Supernova cosmology: legacy and future

Bruno Leibundgut
ESO

Congratulations!

KUNGL. VETENSKAPS-AKADEMIEN
THE ROYAL SWEDISH ACADEMY OF SCIENCES

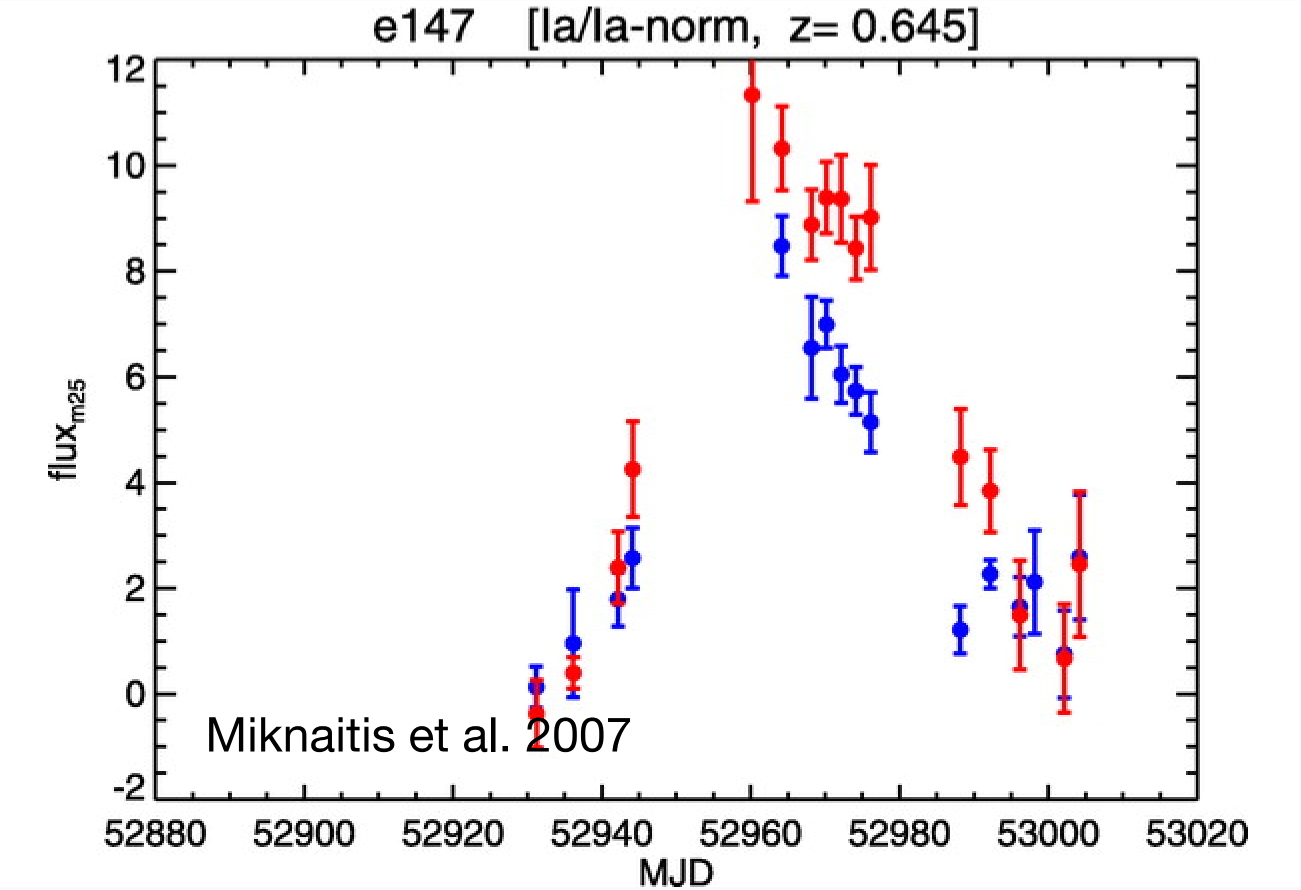
"*for the discovery of the accelerating expansion of the Universe through observations of distant supernovae*"

Supernova Cosmology

- Required observations
  - light curve
  - spectroscopic classification
  - redshift
- Required theory
  - cosmological model
  - (supernova explosions and light emission)
- Required phenomenology
  - calibrations (photometric systems)
  - normalisations (light curve fitters)

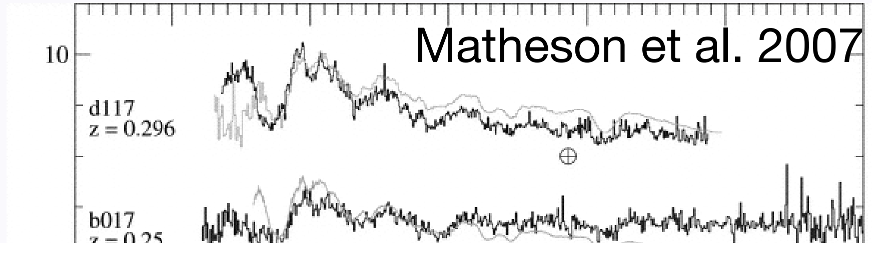
Required observations

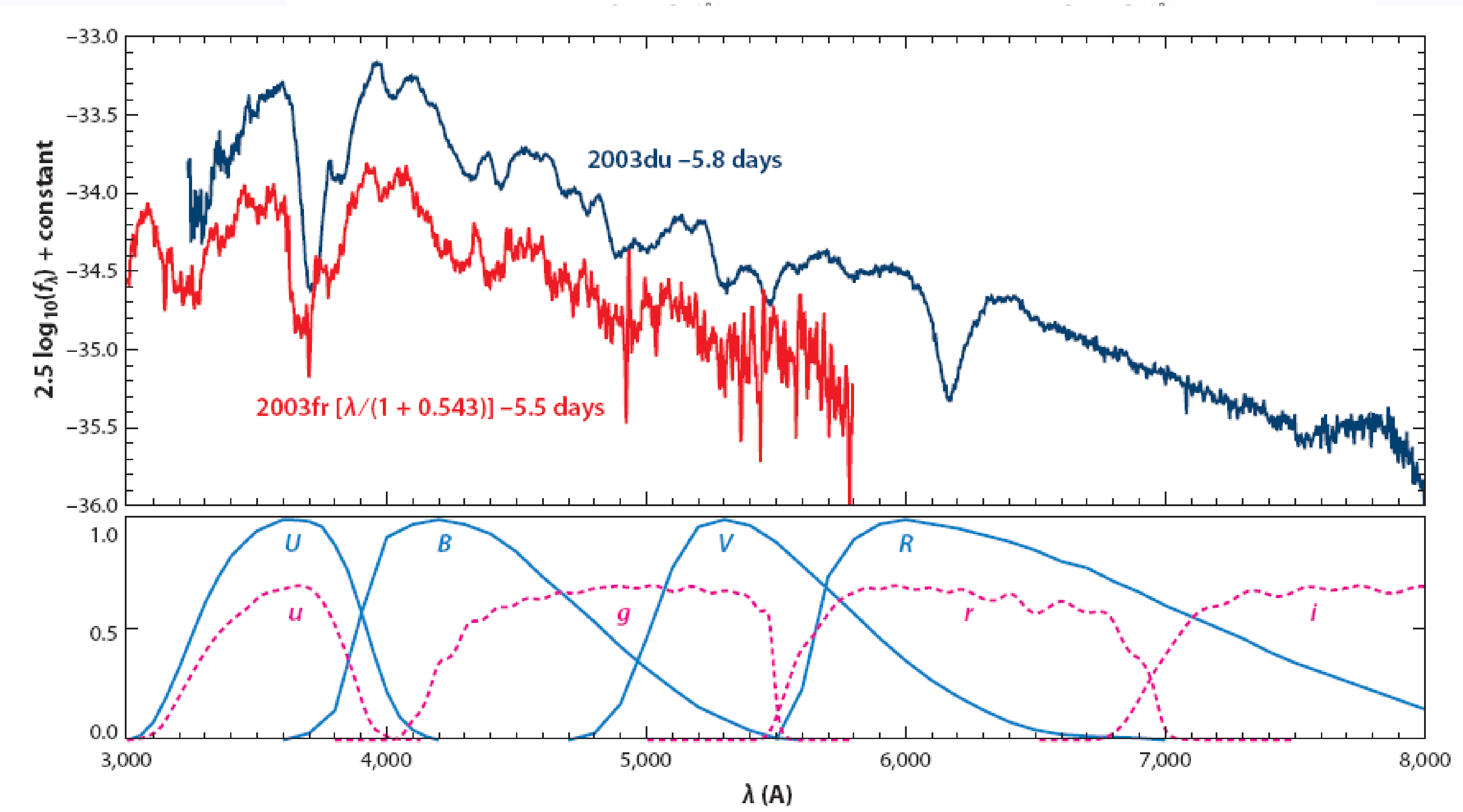
- Light curves



Required observations

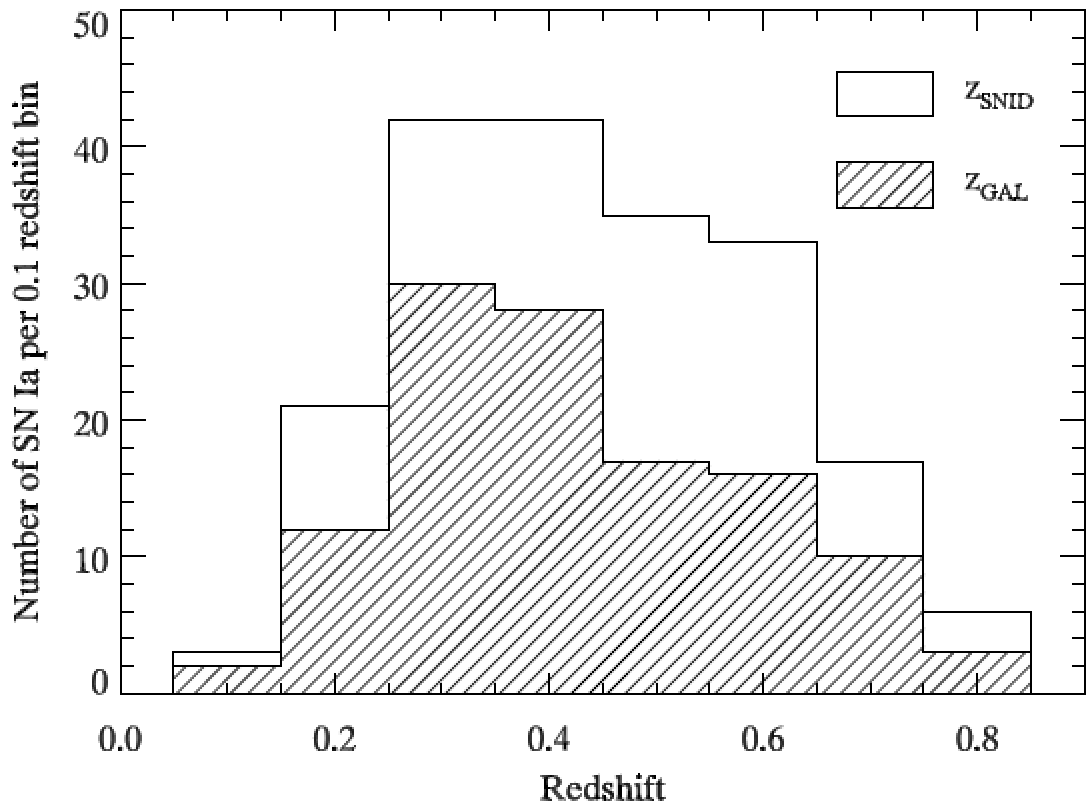
- Spectroscopic classification





Required observations

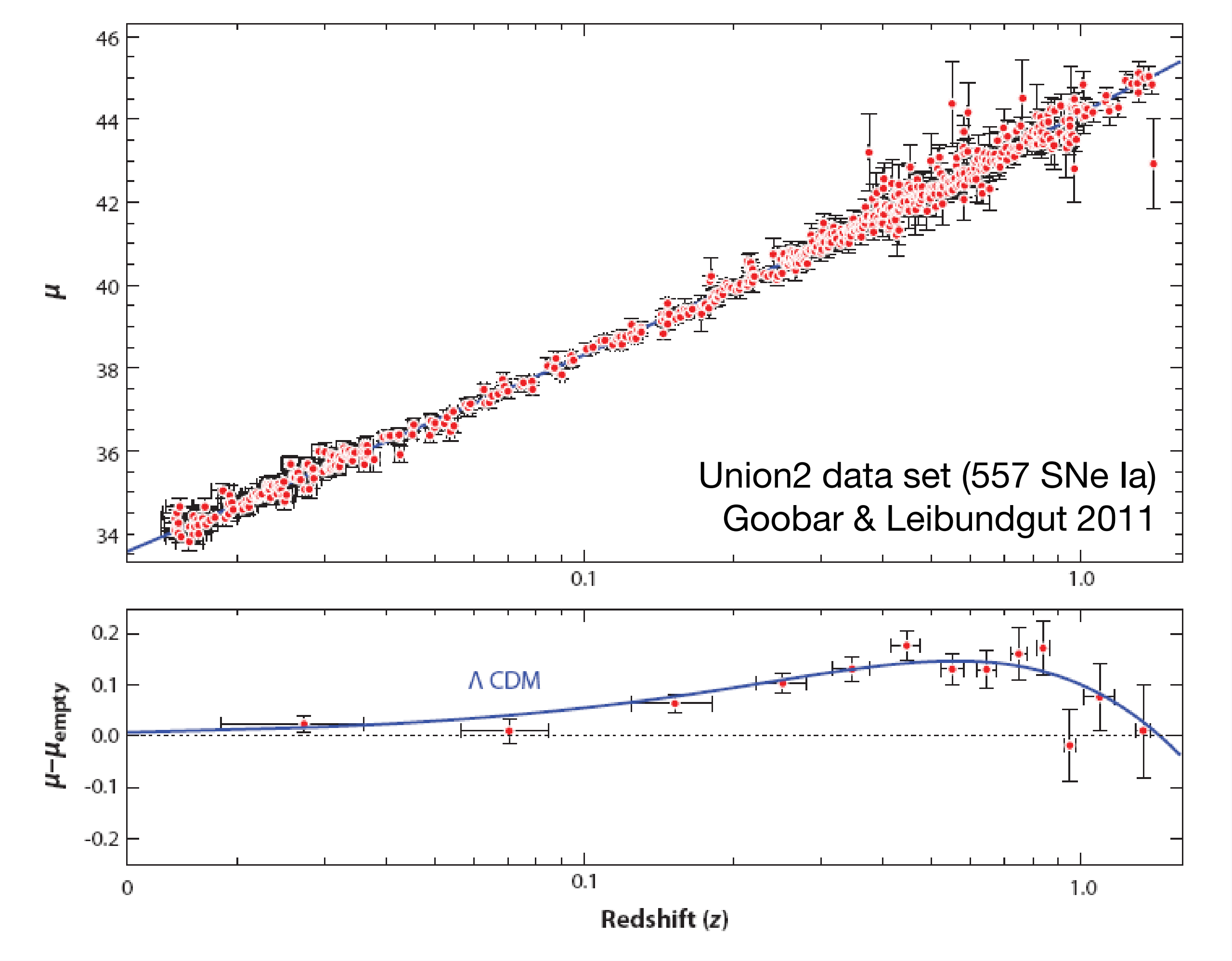
- Redshifts



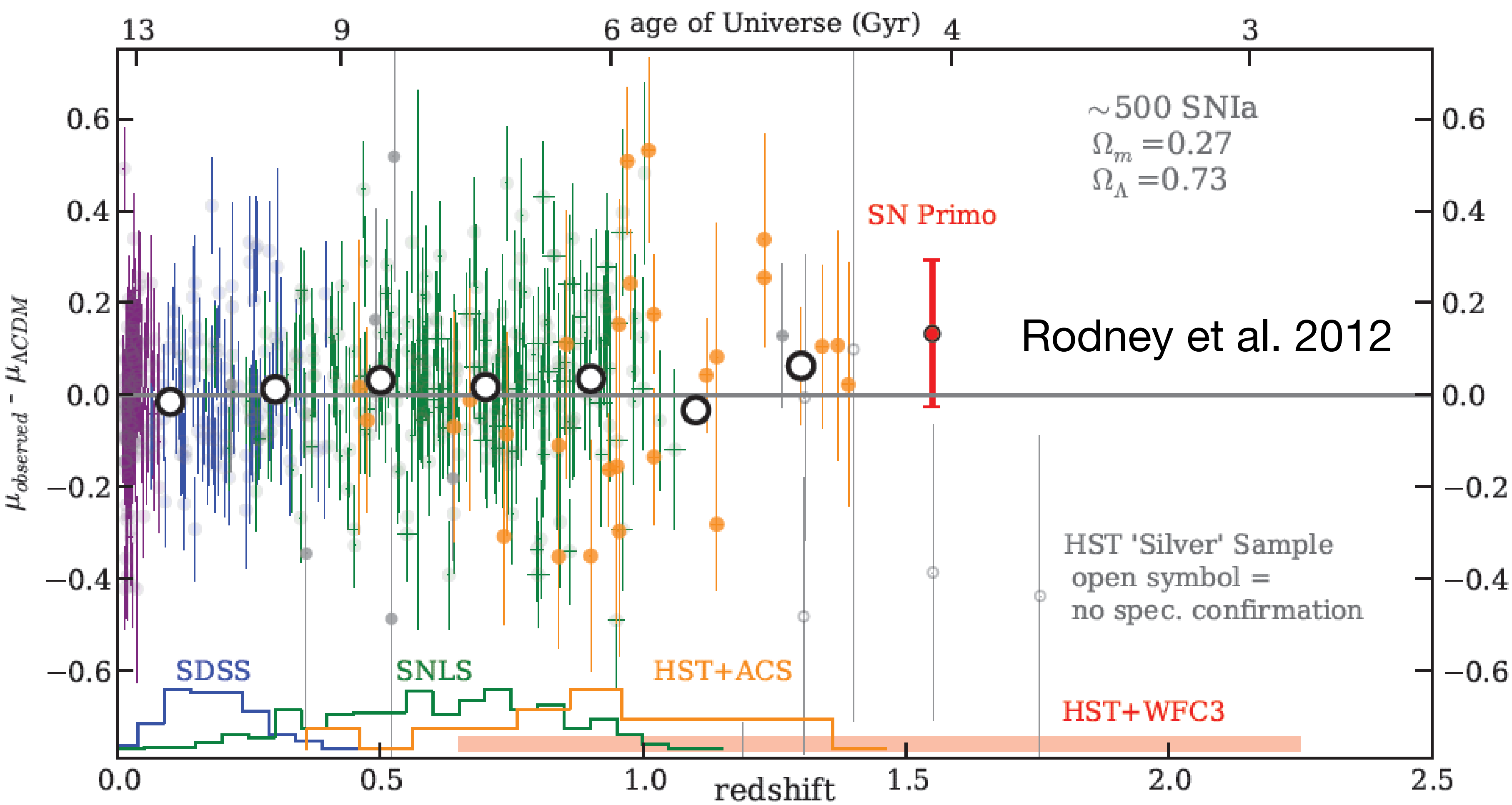
Blondin et al., in prep.

Supernova Cosmology

- Published data sets as of January 2011



A more recent Hubble diagram



Cosmological model

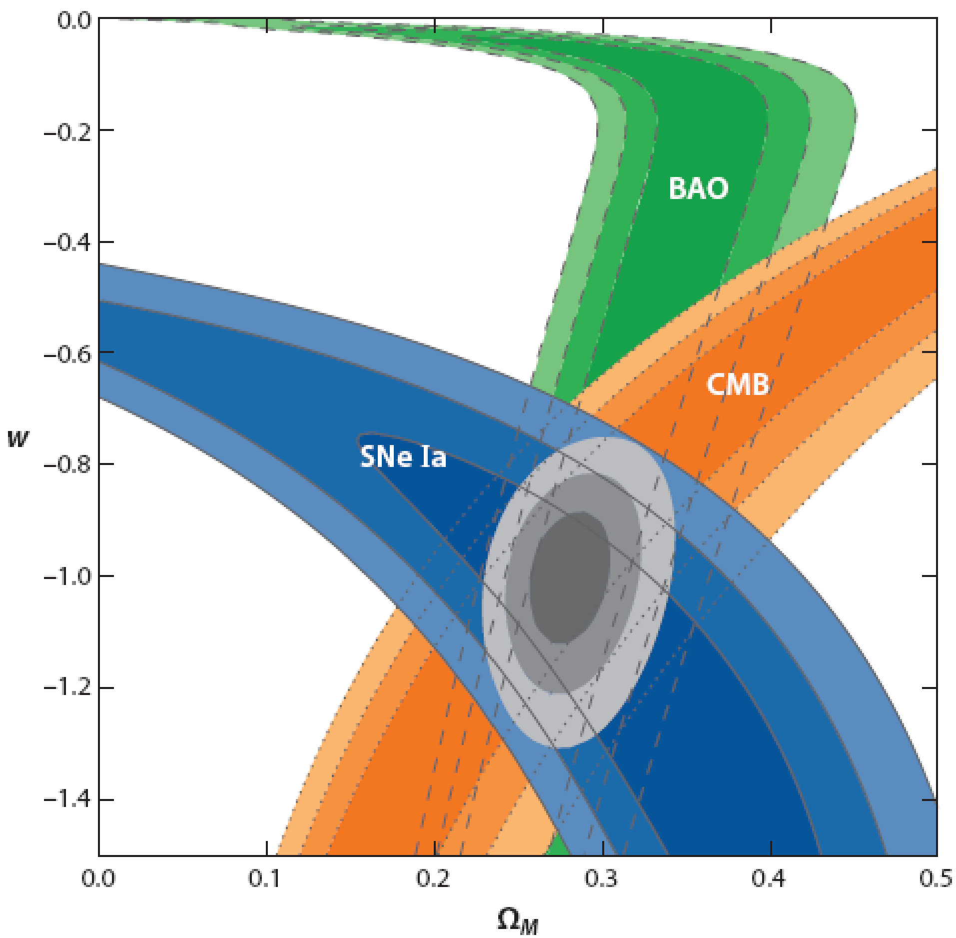
- Theory of Gravity

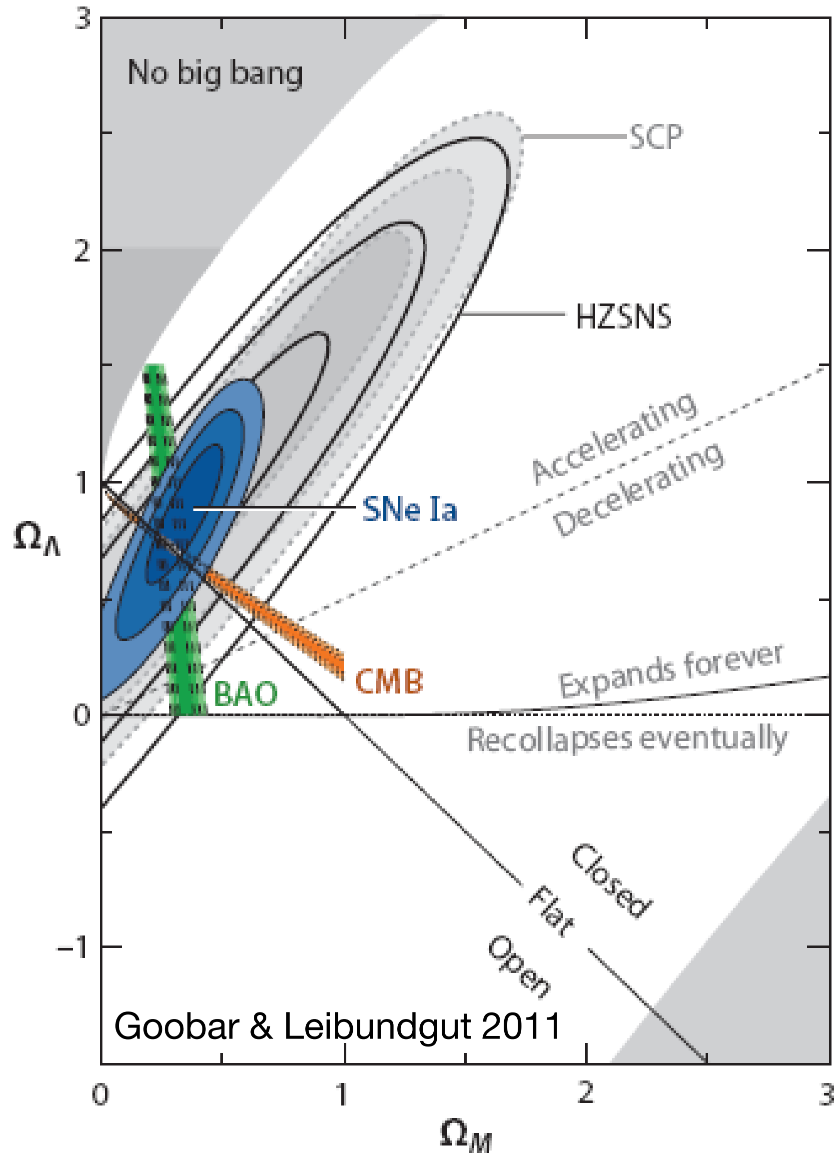
Cosmological model

- Assume isotropy and homology
  - ➔Friedmann-Lemaître model
- for an example of a model-independent interpretation see Sandra Benitez-Herrera's talk

et voilà ...

- 10 years of progress

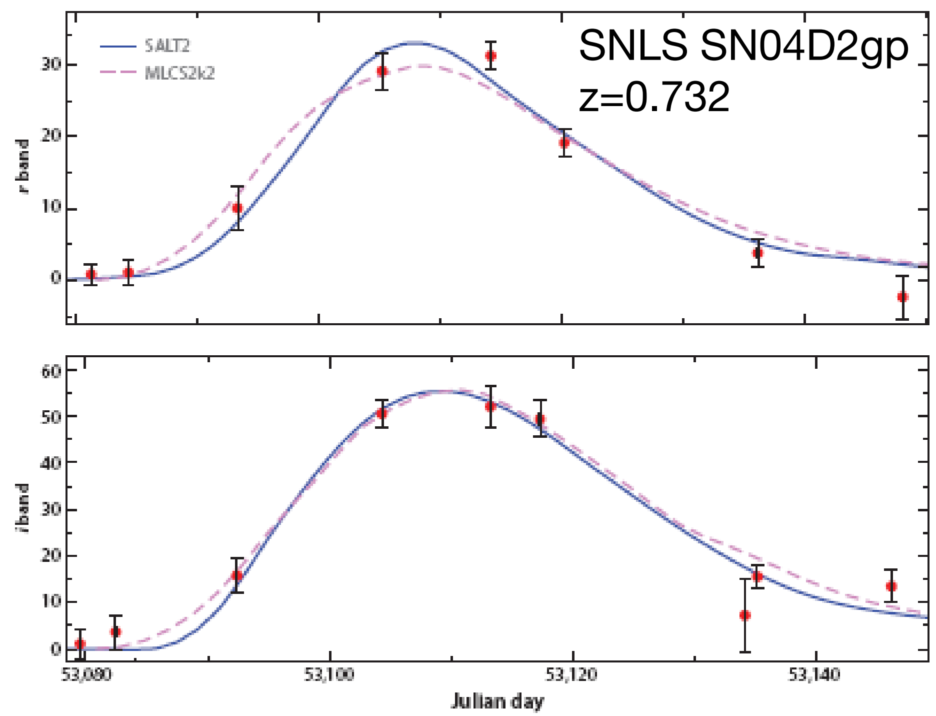




Required phenomenology

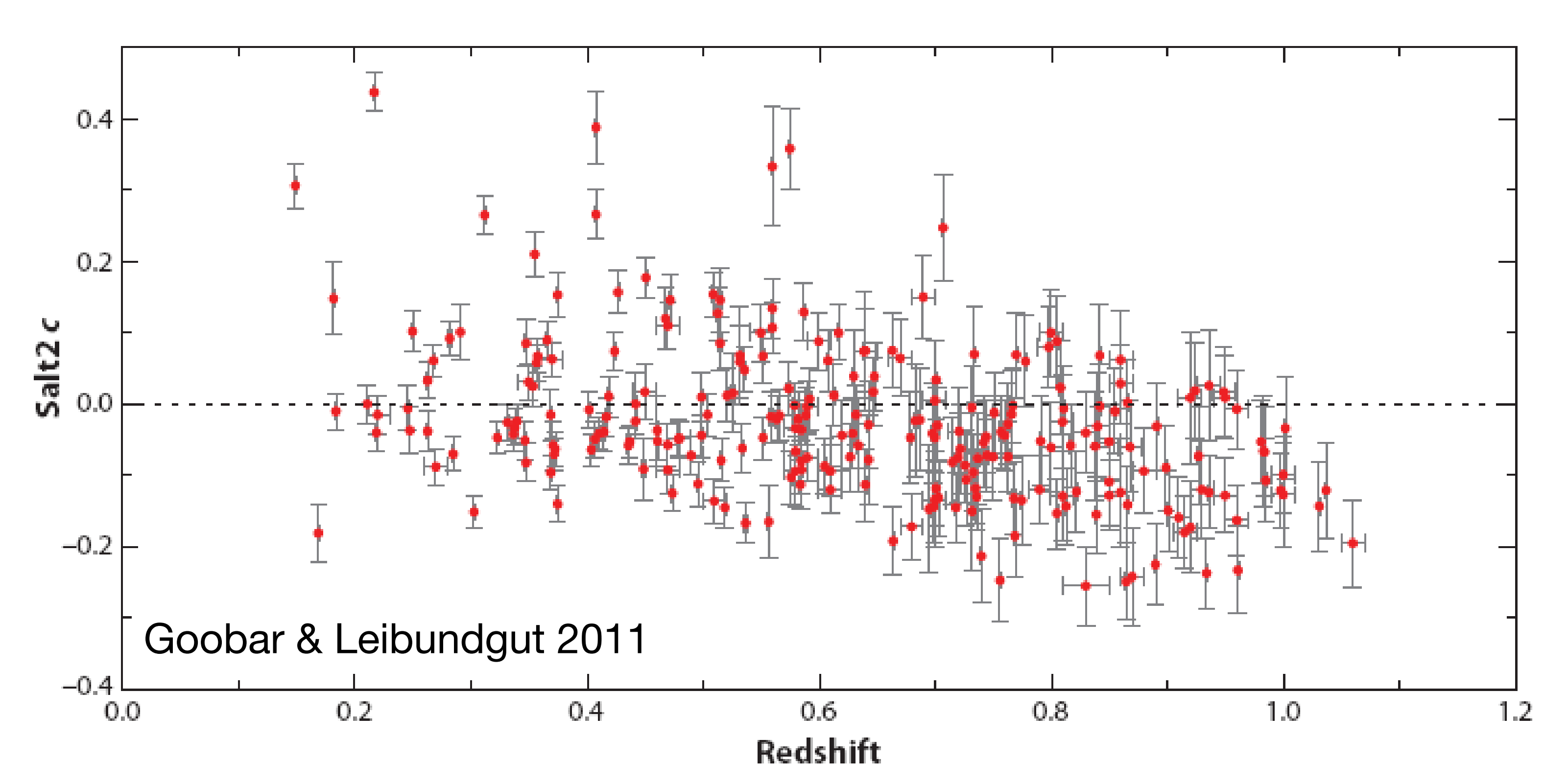
- photometric calibration
  - see Marek Kowalski's talk
- normalisation
  - ("standardisable candle"; "standard crayon")
  - different light curve fitters
    - Δm_{15},SALT, SiFTO, MLCS

Goobar & Leibundgut 2011



Required phenomenology

- Checks
  - selection effects? evolution?



Systematics

- Current questions
  - calibration
  - restframe UV flux
    - redshifted into the observable window
  - reddening and absorption
    - detect absorption
      - through colours or spectroscopic indicators
    - correct for absorption
      - knowledge of absorption law
  - light curve fitters
  - selection bias
    - sampling of different populations
  - gravitational lensing
  - brightness evolution

Supernova cosmology

- ω firmly established
  - general agreement between different experiments

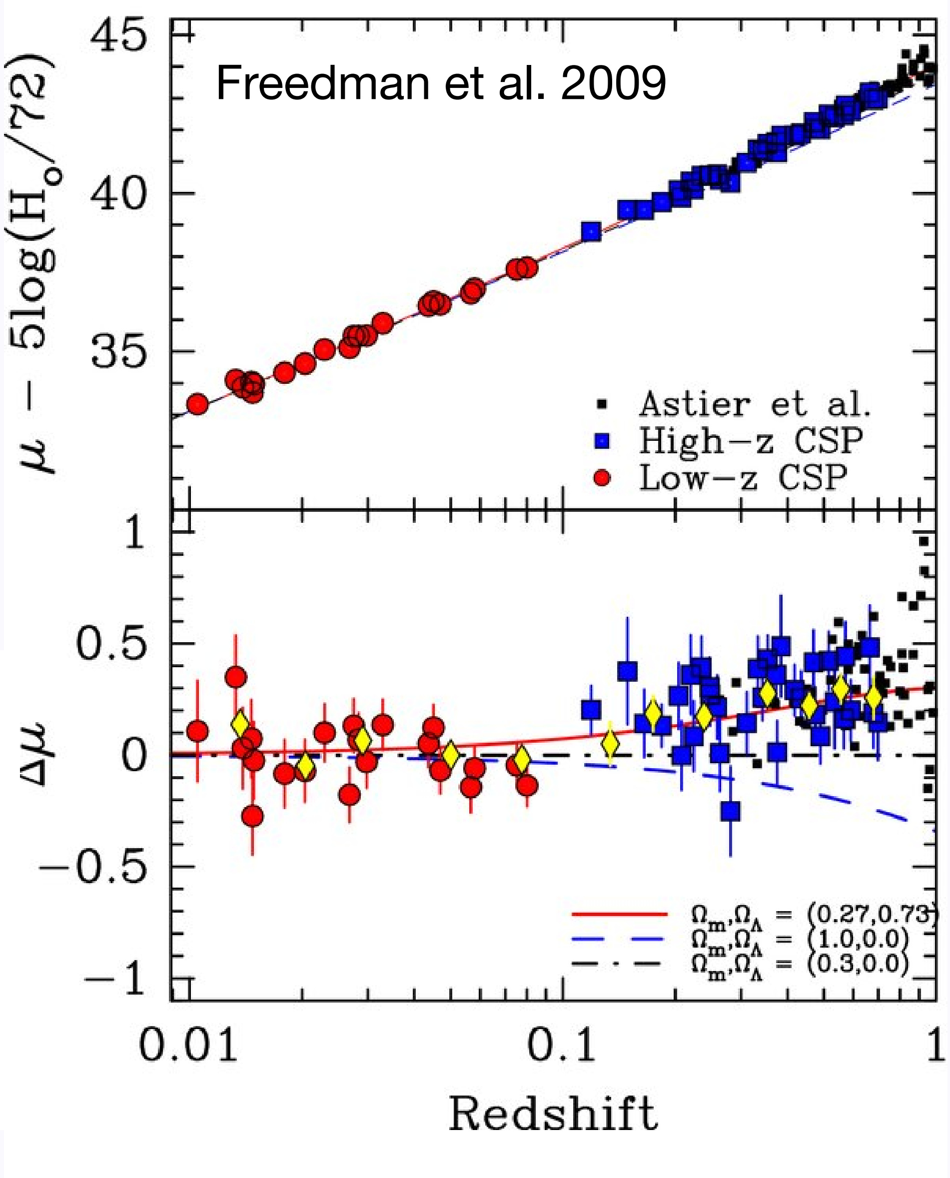
N_{SN}	Ω_M (flat)	w (constant, flat)	Light-curve fitter	Reference
115	$0.263^{+0.042}_{-0.042}{}^{+0.032}_{-0.032}$	$-1.023^{+0.090}_{-0.090}{}^{+0.054}_{-0.054}$	SALT	Astier et al. 2006
162	$0.267^{+0.028}_{-0.018}$	$-1.069^{+0.091}_{-0.093}{}^{+0.13}_{-0.13}$	MLCS2k2	Wood-Vasey et al. 2007
178	$0.288^{+0.029}_{-0.019}$	$-0.958^{+0.088}_{-0.090}{}^{+0.13}_{-0.13}$	SALT2	
288	$0.307^{+0.019}_{-0.019}{}^{+0.023}_{-0.023}$	$-0.76^{+0.07}_{-0.07}{}^{+0.11}_{-0.11}$	MLCS2k2	Kessler et al. 2009
288	$0.265^{+0.016}_{-0.016}{}^{+0.025}_{-0.025}$	$-0.96^{+0.06}_{-0.06}{}^{+0.13}_{-0.13}$	SALT2	
557	$0.279^{+0.017}_{-0.016}$	$-0.997^{+0.050}_{-0.054}{}^{+0.077}_{-0.082}$	SALT2	Amanullah et al. 2010
580	$0.271^{+0.014}_{-0.014}$	$-1.013^{+0.068}_{-0.073}$	SALT2	Suzuki et al. 2011

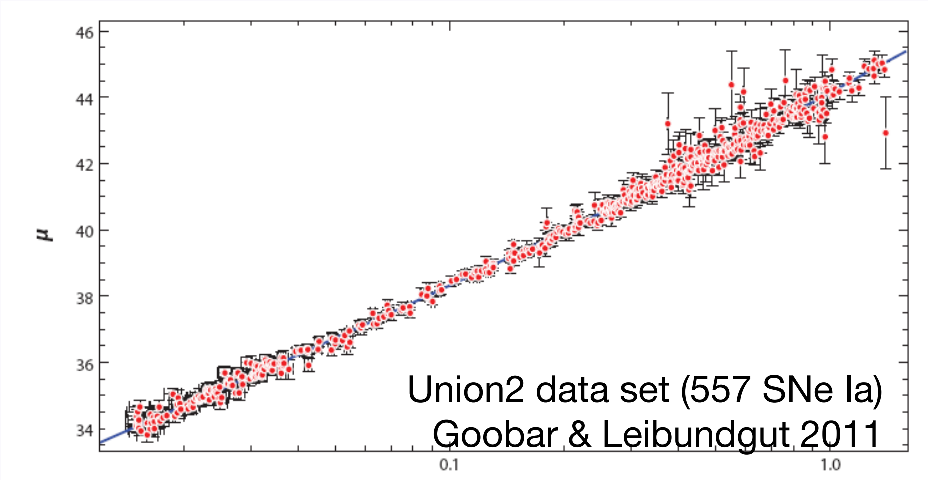
What next?

- Already in hand
  - >1000 SNe Ia for cosmology
  - constant ω determined to 5%
  - accuracy dominated by systematic effects
- Missing
  - good data at z>1
    - light curves and spectra
  - good infrared data at z>0.5
    - cover the restframe B and V filters
    - move towards longer wavelengths to reduce absorption effects
  - I-band Hubble diagram
    - Freedman et al.
    - Nobili et al.

I-band Hubble diagram

- Currently only 35 SNe Ia

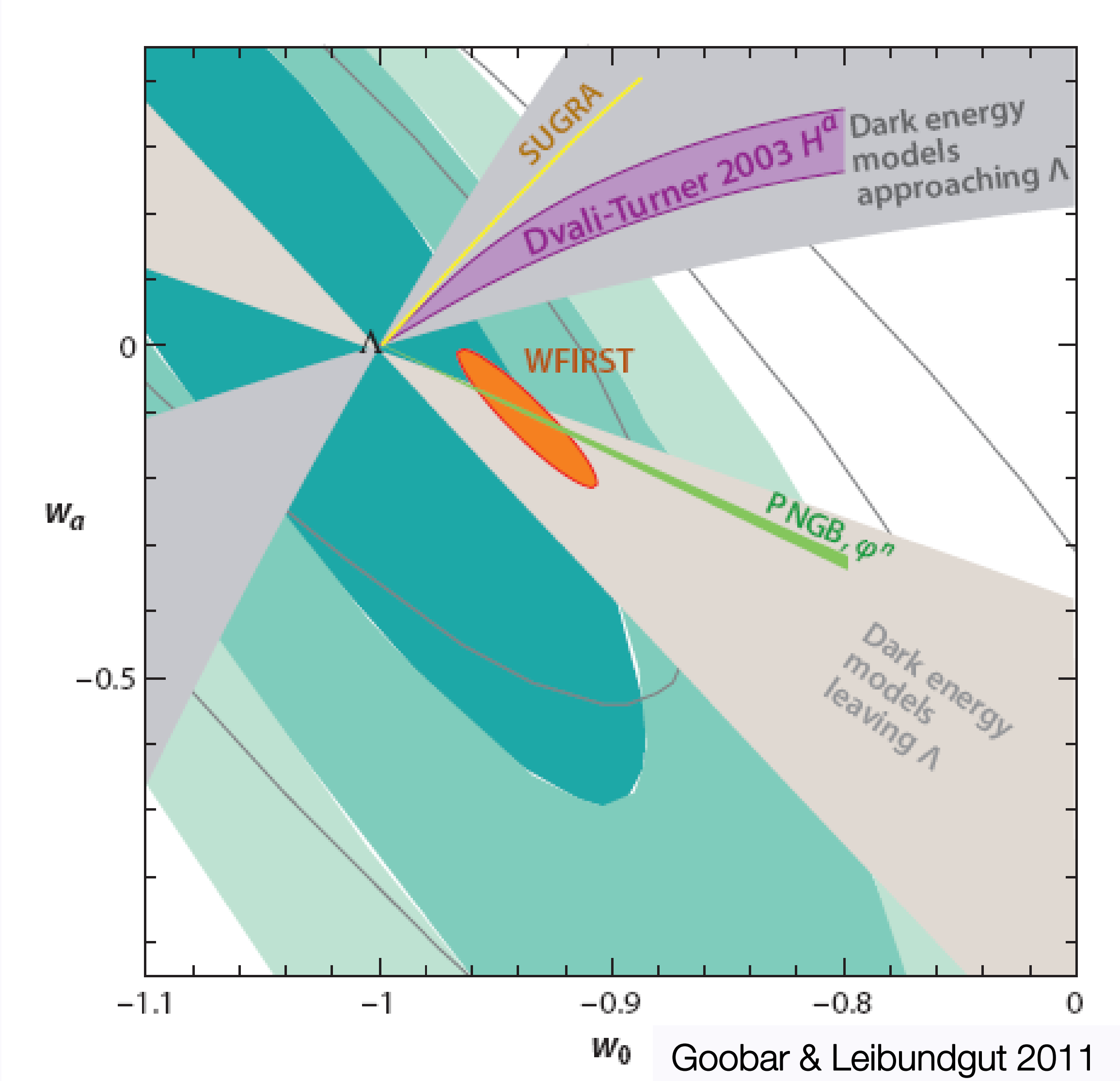




Supernova Cosmology – do we need more?

- Test for variable ω
  - required accuracy ~2% in *individual* distances
  - can SNe Ia provide this?
    - can the systematics be reduced to this level?
    - homogeneous photometry?
    - further parameters (e.g. host galaxy metalicity)
    - handle >100000 SNe Ia per year?
- Euclid
  - 3000 SNe Ia to $z<1.2$ with IR light curves (deep fields) → I-band Hubble diagram
  - 16000 SNe discovered

Cosmology – more?



Goobar & Leibundgut 2011
(courtesy E. Linder and J. Johansson)

Distant SNe with CANDELS and CLASH

- Multi-cycle HST Treasury Programs

PIs: S. Faber/H. Fergusson

PI: M. Postman

HST MCT SN Survey

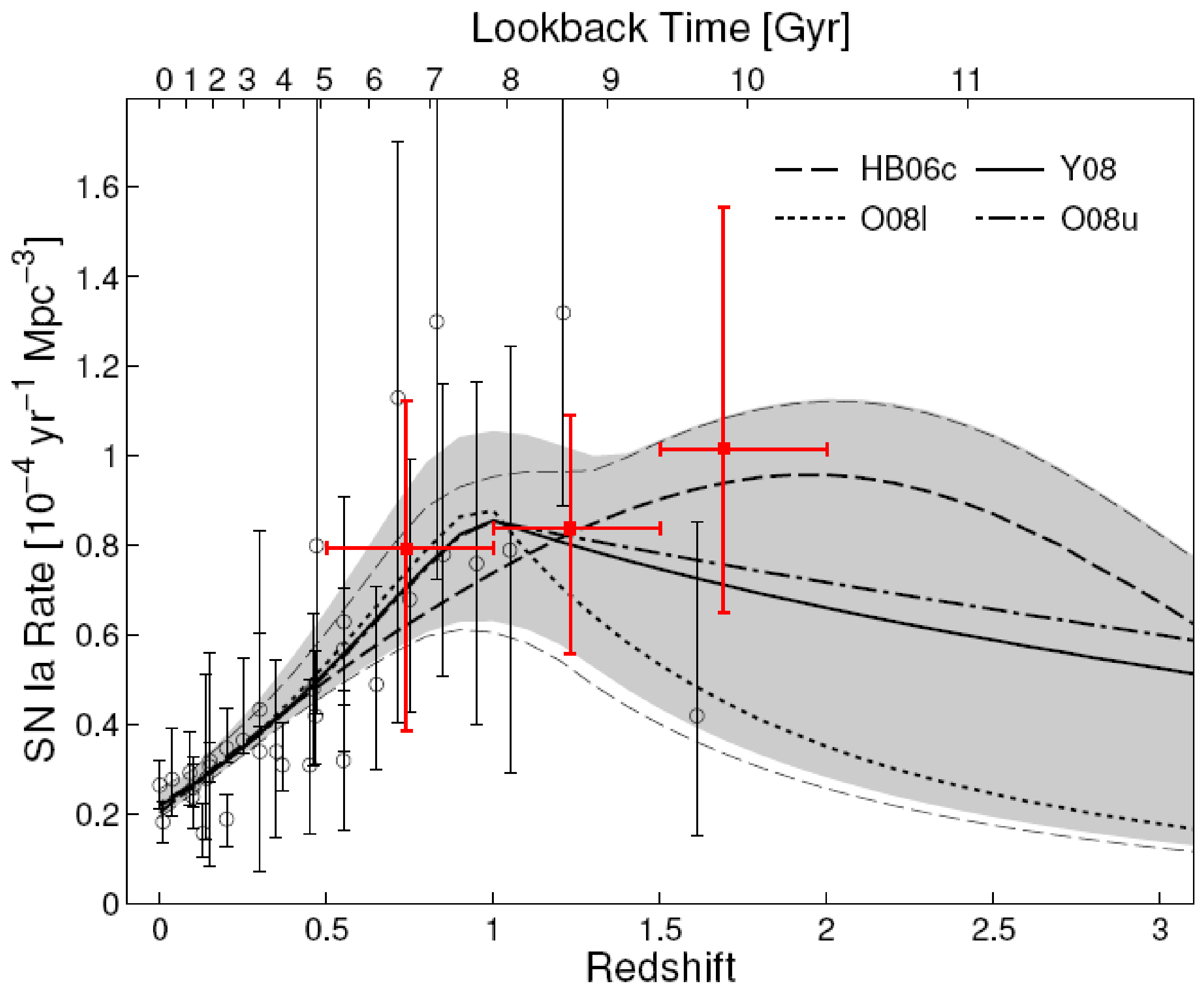
PI: A. Riess

SN discoveries and target-of-opportunity follow-up

SNe Ia out to $z \approx 2$

Determine the SN rate at $z > 1$ and constrain the progenitor systems

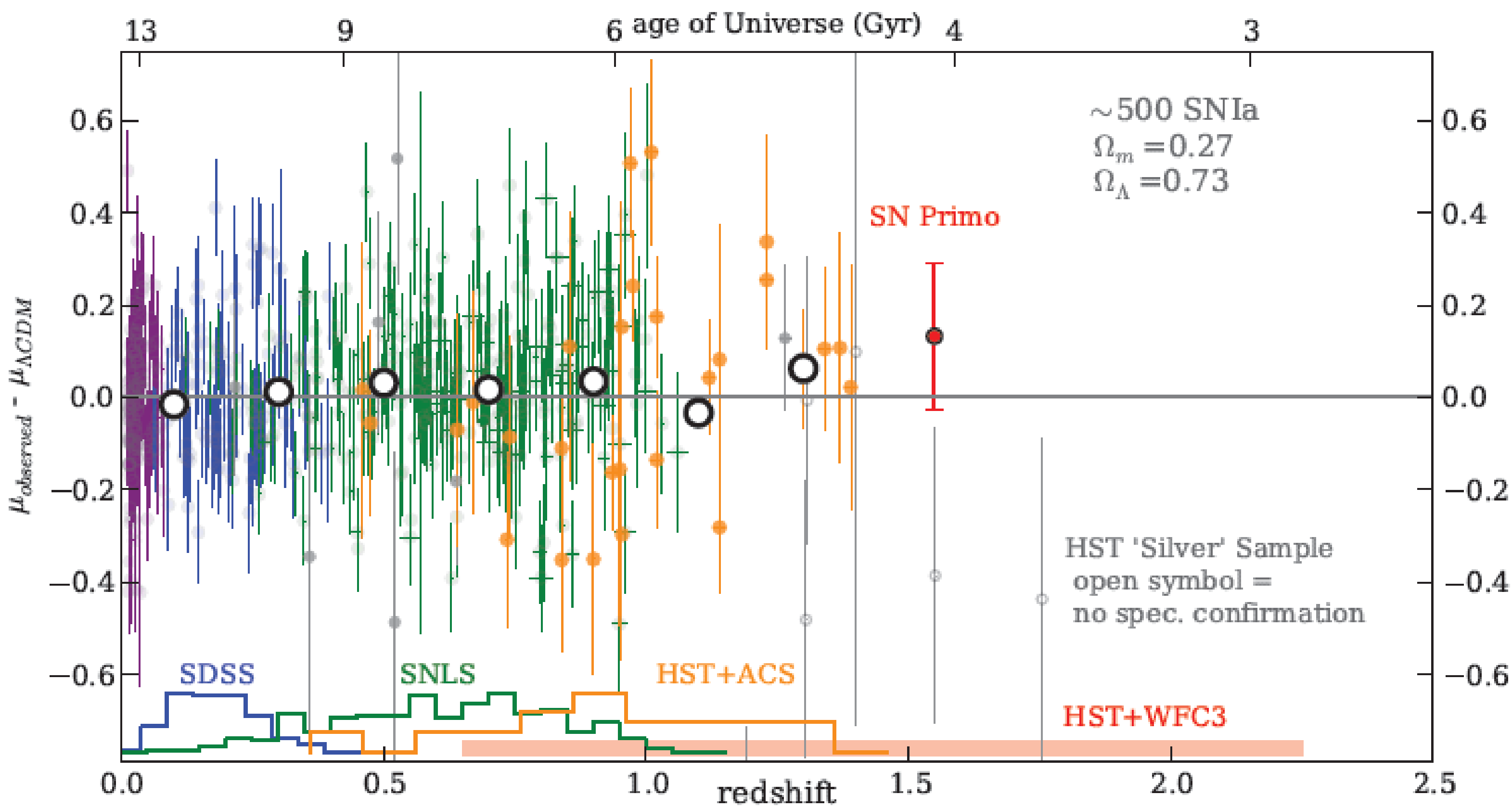
SN rates and what they can tell us



Graur et al. 2011

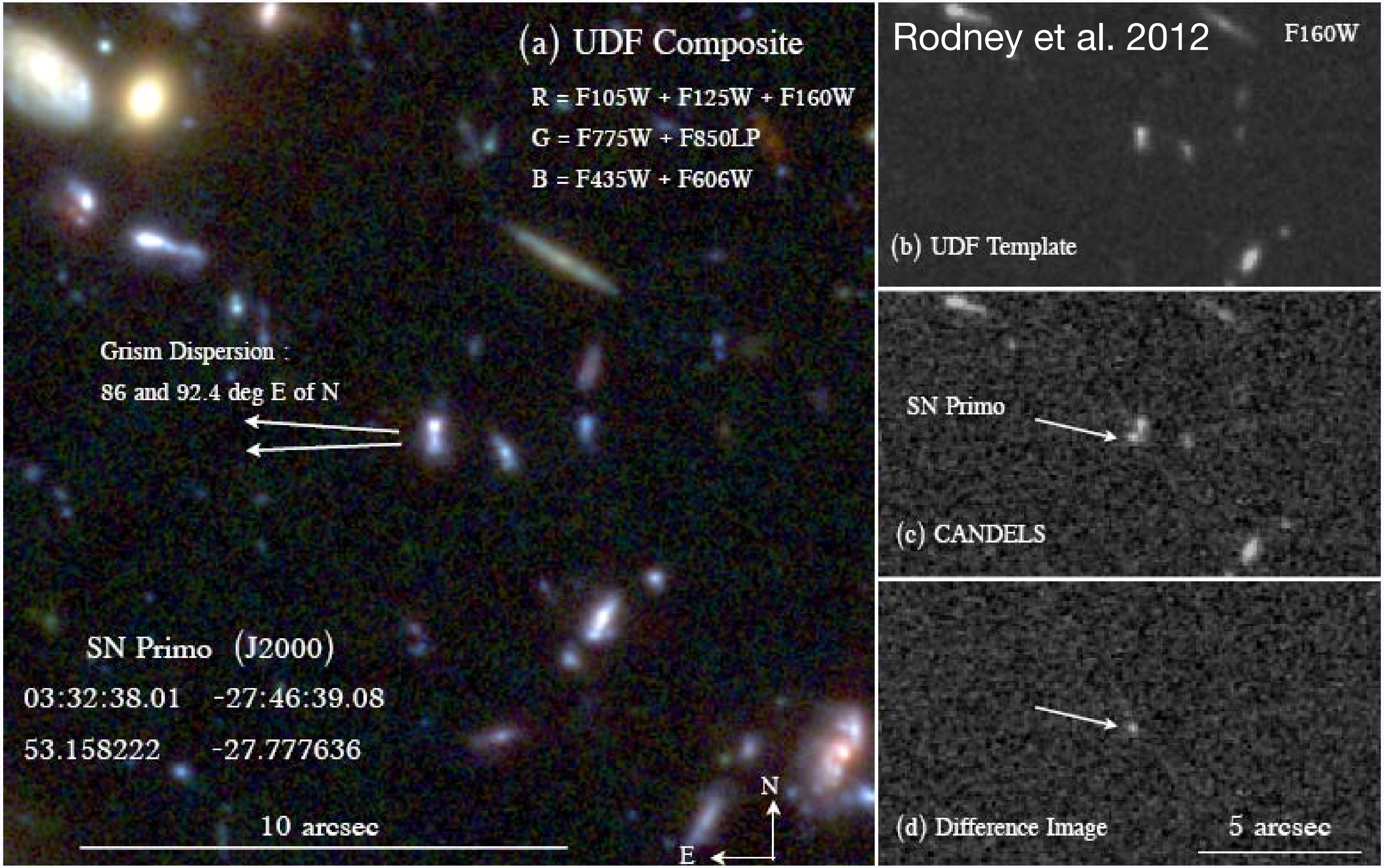
SNe at z>1

- First SN Ia at z=1.55 “Primo”



Rodney et al. 2012

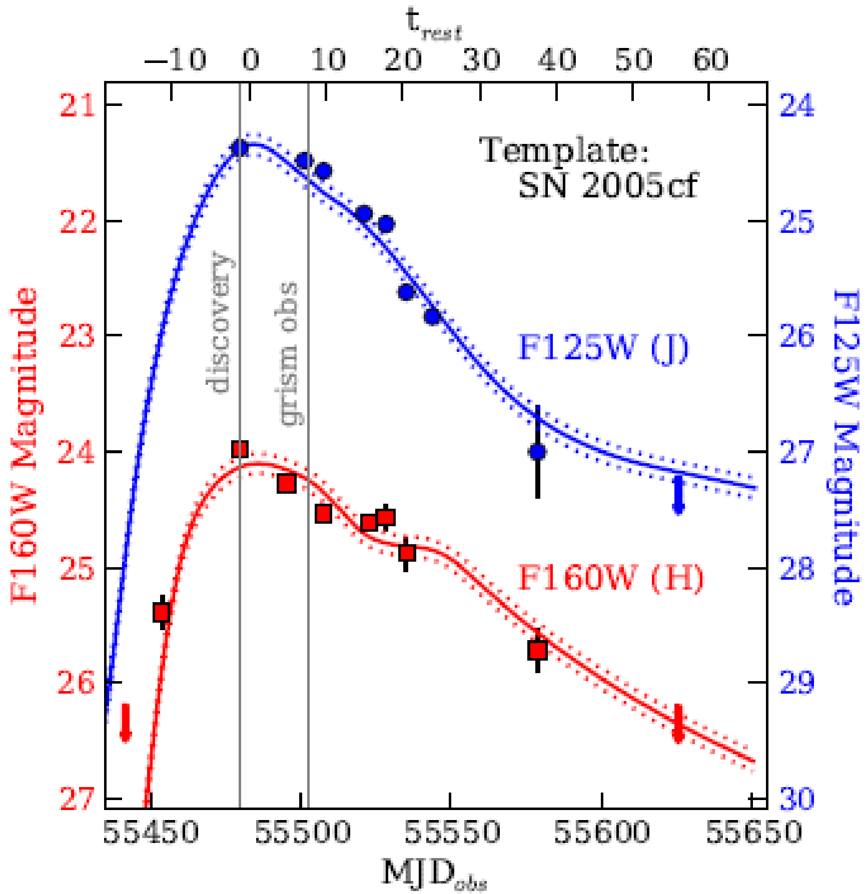
Discovery



(a) UDF Composite
R = F105W + F125W + F160W
G = F775W + F850LP
B = F435W + F606W
Grism Dispersion :
86 and 92.4 deg E of N
SN Primo (J2000)
03:32:38.01 -27:46:39.08
53.158222 -27.777636
10 arcsec
N
E
Rodney et al. 2012
F160W
(b) UDF Template
SN Primo
(c) CANDELS
(d) Difference Image
5 arcsec

Light curve

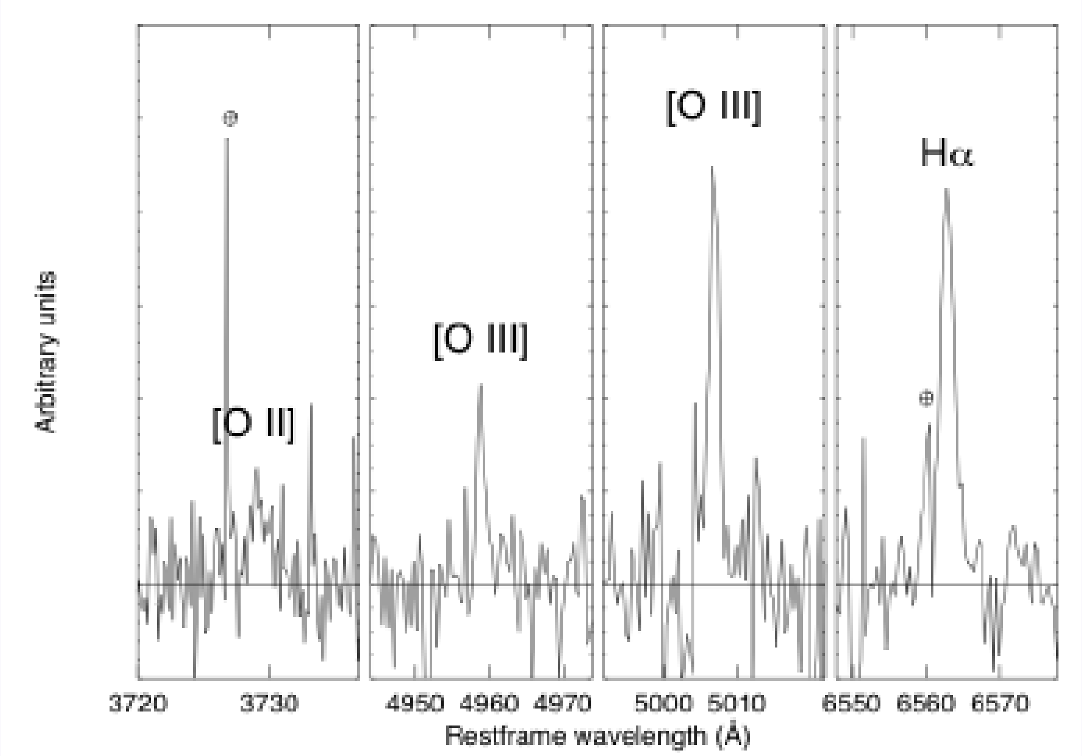
- WFC3 IR light curves



Rodney et al. 2012

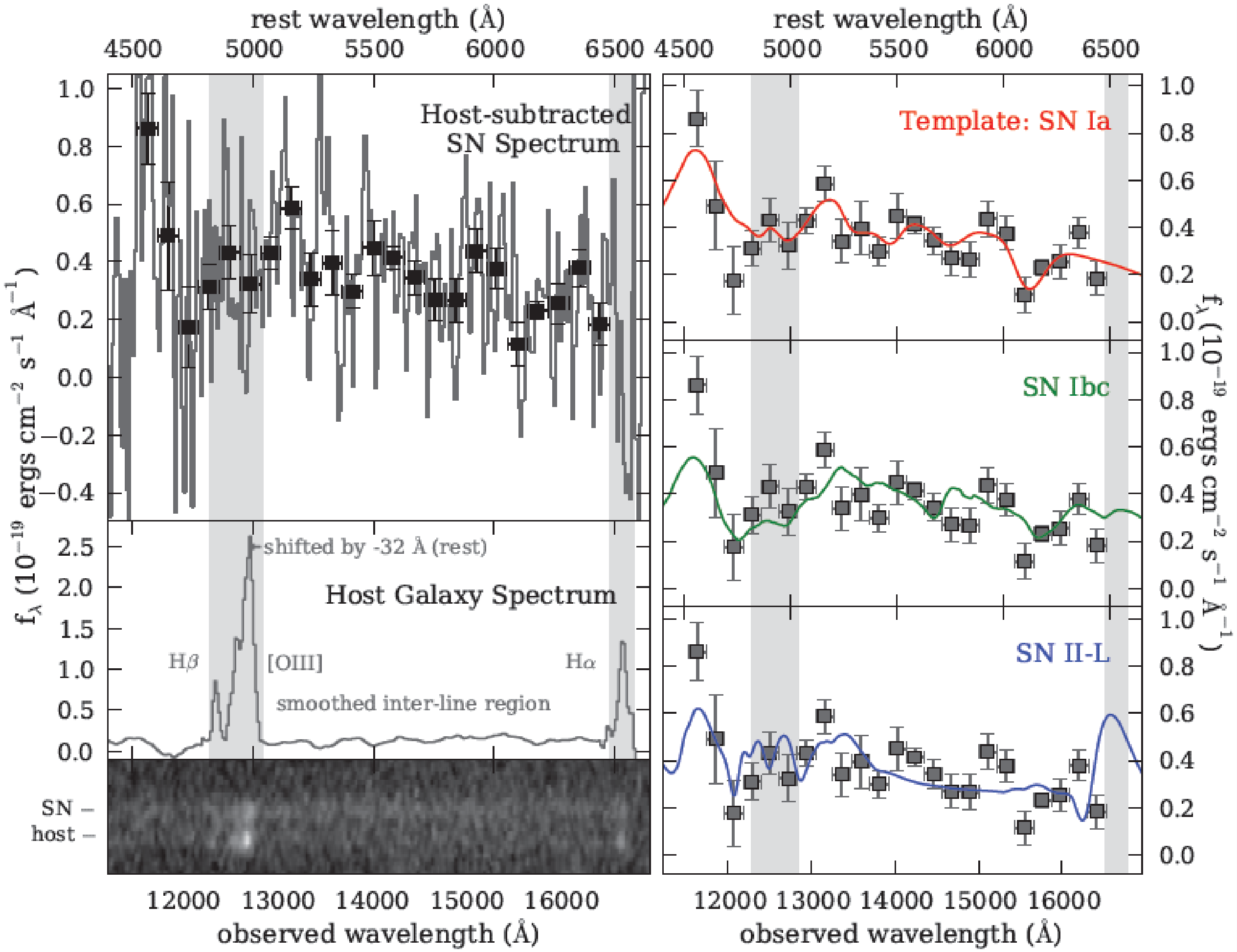
Spectroscopy

- VLT spectrum of host galaxy
  - X-shooter (Frederiksen et al., in prep.)



Spectroscopy

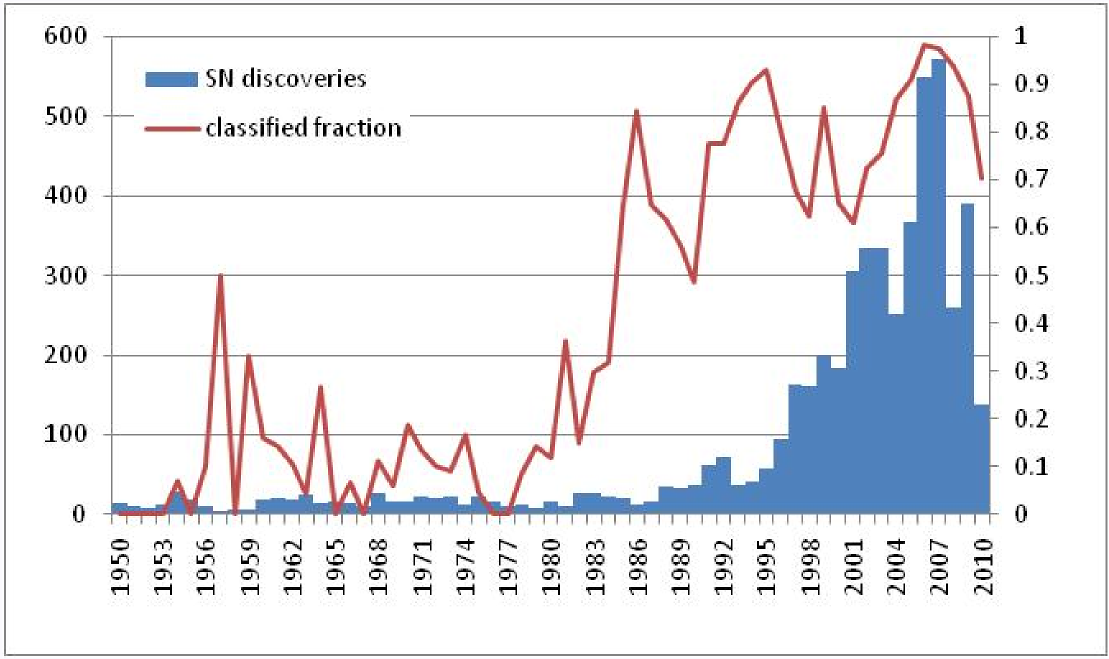
- SN spectroscopy with ACS grism



Rodney et al. 2012

Predicting the future ...

- What will we know about supernovae 10 years from now?
  - ~5400 SNe reported until end of 2009
  - expect up to 100000 SNe (?) for the coming decade
    - PanSTARRS, PTF/PTF2, LSST



Summary

- Concentrate on λ not covered so far
  - particular IR is interesting
    - reduced effect of reddening
    - better behaviour of SNe Ia(?)
- Understand the SN zoo
  - many (subtle?) differences observed in recent samples (PanSTARRS and PTF)
    - subluminous and superluminous
    - see S. Taubenberger's poster for a prominent example (SN 2009dc)
  - understand potential evolutionary effects
    - spectroscopy important → PESSTO
    - DES?, LSST?, Euclid follow-up?