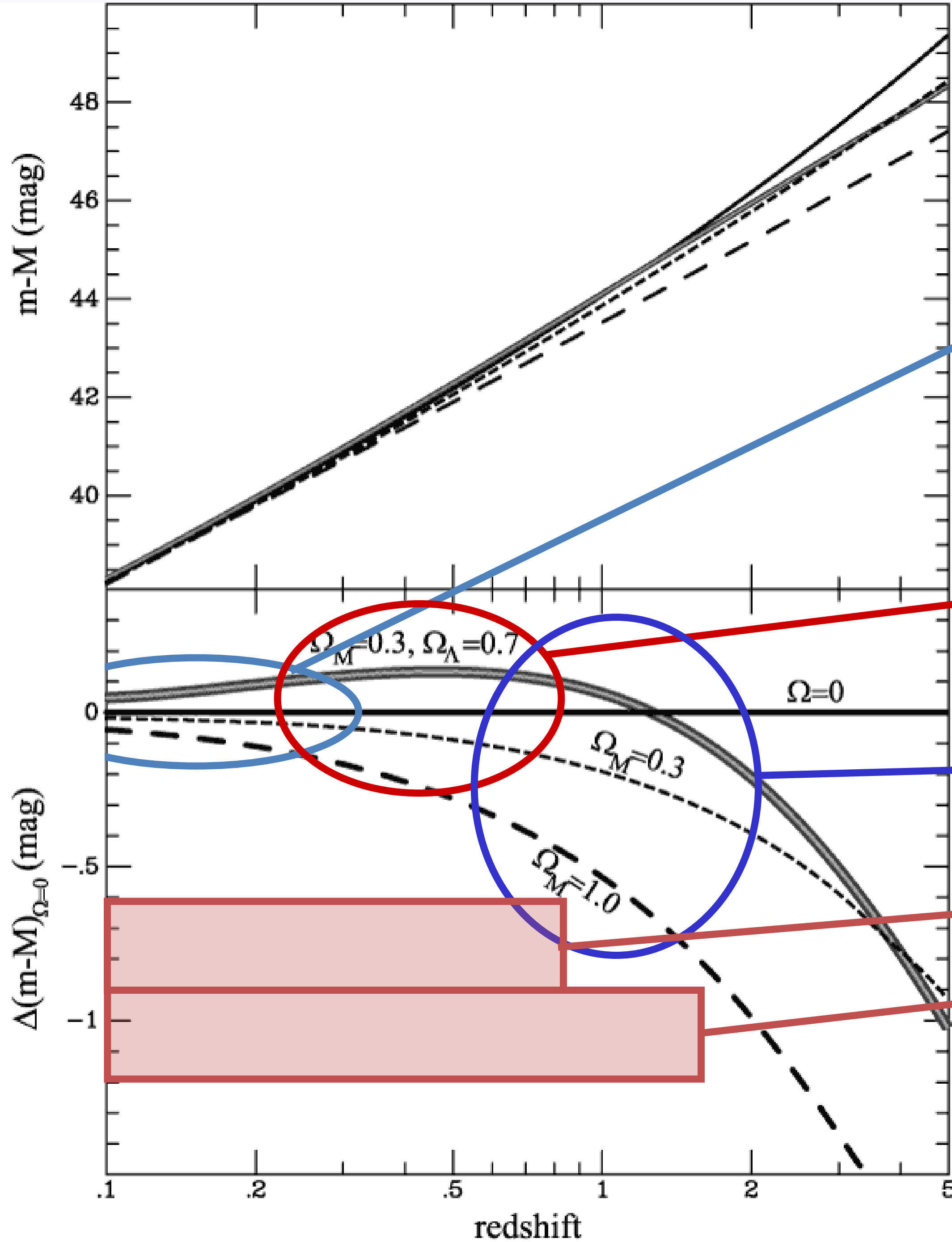
Recent results on supernova cosmology

Bruno Leibundgut

SN Projects



SN Factory
Carnegie SN Project
SDSSII
PanSTARRS
PTF

ESSENCE
CFHT Legacy Survey
Carnegie SN Project

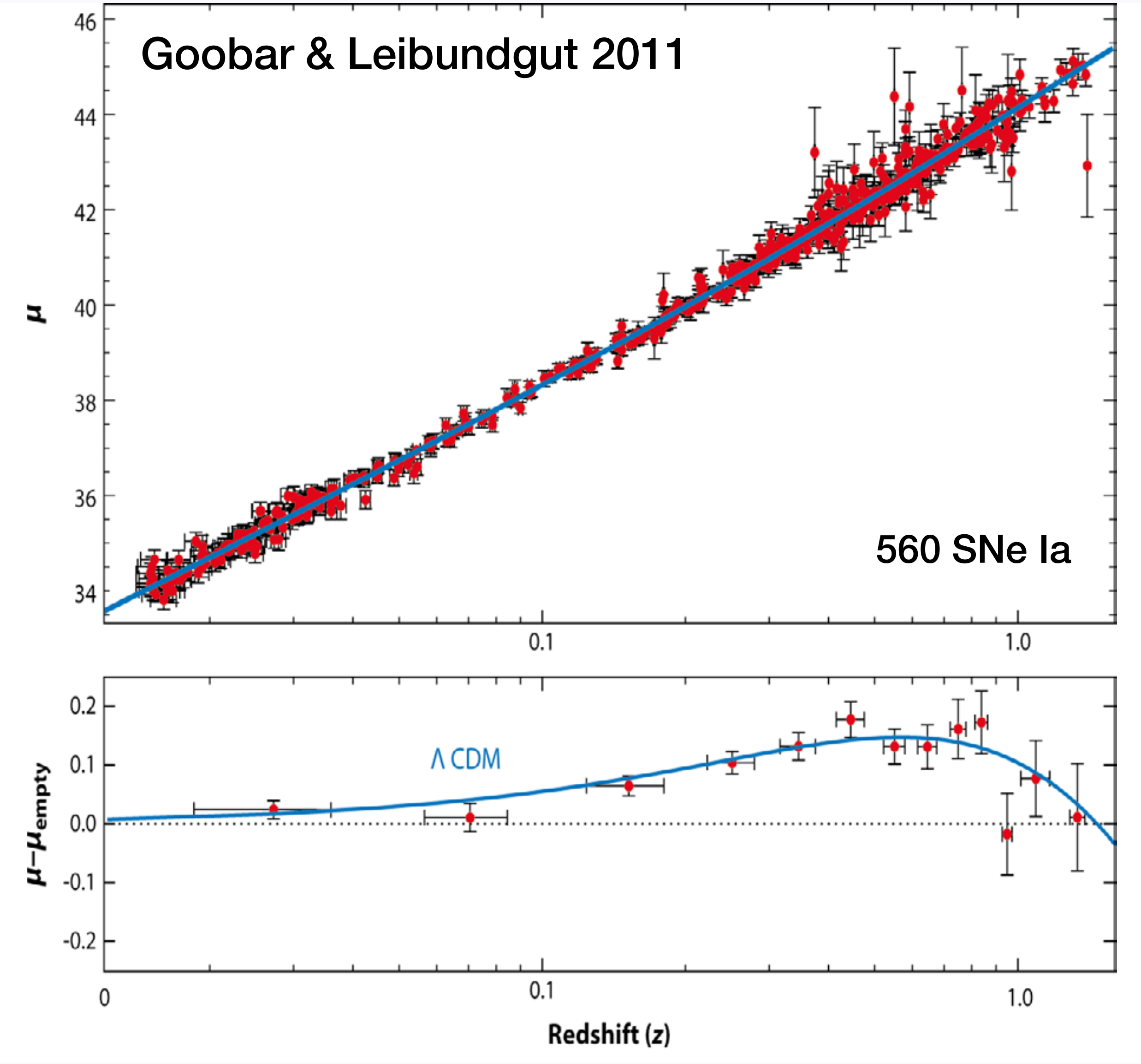
Higher-z SN Search
HST SN Treasury

Euclid/LSST

WFIRST 2.4

Plus the local searches:
LOTOSS, CfA, ESC

Supernova Cosmology 2011

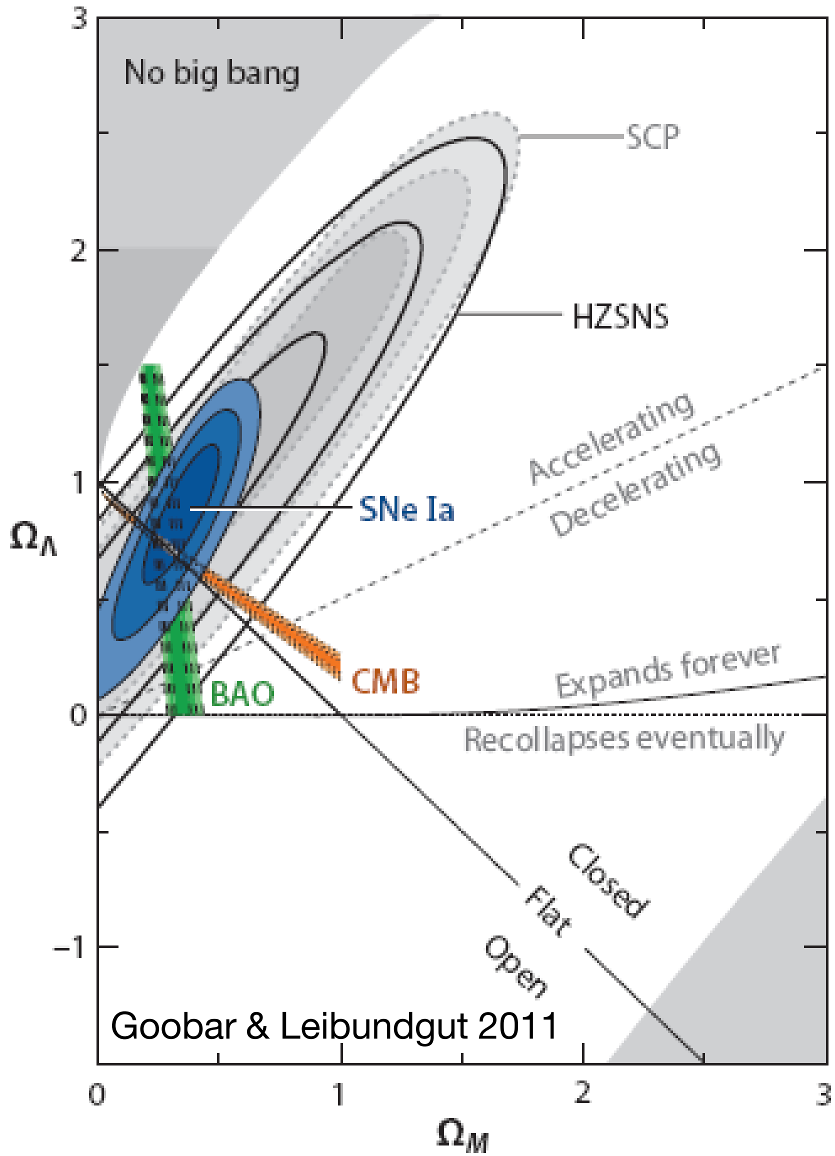


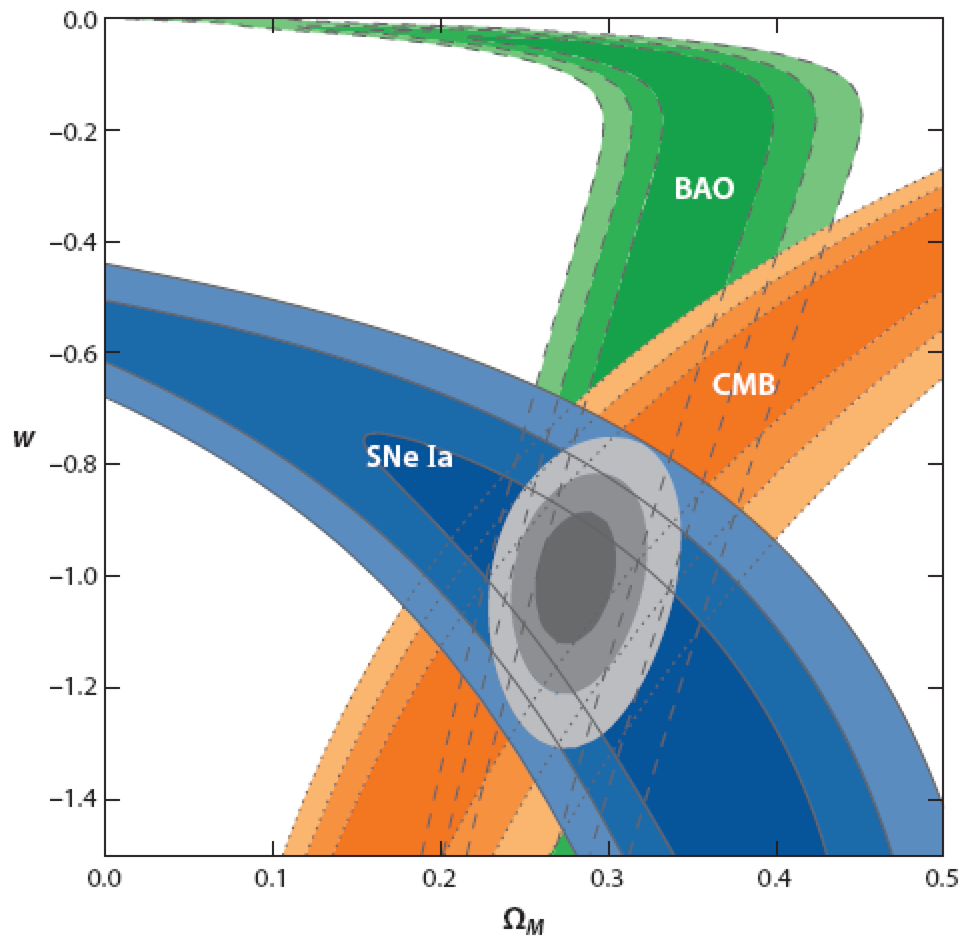
Supernova cosmology

- ω firmly established
  - general agreement between different experiments

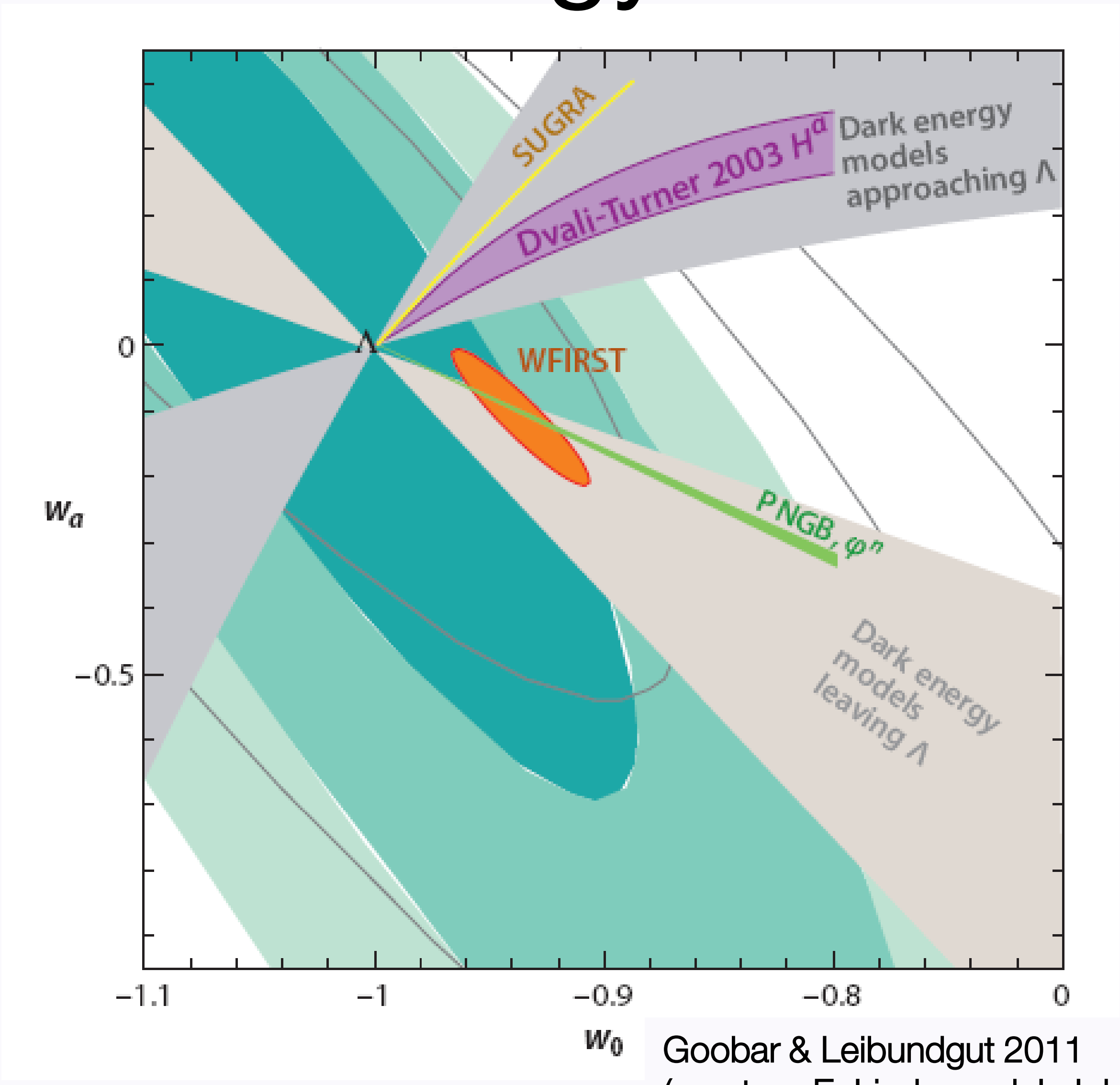
N_{SN}	Ω_M(flat)	w (constant, flat)	Light curve fitter	Reference
115	$0.263^{+0.042\ +0.032}_{-0.042\ -0.032}$	$-1.023^{+0.090\ +0.054}_{-0.090\ -0.054}$	SALT	Astier et al. 2006
162	$0.267^{+0.028}_{-0.018}$	$-1.069^{+0.091\ +0.13}_{-0.083\ -0.13}$	MLCS2k2	Wood-Vasey et al. 2007
178	$0.288^{+0.029}_{-0.019}$	$-0.958^{+0.088\ +0.13}_{-0.090\ -0.13}$	SALT2	
288	$0.307^{+0.019\ +0.023}_{-0.019\ -0.023}$	$-0.76^{+0.07\ +0.11}_{-0.07\ -0.11}$	MLCS2k2	Kessler et al. 2009
288	$0.265^{+0.016\ +0.025}_{-0.016\ -0.025}$	$-0.96^{+0.06\ +0.13}_{-0.06\ -0.13}$	SALT2	
557	$0.279^{+0.017}_{-0.016}$	$-0.997^{+0.050\ +0.077}_{-0.054\ -0.082}$	SALT2	Amanullah et al. 2010
472		$-0.91^{+016\ \pm 0.07}_{-0.20\ -0.14}$	SiFTO/SALT2	Conley et al. 2011
472	0.269 ± 0.015	$-1.061^{+0.069}_{-0.068}$	SALT2	Sullivan et al. 2011
580	$0.271^{+0.014}_{-0.014}$	$-1.013^{+0.077}_{-0.073}$	SALT2	Suzuki et al. 2011

15 years of progress





Cosmology – more?

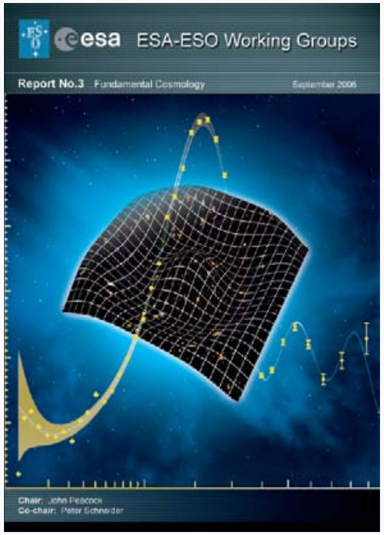


Goobar & Leibundgut 2011
(courtesy E. Linder and J. Johansson)

Systematics

- Contamination
- Photometry
- K-corrections
- Malmquist bias
- Normalisation
- Evolution
- Absorption
- Local expansion field

“[T]he length of the list indicates the maturity of the field, and is the result of more than a decade of careful study.”



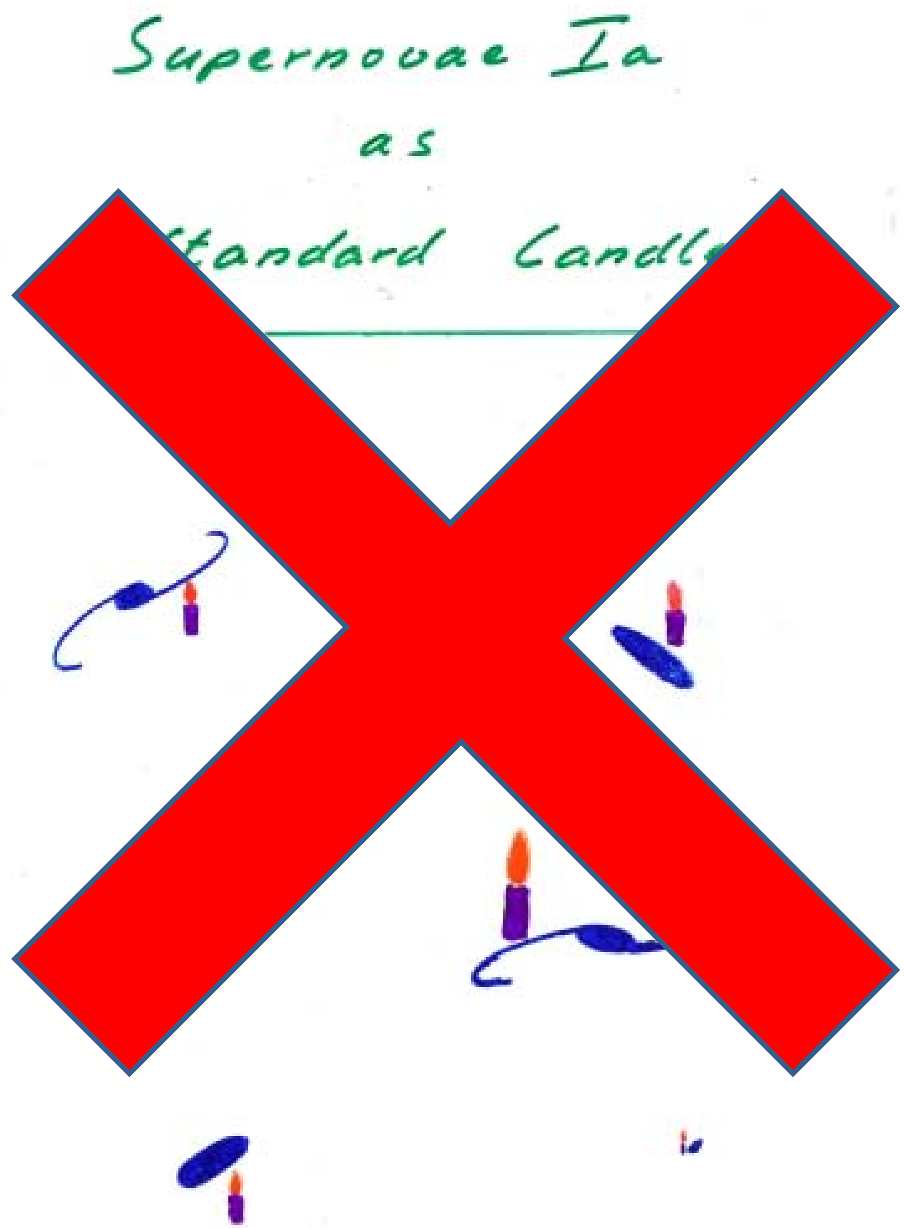
What next?

- Already in hand
  - >1000 SNe Ia for cosmology
  - constant ω determined to 5%
  - accuracy dominated by systematic effects

Type Ia SNe are not standard candles

They are not even standardizable

Maybe some of them can be normalised to a common peak luminosity

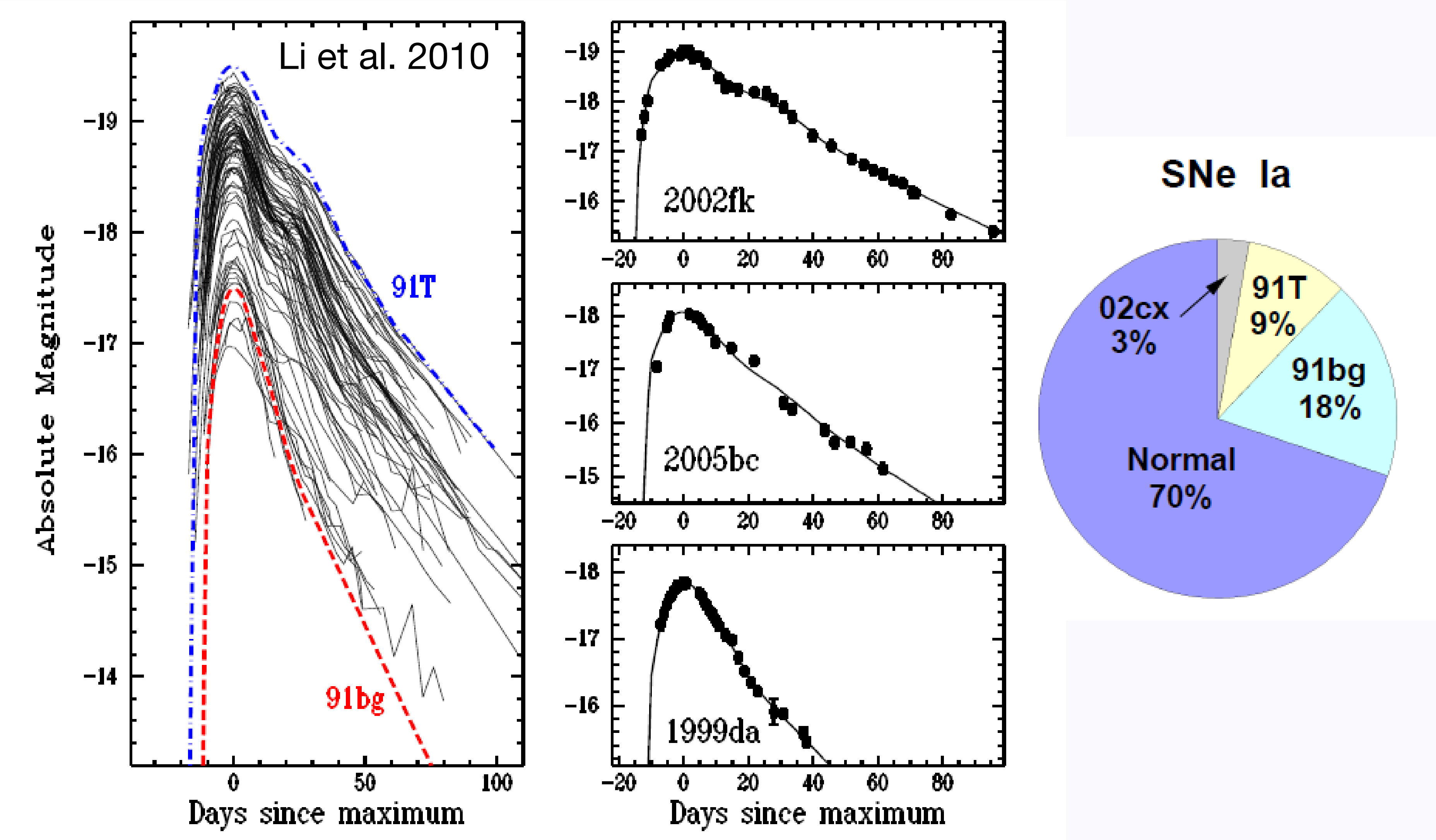


Paradigm 1

Why no standard candle?

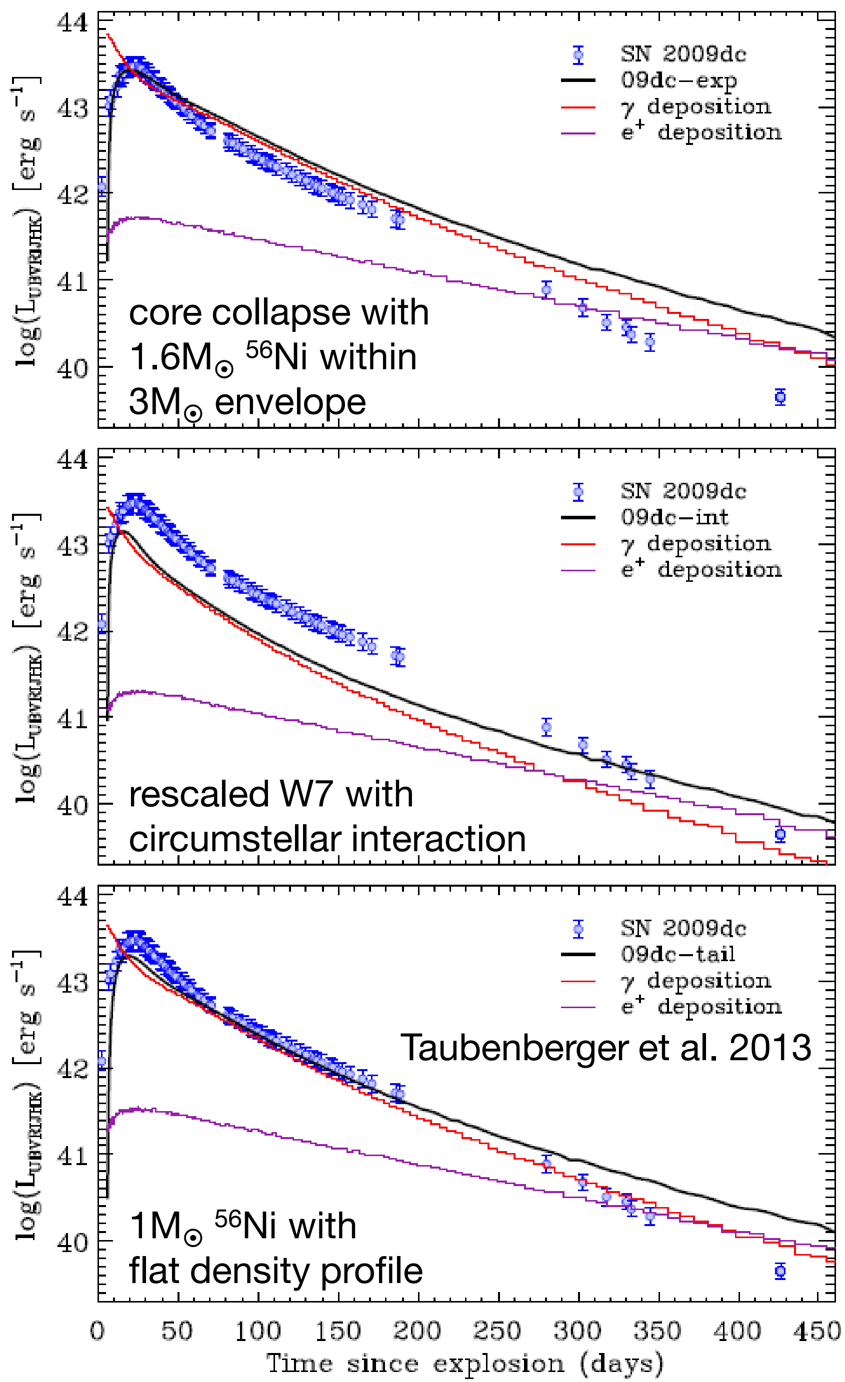
- Large variations in
  - luminosity
  - light curve shapes
  - colours
  - spectral evolution
  - polarimetry
- Some clear outliers
  - what is a type Ia supernova?
- Differences in physical parameters
  - Ni mass

Luminosity distribution



Super-lum

- Unclear nature
- Luminosity drops at late phases
- Model with a circumstellar shell from a double-degenerate merger



Type Ia SNe do not all come from Chandrasekhar-mass white dwarfs

Annu. Rev. Astron. Astrophys. 2000. 38:191–230

Type Ia Supernova Explosion Models

Wolfgang Hillebrandt[1] and Jens C. Niemeyer[2]
[1]*Max-Planck-Institut für Astrophysik, Karl-Schwarzschild-Str. 1, 85740*

There are good reasons to believe that perhaps most type Ia supernovae are the explosions of white dwarfs that have approached the Chandrasekhar mass, $M_{\rm chan} \approx 1.39\,{\rm M}_\odot$, and are disrupted by thermonuclear fusion of carbon and oxygen.

■ **Abstract** Because calibrated light curves of type Ia supernovae have become a major tool to determine the local expansion rate of the universe and also its geometrical structure, considerable attention has been given to models of these events over the past couple of years. There are good reasons to believe that perhaps most type Ia

well as several of the still open questions are addressed in this review. Although the main emphasis is on studies of the explosion mechanism itself and on the related physical processes, including the physics of turbulent nuclear combustion in degenerate stars, we also discuss observational constraints.

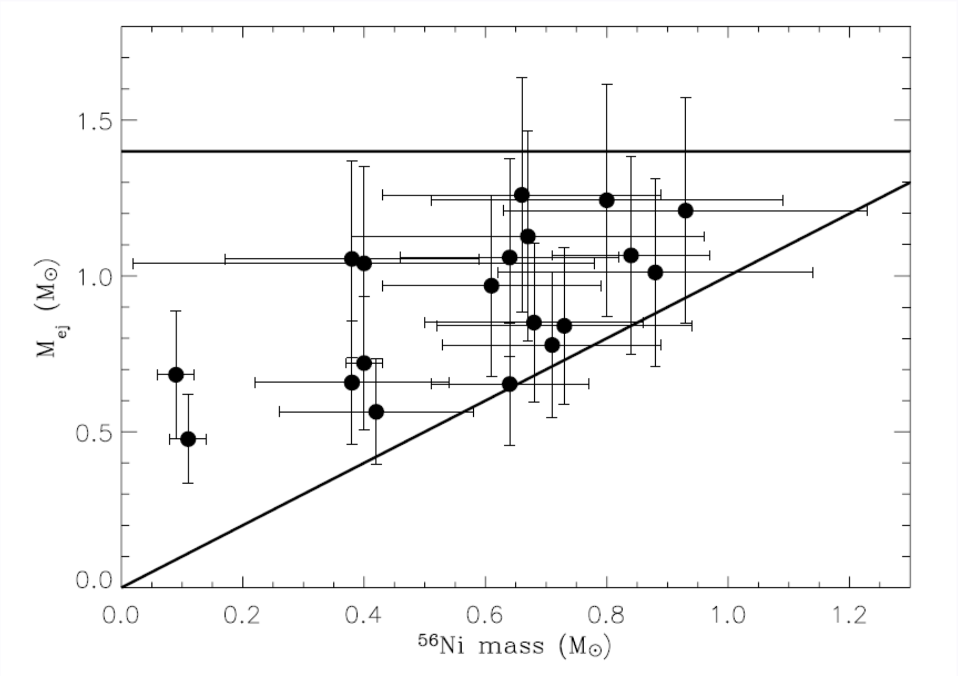
"Type Ia Supernova progenitors are not Chandrasekhar-mass white dwarfs" (2012)

Paradigm 2

Ejecta masses

Large range in nickel and ejecta masses

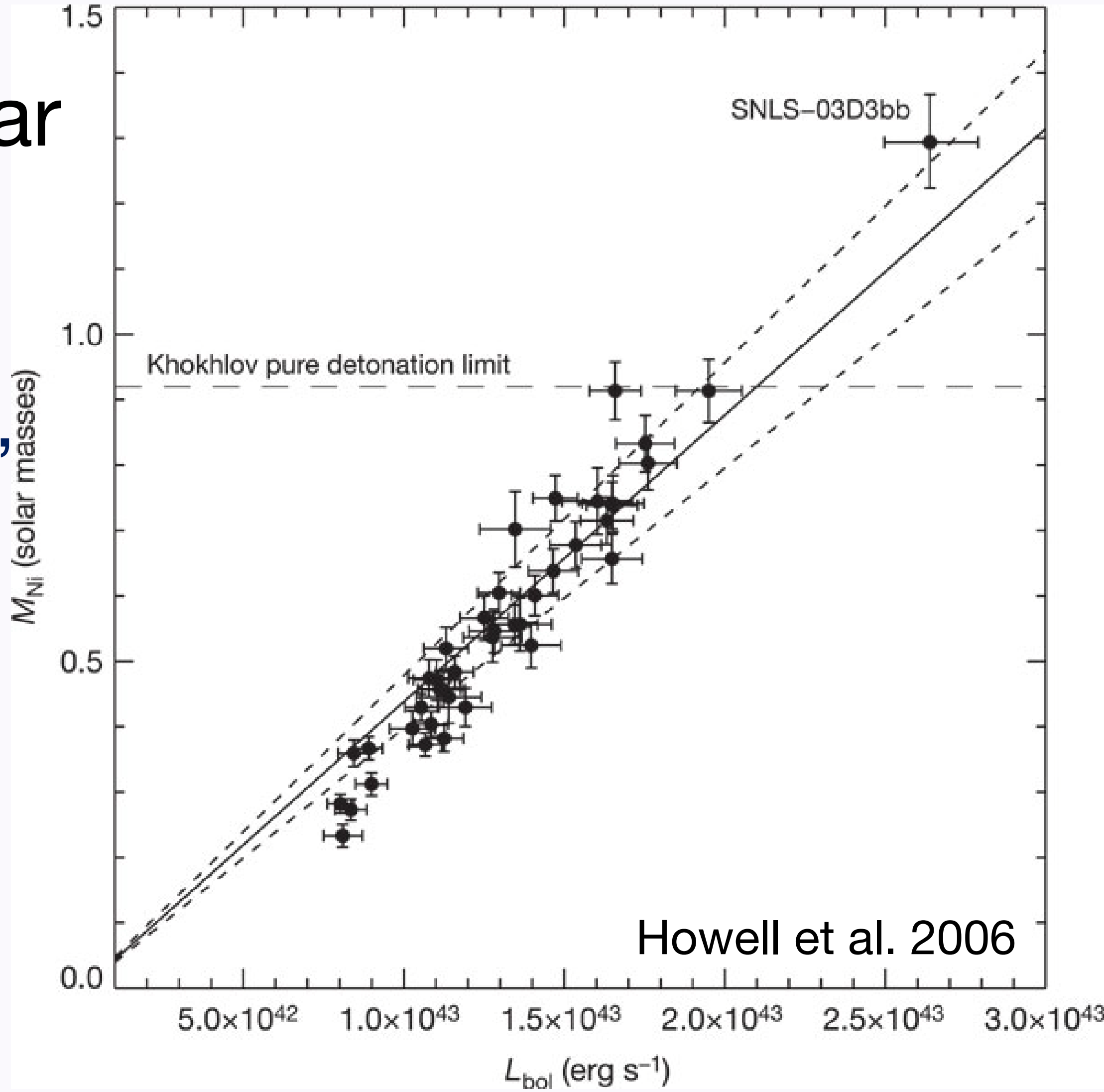
- no ejecta mass at $1.4M_{\odot}$
- factor of 2 in ejecta masses
- some rather small differences between nickel and ejecta mass



Ejecta masses

Super-Chandrasekhar explosions?

- also SN 2006gz, 2007if, 2009dc
- inferred Ni mass > 1 $M_\odot$

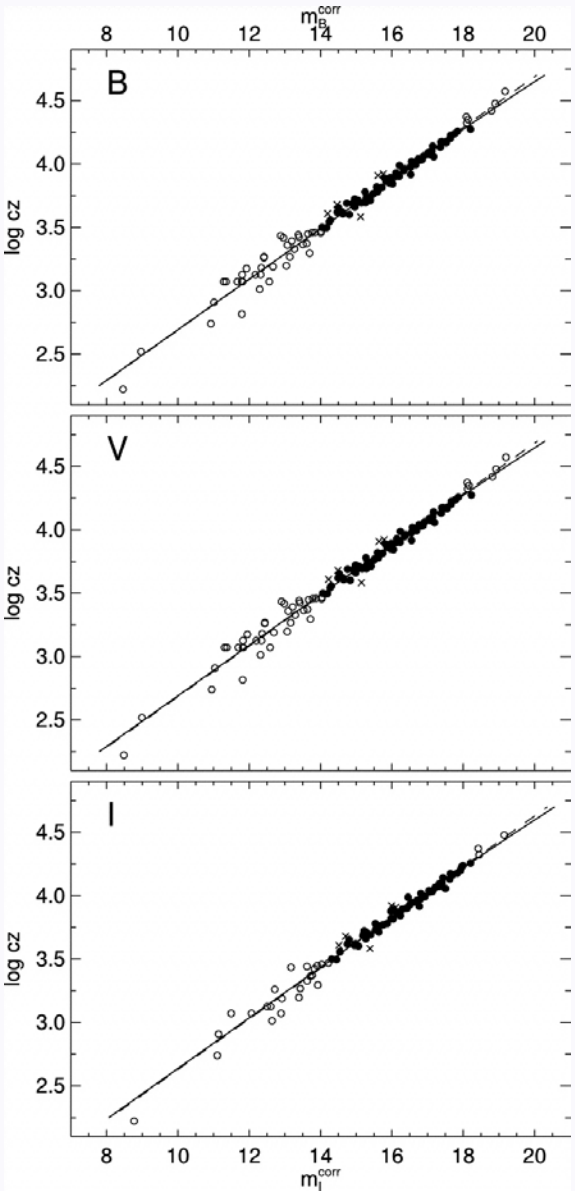


Type Ia supernova cosmoloy

Excellent distance indicators!

SN Ia Hubble diagram

- Excellent distance indicators
- Experimentally verified
- Work of several decades



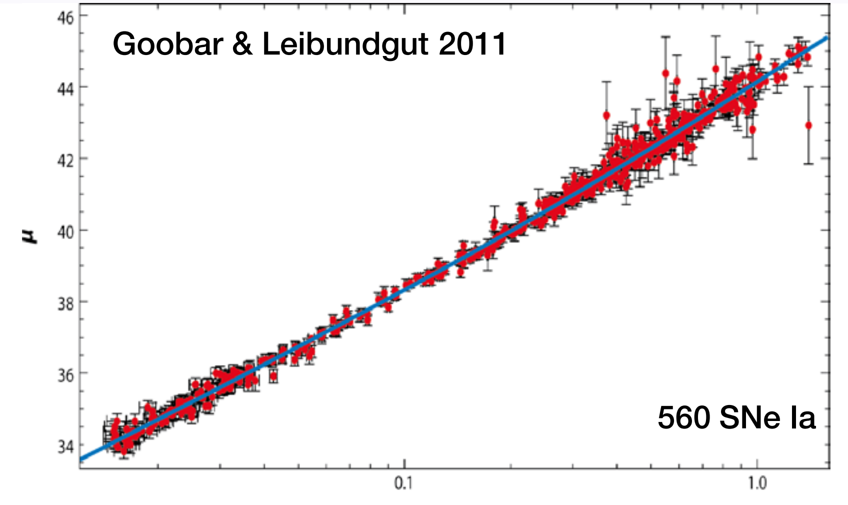
Reindl et al. 2005

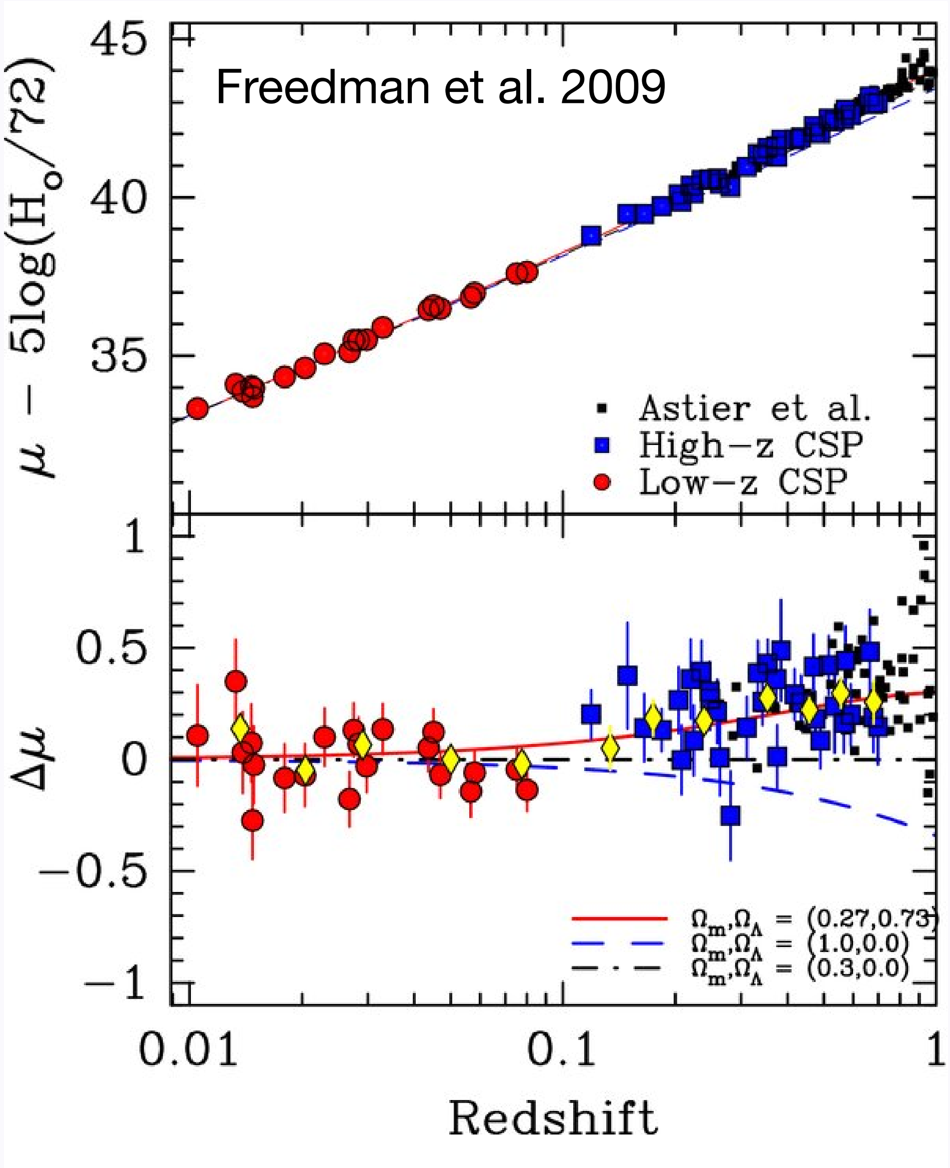
What next?

- 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
  - restframe near-infrared Hubble diagram
    - Nobili et al. 2005, Freedman et al. 2009, Barone-Nugent et al. 2012, Kattner et al. 2012

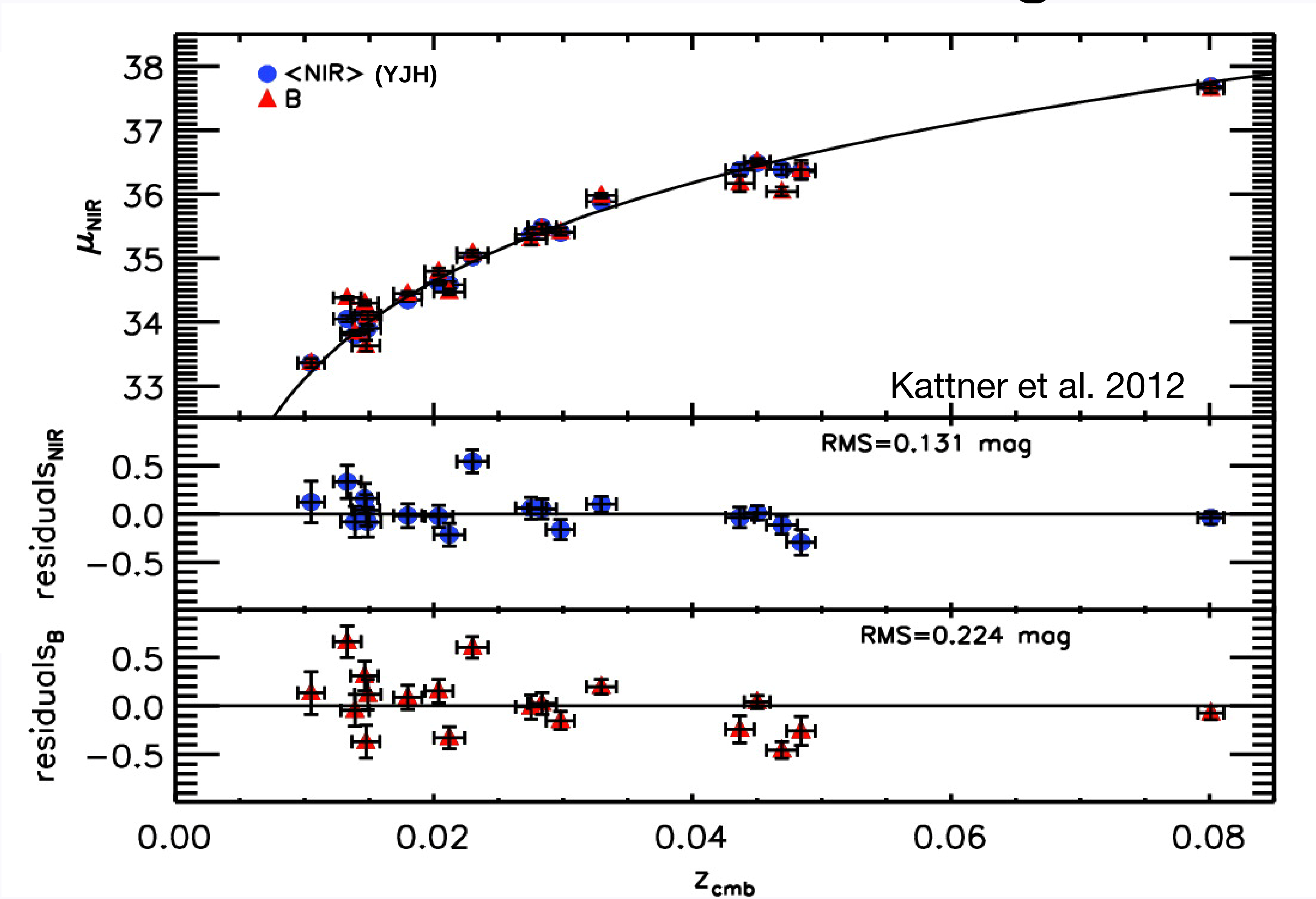
I-band Hubble diagram

- Currently only 35 SNe Ia





J- and H-band Hubble diagrams



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

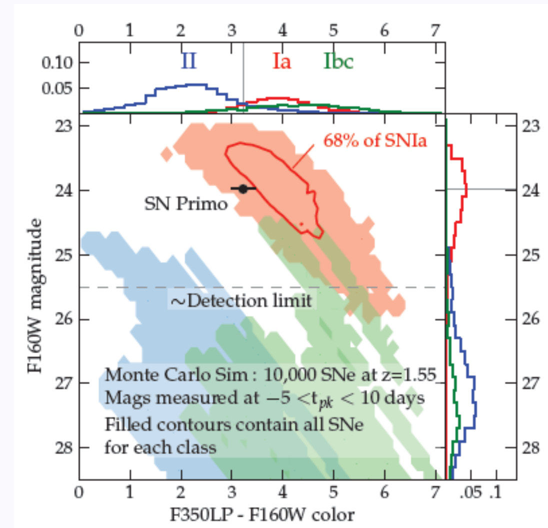
SN discoveries and target-of-opportunity follow-up

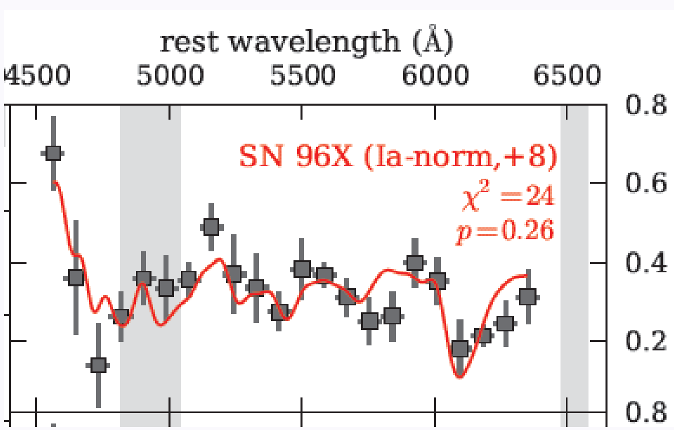
SNe Ia out to $z \approx 2$

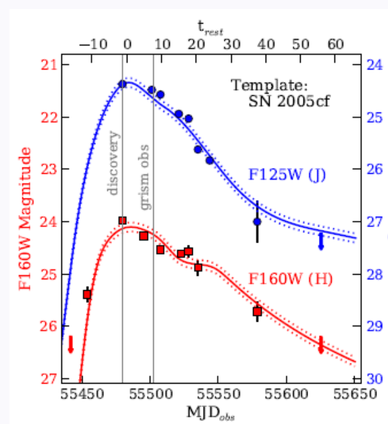
Determine the SN rate at $z > 1$ and constrain the progenitor systems

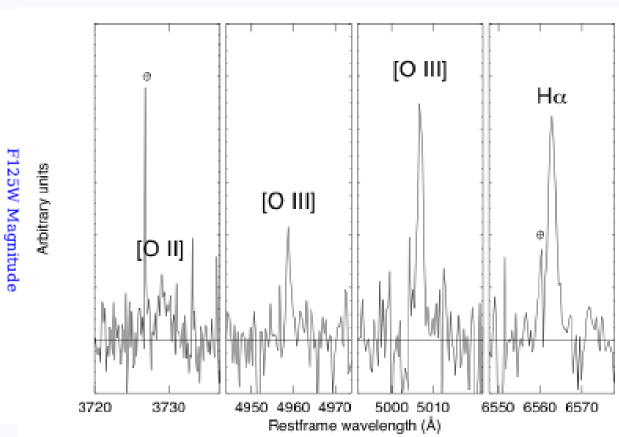
4 arguments for a SN Ia @ z=1.55

1. color and host galaxy photo-z
2. host galaxy spectroscopy
3. light curve consistent with normal SN Ia at z=1.55
4. SN spectrum consistent



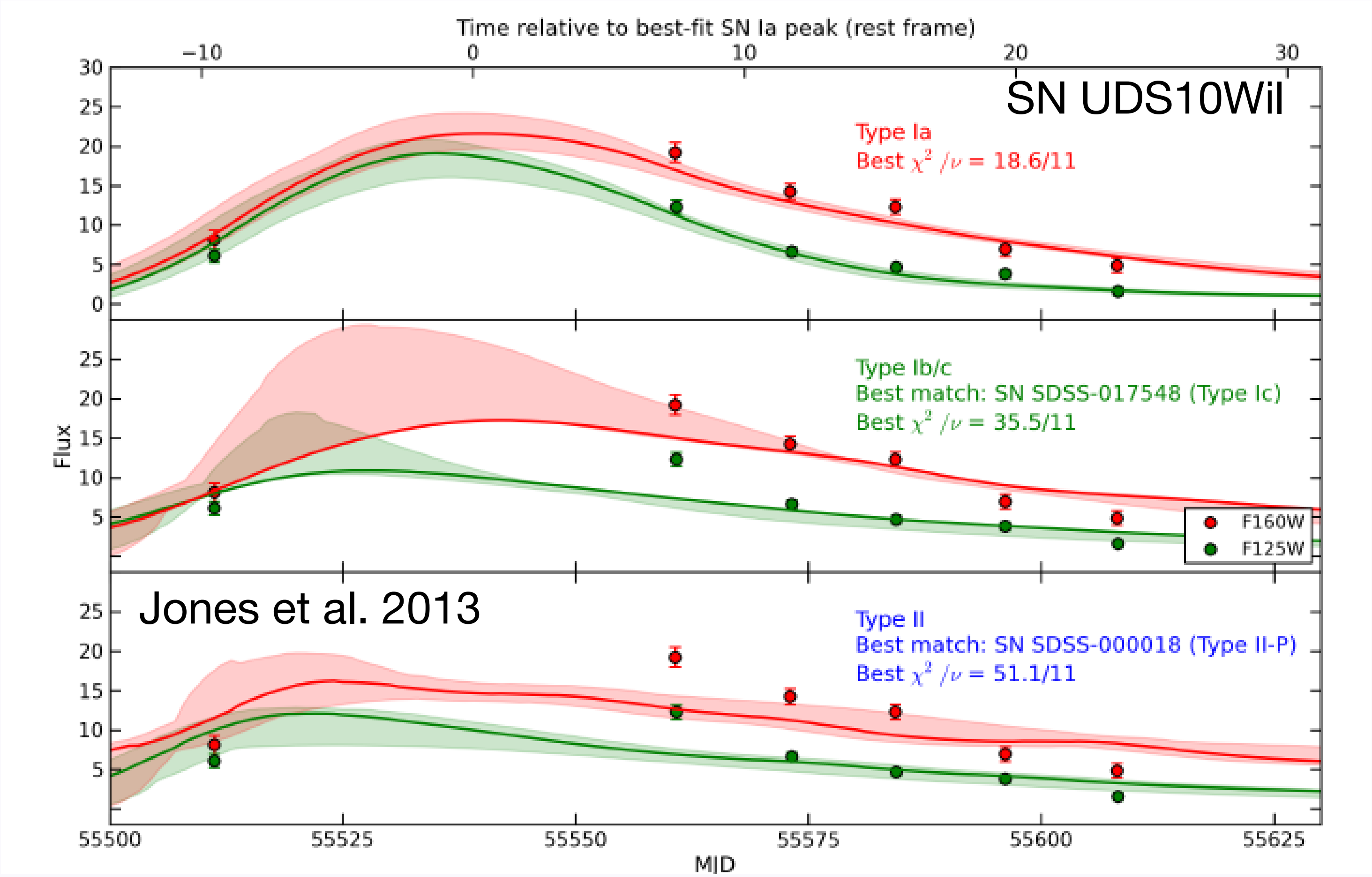




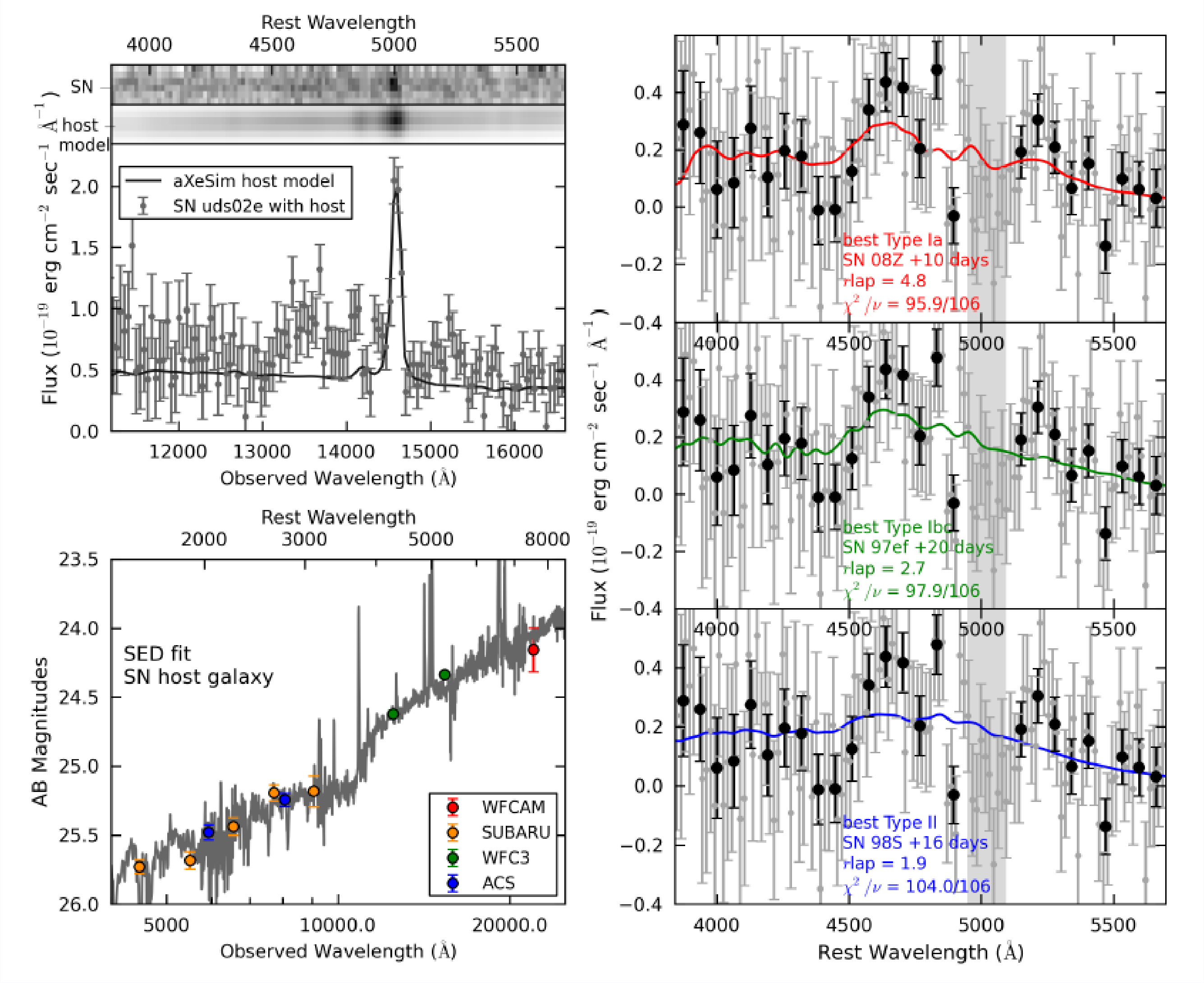


SNe Ia at z>1

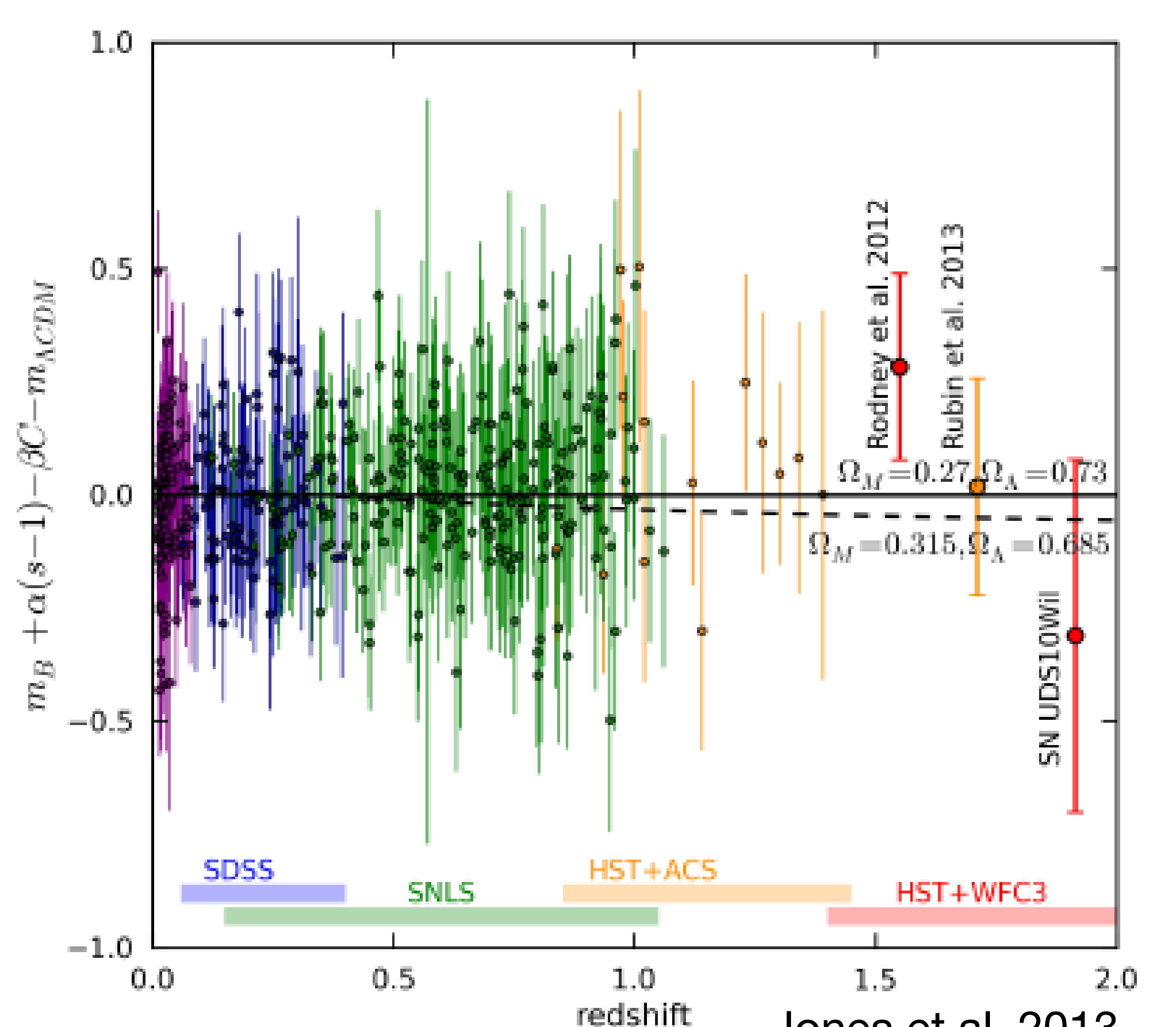
- SN Ia at z=1.91



SN UDS10Wil at z=1.91



SNe at z>1



Jones et al. 2013

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) → restframe I-band Hubble diagram
  - 16000 SNe discovered

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
  - understand potential evolutionary effects
    - spectroscopy important → PESSTO
    - DES, LSST, Euclid follow-up?