Status and prospects of SNIa cosmology

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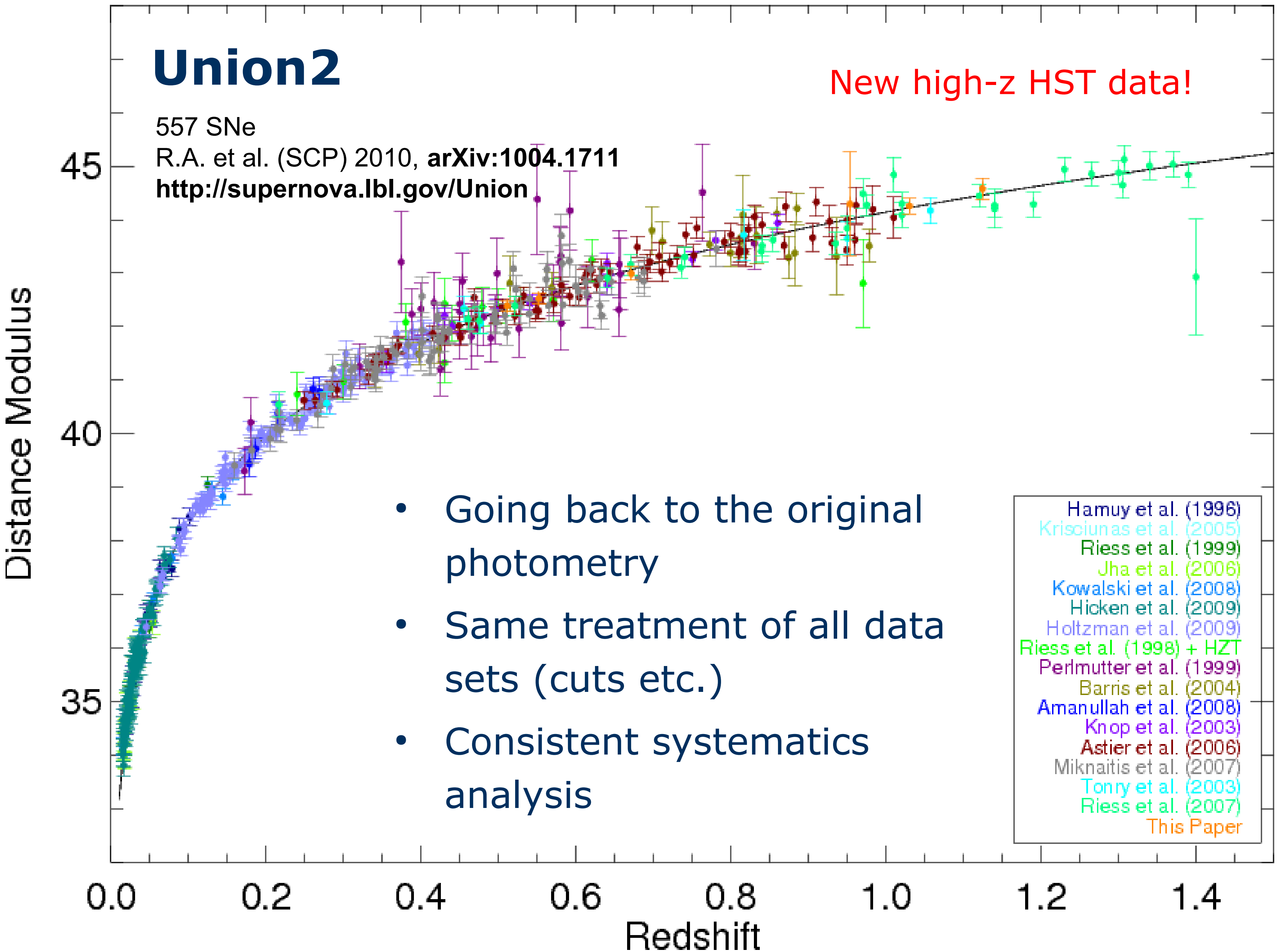
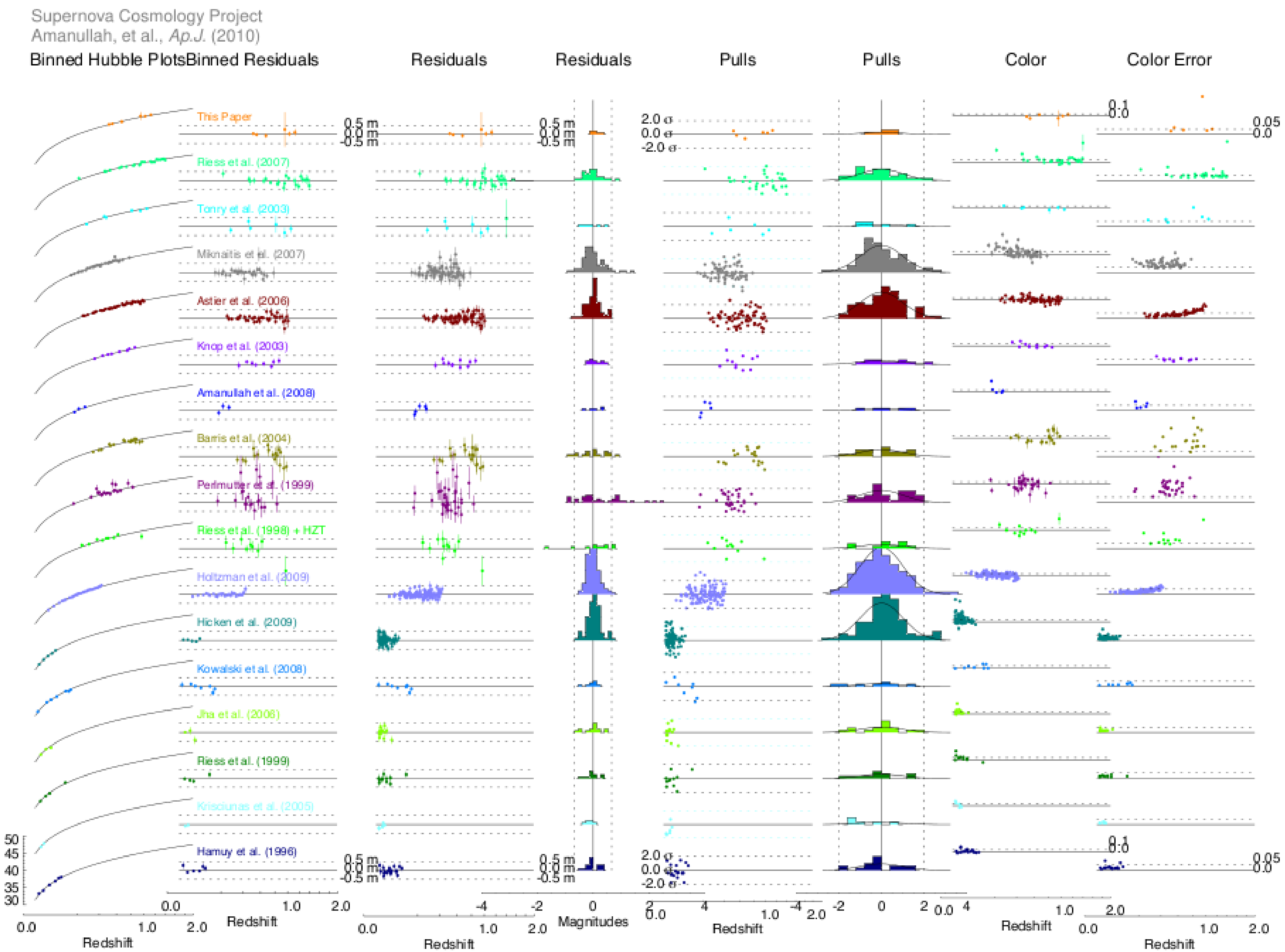
Union2

557 SNe
R.A. et al. (SCP) 2010, **arXiv:1004.1711**
http://supernova.lbl.gov/Union

New high-z HST data!

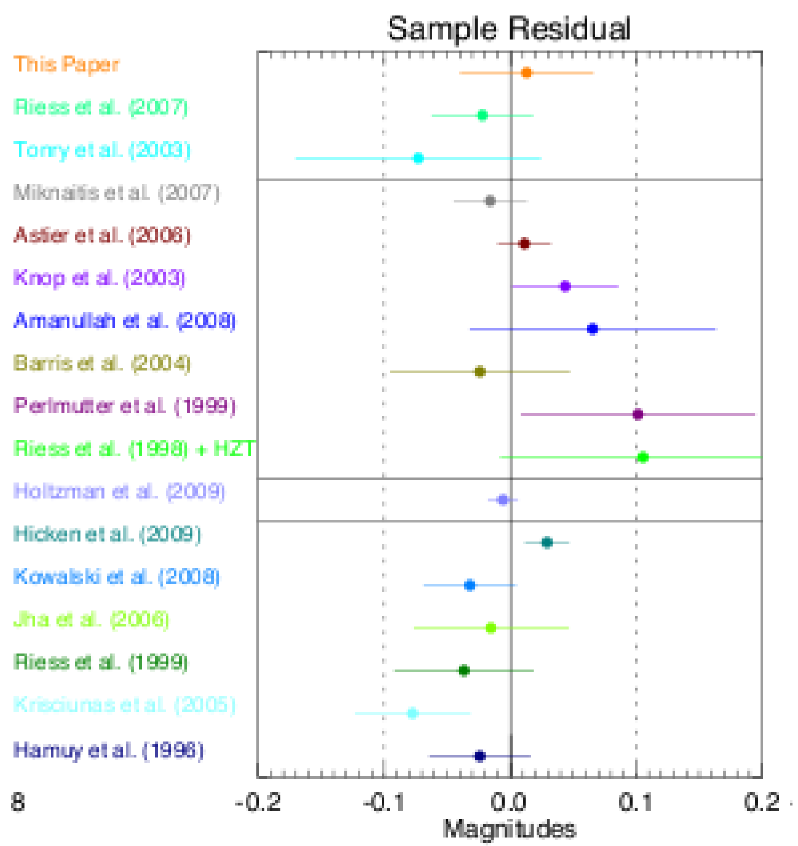


- Going back to the original photometry
- Same treatment of all data sets (cuts etc.)
- Consistent systematics analysis



Supernova Cosmology Project
Amanullah, et al., Ap.J. (2010)
Binned Hubble Plots
Binned Residuals
Residuals
Residuals
Pulls
Pulls
Color
Color Error
This Paper
Riess et al. (2007)
Tonry et al. (2003)
Miknaitis et al. (2007)
Astier et al. (2006)
Knop et al. (2003)
Amanullah et al. (2008)
Barris et al. (2004)
Perlmutter et al. (1999)
Riess et al. (1998) + HZT
Holtzman et al. (2009)
Hicken et al. (2009)
Kowalski et al. (2008)
Jha et al. (2006)
Riess et al. (1999)
Krisciunas et al. (2005)
Hamuy et al. (1996)
Redshift
Magnitudes

Tension between datasets?



Systematics impact on *w* for the Union2 sample

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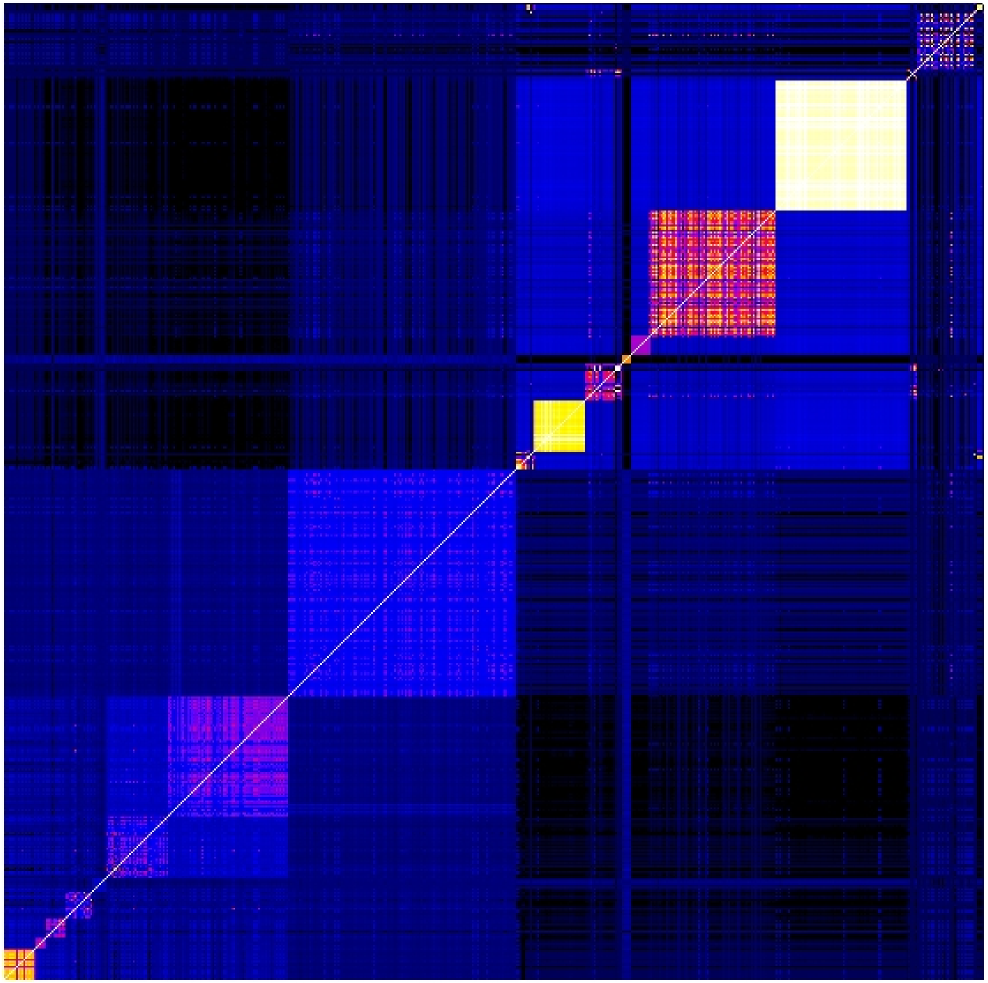
Table 9

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.

Correlated systematics for Union2

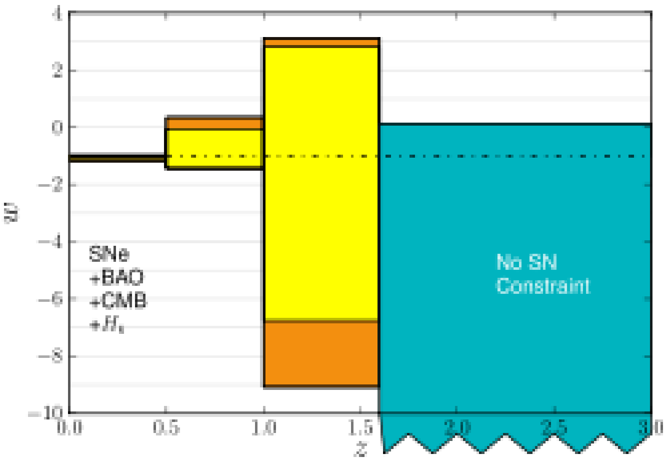


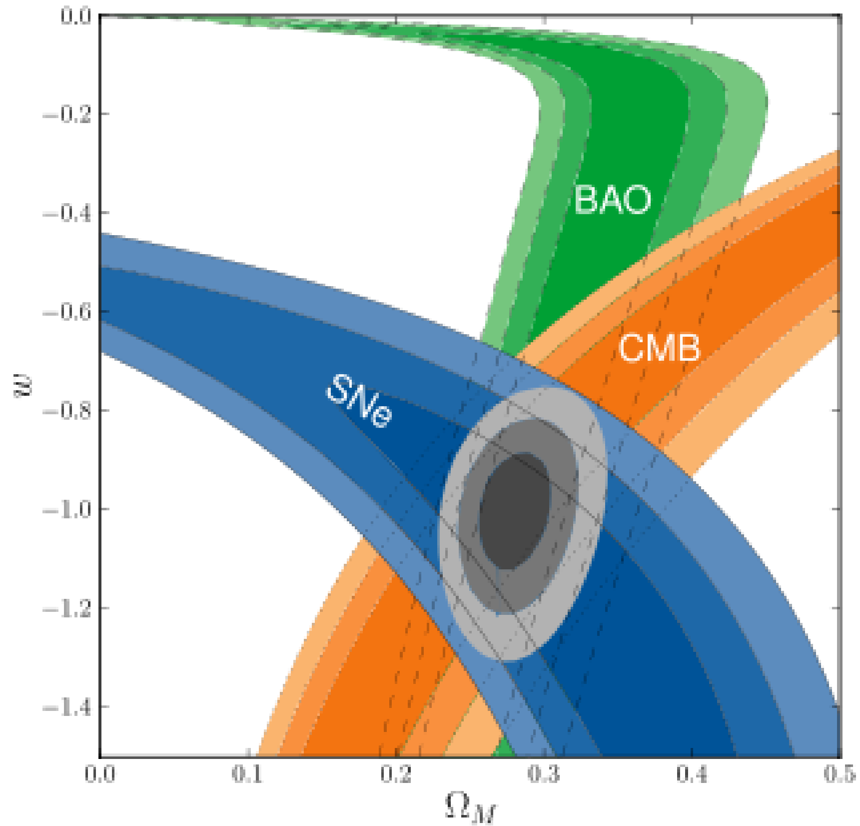
Cosmological constraints from Union2

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

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

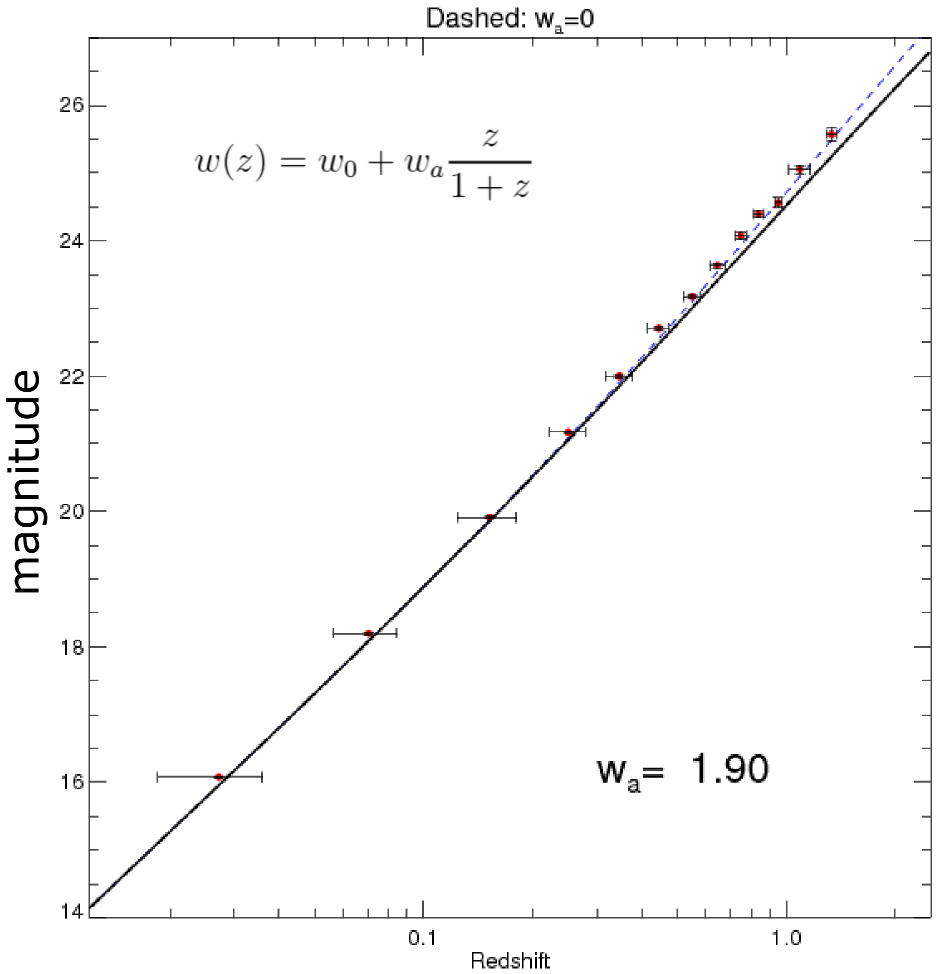
time-dependent *w*...





R.A. et al. (SCP), 2010

The challenge of SN Ia cosmology



A 5% change in w corresponds to a 1% change in distances out to z=1!

1) Improve SNe Ia as standard candles
2) Extend observations to higher redshifts

Supernova Ia cosmology HOWTO

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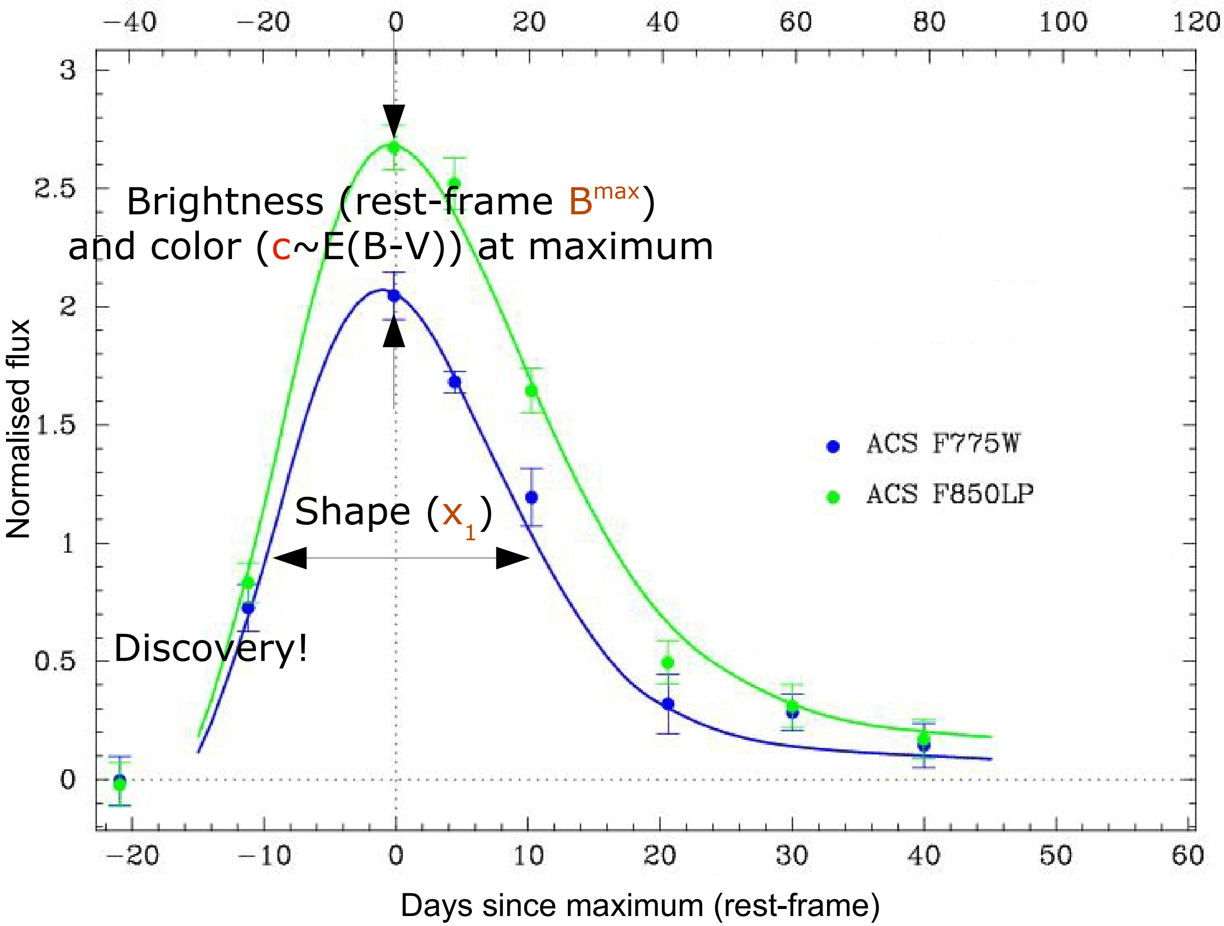
SN distance modulus | Cosmology

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



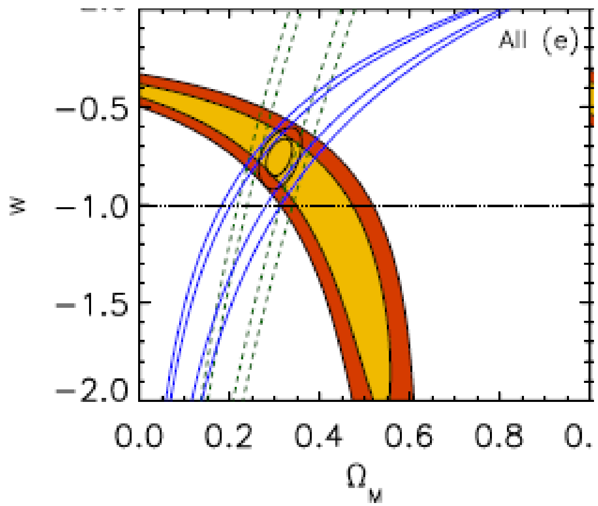
Measured SN properties

Fitted parameters

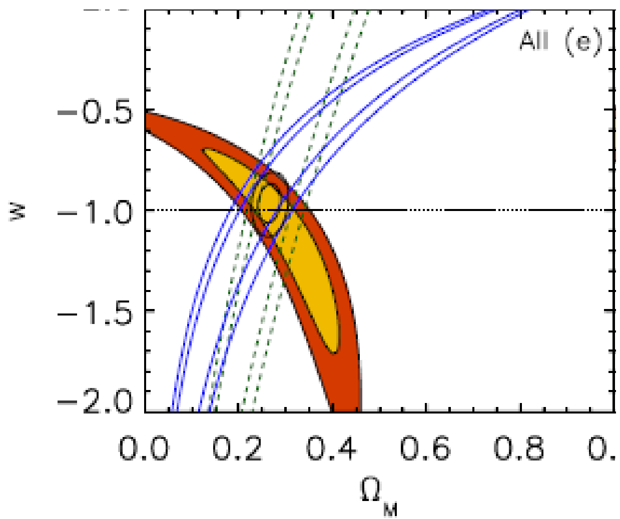
Fitted peak brightness can be color and light-curve shape corrected to form a standard candle that can be used for measuring relative cosmological distances.

The MLCS2k2 vs SALT2 discrepancy

MLCS2k2



SALT2



This deviation originates almost exclusively from the difference between the two fitters in the rest-frame *U*-band region, and the color prior used in MLCS2k2.

Kessler et al. (2009)

Why we used SALT2 for Union2

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- SALT2 and SiFTO (not yet public) performs better than than SALT and MLCS2k2 when judged by Hubble residual scatter (Conley et al. 2008)
- SALT2 and SiFTO produce consistent cosmological results when both are trained on the same data (Conley et al. 2008)
- MLCS2k2 is less accurate at predicting the rest-frame U -band using data from filters at longer wavelengths (Kessler et al. 2009)
- Our own MC study of agreement between fitted SALT2 parameters from a mock sample

Evolution?

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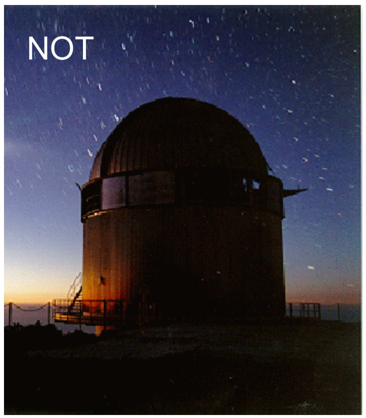
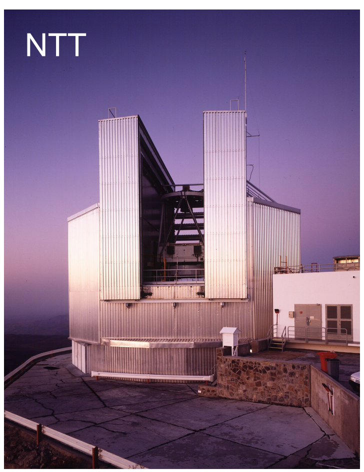
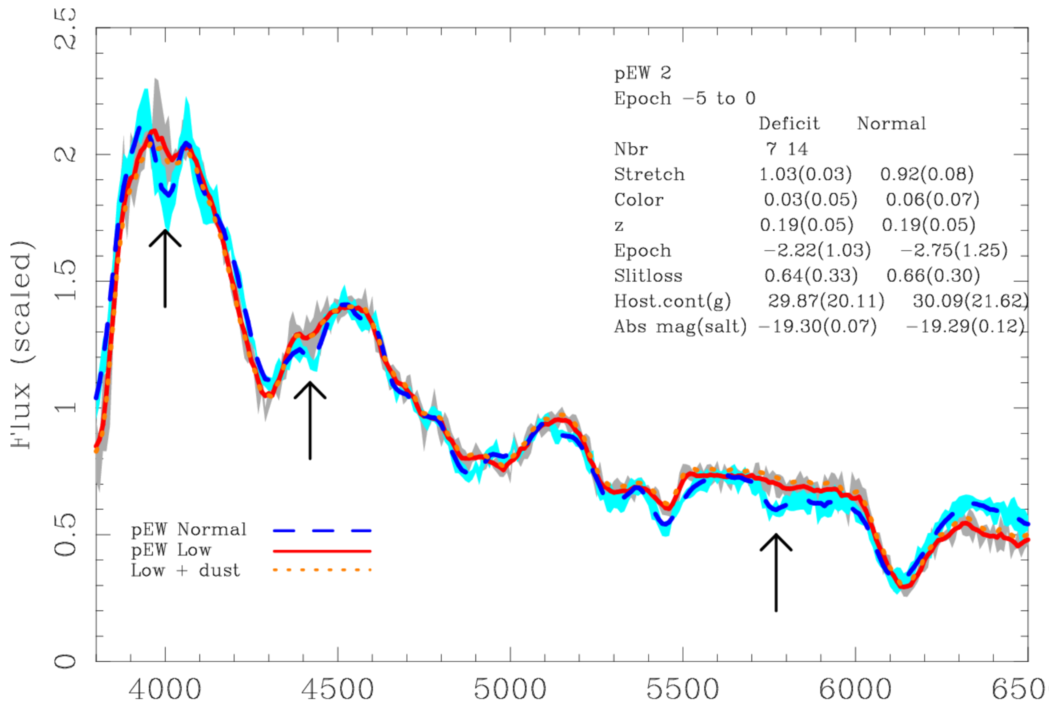




200 SN candidate SN spectra with NTT/NOT telescopes for the SDSS-II SN survey

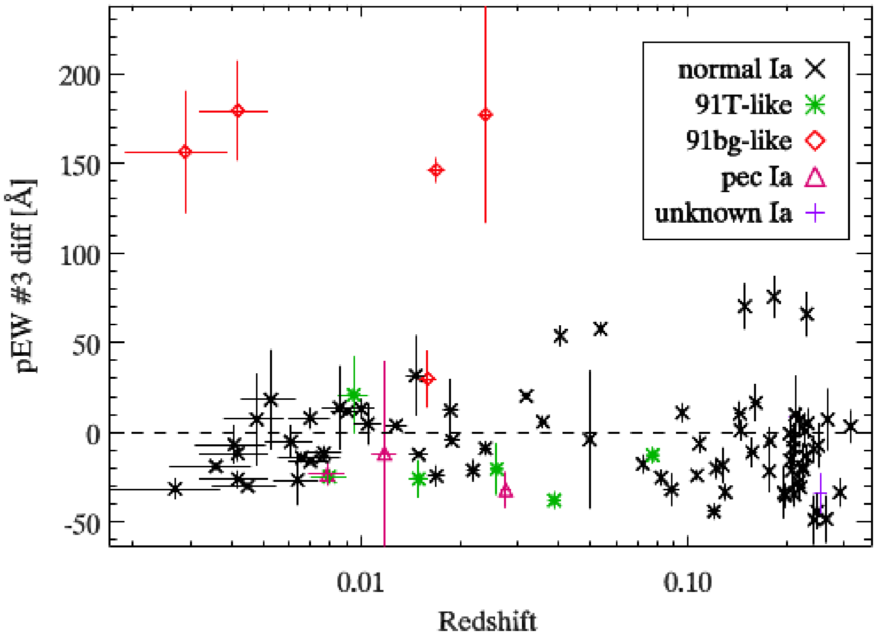
Östman et al. (2011)



Courtesy of Jakob Nordin

Evolution of spectroscopic features

- We do know that some demographic evolution takes place.
- If this is accounted for SNe at cosmological distances are indeed very similar to local!



Nordin et al. (2011)

SN properties vs host properties

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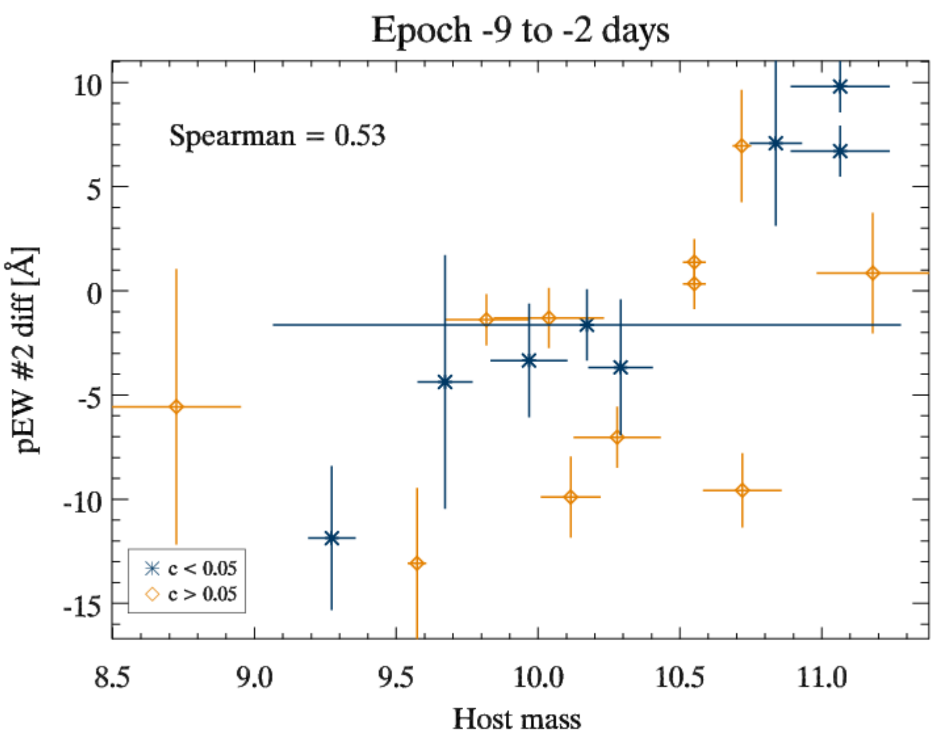
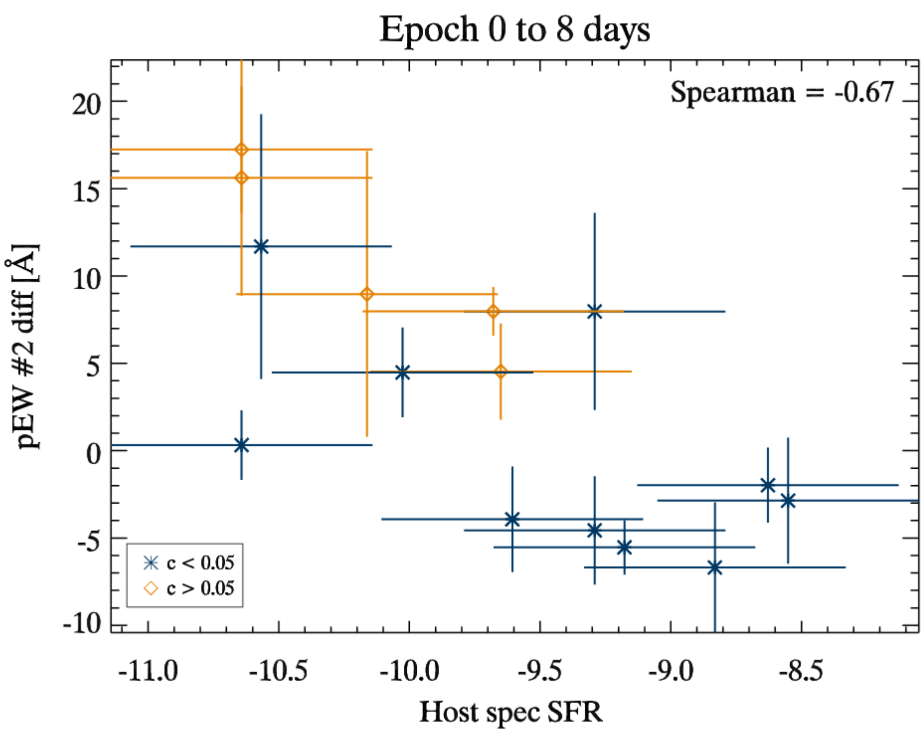


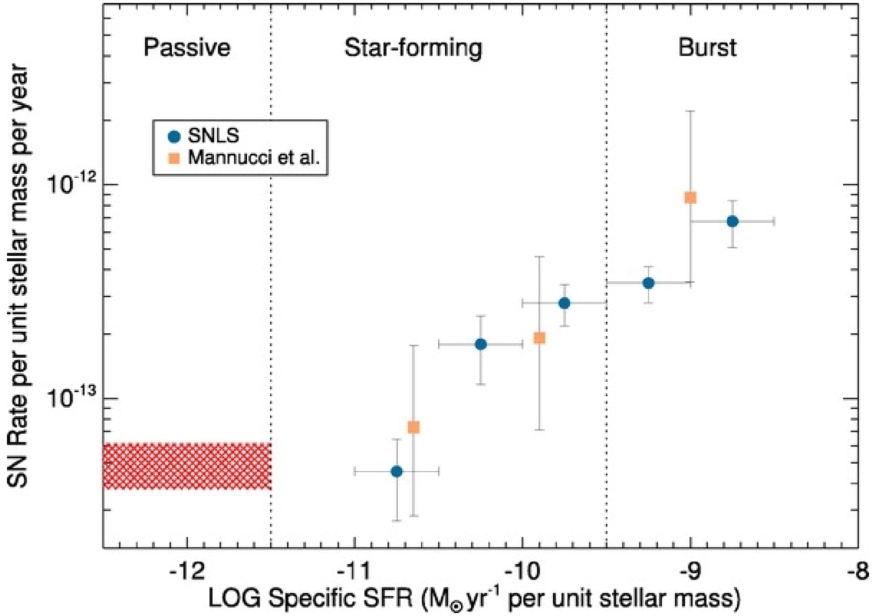


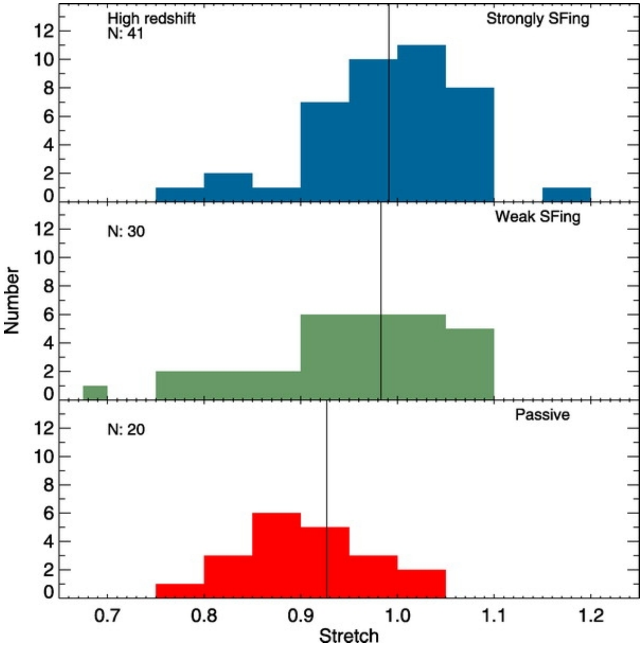
Nordin et al. (2011)

The SN Ia host environment

Red vs blue galaxies

Sullivan et al. (2006)





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., 2011 *submitted*)

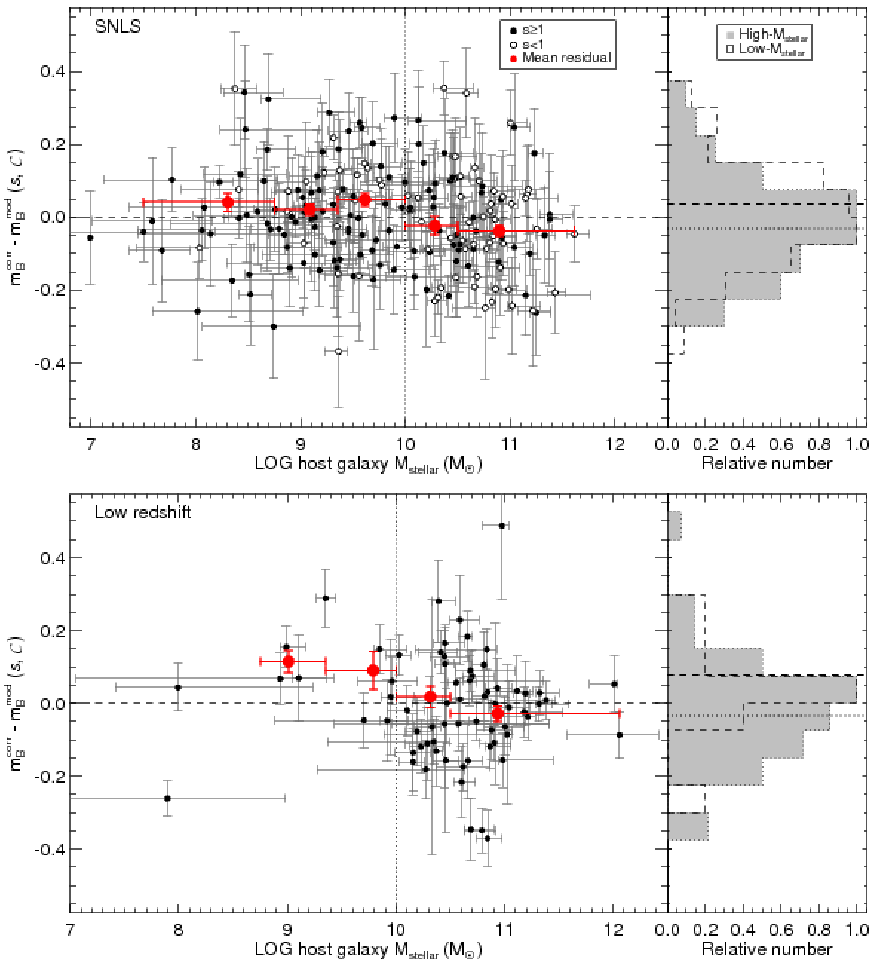
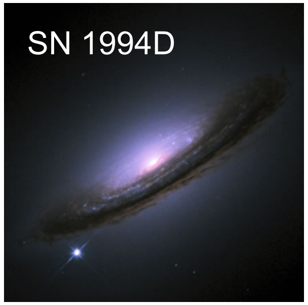


Figure 4. As Fig.3, but for $M_{\rm stellar}$ instead of sSFR.

Sullivan et al. (2010)



The origin of SN Ia reddening?

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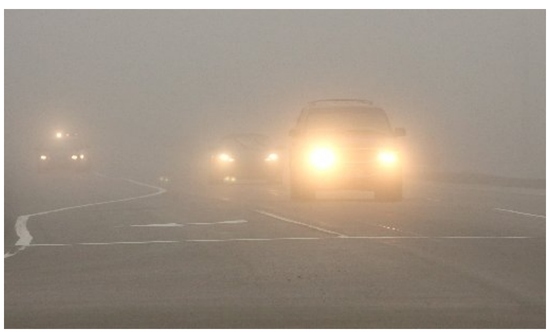
Probably not due to Milky Way-like dust!

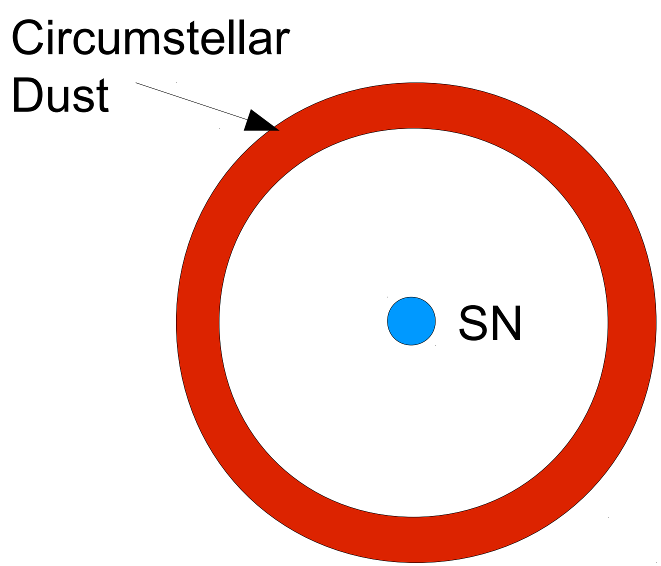
Extinction?



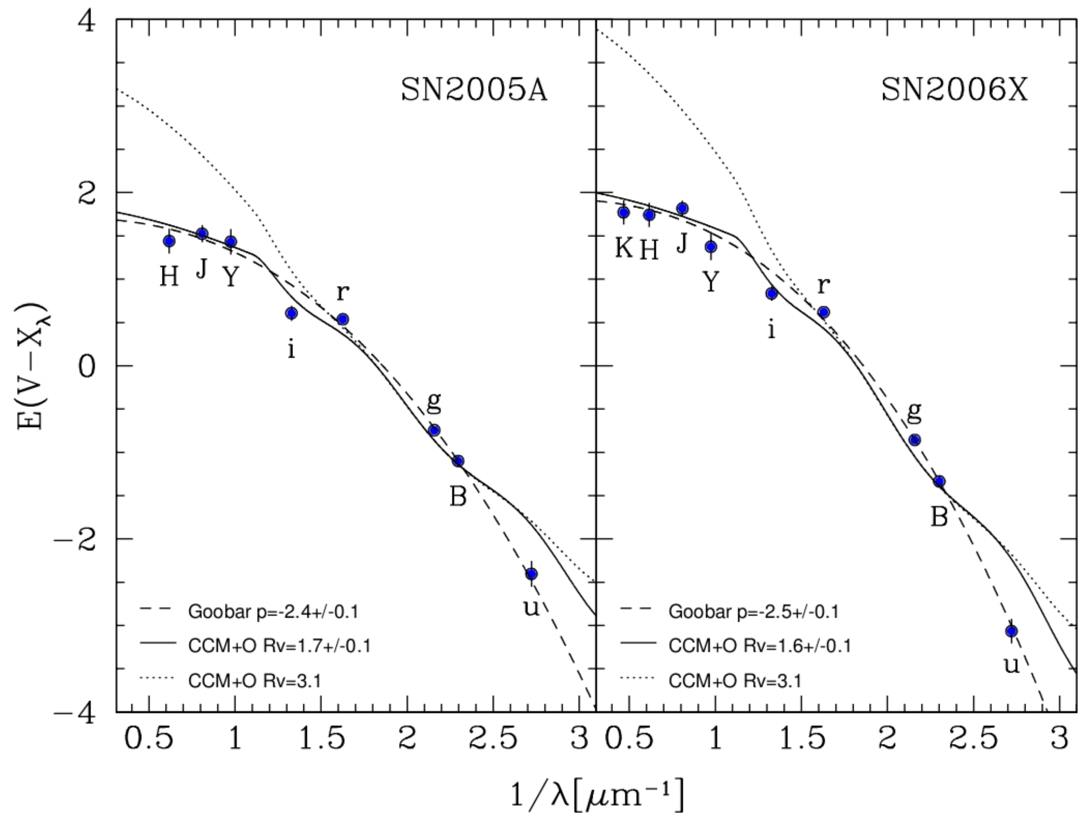
Intrinsic variations?

Circumstellar Dust

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



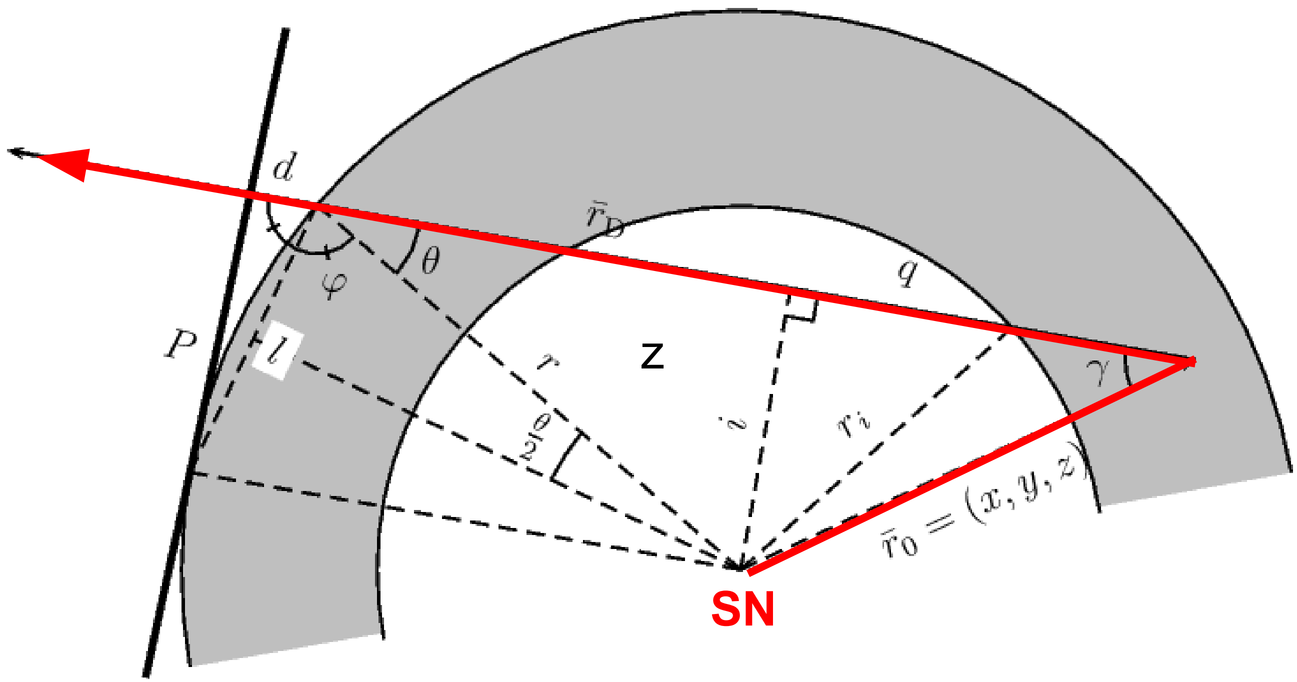
Folatelli et al. (2010)



Time delay of photons

Implications on SN Ia observables beyond the reddening law!

R.A. & Goobar (2011) arXiv:1103.1960



Time delay distribution

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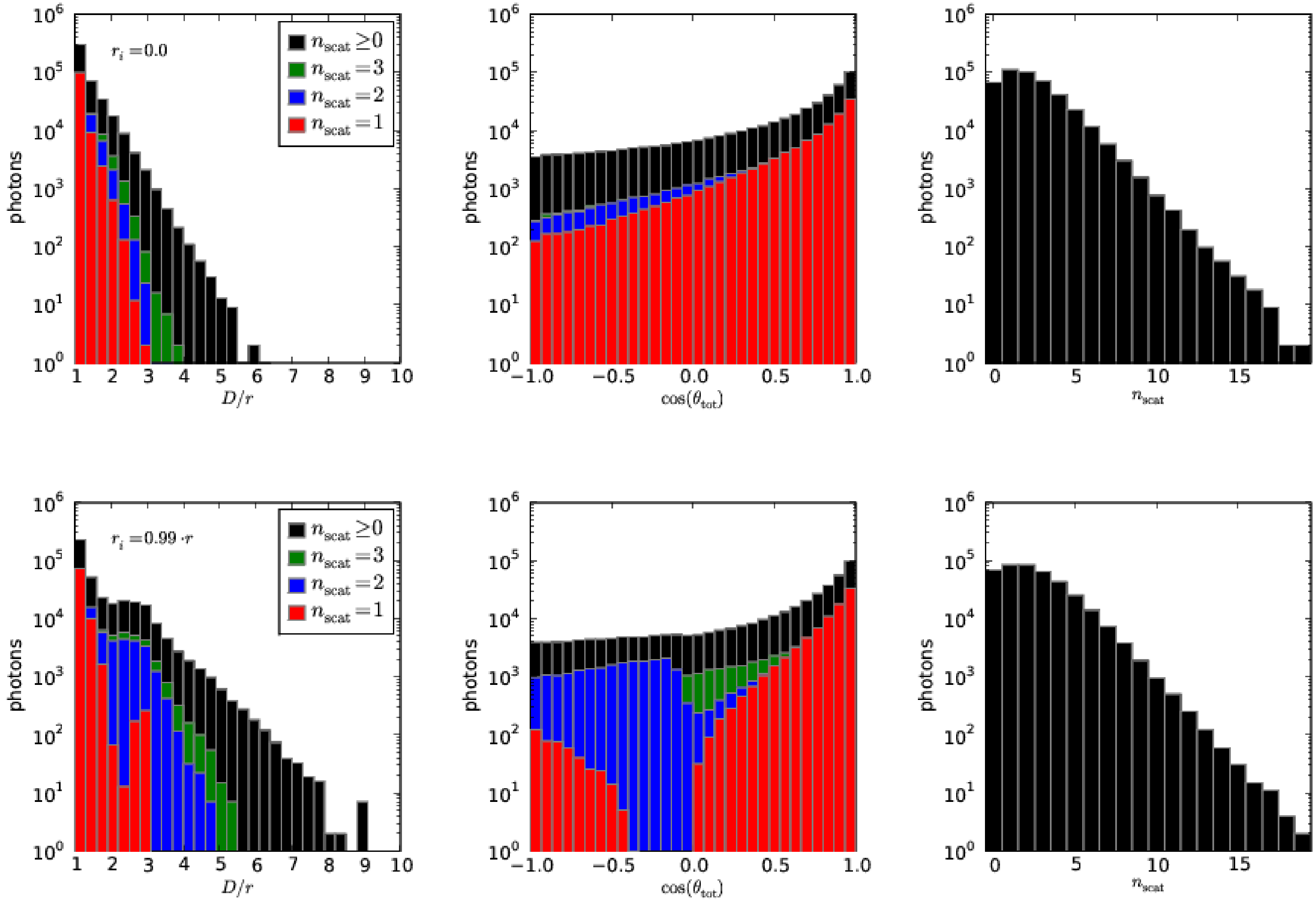
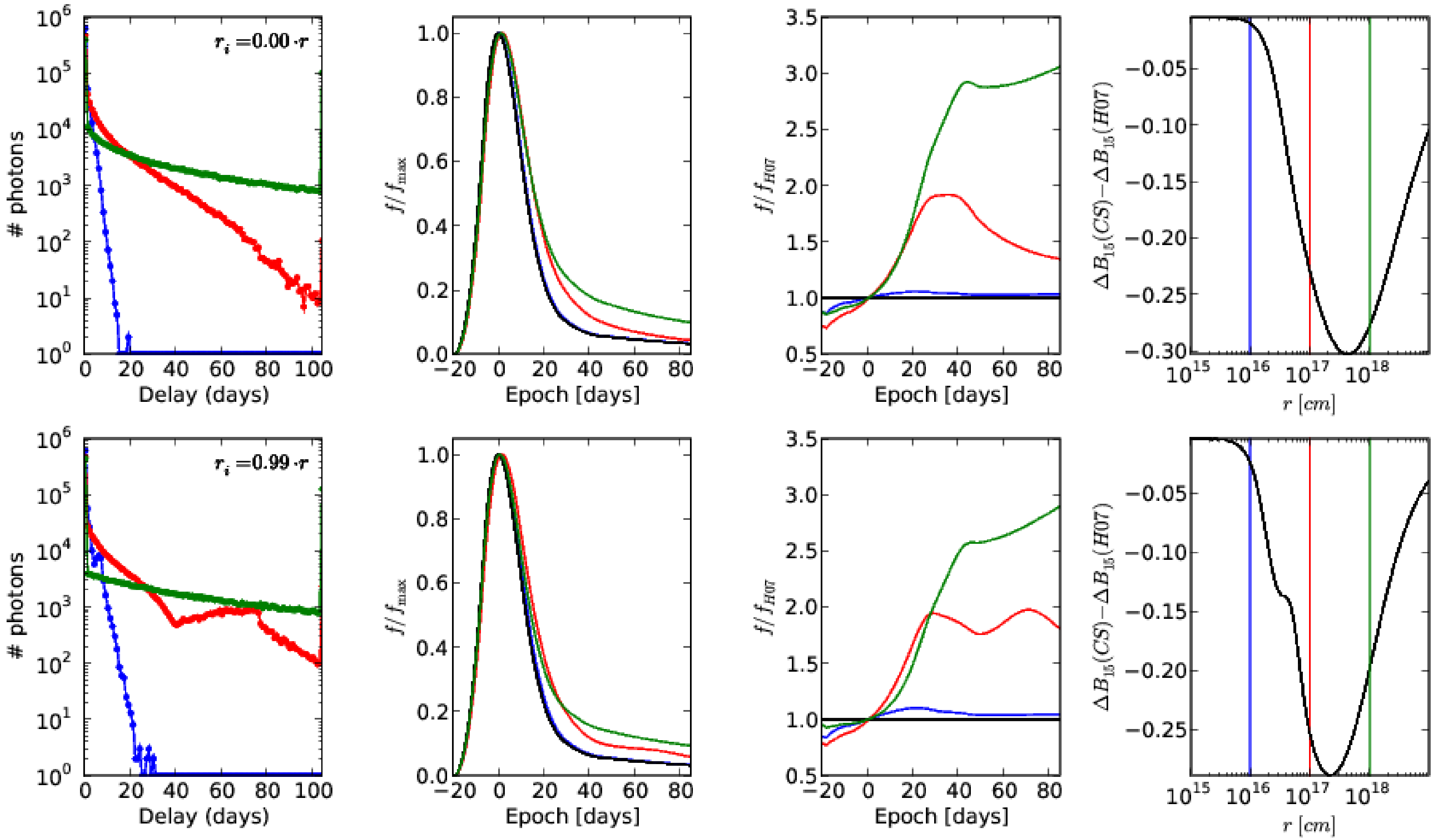
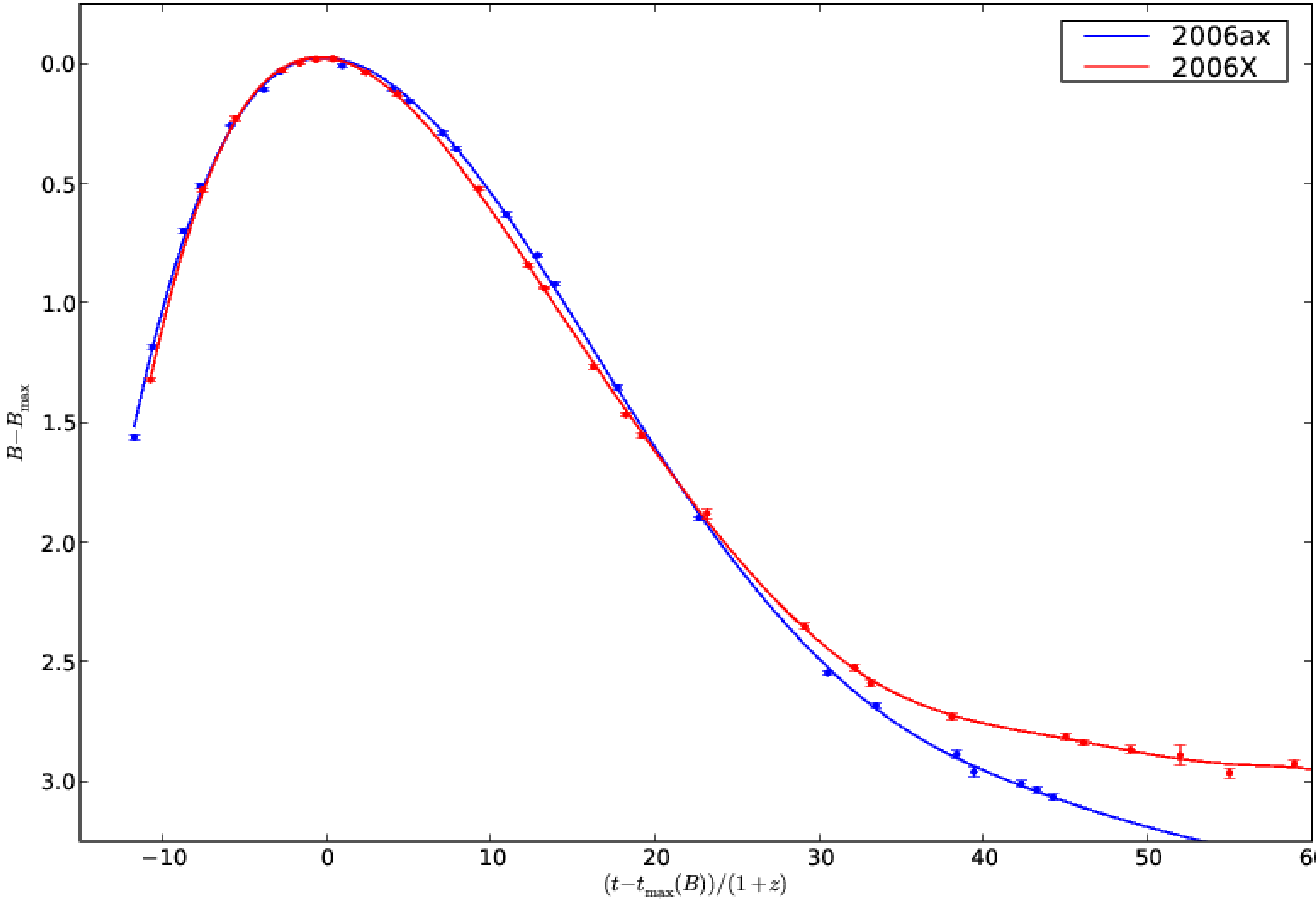


Convolving the Hsiao template





Folatelli et al. (2010)

Implications on lightcurve shape

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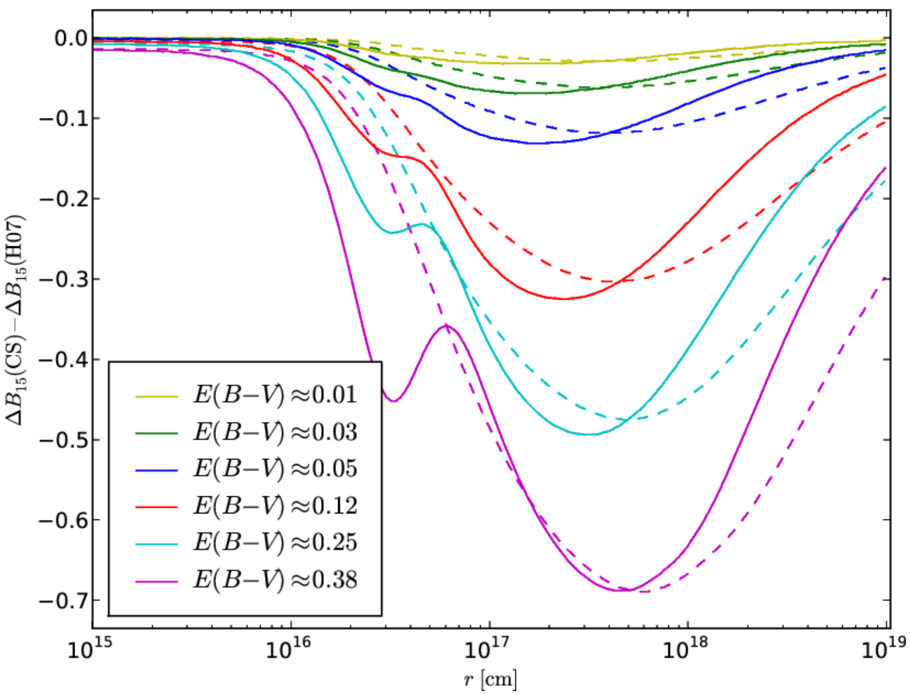
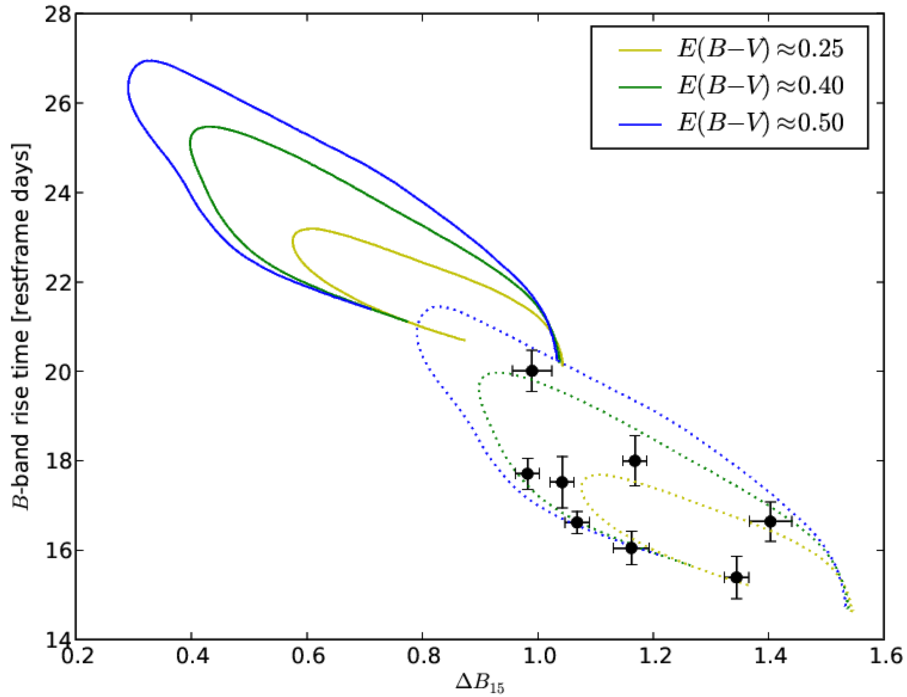
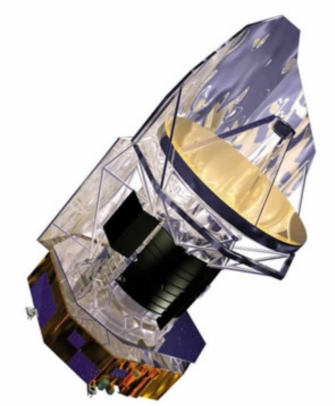




Re-emission of absorbed light

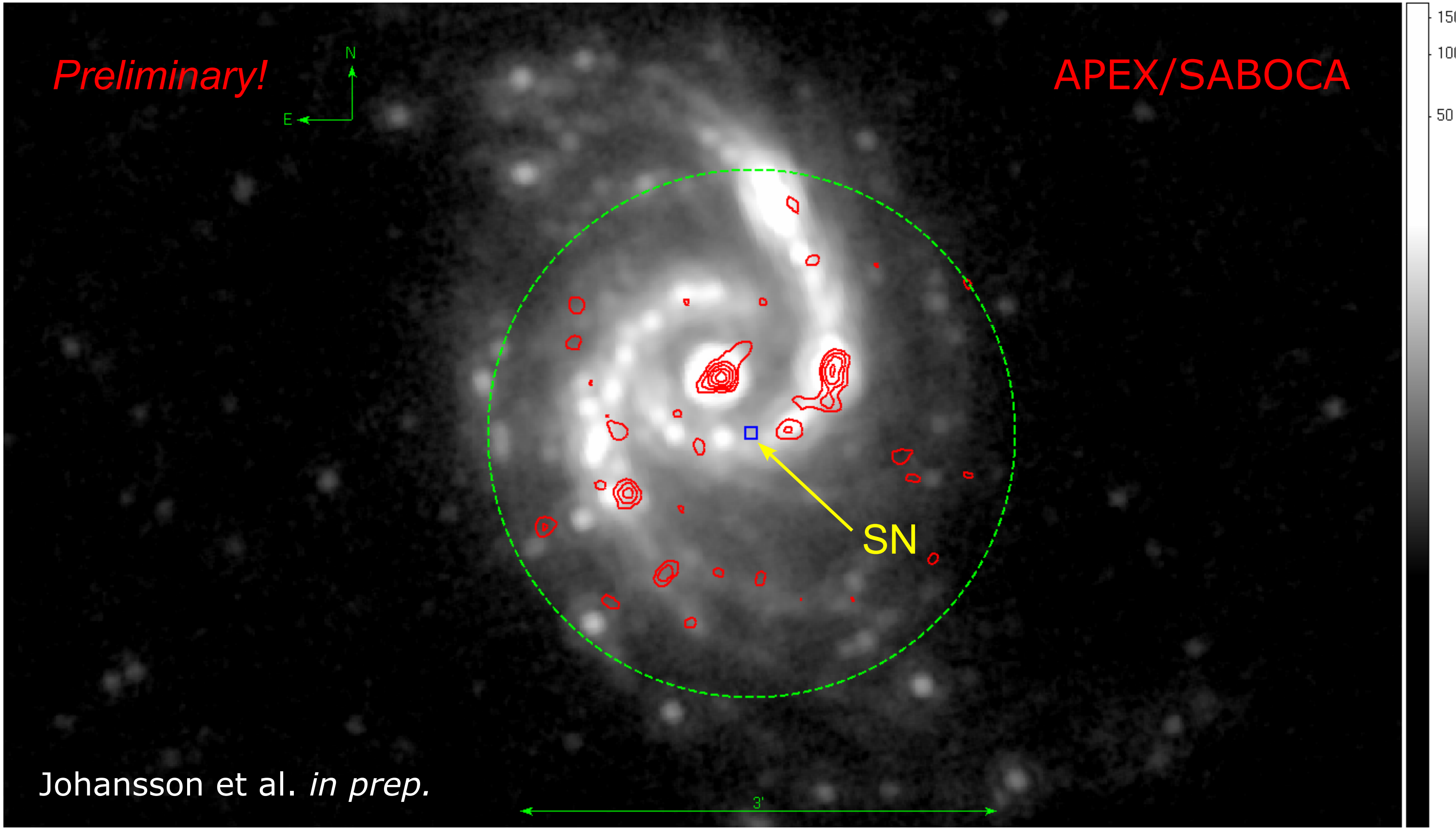
We have Apex and Herschel time to study reddened SNe Ia in sub-mm to search for re-emission.

APEX



Herschel

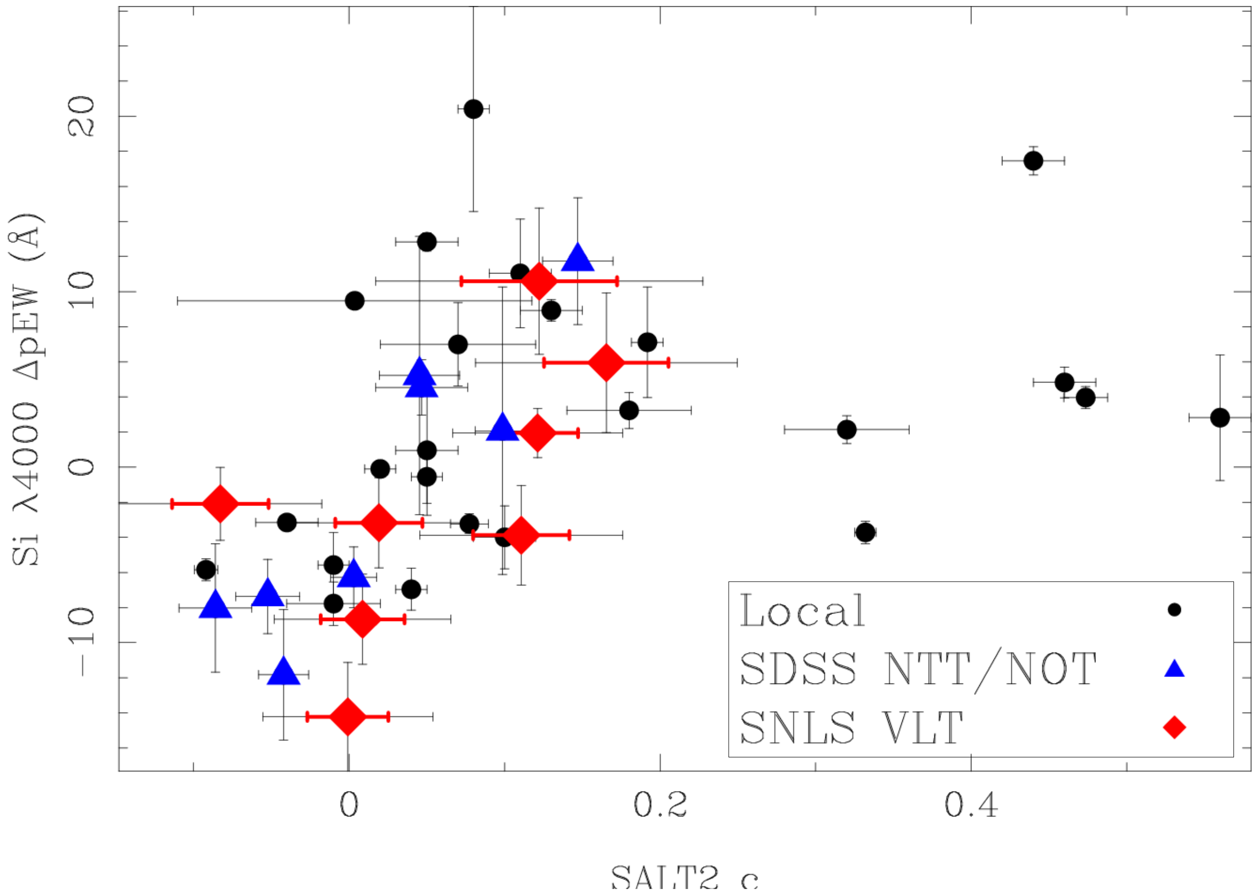
SN2010el


Preliminary!
N
E
APEX/SABOCA
150
100
50
SN
Johansson et al. *in prep.*
3'

CS dust and observables

- Striking differences in the UV for multiple scattering
- Lightcurve shape
  - CS gives Δm_{15} perturbations up to 1 mag
  - Falltime will be affected more than risetime
  - Lightcurve tail depends on CS shell radius
- Time of maximum between filters
- Color
  - No trivial relation between $(B-V)_0$ and Δm_{15}
  - Time dependent color excess (decreases with time)
- Blending of spectral features
  - Features become shallower from CS interaction
- Re-emission in sub-mm? (Apex/Herschel)

Different sources of reddening



Courtesy of Jakob Nordin

Reddening vs ejecta velocity?

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Wang et al. (2009)

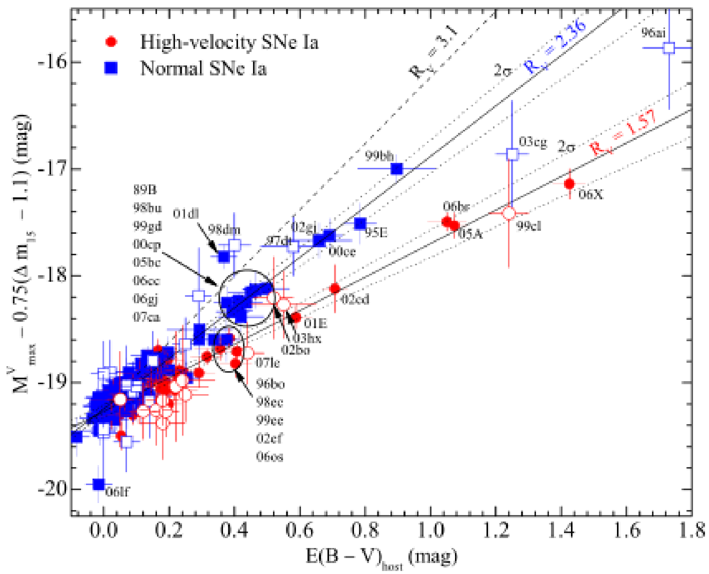
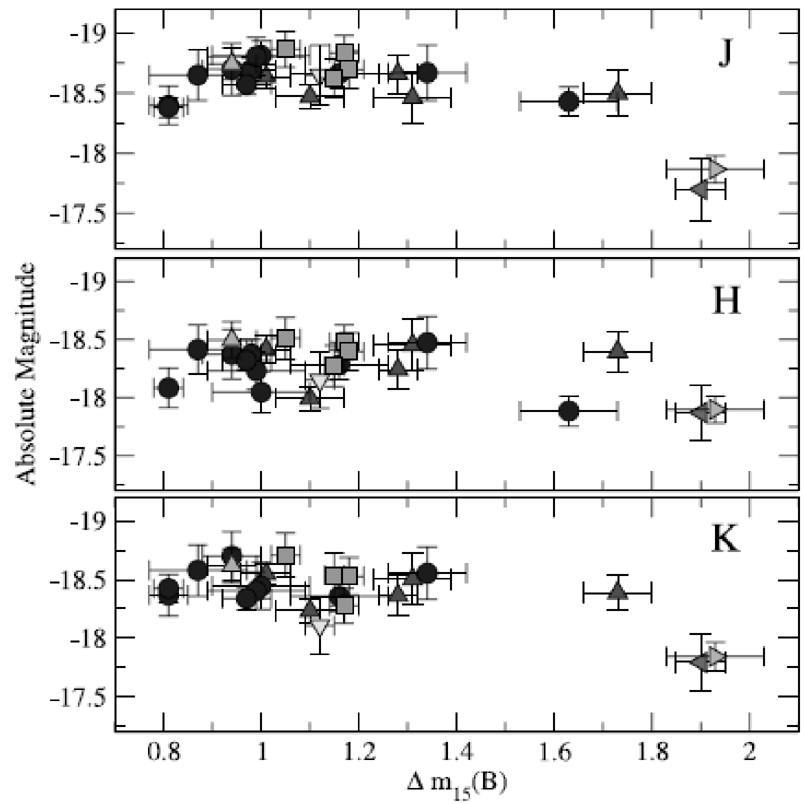


Figure 4. Δm_{15}-corrected absolute V mag at maximum brightness vs. the host-galaxy reddening. The filled symbols are SNe with $z \gtrsim 0.01$ or Cepheid-based distances, and the open symbols are nearby objects that were not included in the fit. The two solid lines show the best-fit R_V for SNe in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

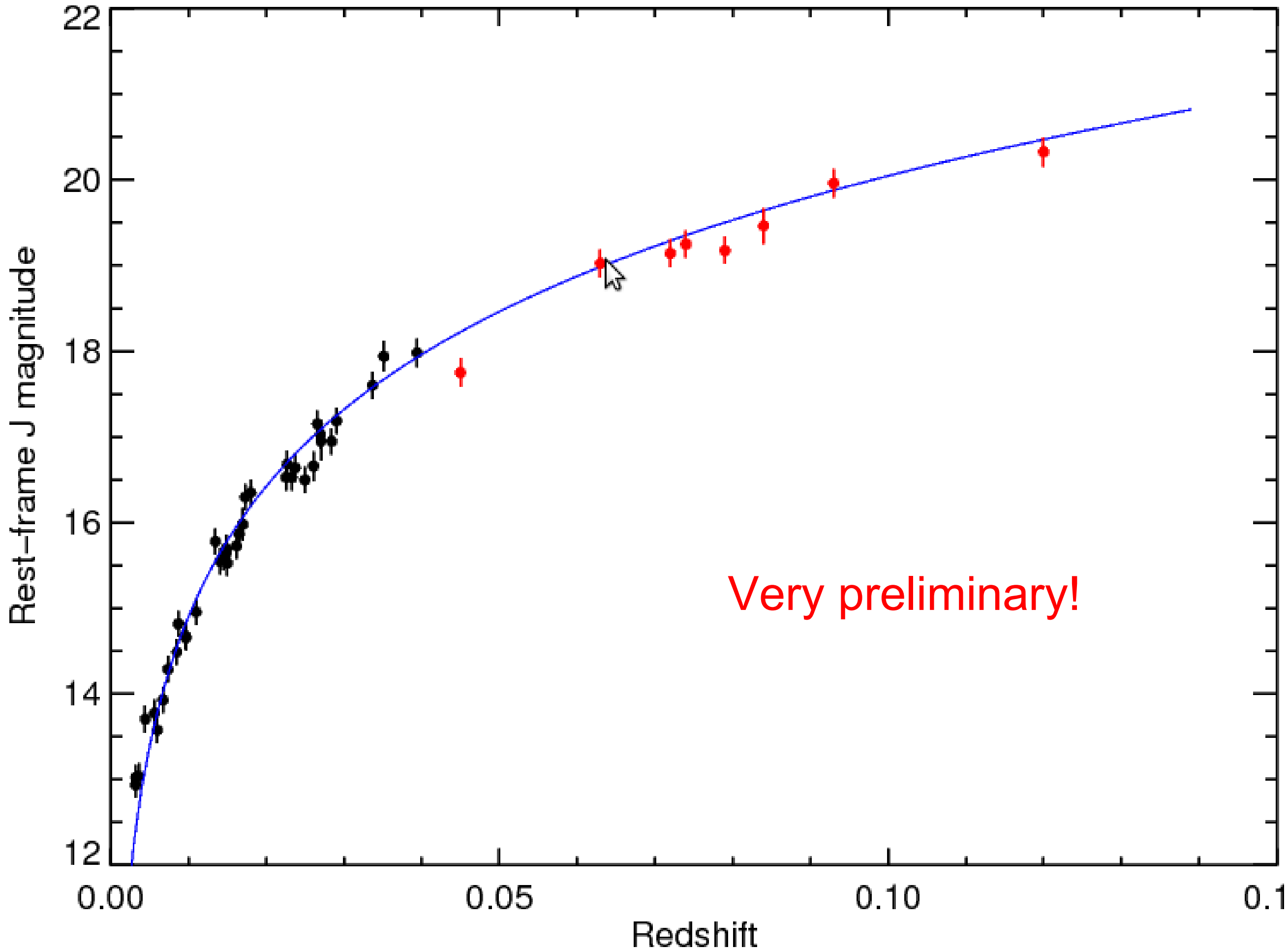
Type Ia SNe in the NIR

- SNe Ia do not require LC-shape correction
- Less affected by extinction
- Better standard candles
- But... low flux, and much more difficult to observe

Krisciunas et al. (2004)



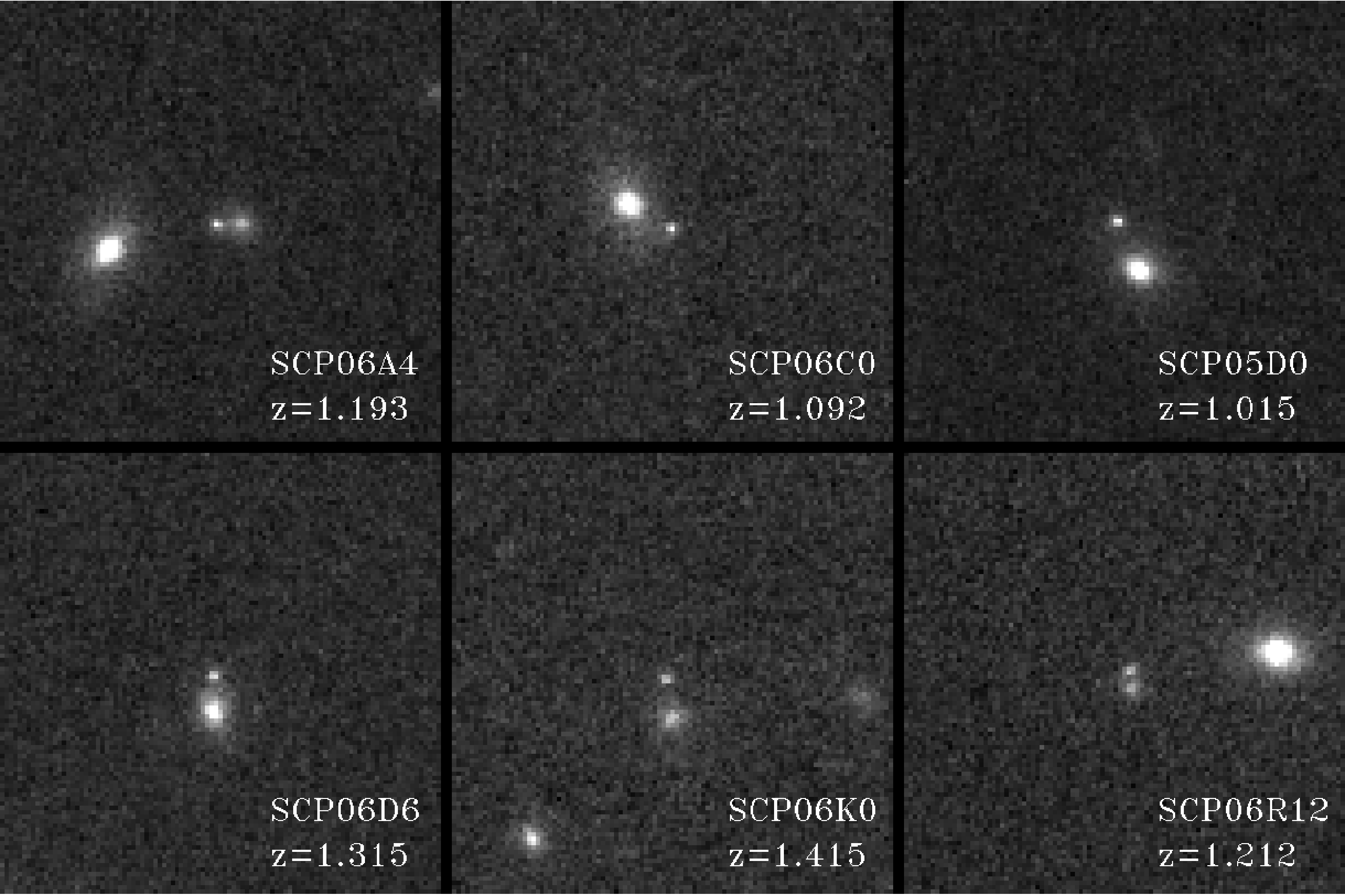
Building up the NIR Hubble diagram



Stanishev et al. *in prep*

Searching for Type Ia SNe in distant galaxy clusters

- Rich clusters → more SN Ia discoveries within a small FoV.
- But also other advantages:
  - Only SNe of type Ia occur in cluster ellipticals.
  - Cluster ellipticals generally have relatively little dust.
- Collaboration lead by the Supernova Cosmology Project
  - Rolling search, 219 HST orbits with ACS *i* and *z* bands and NICMOS J
  - Targeting 25 clusters at $0.9 < z < 1.5$


SCP06A4
z=1.193
SCP06C0
z=1.092
SCP05D0
z=1.015
SCP06D6
z=1.315
SCP06K0
z=1.415
SCP06R12
z=1.212

SN survey of the cluster project

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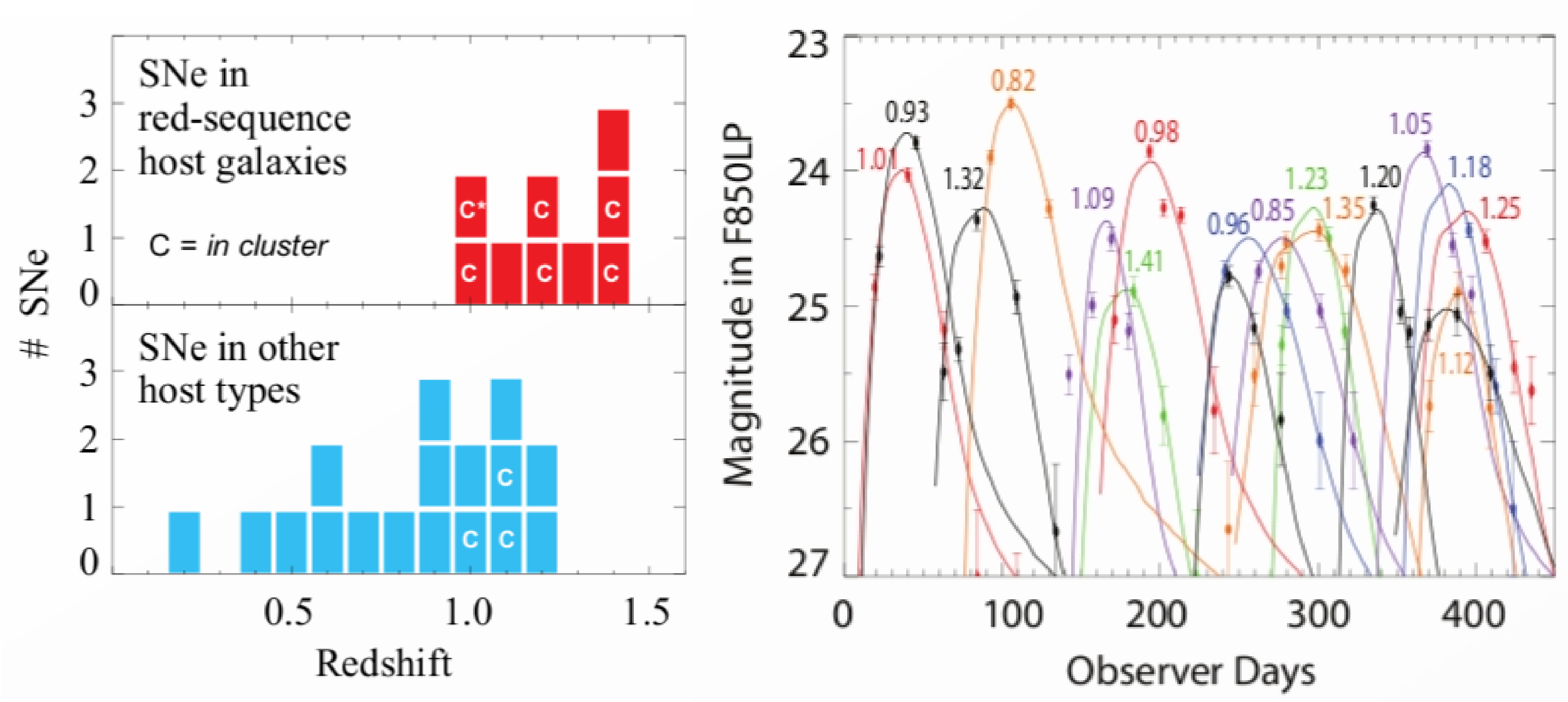
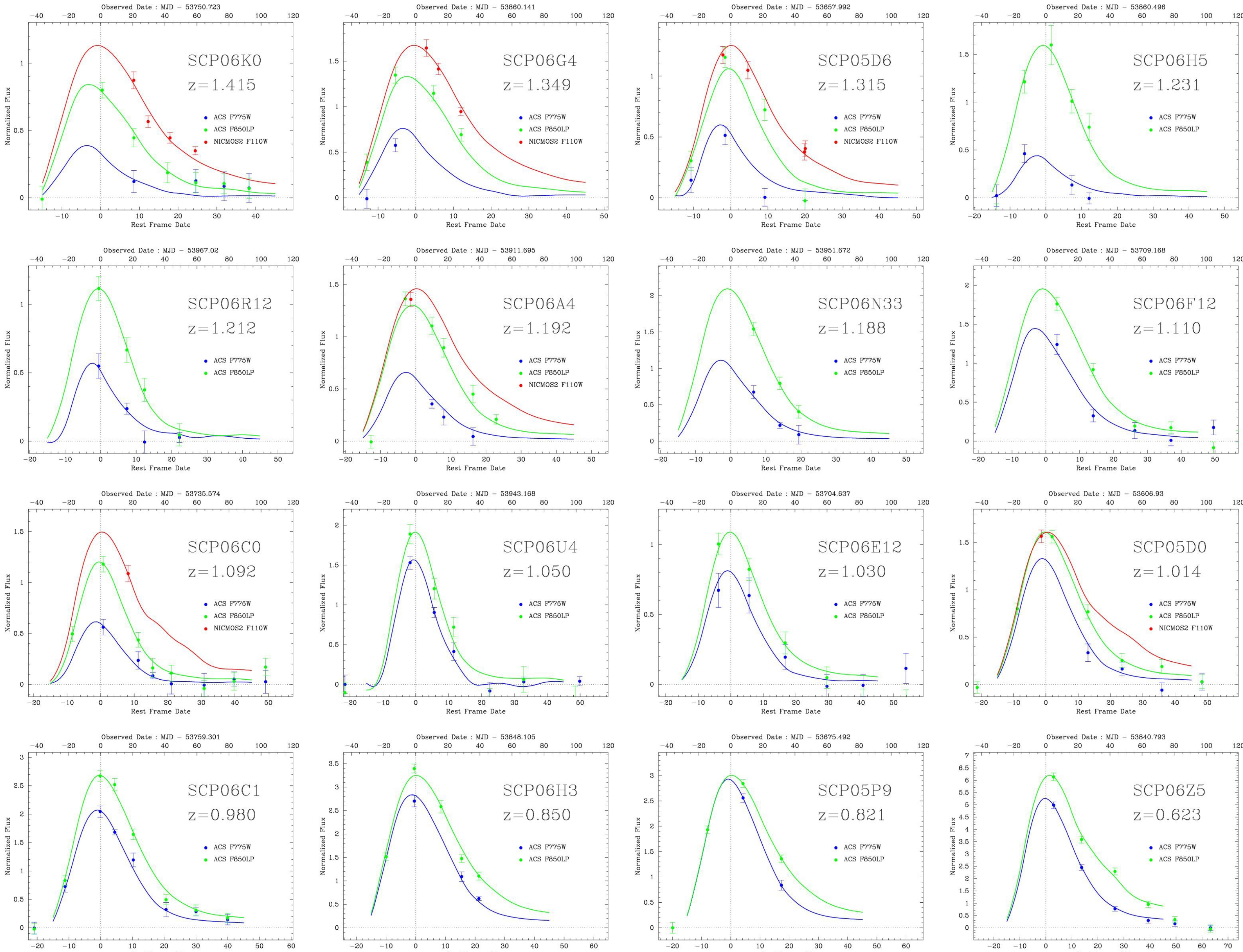


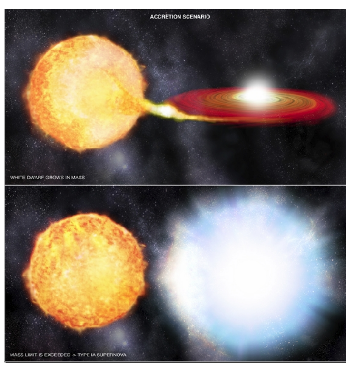
Dawson et al. (2009)


Observed Date : MJD − 53750.723
SCP06K0
z=1.415
ACS F775W
ACS F850LP
NICMOS2 F110W
Observed Date : MJD − 53860.141
SCP06G4
z=1.349
ACS F775W
ACS F850LP
NICMOS2 F110W
Observed Date : MJD − 53657.992
SCP05D6
z=1.315
ACS F775W
ACS F850LP
NICMOS2 F110W
Observed Date : MJD − 53860.496
SCP06H5
z=1.231
ACS F775W
ACS F850LP
Observed Date : MJD − 53967.02
SCP06R12
z=1.212
ACS F775W
ACS F850LP
Observed Date : MJD − 53911.695
SCP06A4
z=1.192
ACS F775W
ACS F850LP
NICMOS2 F110W
Observed Date : MJD − 53951.672
SCP06N33
z=1.188
ACS F775W
ACS F850LP
Observed Date : MJD − 53709.168
SCP06F12
z=1.110
ACS F775W
ACS F850LP
Observed Date : MJD − 53735.574
SCP06C0
z=1.092
ACS F775W
ACS F850LP
NICMOS2 F110W
Observed Date : MJD − 53943.168
SCP06U4
z=1.050
ACS F775W
ACS F850LP
Observed Date : MJD − 53704.637
SCP06E12
z=1.030
ACS F775W
ACS F850LP
Observed Date : MJD − 53606.93
SCP05D0
z=1.014
ACS F775W
ACS F850LP
NICMOS2 F110W
Observed Date : MJD − 53759.301
SCP06C1
z=0.980
ACS F775W
ACS F850LP
Observed Date : MJD − 53848.105
SCP06H3
z=0.850
ACS F775W
ACS F850LP
Observed Date : MJD − 53675.492
SCP05P9
z=0.821
ACS F775W
ACS F850LP
Observed Date : MJD − 53840.793
SCP06Z5
z=0.623
ACS F775W
ACS F850LP
Normalized Flux
Rest Frame Date

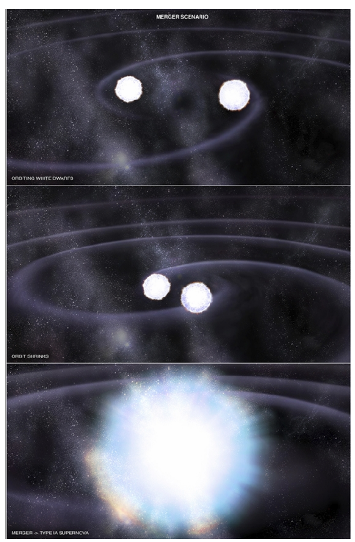
SN Ia rate in high-z clusters

Measuring the delay time distribution is an effective method for constraining the progenitor scenario

Single degenerate



Double degenerate



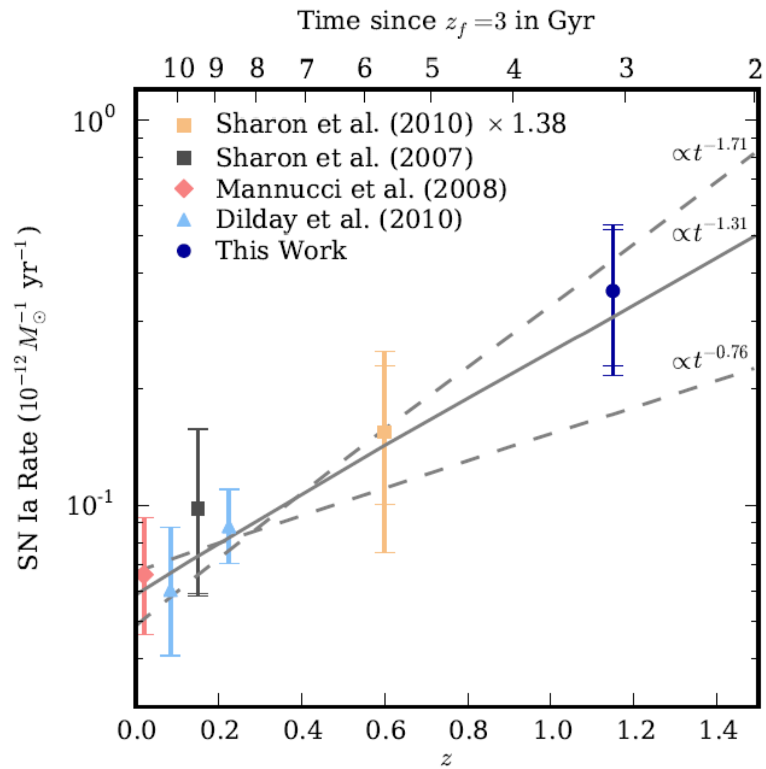


Figure 14. Cluster rate measurements (all galaxy types) from this work and the literature. The rate of Sharon et al. (2010) shown has been adjusted upward by 38% from the reported rate (see text). The top axis shows the time elapsed since an assumed cluster formation redshift of $z_f = 3$. The *solid grey line* represents the best-fit power-law DTD ($\Psi(t) \propto t^s$), while the *dotted grey lines* show the range of 1σ error on s.

Barbary et al. (2011)

New exotic objects

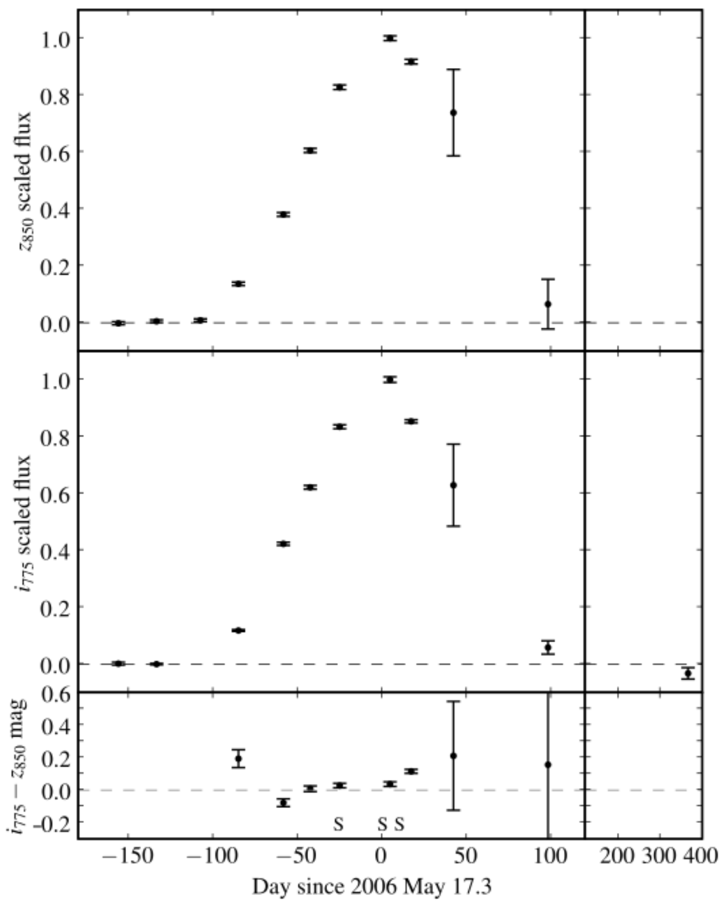


Figure 2. Flux light curve for z_{850} (top panel) and i_{775} (middle panel) scaled to maximum flux. The last three epochs (starting at +42 days) are Subaru FOCAS observations. Bottom panel: $i_{775} - z_{850}$ color for epochs with significant detection in both bands. Though the color only varies ~ 0.2 mag among the five best measured epochs, there is evidence for evolution. The spectral epochs are marked along the abscissa with an "S."

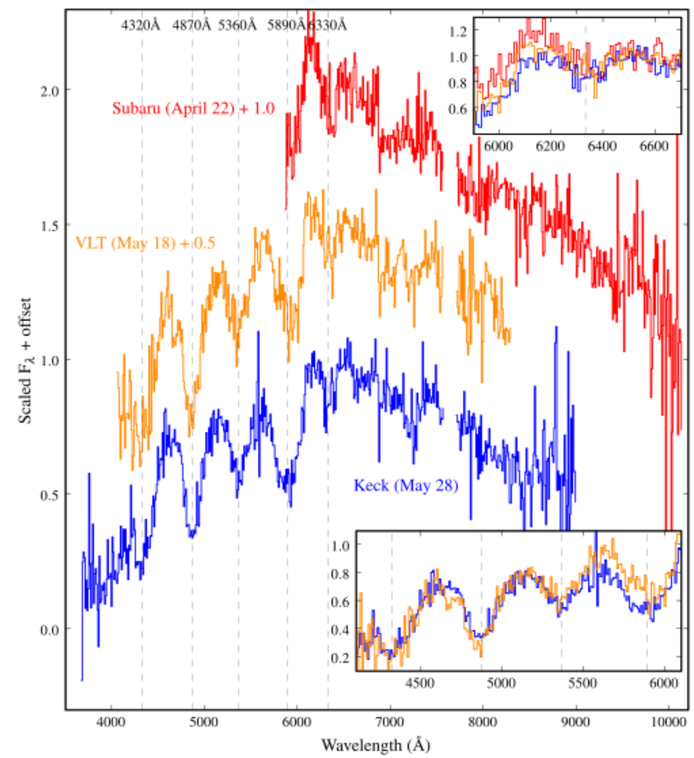


Figure 3. Spectra averaged in 10 Å bins. Vertical dotted lines indicate the approximate absorption-band centroids. Spectra are normalized to match in the red continuum. Inset figures show regions where the spectra differ. Top inset: overplot of all three spectra (no offset) in the range 5900–6700 Å, demonstrating apparent evolution of the flux at ~ 6150 Å relative to the red continuum. Bottom inset: overplot of the VLT and Keck spectra (no offset) demonstrating apparent evolution at 4670 Å and of the absorption feature at 5890 Å. The spectra are available in tabular form within a tar.gz file from the online journal.

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

Barbary et al. (2009)

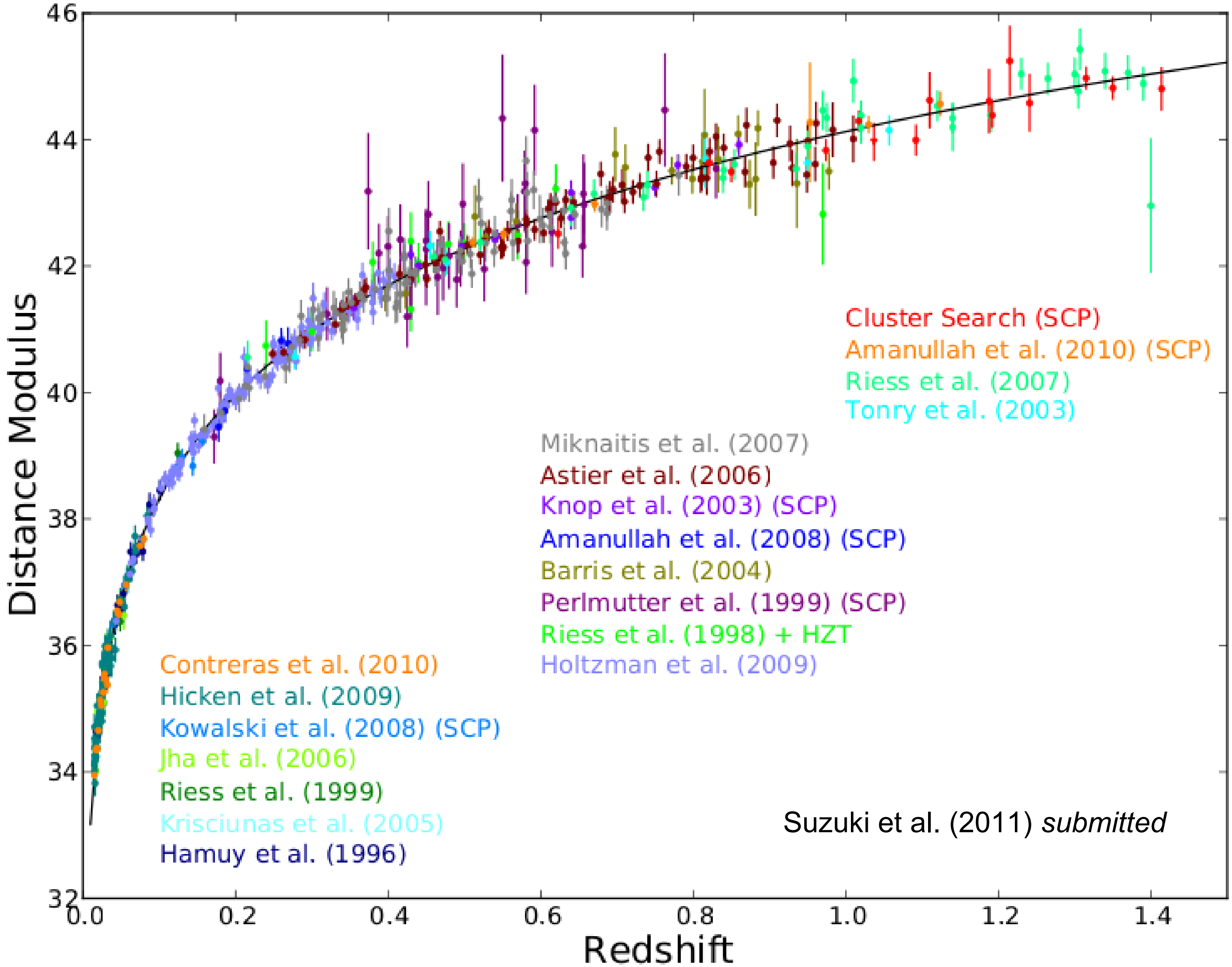


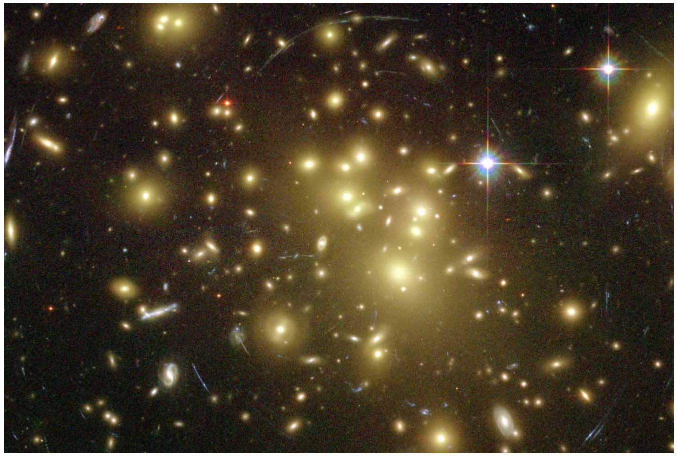
Figure 4. Hubble diagram for the Union2.1 compilation. The solid line represents the best fitted cosmology for a flat Universe for supernovae alone. SN SCP06U4 falls outside the allowed x_1 range and is excluded from the current analysis. When fit with a newer version of SALT2, this supernova passes the cut and would be included, so we plot it on the Hubble diagram, but with a red triangle symbol.

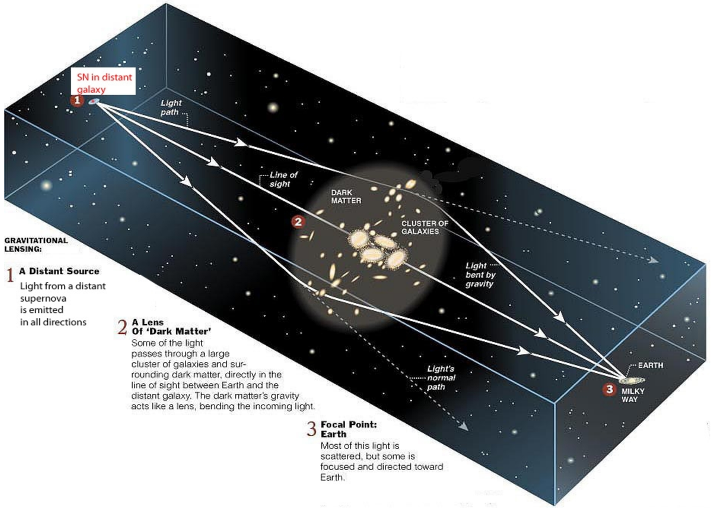
Using massive galaxy clusters as natural telescopes

Search for faint high-z supernovae in the near-IR
magnified by massive clusters

Stanishev et al., 2009, A&A, 507, 61

Goobar et al., 2009, A&A, 507, 71





Monthly near-IR VLT + NOT search

Stockholms universitet

Period (Instrument)	A1689	A1835	AC114
Apr 2007 – Sep 2007 (ISAAC)	3	6	4
~~Mar 2008 – Sep 2008 (HAWK-I)~~	~~3~~		
Oct 2008 – Sep 2009 (HAWK-I)	7		
Apr 2009 – Present (NOT)	14		

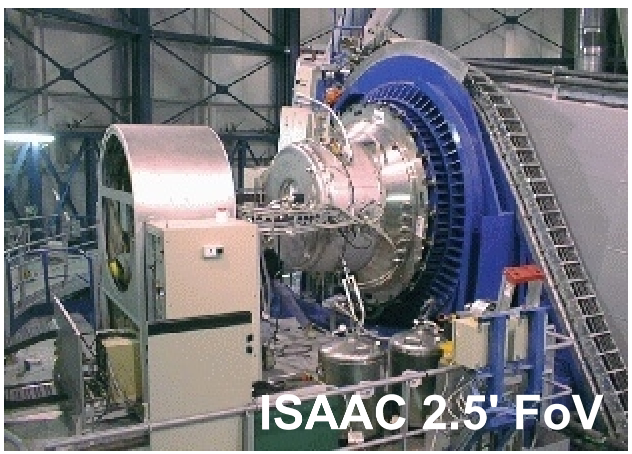
1 pointing ≈ 2h

Goobar et al. (2009)

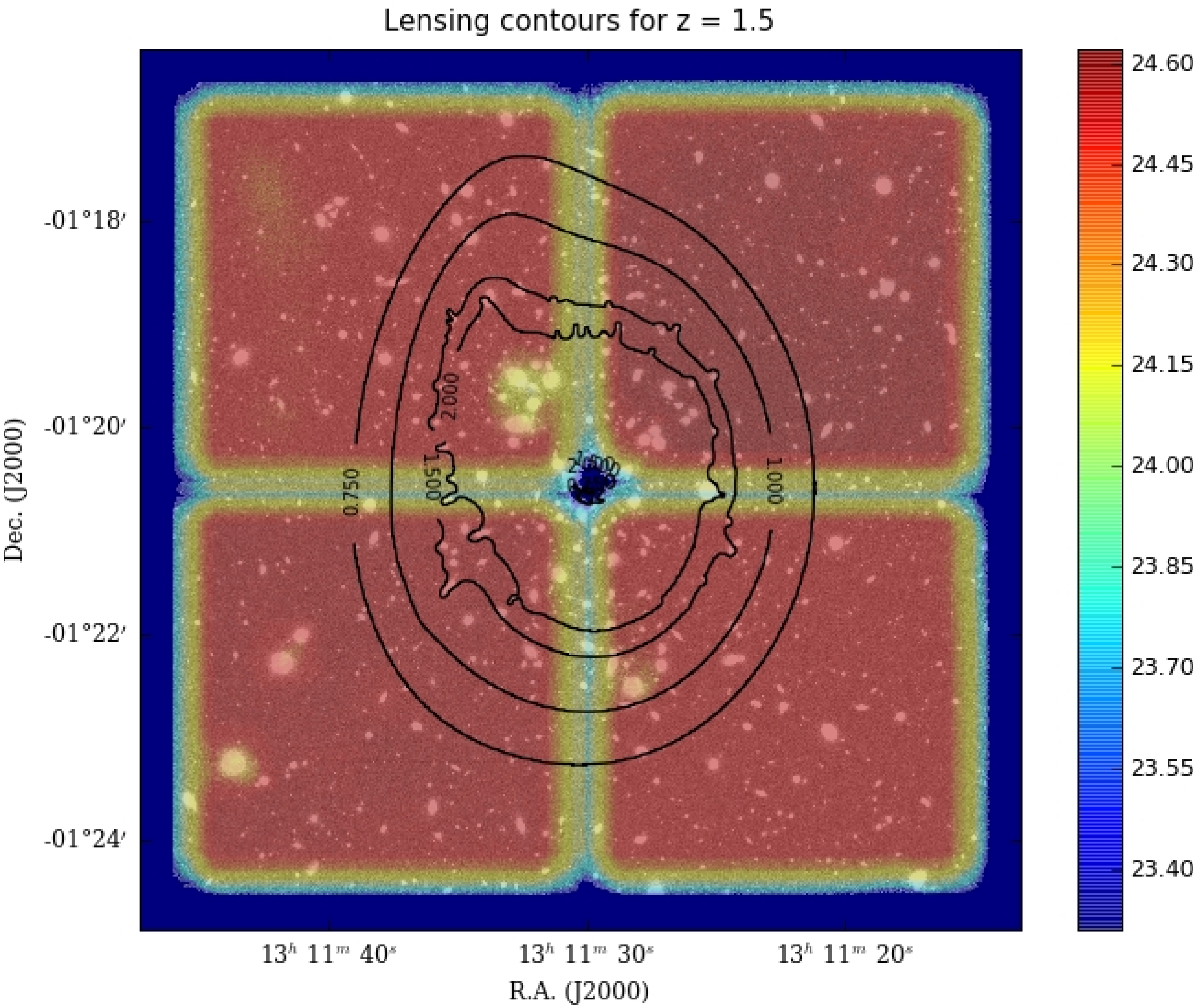
Instrument failure!

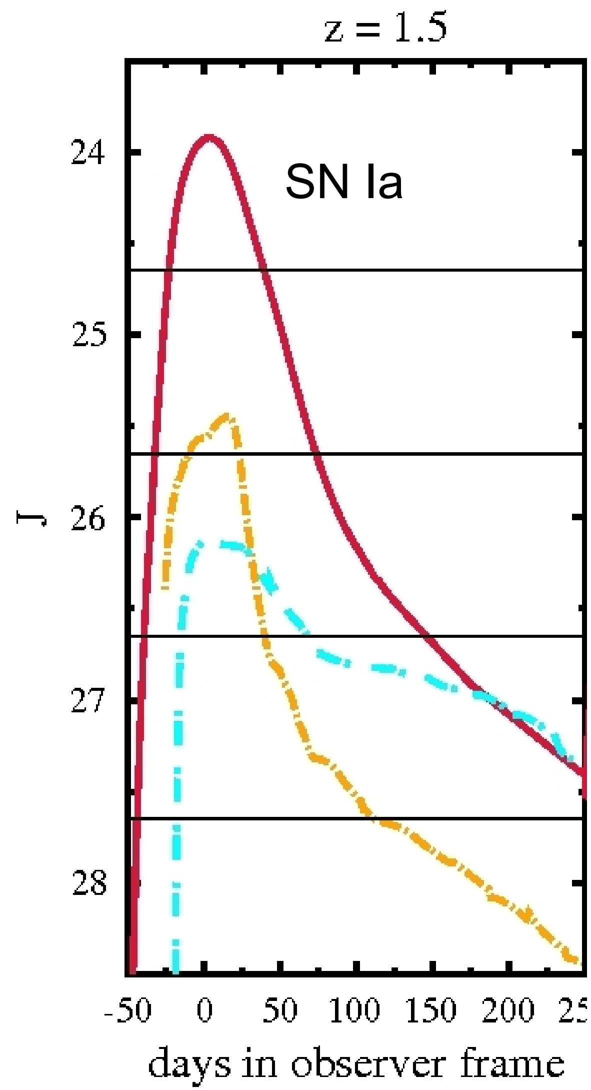
Special thanks to Håkon Dahle's group!

Unfortunately, irregular cadence in practice!



How much deeper?

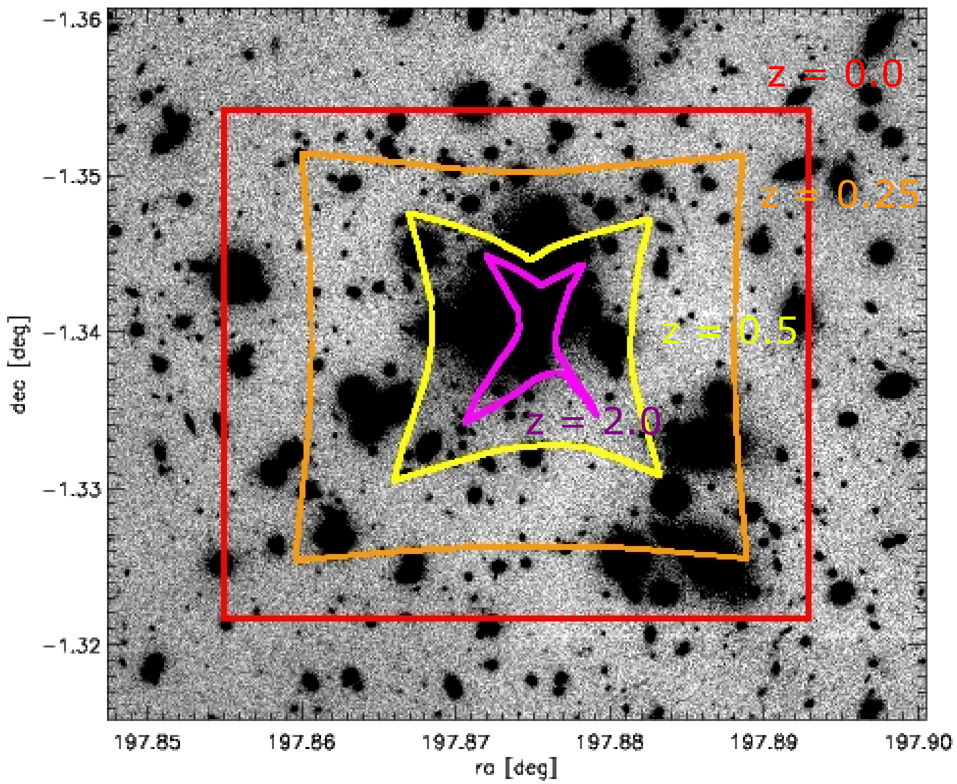


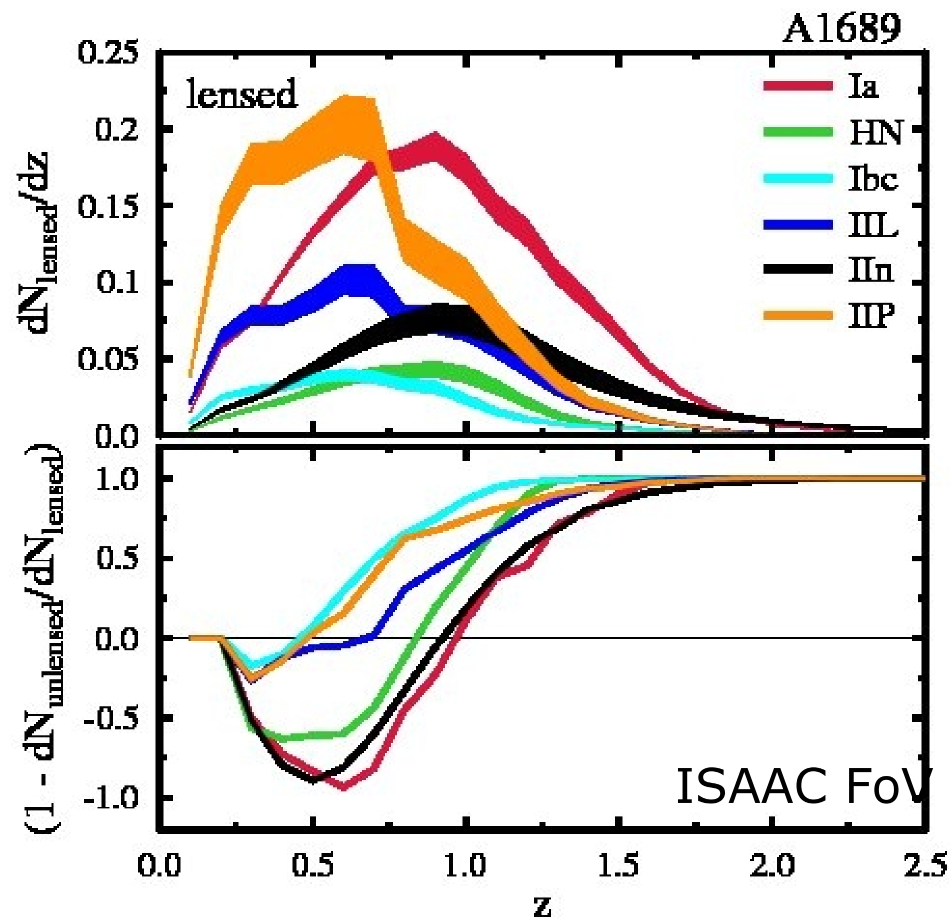


LENSTOOL (Jullo et al 2007); Limousin et al 2007

Gravity gives – gravity takes!

Source plane area for A1689

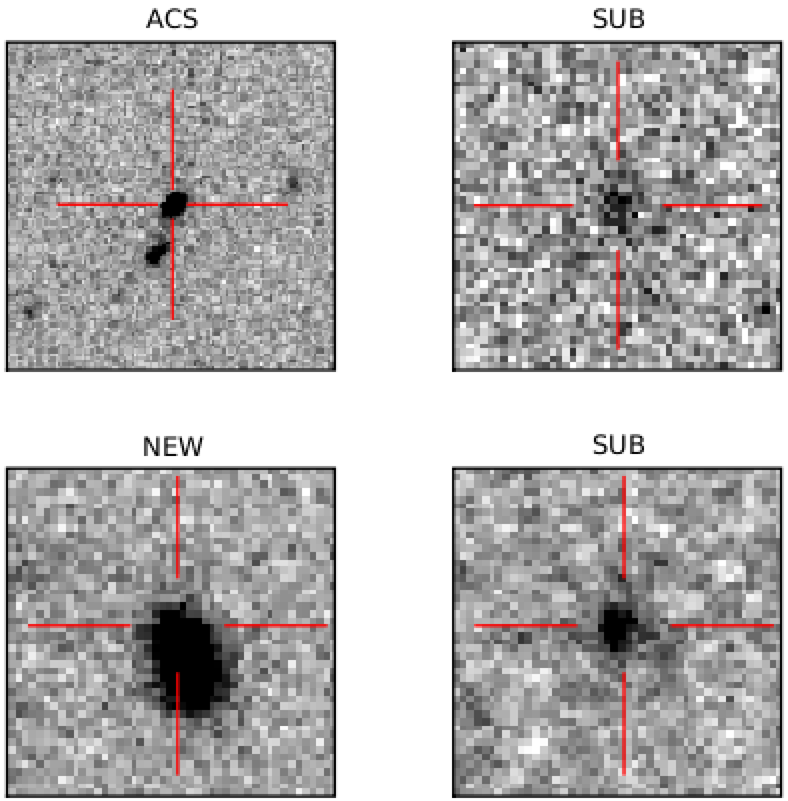


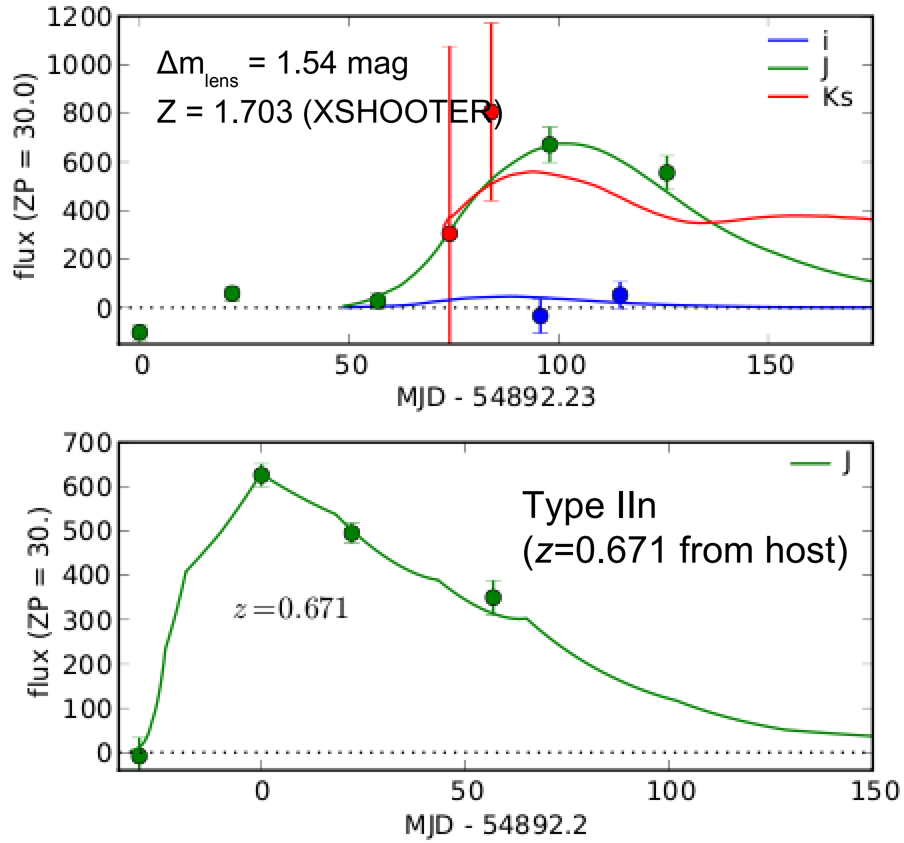


Less area covered at high redshift!

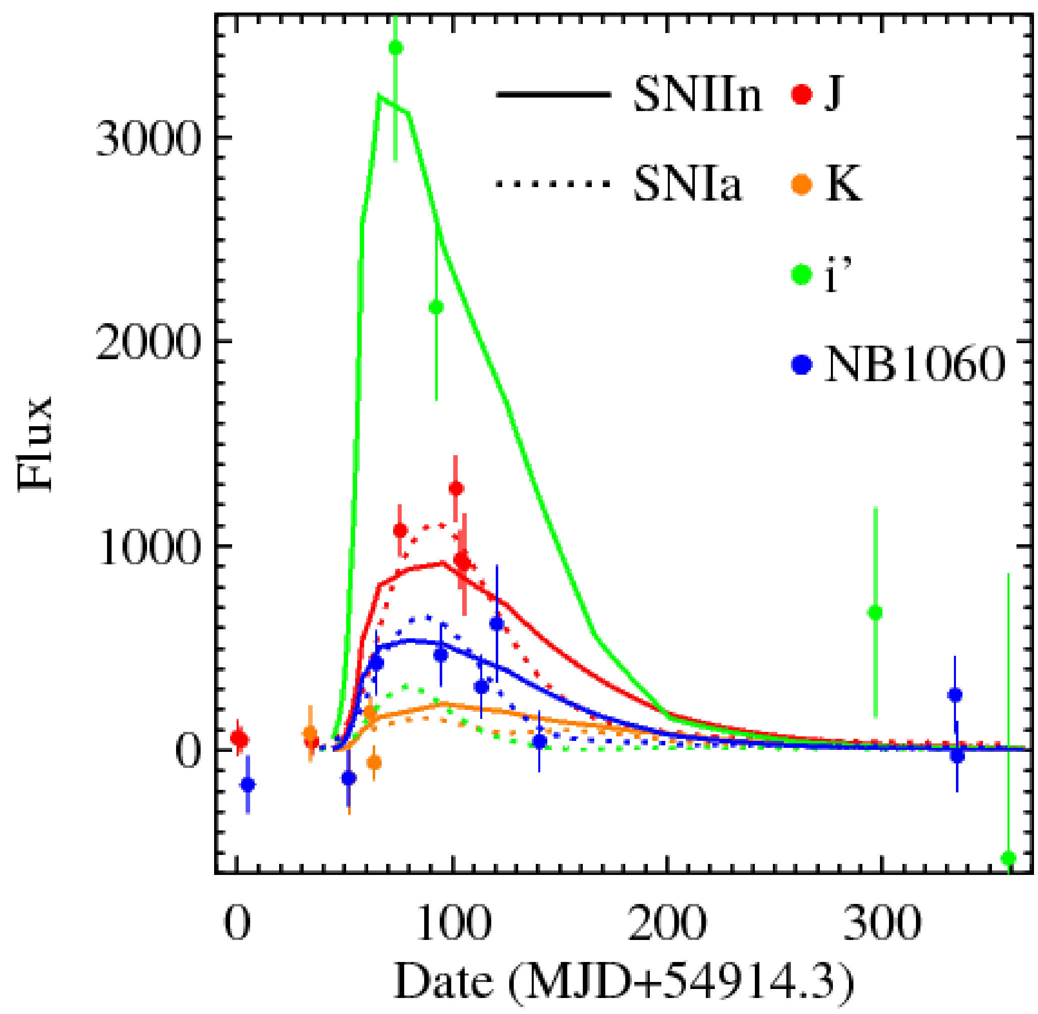
Core-collapse SNe are fainter
Than Ia:s but more frequent!

SN Ia candidate at z ~ 1.703

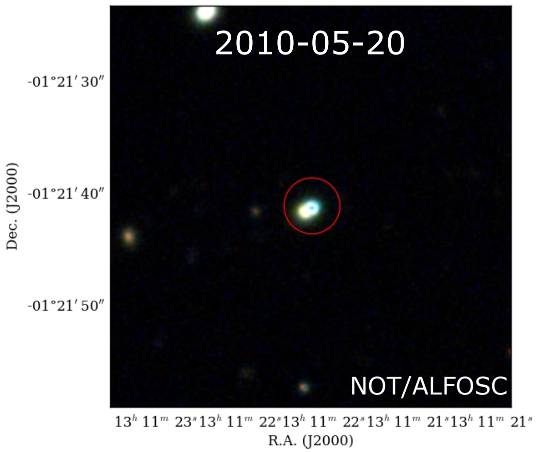


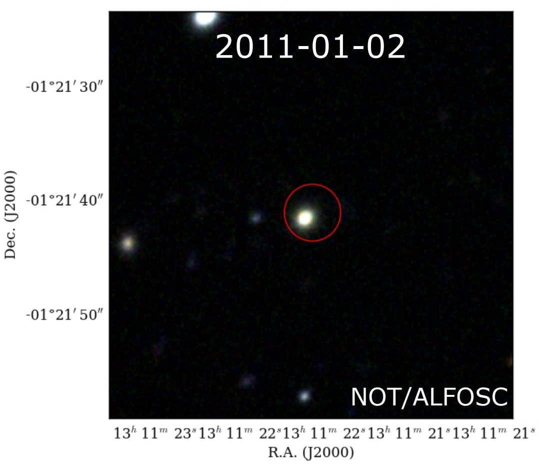


Excessive UV flux

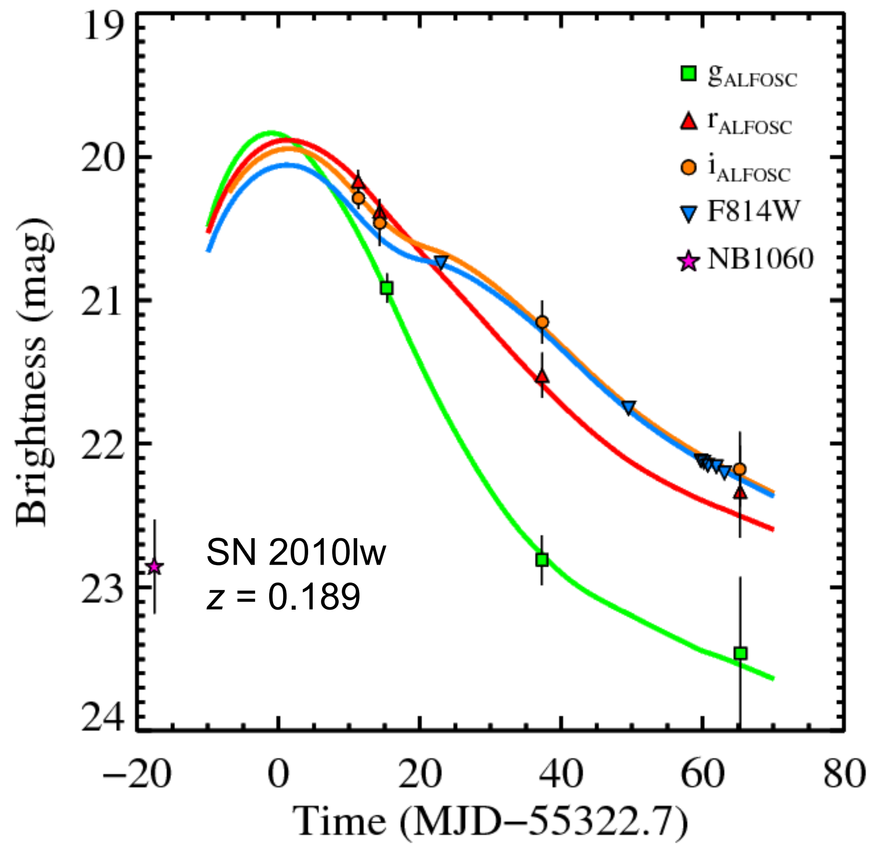


Finding SNe in the foreground





Jönsson et al. *in prep.*



The Refsdal method (1966)

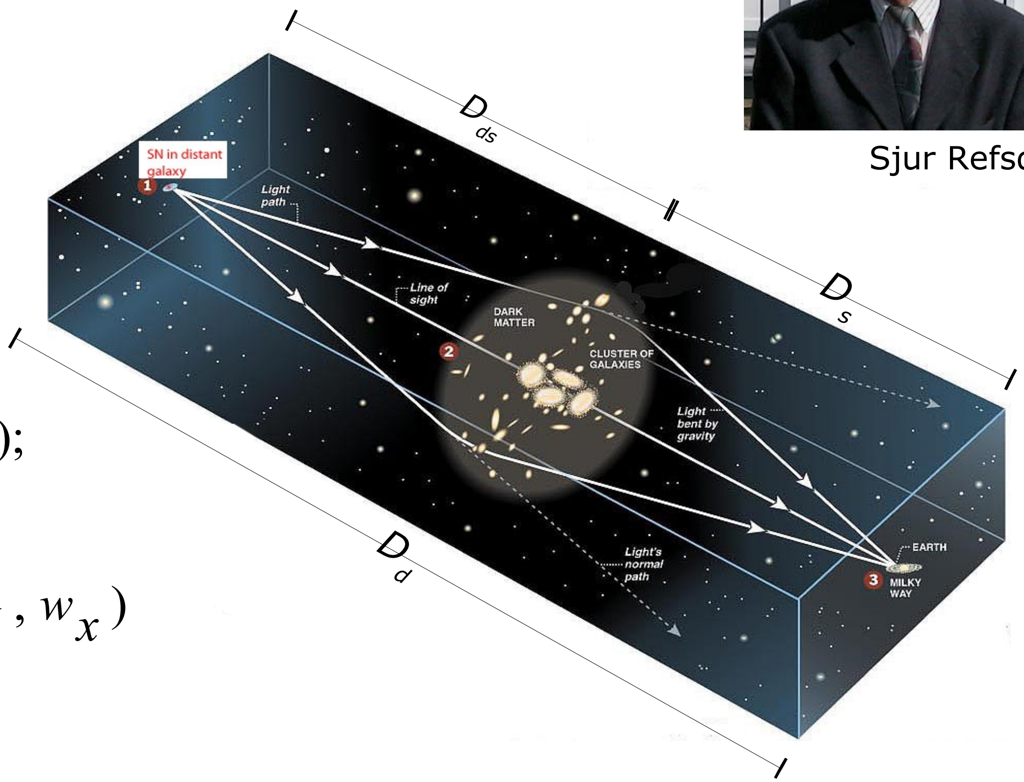
Primarily the Hubble constant,
but also DE!

Sjur Refsdal

Measure!

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

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



Conclusions

- Our knowledge of SNe Ia have increased dramatically the last few years
- Galaxy clusters are excellent for extending the depth of transient surveys and for boosting the discovery rate of type Ia SNe
  - Our VLT survey have been successful in discovering magnified transients behind massive galaxy clusters
  - We discovered 16 type Ia SNe at $z > 0.9$ in our HST cluster survey, of which 6 were found in cluster ellipticals.
- Both these techniques are promising for future surveys!
  - Searching for SNe behind galaxy clusters could result in multiply lensed events – H_0 through the Refsdal-method!