Type Ibn Supernovae

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Overview

- Introduction; SN 2006jc
- Heterogeneity of SN Ibn observables
- The progenitors of SNe Ibn: low or high mass stars?
- Conclusions

Timeline

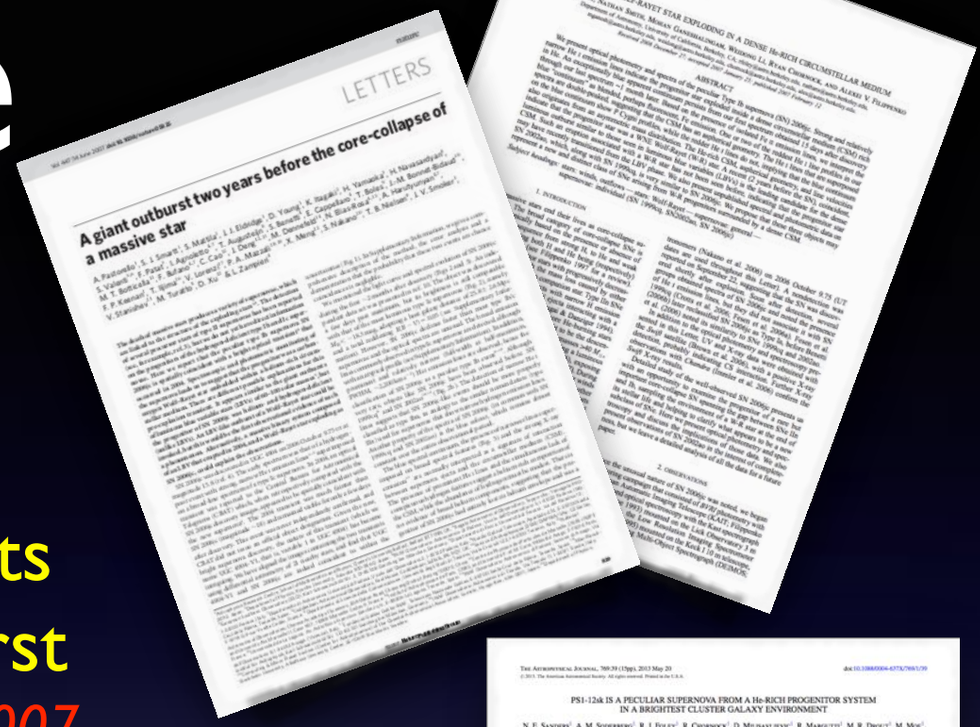

HELIUM EMISSION LINES IN THE TYPE Ic SUPERNOVA 1999cq


Massive stars exploding in a He-rich circumstellar medium – I. Type Ibn (SN 2006jc-like) events


Massive stars exploding in a He-rich circumstellar medium – IX. SN 2014av, and characterization of Type Ibn SNe

Type Ibn Supernovae Show Photometric Homogeneity and Spectral Diversity at Maximum Light

- SN 1999cq, the first "Ibn"
  Matheson+ 2000


A giant outburst two years before the core-collapse of a massive star

- SN 2006jc & its pre-SN outburst
  Pastorello+ 2007; Foley+ 2007

- SN Ibn designation
  Pastorello+ 2008

- An SN Ibn in an E host
  Sanders+ 2013


PS1-12sk IS A PECULIAR SUPERNOVA FROM A He-RICH PROGENITOR SYSTEM IN A BRIGHTEST CLUSTER GALAXY ENVIRONMENT

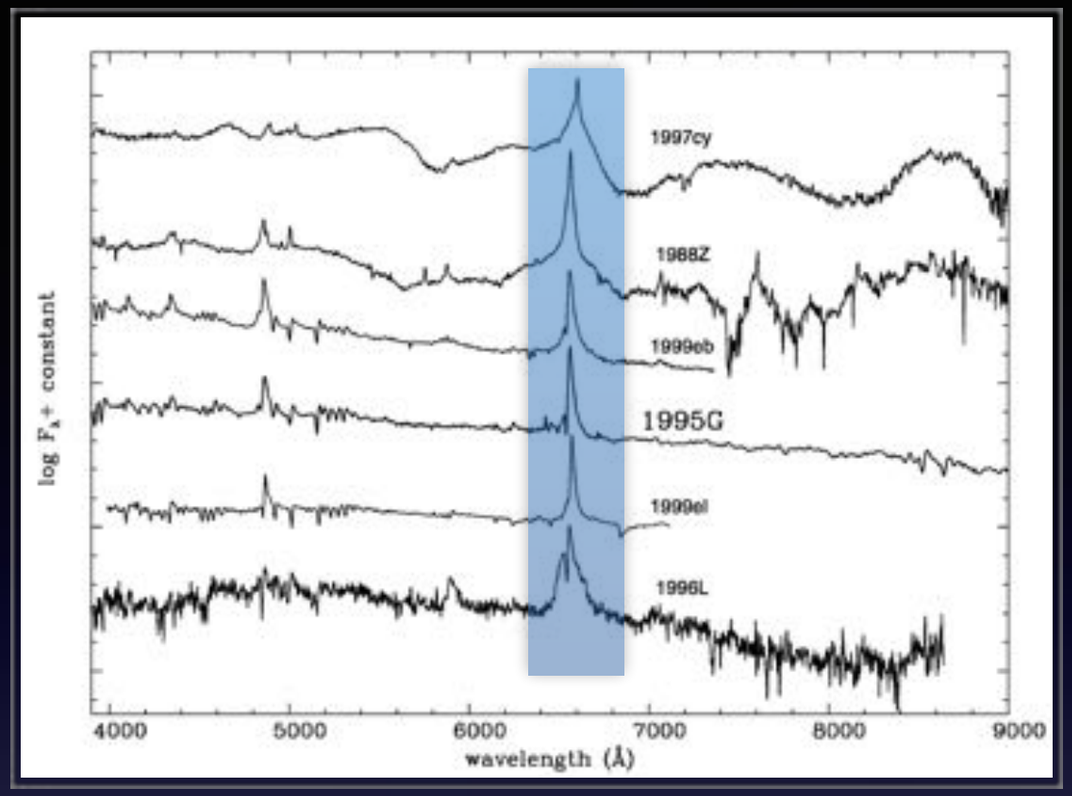
- Large SN Ibn samples
  Pastorello+ 2016; Hosseinzadeh+ 2017

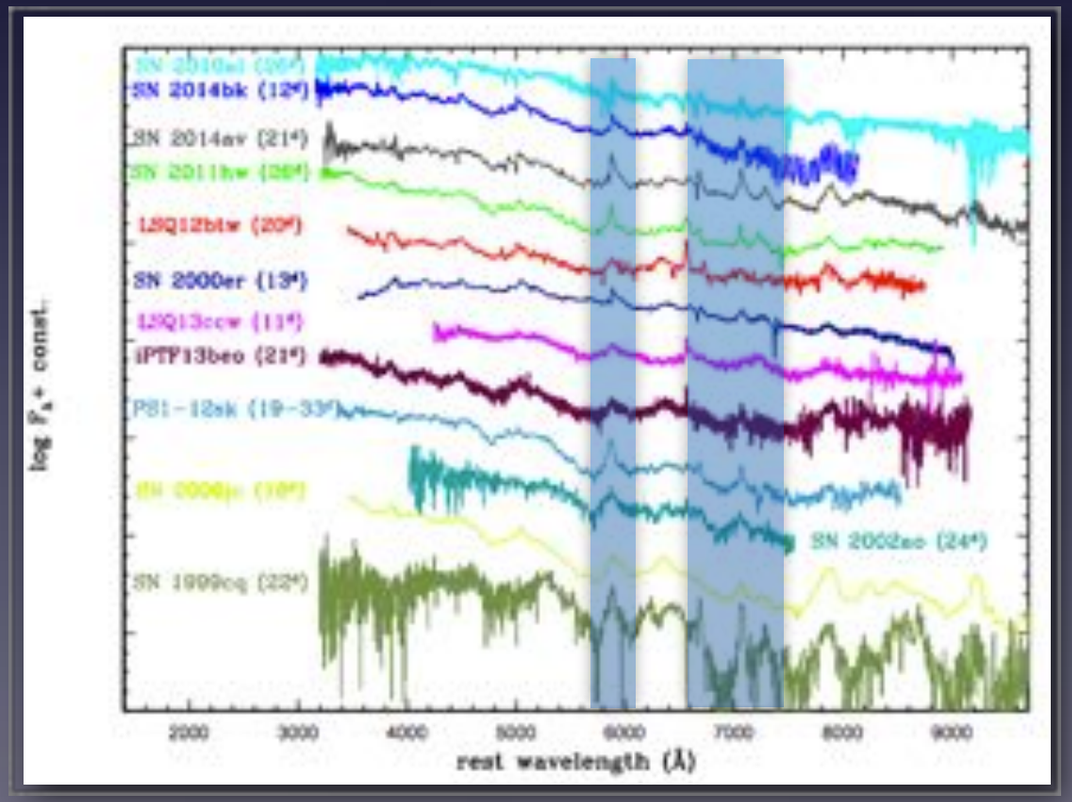
- The first SLSN Ibn
  Vallely+ 2018


The highly luminous Type Ibn supernova ASASSN-14ms

Mass loss and interacting SNe

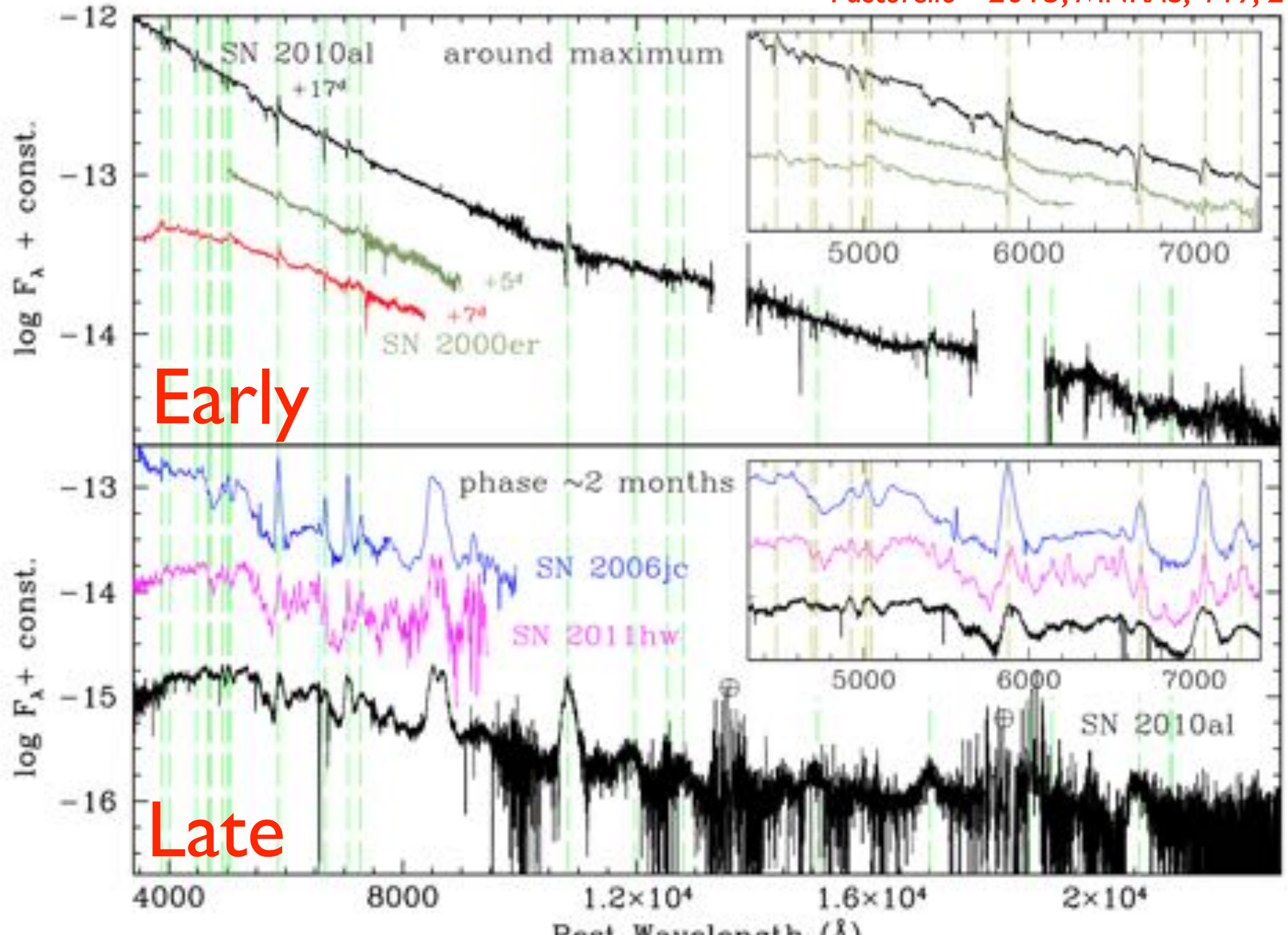
- Massive stars lose mass (via stellar winds, binary interaction, major outbursts), and form circumstaller cocoons.
- SN explosions in H-rich CSM produce SNe IIn
  (Schlegel 1990, MNRAS, 244, 269)
- SN explosions in H-poor and He-rich CSM produce SNe Ibn
  (Matheson+ 2000, AJ, 119, 2303; Pastorello+ 2008, MNRAS, 389, 113)



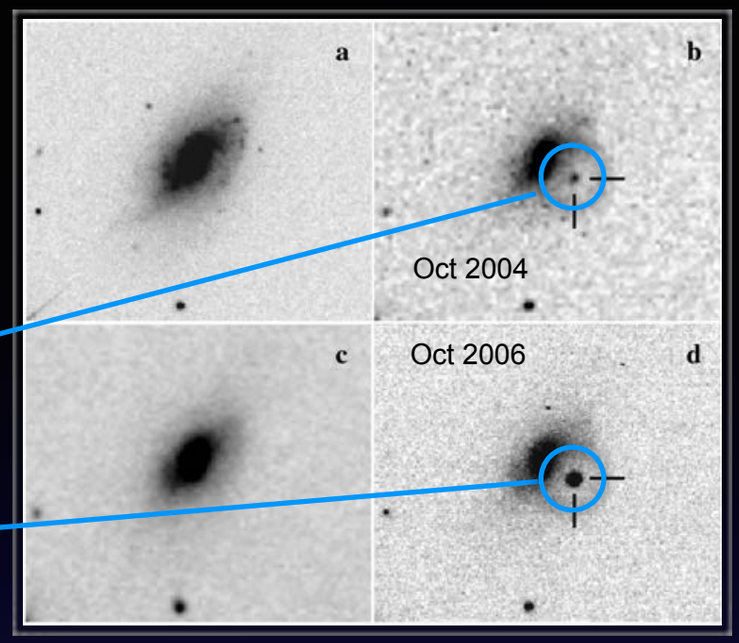


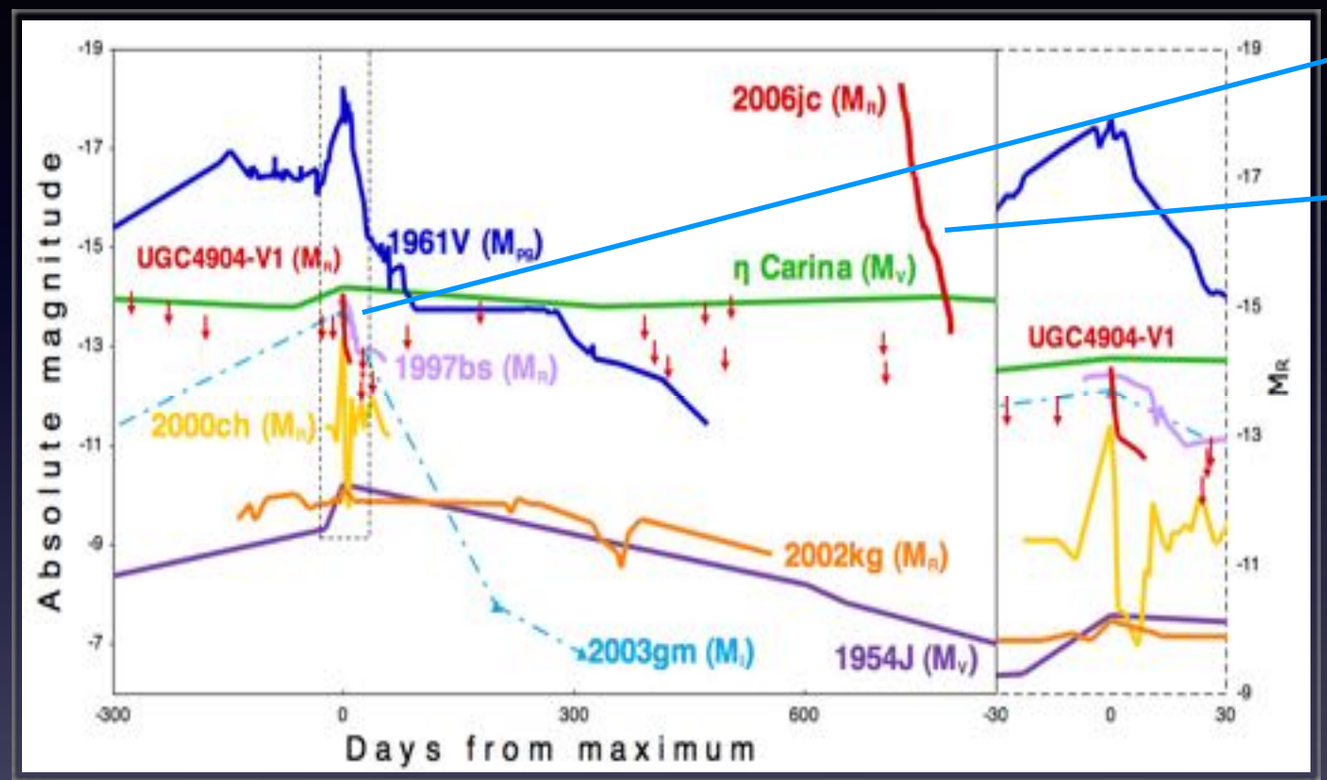
SN Ibn spectra

Pastorello+ 2015, MNRAS, 449, 2921



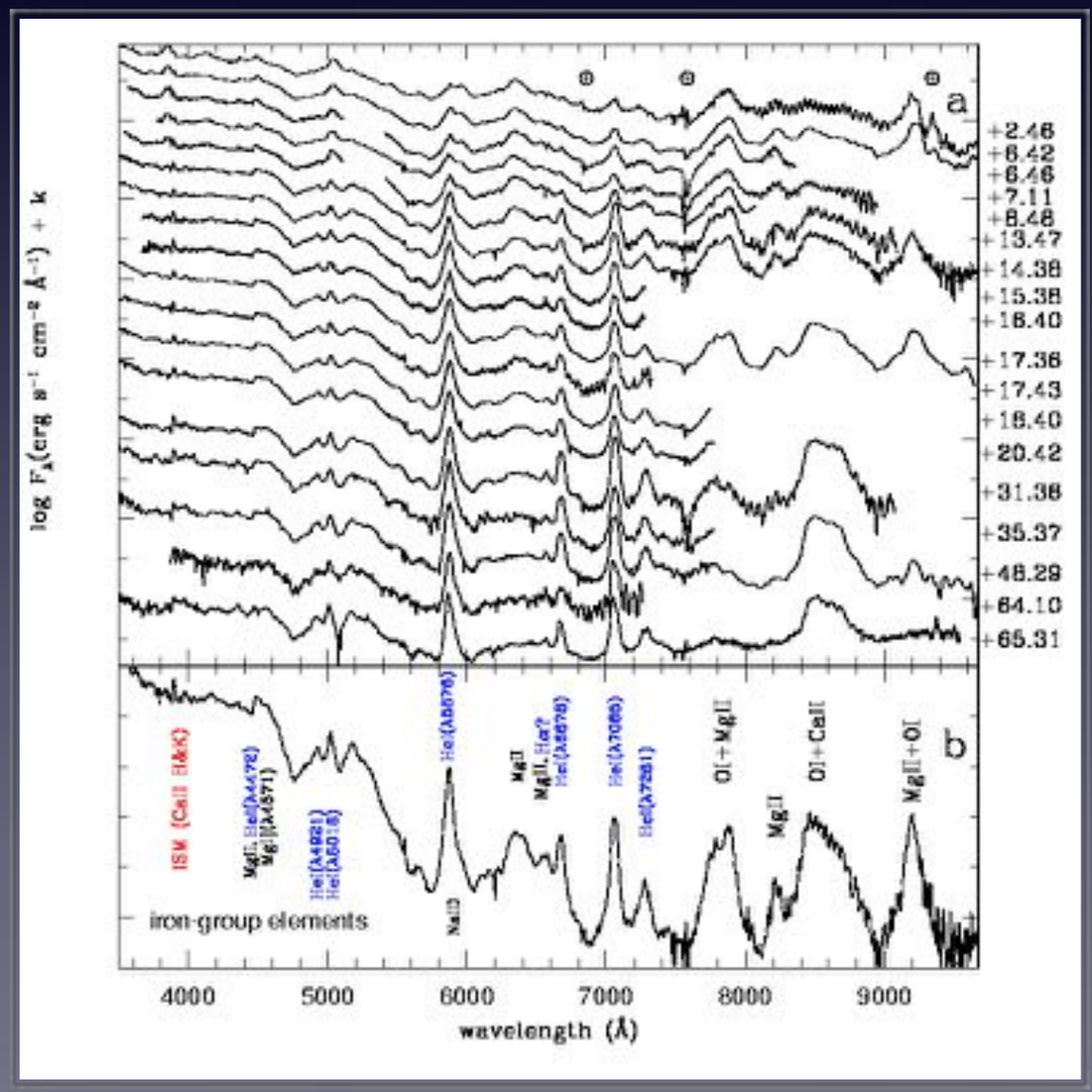
An outburts heralds the SN Ibn explosion





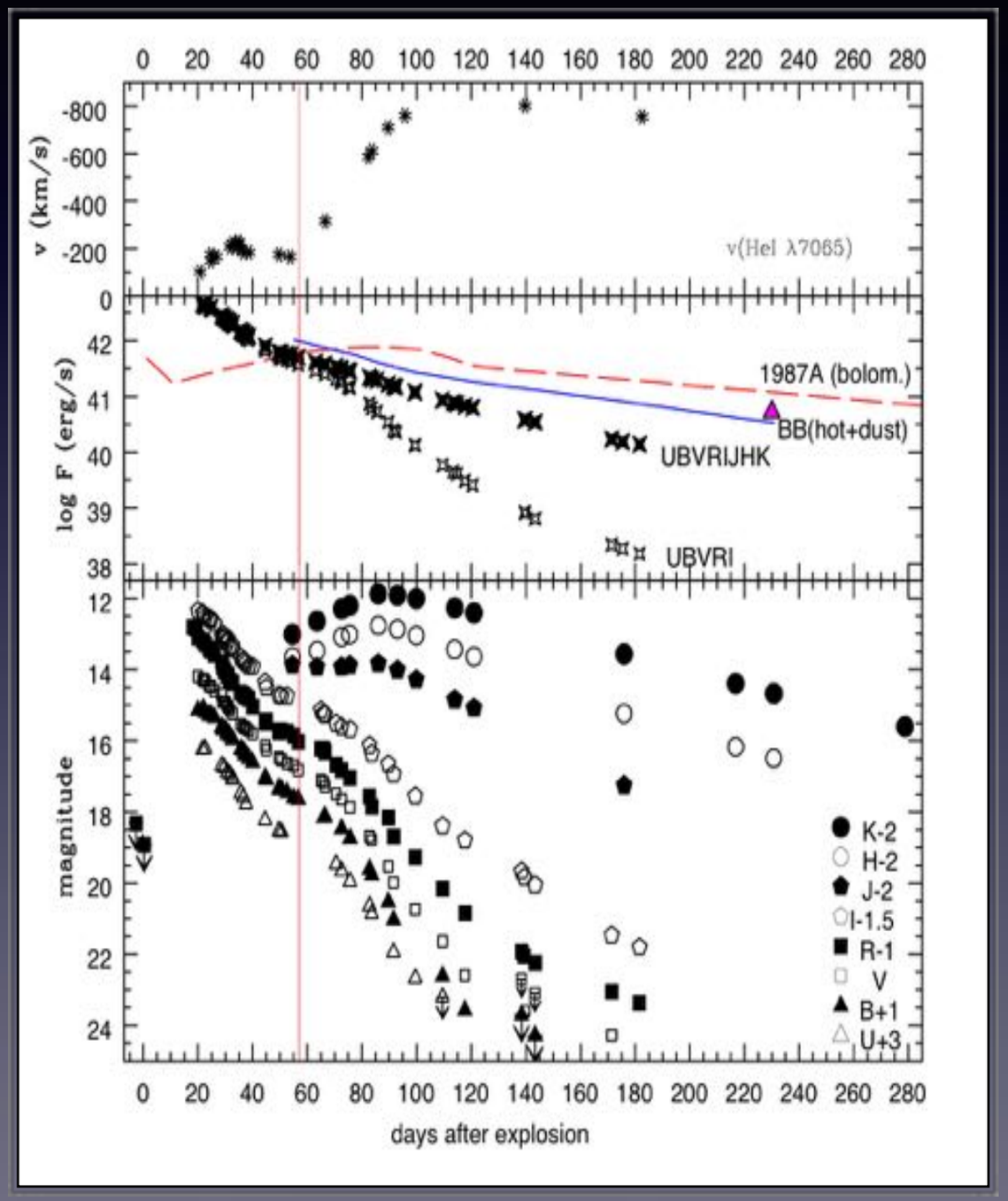
SN 2006jc *Pastorello+ 2007, Nature, 447, 829 (also Foley+ 2007, ApJ, 657, L105)*

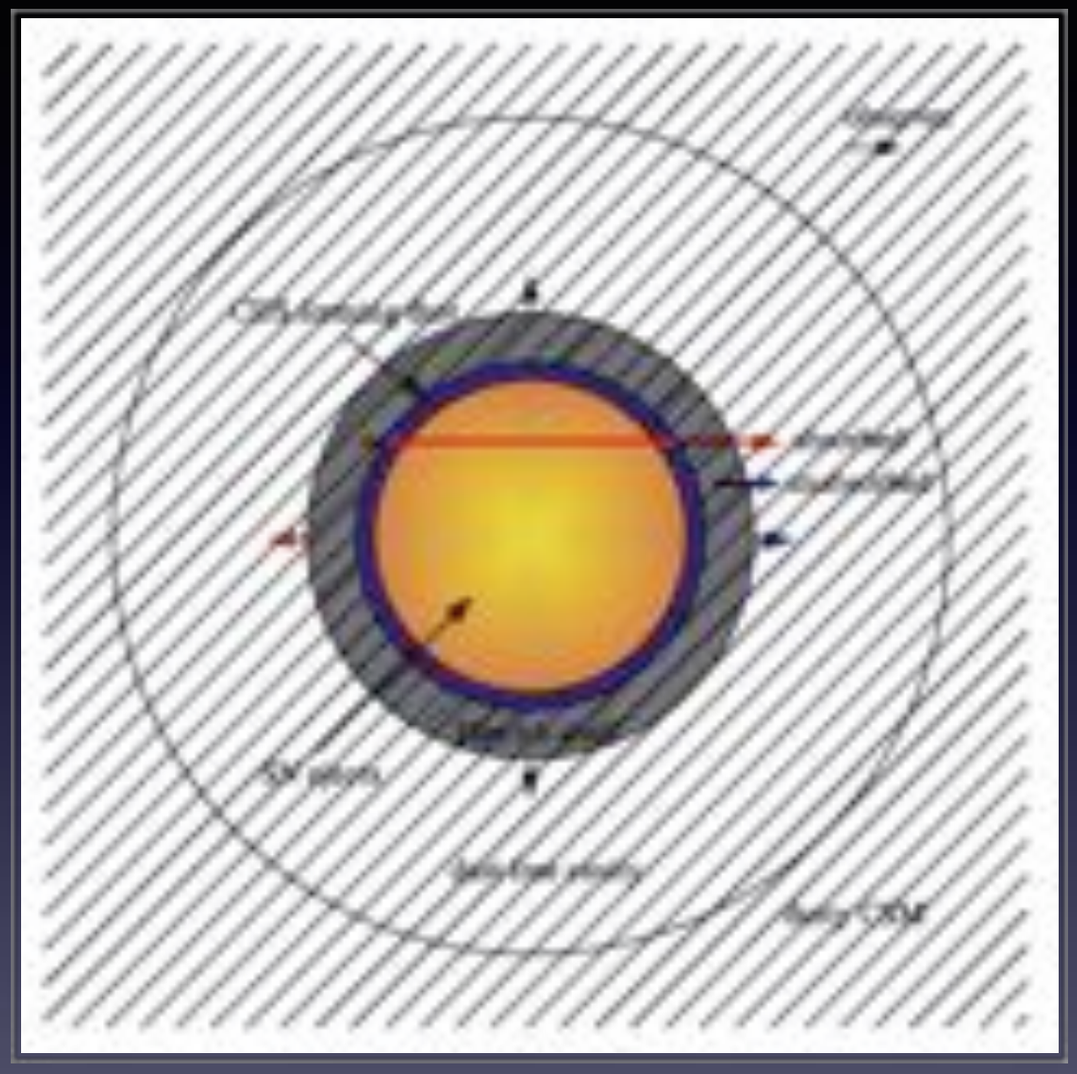
- 2004 => Major outburst (M_R = -14)
- 2006 => SN explosion as SE-SN interacting with He-rich CSM



Dust in a CDS

Mattila et al. 2008, MNRAS, 389, 141

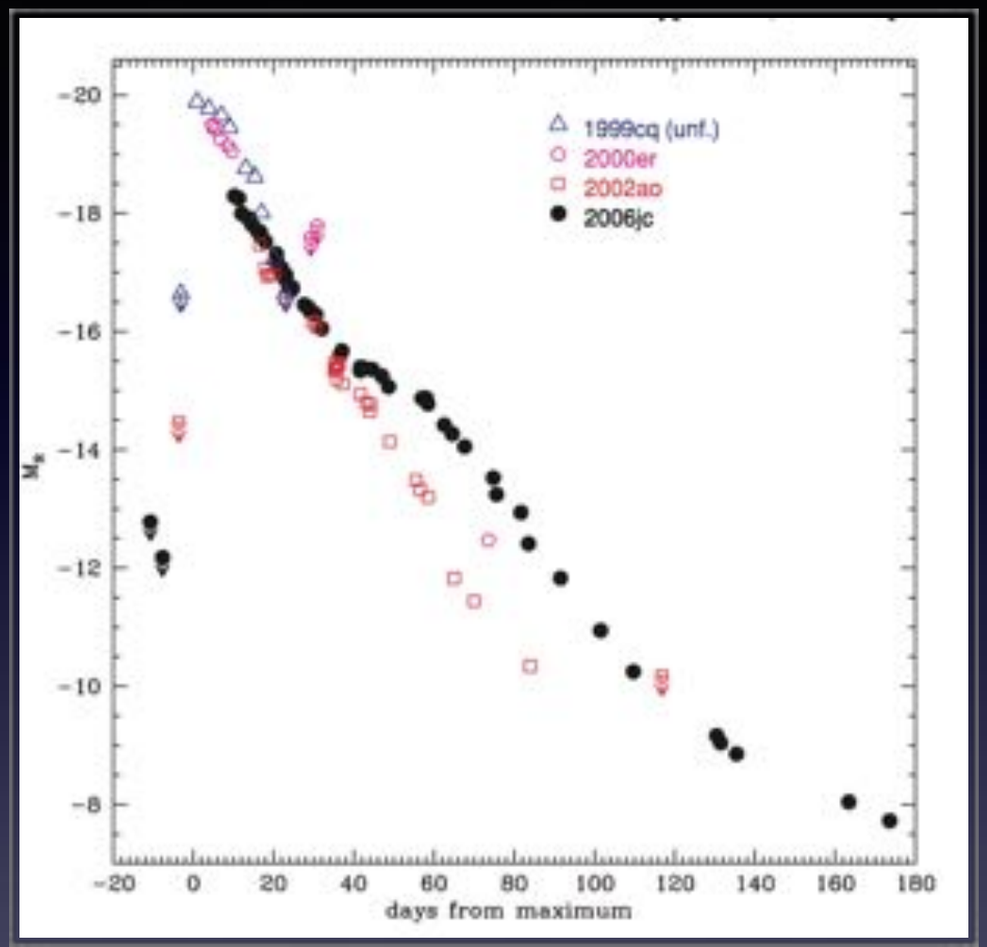


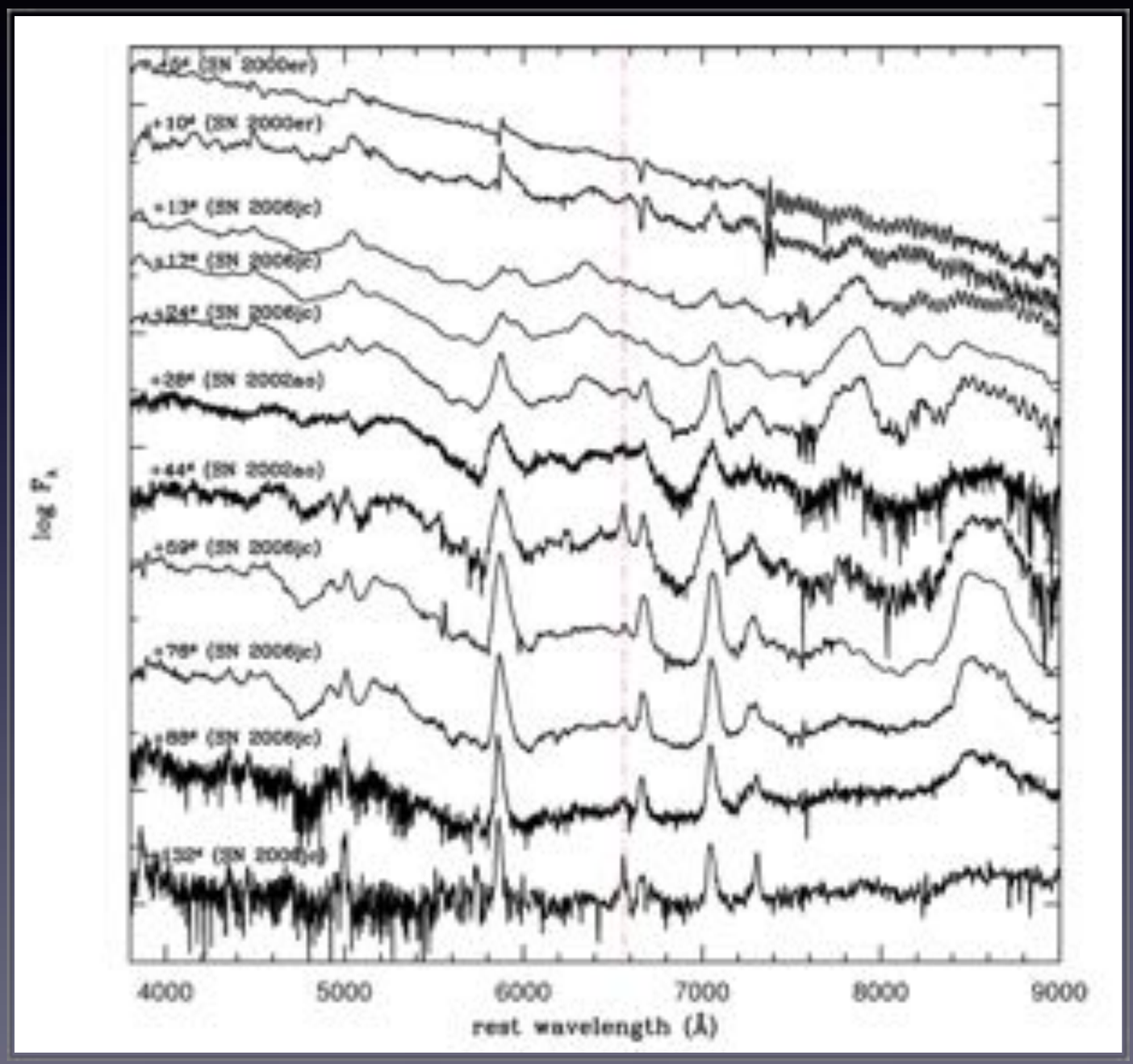


Late time optical deficit & NIR excess
=> old dust, and new dust in a CDS

Smith+ 2008, Mattila+ 2008,
Di Carlo+ 2008, Tominaga+ 2008

An homogeneous group?





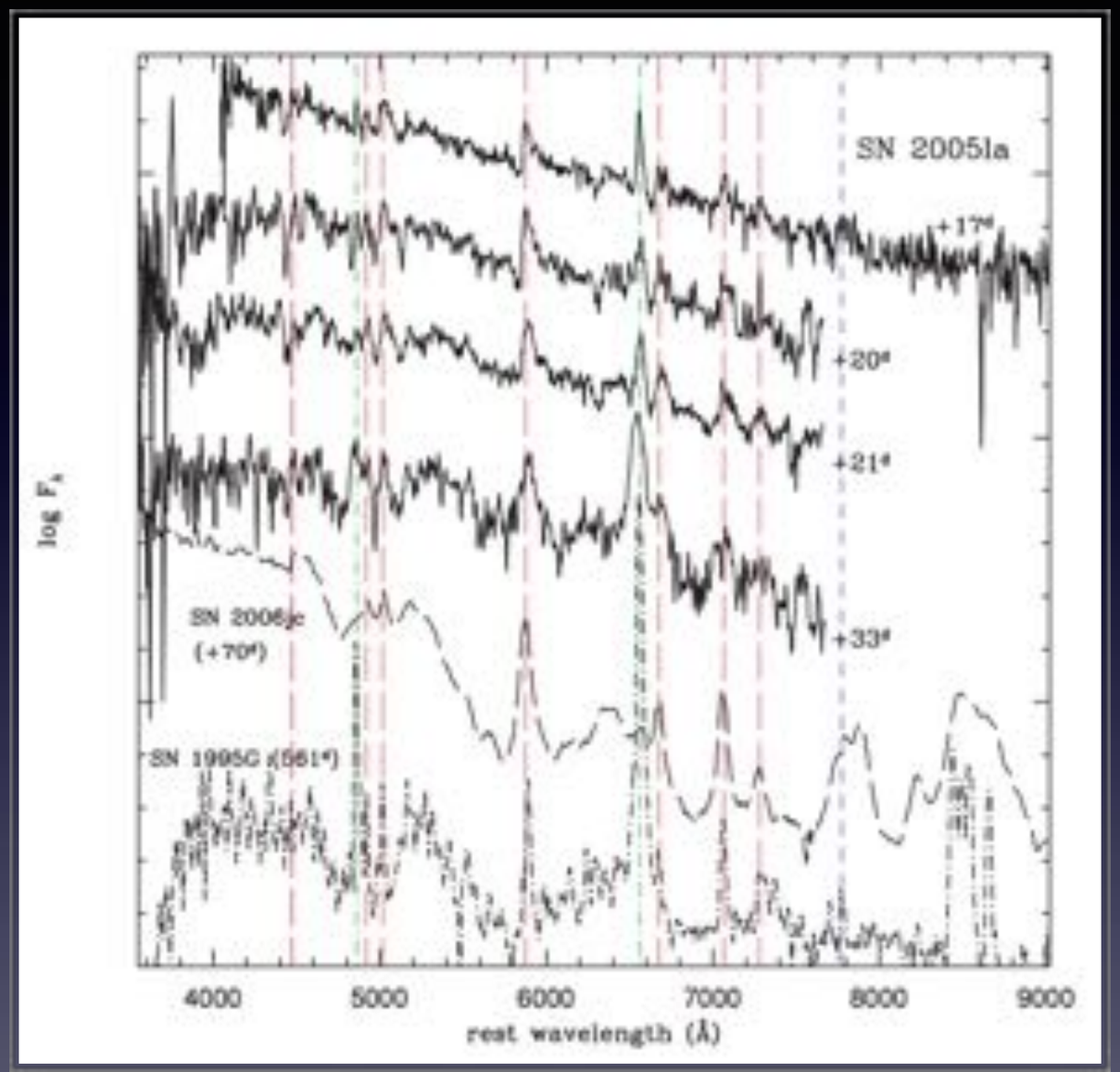
- Luminous: M_V ~ -18.5 to -20 mag
- Extremely fast rise to maximum
- Fast optical decline (dust formation?)
- Spectra (almost) H-free, with narrow He I emissions and broad IME lines

Pastorello+ 2008, MNRAS, 389, 113

An updated catalogue of SNe Ibn

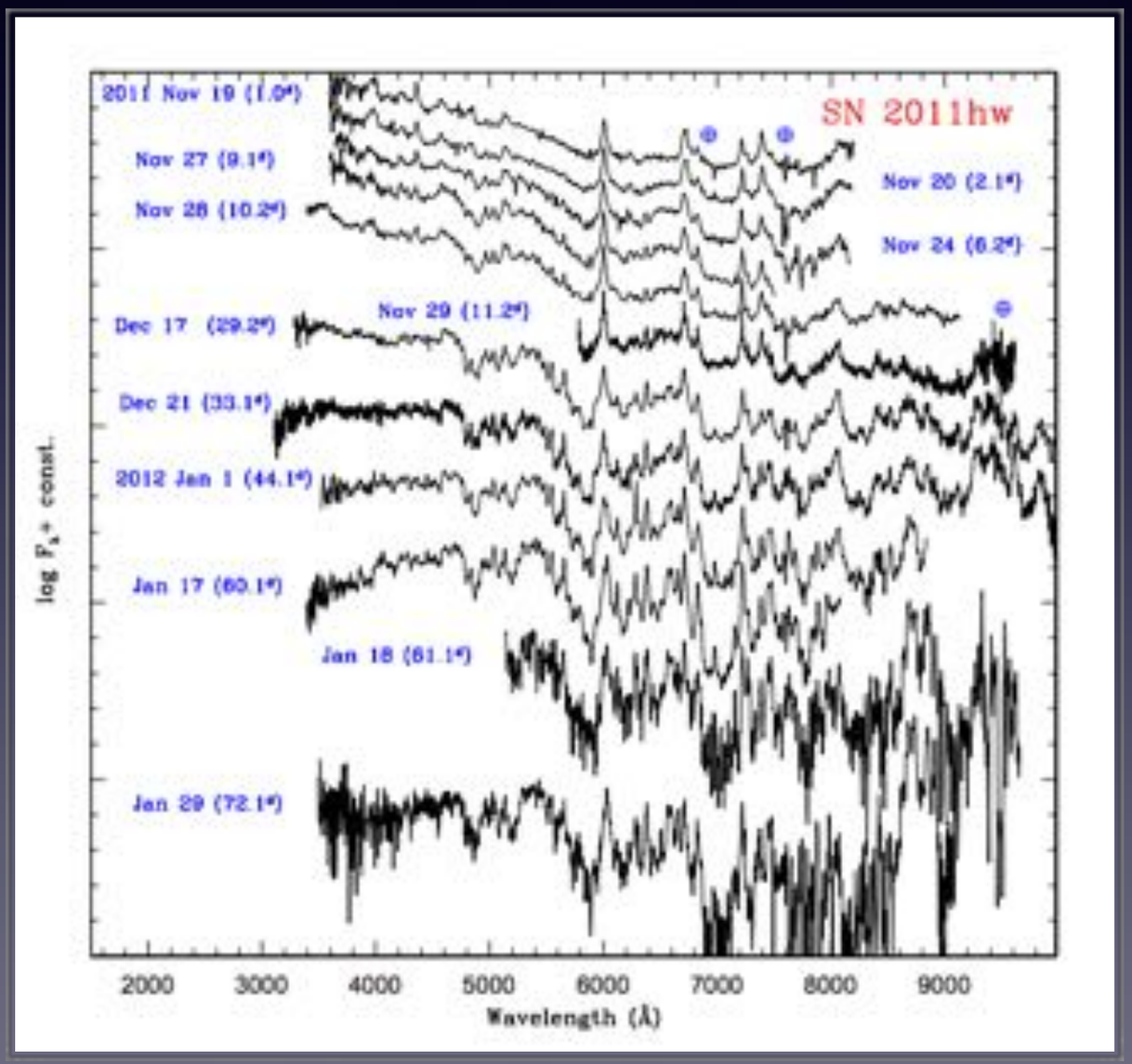
- SN 1885A? *(Ia-pec o Ibn? Pastorello+ 2008)*
- SN 1999cq
- SN 2000er
- SN 2002ao
- SN 2005la *(Ibn/IIn)*
- SN 2006jc
- SN 2010al *(Ibn/Ib)*
- SN 2011hw *(Ibn/IIn)*
- PTF11rfh
- PS1-12sk *(E-type galaxy)*
- OGLE-2012-SN-006 *(Ibn pec)*
- LSQ12btw
- PTF12ldy
- iPTF13beo
- LSQ13ccw *(Ibn pec)*
- SN 2014av
- iPTF14aki/CSS140421:142042+031602
- ASASSN-14dd
- OGLE-2014-SN-131 *(Ibn pec)*
- ASASSN-14ms *(SL Ibn)*
- ASASSN-15ed/PS15nk *(Ibn/Ib)*
- SN 2015G *(Ibn/Ib)*
- SN 2015U *(reddened Ibn)*
- iPTF15ul *(Ibn pec)*
- iPTF15akq *(Ibn/IIn)*
- PS15dpn
- SN 2016Q/PS16hy
- SN 2016cyj/ASASSN-16gn
- SN 2017ecp/ASASSN-17gi
- SN 2017fav/ATLAS17hrf *(Ibn/IIn pec)*
- SN 2017hyy/ASASSN-17os *(Ibn/IIn pec)*
- SN 2017iwp/Gaia17dgi *(Ibn/IIn)*
- SN 2017jfv/Gaia17dkl

SN Ibn variety: transitional Ibn/IIn events



SN 2005la

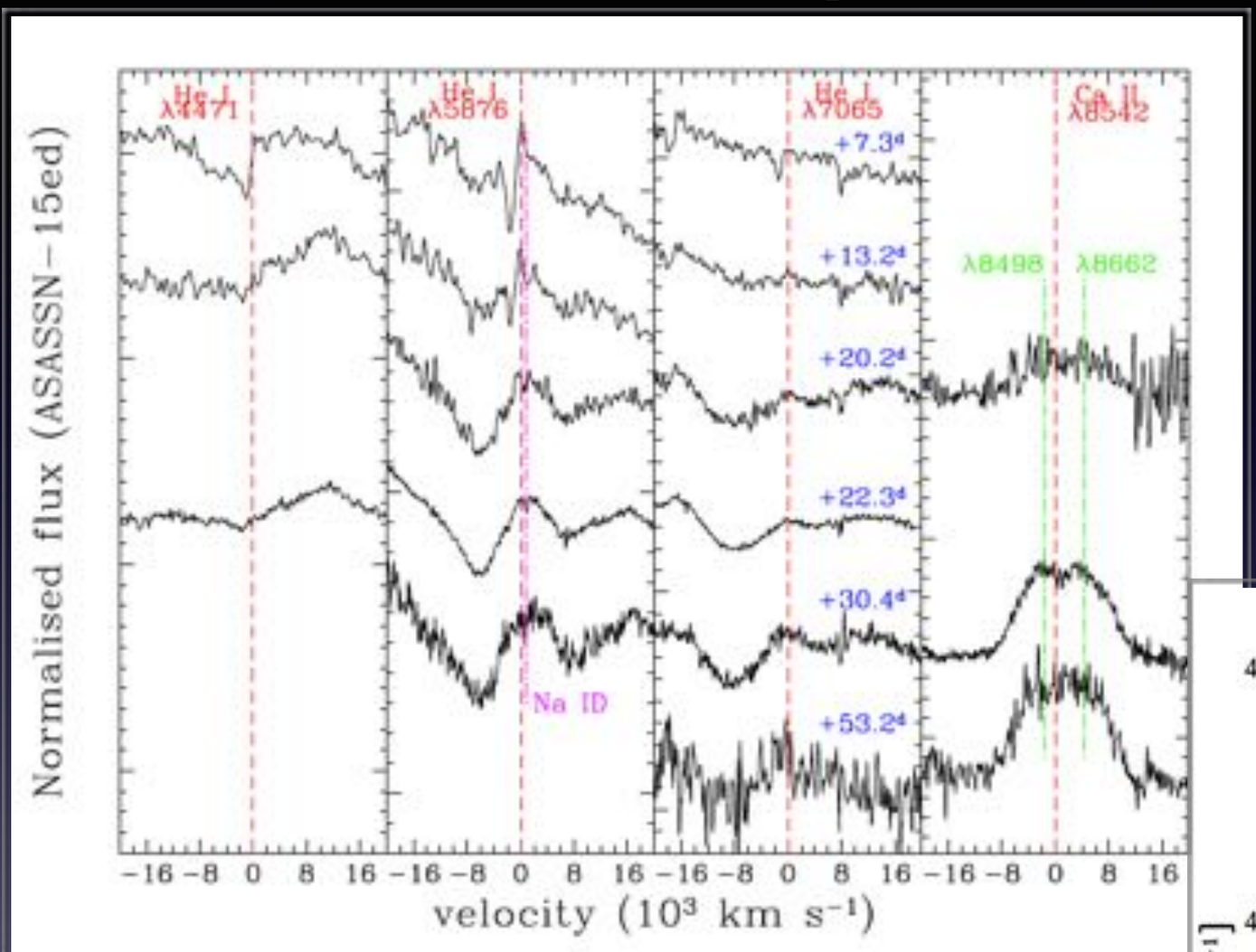
Pastorello+2008, MNRAS, 389, 131
Modjaz+ 2014,AJ, 147, 99

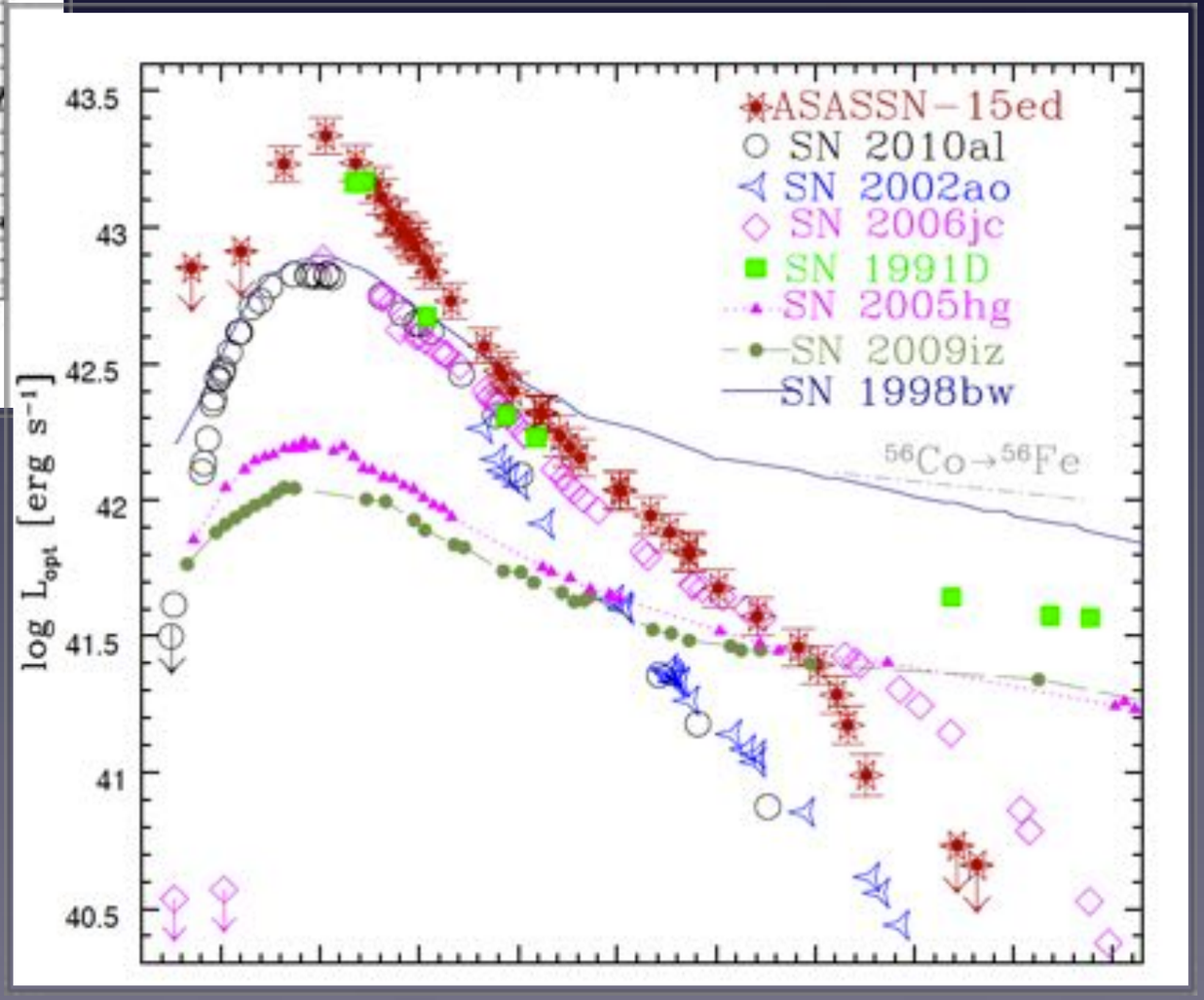


SN 2011hw

Smith+ 2012, MNRAS, 426, 1905
Pastorello+ 2015, MNRAS, 449, 2921

SN Ibn variety: transitional Ibn/Ib events

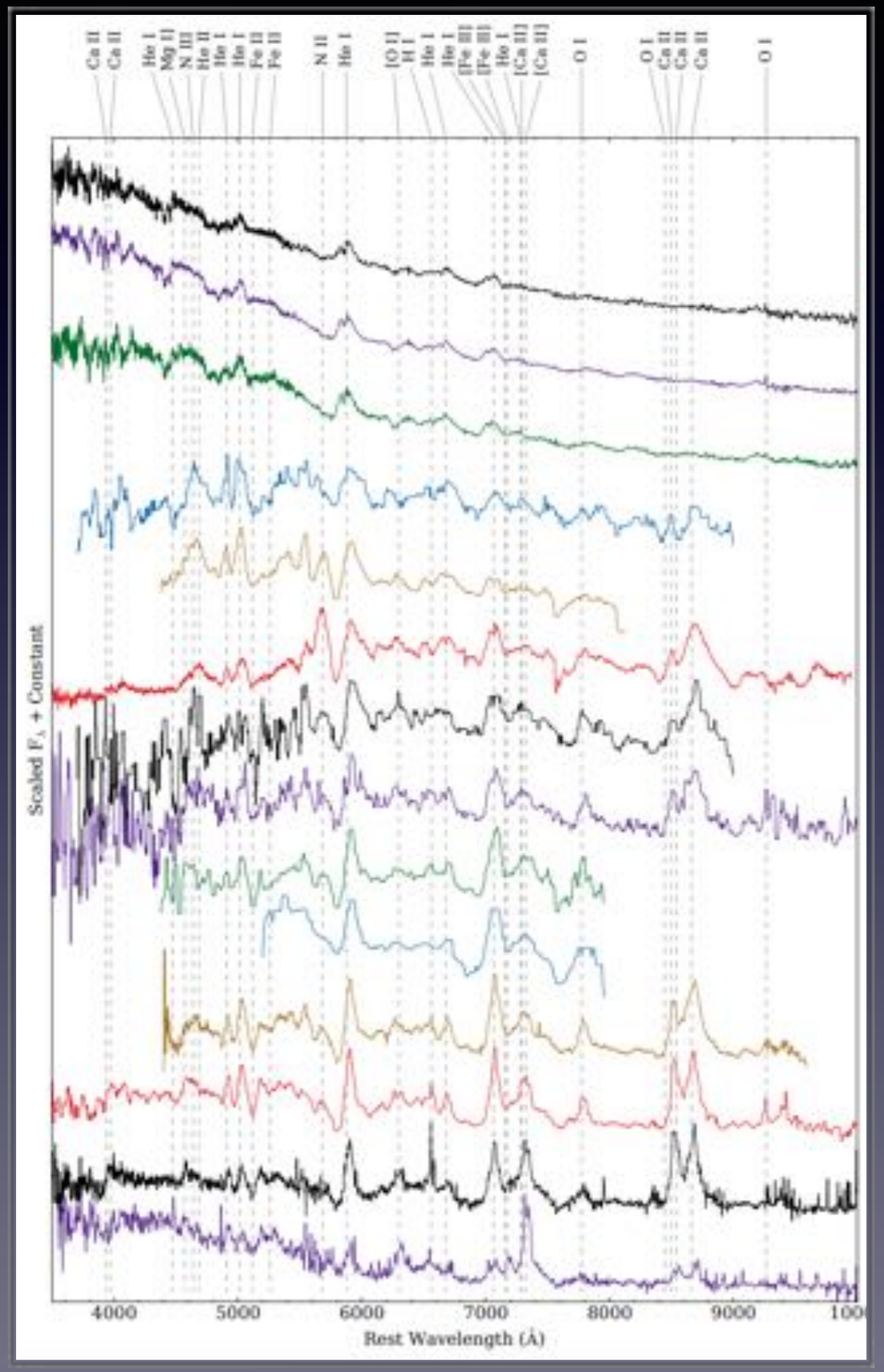


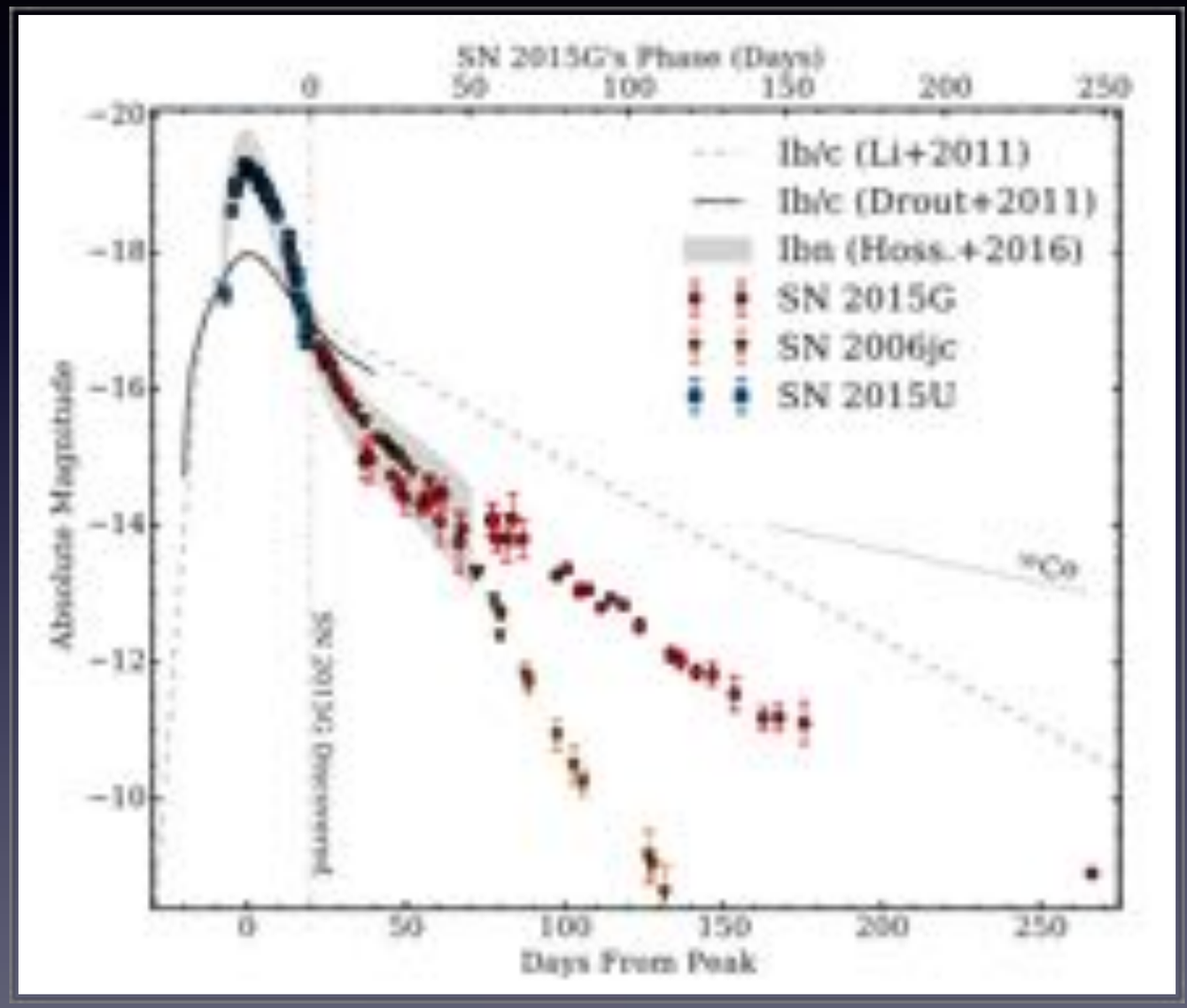


ASASSN-15ed

Pastorello+ 2015b, 453, 3649

SN Ibn variety: transitional Ibn/Ib events



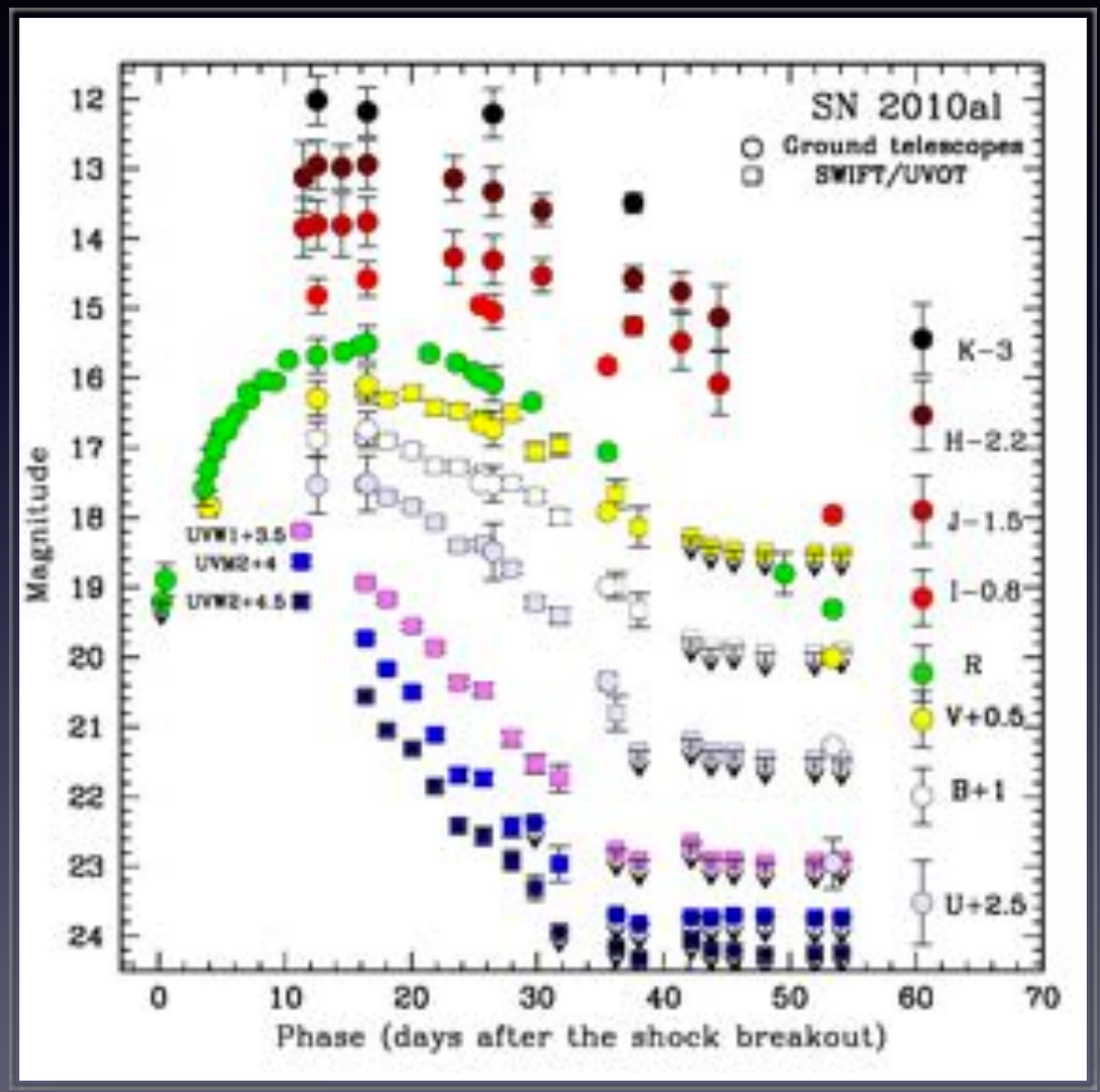


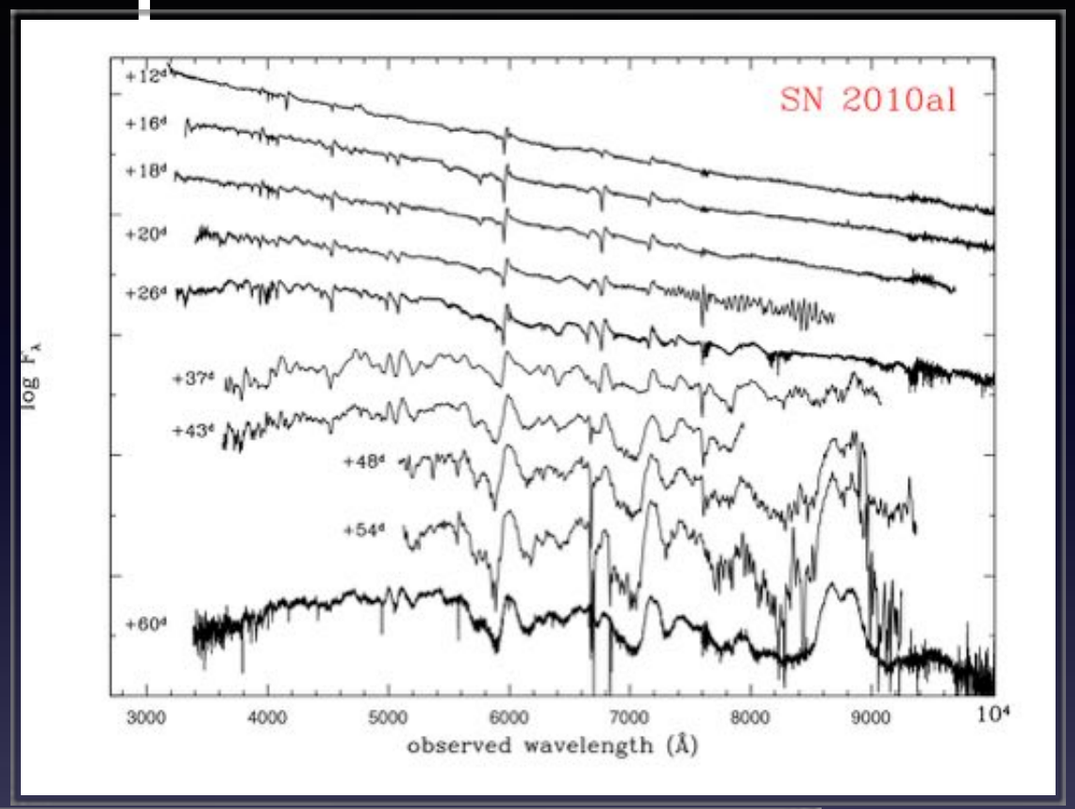
SN 2015G

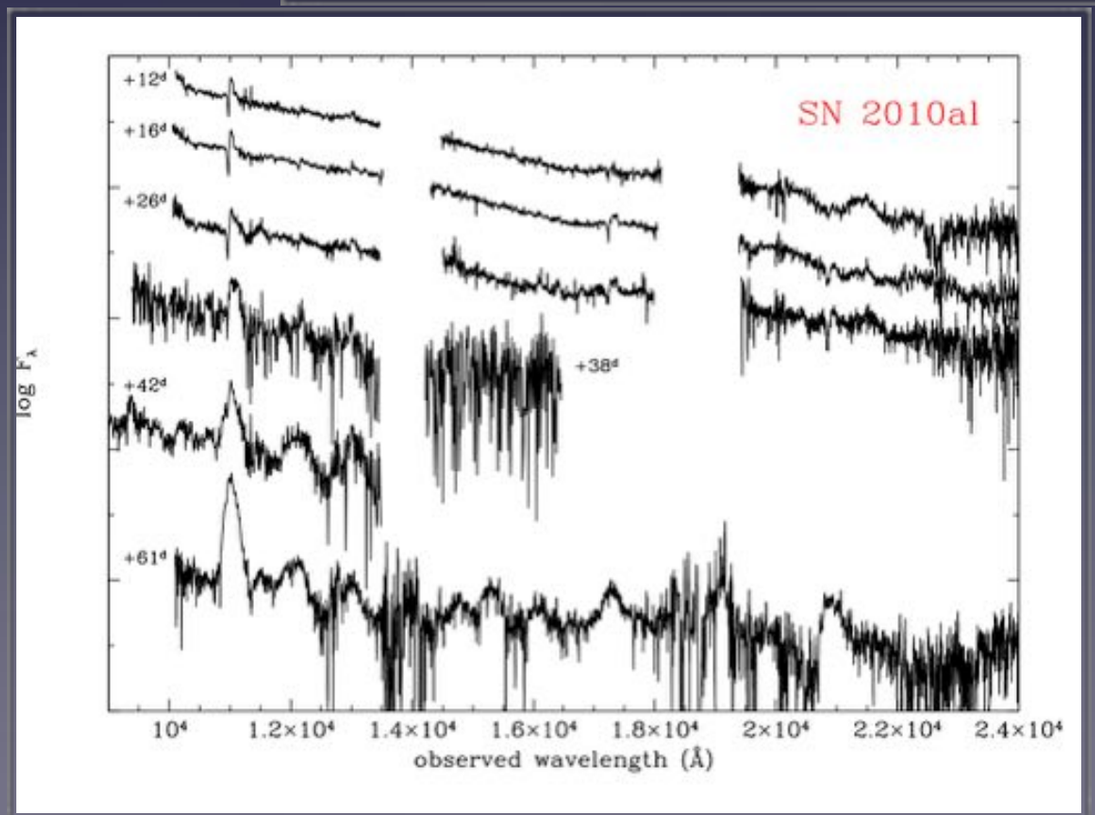
Shivvers+ 2017, MNRAS, 471, 4381

SN Ibn photometric variety

Broad light curve peak





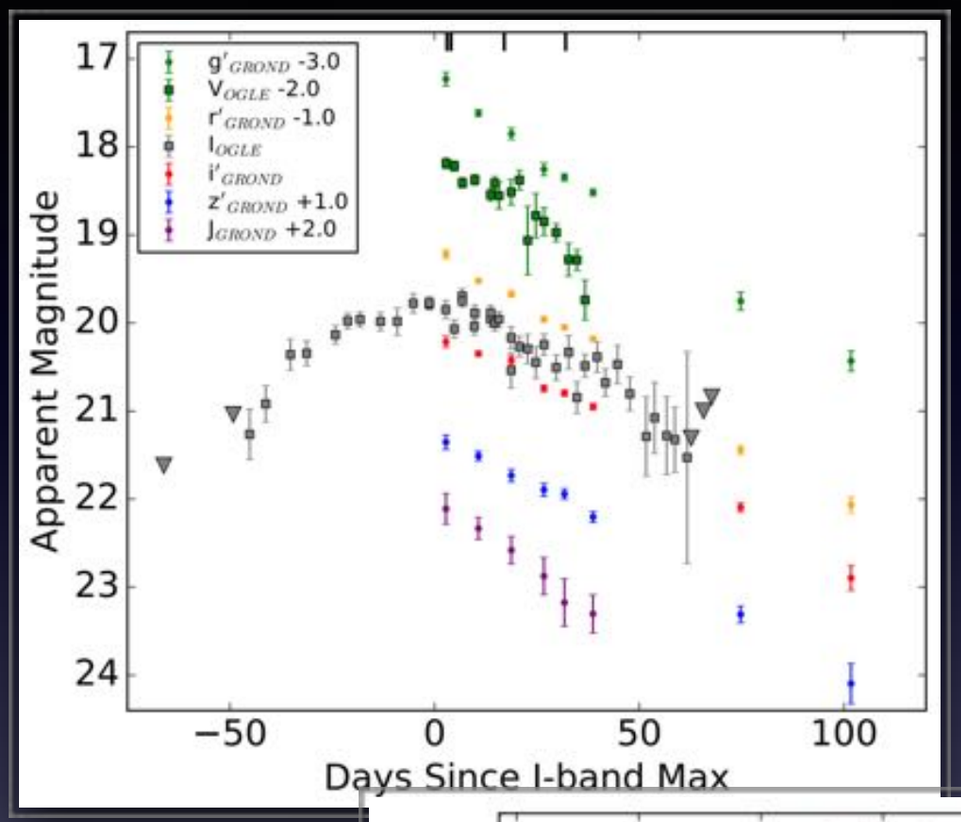


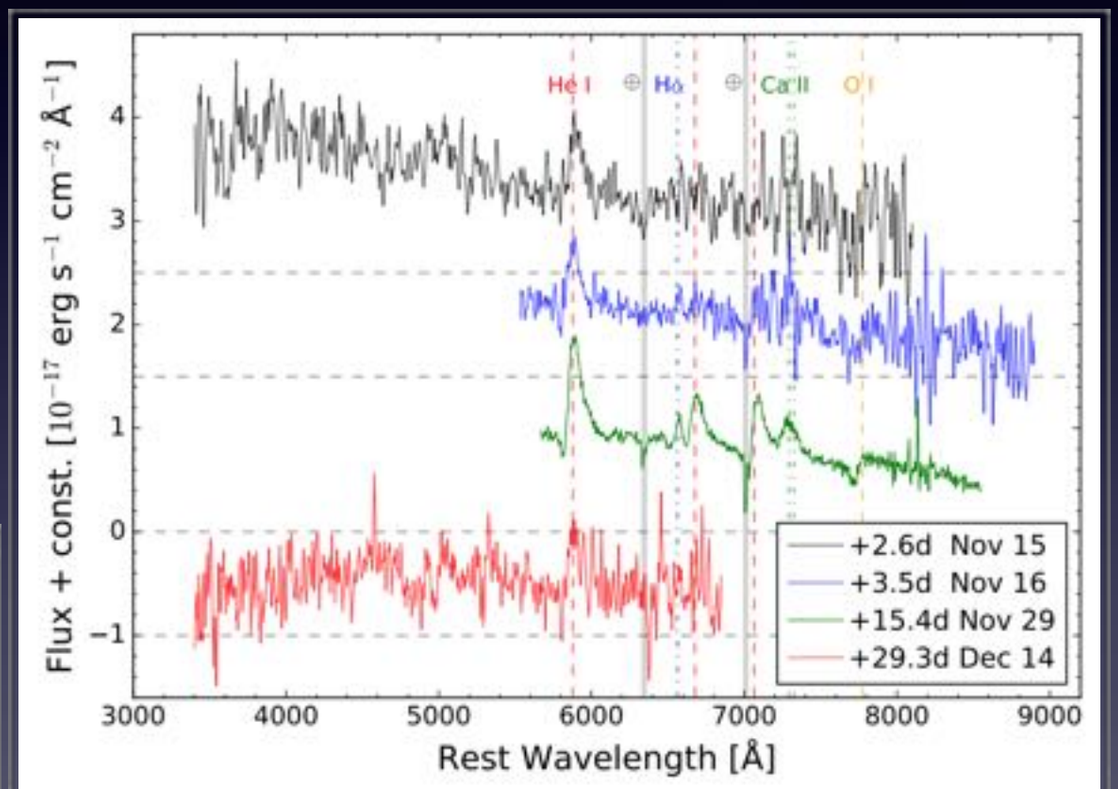
SN 2010al

Pastorello+ 2015, MNRAS, 449, 2921

SN Ibn photometric variety

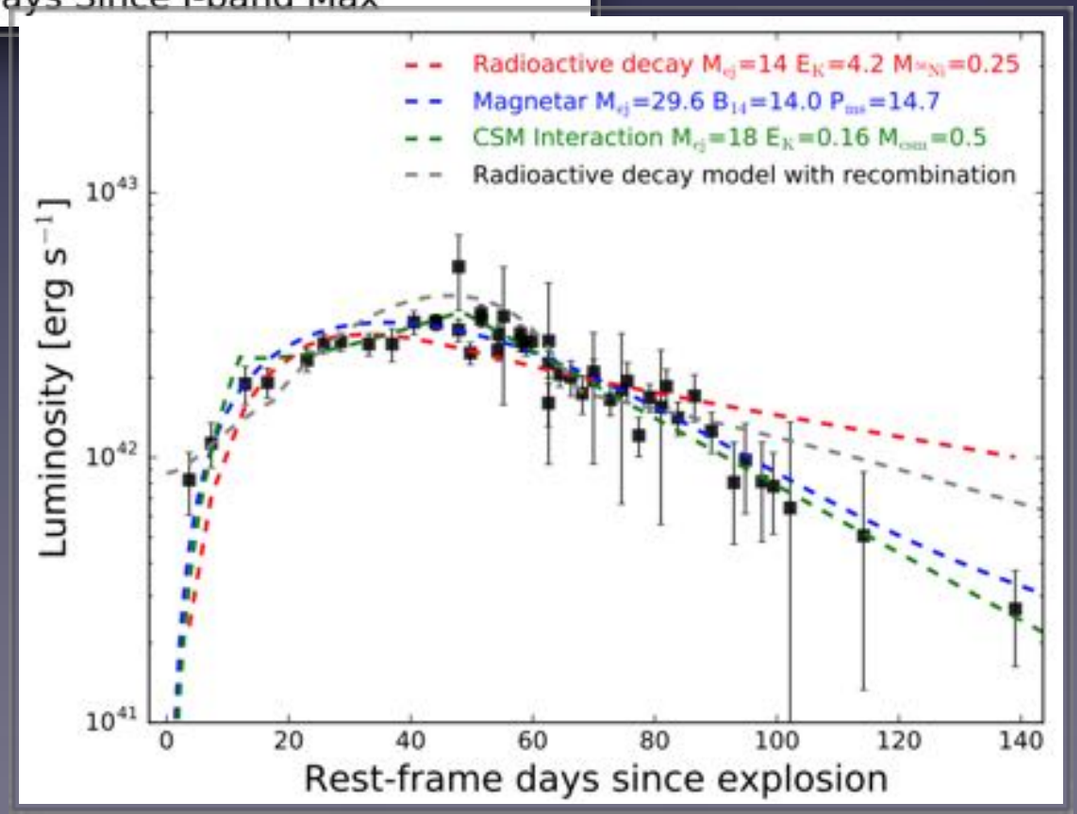
Broad light curve peak





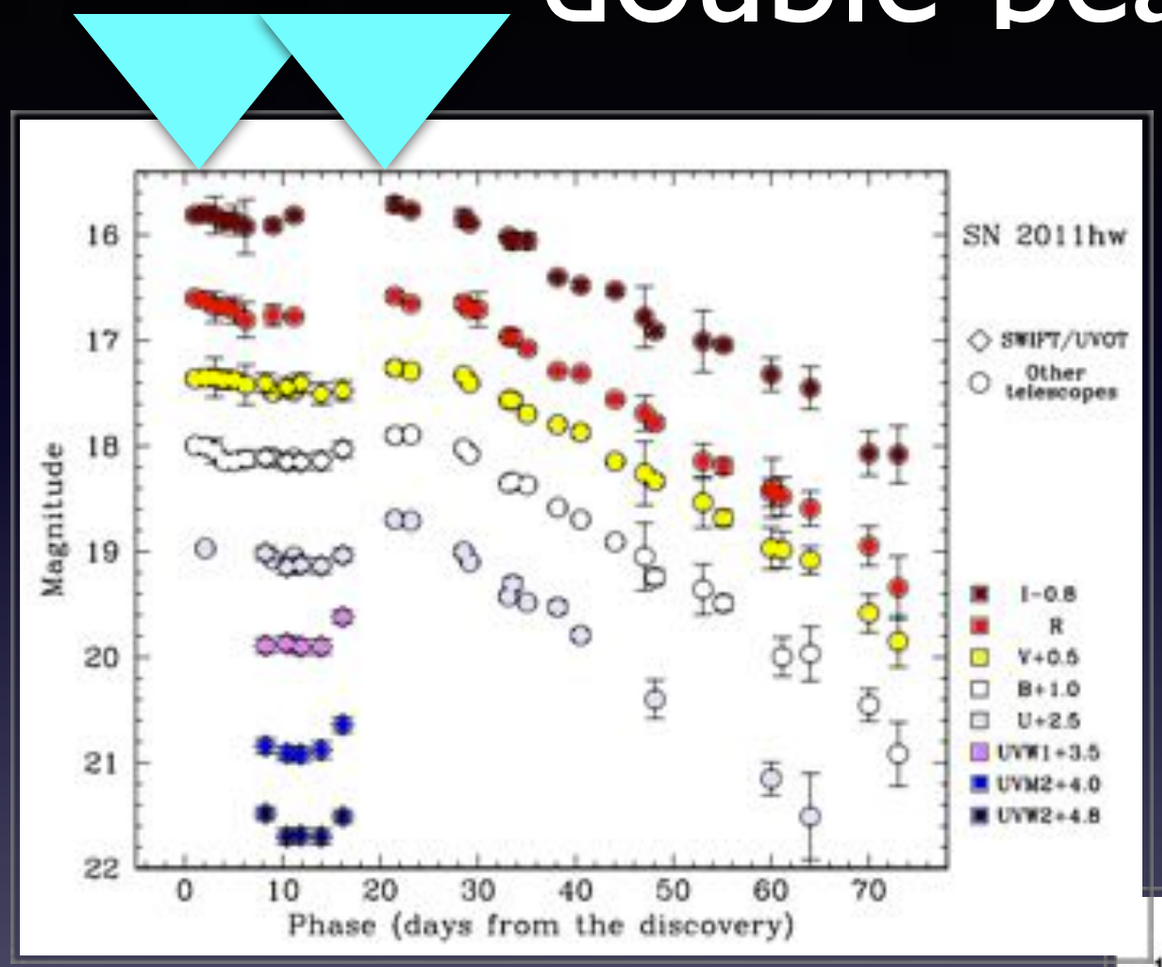
OGLE-2014-SN-131

Karamehmetoglu+ 2017, A&A, 602, 93



With a 50d risetime!

SN Ibn photometric variety double-peak light curves

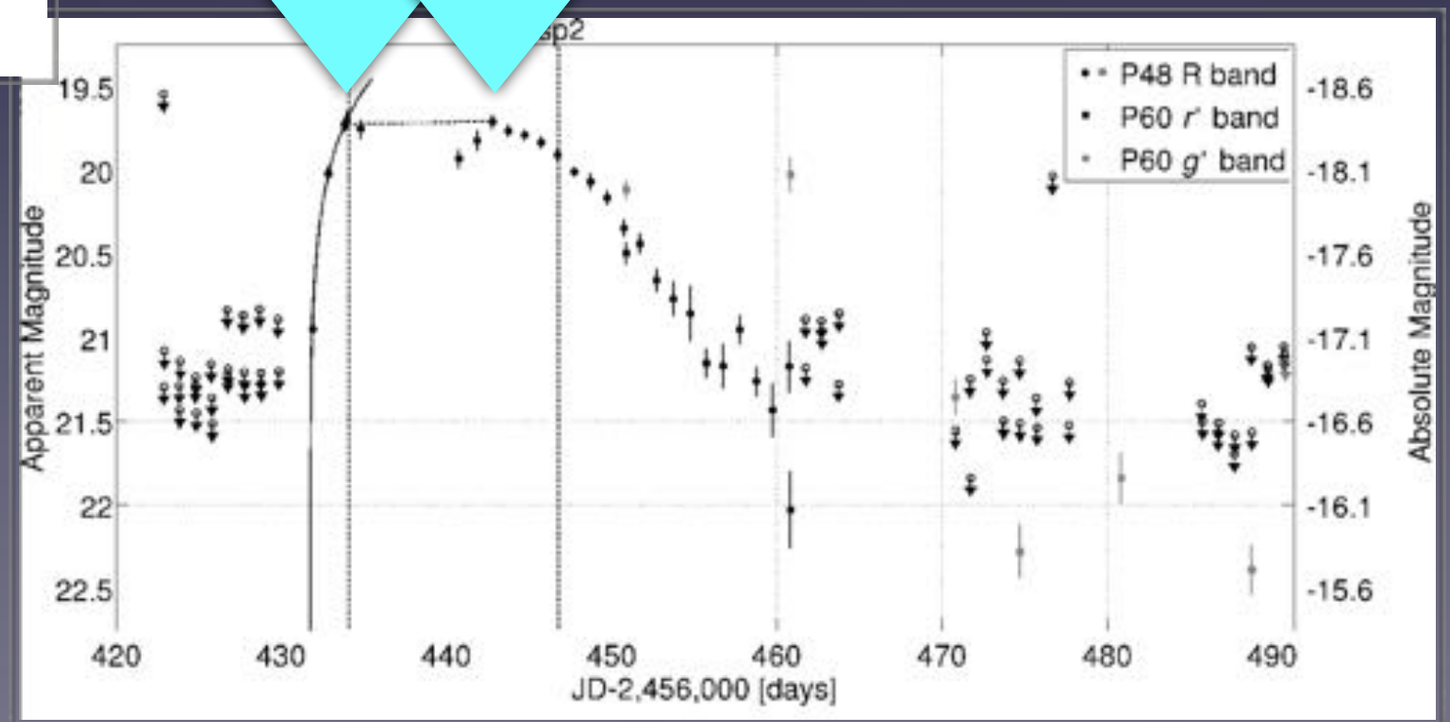


SN 2011hw

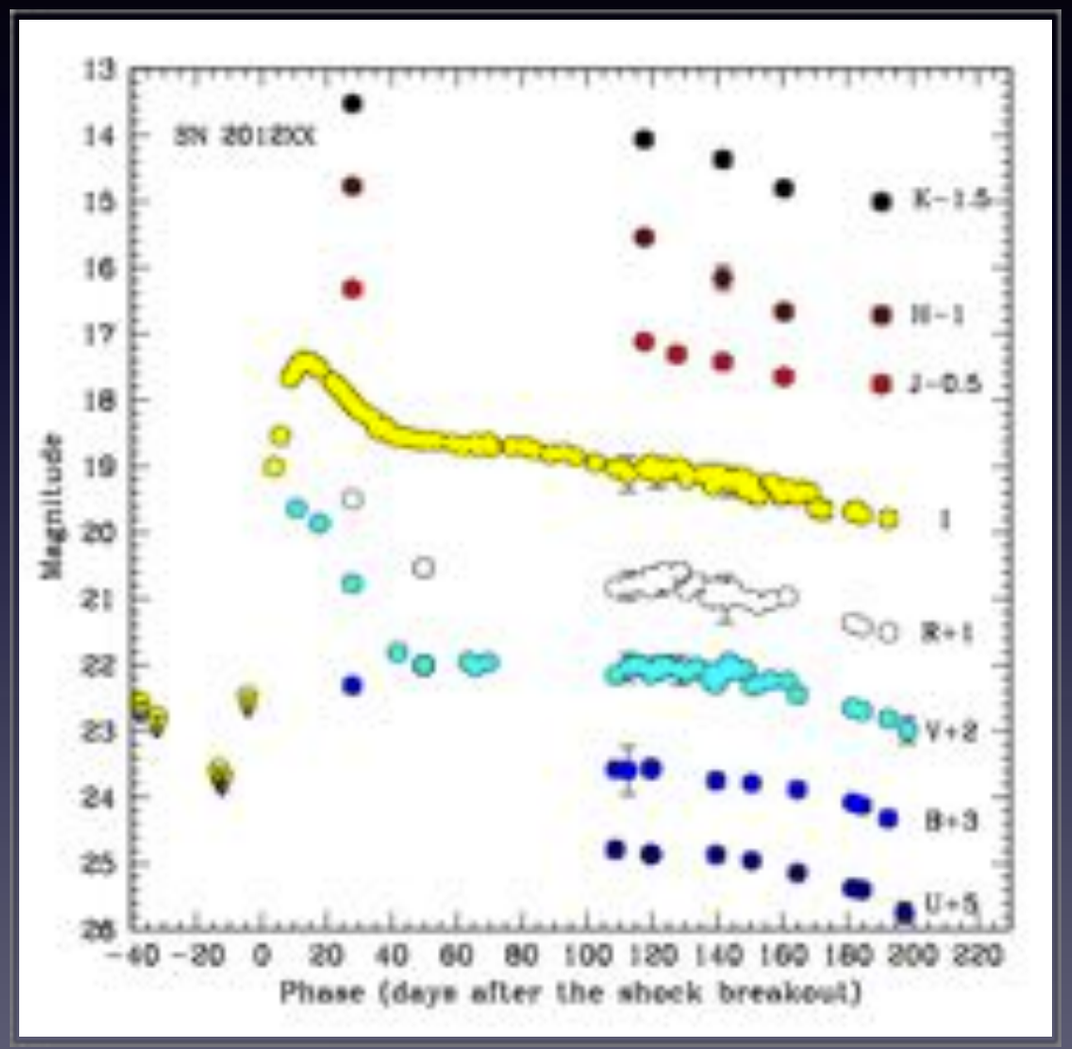
Pastorello+ 2015, MNRAS, 449, 2921

iPTF13beo

Gorbikov+ 2014, MNRAS, 443, 671

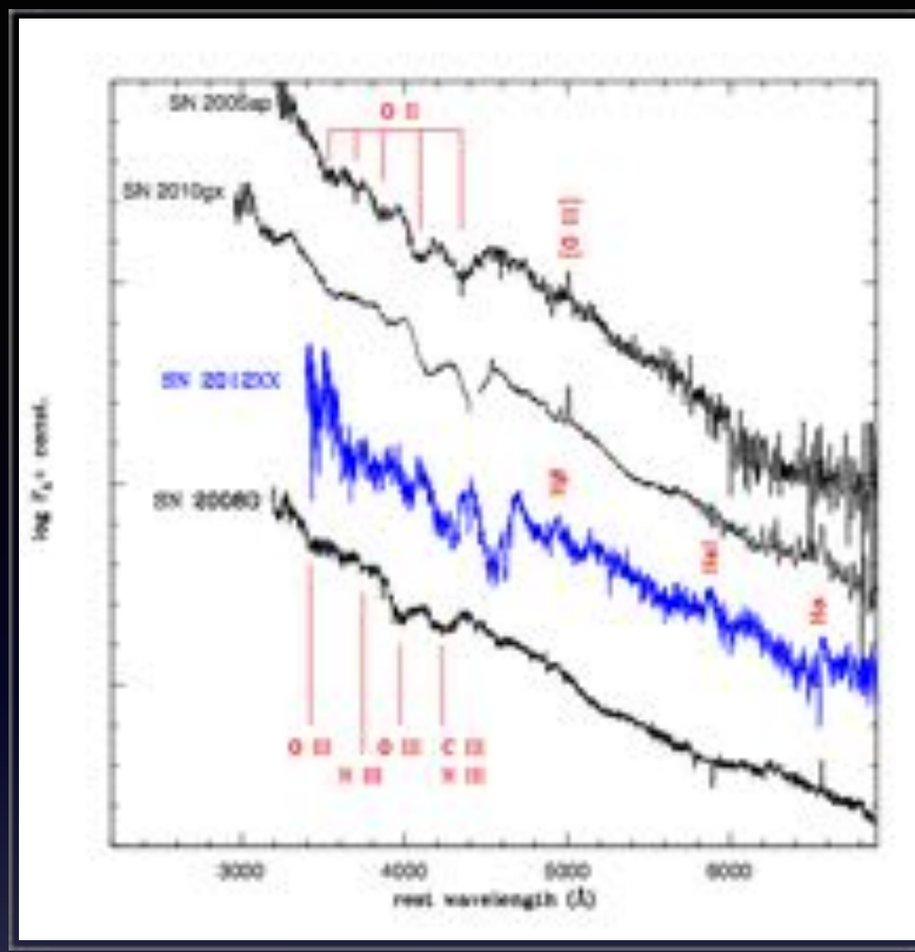


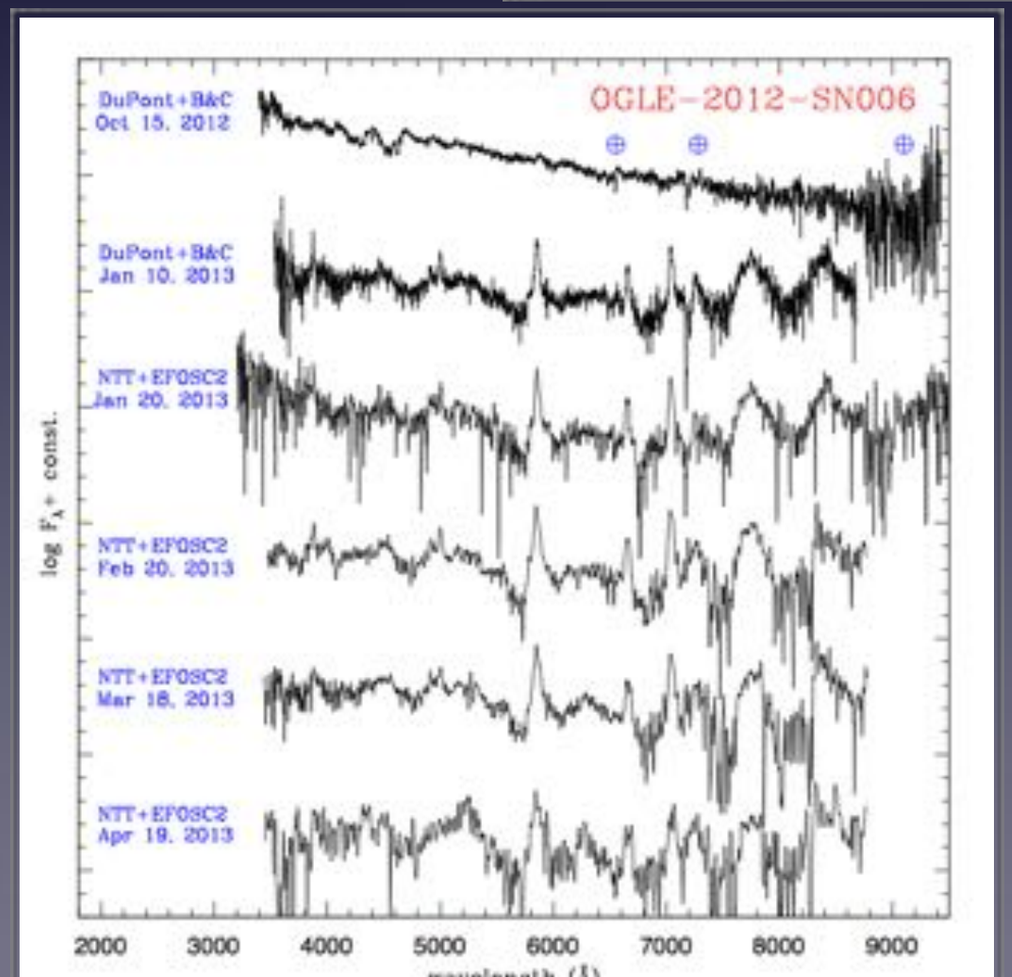
SN Ibn photometric variety slow-evolving late declines



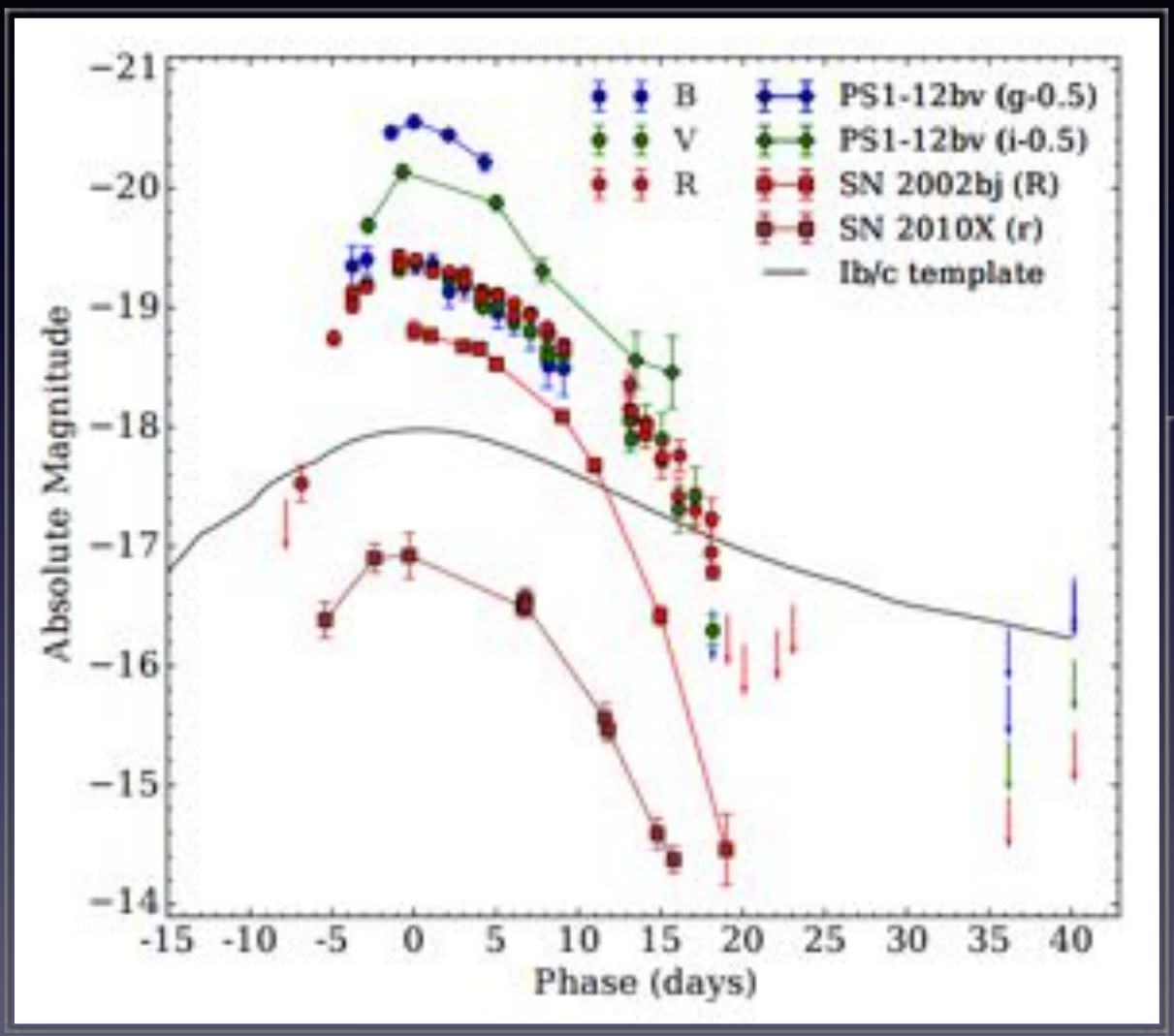
OGLE-2012-SN006

Pastorello+ 2015, MNRAS, 449, 1941





SN Ibn photometric variety
fast-evolving light curves



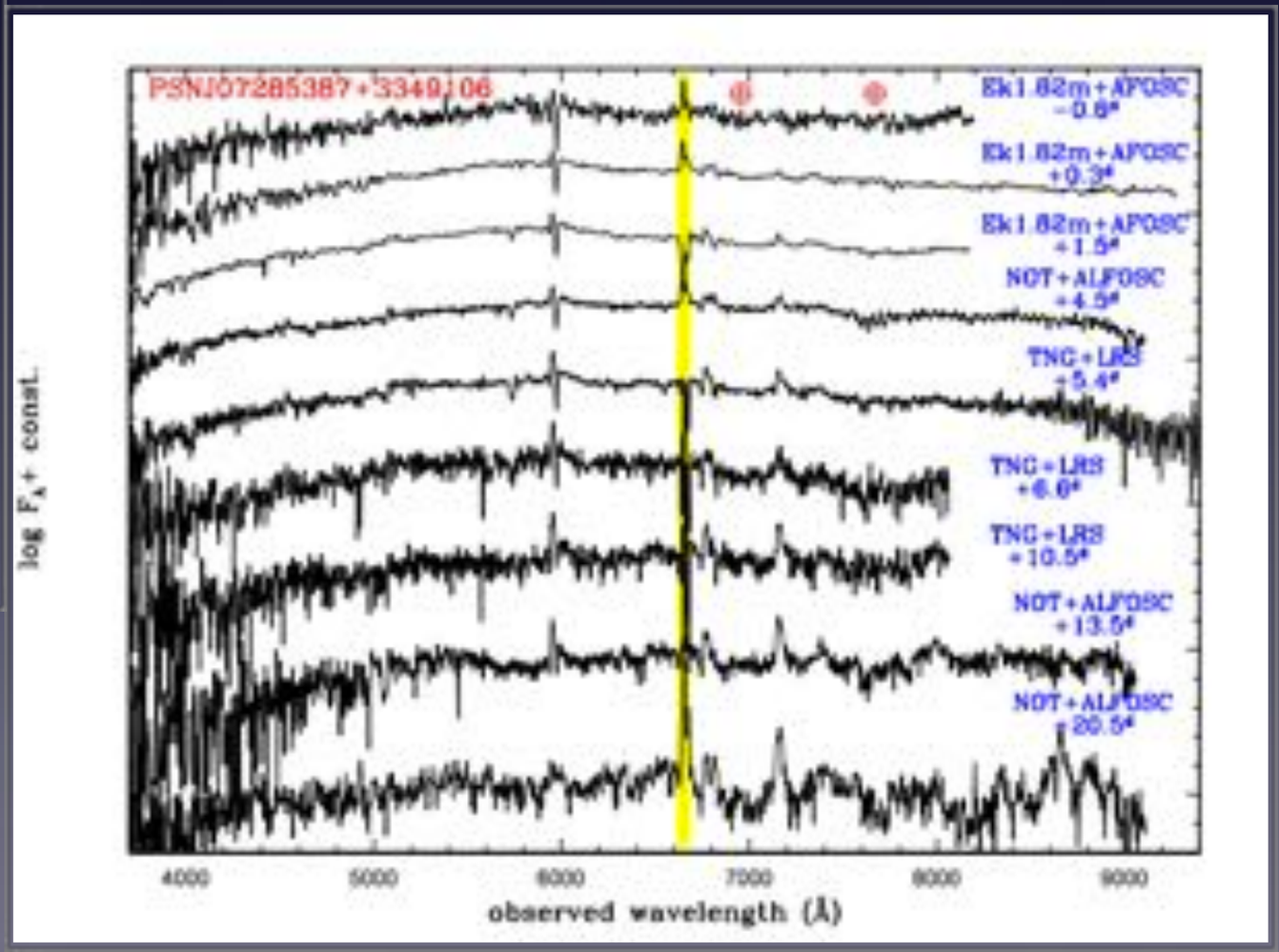
SN 2015U

Shivvers+ 2016, MNRAS, 461, 3057

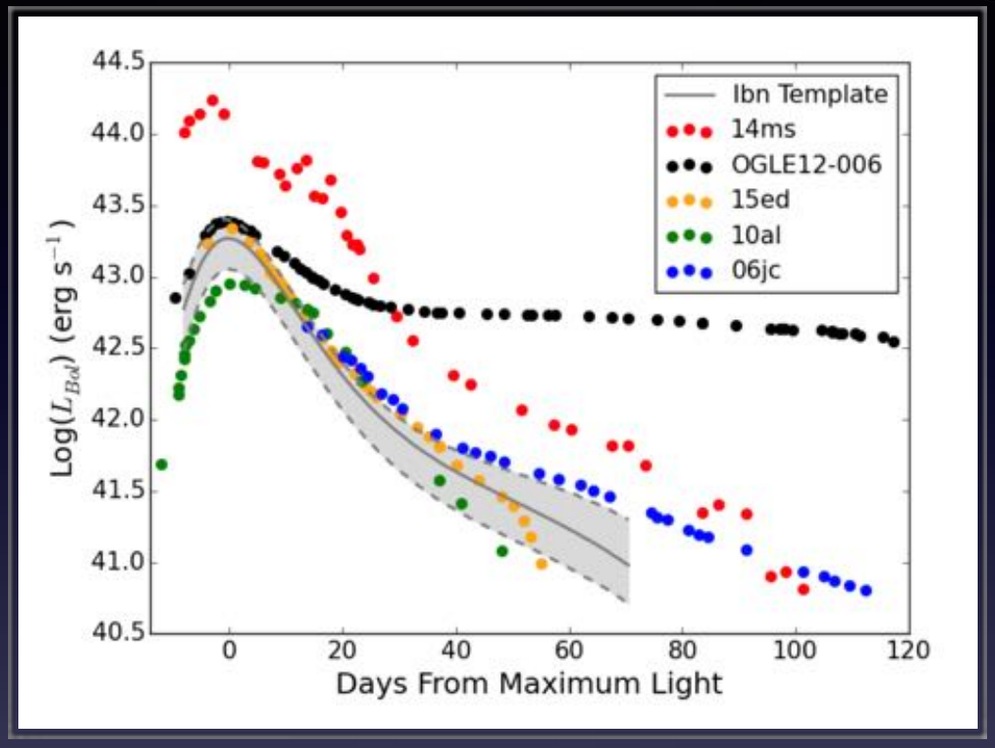
Highly reddened (Av > 1)

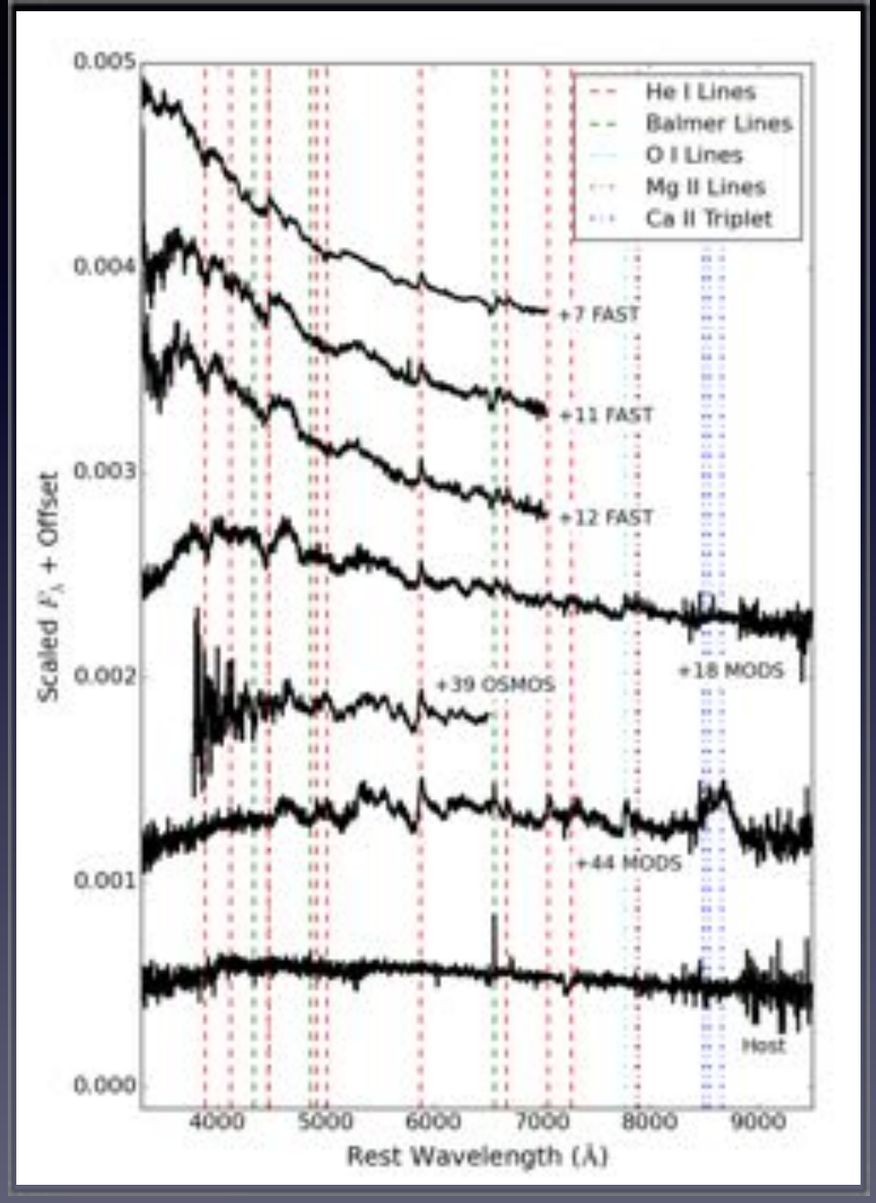
Pastorello+ 2015, MNRAS, 454, 4293

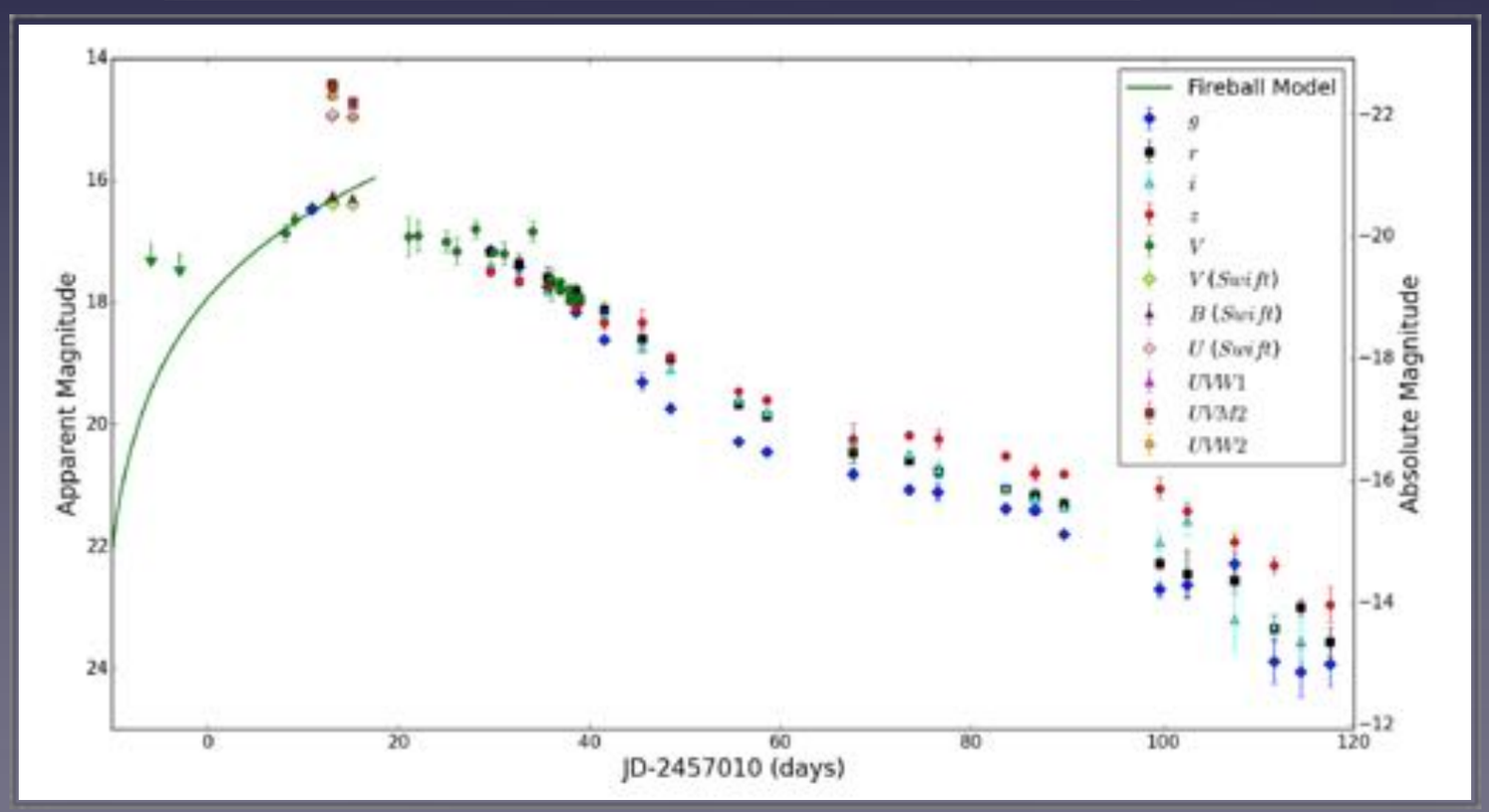
Hosseinzadeh+ 2017, ApJ, 836, 158



SN Ibn photometric variety luminous lightcurve peak







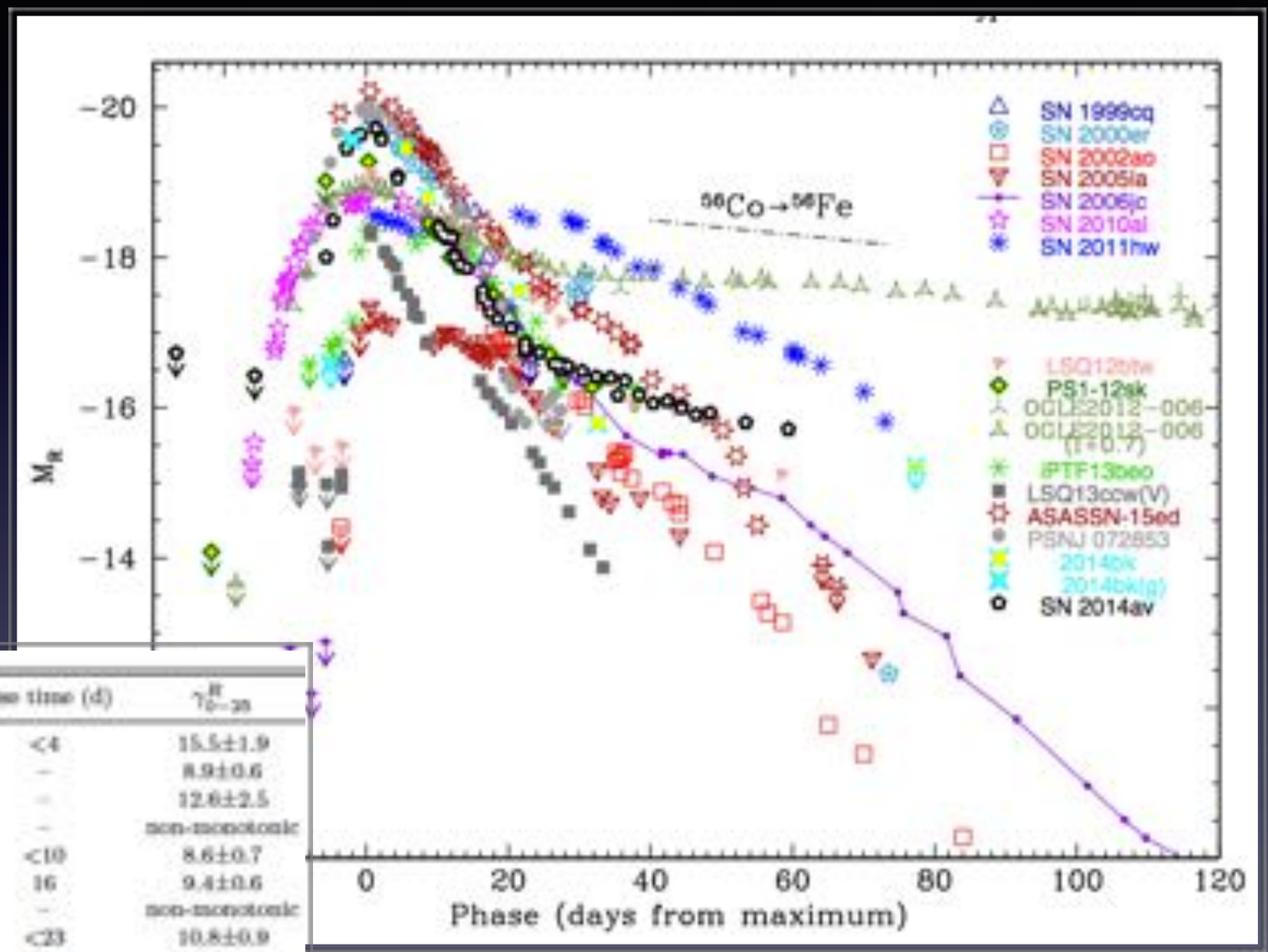
ASASSN-14ms

Vallely et al. 2018, MNRAS, 475, 2344

…hence, not so uniform...

- one heralded by an LBV-like ourburst (2006jc)
- transitioning to Type IIn SNe (2005la, 2011hw)
- transitioning to Type Ib (2010al, ASASN-15ed, 2015G)
- fast evolving (LSQ13ccw, iPTF15ul, 2015U)
- slow-evolving at early phase (OGLE-2014-SN131)
- slow-evolving at late phases (OGLE-2012-SN-006)
- with double-peaked light curves (2011hw, iPTF13beo)
- super-luminous (ASASSN-14ms, iPTF15ul)
- one exploded in the outskirts of an E/S0 galaxy (PS1-12sk)

SN Ibn: photometric variety

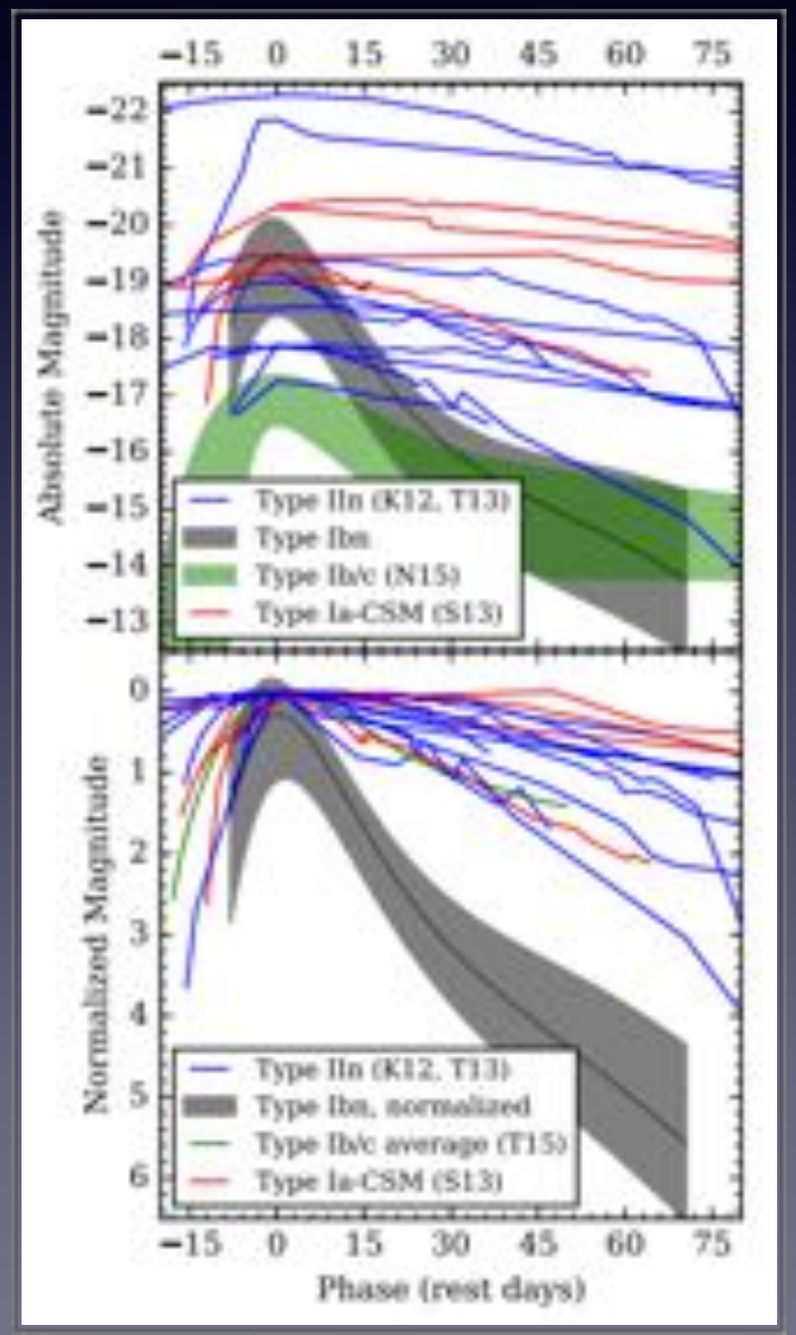


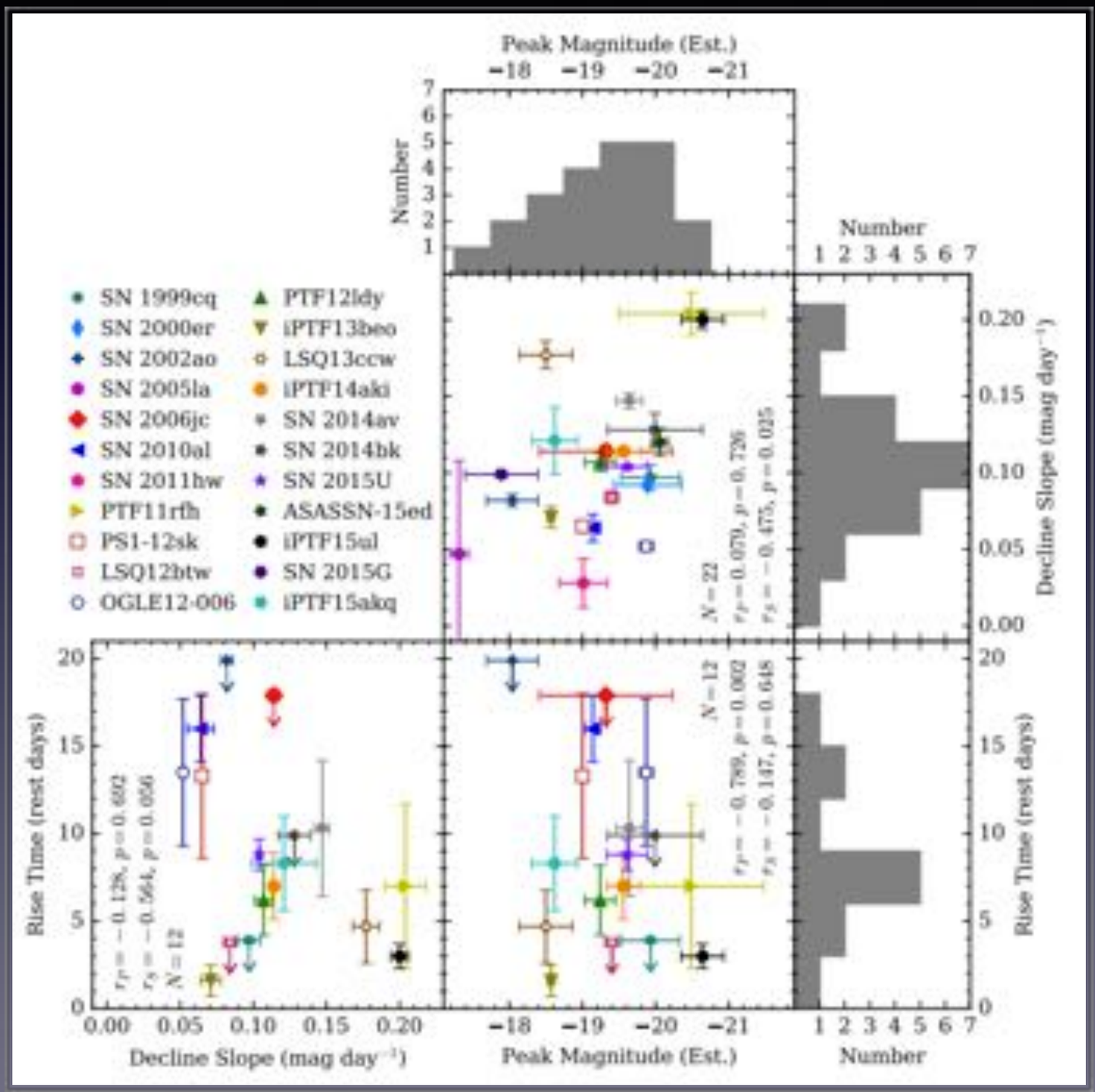
SN	Type	μ	$E(B-V)_{host}$	$M_{R,peak}$	Rise time (d)	γ^{R}_{0-20}
SN 1999cq	Ibn	35.27	0.15	−19.87	<4	15.5±1.9
SN 2000er	Ibn	35.52	0.11	< −19.49	–	8.9±0.6
SN 2002ao	Ibn	31.73	0.25	< −17.41	–	12.6±2.5
SN 2005la	Ibn/IIn	34.49	0.01	−17.19	–	non-monotonic
SN 2006jc	Ibn	32.01	0.04	< −18.61[‡]	<10	8.6±0.7
SN 2010al	Ibn	34.27	0.06	−18.86	16	9.4±0.6
SN 2011hw	Ibn/IIn	34.92	0.10	< −18.54	–	non-monotonic
PS1-12sk	Ibn	36.84	0.03	−19.21	<23	10.8±0.9
OGLE-006*	Ibn	36.94	0.07	−19.65	15.6	4.8±0.1
LSQ12btw	Ibn	36.97	0.02	−19.14	<4	7.3±0.4
iPTF13beo	Ibn-pec	38.01	0.04	−18.39	–	non-monotonic
LSQ13ccw[◎]	Ibn-pec	37.07	0.04	−18.36	<6	12.6±0.2
CSS140421[†]	Ibn	37.41	0.03:	−19.4:	–	–
ASASSN-14dd[⊙]	Ibn	34.23	0.15:	−19.1:	–	–
SN 2014av*	Ibn	35.56	0.02	−19.75	10.6	12.1±0.7*
SN 2014bk	Ibn	37.40	0.05	< −19.47	–	13.1±1.1
ASASSN-15ed	Ibn/Ib	36.59	0.14	−20.19	–	11.4 ± 0.2
PSN J07285387+3349106	Ibn	33.85	1.02	−19.95[◇]	>8.7	19.7±1.6
SN 2015G	Ibn/Ib	31.80	0.33	< −17.1	–	–

Pastorello+ 2016, MNRAS, 456, 853;
See also Hosseinzadeh+ 2017, ApJ, 836, 158

SN Ibn: photometric variety

"SNe Ibn are more homogeneous than SNe IIn"
(Hosseinzadeh+ 2017, ApJ, 836, 158)





Type SN Ibn progenitors

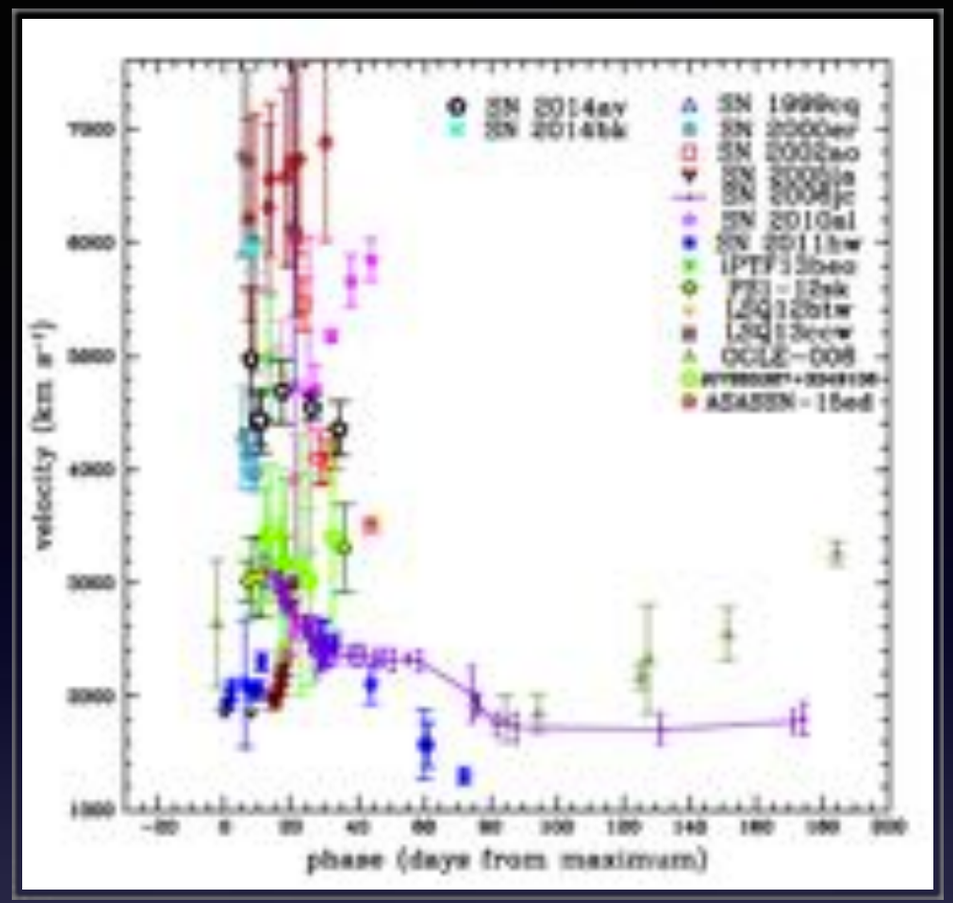
Methods:

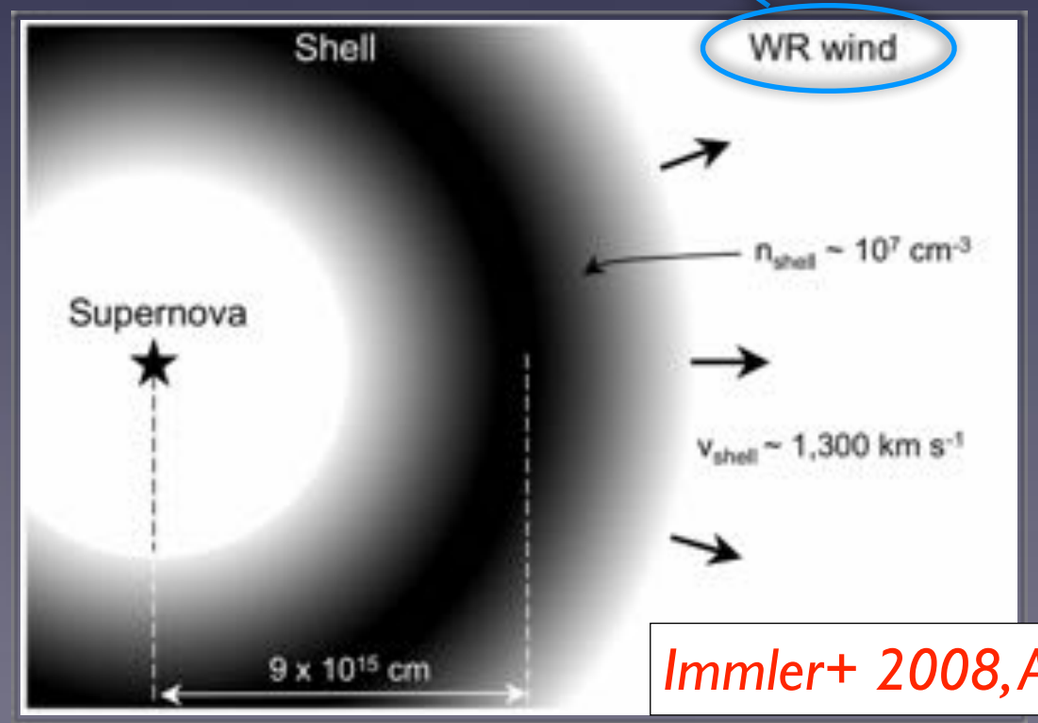
- Characterization of the pre-SN wind
- SN site (progenitor, survived companion, local stellar population)
- Light curve modelling
- Suggestions are welcome

Line velocities

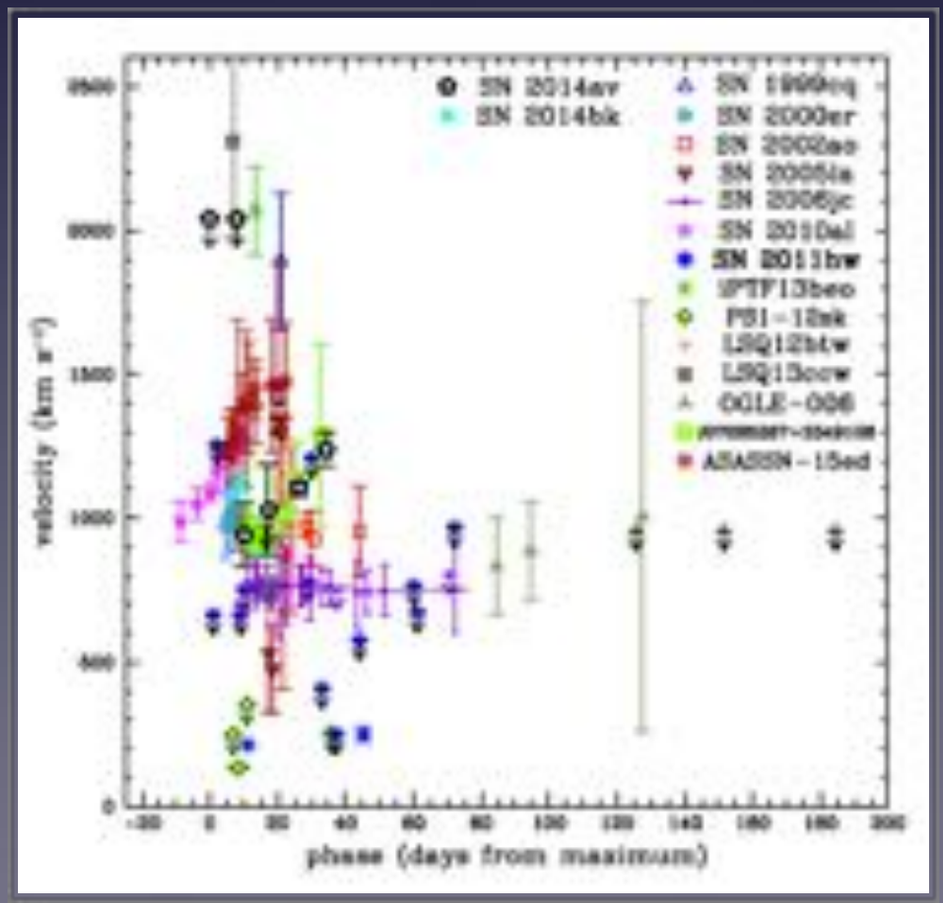
Pastorello+ 2016, MNRAS, 456, 853

SN	Type	v_{narrow}(HeI) (km s^{-1})	v_{broad}(HeI) (range; km s^{-1})	Ha detection	source
SN 1999cq	Ibn	1900	6150	no	1
SN 2000er	Ibn	1000	3950-4300	no	2
SN 2002ao	Ibn	940	3500-6050	weak	2
SN 2005la	Ibn/IIn	500	2000-4200	strong	3,a
SN 2006jc	Ibn	760	1700-3100	weak	3,4,5
SN 2010al	Ibn	1000-1250	2550-5800	weak	8
SN 2011hw	Ibn/IIn	210-250	1350-2350	moderate	8
PS1-12sk	Ibn	130	3100-3300	weak	9
OGLE-006	Ibn	800-1000	2400-3250	weak	10
LSQ12btw	Ibn	970	3200-5250	no	11
iPTF13beo	Ibn-pec	2070	4970	no	12
LSQ13ccw	Ibn-pec	2300	6750	uncertain	11
CSS140421	Ibn	unknown	unknown	unknown	13
ASASSN-14dd	Ibn	unknown	unknown	unknown	14
SN 2014av	Ibn	840-1240	4350-5000	weak	15
SN 2014bk	Ibn	1100	5950	uncertain	15
ASASSN-15ed	Ibn/Ib	1200-1500	6000-7000	no	16
N J07285387+3349106	Ibn	1000-1400	3000-3450	no	17
SN2015G	Ibn/Ib	~1300	~5500	no	18,19





Immler+ 2008, ApJ, 674, L85



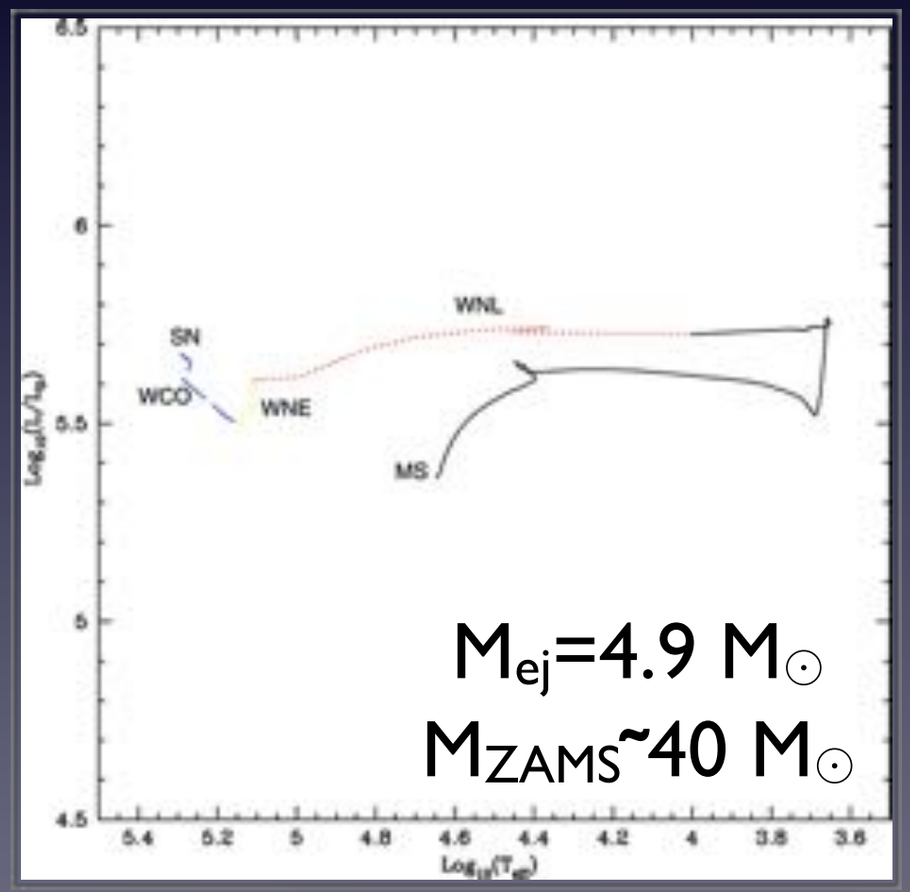
SN Ibn Progenitors

What about SN 2006jc?

MARRIED OR SINGLE LIFE?

1. High-velocity (10^3 km s^{-1}) He rich pre-SN wind
2. Luminous Pre-SN outburst
   - Single massive WR star that eruptively expelled He-rich CSM before core-collapse *(Foley+ 2007, Pastorello+ 2007, Tominaga+ 2008)*
   - Binary: erupting LBV+exploding WR *(Pastorello+ 2007, Nature, 447, 829)*

In either case, the progenitor of SN 2006jc was likely <u>very massive</u>…



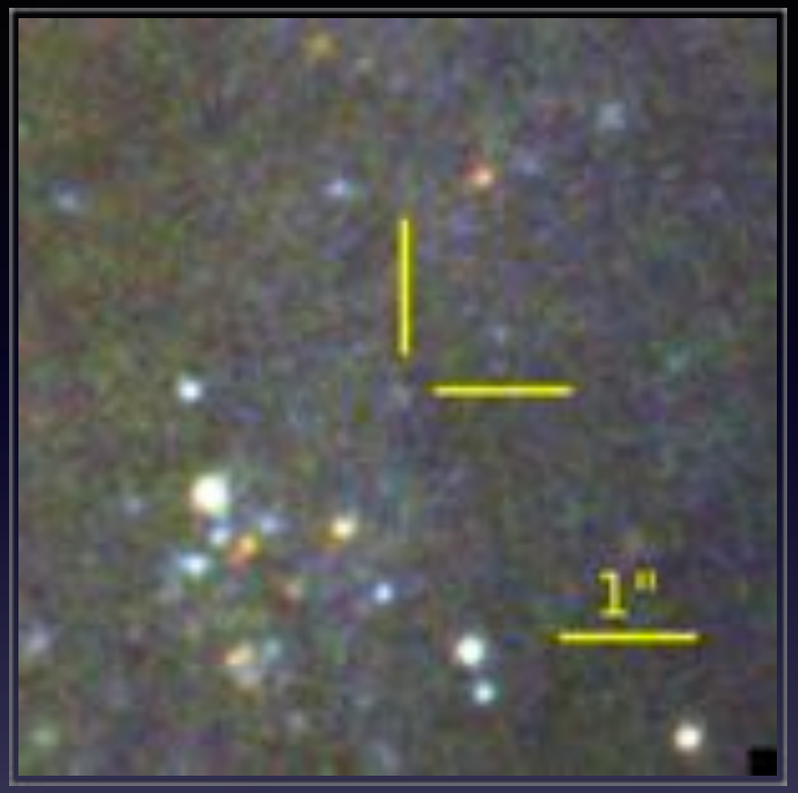
M_{ej}=4.9 $M_\odot$

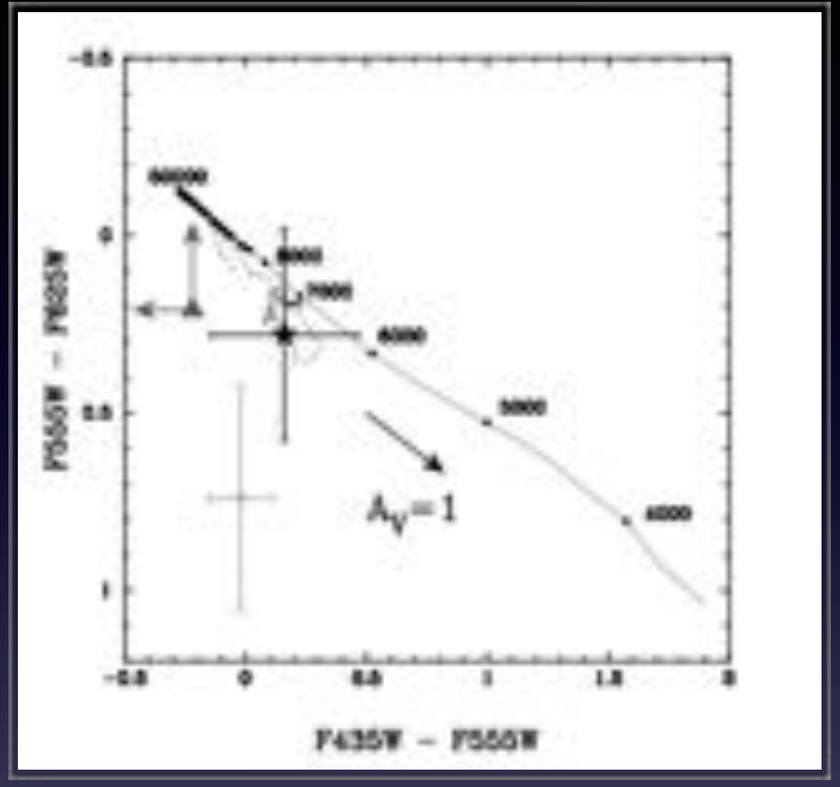
M_{ZAMS}~40 $M_\odot$

Tominaga+ 2008, ApJ, 687, 1208

SN Ibn Progenitors

SN 2006jc Location



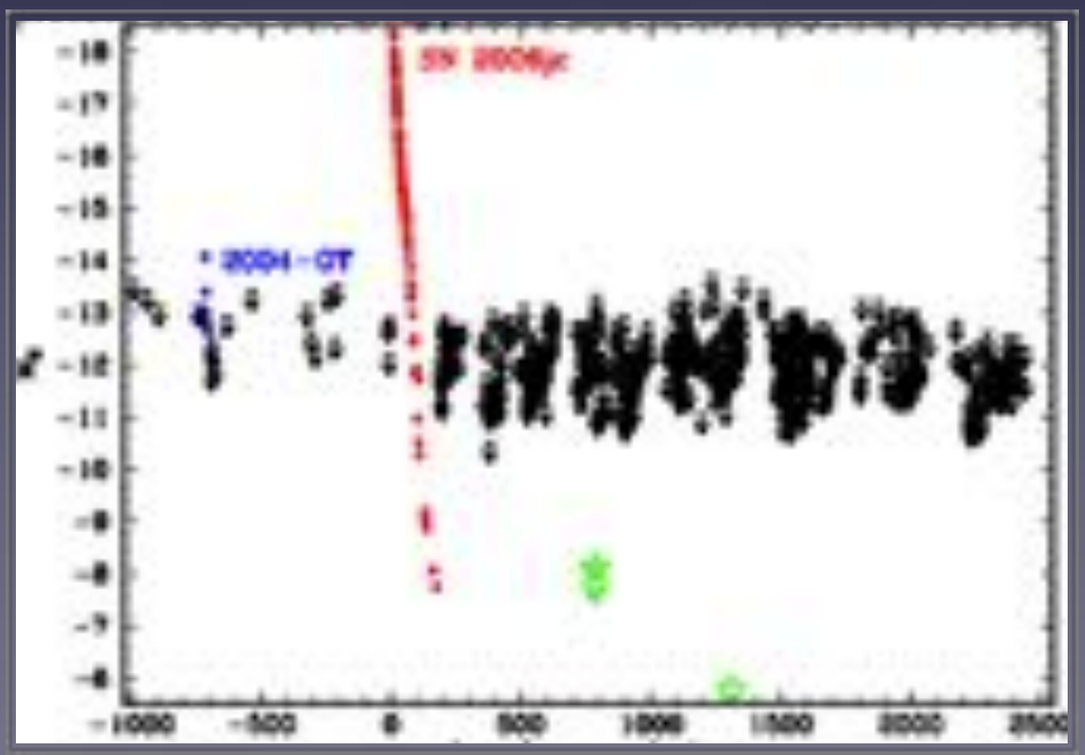


(Maund+ 2016, ApJ, 833, 128)

- A weak blue source detected in 3 bands at the SN location, (mags 26.3-26.8) => $M_V \sim -5.6$
- No outbursts detected after the SN explosion

<u>No massive LBV companion</u>

(A-F supergiant with $M < 10\ M_\odot$)

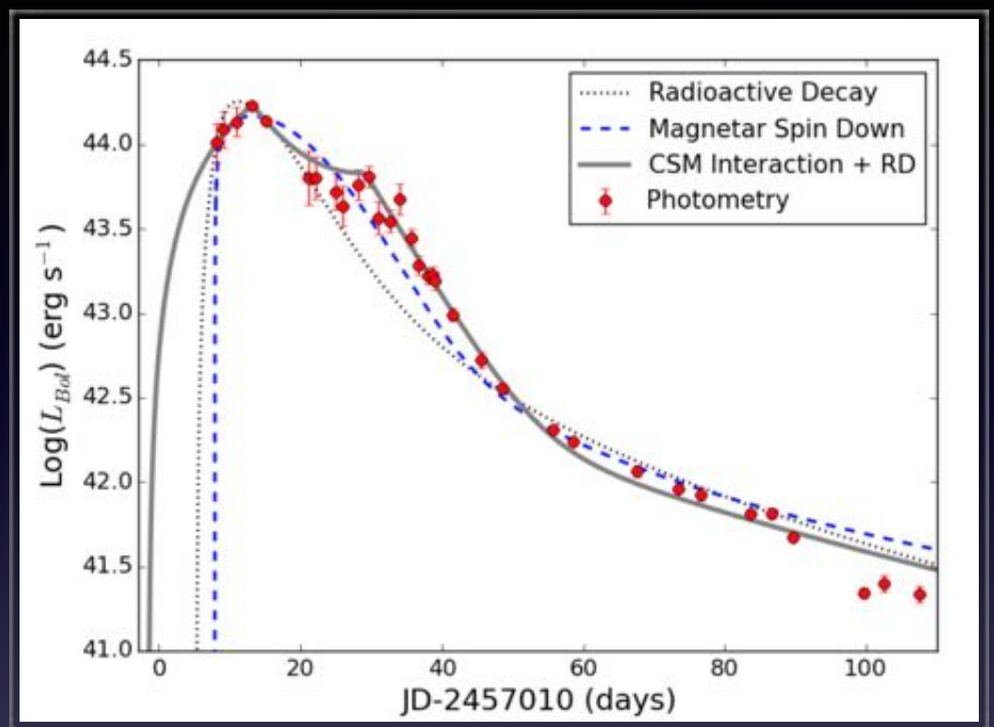


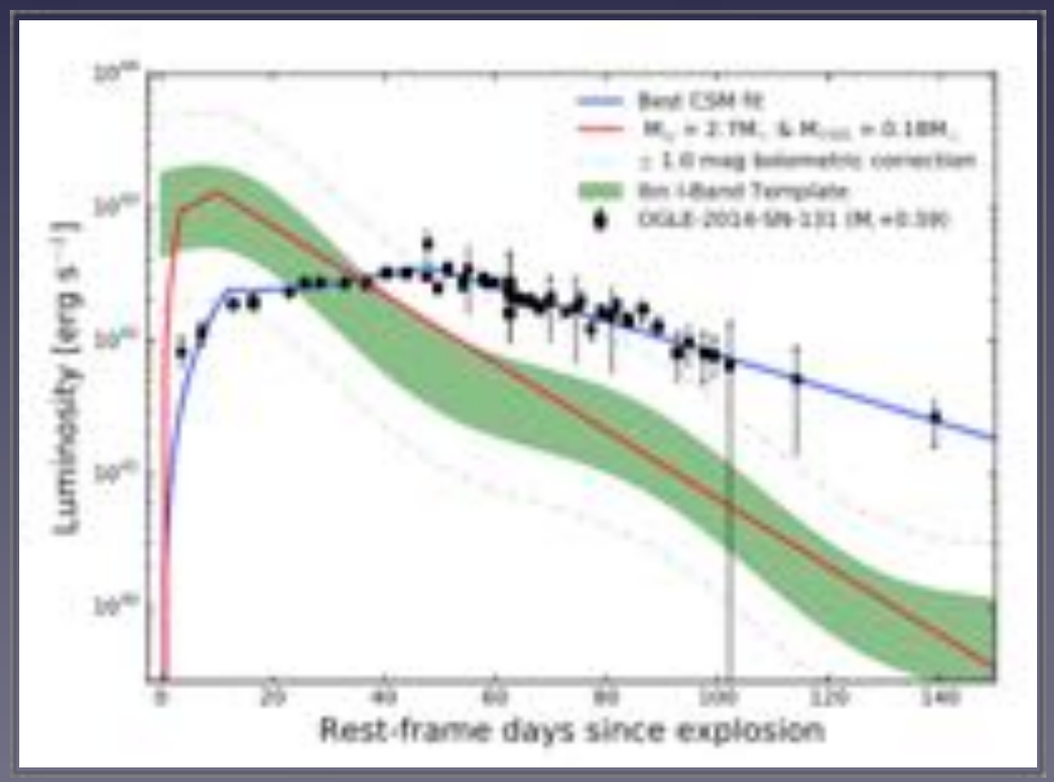
SN Ibn Progenitors

ASASSN-14ms

- Pure radioactive decay ($M_{ej}<M_{Ni}$! unphysical)
- Magnetar spin-down ($P_{in,spin}$=1 ms, $M_{ej}=3.3M_{\odot}$)
- CSM interaction model (with $M_{ej}=4.3M_{\odot}$; $M_{CSM}=0.5M_{\odot}$; 0.23 $M_{\odot}$ of ^{56}Ni) => M_{ZAMS}>a few x10 $M_{\odot}$ (host: 12+log(O/H) < 8.3)

Vallely+ 2018, MNRAS, 475, 2344





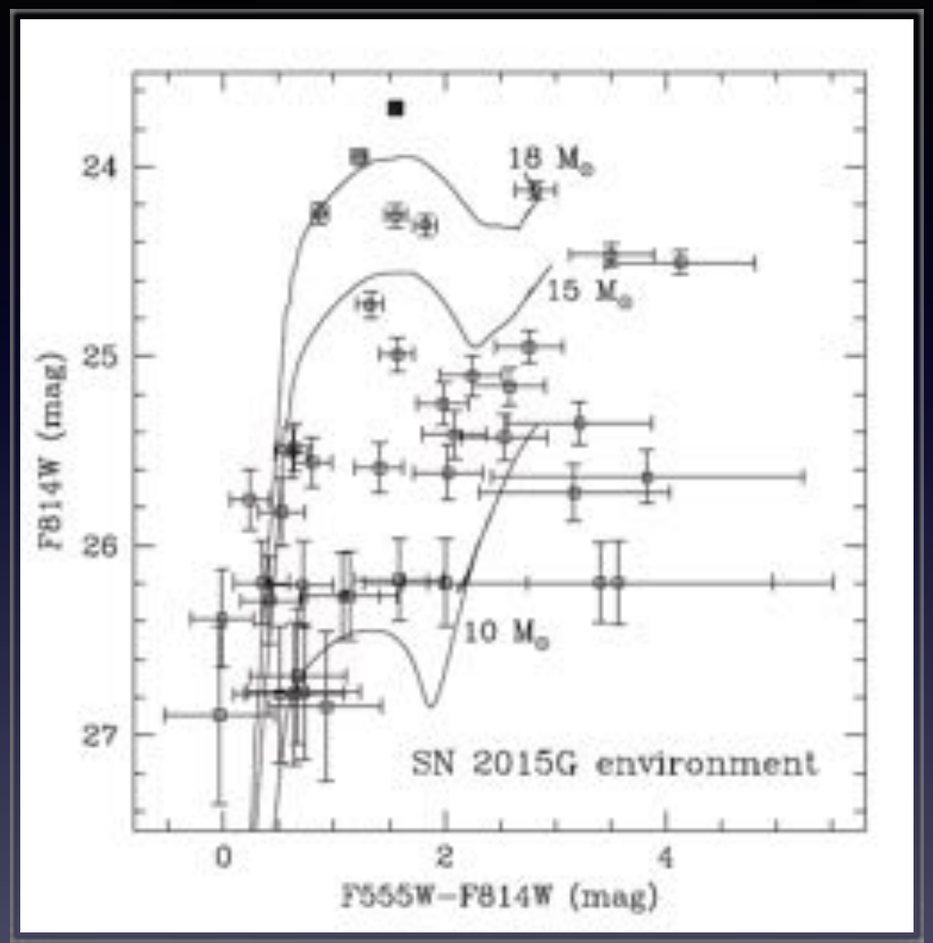
SEE POSTER SECTION!

OGLE-2014-SN-131

Fair fits with the (usual) magnetar, and CSM-interaction models; low-metallicity (SMC-like) host; M_{ZAMS} > 40 $M_{\odot}$

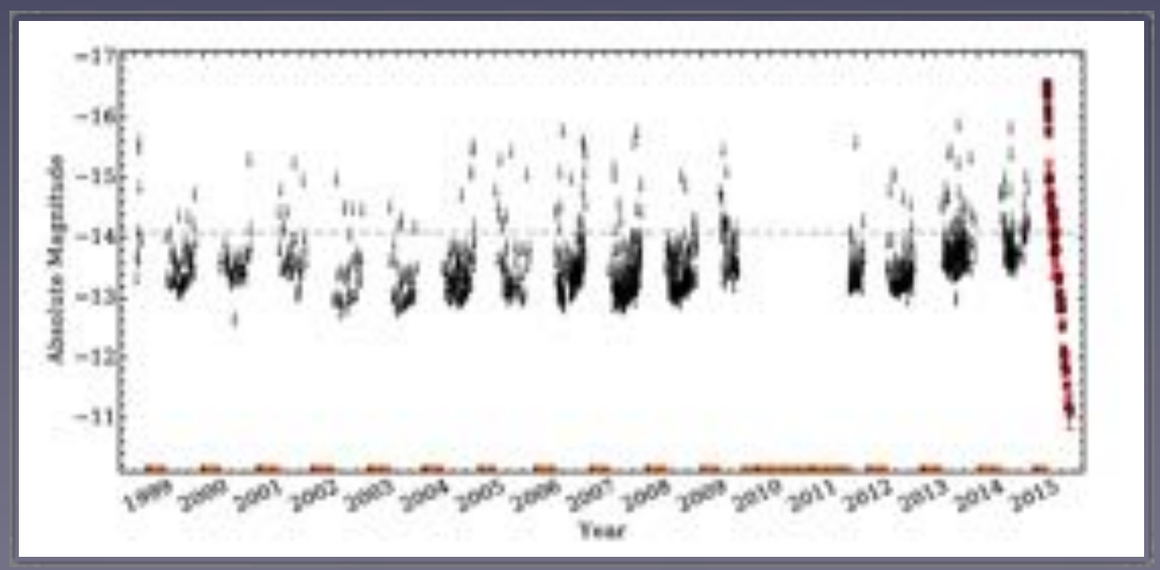
Karamehmetoglu+ 2017, A&A, 602, 93

SN Ibn Progenitors



- From the non-detection of the progenitor in pre-SN HST images (M_{F555W} > -6.4; M_{F814W} > -7.1 mag)
- From the stellar environment analysis
- No pre-SN outbursts in ~20 yrs

- No single massive (>30 $M_\odot$) star
- M_{ZAMS} < 18-20 $M_\odot$ in a binary system

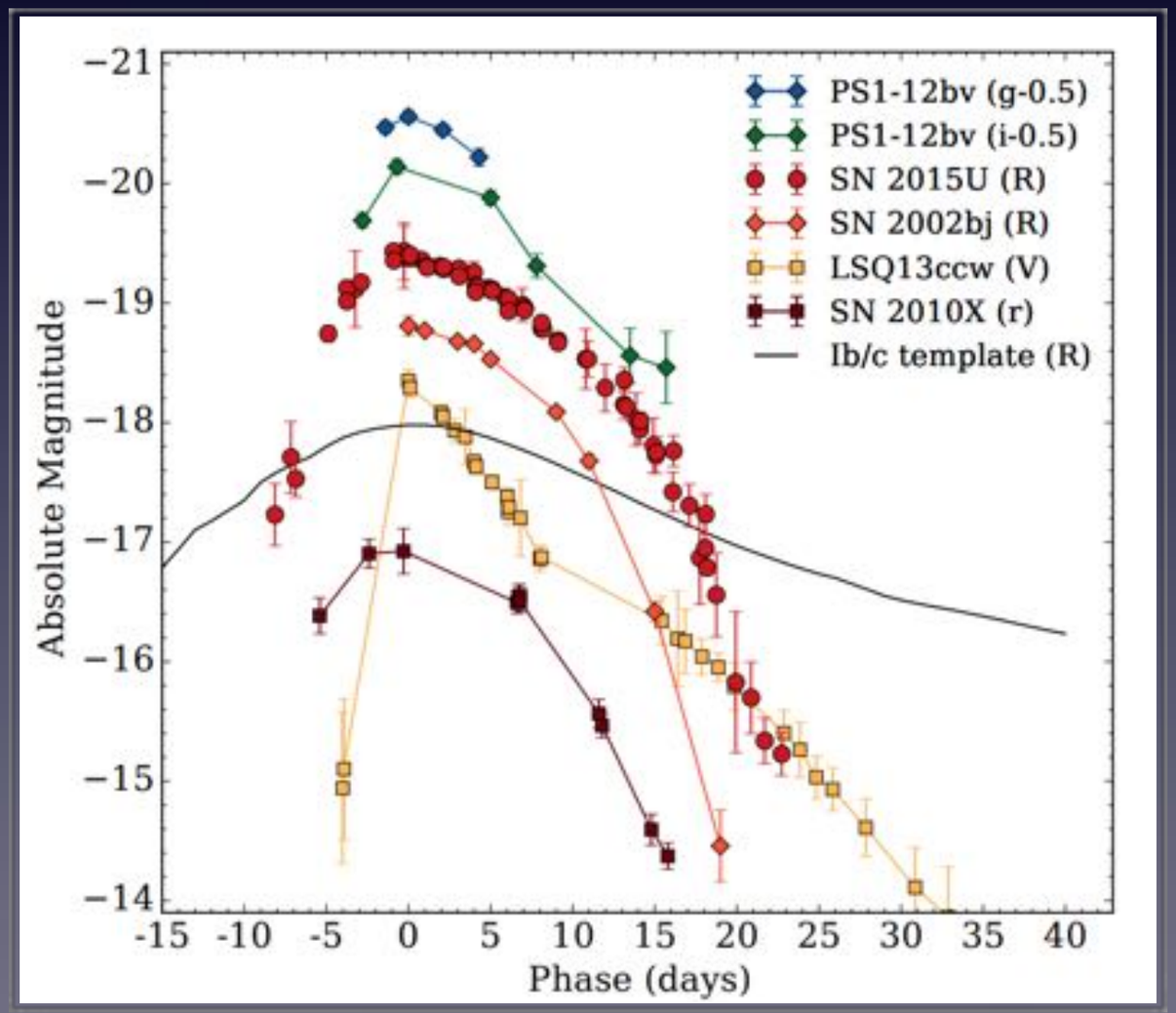


SN 2015G

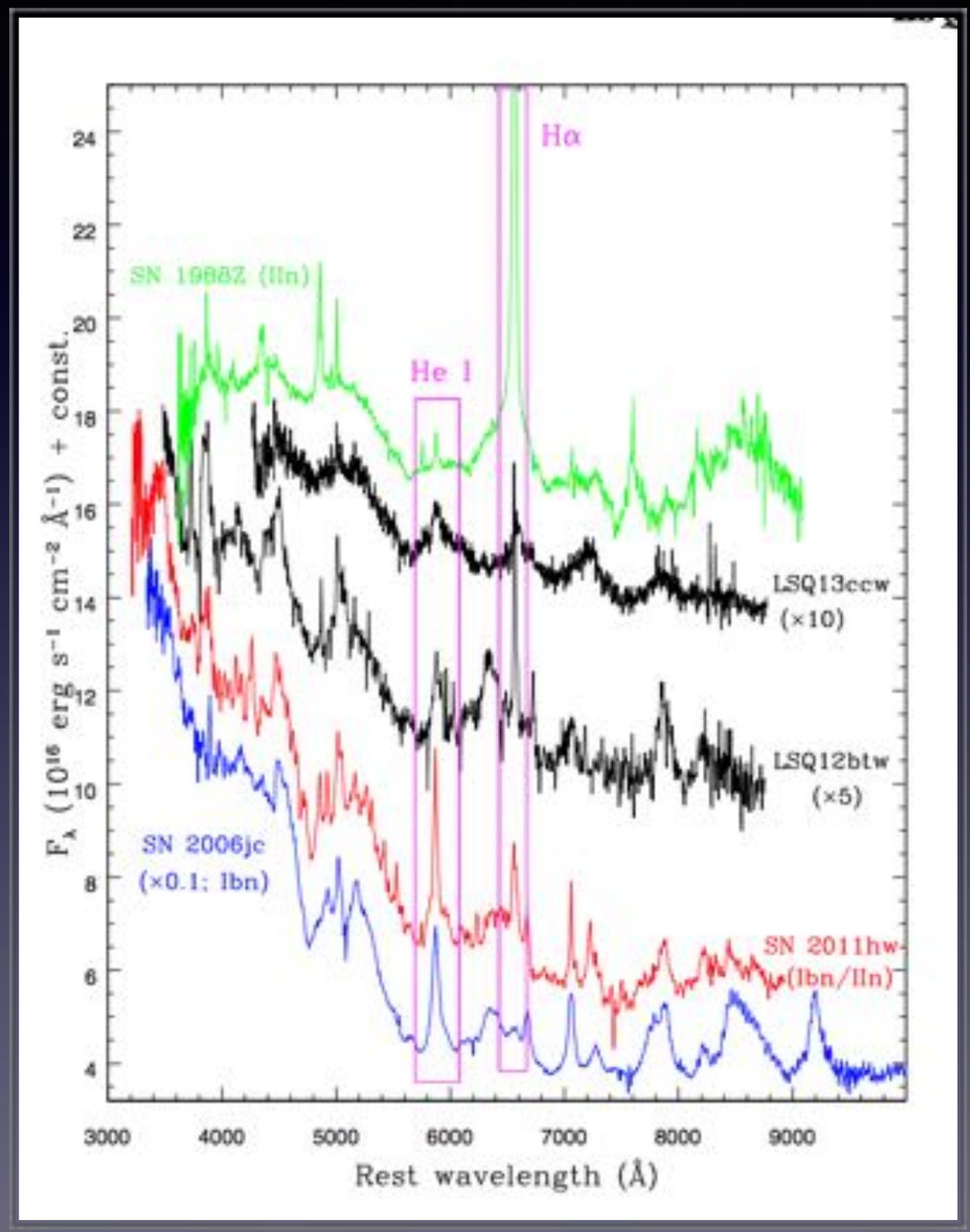
Shivvers+ 2017, 471, 4381

SN Ibn Progenitors

In some cases, SNe Ibn are hardly reconciled with massive ejecta, e.g. some "fast and furious SNe Ibn".



Shivvers+ 2016, 461, 3057



Pastorello+ 2015, MNRAS, 449, 1954

SN 2015U, LSQ12btw, LSQ13ccw

SN Ibn variety
Weird locations

SNe Ibn are usually hosted in spiral galaxies/star-form. environments

An international team of astronomers has announced the discovery of a very rare Type Ibn supernova on the outskirts of a bright elliptical galaxy located about 780 million light-years away.

Sanders et al. 2013, ApJ, 769, 39

PS1-12sk, circled, is classified as a very rare Type Ibn supernova – only the sixth such example found out of thousands of supernovae (CfA / PS1 Science Consortium)

PS1-12sk

A SN Ibn apparently in a remote location of an early-type host! => an SN in a low-mass degenerate progenitor system?

Alternatively, a dwarf host? => massive star precursor for PS1-12sk

Conclusions

- SNe Ibn show a wide range of observational properties (in light curve shape, luminosity, spectral evolution, line profiles)
- Their peak luminosities span two orders of magnitude (10^{42} to over 10^{44} erg s^{-1})
- From the CSM velocity (from the narrow line profiles) and the light curve modelling => different types of progenitor stars may produce SNe Ibn.
- SNe Ibn are rare: 5-6% of stripped-envelope SN discoveries; 2% of all CCSNe