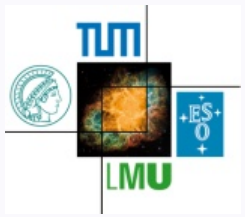
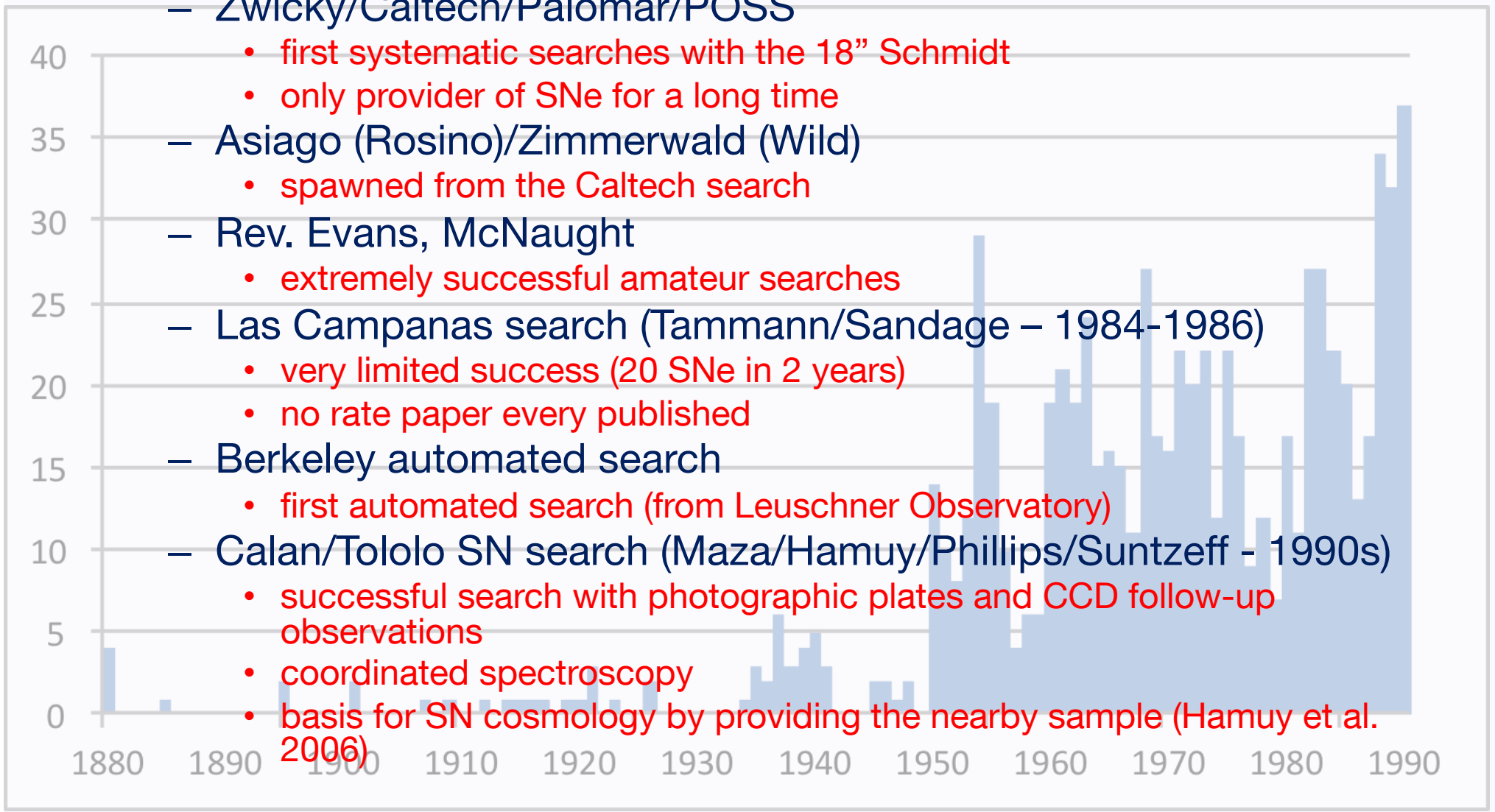
Past Supernova Surveys
What have we learned?

Bruno Leibundgut



Some past supernova surveys

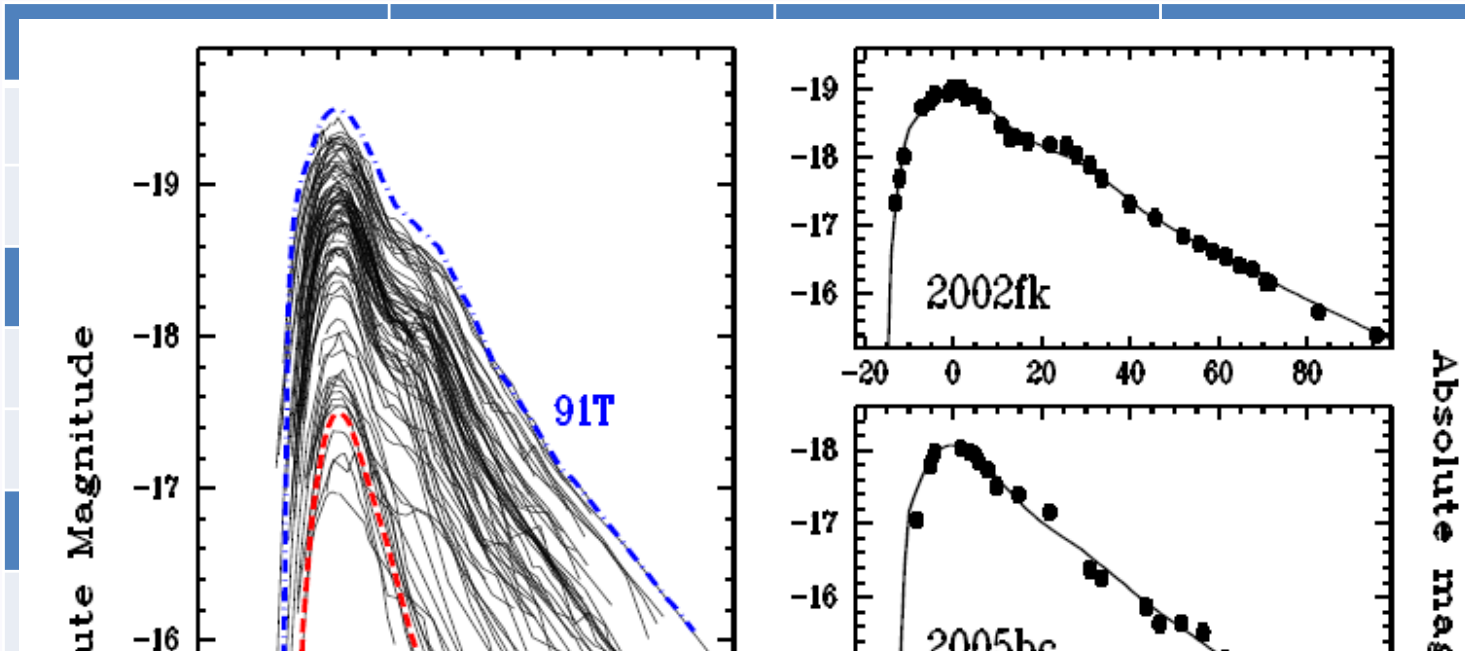
- Historical surveys
  - Zwicky/Caltech/Palomar/POSS
    - first systematic searches with the 18” Schmidt
    - only provider of SNe for a long time
  - Asiago (Rosino)/Zimmerwald (Wild)
    - spawned from the Caltech search
  - Rev. Evans, McNaught
    - extremely successful amateur searches
  - Las Campanas search (Tammann/Sandage – 1984-1986)
    - very limited success (20 SNe in 2 years)
    - no rate paper every published
  - Berkeley automated search
    - first automated search (from Leuschner Observatory)
  - Calan/Tololo SN search (Maza/Hamuy/Phillips/Suntzeff - 1990s)
    - successful search with photographic plates and CCD follow-up observations
    - coordinated spectroscopy
    - basis for SN cosmology by providing the nearby sample (Hamuy et al. 2006)



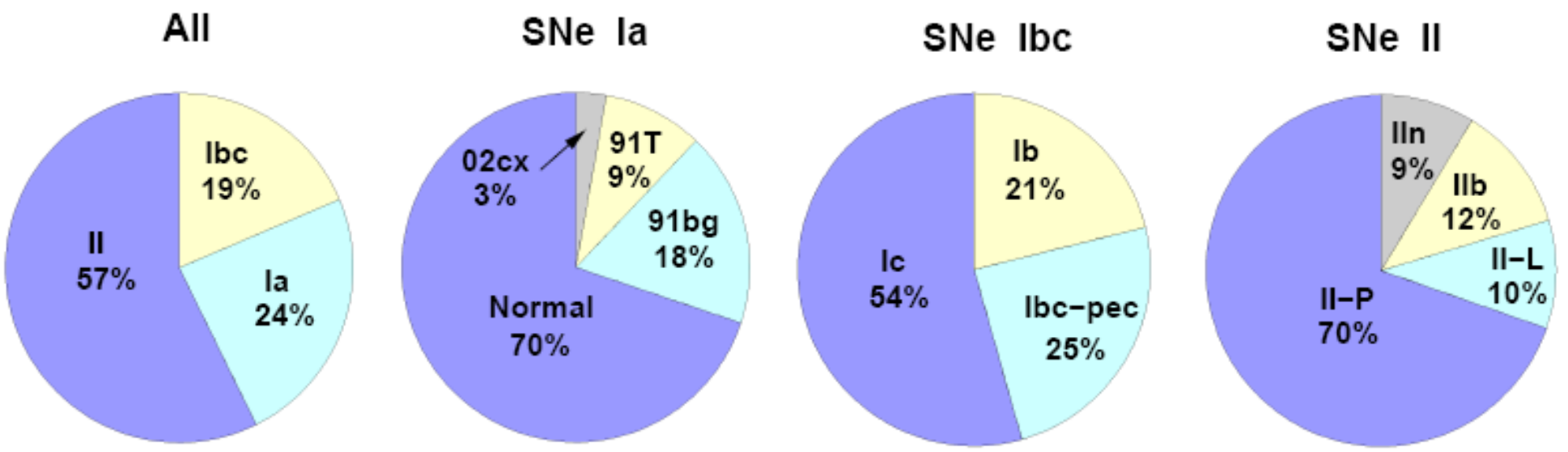
Supernova Searches

- Early searches
  - find supernovae!
    - Zwicky, Asiago, Zimmerwald, Rev. Evans
- Targeted searches
  - Hubble diagram → Hubble constant
    - Las Campanas, Calán-Tololo, Berkeley automated search, SN Factory
  - Distant supernovae → decelaration
    - Danish Search, SCP, High-z SN Search Team, SNLS, ESSENCE, SDSS
- Nearby robotic searches
  - SN physics
  - SN rates
    - LOSS, CHASE

Lick Observatory Supernova Search



	no classification
	14
	1.6%
	12
	1.6%

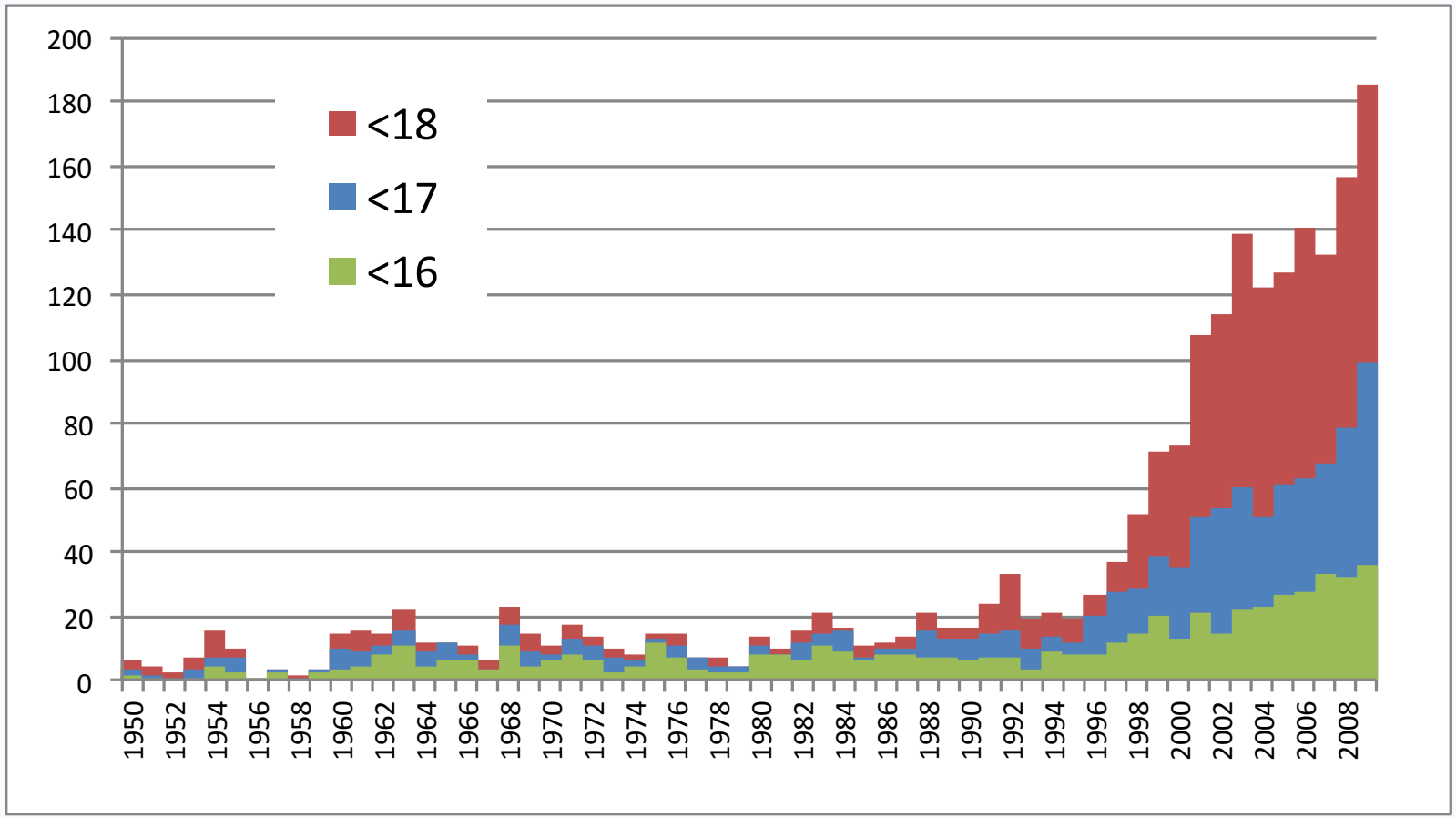


Supernova Searches

- ‘Indiscriminant’ searches
  - sky monitoring
    - as opposed to galaxy monitoring
    - ➔ several new SN classes
    - ROTSE-III, QUEST, Catalina Ridge, ASASSN, (i)PTF, PanSTARRS-1, ZTF, LSST
  - special monitoring
    - LMC/OGLE
    - VVV, UltraVISTA, VIDEO, VEILS → no results so far
    - planet transit projects, e.g. WASP, HAT, NGTS
- Special projects
  - search in special regions
    - IR search in star formation region → CC rates
  - ν and gravitational wave searches

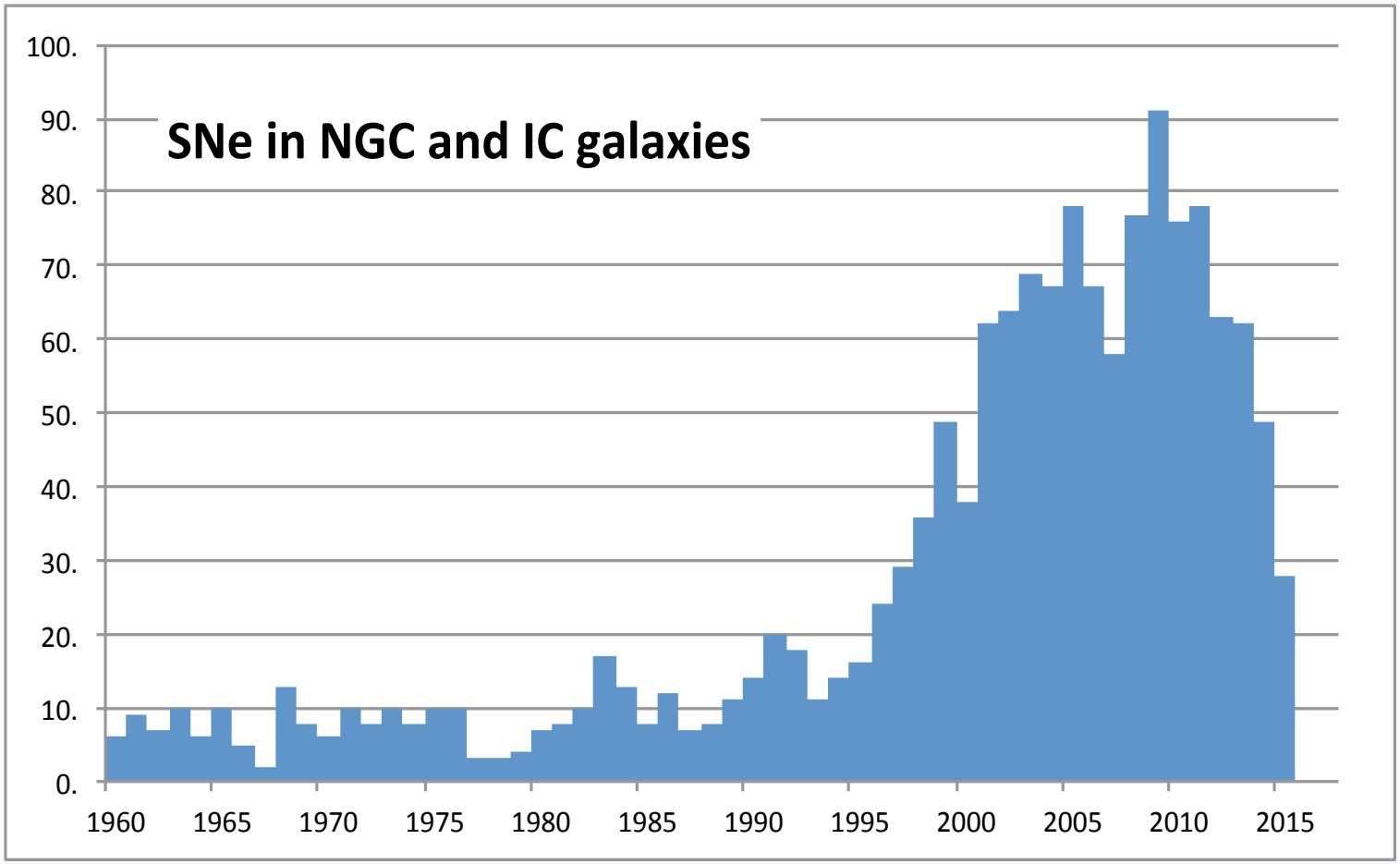
Do we find all nearby SNe?

- Searching the local volume
  - requires all-sky searches



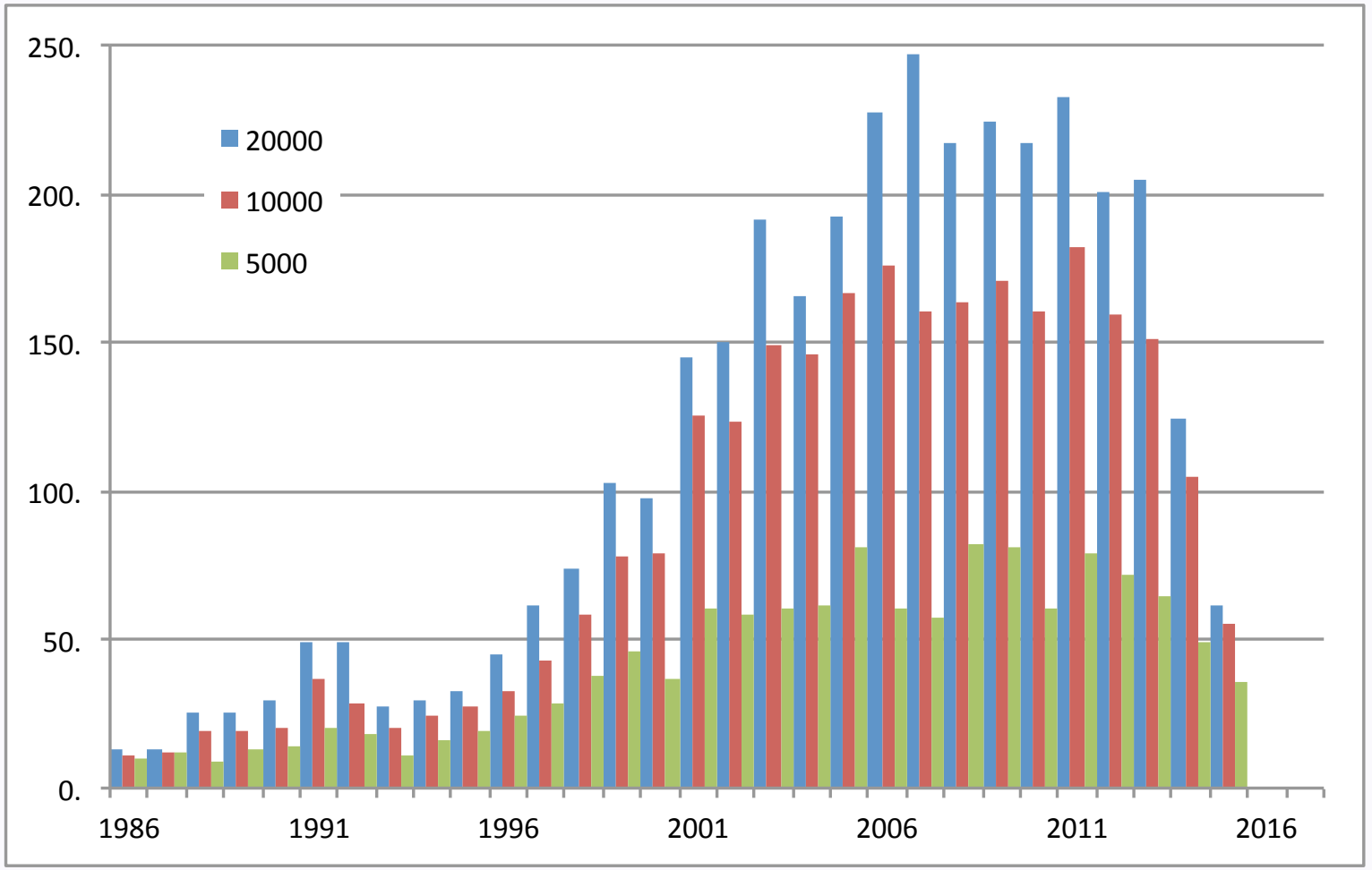
Nearby supernovae

- Decline after 2010

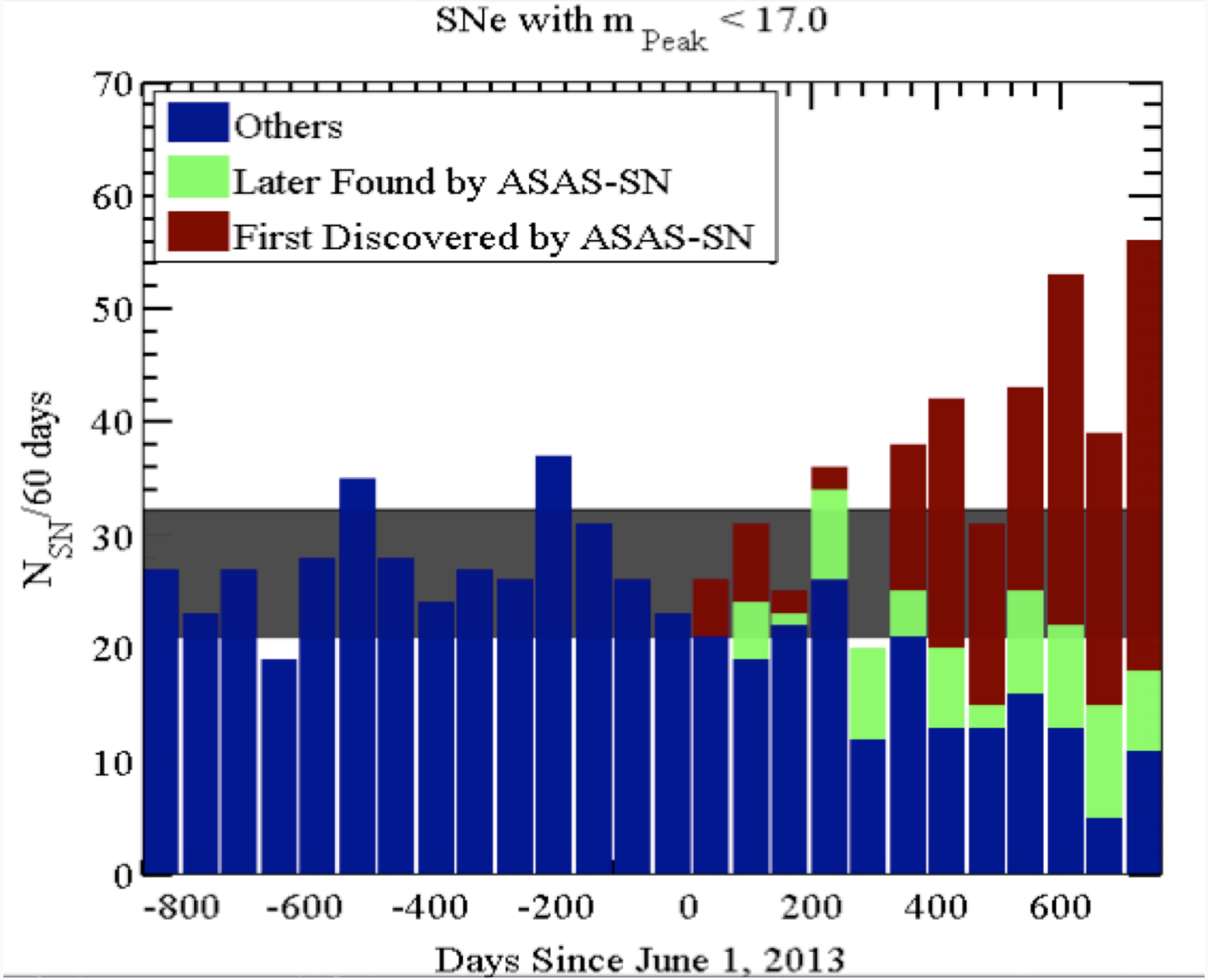


Nearby Supernovae

- As distances



Do we find all nearby SNe?



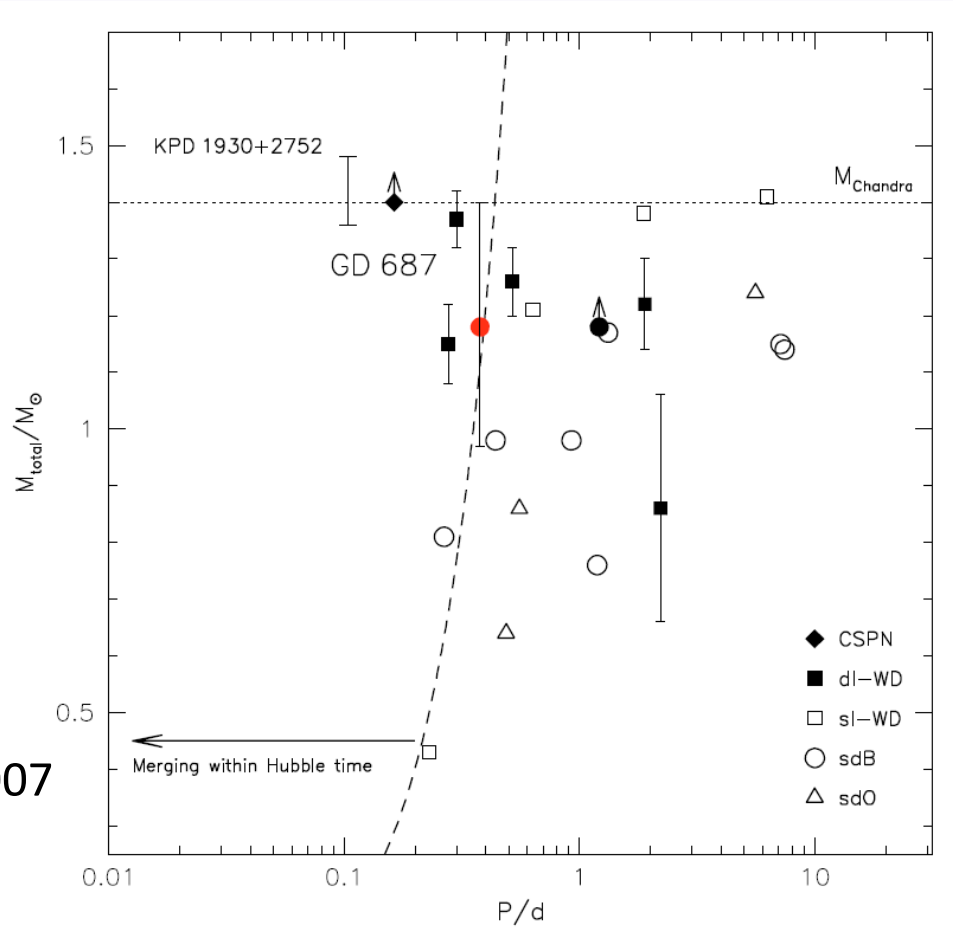
Ben Shappee, Easter Island

Synoptic Programs

- Follow-up
  - SN physics
    - CfA, CSP, PESSTO
    - light curves, spectral series
- Search for progenitors
  - Imaging of nearby explosion sites
    - HST, AO supported (Smartt, van Dyk)
  - Radial velocity survey
    - Supernova Progenitor surveY (SPY; VLT/UVES), SDSS

Supernova Progenitor surveY

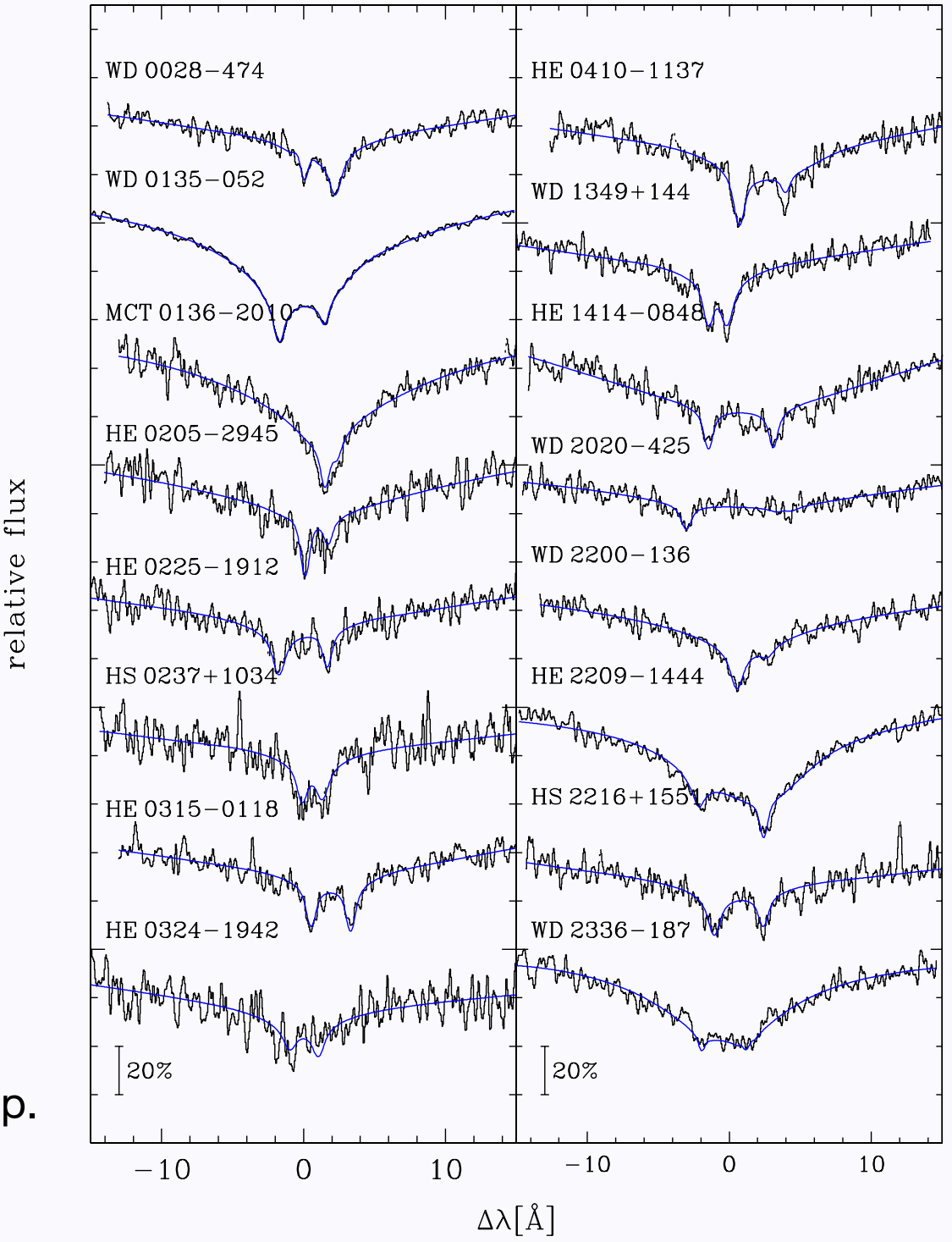
- 644 DA white dwarfs checked for radial velocity changes → search close binaries
  - are there double degenerate white dwarfs in the solar neighbourhood?
  - discovered ~35 double degenerate systems



Napiwotzki et al. 2007
Geier et al. 2010

SPY

- Example of the double-lined WDs



Napiwotzki et al., in prep.

Future surveys

- Several searches/surveys continue:
  - Amateurs, LOSS, CfA, CHASE, New surveys
  - SkyMapper
  - GAIA transient sources
  - Dark Energy Survey
  - Zwicky Transient Factory
    - Avishay Gal-Yam
  - LSST
    - Melissa Graham
  - EUCLID
    - DESIRE → Astier et al. 2014
  - WFIRST
    - Ryan Foley et al.; Saul Perlmutter et al.

Cosmology - do we need more?

- Already in hand
  - >1000 SNe Ia for cosmology
  - constant ω determined to 5%
  - accuracy dominated by systematic effects
    - reddening, correlations, local field, evolution
- 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 mass, metalicity)

More supernovae

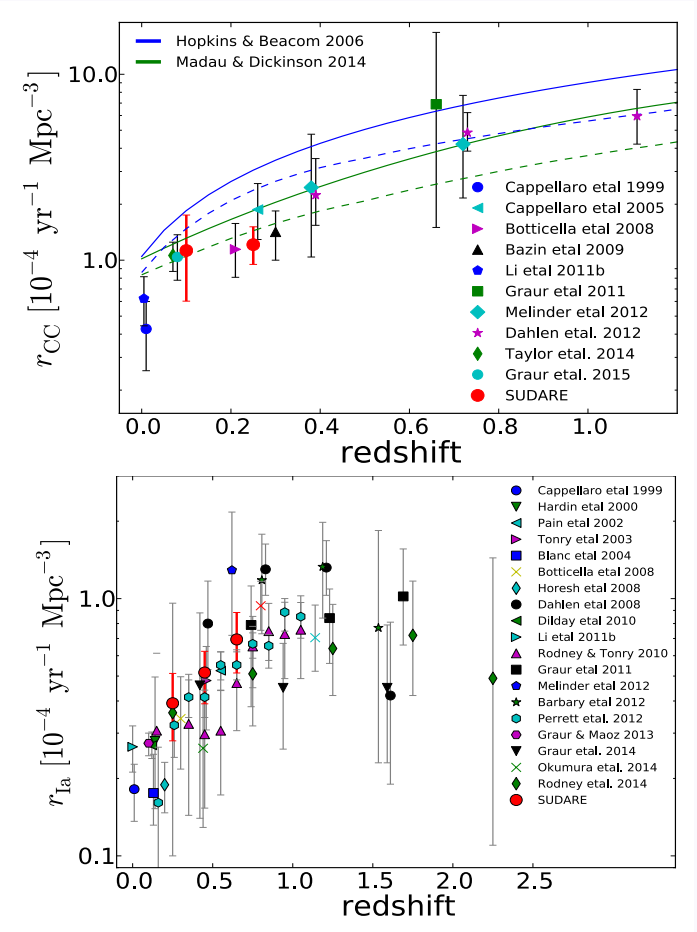
- Increase the number of interesting supernovae
  - many more general searches
    - remove paradigms
  - possible through the technological progress
    - detectors, data storage, data handling and processing
  - Need to keep the overview
  - Need to keep the focus on science results
- Improved understanding
  - hints on explosion physics
  - statistical samples → rare objects

Supernovae at ESO

- Many long-term programs
  - Large Programs before 2010
    - Danziger, Turatto, Benetti
  - PESSTO (survey) → SOXS in the future
    - spectroscopic follow-up with NTT/EFOSC2/SOFI
    - focussed on special objects
      - superluminous SNe, etc.
  - Spectropolarimetry
    - Patat, Maund, Baade, Spyromilio
  - SN 1987A
    - nearly unbroken spectroscopic record
  - Monitoring of old supernovae

Supernovae at ESO

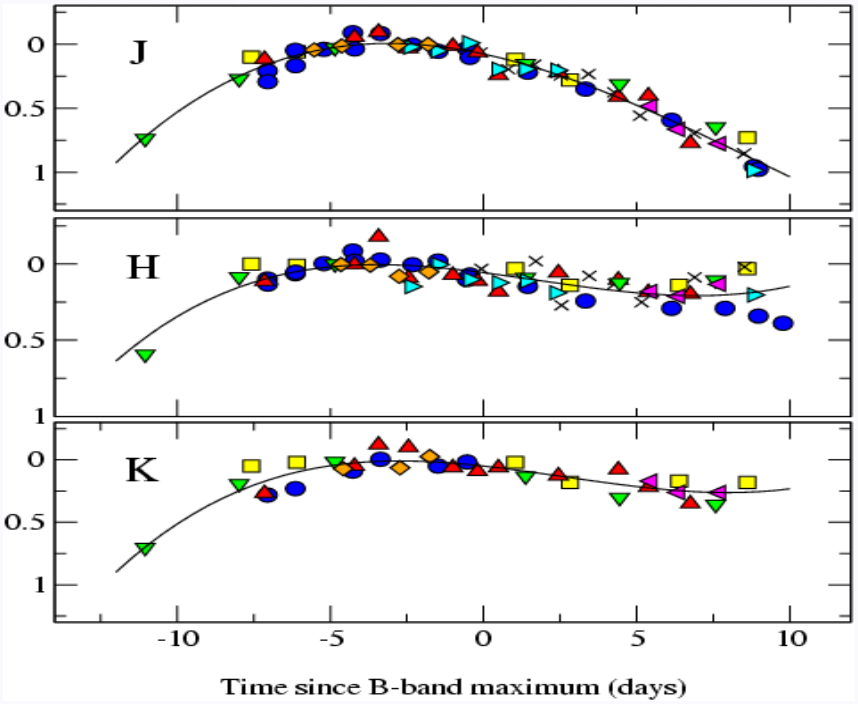
- Searches
  - mostly attached to survey programs
    - UltraVISTA, VVV, VIDEO
    - no results presented so far
  - VEILS
    - dedicated IR search in connection with DES
    - starts next year
  - SUDARE
    - rates as a function of redshifts



Cappellaro et al. 2015

The promise of the (near-)infrared

- Extinction is much reduced in the near-IR
  - $A_H/A_V \cong 0.19$ (Cardelli et al. 1989)
- SNe Ia much better behaved



SN m_{15}(B)

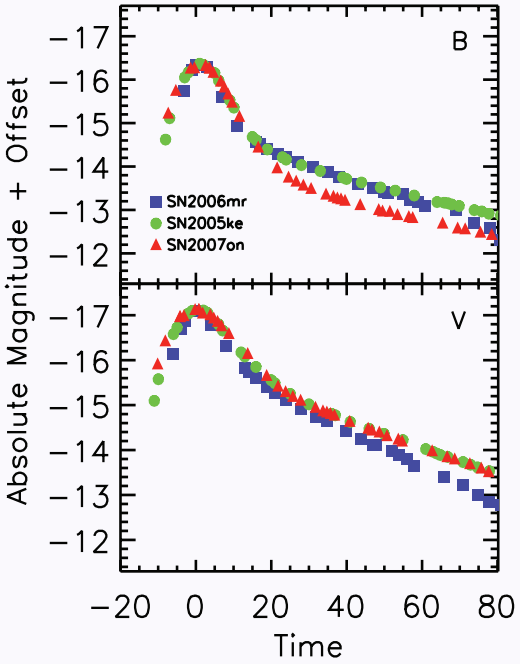
= 1980N (1.29)
= 1986G (1.79)
= 1998bu (1.05)
= 1999aw (0.81)
= 1999ee (0.94)
= 2000ca (1.01)
= 2001el (1.15)

Krisciunas et al. (2004)

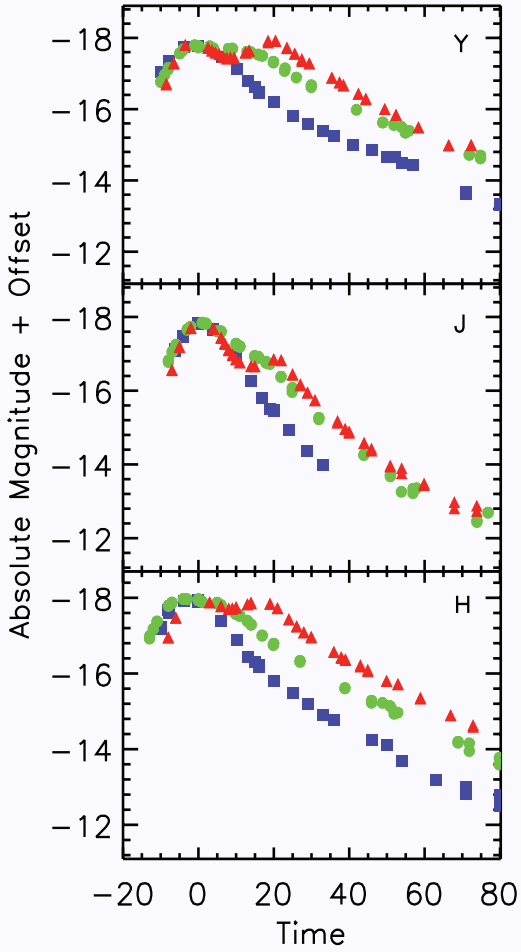
Mark Phillips

Others find this too

- Light curves in the near-IR very uniform at peak, but large differences at later times



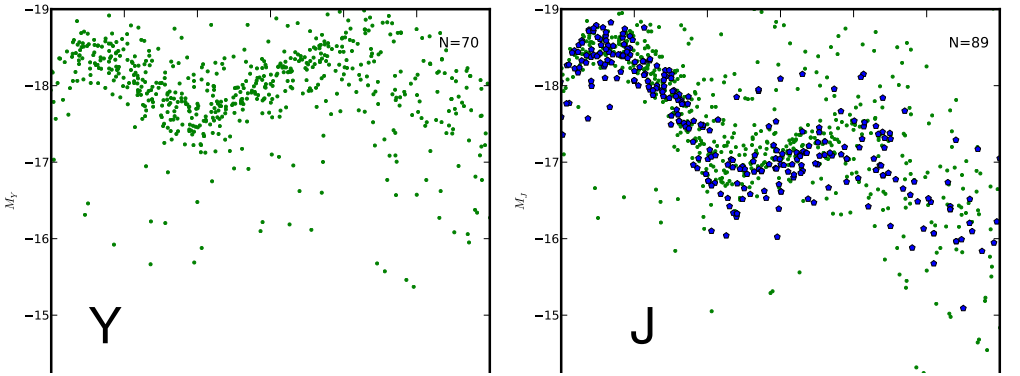
SN 2006mr
SN 2005ke
SN 2007on
Kattner et al. 2012



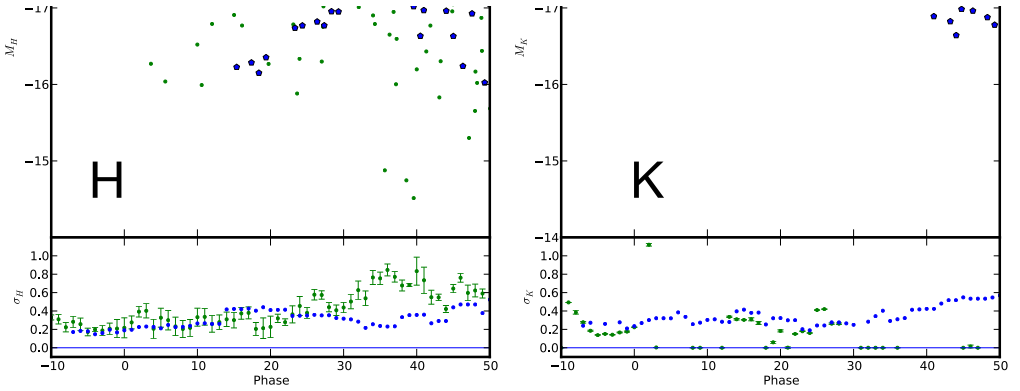
At least around maximum

Dhawan et al. 2015

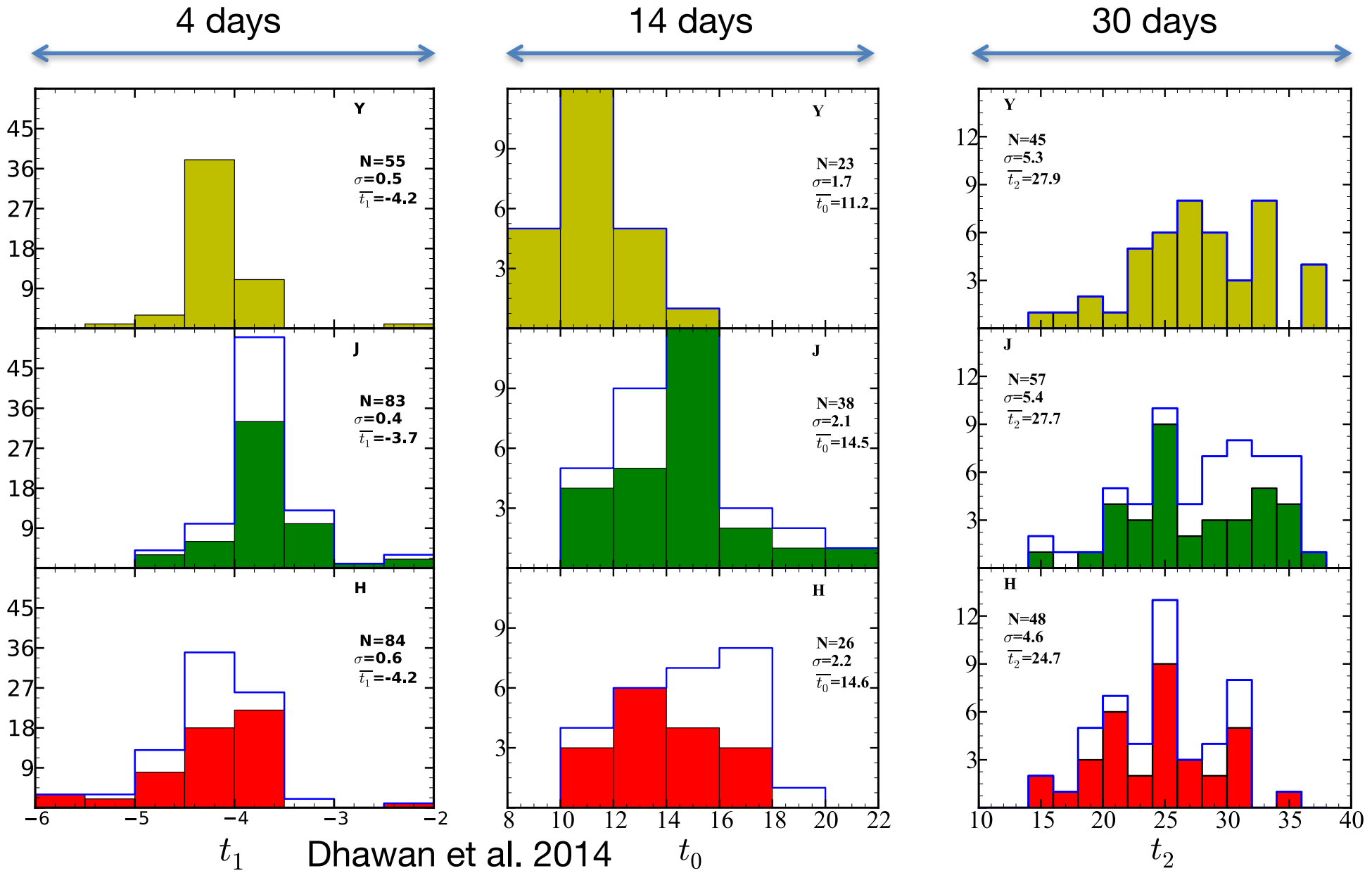
- Scatter minimal at first maximum in Y (1.04μm), J (1.24μm), H (163μm) and K (2.14μm)
- ~90 objects in J and H
  - 70 in Y, 20 in K
- Mostly Carnegie SN Project data (Contreras et al. 2010, Stritzinger et al. 2011)



Filter	Opt. Phase	sigma	Phase range	sample
Y	−4.4	0.15	−4— +1	CSP
J	−3.6	0.16	−4— +3	CSP
H	−5.1	0.17	−5— +1	CSP
J	−3.8	0.17	−6 — +1	non-CSP
H	−4.7	0.14	−7 — +2	non-CSP



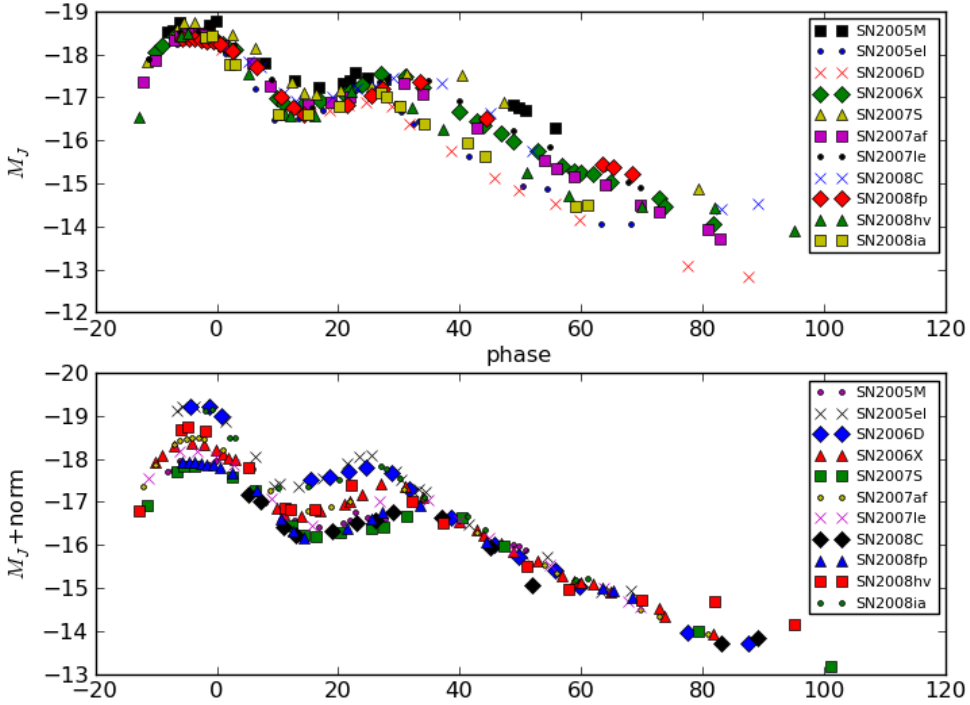
NOT after maximum



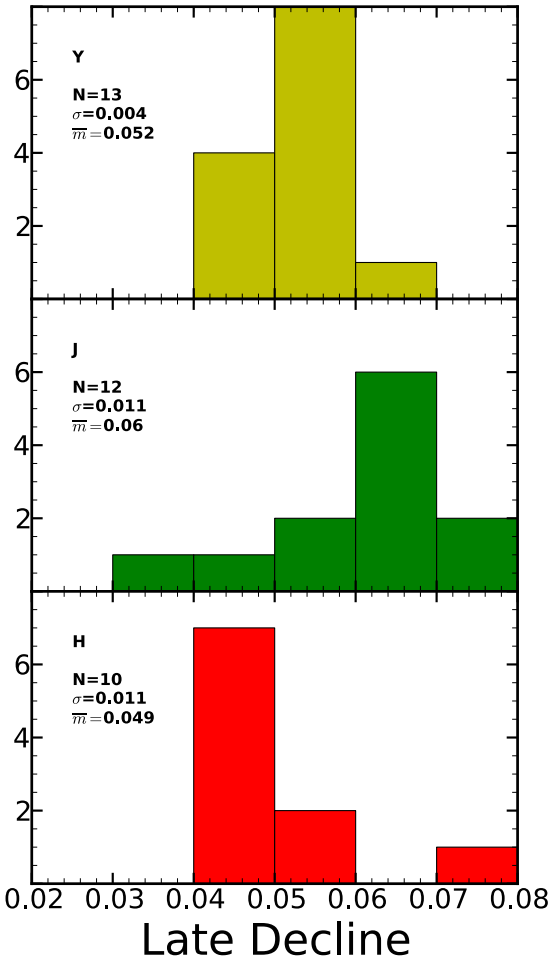
Dhawan et al. 2014

Other light curve parameters

- Late decline (t>40 days)



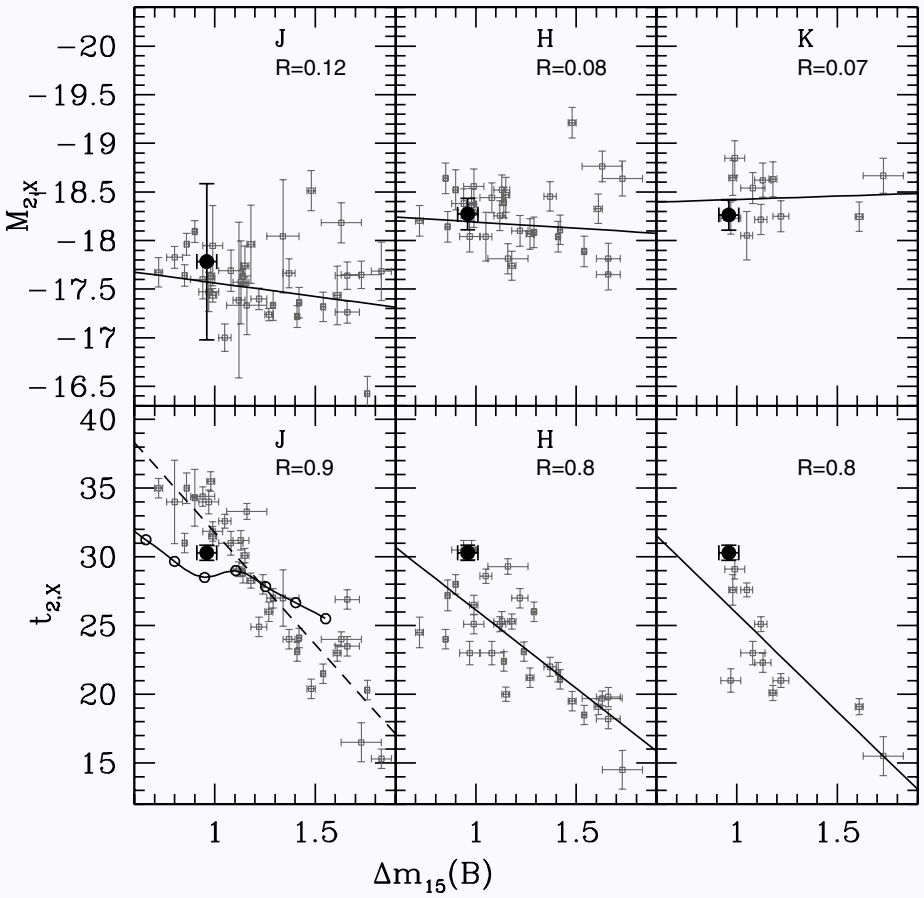
Dhawan et al. 2014



Correlations

- IR properties correlate with optical decline rate
- Phase of secondary maximum strongly correlated Δm_{15}

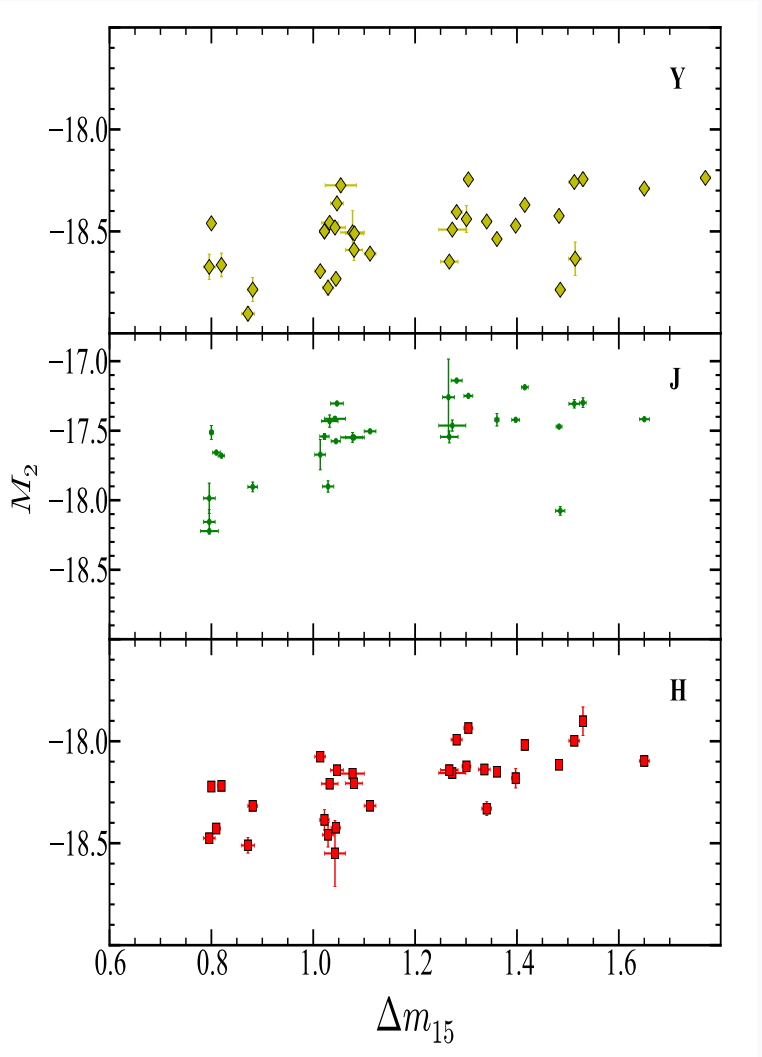
Biscardi et al. 2012



Correlations

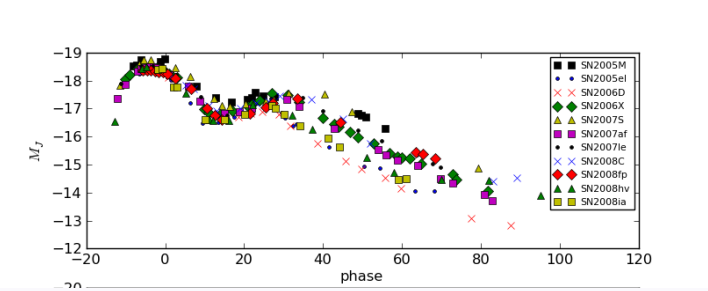
- Second maximum
  - phase strongly correlated with Δm_{15}
  - strength only weakly correlated

Dhawan et al. 2015



Consistent picture emerging

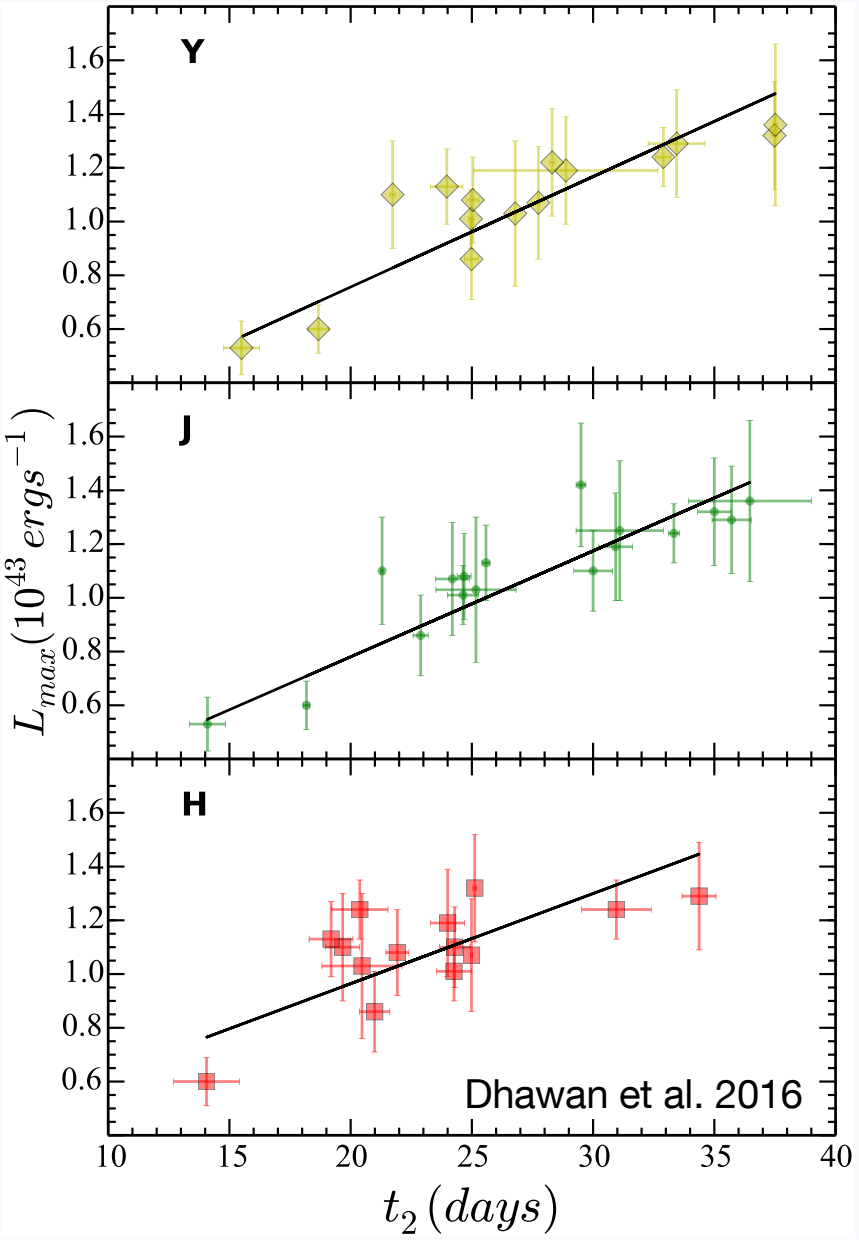
- Second peak in the near-IR is the result of the recombination of Fe^{++} to Fe^{+} (Kasen 2006)
- The ejecta structure rather uniform
  - late declines very similar



- higher luminosity indicates a higher Ni mass
- later secondary peak also indicated higher Ni mass
- Ni mass and (optical) light curve parameters correlate (Scalzo et al. 2014)

Luminosity function of SNe Ia

- Use the phase of the second maximum to derive the bolometric peak luminosity
  - calibrated on a sample of reddening-free SNe Ia
  - apply to reddened objects



Luminosity function of SNe Ia

M_{Ni} (inferred)	σ	Method	Reference
0.62	0.13	γ ray lines	Churazov et al. (2014)
0.56	0.10	γ ray lines	Diehl et al. (2015)
0.37	...	Bolometric light curve $A_V = 1.7$ mag	Churazov et al. (2014), Margutti et al. (2014)
0.77	...	Bolometric light curve $A_V = 2.5$ mag	Churazov et al. (2014), Goobar et al. (2014)
0.64	0.13	NIR second maximum	this work (combined fit)
0.60	0.10	NIR second maximum + measured rise	this work

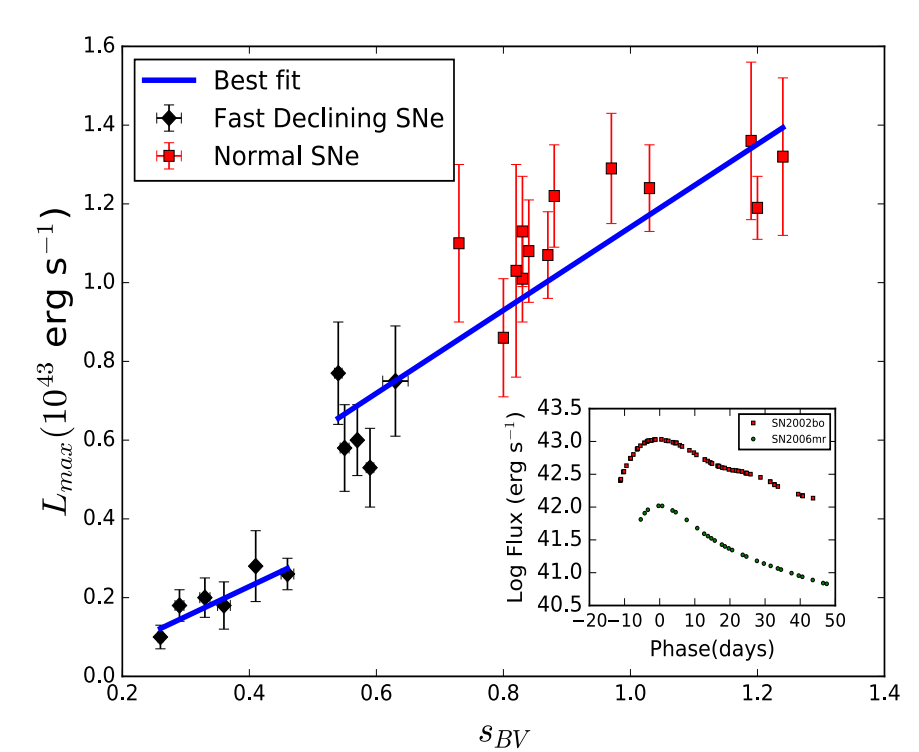
- SN 2014J test passed
- Potential to determine the luminosity function and Ni distribution

Fast-declining SNe Ia

- Two groups?
  - separation in
    - bolometric luminosity
    - phase of NIR first peak
    - lack of second second NIR maximum

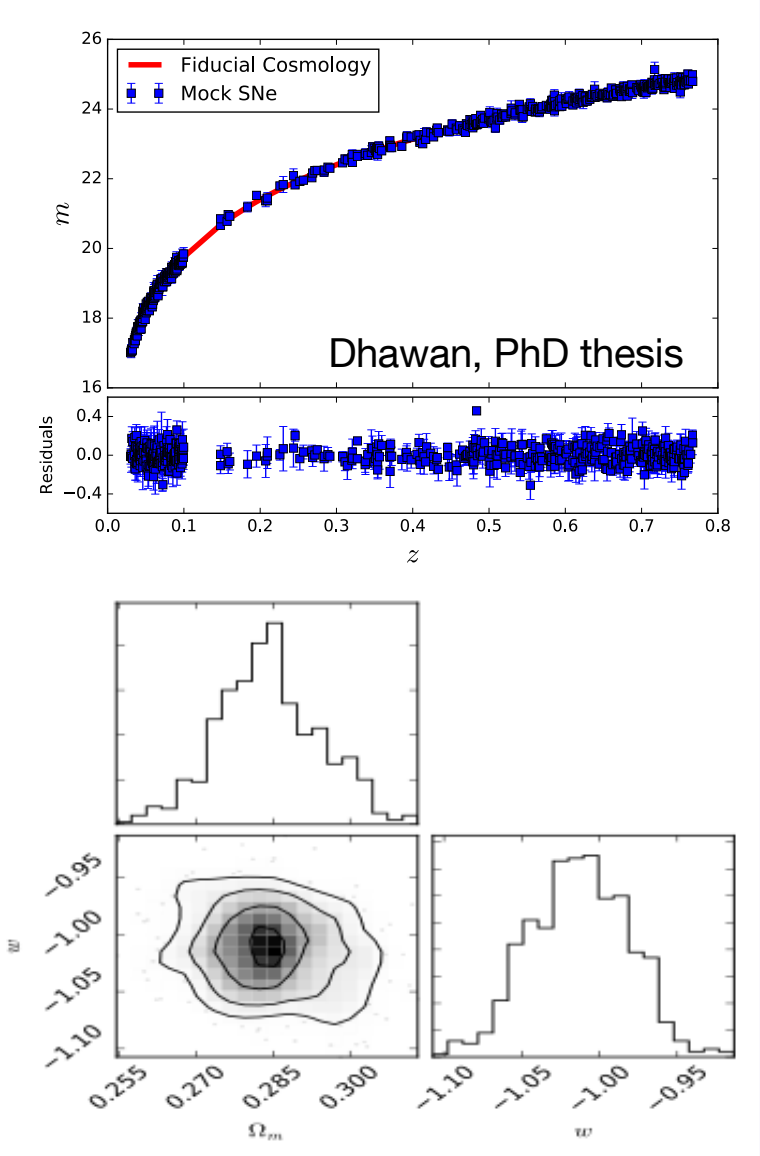
➔ Suhail Dhawan's talk next week

Dhawan et al., in prep



SNe and EUCLID

- DESIRE - special SN project as extension of the EUCLID mission
  - Astier et al. 2015
  - SNe Ia with 0.8<z<1.5
- Alternative
  - use EUCLID Deep Fields
    - NIR light curves (only few points)
    - construct NIR Hubble diagram to z<0.8



SNe and EUCLID

- Shadow the EUCLID deep fields at optical wavelengths
  - high cadence (every night?)
  - provide accurate optical light curves
    - important for phase information
  - compare optical and NIR Hubble diagrams
    - tests systematics
    - reddening