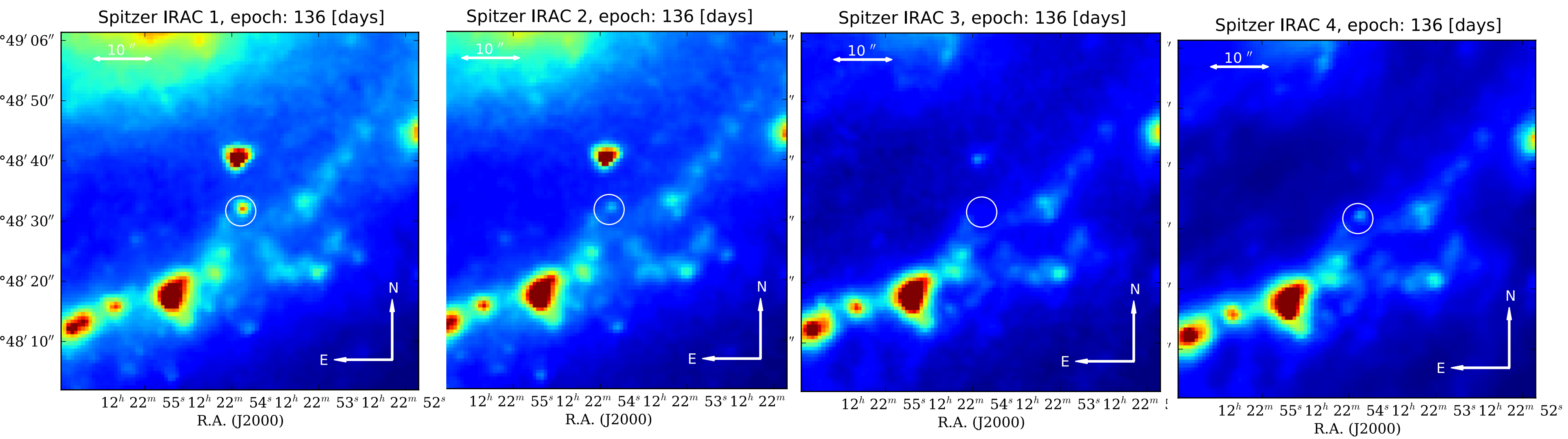


3.6 μ   4.5 μ   5.8 μ   8.0 μ

Data compatible with 10^{-2} $M_{\odot}$ dust at T~250 K

but(!) signal around 8μm degenerate with SN physics… line emission.

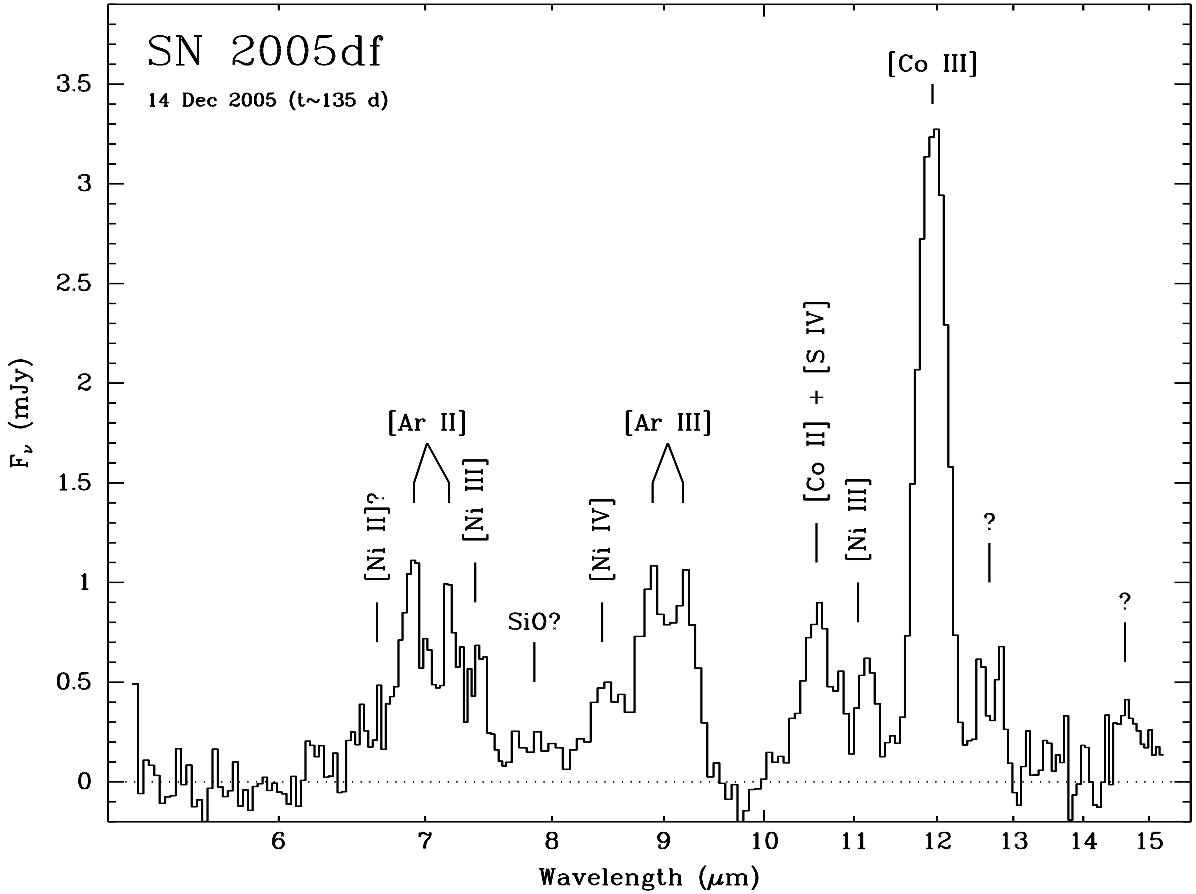


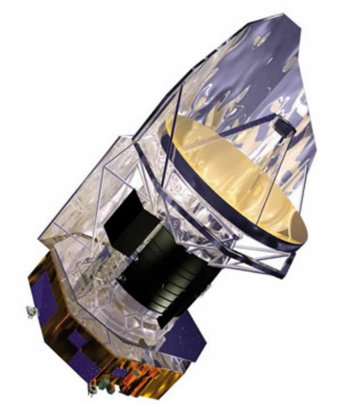
FIG. 2.— The observed mid-infrared spectrum of SN 2005df. Wavelengths are shown as vacuum coordinates in the observer's frame, and are plotted on a logarithmic scale so that the observed line width is proportional to the velocity line width throughout the large wavelength span. See text for discussion of line identifications.

Gerardy et al (2007)

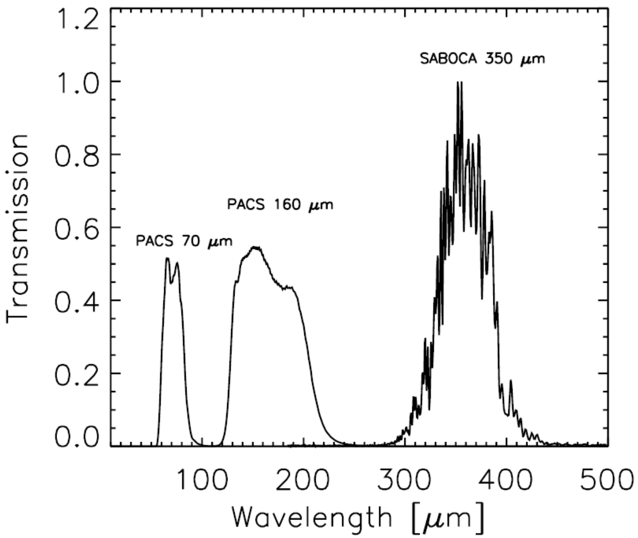
Searches for re-emission by dust in sub-mm

We have used Apex and Herschel to study near-by SNe Ia in sub-mm to search for re-emission.

APEX

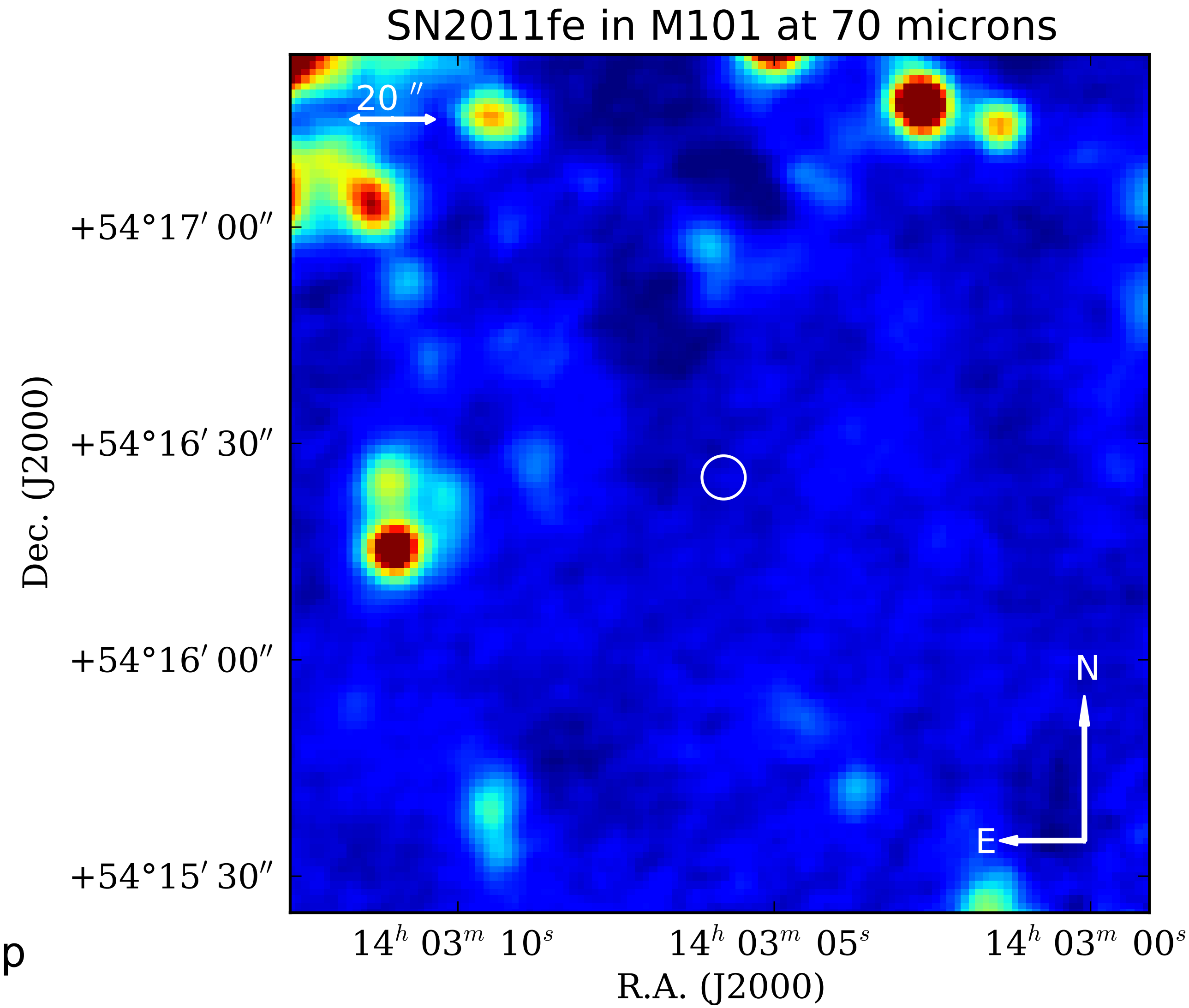


Herschel



SN2011fe in M101 – E(B-V)~0.01

Preliminary!



Johansson et al, in prep

What to expect? Low sensitivity

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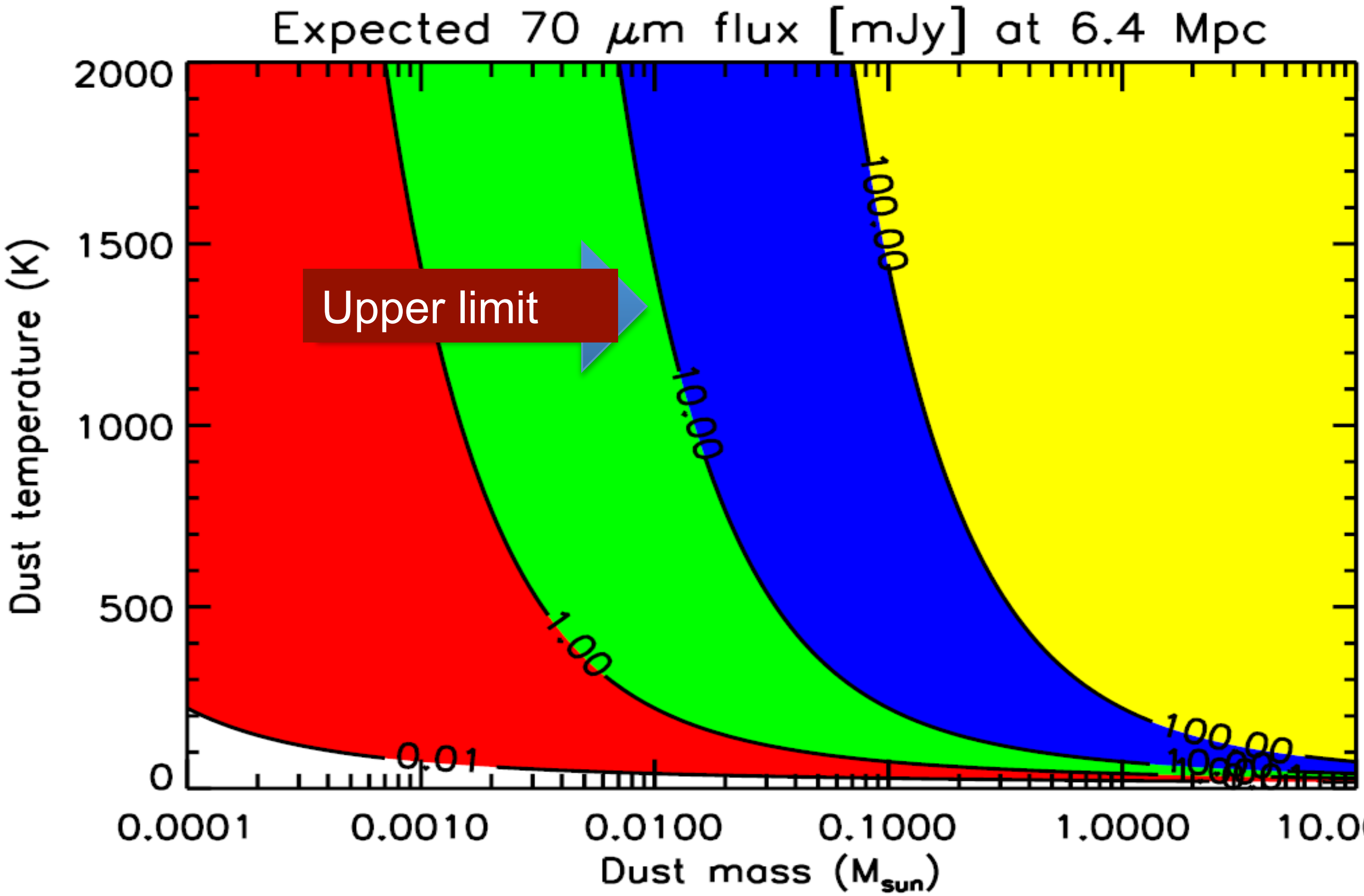
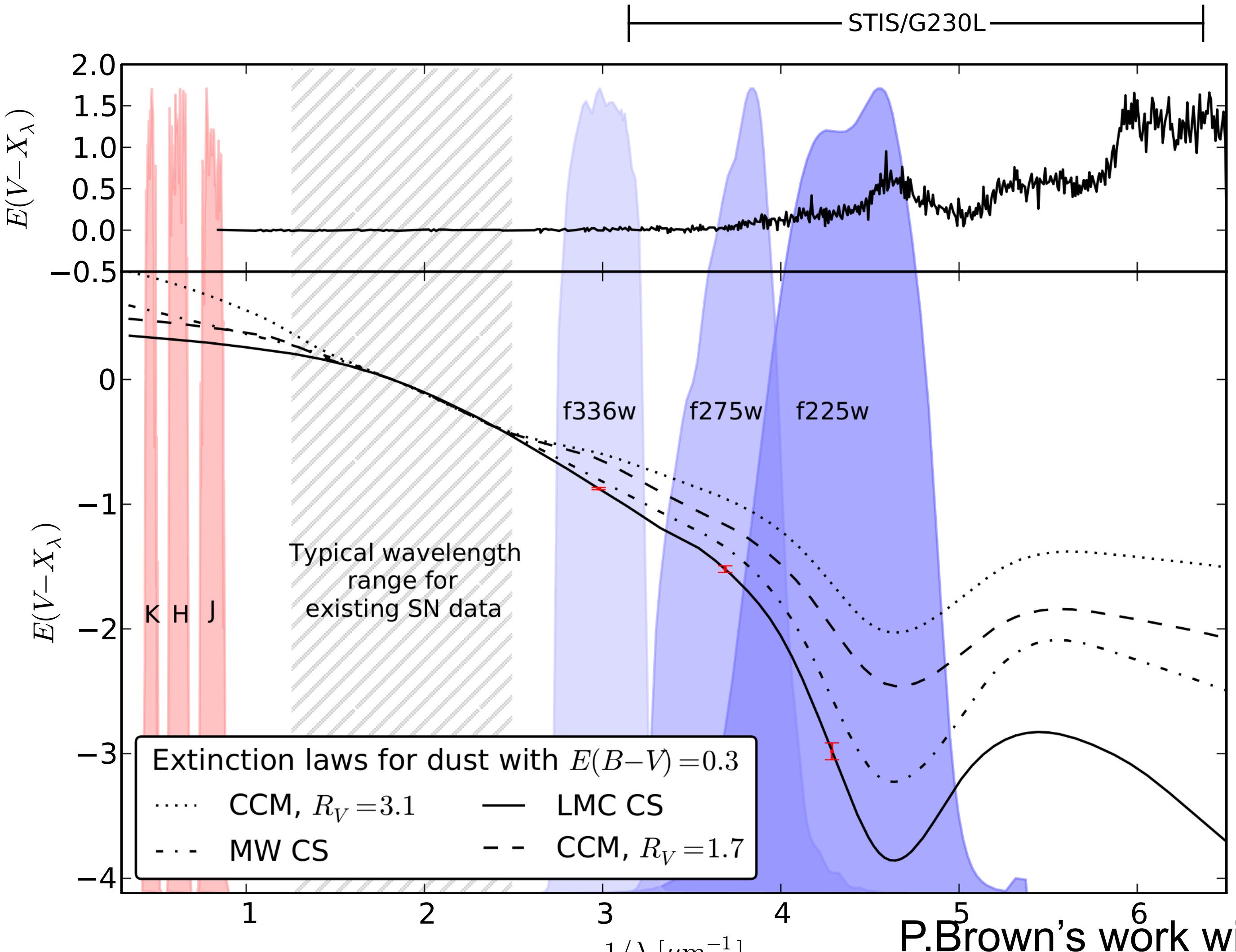


Johansson et al, in prep

Preliminary!

What else should we see?
(III) Enhanced dimming in UV

Ongoing C19 HST program



Up-scattering of photons from collisions with shocked gas (P.Lundqvist)

Dimming by dust

P.Brown's work with Swift very interesting

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Metal lines as tracers of dusty environments

INTERSTELLAR DUST REVISITED

Detection of MgII 2800 doublet
Clumped dust in large scale outflows?

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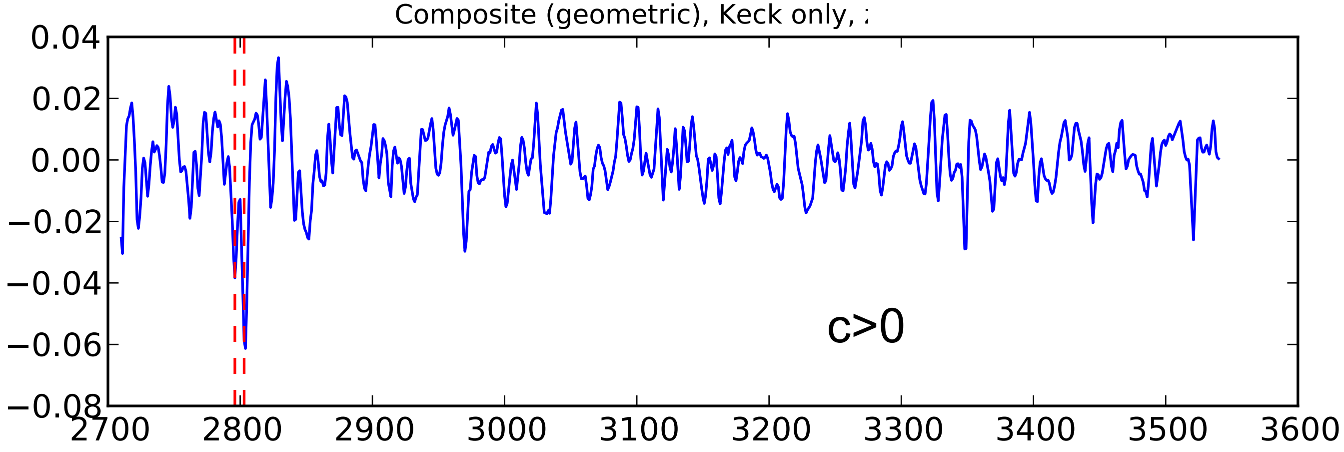
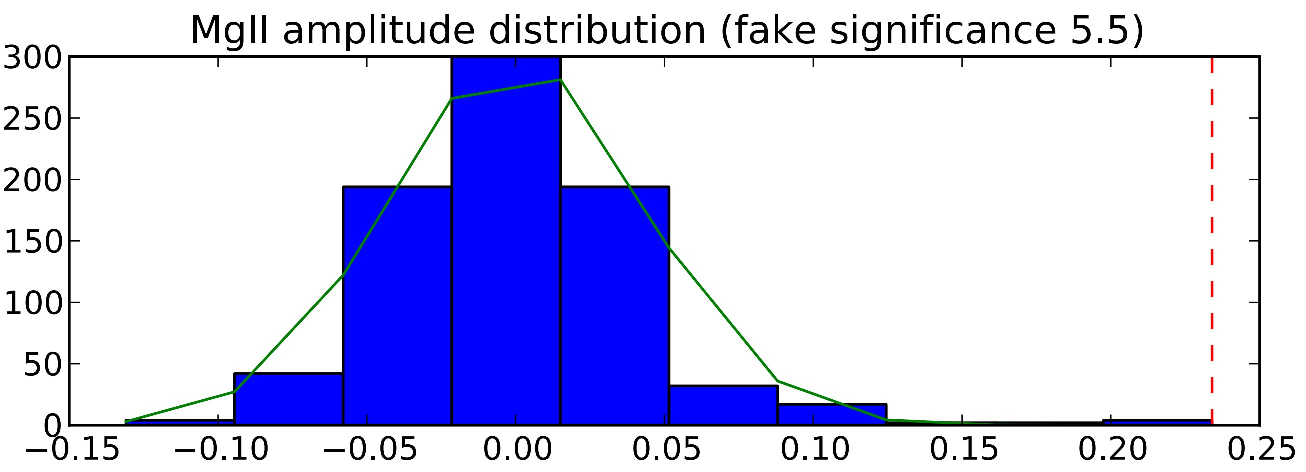
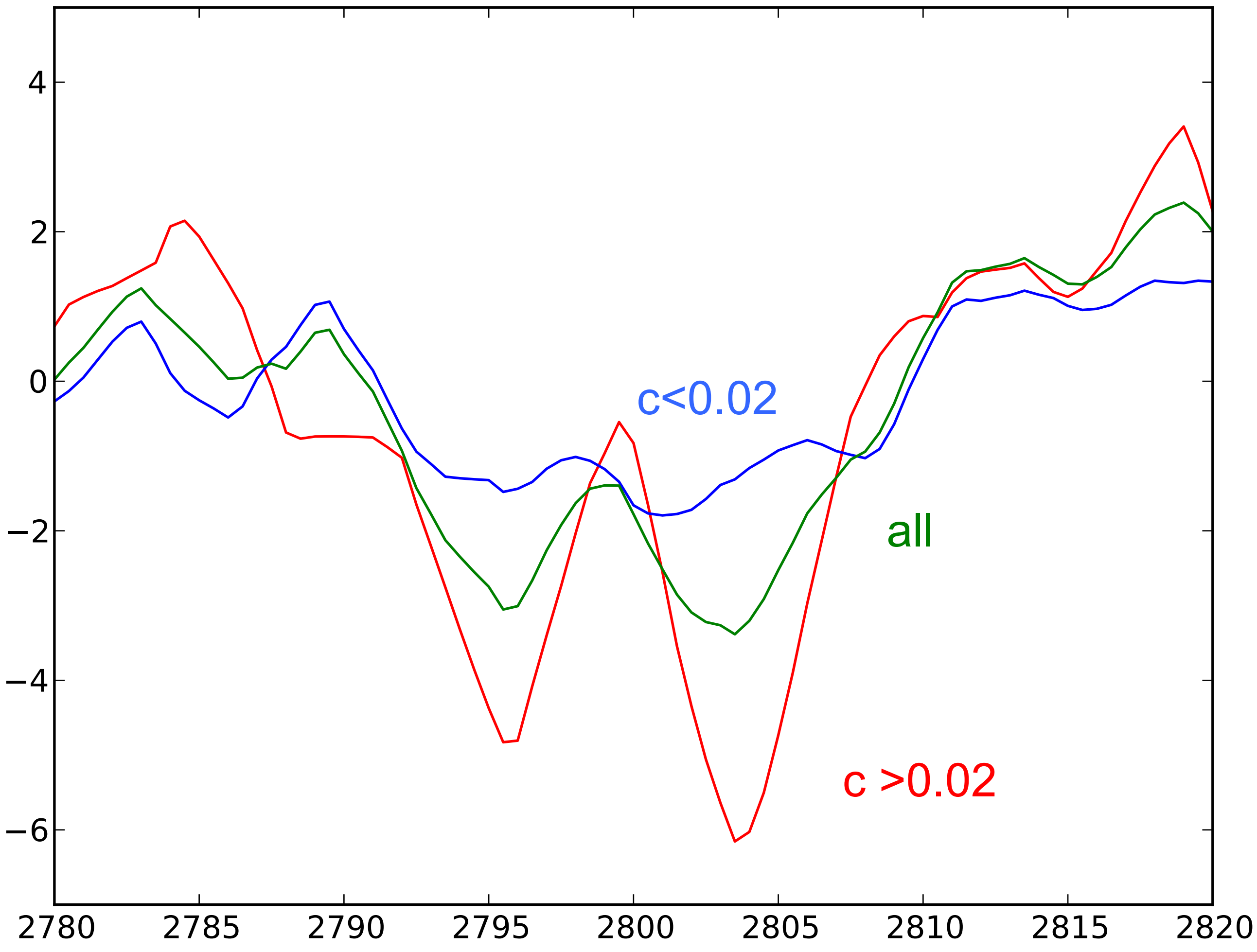
SNLS z>0.4
Keck spectra

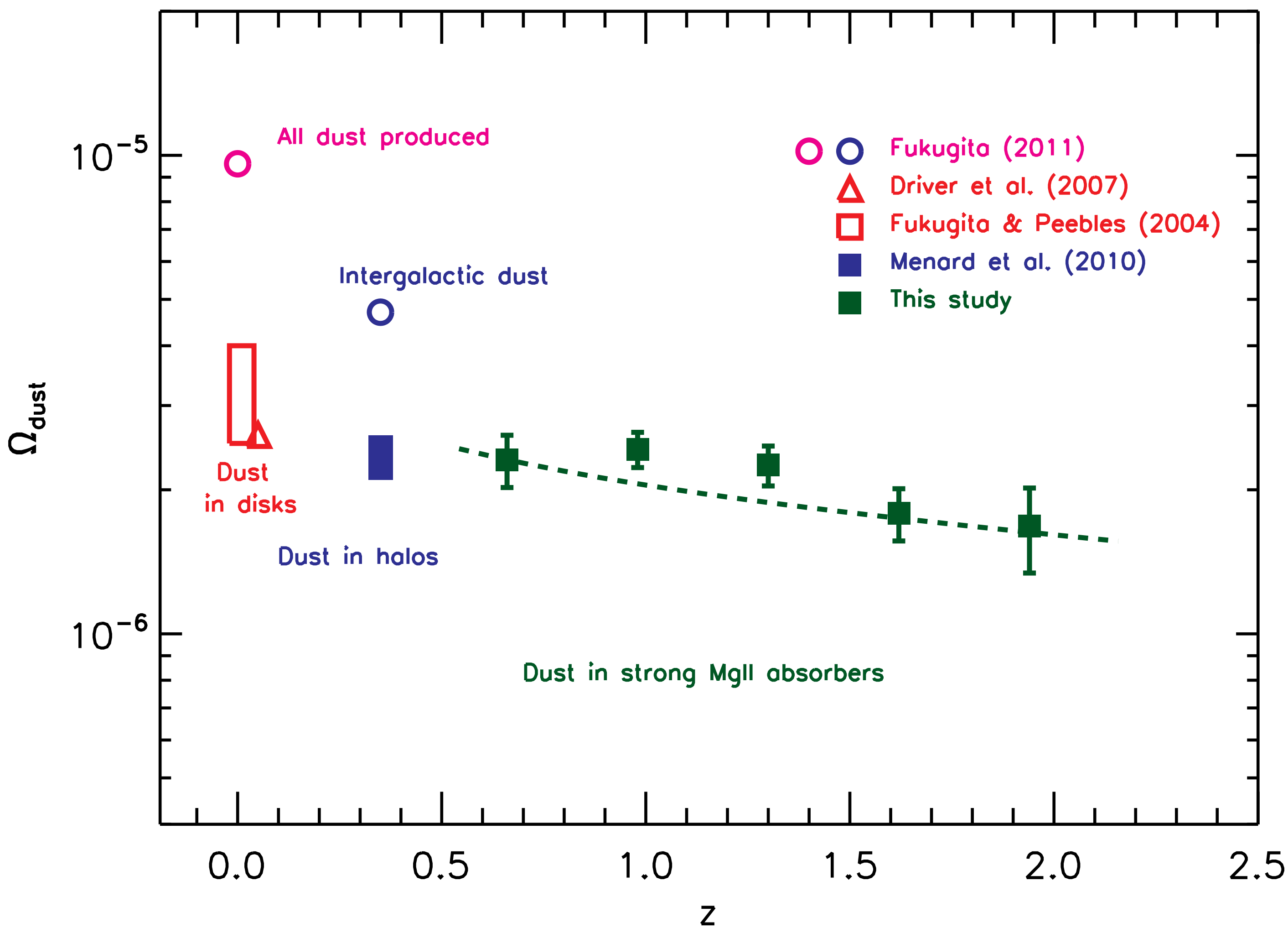


Nordin, Goobar, Menard in prep.



One step closer to breaking degeneracy between sources of dimming





Menard & Fukugita 2012

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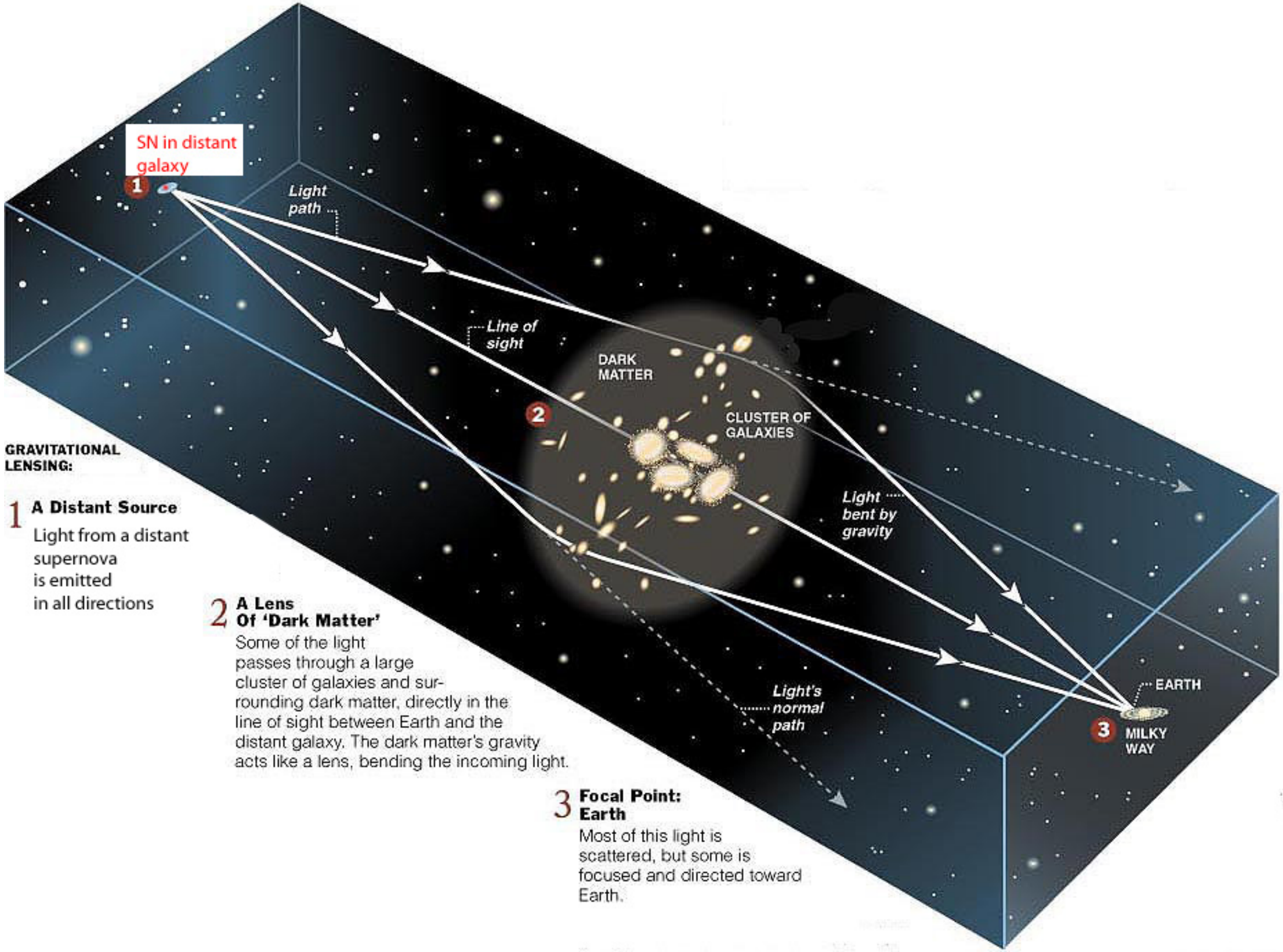
Part II

SUPERNOVAE OBSERVED THROUGH GRAVITATIONAL TELESCOPES

Gunnarsson & Goobar (2003)
Goobar et al (2009)
Stanishev, Goobar, et al (2009)
Amanullah, Goobar et al (2011)
Riehm, Mörtsell, Goobar et al (2011)

Nature's own gravitational telescopes



A1689: magnification map for source at z=2

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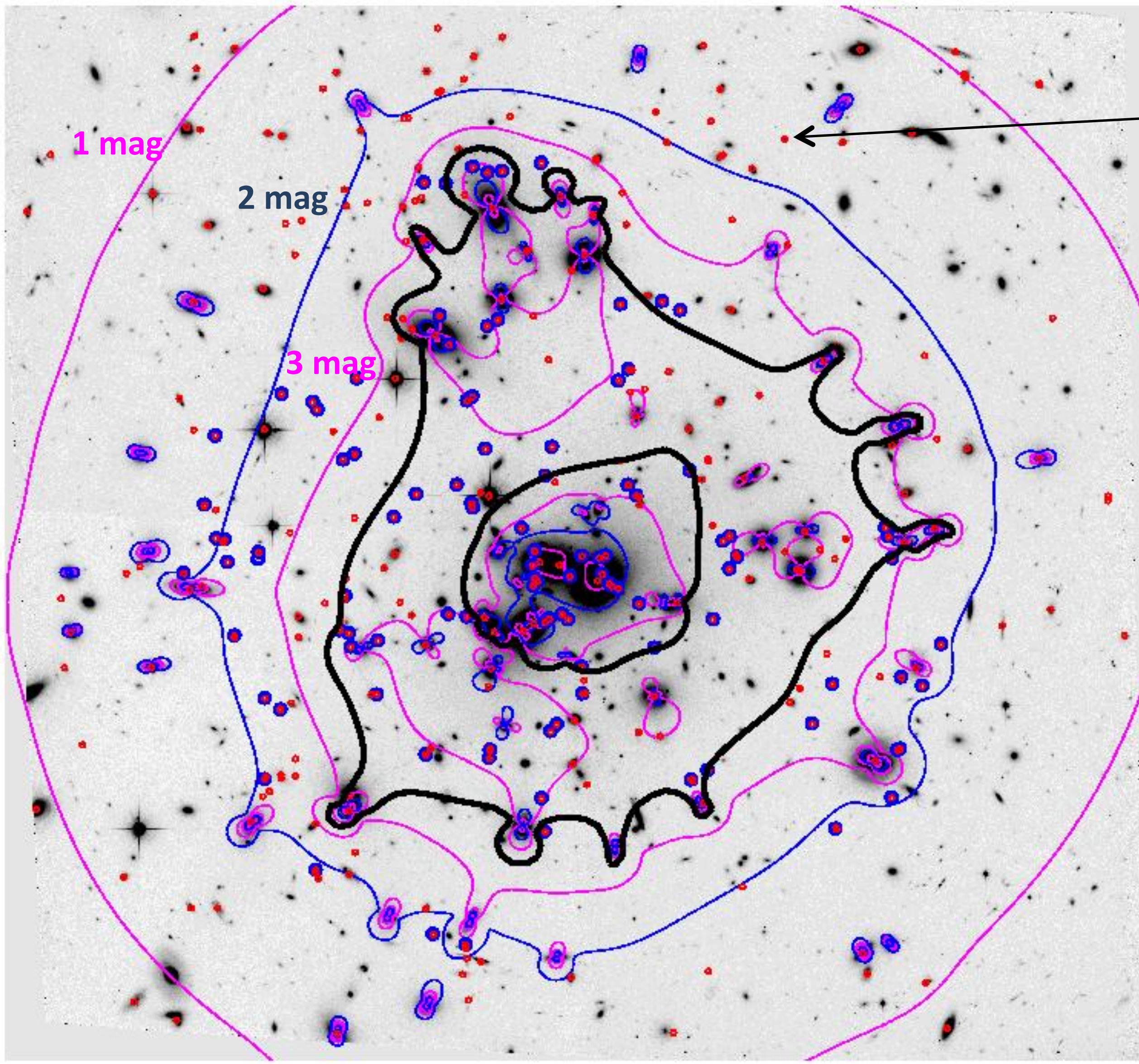
3.4’



Galaxies with spectro-z

~40 strongly lensed galaxies, more than 115 images!

Limousin et al (2007)

ESO “pilot”: ISAAC (6 hs, Y) and HAWK-I (17 hs, J) on A1689

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- Archival data from FORS2, HST
- Optical Monitoring in NOT 2.5m
- Unrelated ESO program in parallel with our HAWKI obs:

  Ks + NB1060 (1.06 μm)

Gravity gives, gravity takes: focusing means also smaller survey area.

12 A. Goobar *et al.*: Near-IR search for lensed

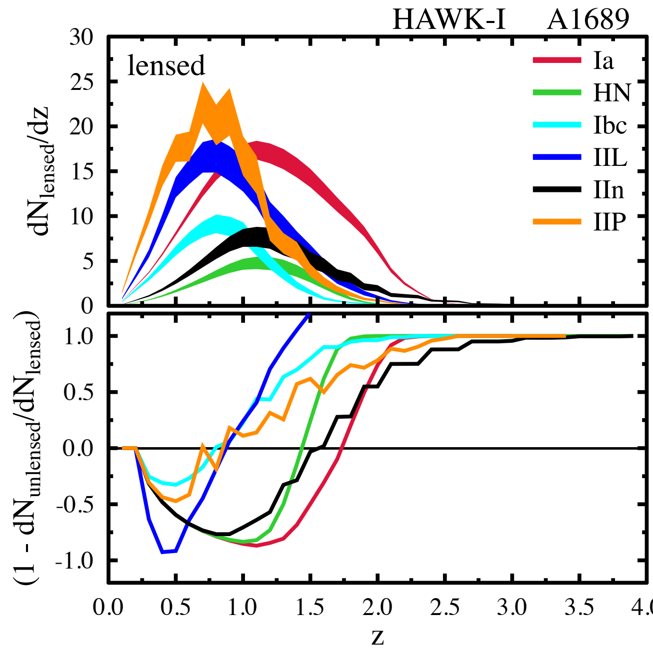

Fig. 15. Upper: Redshift distribution of SN discoveries in a 5-year survey behind a very massive cluster (model of A1689 used). Lower: Gain/loss of using a A1689-like cluster as a lens compared to an equivalent survey without the lens for different redshifts. The crossing of the curves through the zero line indicates the redshift for which a transition to a net gain in SN discoveries is obtained due to the gravitational telescope. An average Milky-Way-like extinction with $E(B-V) = 0.15$ was assumed together with SN rates from M07.

Some of the transients we found

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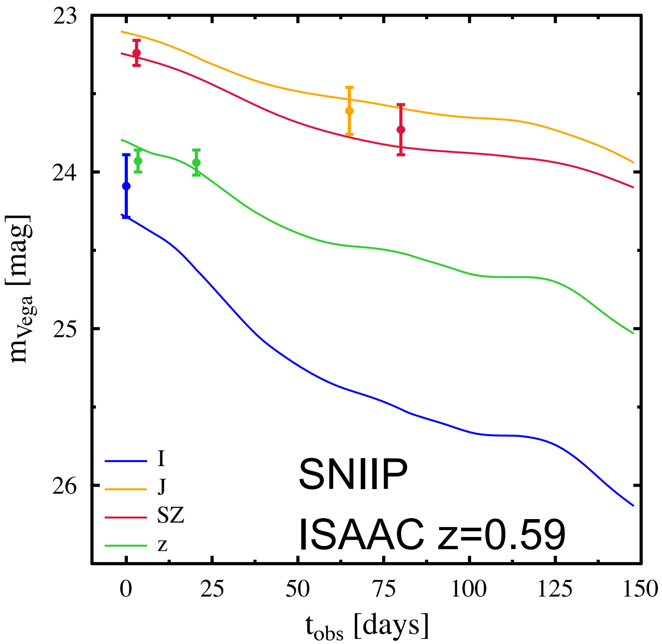
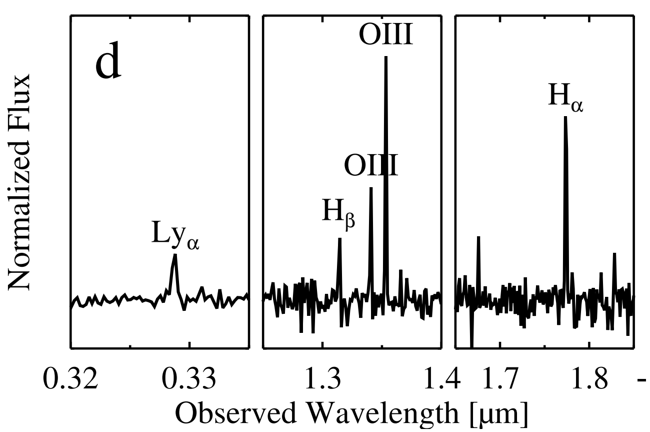
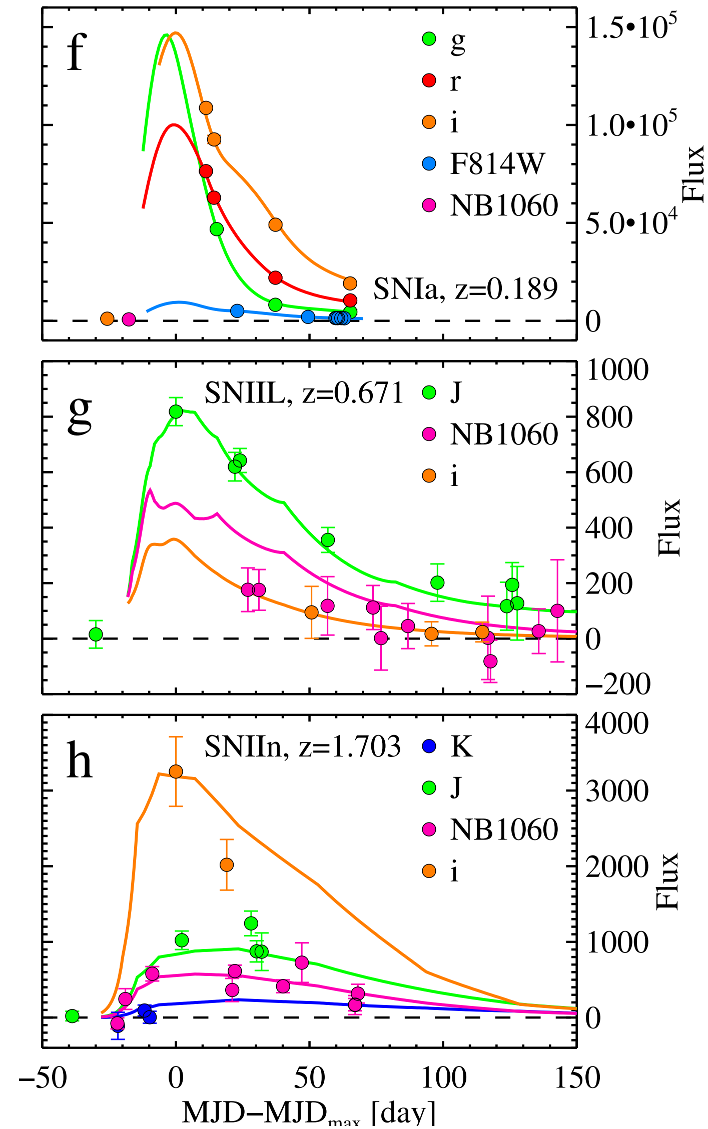




Xshooter: host galaxy



The importance of exploring the highest-z SNe Ia

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Large lever arm in studies for evolutionary effects.

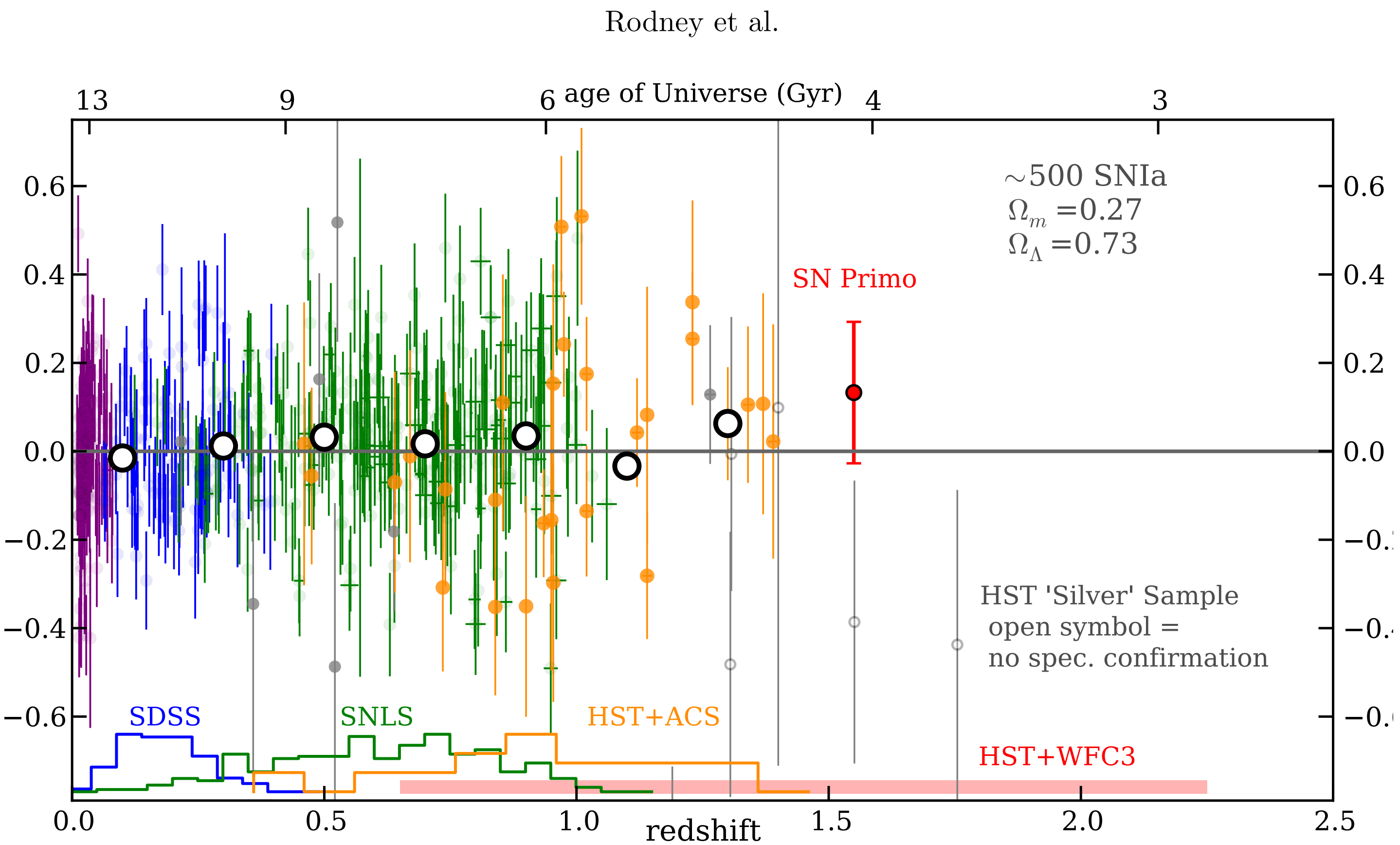
At z~1.5, t~4 Gyrs since Big Bang, i.e., *short lived progenitors*.

WDs at very high-z likely to originate from more massive stars

Dominguez, Höflich & Straniero (2001):

- CO mass and the C/O ratio are expected to depend on the progenitor mass
- Because of the lower C/O ratio in more massive progenitors, smaller amounts of ^{56}Ni are synthesized.
- ~3% change in peak luminosity per 1 $M_{\odot}$ change in progenitor star.

State of the art at highest-z from HST



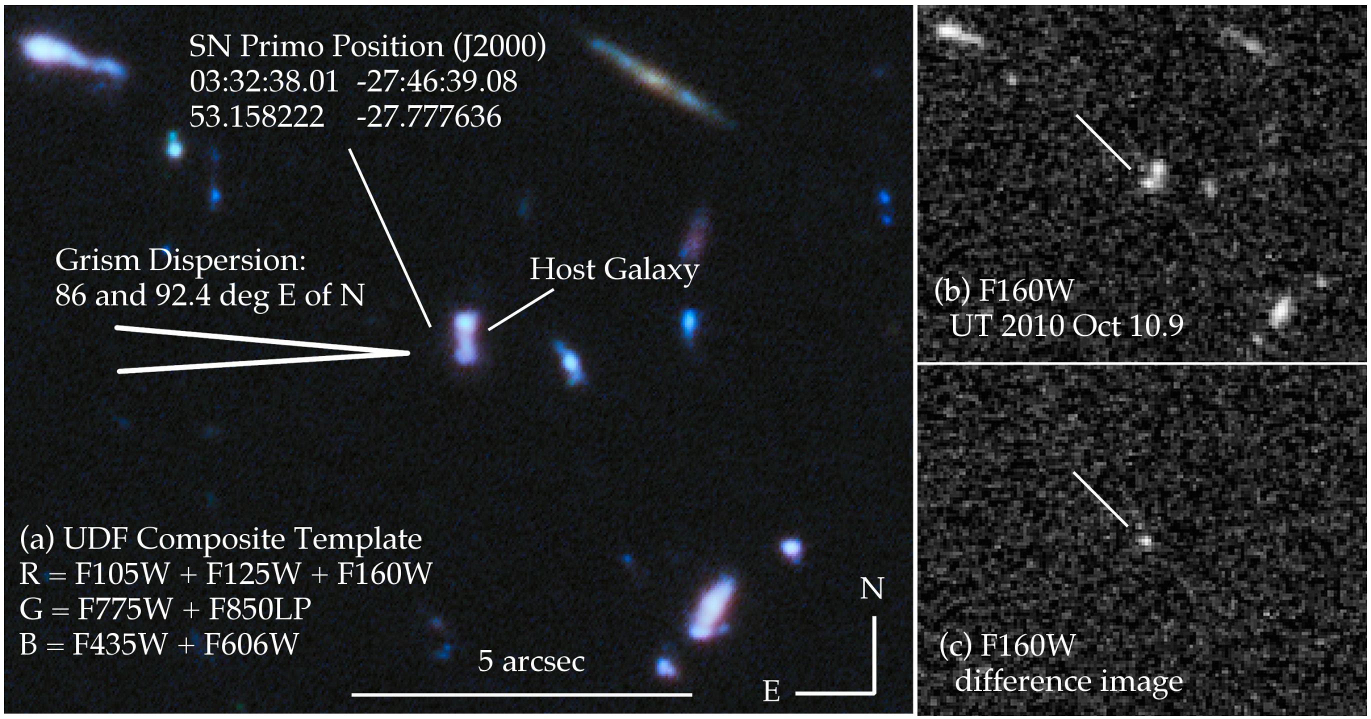


FIG. 2.— (a) Composite image of the SN Primo host galaxy and surroundings in the UDF, from pre-explosion imaging. (b) CANDELS search-epoch image in F160W (H band), from 2010 October 10. (c) F160W difference image, showing SN Primo near peak brightness.

SN Ia at $z = 1.55$ from CANDELS

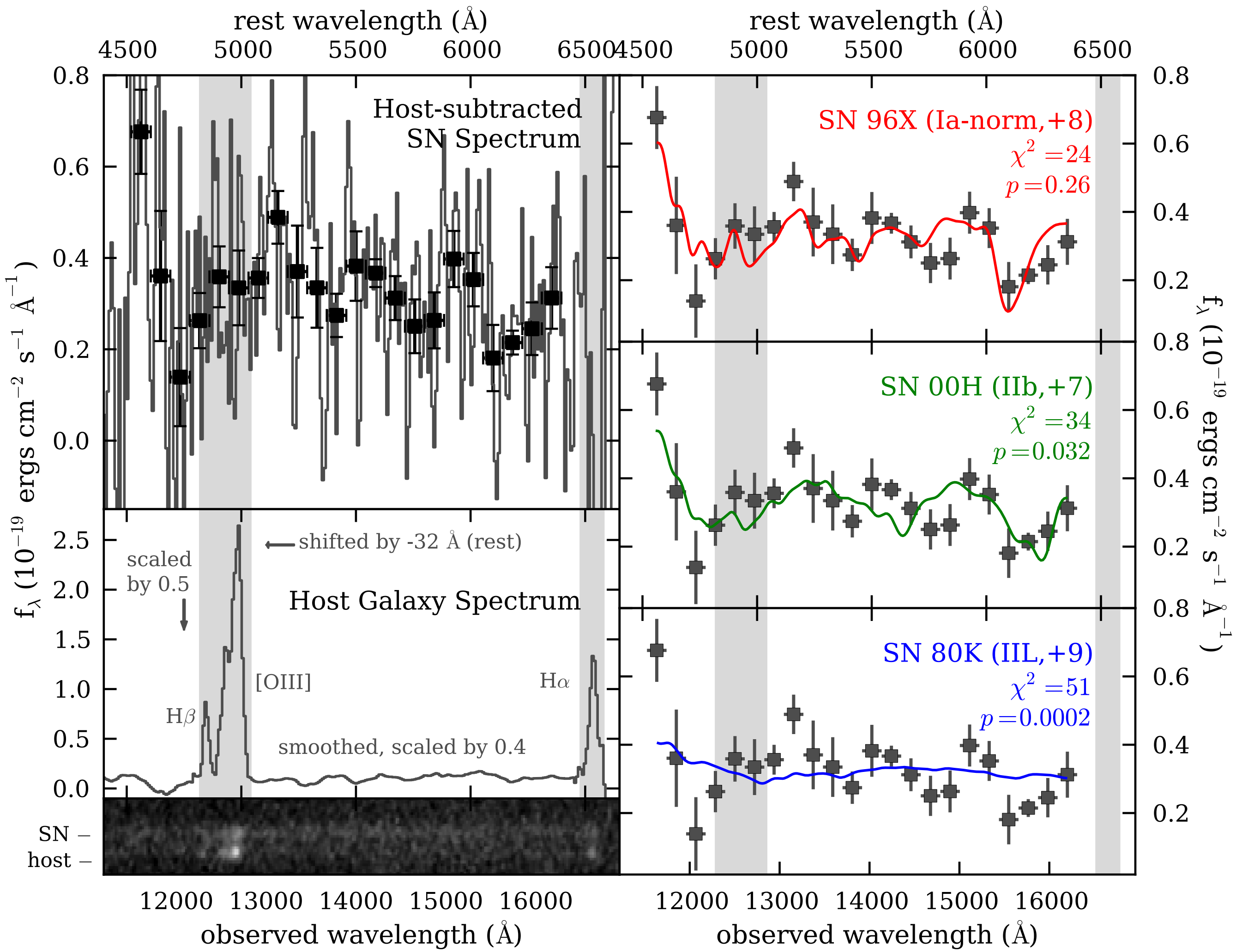
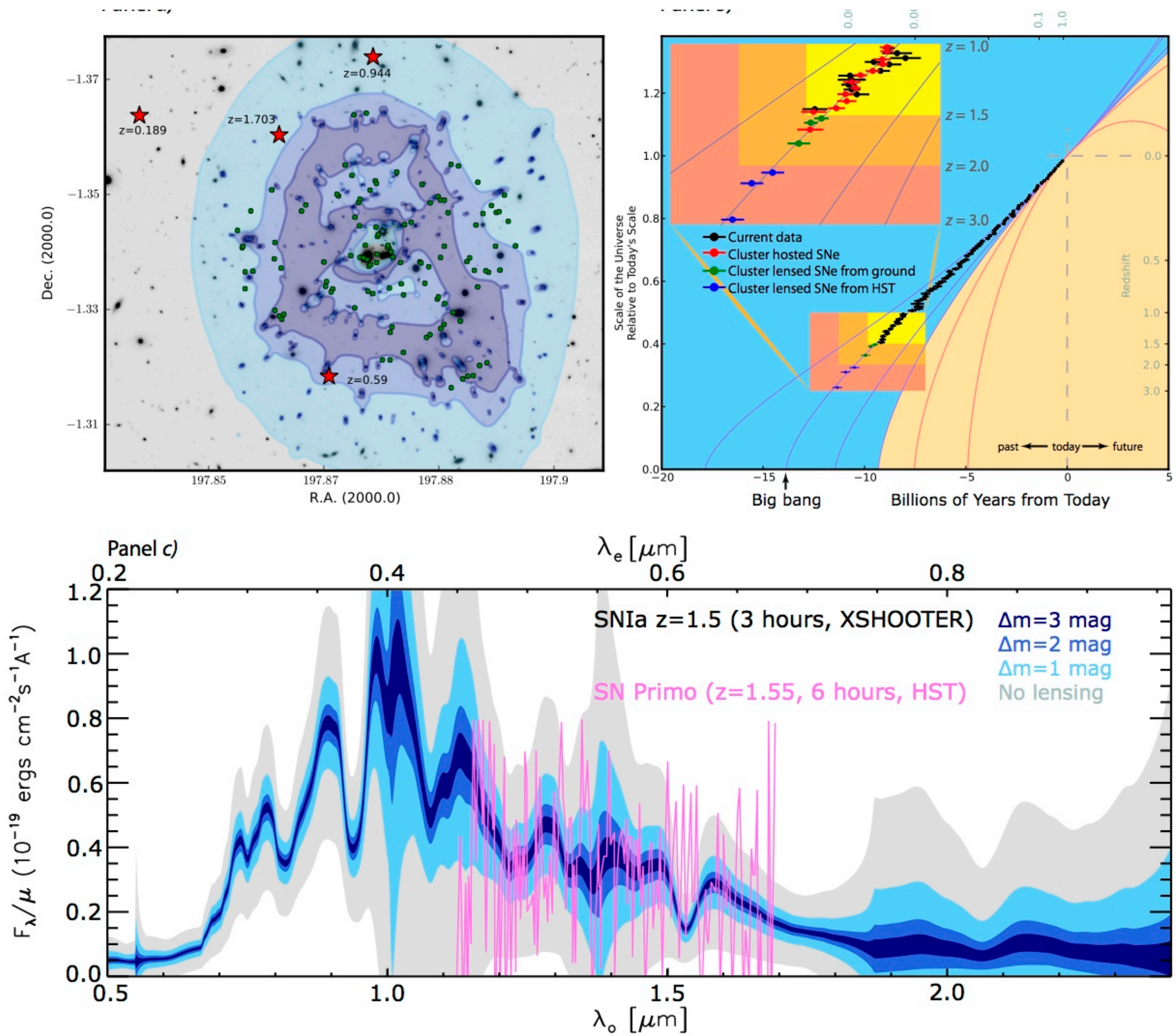
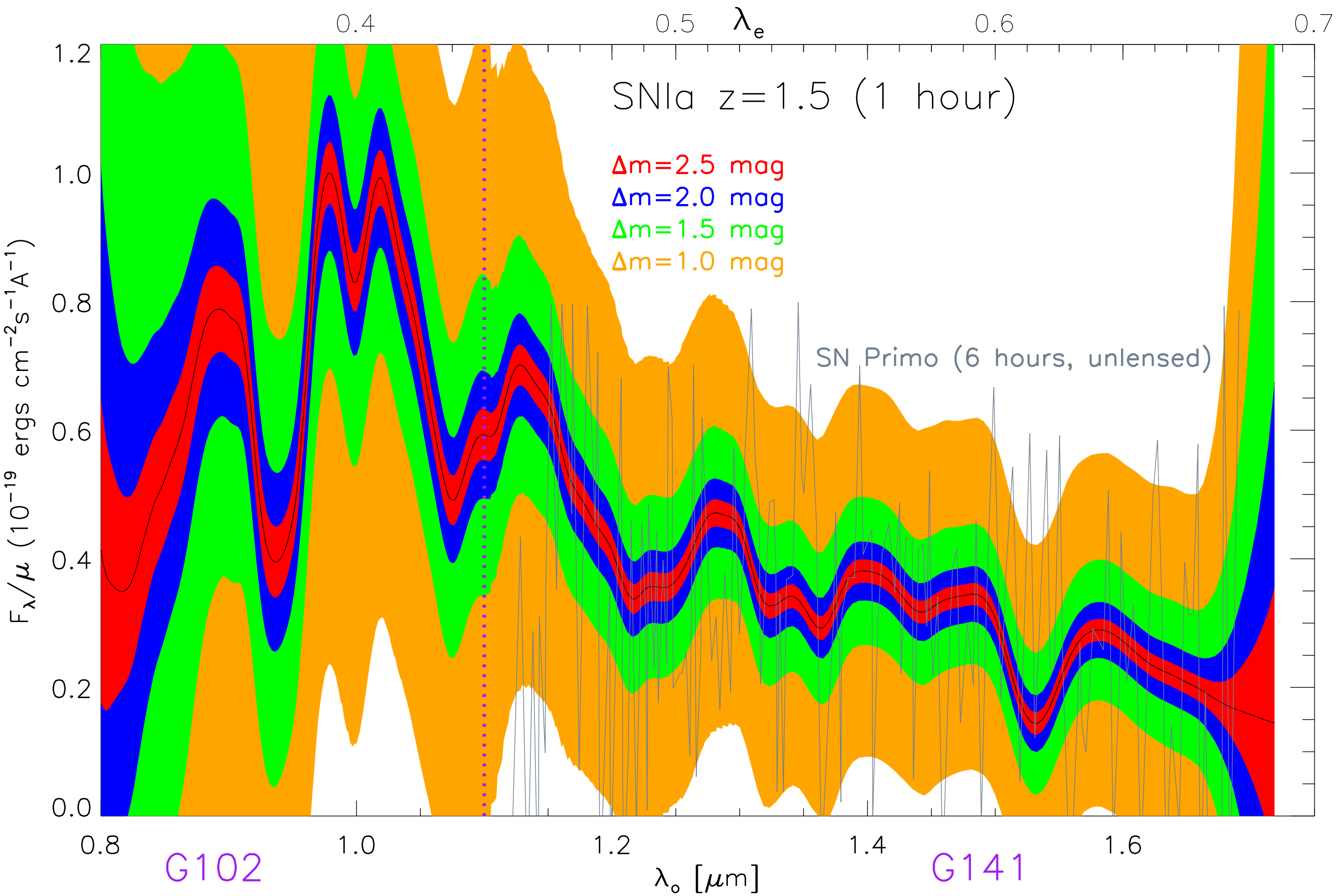


Fig. 6.— The HST G141 grism spectrum of SN Primo. The left side depicts the spectral data reduction process: the bottom panel shows the 2D grism spectrum, the center panel shows the host-galaxy spectrum, smoothed and shifted as described in the text, and the top panel shows the host-subtracted SN spectrum. Grey lines show the unbinned spectrum in rest wavelength for the known redshift $z = 1.55$. Solid points show the mean values in 80 Å bins. On the right side, the same binned points are shown in each of the three panels, with three template spectra overlaid as solid lines for SNe of Type Ia, Ibc, and II. All templates are depicted for the known age of the SN at the time of the grism observation: 6 rest-frame days past peak brightness. The vertical grey bands indicate regions where the SN spectrum was contaminated by bright emission lines from the host galaxy: Hβ and [O III] on the blue side, and Hα on the red side.

We can get great spectra of high-z lensed SNe!

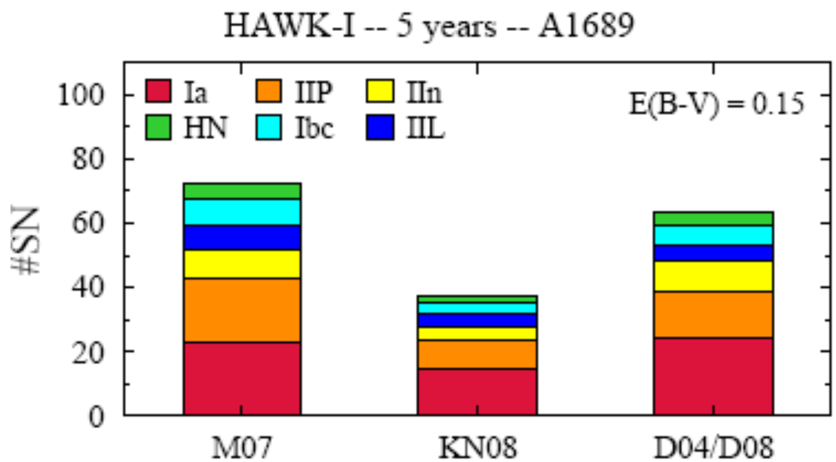


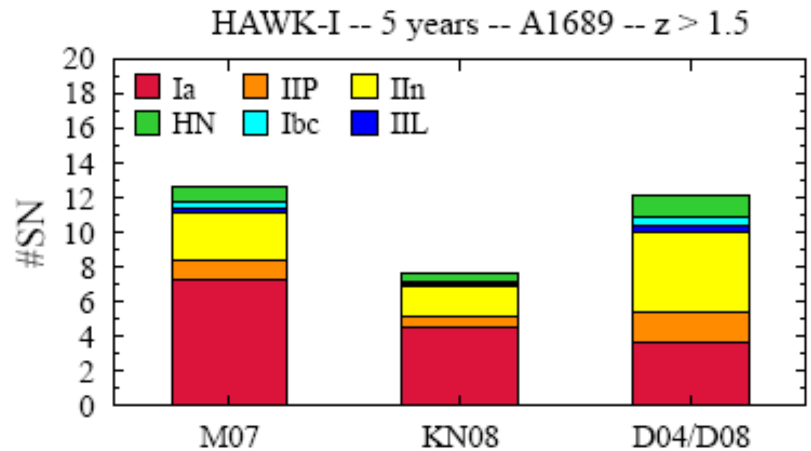
...or with HST WFC3 grisms

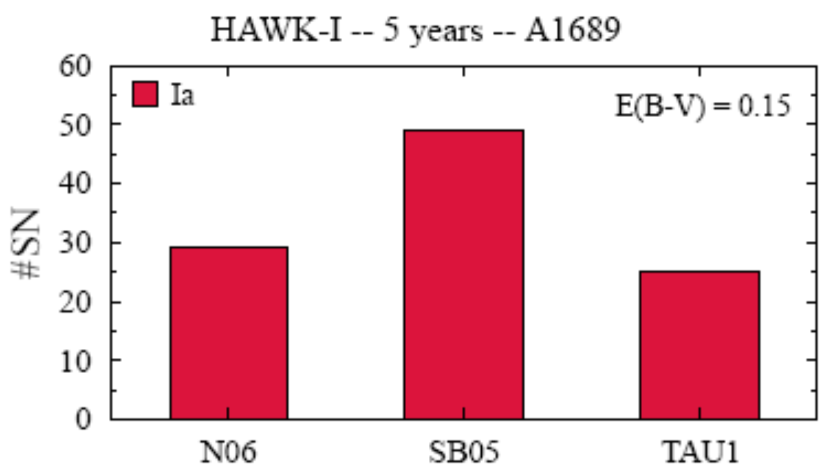


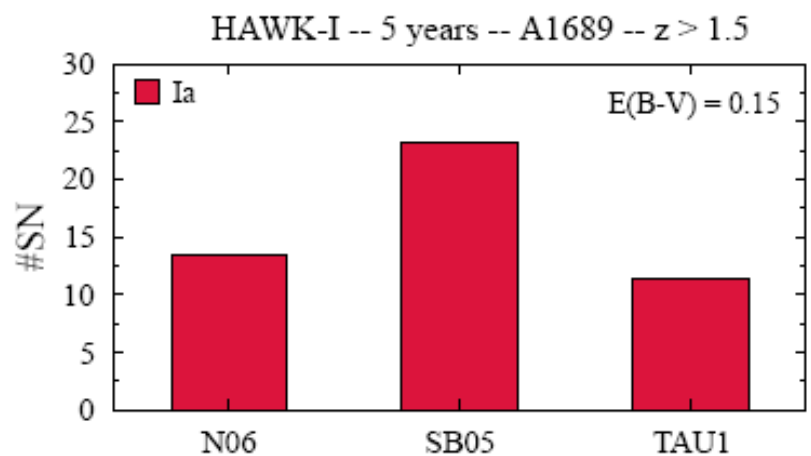
Predictions for 5-year Monitoring of A1689...

A handful of good z>1.5 spectra would be very exciting, to me at least…

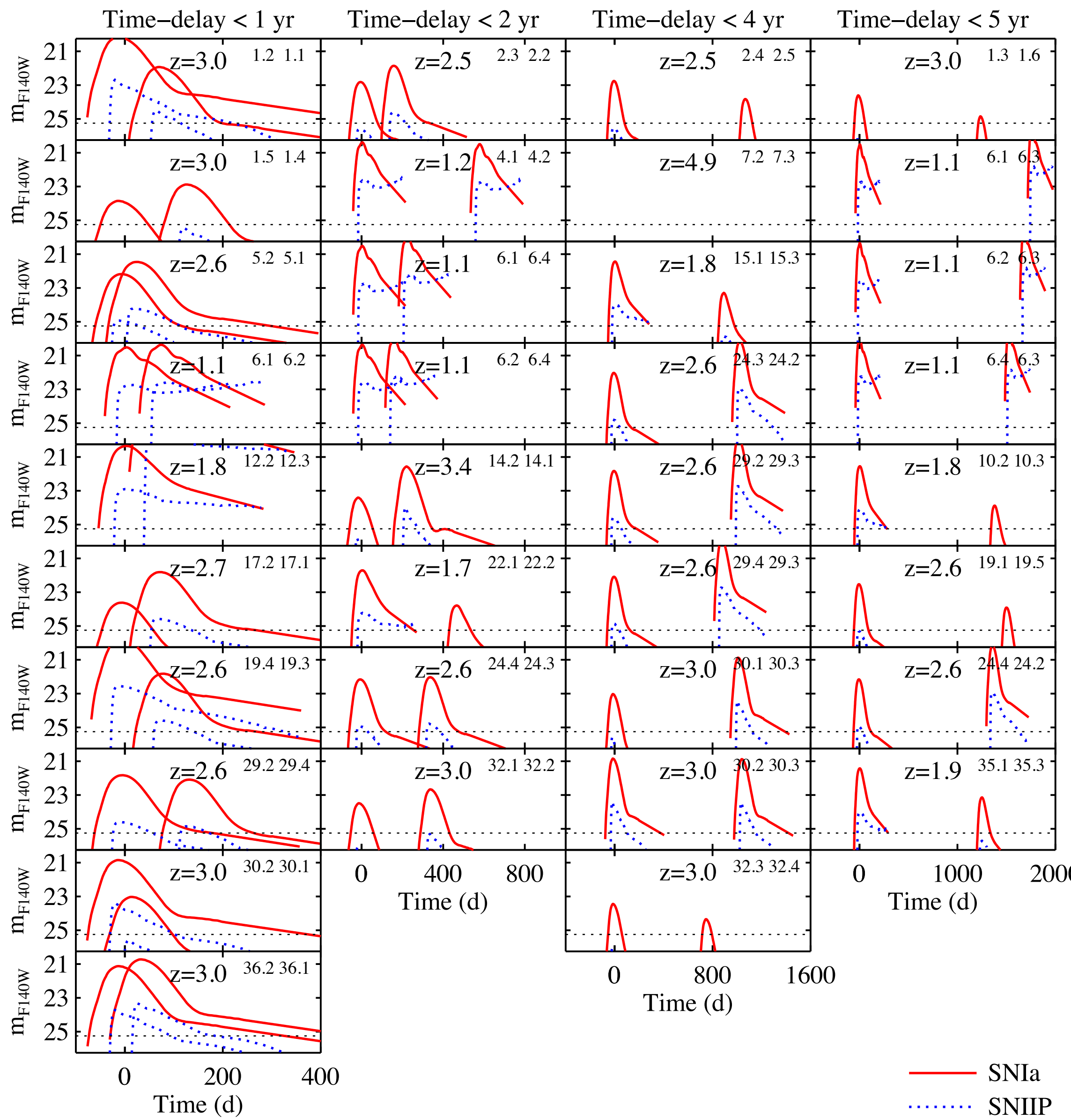








And with some luck… multiple images and independent way to measure cosmological distances, including H_0



Riehm et al

Summary

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- Multiple scattering on dust is a viable model for non-standard reddening laws.
- *Circumstellar dust* would be a “natural” set-up, at least for some SNe, and can be tested by (ongoing) UV and IR+sub-mm observations.
- We have found evidence for MgII in reddened SNLS SNe, i.e., signature of *interstellar dust* in the host galaxies, possibly associated with clouds of outflowing material.
- Studies of lensed SNe are very promising and our “best bet” today to explore SN properties at z~1.5 and beyond: it is feasible!