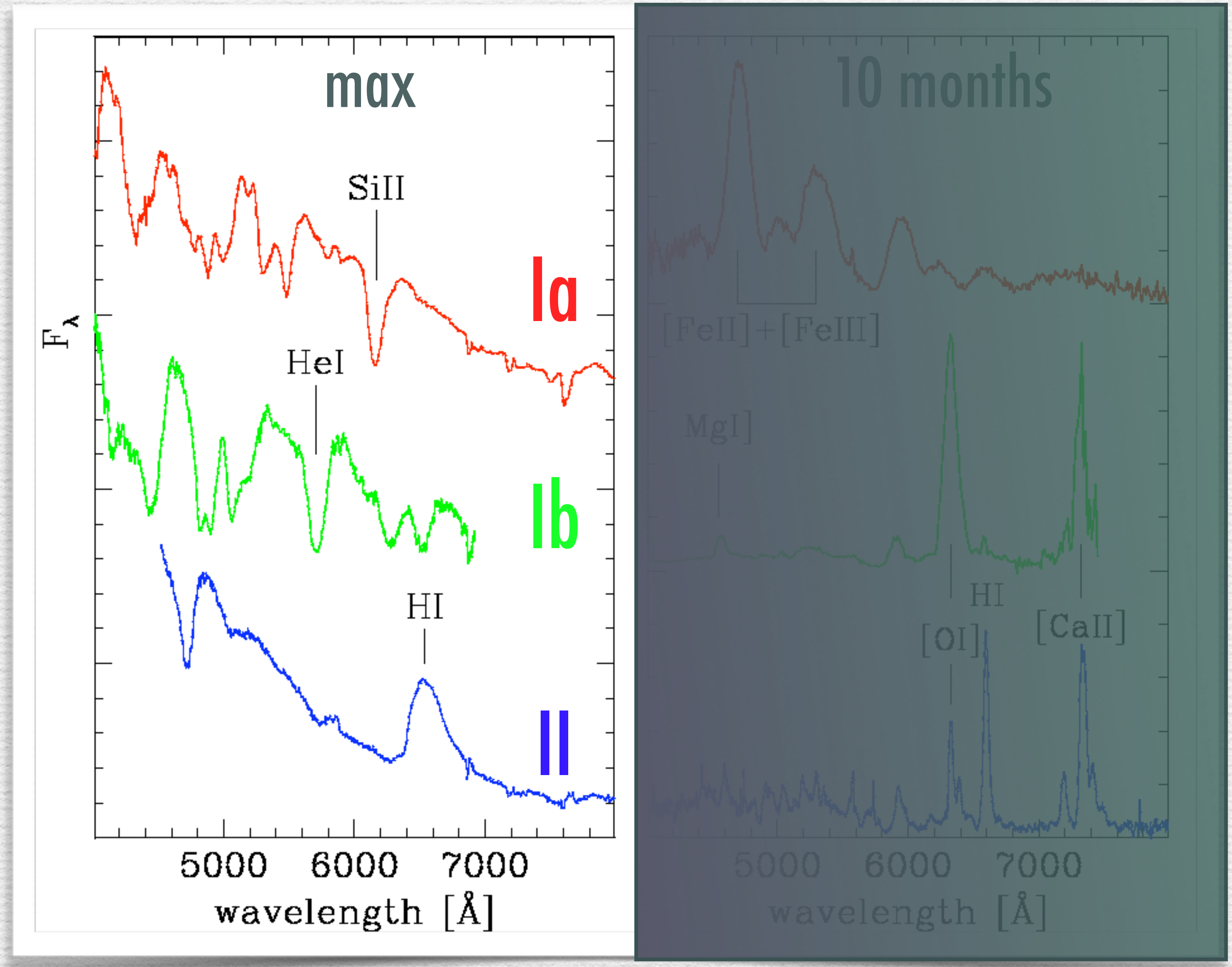
Supernova types and rates

Enrico Cappellaro
Istituto Nazionale di Astrofisica

SN: a very bright transient (luminosity > 10^8 L_{sun})
of stellar origin (mass < 2×10^2 M_{sun})

SN types

SN types: basics



Textbook scenarios

3 - 8 M_{SUN} Thermonuclear explosion of a C-O WD in a close binary system

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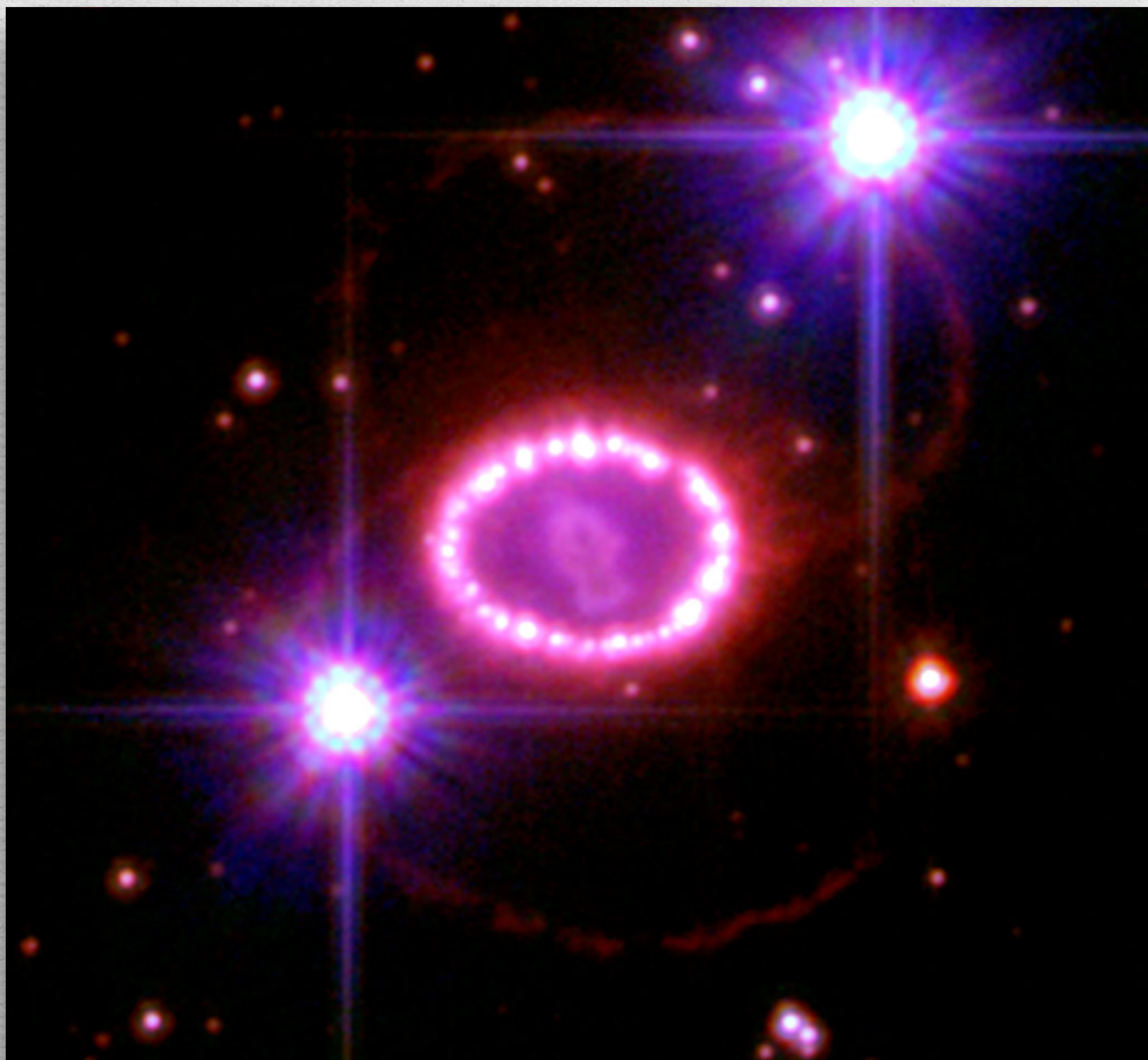
30 - 60 M_{SUN} Core-collapse of a massive star after strong mass loss

8 - 30 M_{SUN} Core-collapse of a massive star after low/moderate mass loss

SN II core collapse

1987A: the closer SN in 400yr



Neutrino detection probes core collapse

Progenitor identification

20 $M_\odot$

5 $M_\odot$ H envelope, 6 $M_\odot$ He core, 1.5 $M_\odot$ Fe core, 0.07 $M_\odot$ Ni^{56}

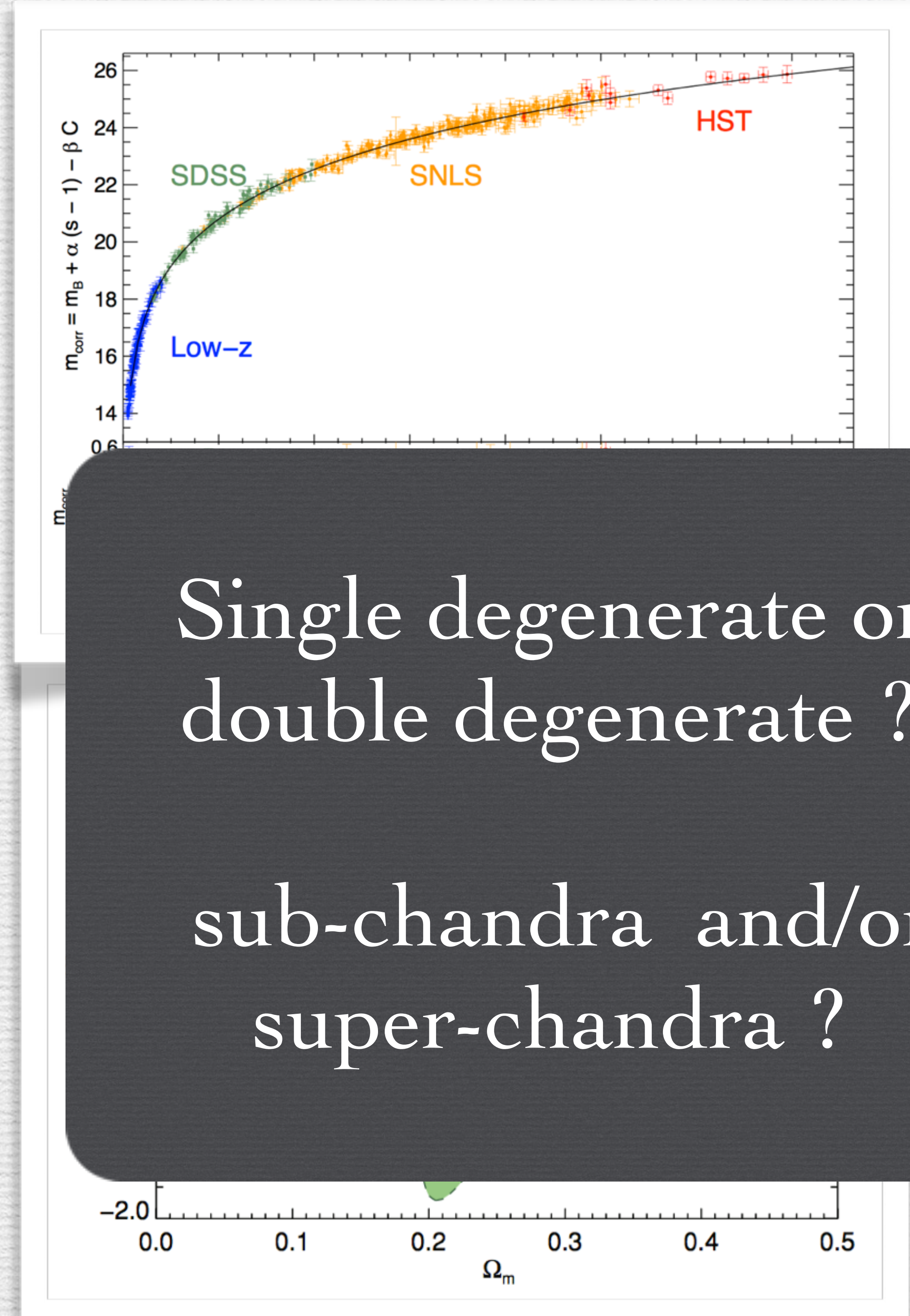
radius $3x10^{12}$ cm
blue [not red] supergiants

where is the neutron star ?

SN Ia and Dark Energy

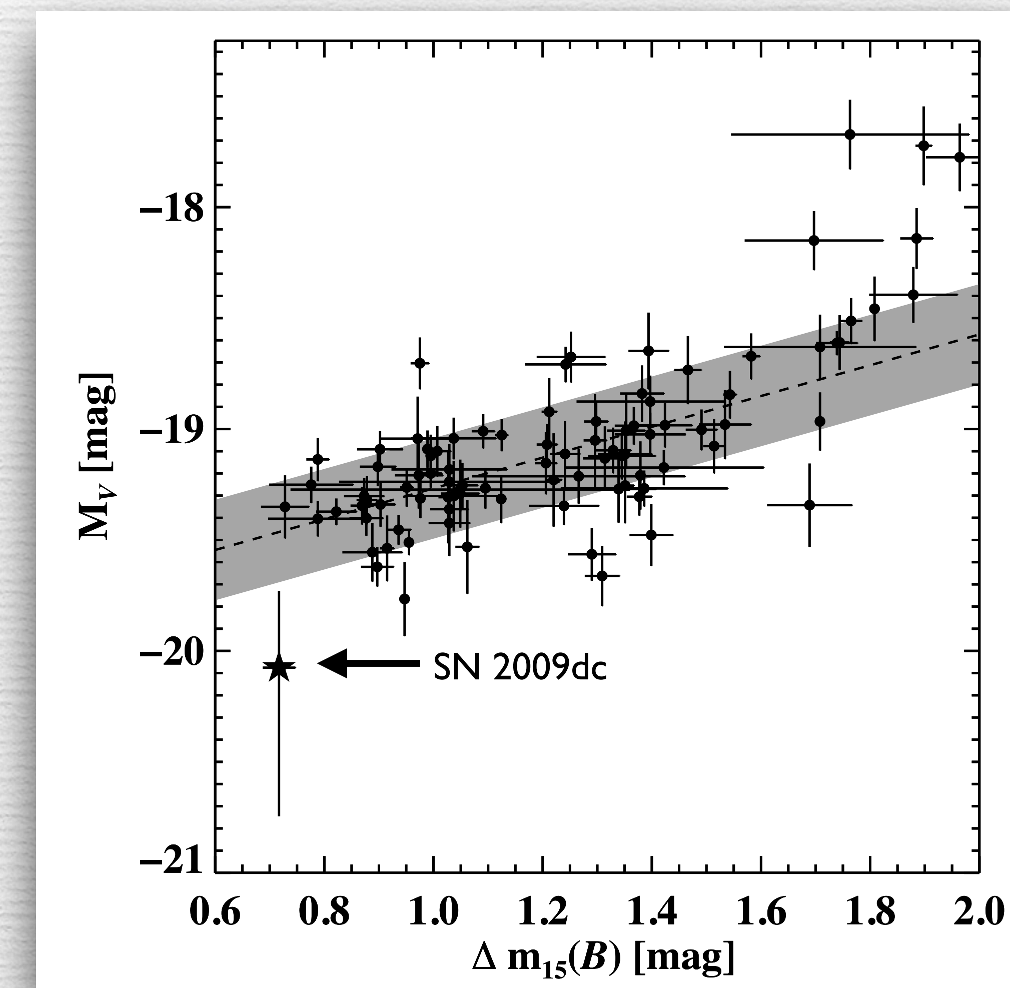
Conley et al. 2011 ApJS 192,1
Sullivan et al. 2011 ApJ 737, 102

Flat Universe Ω_m=0.269±0.015
ω= -1.068±0.080



Single degenerate or double degenerate ?

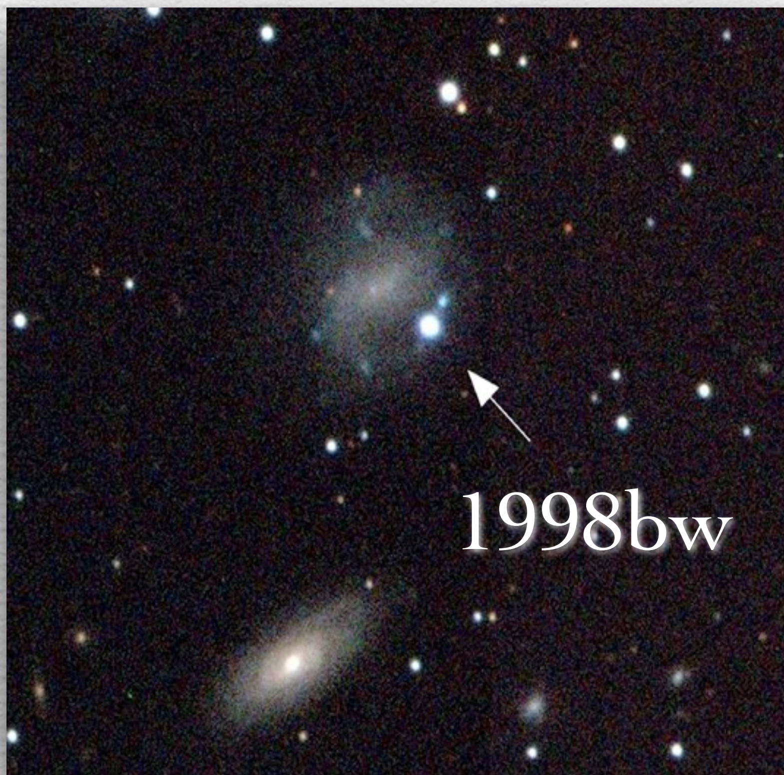
sub-chandra and/or super-chandra ?



Silverman el al. 2011 MNRAS 410, 585

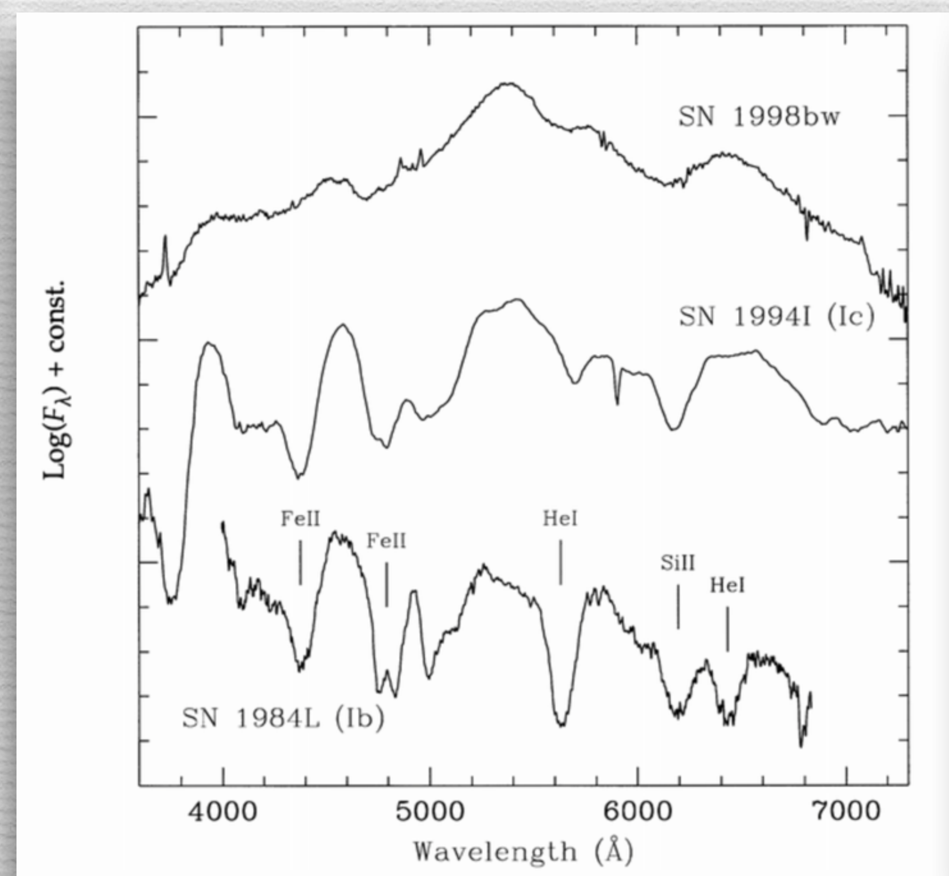
SN Ib/c and GRBs

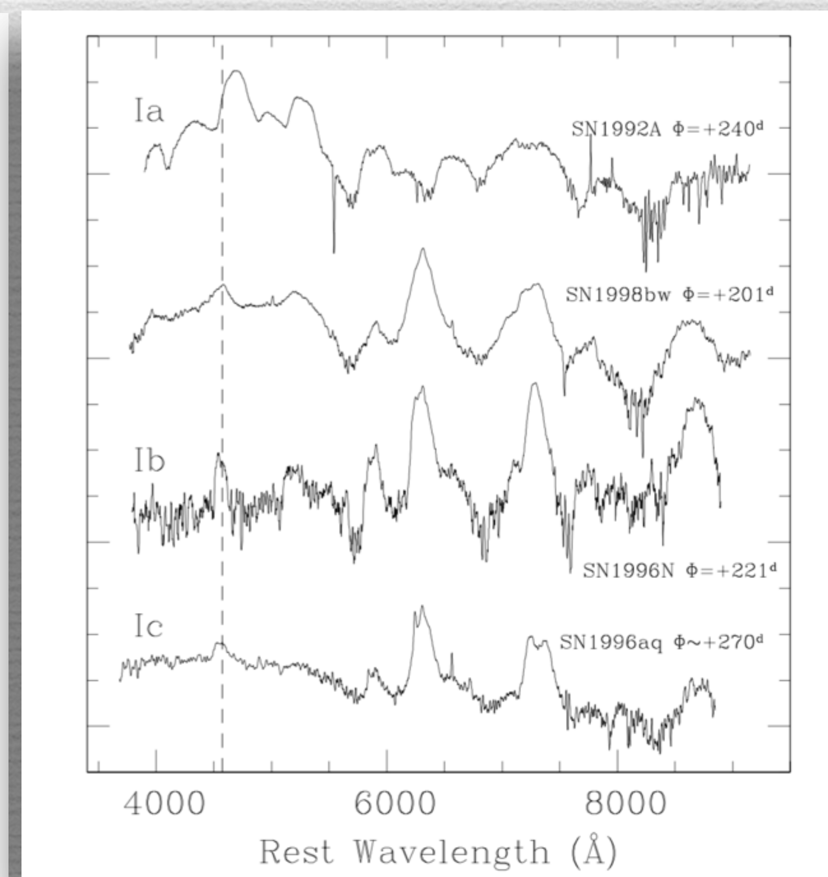
Long GRBs are linked to highly energetic SN Ic



Galama et al. 1998 Nat. 395, 670
Pian et al. 1999 A&A 138, 463
Patat et al. 2001 ApJ 555, 900

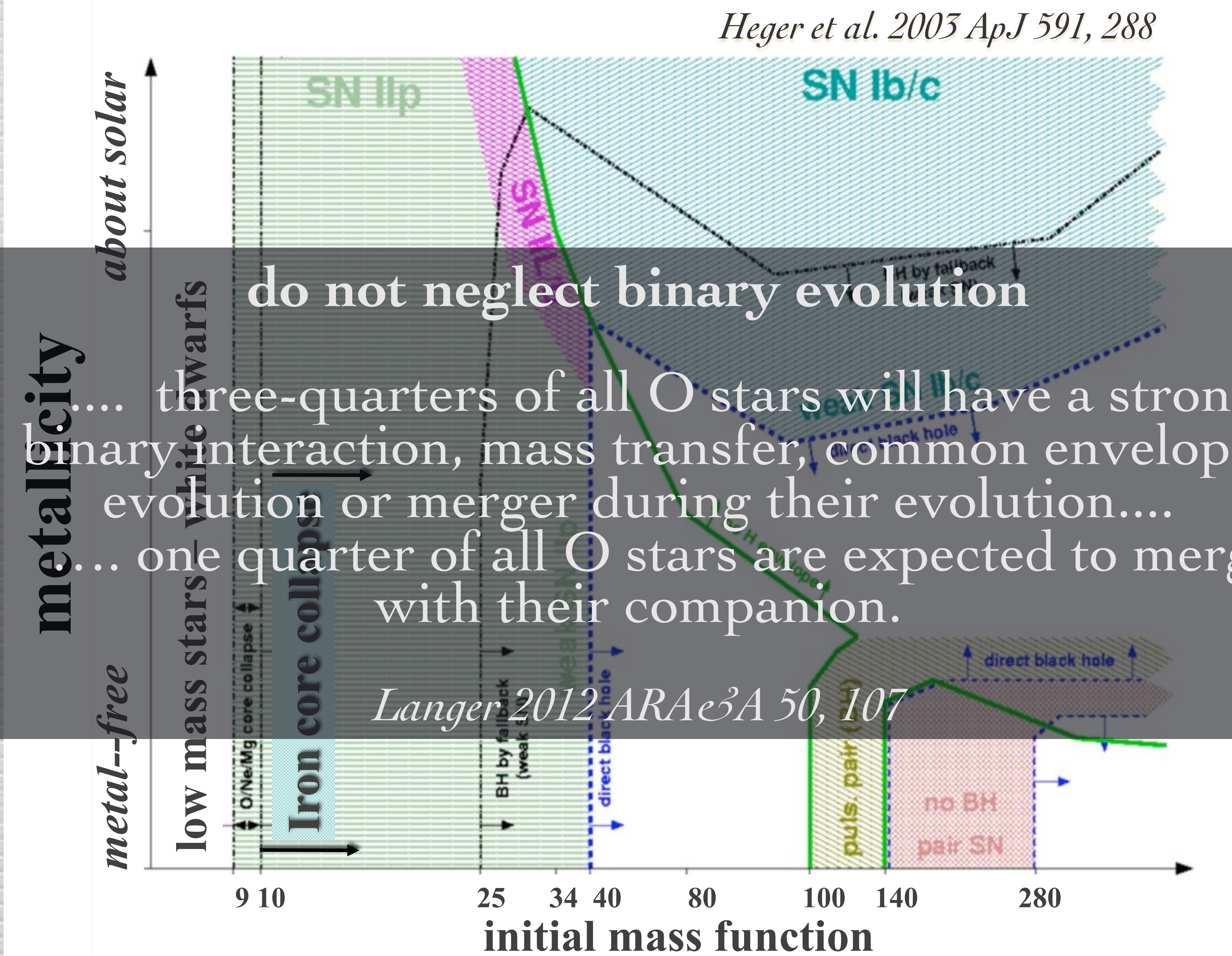
25/04/1998 **BeppoSAX** and **Batse** detected a GRB
26/04/1998 **SN1998bw** in the 8 arcmin error-box





Not all Ib/c make relativistic ejecta, hence GRBs
Not all long GRBs show a related SN

The fate of massive stars



do not neglect binary evolution

- .... three-quarters of all O stars will have a strong binary interaction, mass transfer, common envelope evolution or merger during their evolution....
- .... one quarter of all O stars are expected to merge with their companion.

Langer 2012 ARA&A 50, 107

Smith et al. 2014 ARA&A 52, 587

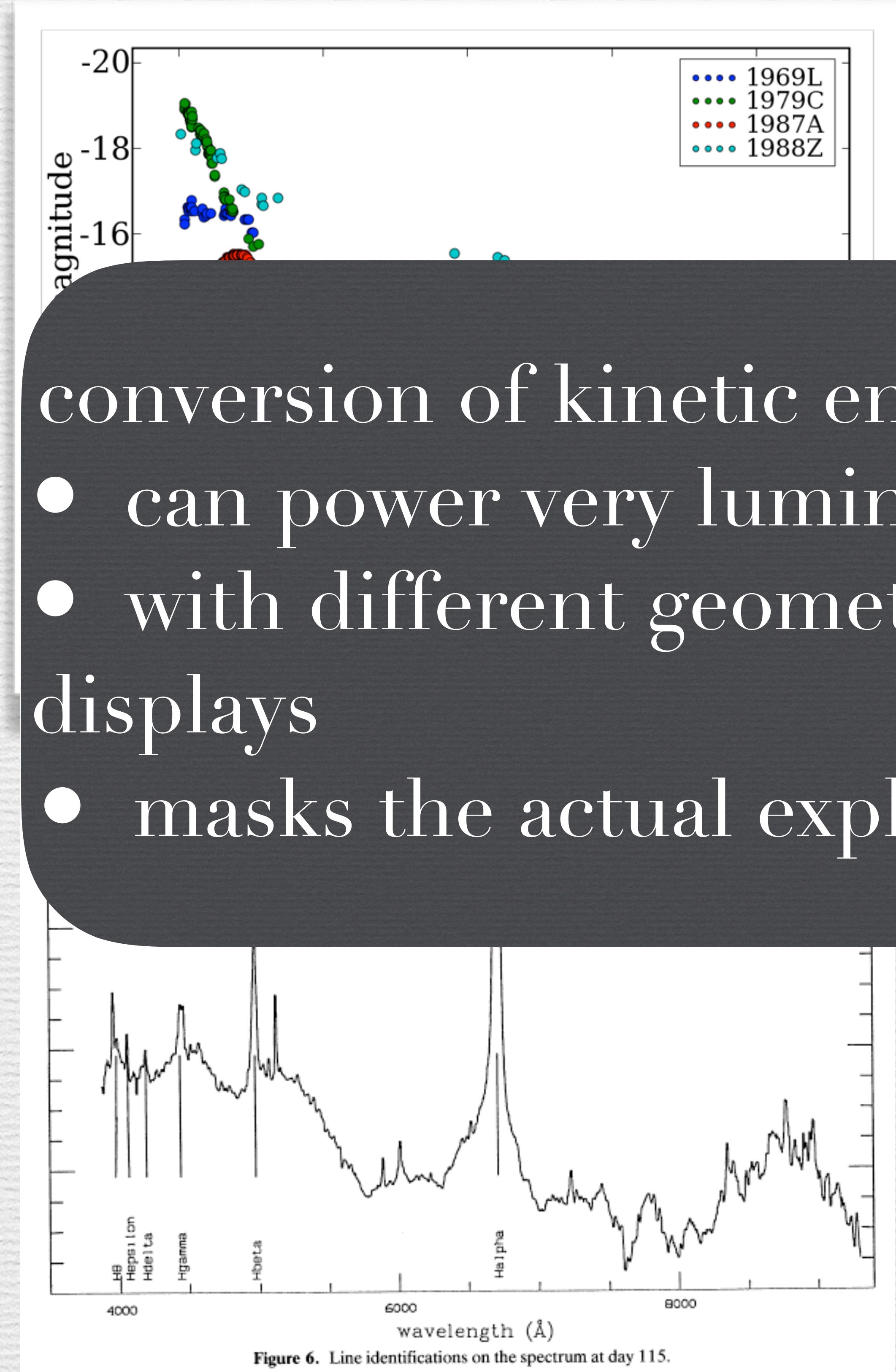
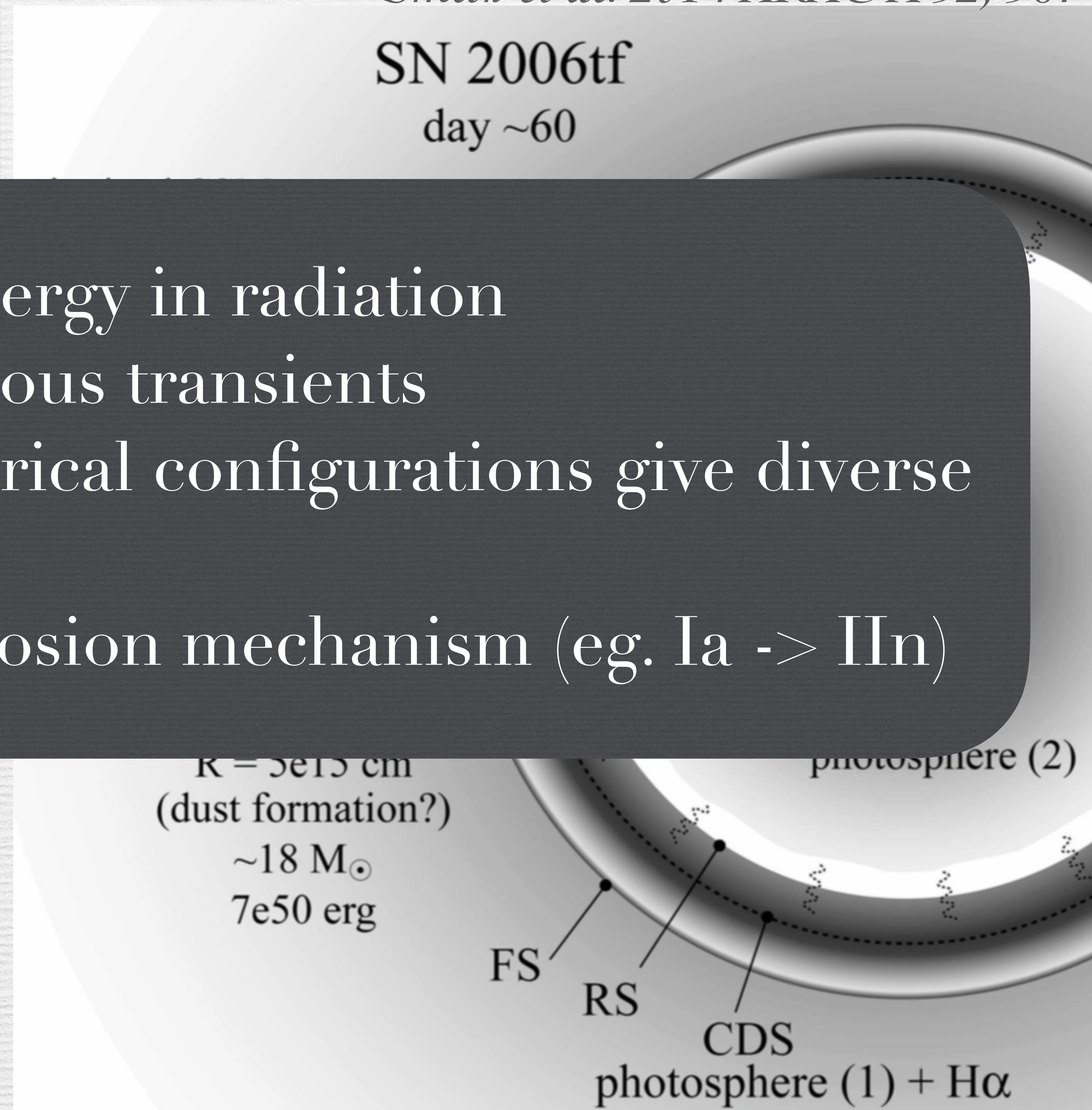


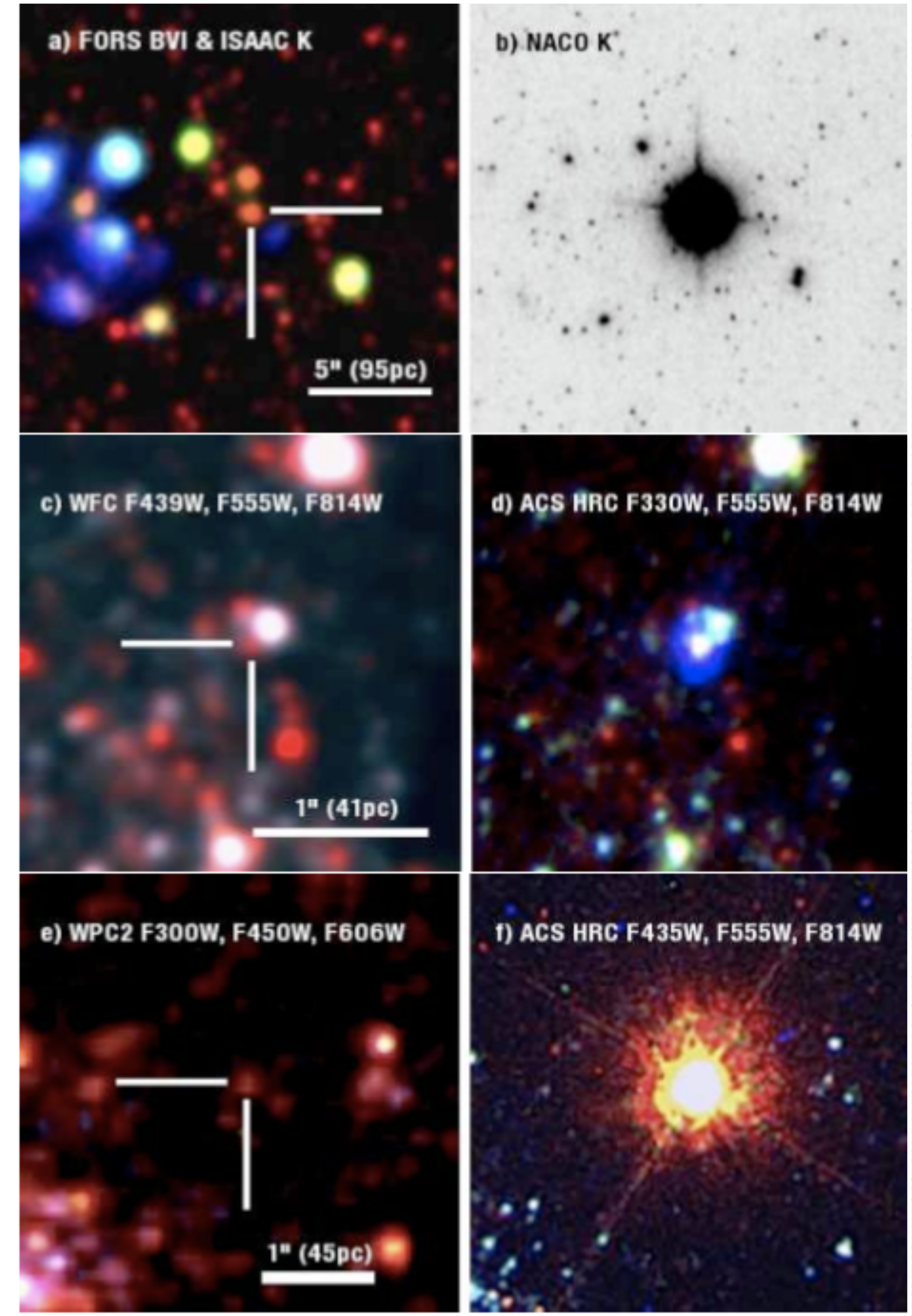
Figure 6. Line identifications on the spectrum at day 115.



conversion of kinetic energy in radiation

- can power very luminous transients
- with different geometrical configurations give diverse displays
- masks the actual explosion mechanism (eg. Ia -> IIn)

Progenitor masses



Smart 2015 PASA 31,16

from a dozen II events (+ upper limits)

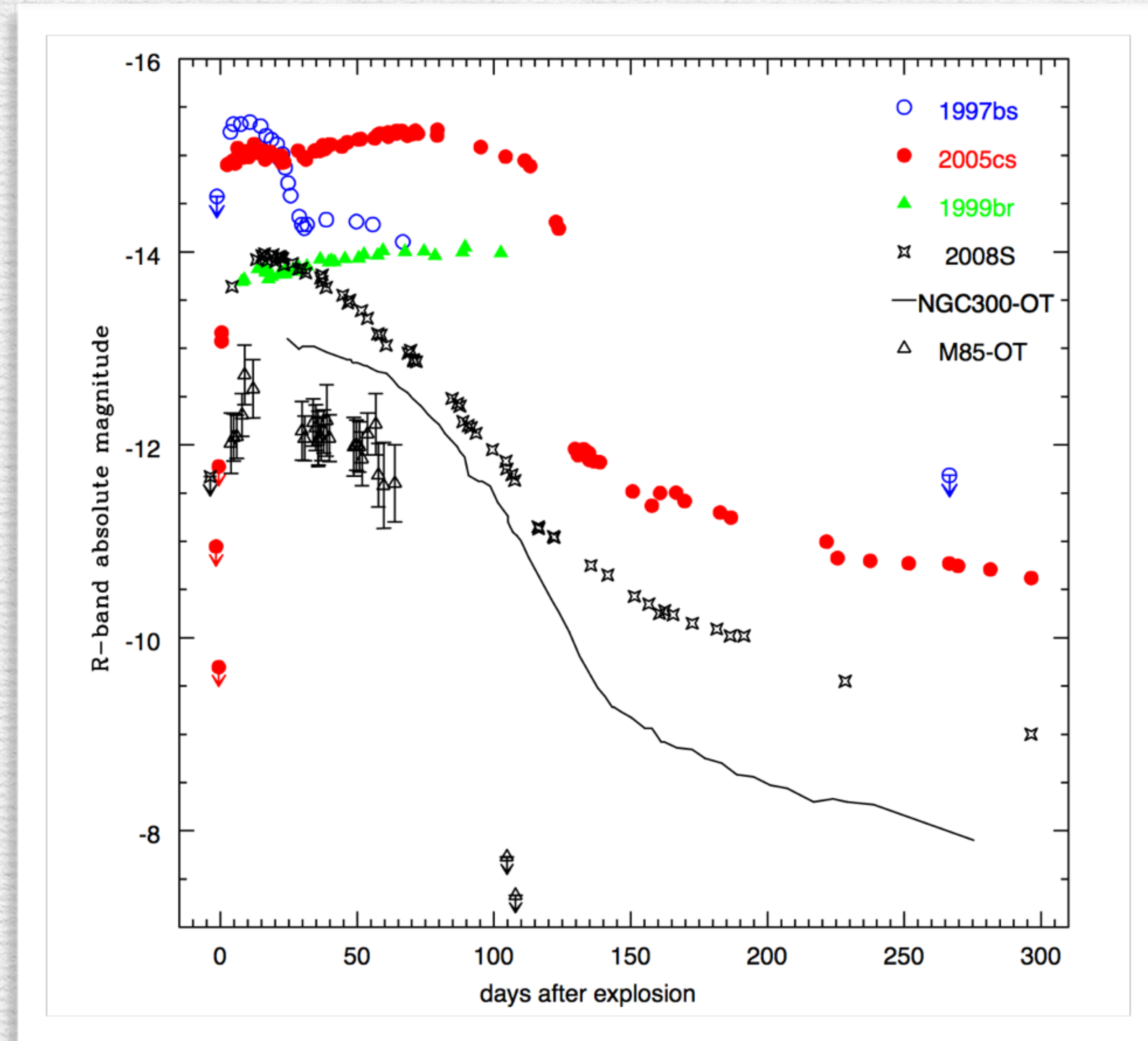
8-9<M<16-20 $M_\odot$

Maund et al. 2015 MNRAS 447, 3207

Whatever happened to the progenitors of supernovae 2008cn, 2009kr and 2009md?

Probably wrong/misleading progenitor identification

Ultra-faint SN or bright outburst

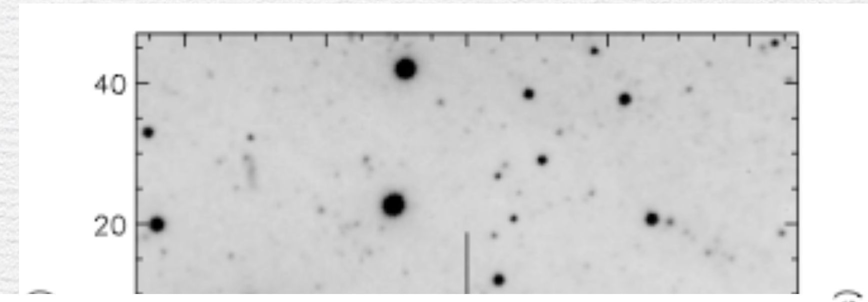


Giant outburst of LBV

Smith et al 2009 ApJ 697, L49

Electron capture in a 6-8 M$_\odot$

Botticella et al. 2009 MNRAS 398, 1041



Adams et al. 2015 arXiv151107393

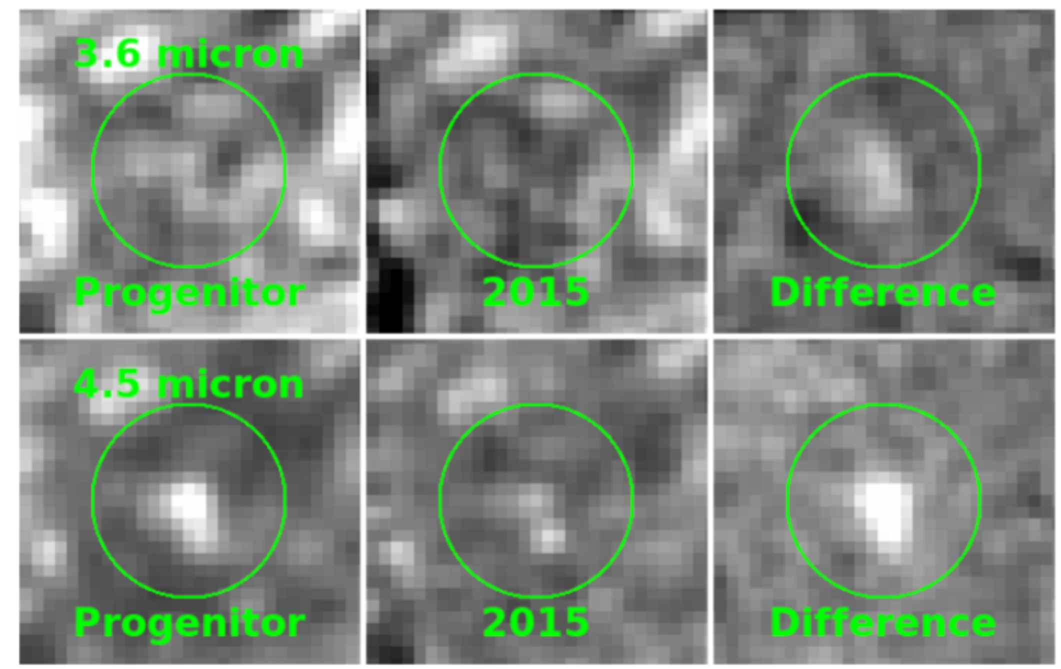
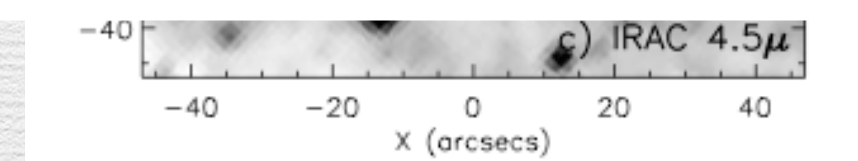
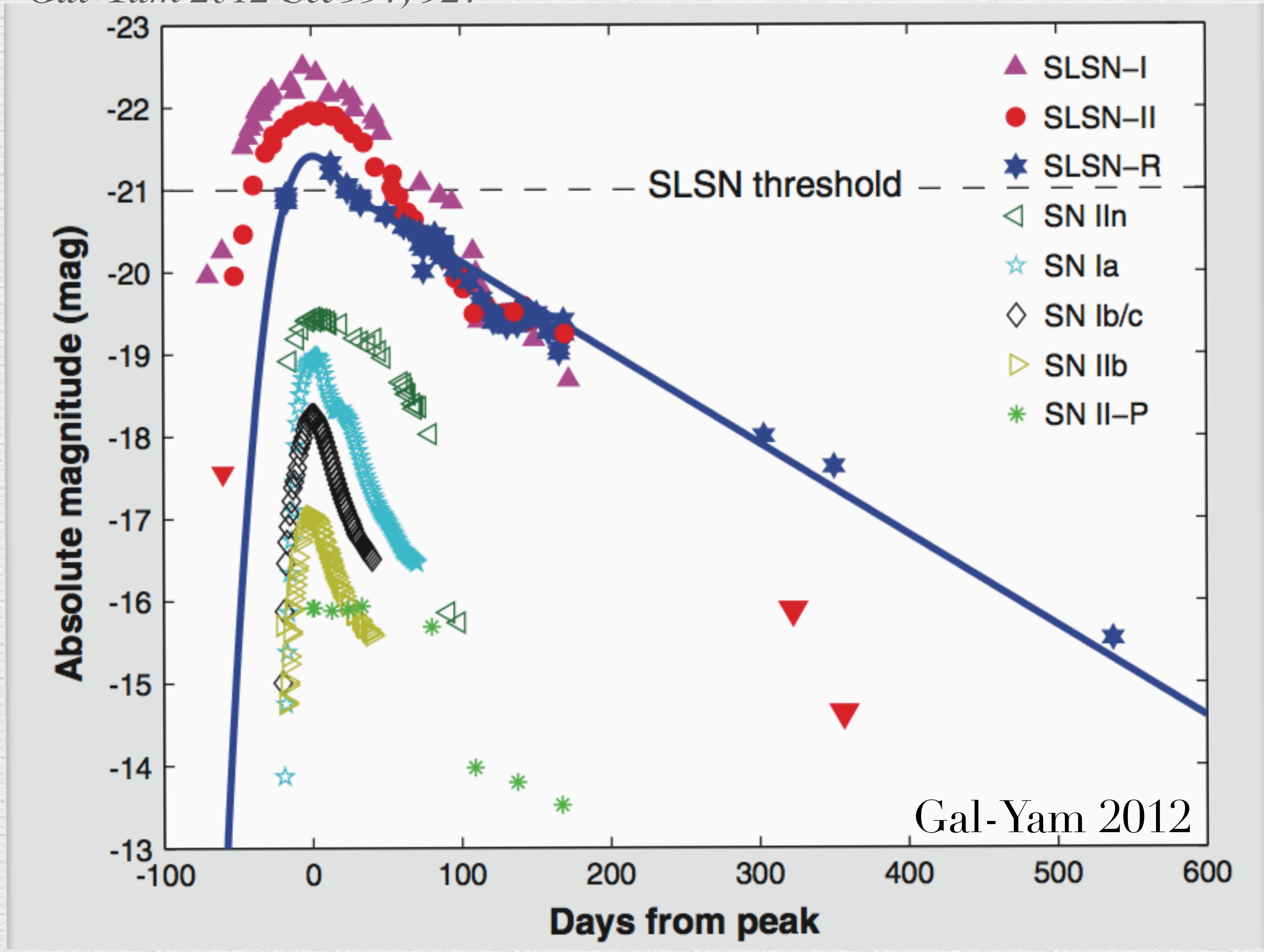


Figure 2. *SST* images of the region surrounding SN 2008S. The top row shows the 3.6 μm images and the bottom row shows the 4.5 μm images. The left-hand panels are pre-eruption images, the center panels are the latest epochs, and the right-hand panels are the difference between the two, where flux decreases are white. Each green circle is centered on the transient location and has a 5” radius. The difference images show that SN 2008S is now fainter than its progenitor at both 3.6 and 4.5 μm.



Superluminous SNe (SLSN)

Gal-Yam 2012 Sci 337, 927



pair instability

Gal-Yam et al. 2009 Nat 462, 624

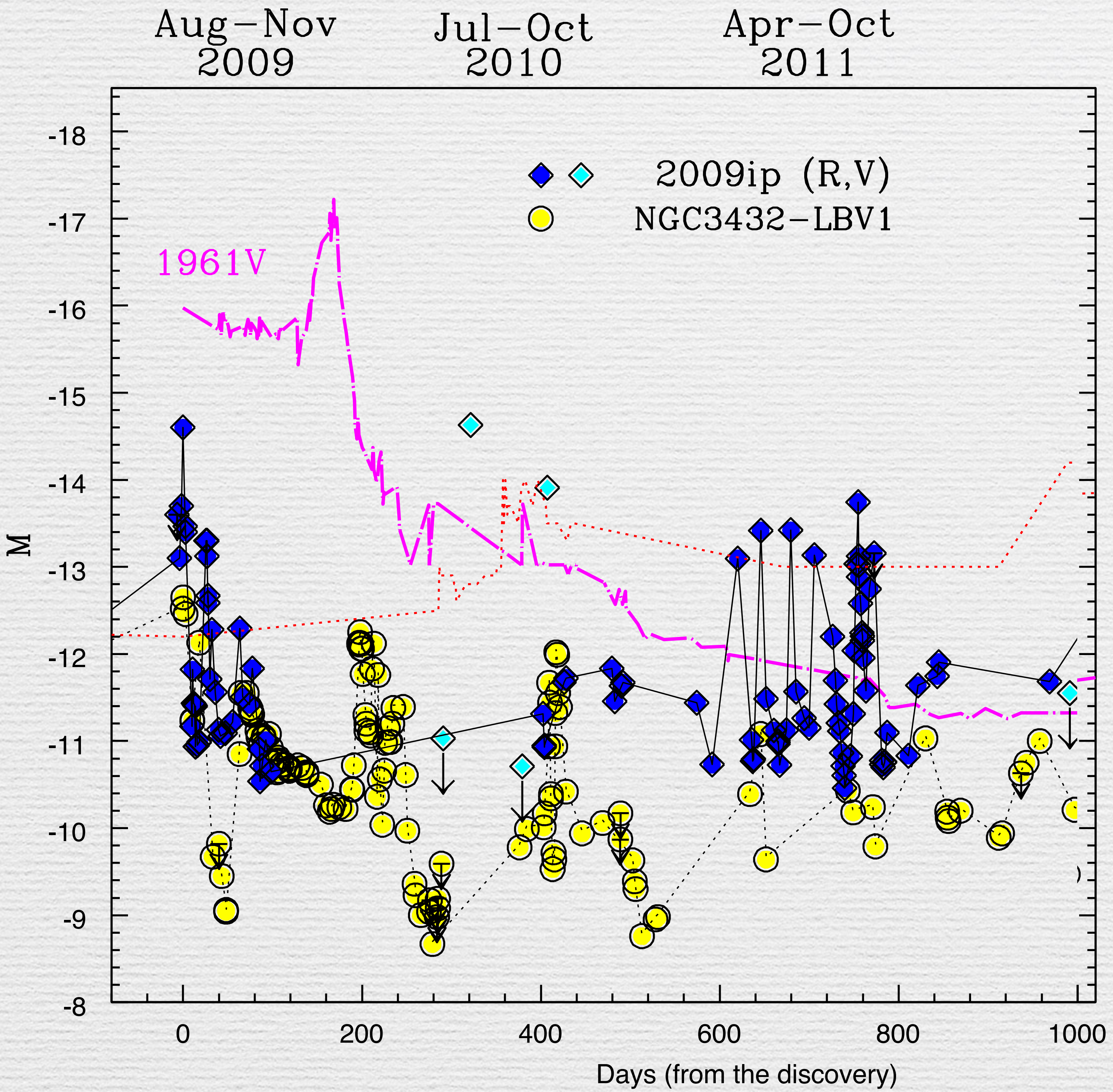
magnetar rotational energy

Dessart et al 2012 MNRAS 426, 76

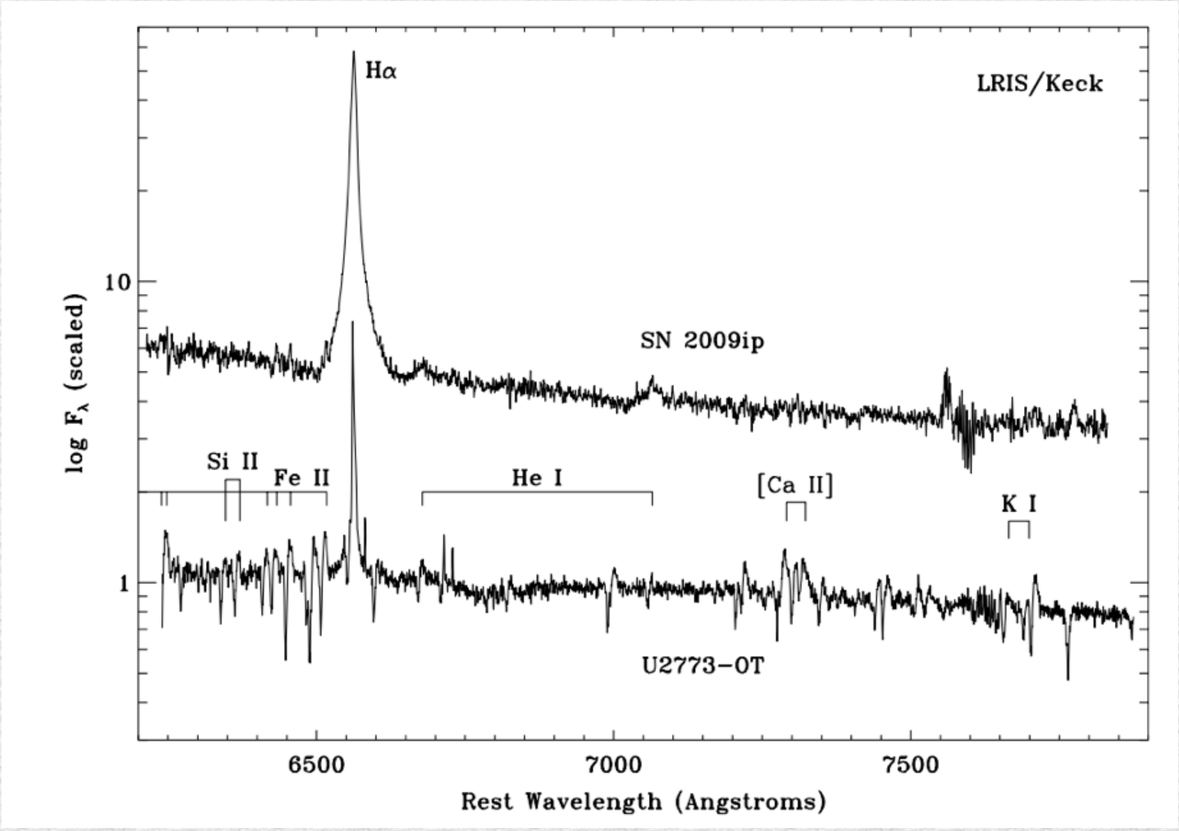
core collapse then shell collision

Benetti et al 2014 MNRAS 441, 298

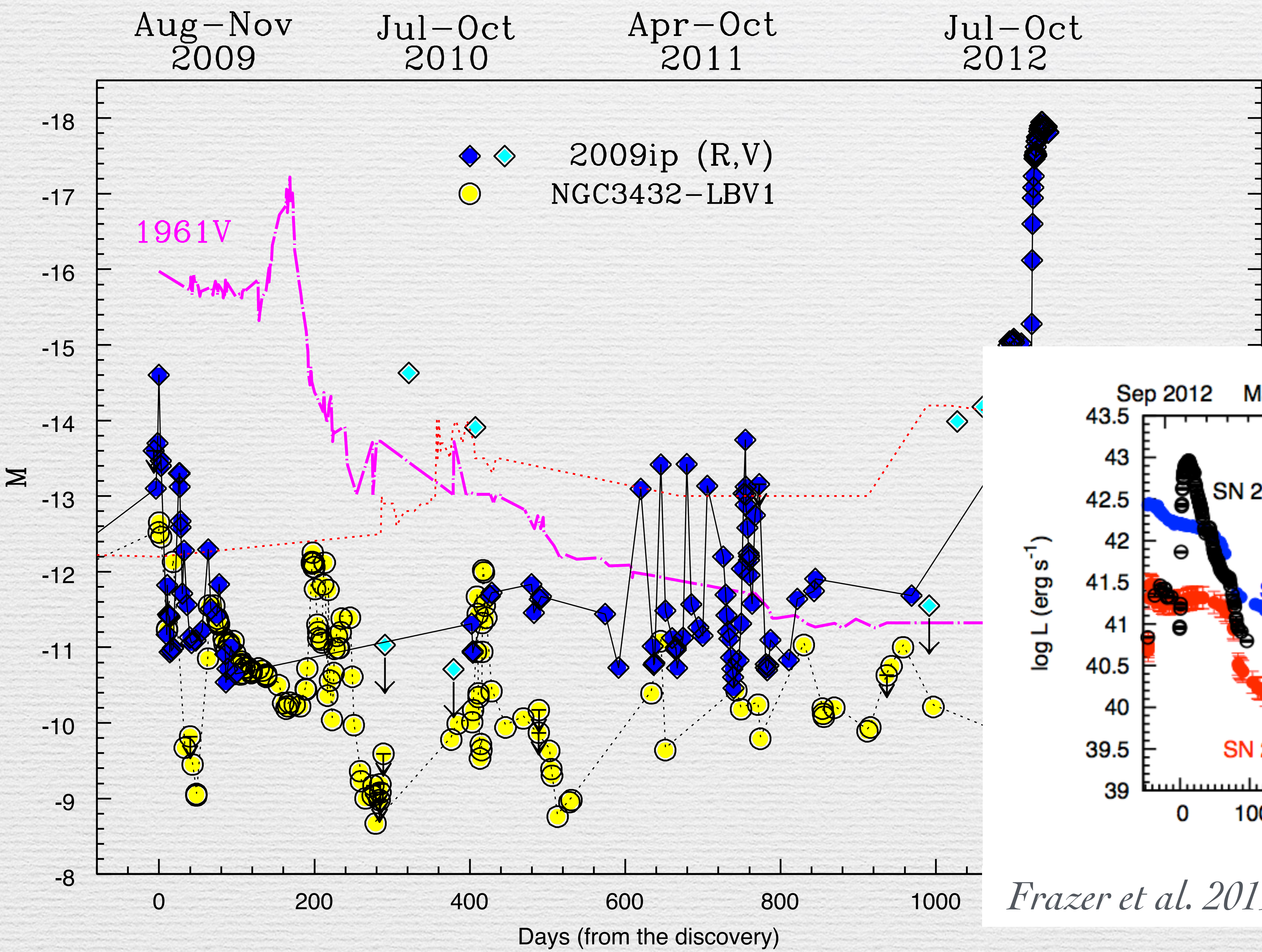
SN Impostors



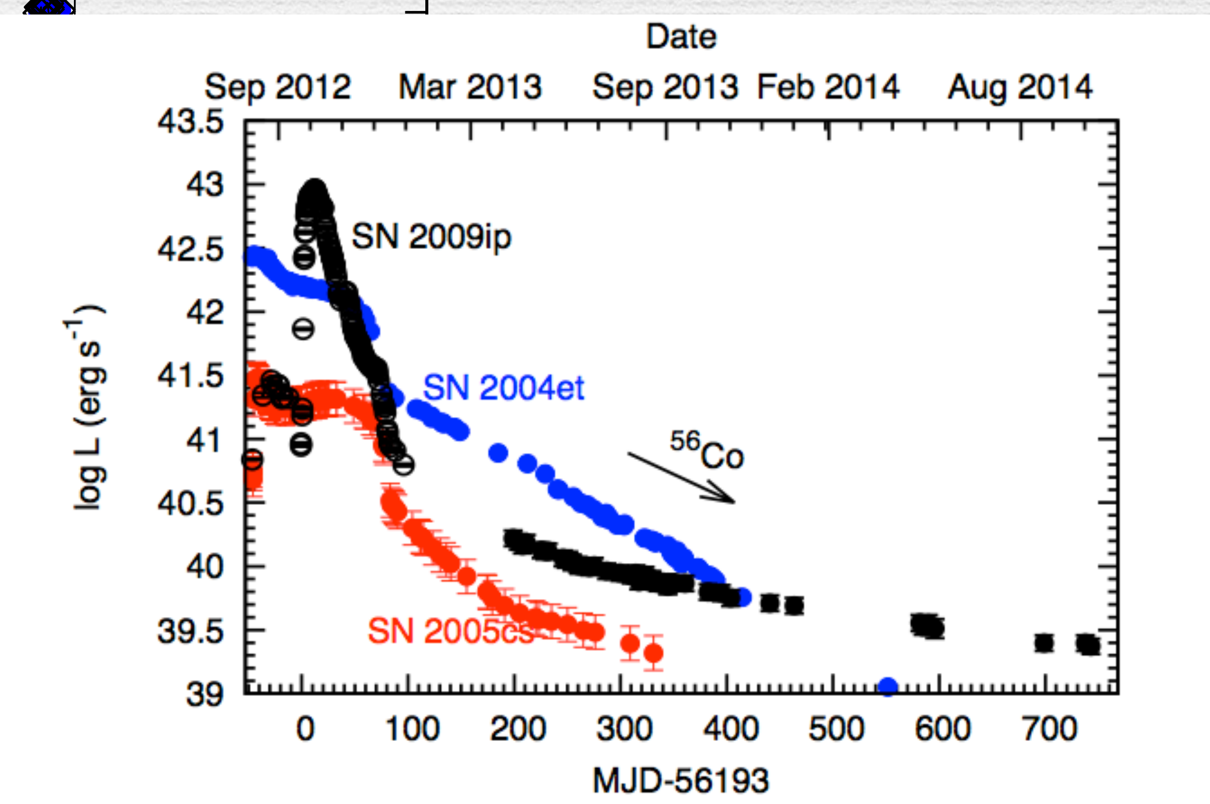
Pastorello et al. 2013 ApJ 767,1



SN Impostors explode for real



Pastorello et al. 2013 ApJ 767,1



Frazer et al. 2015 MNRAS 453, 3886

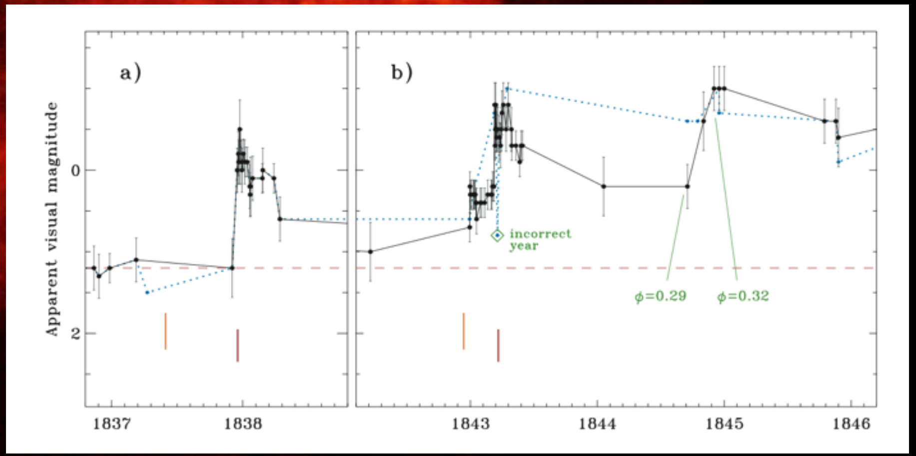
The fate of very massive stars

the case of Eta Carinae

HST treasury program

A binary system

1. LBV $M_0 \sim$ 150-250 $M_\odot$ (30 $M_\odot$ mass loss)
2. hot supergiant 30-80 $M_\odot$



summary

- Most massive stars end as core collapse SNe
  >90%   >8-10 M_{sun} IIP-IIL-IIb-Ib-Ic
  NS as compact remnant

- type IIn include type Ia, impostors, e^- capture….
  and also standard Fe core collapse

- SLSN may be powered by magnetar or CSM/ejecta shock. Progenitors are massive (>50 M_{sun})

- Not all bright transients are "super-novae"
  .. kilo-novae, tidal disruption

… not found yet

- pair instability SNe (>140 M_{sun})
- failed SNe (dark collapses) (40-100 M_{sun})

SN rates

Local SN rate <100 Mpc

Photographic/visual

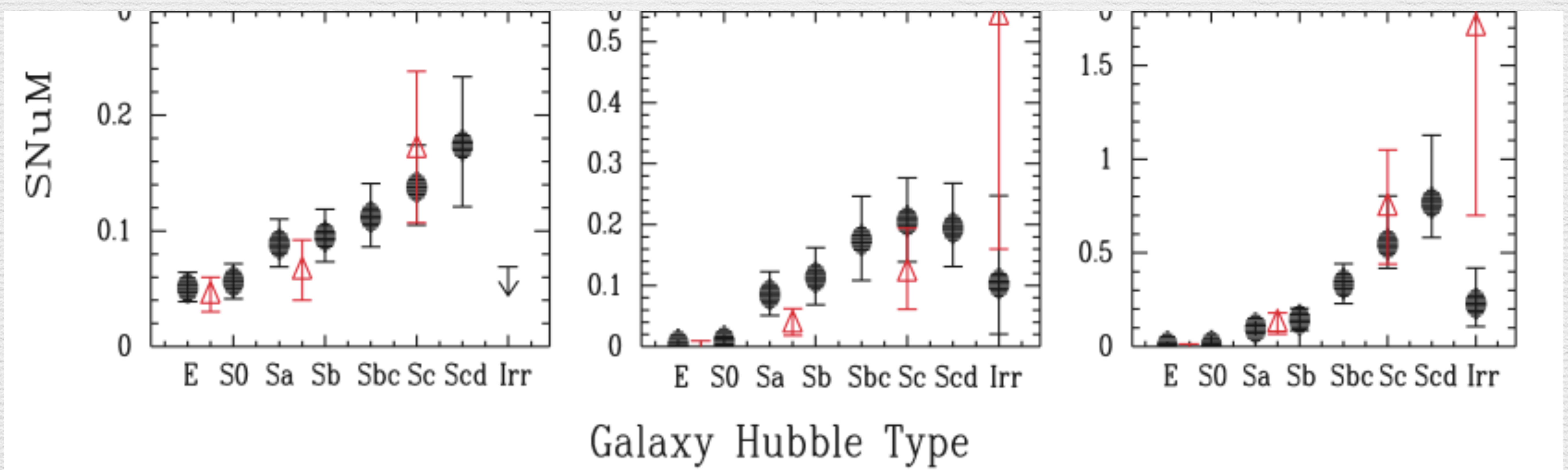
136 SNe

▲ *Cappellaro et al 1999 A&A 351, 459*
Mannucci et al 2005 A&A 433, 807

CCD

726 SNe

● *Li et al 2011 MNRAS 412, 1463*



SN rate in the Galaxy

Li et al.

the Galaxy

type

L_B =2.0-4.3

N /century

0.5 ± 0.1

C 2.3 ± 0.5

2.8 ± 0.6

other uncert

iable range

galaxy ty

a 0.3-0.9

Ia CC

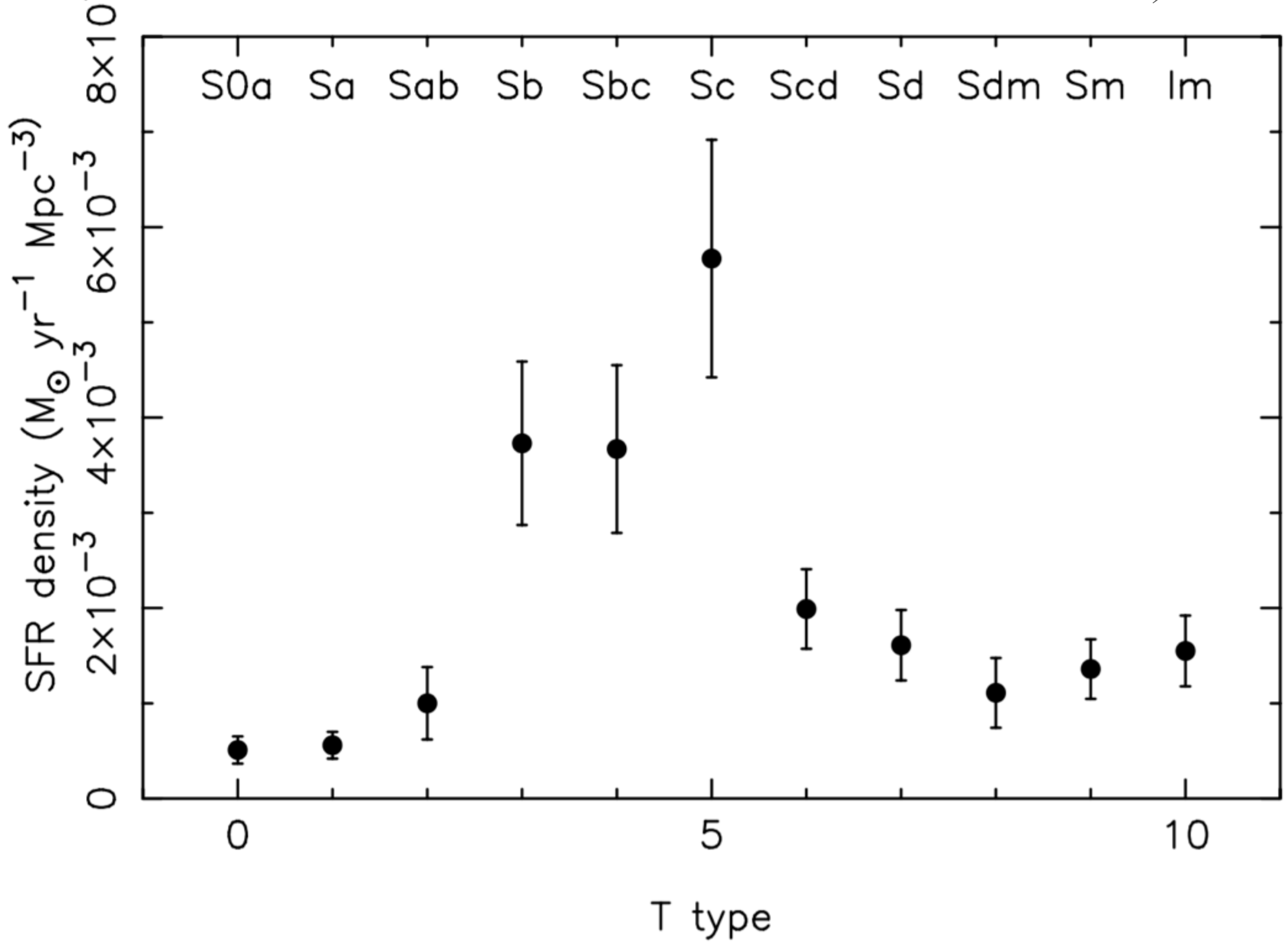
CC 0.8-3.5

Sb 0.18 0.49

~ 30%

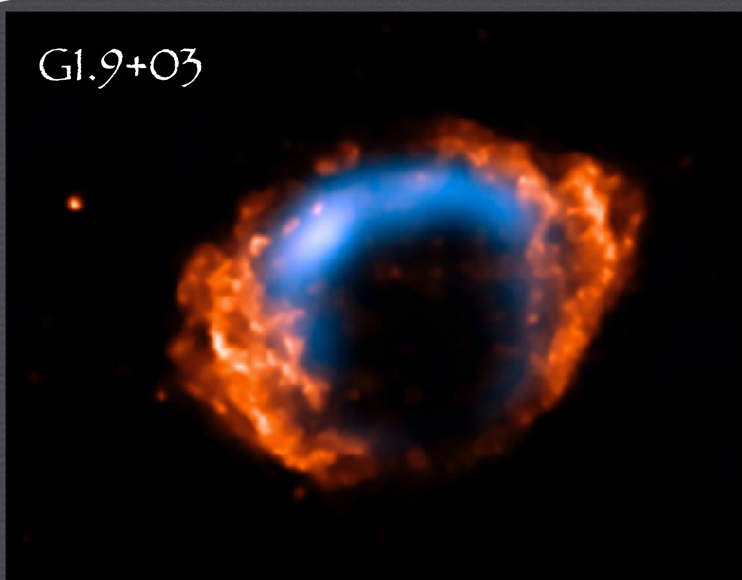
all 1.1-4.4

James 2008 A&A 482, 507



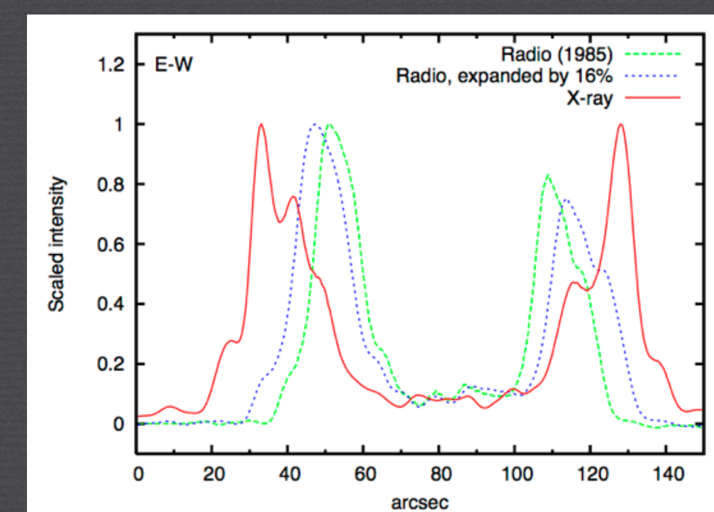
SN rate in the Galaxy

1.7 ± 0.9 per century, CC 1.4 ± 0.7 *Cappellaro et al. 1997*



The youngest known SN remnants in the galaxy
Reynolds et al 2008

- detected in X-ray and radio
- near the galactic center
- $A_V > 30$ mag
- 15% expansion in 20 years
- dynamical age 100-200 yr



Al26 mass CC 1.9 ± 1.1 *Diehl et al 2006*

neutrino detector CC <11.4 *Agafonova et al 2015*

From star formation to SN

$$r_{cc} = K_{cc} \times SFR$$

$$K_{cc} = \frac{\int_{m_{L^{cc}}}^{m_{U^{cc}}} \varphi(m)dm}{\int_{m_L}^{m_U} m\varphi(m)dm}$$

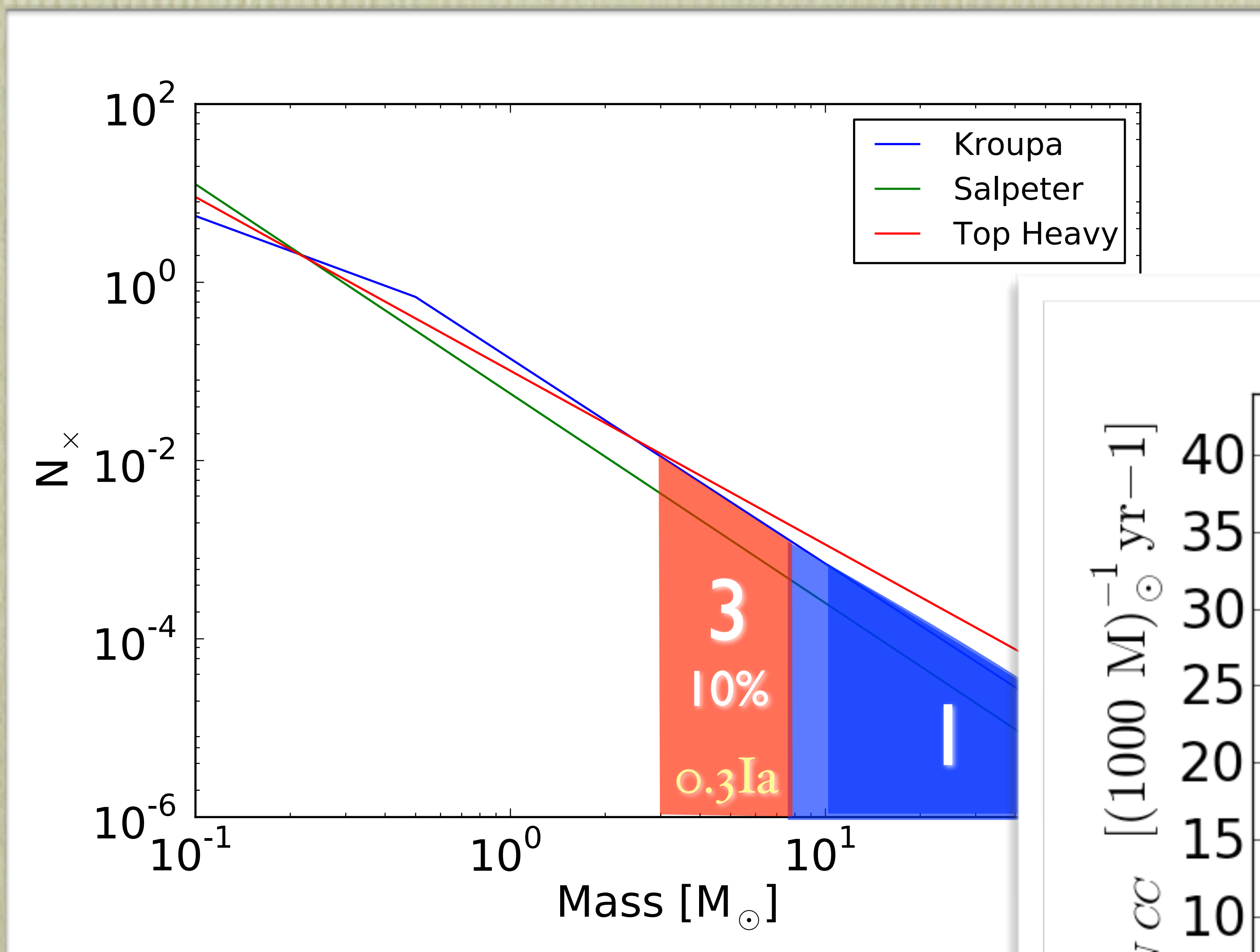
$\varphi(m) = IMF$ 8-10 < M_{CC} < 40-100 Mo

$$\dot{n}_{Ia}(t) = k_{Ia} \int_{t=0}^{t} DTD(t_d)\psi(t - t_d)\mathrm{d}t_d$$

DTD
delay time distribution

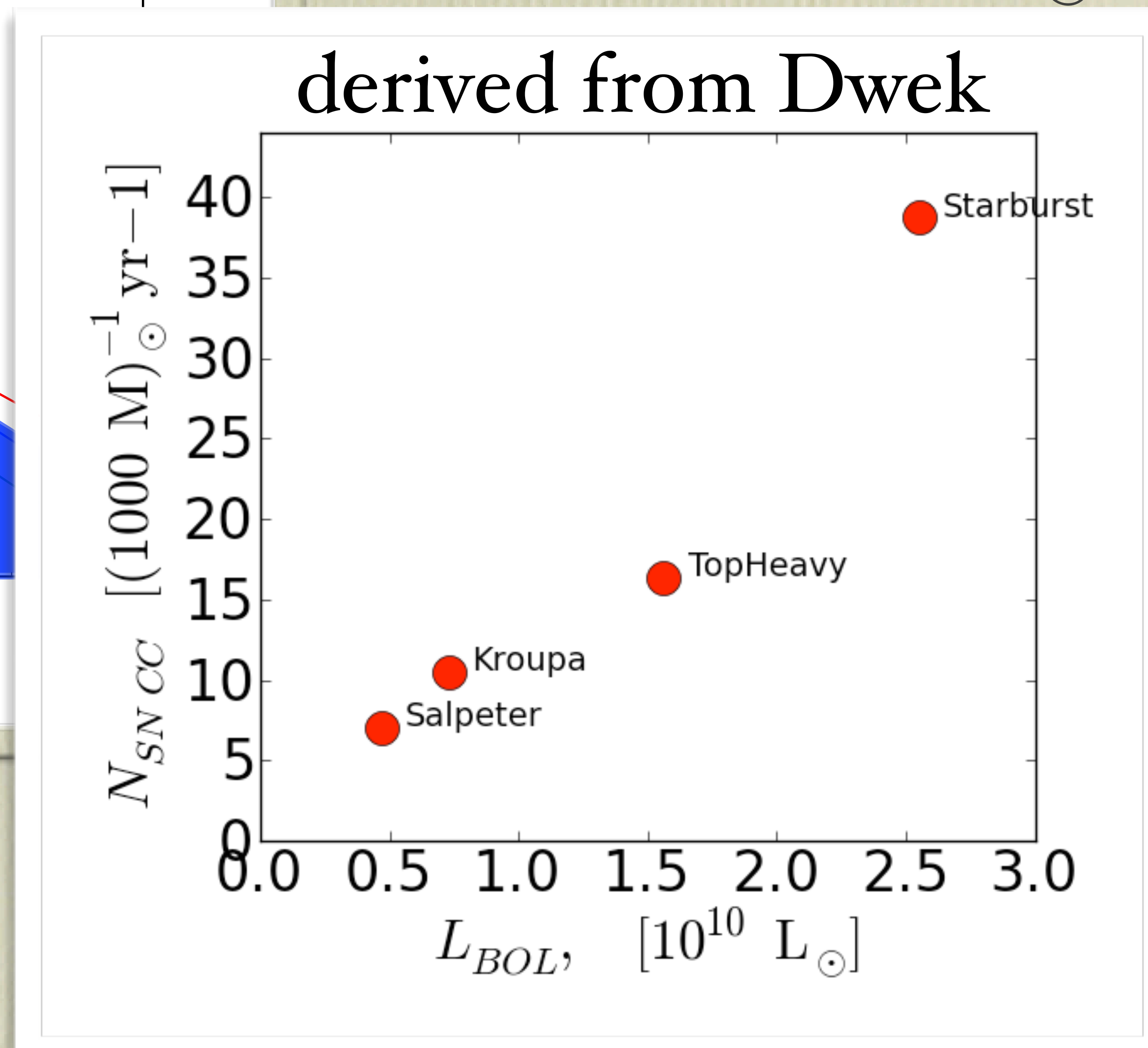
k_{Ia} {
3< M_{Ia}< 8 Mo
realisation fraction 3-10%

SNR / SFR / IMF



SF = 1000 $M_\odot$

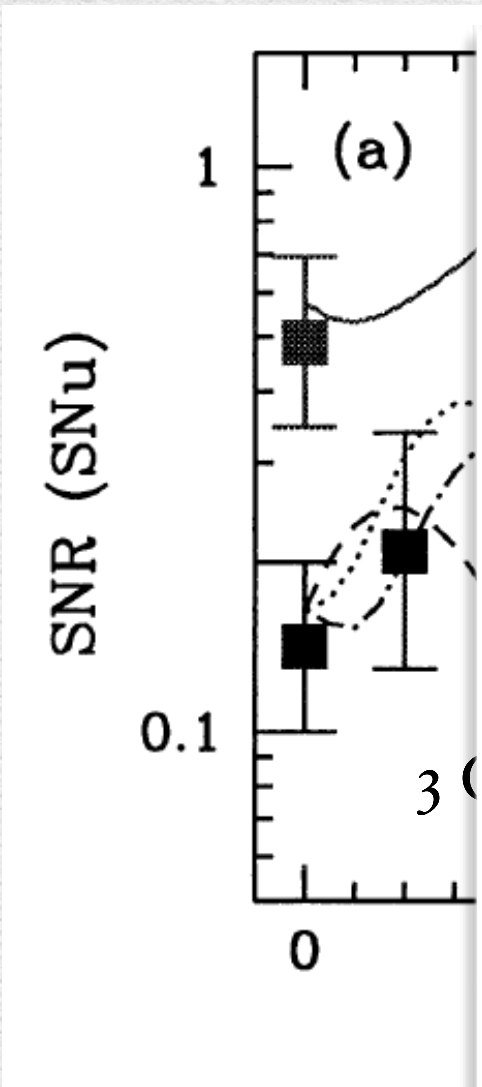
10-40 $M_\odot$



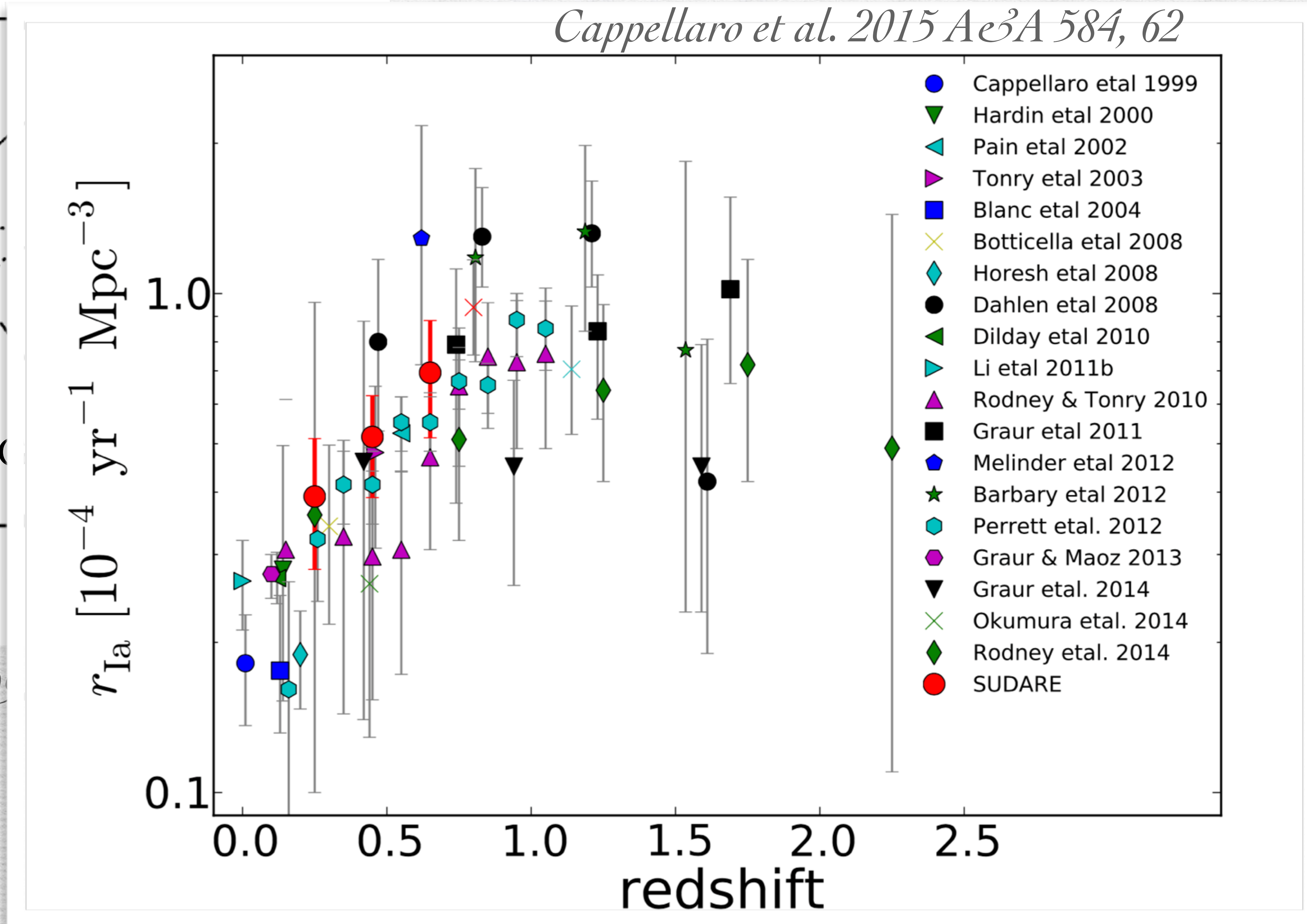
m_U 40 -> 100 $M_\odot$ +10%

m_L 10 -> 8 $M_\odot$ +40%

SN Ia rate and progenitor scenarios



Madau et al 19

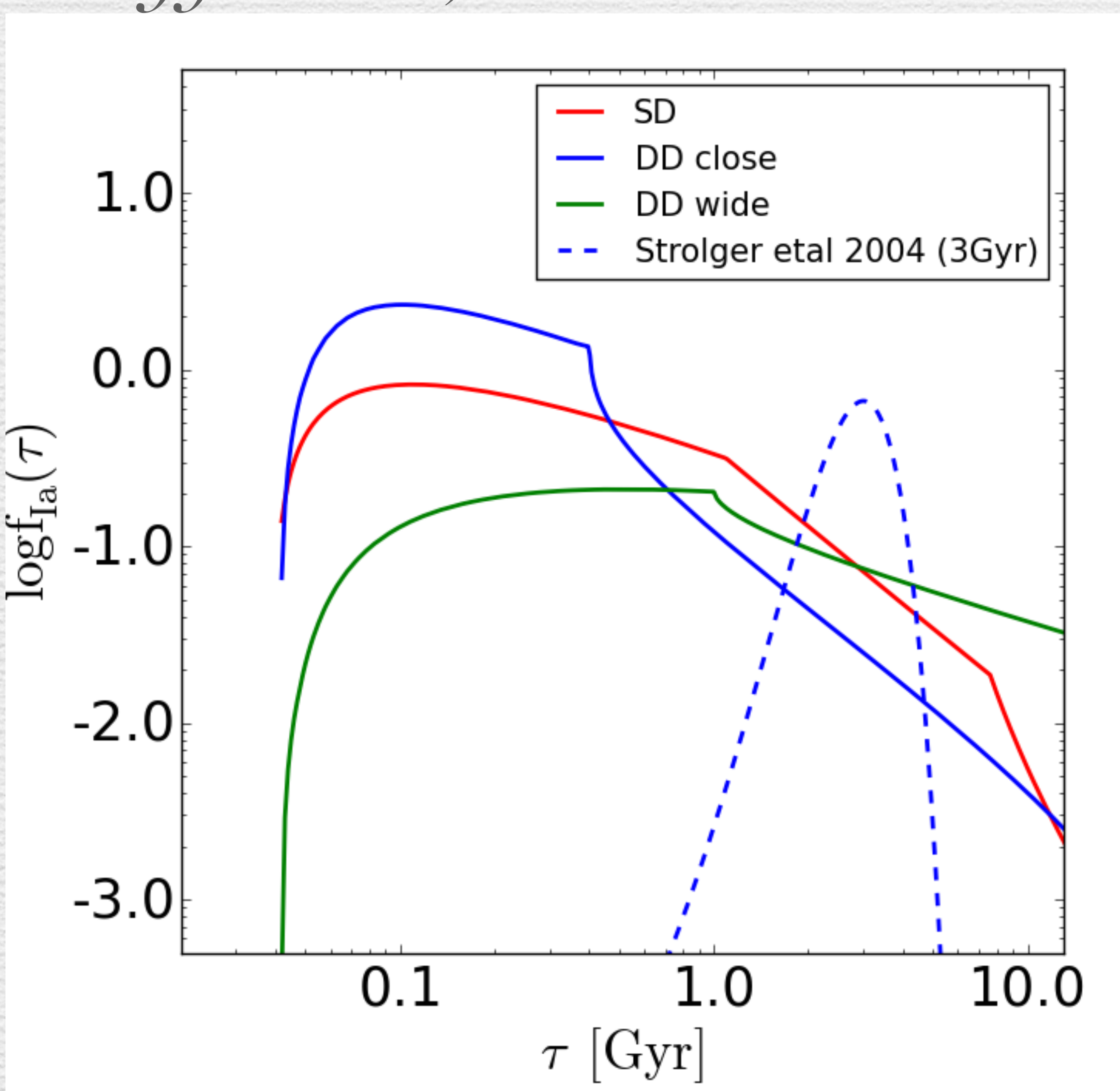


SN Ia rate and progenitor scenarios

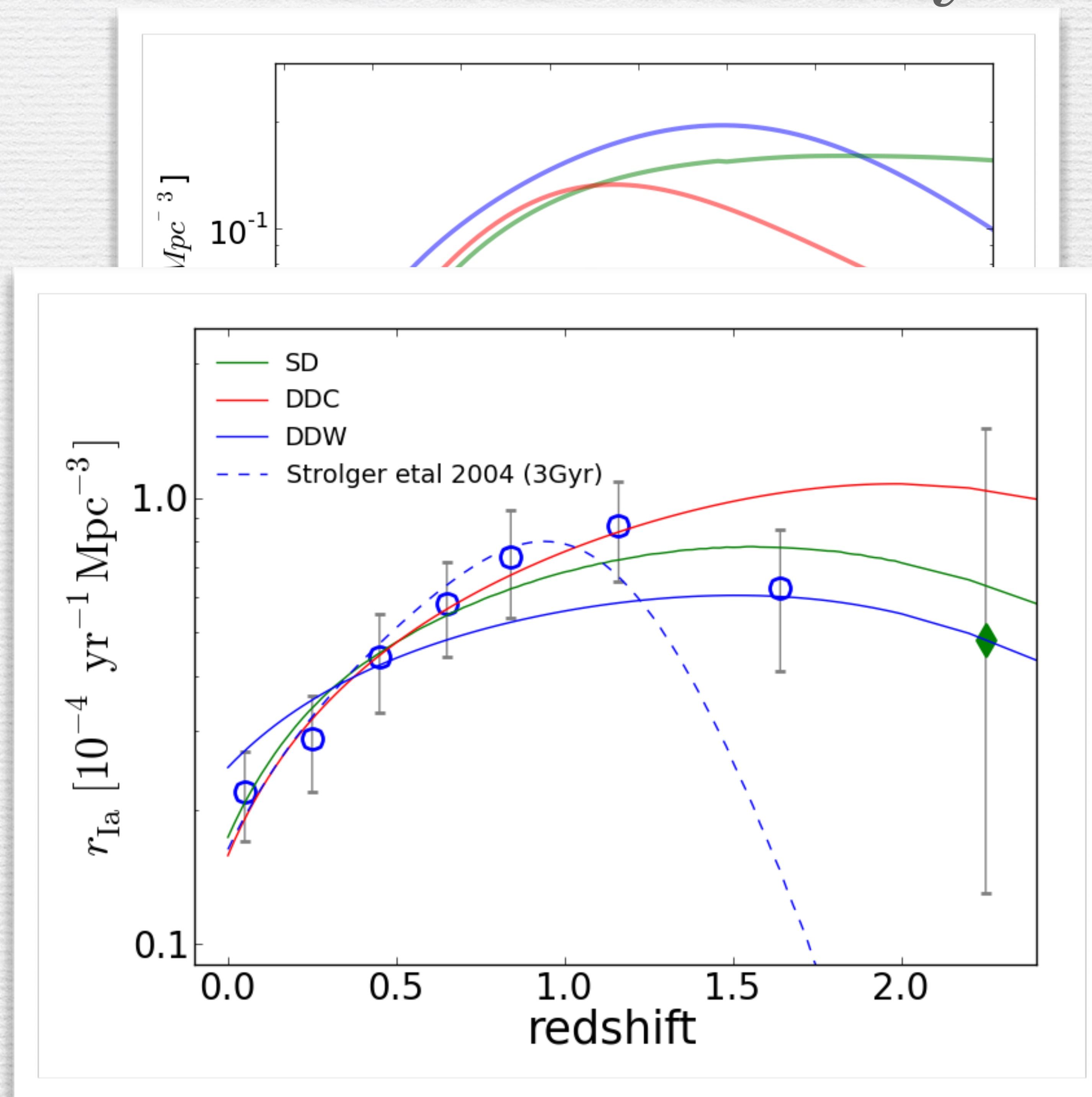
Cappellaro et al. 2015 A&A 584, 62

Delay time distribution

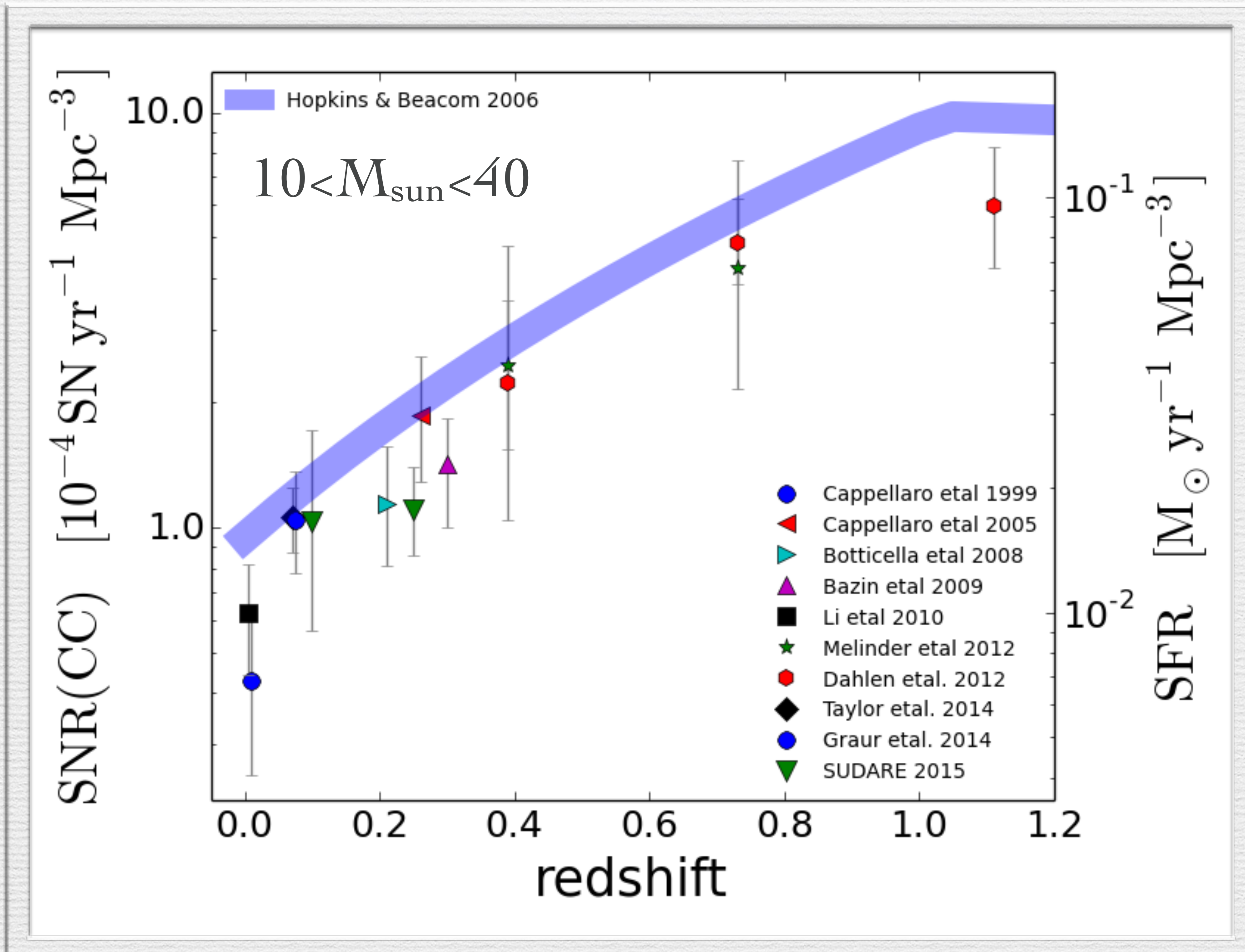
Greggio 2005, 2010



Star formation history



CC SN rate with redshift



Cappellaro et al. 2015 A&A 584, 62

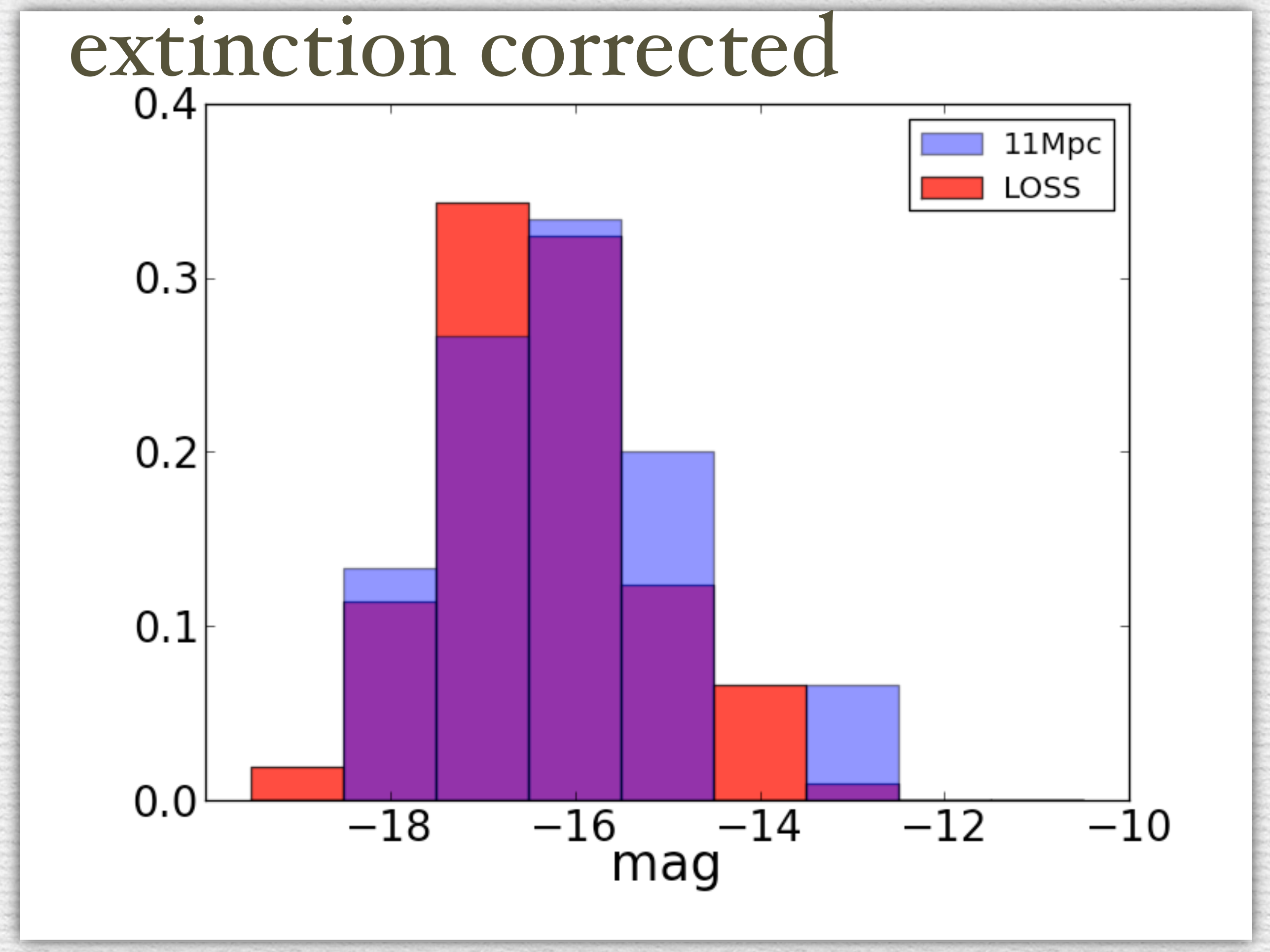
The Cosmic Core-collapse Supernova Rate Does Not Match the Massive-star Formation Rate

Horiuchi etal 2011 (ApJ 738,154)

assuming SFR from Hopkins and Beacom 2006
progenitor mass range 8-40 M_{sun}

<u>We identify a "supernova rate problem”</u>: the measured cosmic core-collapse supernova rate is a factor of ~2 smaller … than that predicted from the measured cosmic massive-star formation rate.

… likely many supernovae are missed because they are either optically dim (low-luminosity) or dark, whether intrinsically or due to obscuration



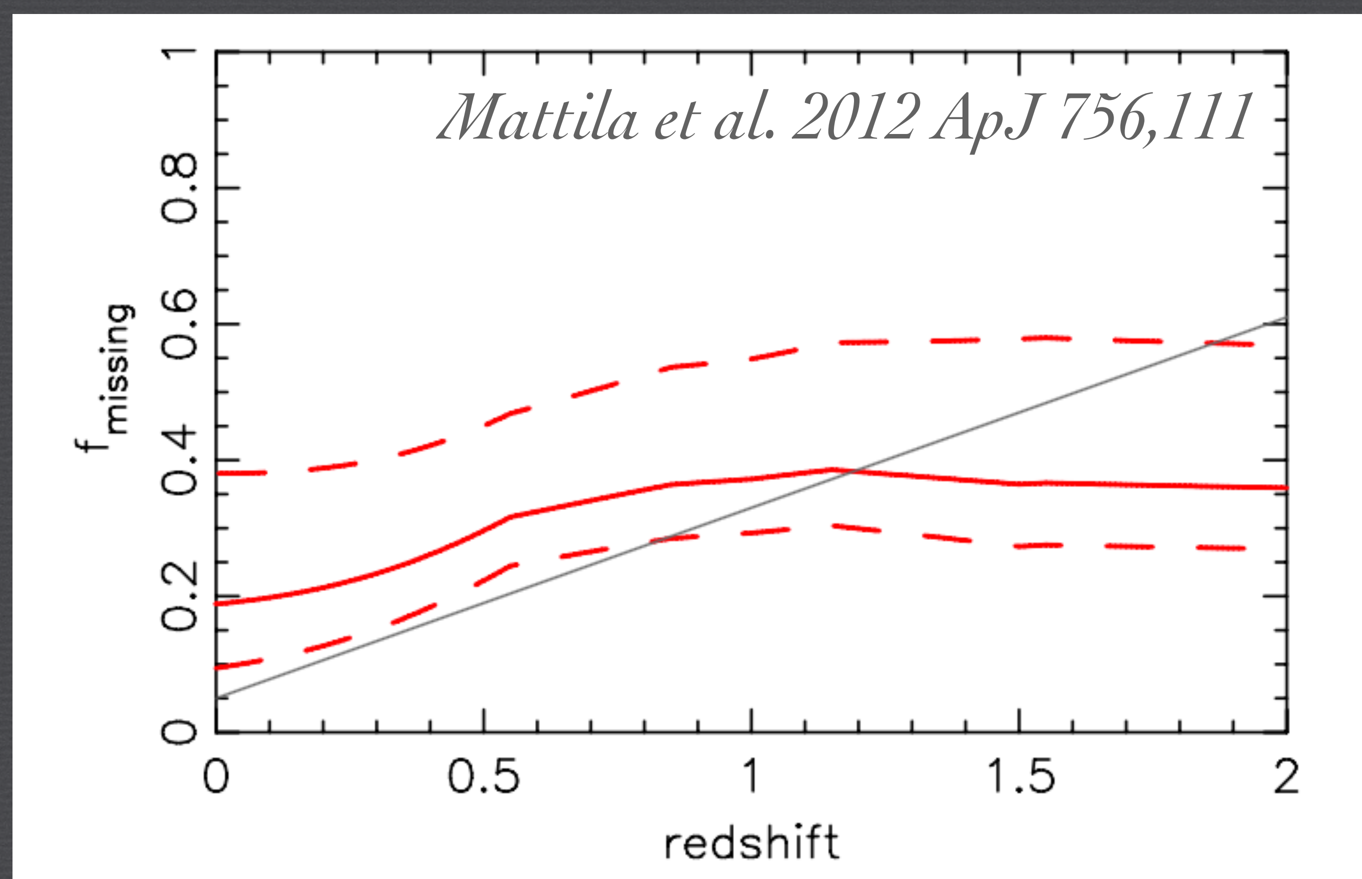
Obscured SNe

HAV

a sa

Mi

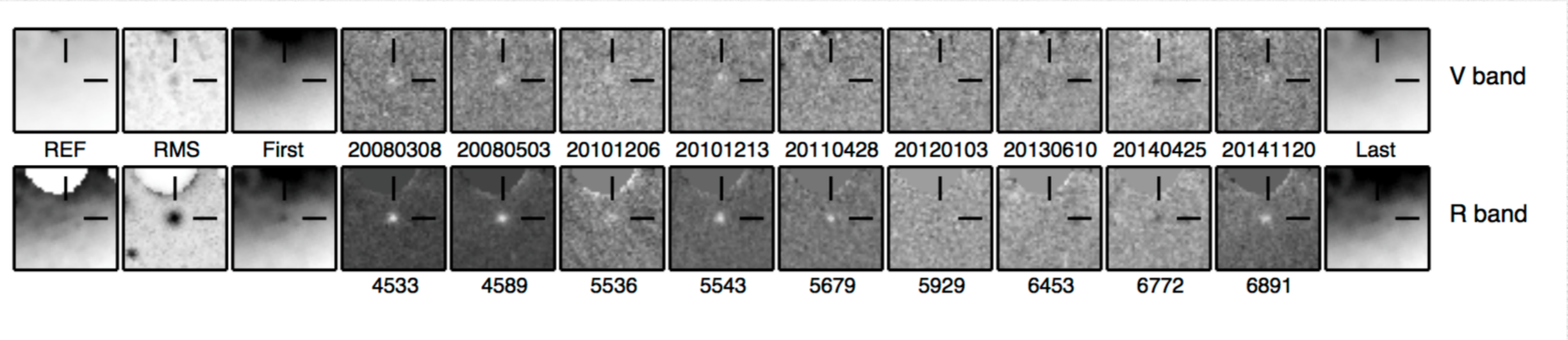
60% of SN in Starburst galaxies remain hidden in the nuclear regions due to a combination of high extinction and reduced detection efficiency



30 g

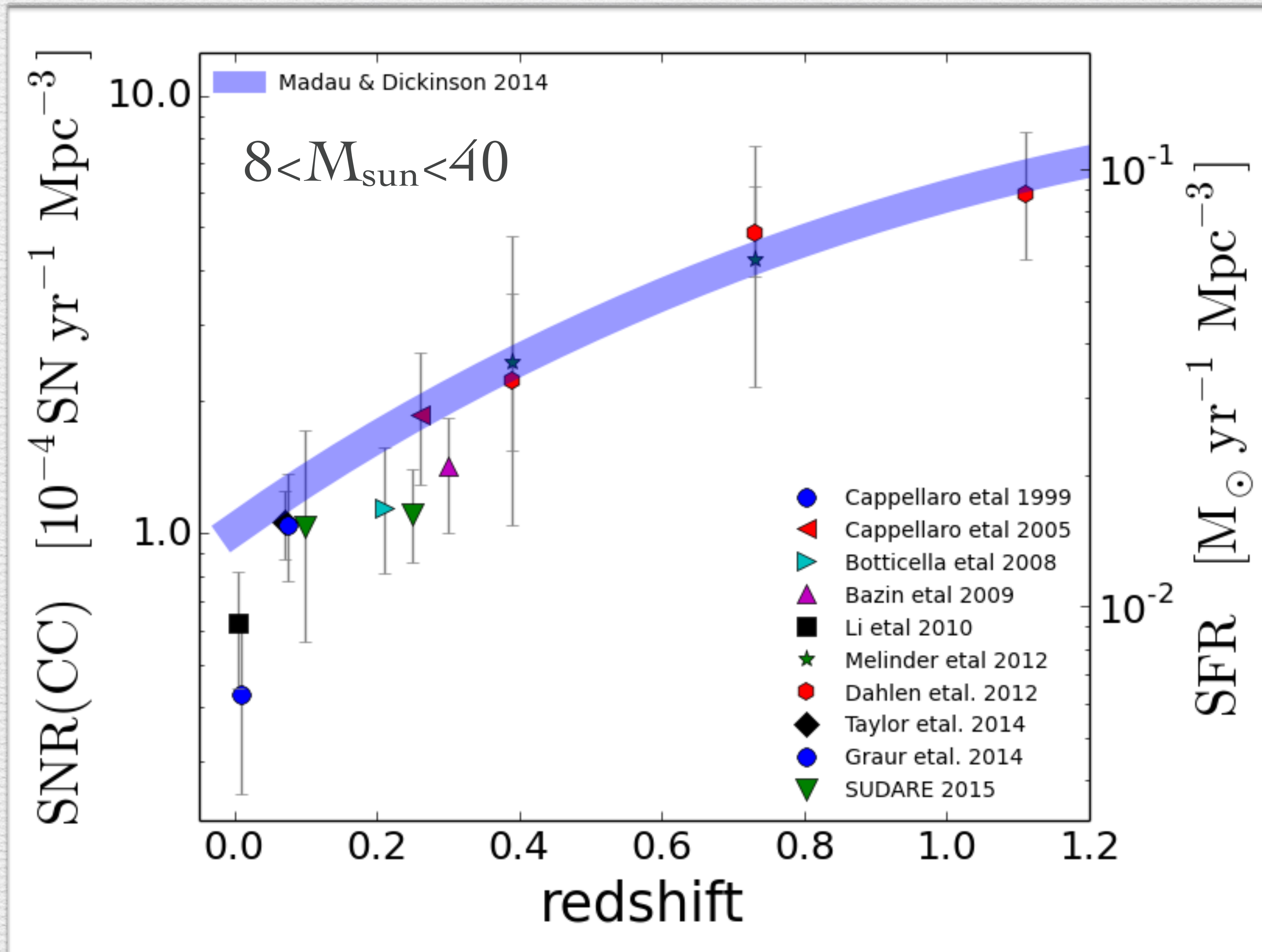
Search for failed supernovae

Gerke et al. 2015 MNRAS 450, 3289



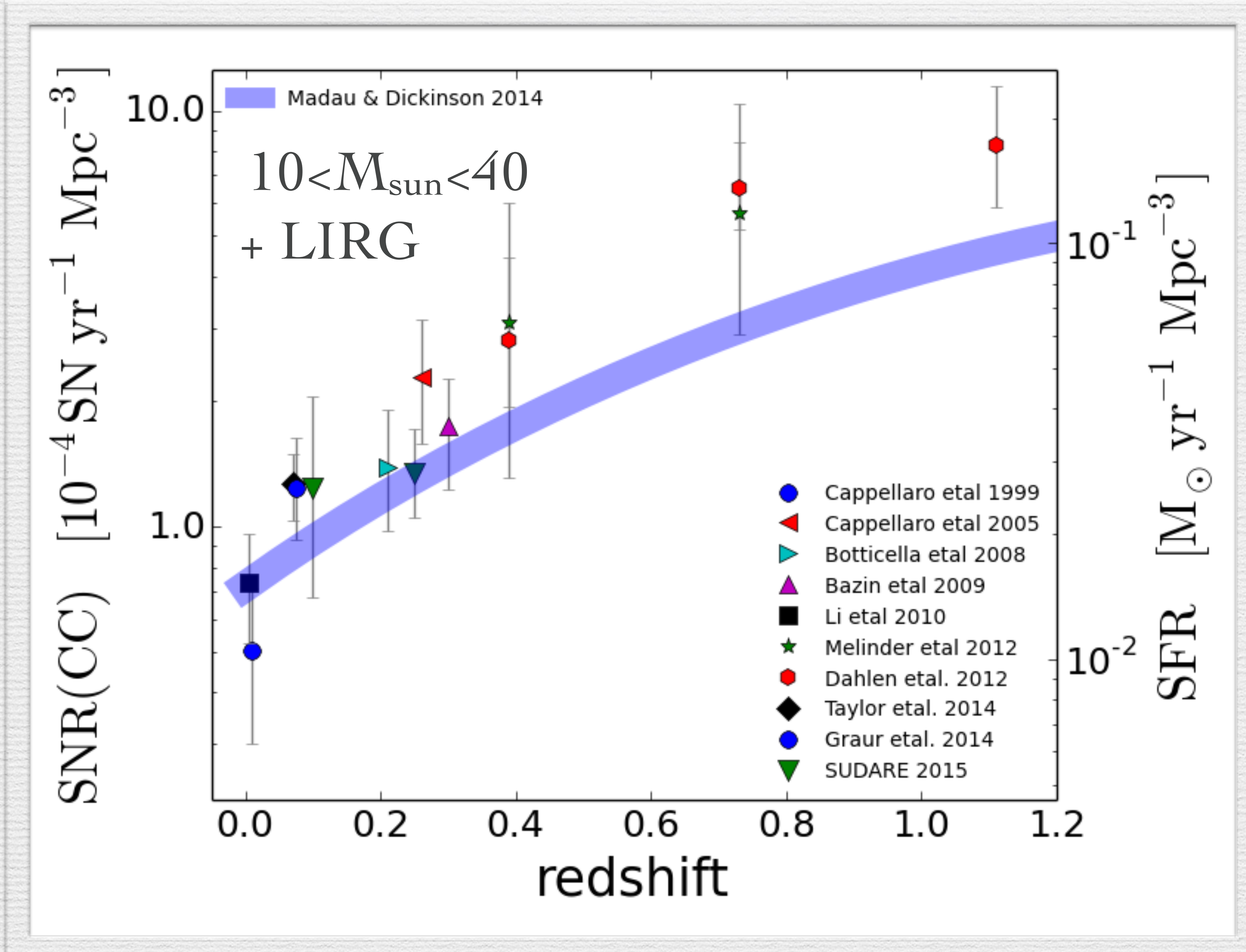
none yet confirmed

CC SN rate with redshift

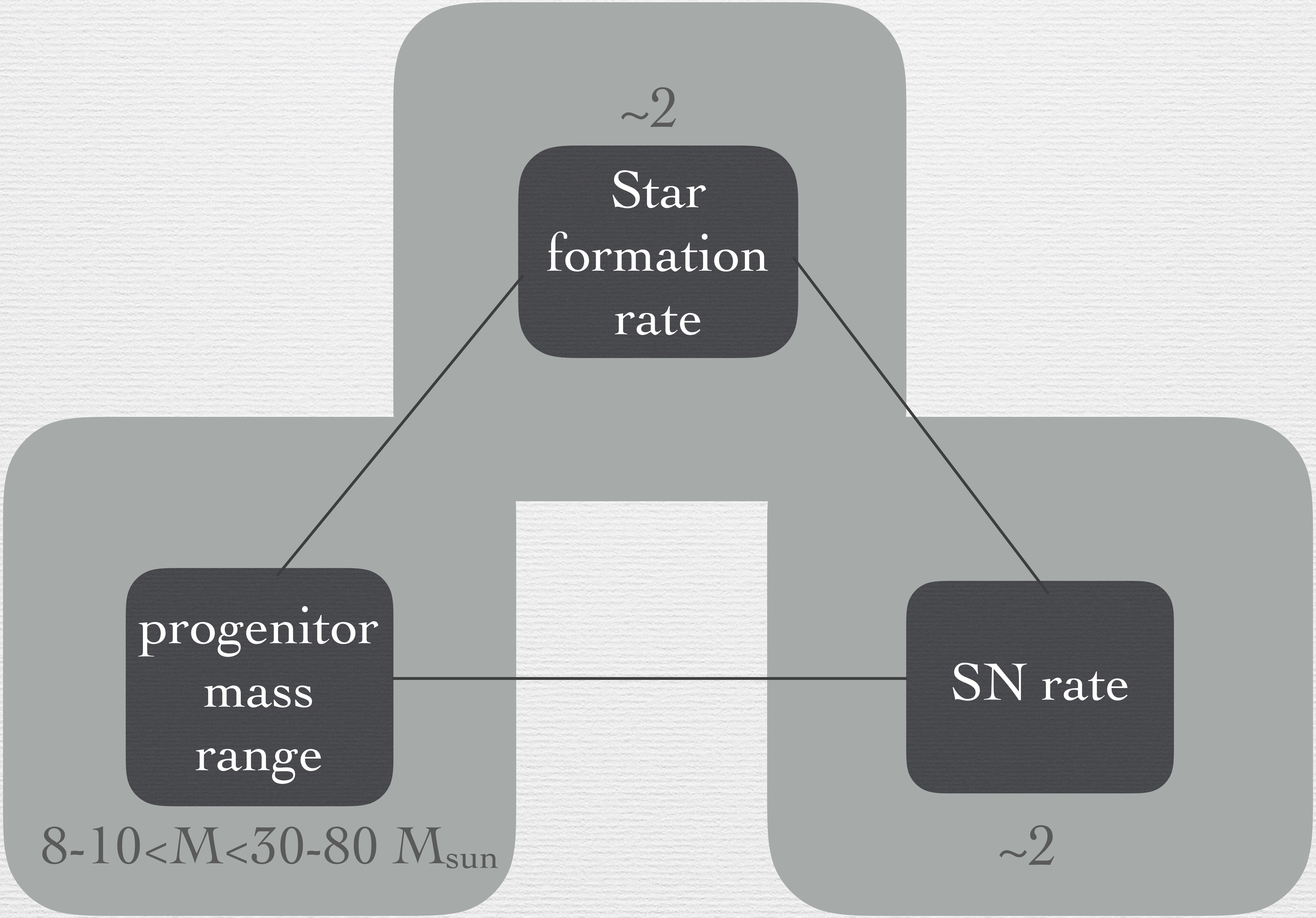


Cappellaro et al. 2015 A&A 584, 62

CC SN rate with redshift



Cappellaro et al. 2015 A&A 584, 62

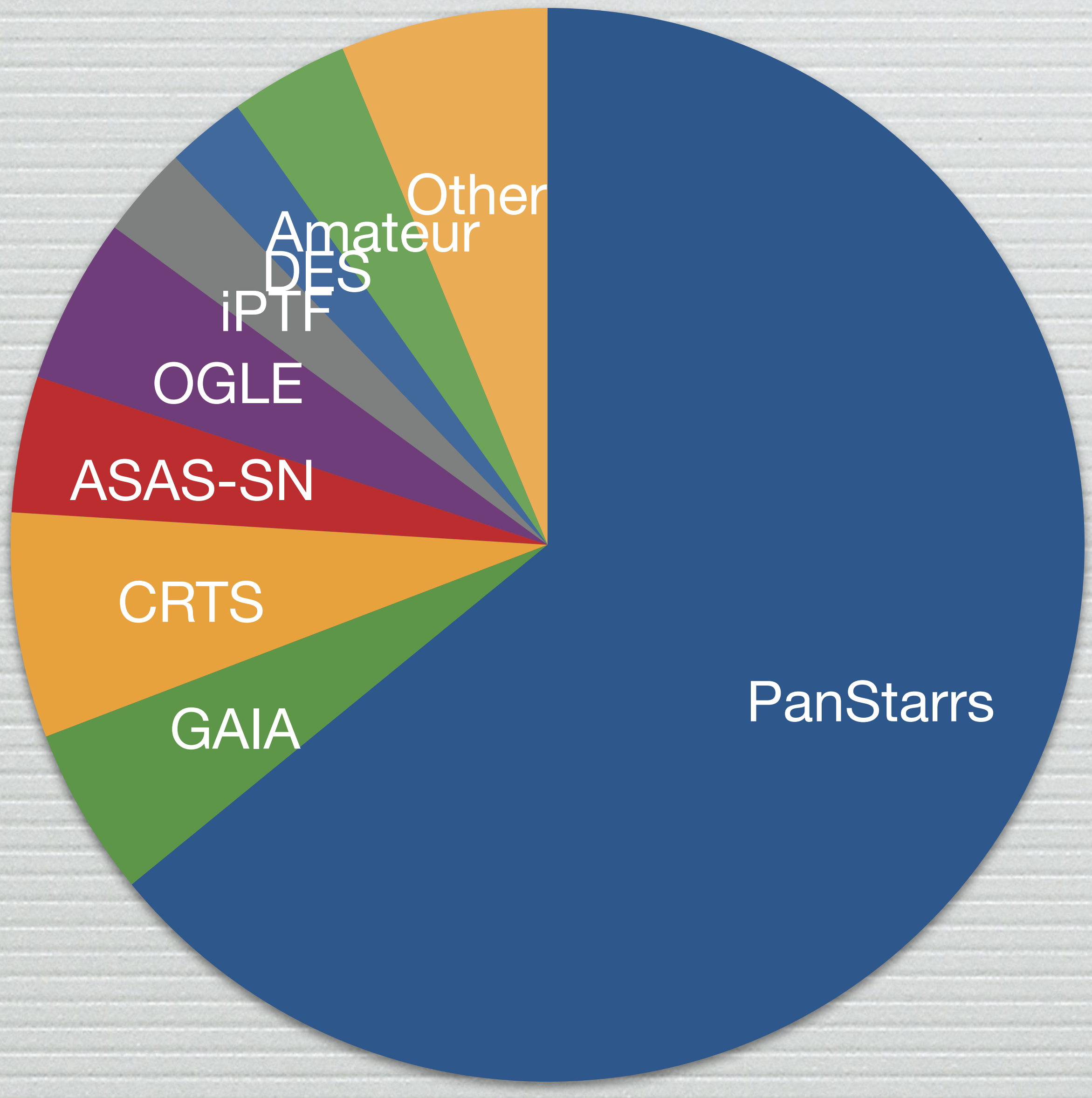

~2
Star formation rate
progenitor mass range
SN rate
8-10<M<30-80 Msun
~2

SN searches

Optical transient searches

1/1/2015-23/4/2016

2015: ~ 3500 SN candidates



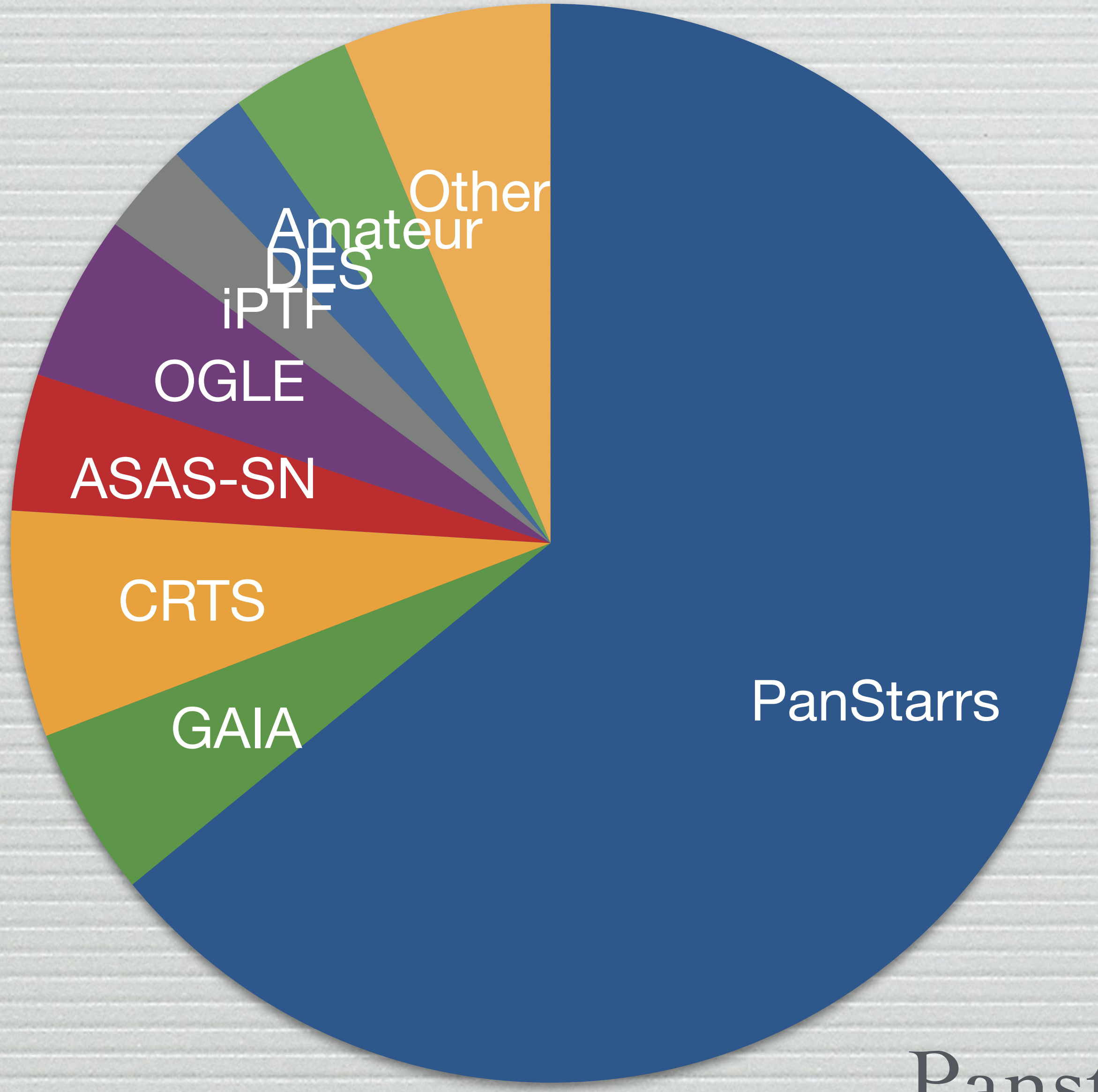
SN candidates

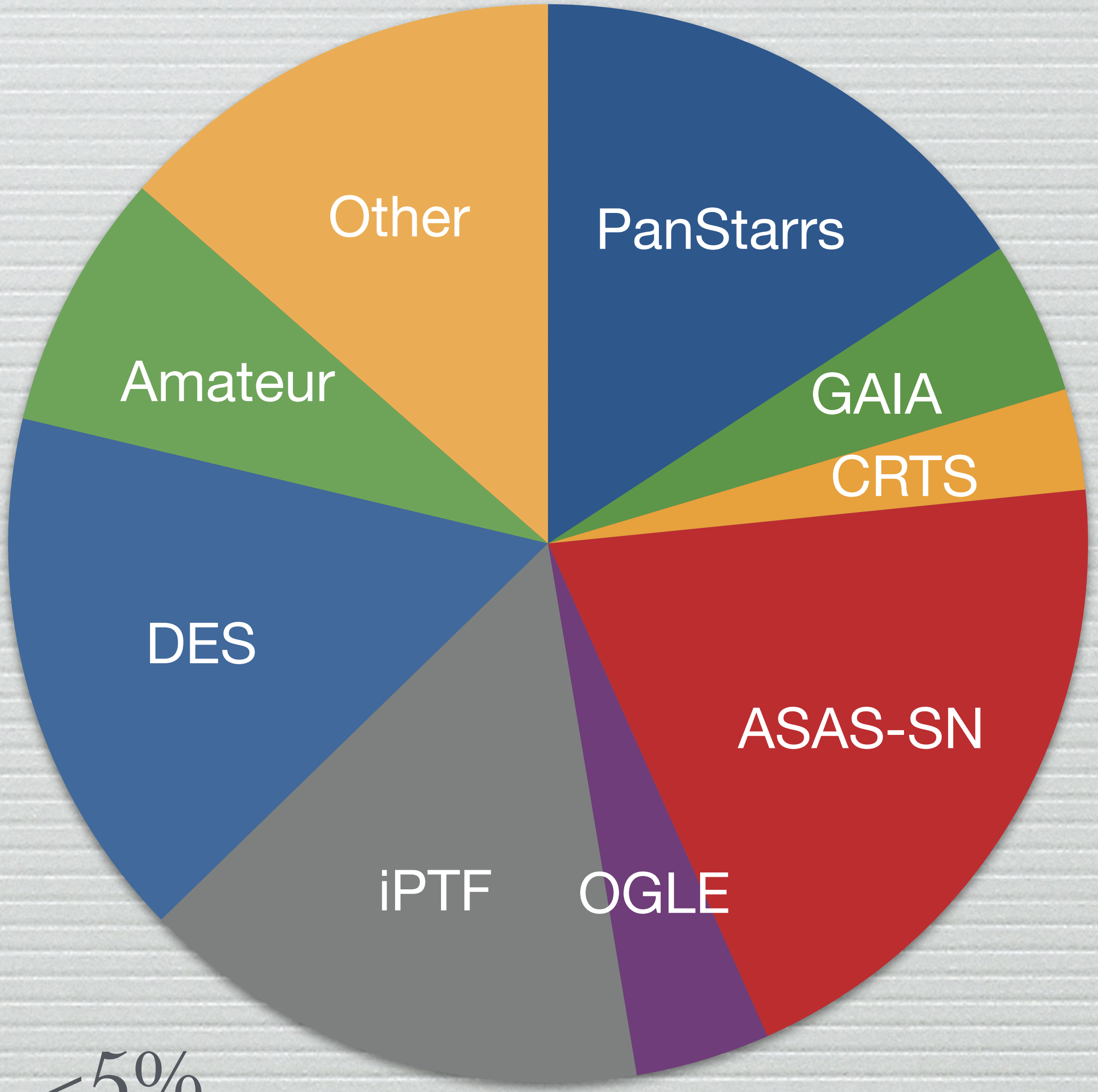
name	telescope	FoV deg²	cadence	sky coverage
ASAS-SN	14cm	20	1d	20000
CTRS	0.5,0.68,1.5 m	9-1	600s-5d	2200
GAIA	1.5x0.5m	scanning mode	30d	all sky in 5 yr
iPTF	Palomar 48inch	7.8	5 d 90s - 1d	1000
OGLE-IV	Warsaw 1.3m	12	1-10d	300
PAN-STARRS	PS1 1.8m	3	0.2-20d	1000
DES	Blanco 4m	2.2	8d	30

Optical transient searches

1/1/2015-23/4/2016

~20% of posted transients are classified





Panstarrs <5%

ASAS-SN >70%

Zwicky Transient Facility

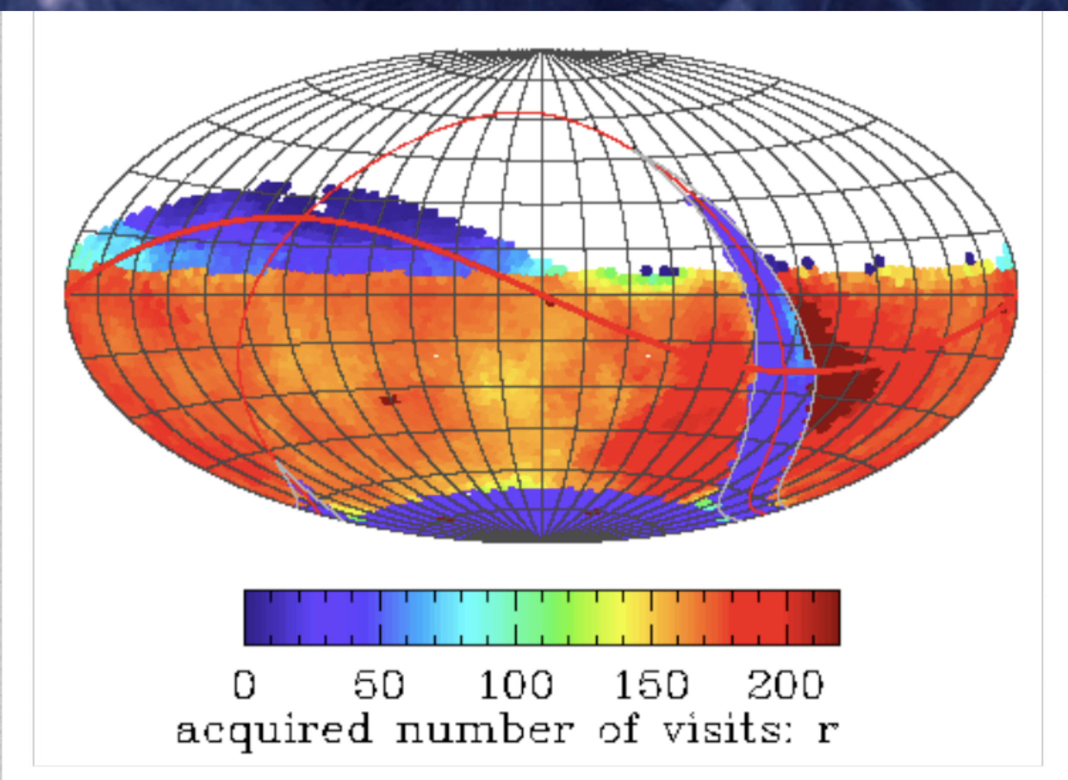
First light at Palomar Observatory in 2017.. By scanning more than 3750 square degrees an hour to a depth of 20.5-21 mag, ZTF will discover a young supernova less than 24 hours after its explosion each night

LSST Corporation

The Large Synoptic Survey Telescope Corporation

8.4m telescope

FoV 9.6 deg^2



10.000 deg^2 per night

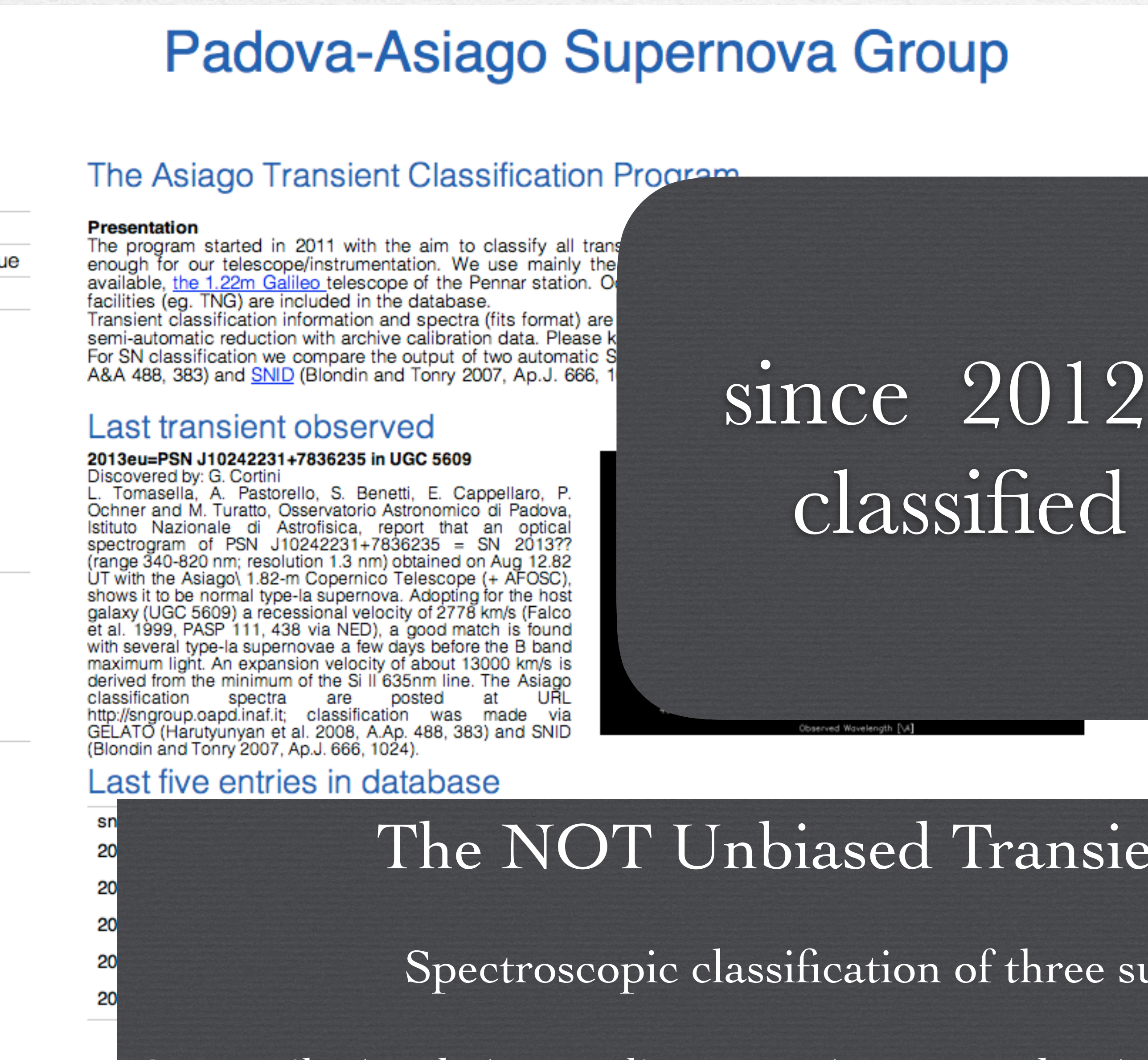
limit r ~ 24

alerts per night 10.000.000

real time alert latency 60 sec

survey operation: 2022

The bottle neck is transient classification


Padova-Asiago Supernova Group

The Asiago Transient Classification Program

Presentation

The program started in 2011 with the aim to classify all trans
enough for our telescope/instrumentation. We use mainly the
available, the 1.22m Galileo telescope of the Pennar station. O
facilities (eg. TNG) are included in the database.
Transient classification information and spectra (fits format) are
semi-automatic reduction with archive calibration data. Please k
For SN classification we compare the output of two automatic S
A&A 488, 383) and SNID (Blondin and Tonry 2007, Ap.J. 666, 1

Last transient observed

2013eu=PSN J10242231+7836235 in UGC 5609

Discovered by: G. Cortini

L. Tomasella, A. Pastorello, S. Benetti, E. Cappellaro, P. Ochner and M. Turatto, Osservatorio Astronomico di Padova, Istituto Nazionale di Astrofisica, report that an optical spectrogram of PSN J10242231+7836235 = SN 2013?? (range 340-820 nm; resolution 1.3 nm) obtained on Aug 12.82 UT with the Asiago\ 1.82-m Copernico Telescope (+ AFOSC), shows it to be normal type-Ia supernova. Adopting for the host galaxy (UGC 5609) a recessional velocity of 2778 km/s (Falco et al. 1999, PASP 111, 438 via NED), a good match is found with several type-Ia supernovae a few days before the B band maximum light. An expansion velocity of about 13000 km/s is derived from the minimum of the Si II 635nm line. The Asiago classification spectra are posted at URL http://sngroup.oapd.inaf.it; classification was made via GELATO (Harutyunyan et al. 2008, A.Ap. 488, 383) and SNID (Blondin and Tonry 2007, Ap.J. 666, 1024).

Last five entries in database

since 2012 our collaboration classified 40% of all SNe

The NOT Unbiased Transient Survey (NUTS) collaboration

Spectroscopic classification of three supernovae with the Nordic Optical Telescope

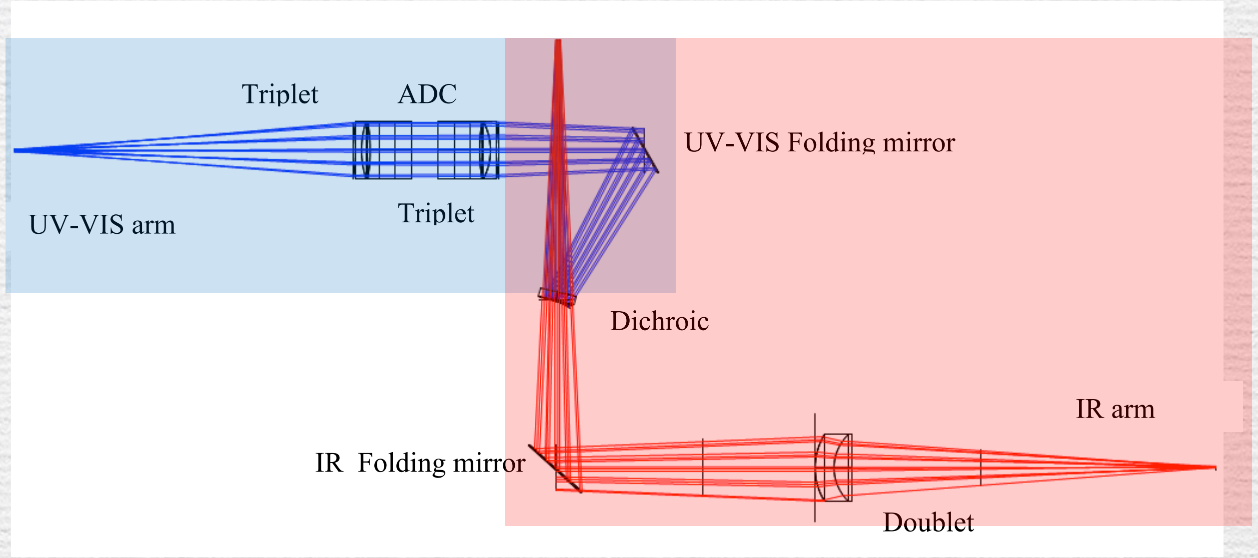
S. Mattila (Turku), N. Elias-Rosa (INAF-Padova), P. Lundqvist (Stockholm), M. Stritzinger (Aarhus U), H. Kuncarayakti (MAS, DAS), …….

FIRST ATEL TODAY

SOXS @ NTT

PI Sergio Campana

A possible optical layout of the Common Path



- two beams spectrograph
- wide spectral coverage (0.35-1.75 μm)
- good spectral resolution (R~4,500)
- to be installed at the ESO- NTT at La Silla (Chile)

Jun 2014 ESO call for new instruments at NTT (06/2014)
Feb 2015 Proposal submission (02/2015)
May 2015 SOXS selected by ESO (out of 19 proposal)

cost: ~5 M€
goal: 60% funding from INAF

Instrument in operation: 2020