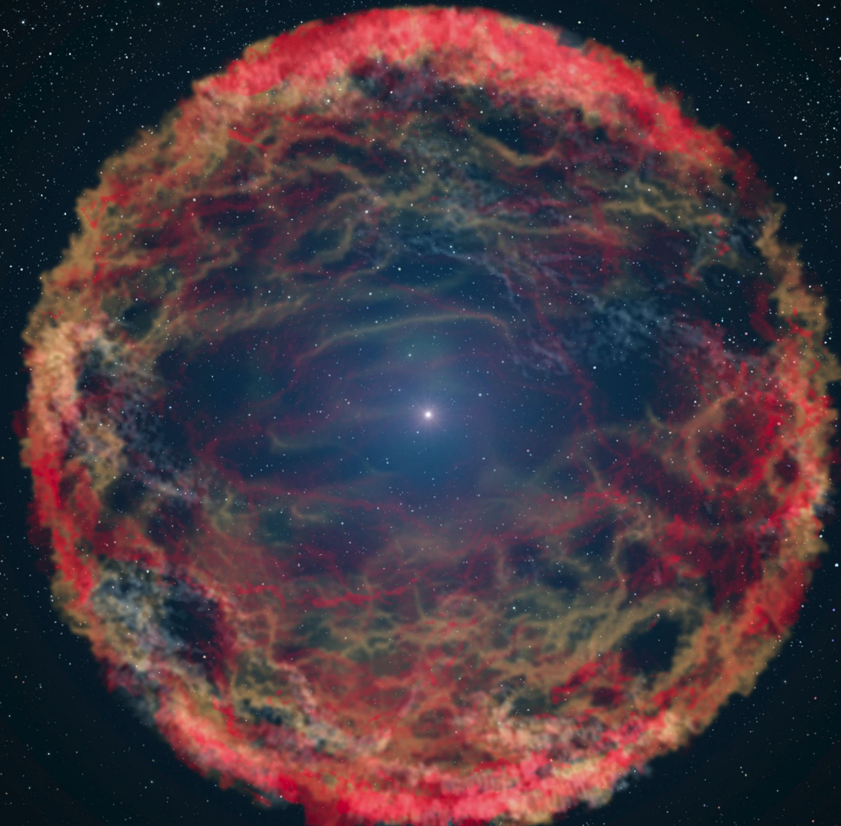
超新星探测与中微子

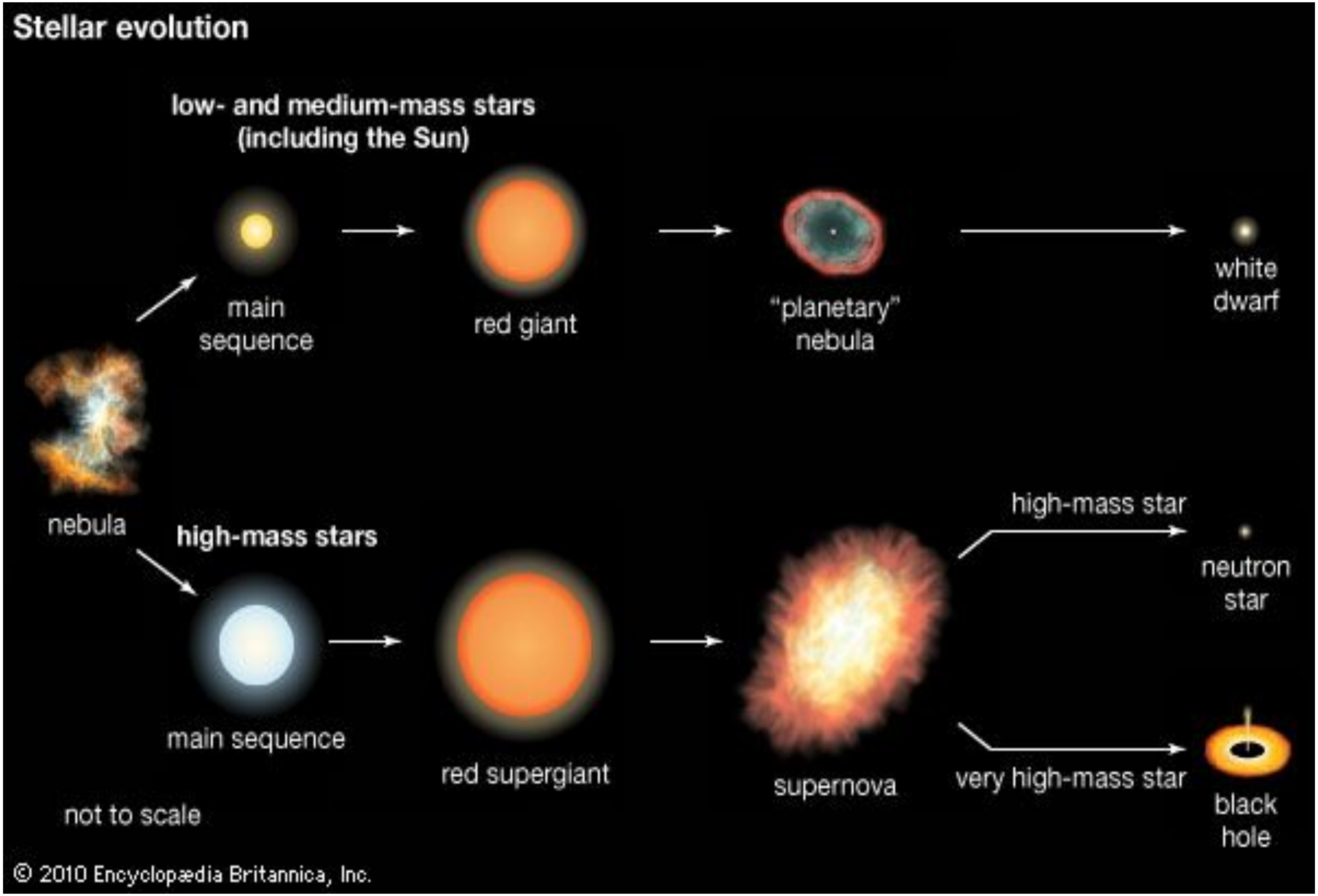


王 晓 锋
清 华 大 学

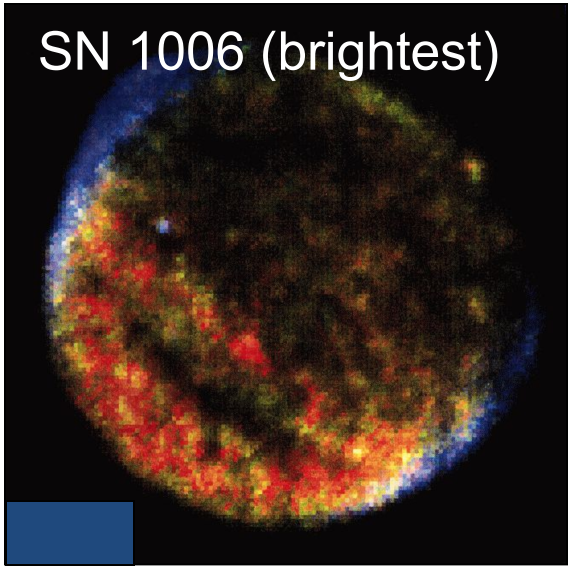
JUNO中微子天文和天体物理学研讨会

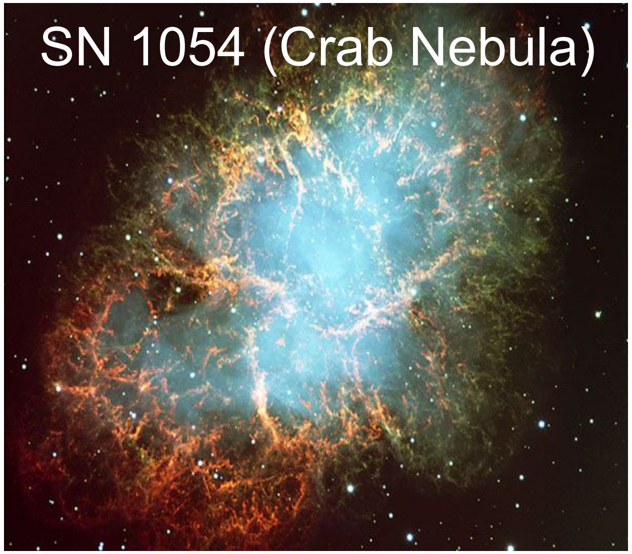
IHEP，July 10-11, 2015

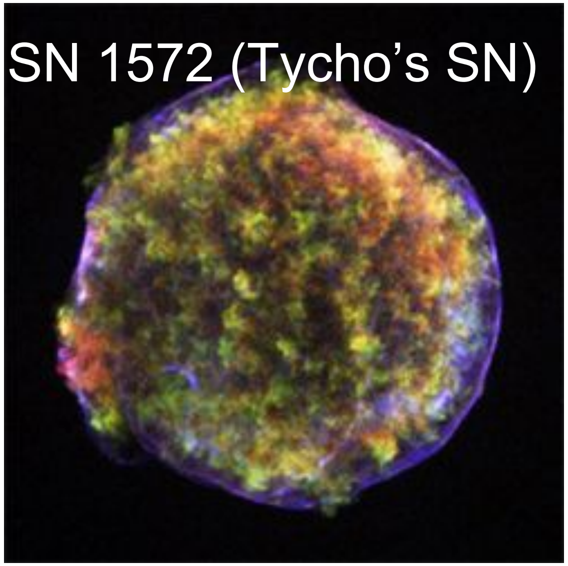
Supernovae represent the catastrophic end of stellar evolution

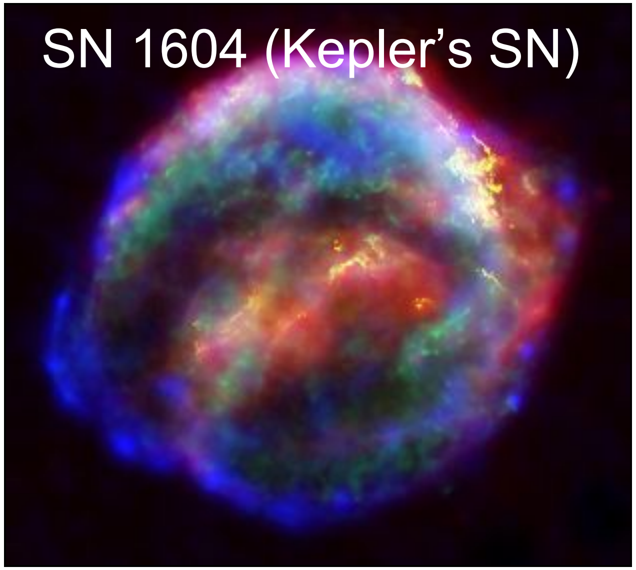


Milky Way SNe in the past millennium









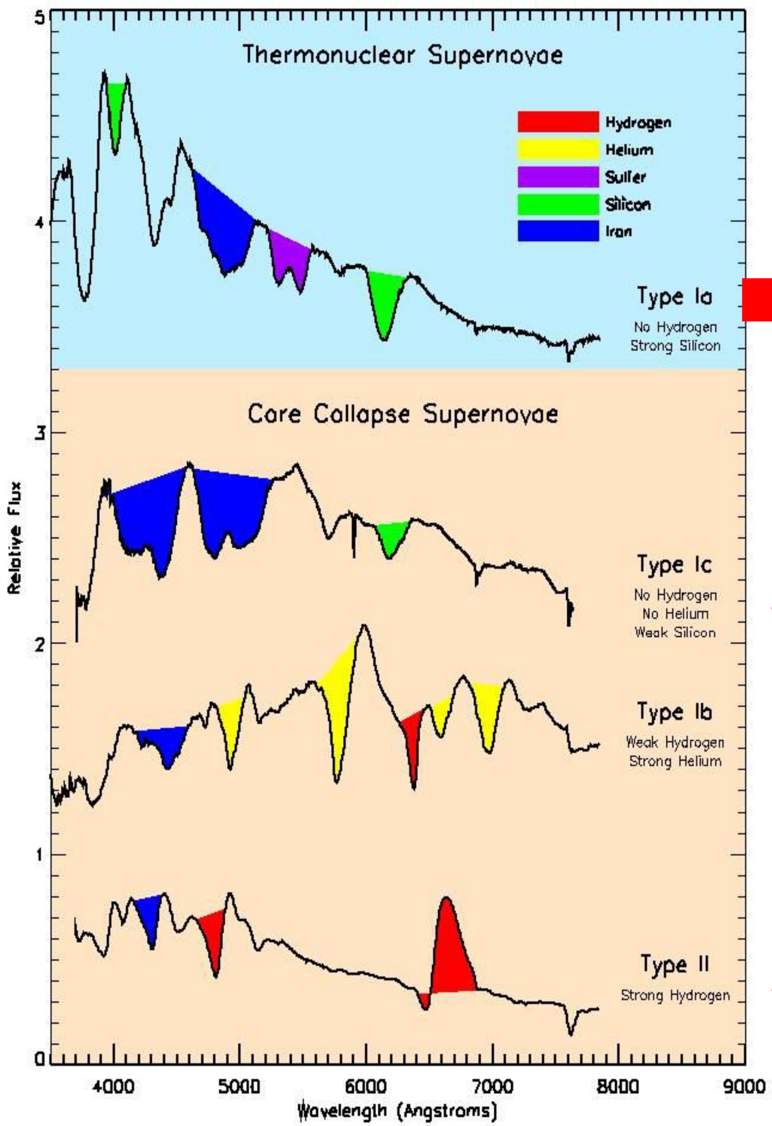
Next one?
SN 202X?

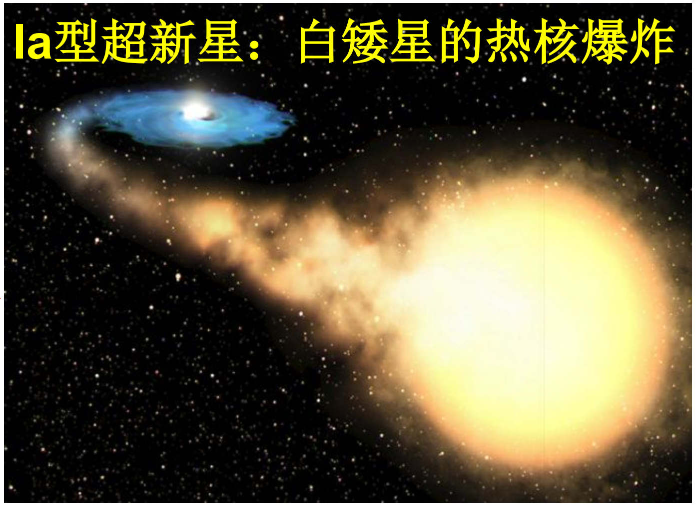
Explosion Mechanism of Supernovae

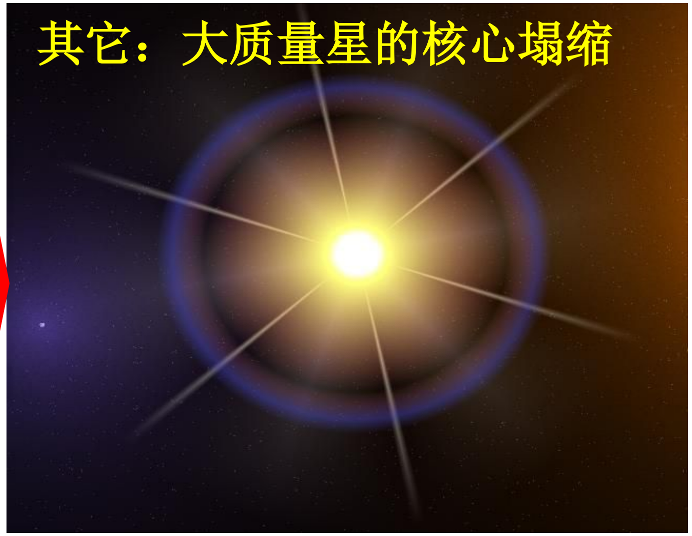
Thermonuclear Explosion
(SN 1006)

Core-Collapse of Massive Stars
(SN 1054)

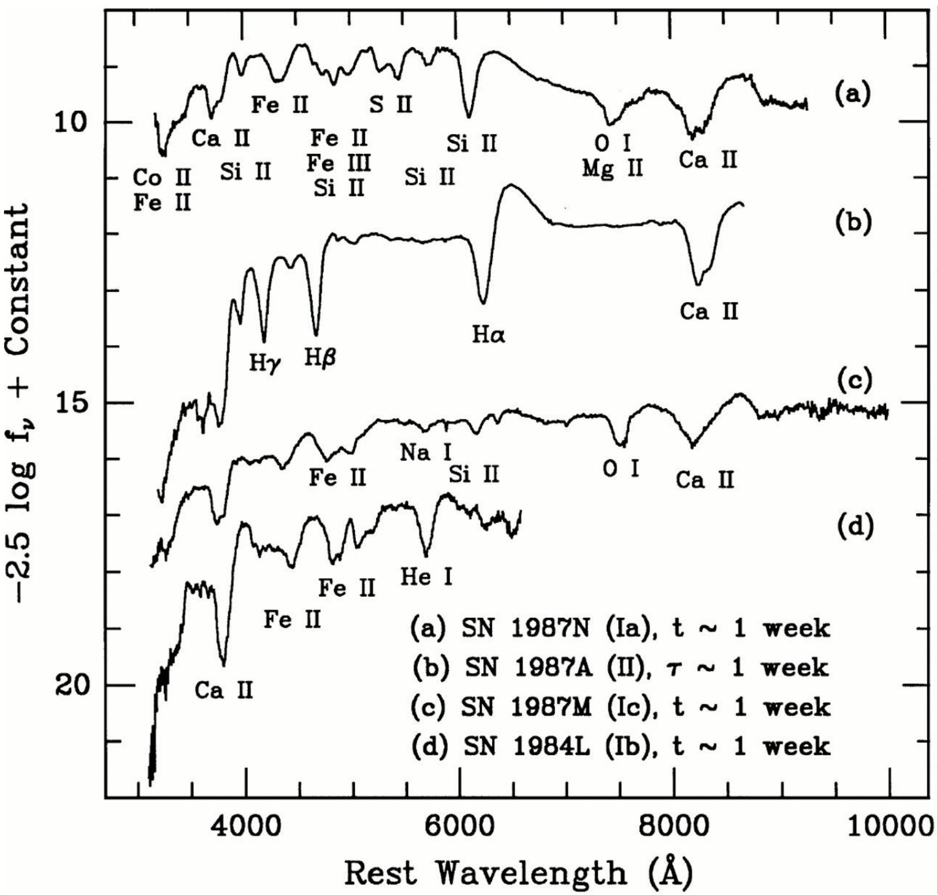
Supernova Classification

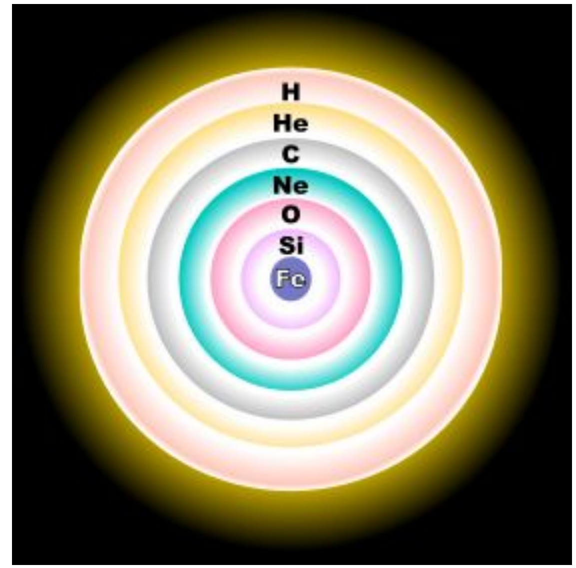


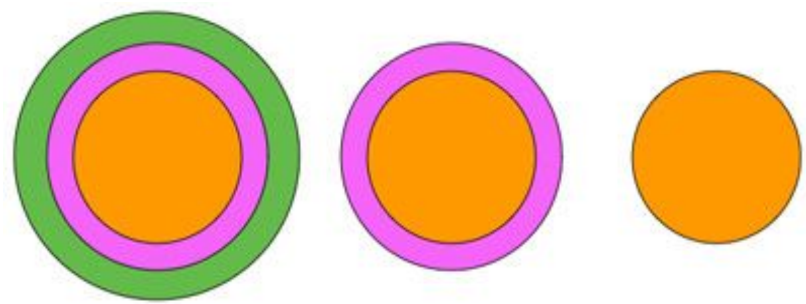




Comparison of type II， Ib and Ic supernovae





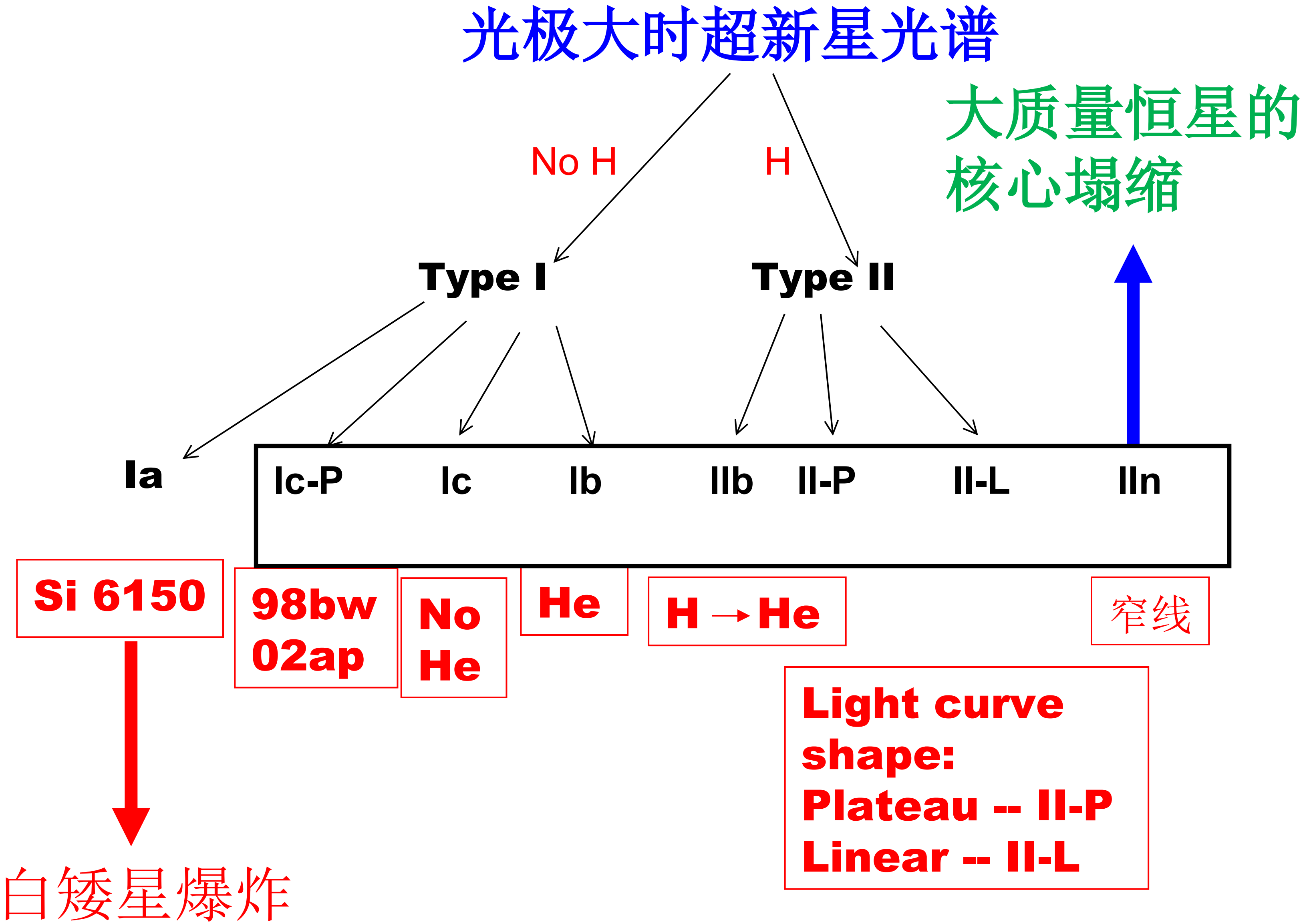


Type II
H and He shells

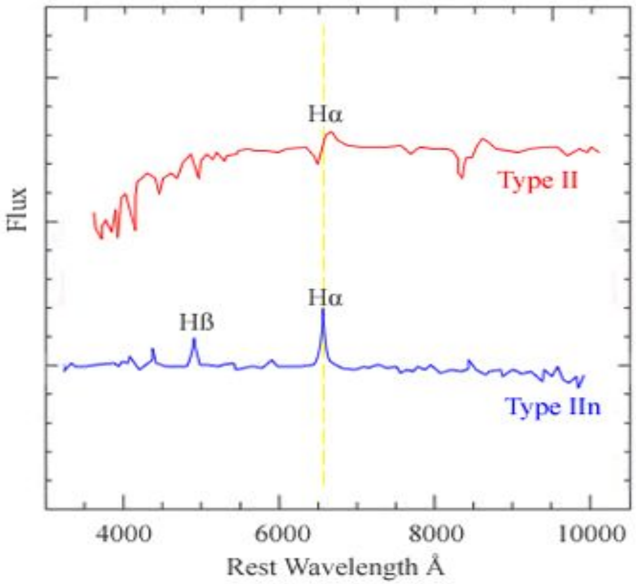
Type Ib
He shell only
no H shell

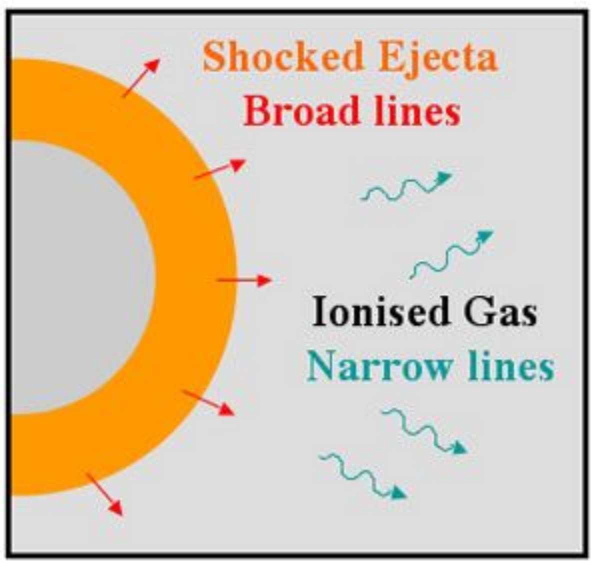
Type Ic
no H nor He
shells

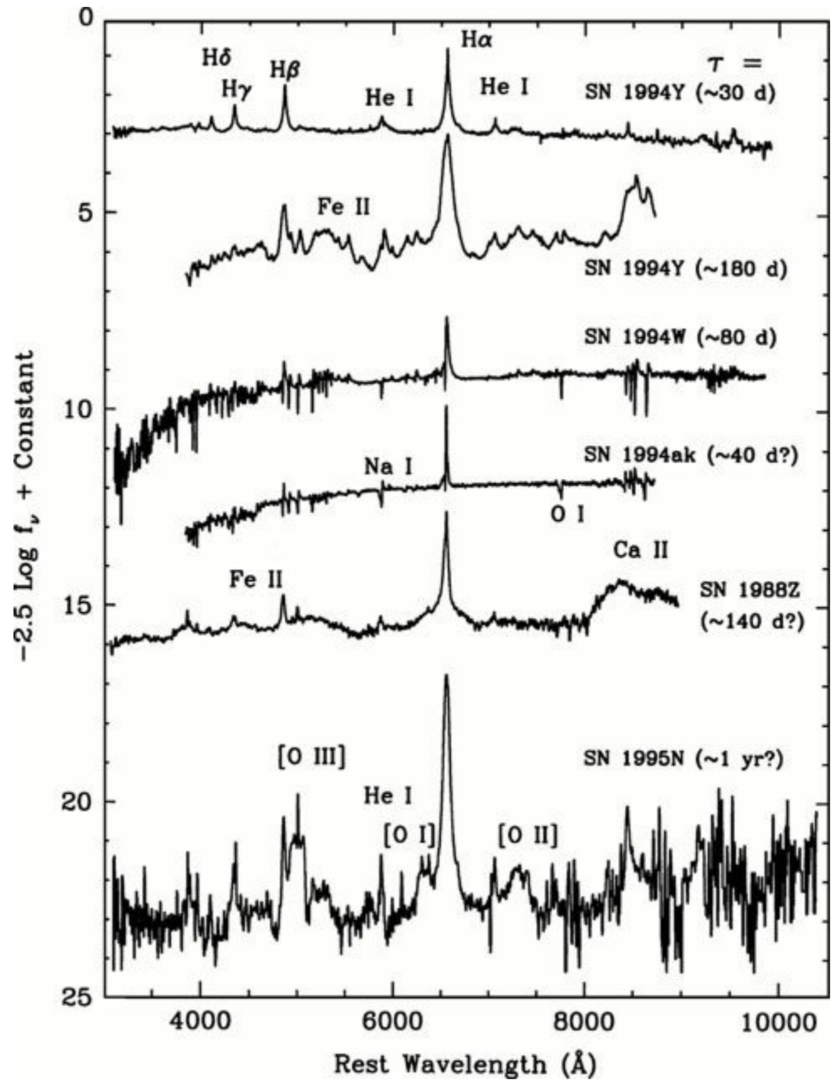
Supernova Zoo



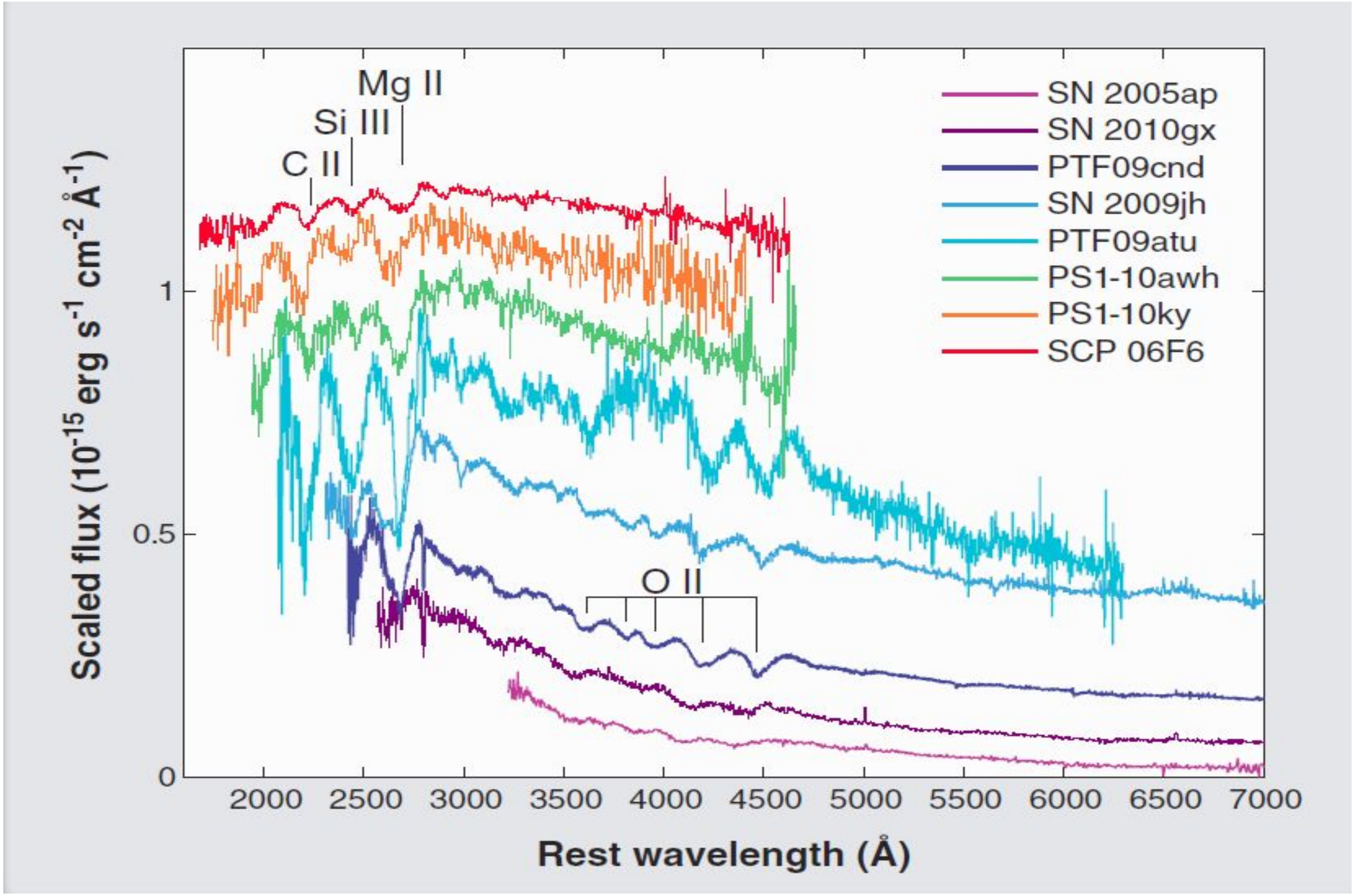
Type IIn Supernova





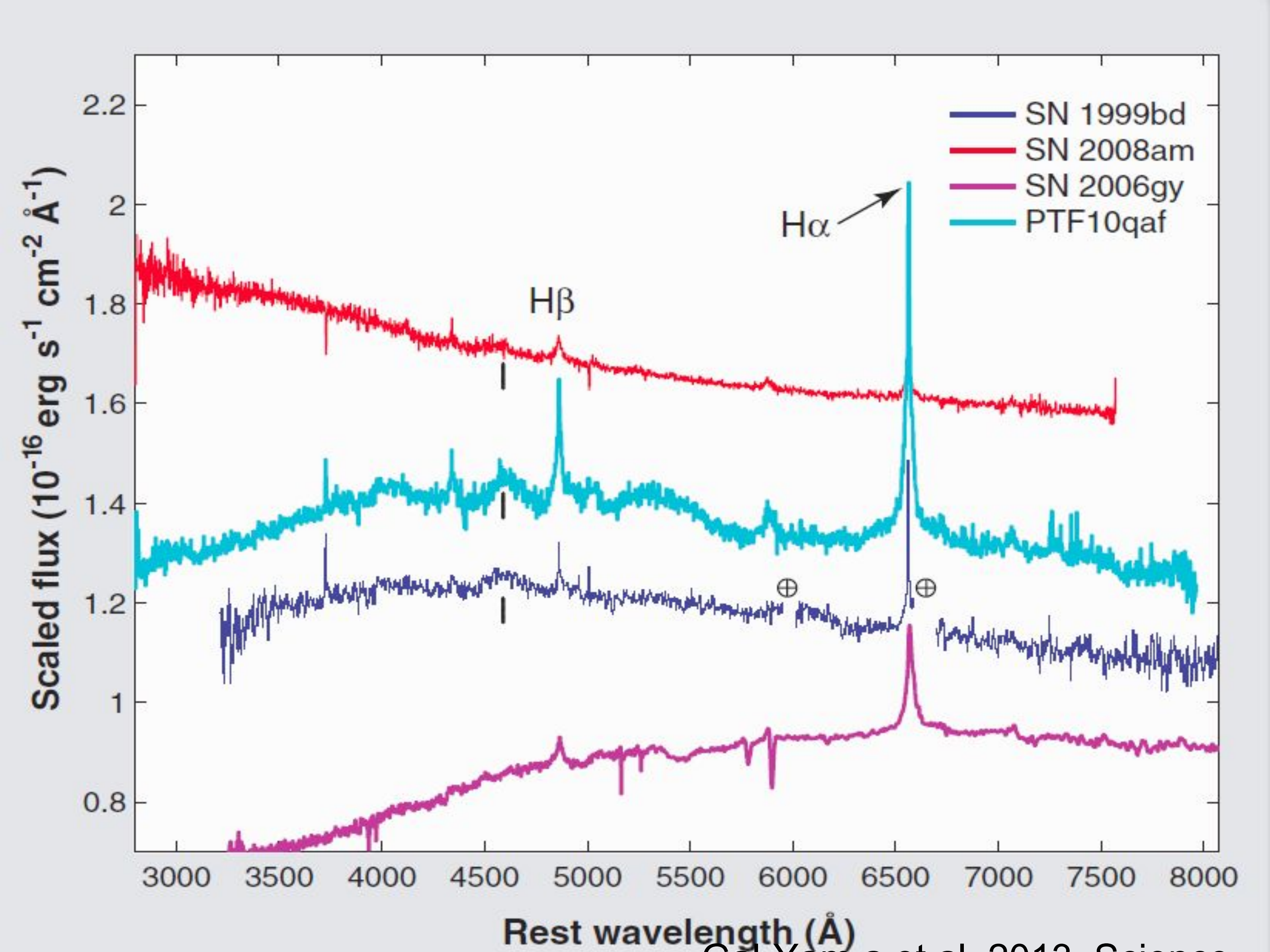


Superluminous Supernova (SLSN -I)



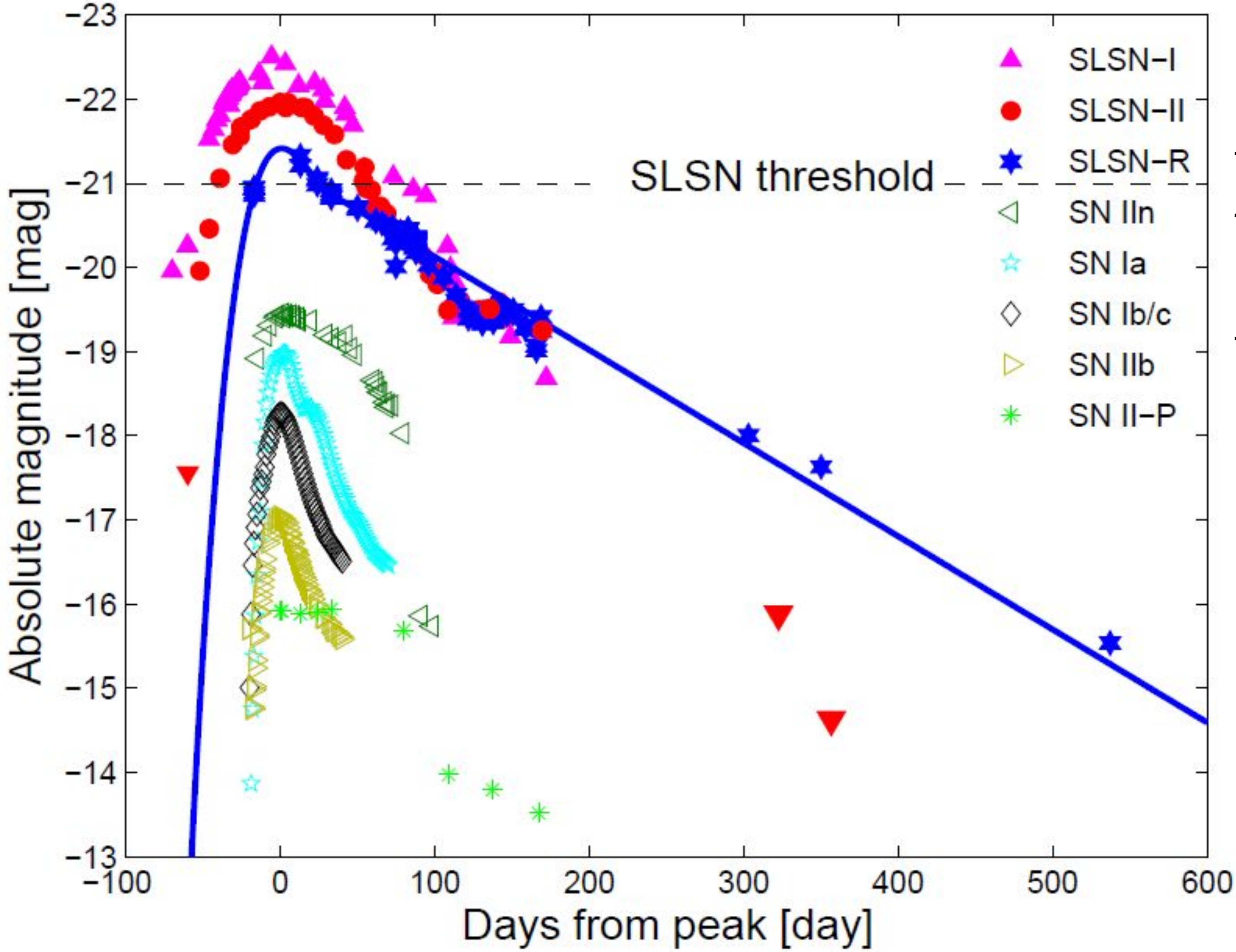
Gal-Yam a et al. 2013, Science

SLSN-II



Gal-Yam a et al. 2013, Science

Luminosity Evolution of Supernovae



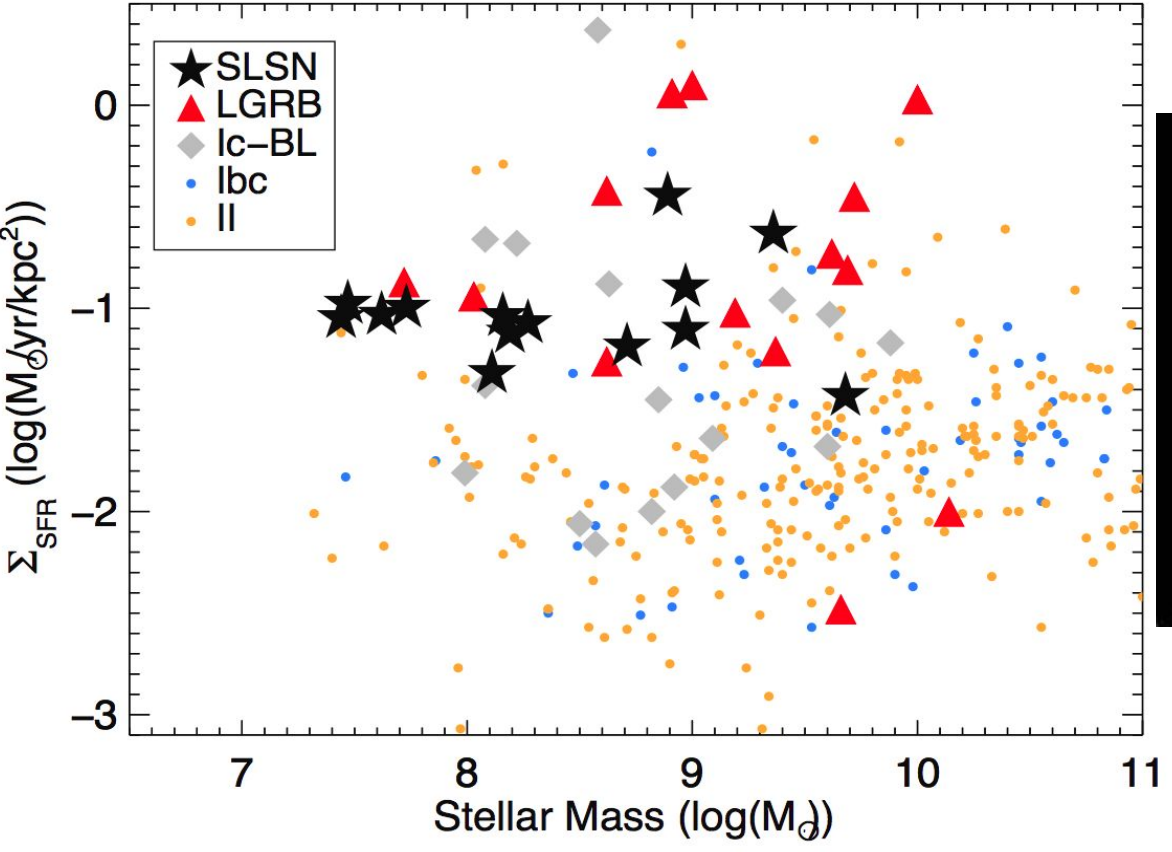
- Shock
  - breakout
  - kinematic energy
- Cooling
  - expansion of ejecta
- radioactive decay

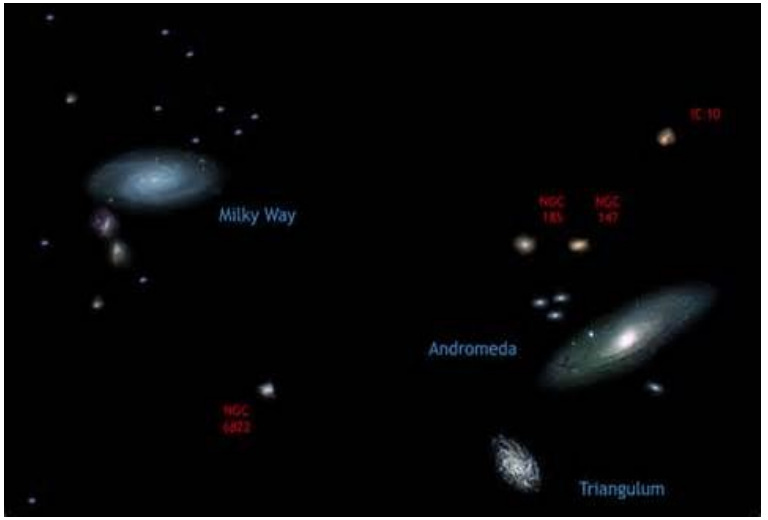
- recombination

$L \propto M(^{56}Ni)$
Shape: M_{ej}

Gal-Yam a et al. 2013, Science

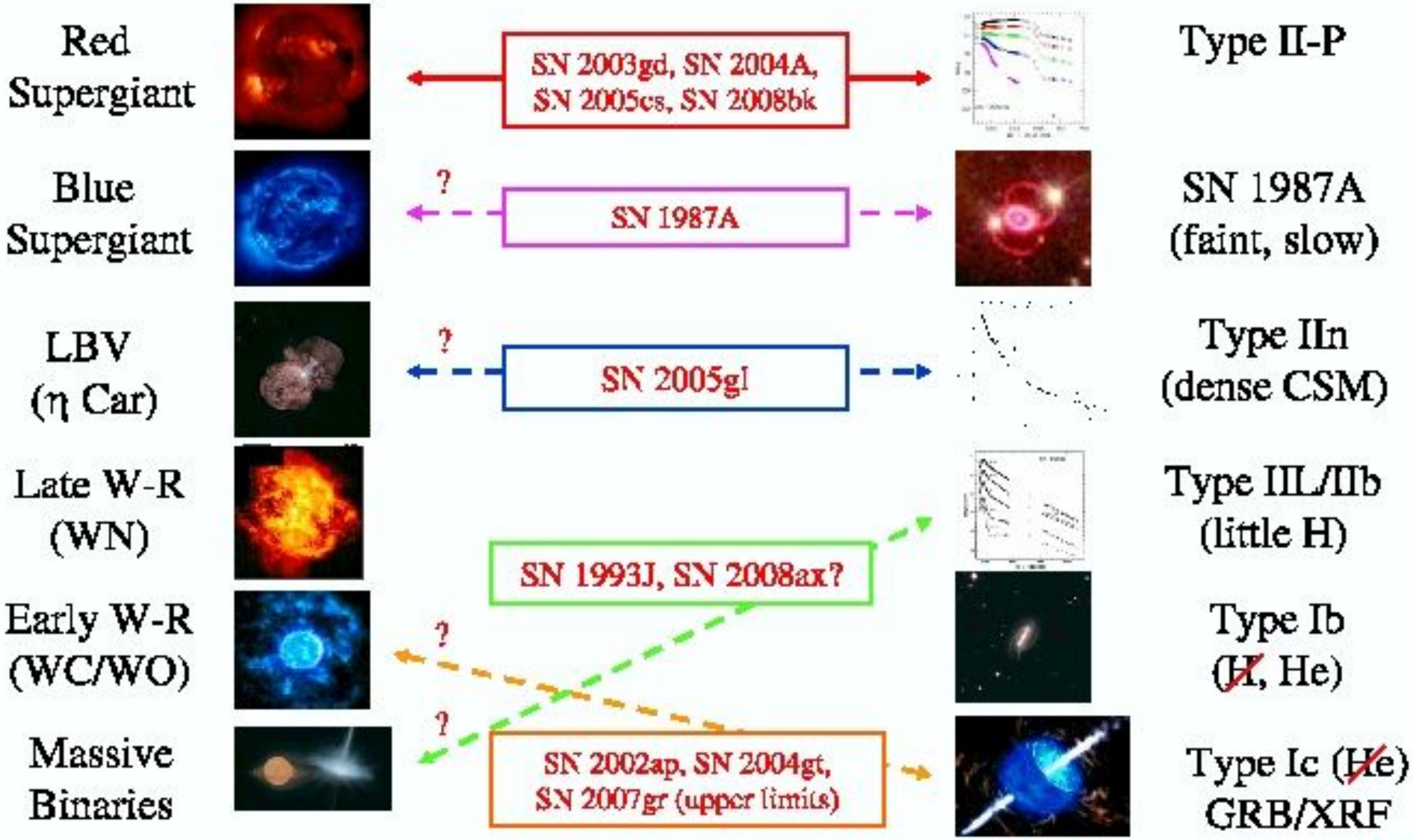
Host Galaxies of Core-Collapse Supernovae





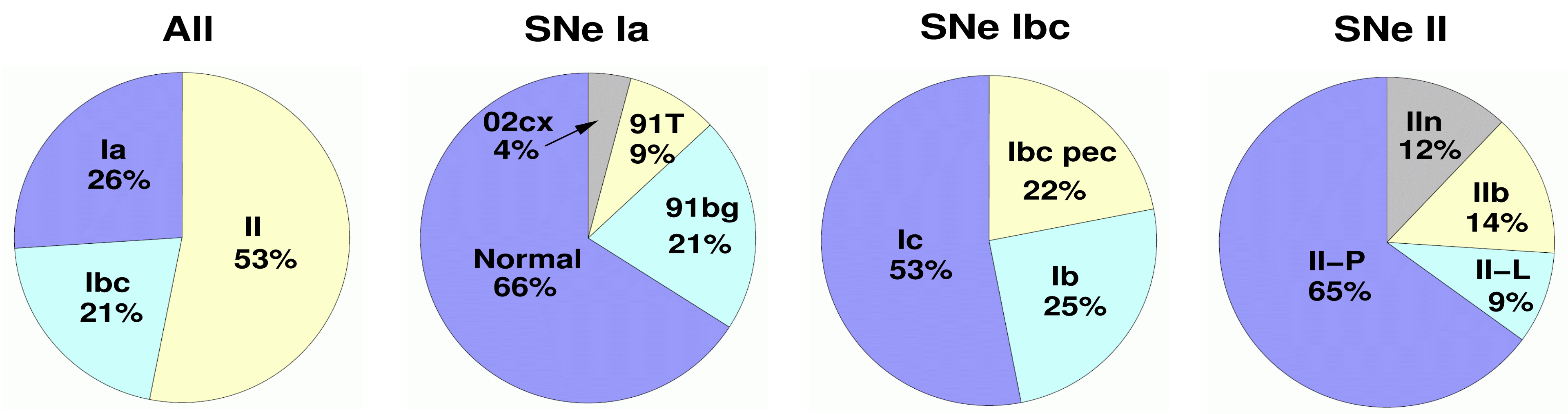
Lunnan et al. 2015

The Progenitor – SN Map

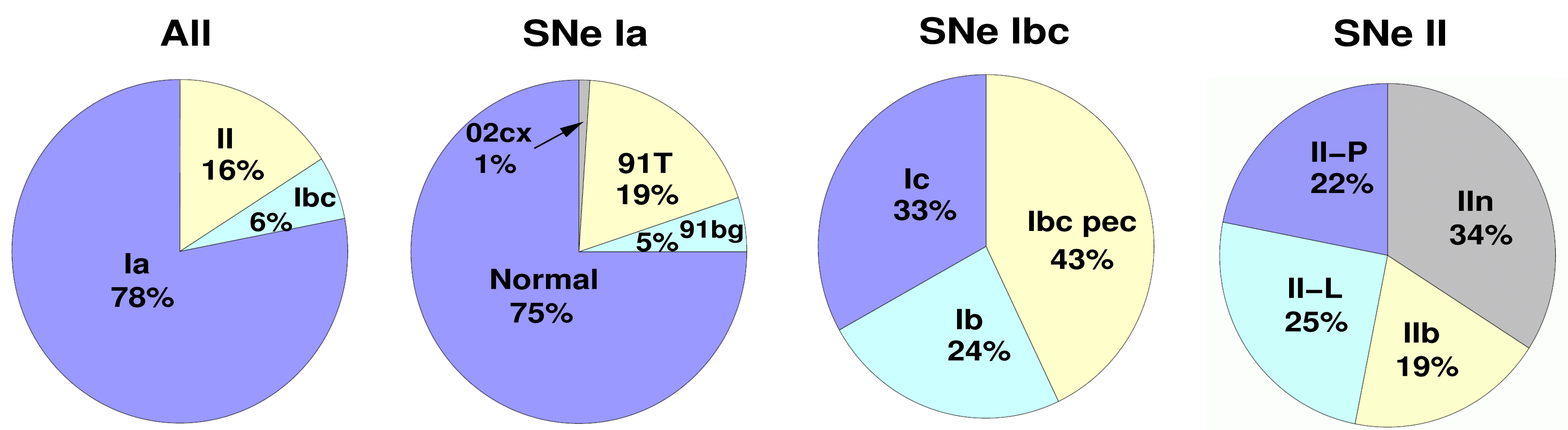


Based on Gal-Yam et al. 2007; updated

Fraction of different types of supernovae(volume-limited sample)



Fraction of different types of supernovae(magnitude-limited sample)



Li et al. 2011, MNRAS

寻找超新星的动机

- 恒星演化的终点; 验证恒星演化理论
- 致密遗迹(中子星，黑洞)
- 星系的化学演化
- 与伽玛射线暴, 宇宙线及中微子的关联
- 宇宙学用途!

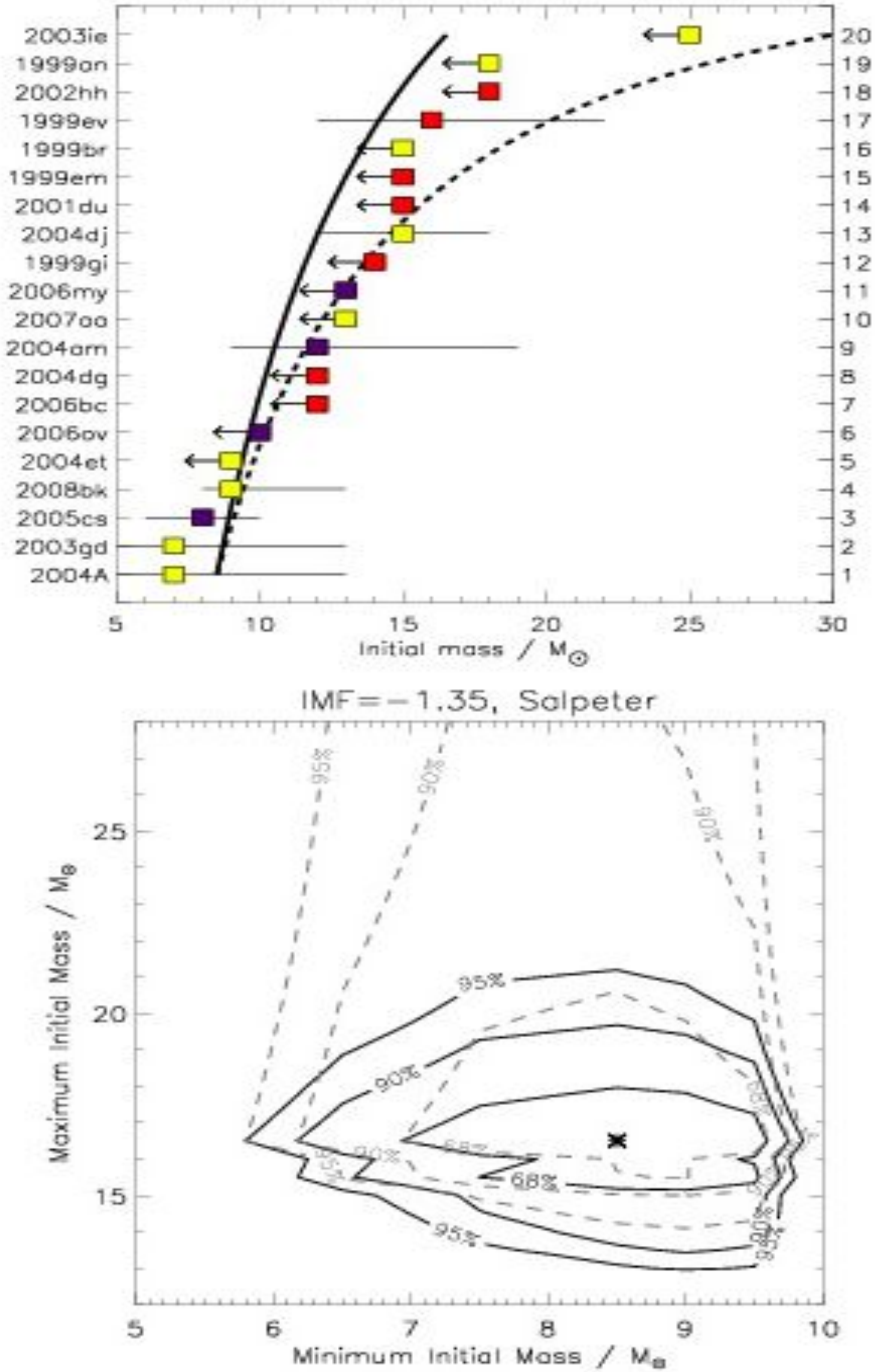
Evolution of Massive Stars

For stars of ~75 M_S
O → WN(H-rich) →LBV → WN(H-poor) → WC → SN Ic

For stars of ~40-75 M_S
O → LBV → WN(H-poor) → WC → SN Ic

For stars of 25-40 M_S
O → LBV → WN(H-poor) → SN Ib
OR
O →RSG → WN(H-poor) → SN Ib

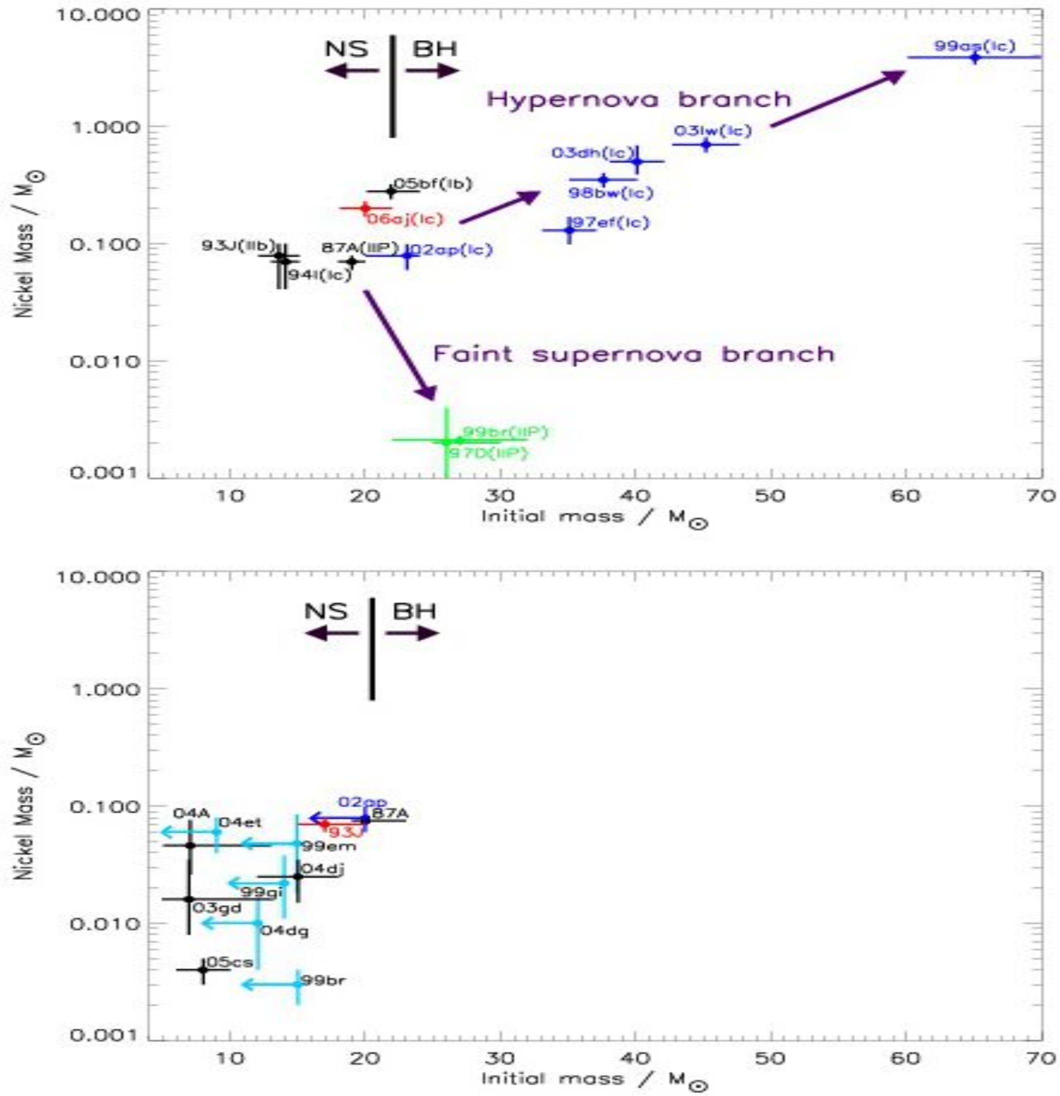
For stars of 15-25Ms
O, B--> RSG, YSG-->SN IIL
For stars of 8-15Ms
O,B--> RSG, YSG, BSG--> SN IIP



(a): A cumulative frequency plot of the masses of type IIP progenitors, taken from Smartt et al. (2009). The right and axis is a simple number count and the SNe are ordered in increasing mass or mass limit. The solid line is a Salpeter IMF (a= -2.35) with a minimum mass of 8.5M sun and maximum mass of 16.5Msun which is the most likely fit to the data. The dotted line is a Salpeter IMF but with a maximum mass of 30Msun. The SNe are grouped in metallicity bins log O/H+12 = 8.3 -8.4 (yellow), 8.5-8.6 (red), 8.7-8.9 (purple). (b): The maximum likelihood analysis of the IIP progenitor sample

gives the most likely value for initial and final mass and the likelihood contours (also from Smartt et al. 2009). The dashed lines are those calculated with detections only and the solid lines represent the contours calculated including the upper masses.

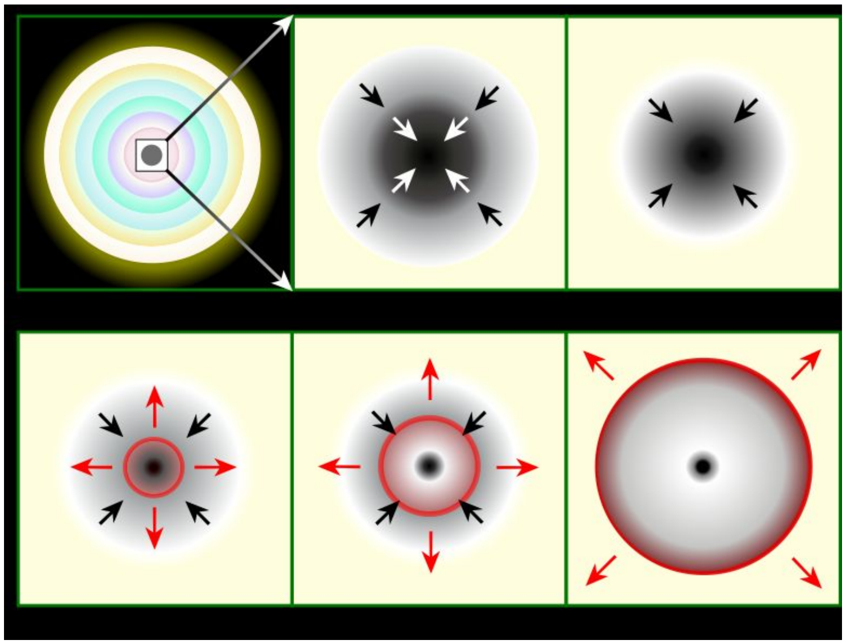
Smartt et al. 2009



Smartt 2009

Figure 11: ^{56}Ni mass vs main-sequence initial mass with the upper panel taken Nomoto *et al.* (2006) and the lower plot from Smartt *et al.* (2009). The initial mas this plot are estimated from the ejecta masses derived from lightcurve modelling. lower plot shows the ^{56}Ni masses for nearby SNe for which there are reliable restric on the progenitor masses from direct constraints.

Neutrinos from Supernovae



$$e^{-} + p \rightarrow n + \nu_e$$

引力束缚能

$E_b \approx 3 \times 10^{53}$ erg $\approx$ 17% $M_{SUN} c^2$

M_{Ch}~1.26 $M_{\odot}$ 铁核有10^{57}个电子→ 10^{57}个中微子

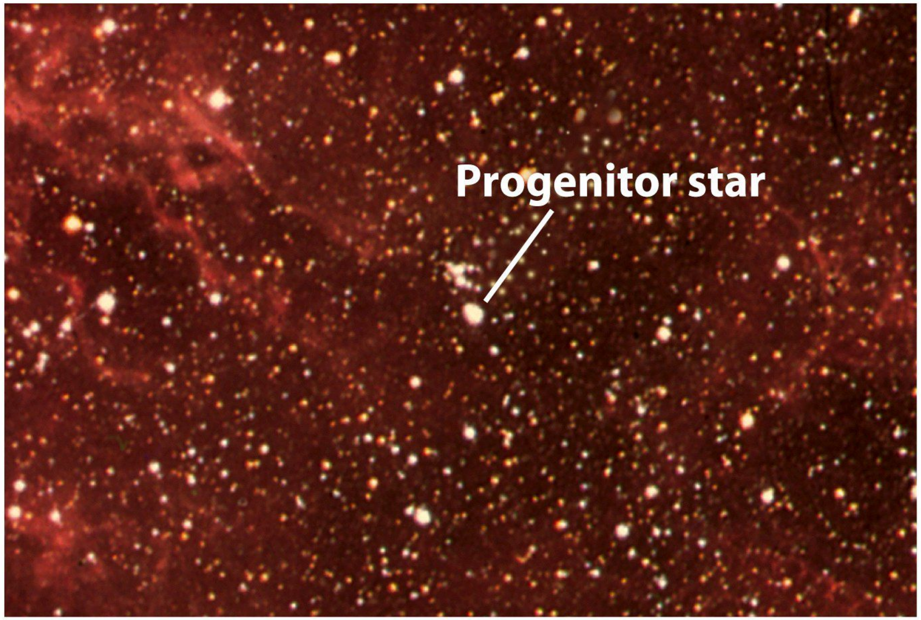
$L_{\nu} \approx 3 \times 10^{53}$ erg / 3 sec

$$^{56}\mathrm{Ni} \xrightarrow[6.6\mathrm{d}]{\gamma} {}^{56}\mathrm{Co} \xrightarrow[78\mathrm{d}]{\gamma} {}^{56}\mathrm{Fe}$$

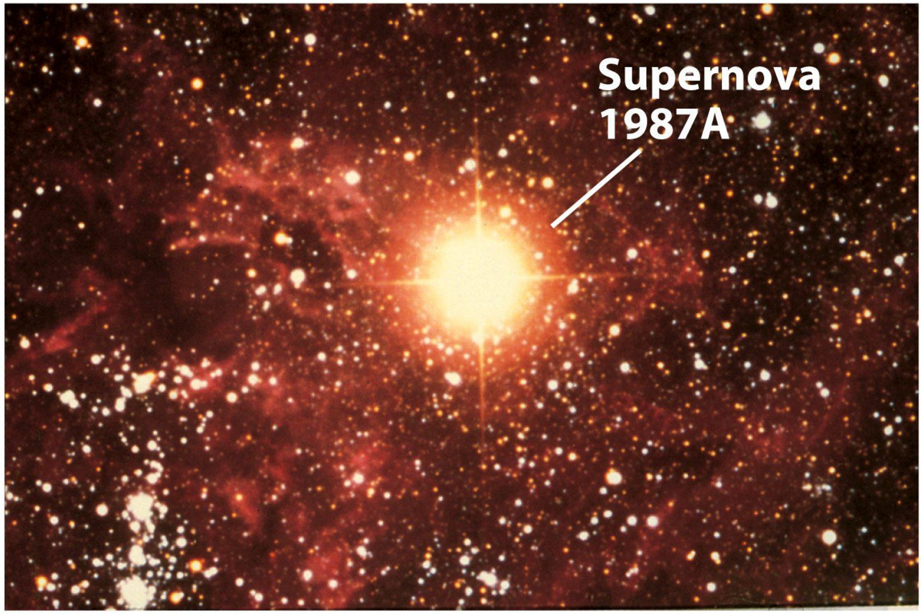
$$^{56}Ni \rightarrow {}^{56}Co + e^{+} + \nu_e + \gamma \quad (\tau_{1/2} = 6 \text{ days})$$

$$^{56}Co \rightarrow {}^{56}Fe + e^{+} + \nu_e + \gamma \quad (\tau_{1/2} = 77.1 \text{ days})$$

The brightest SN in the past century SN 1987A in the LMC



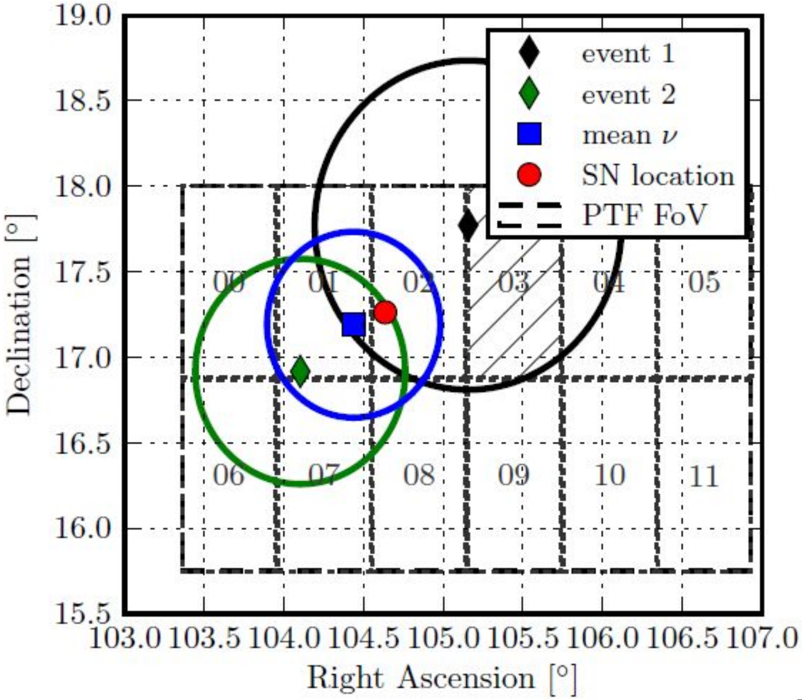
Before the star exploded

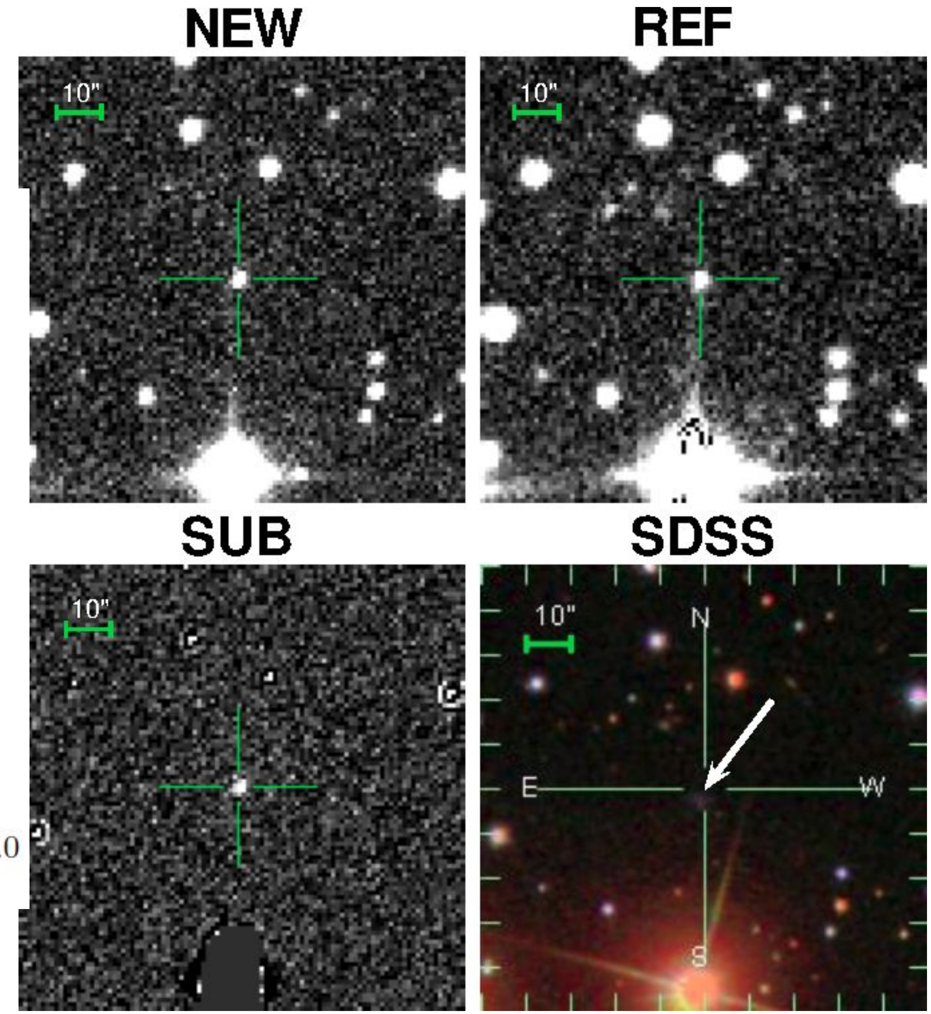


After the star exploded

A core collapse supernova will produce a burst of neutrinos of all favors with a few tens of MeV energy, over a period of a few tens of seconds.

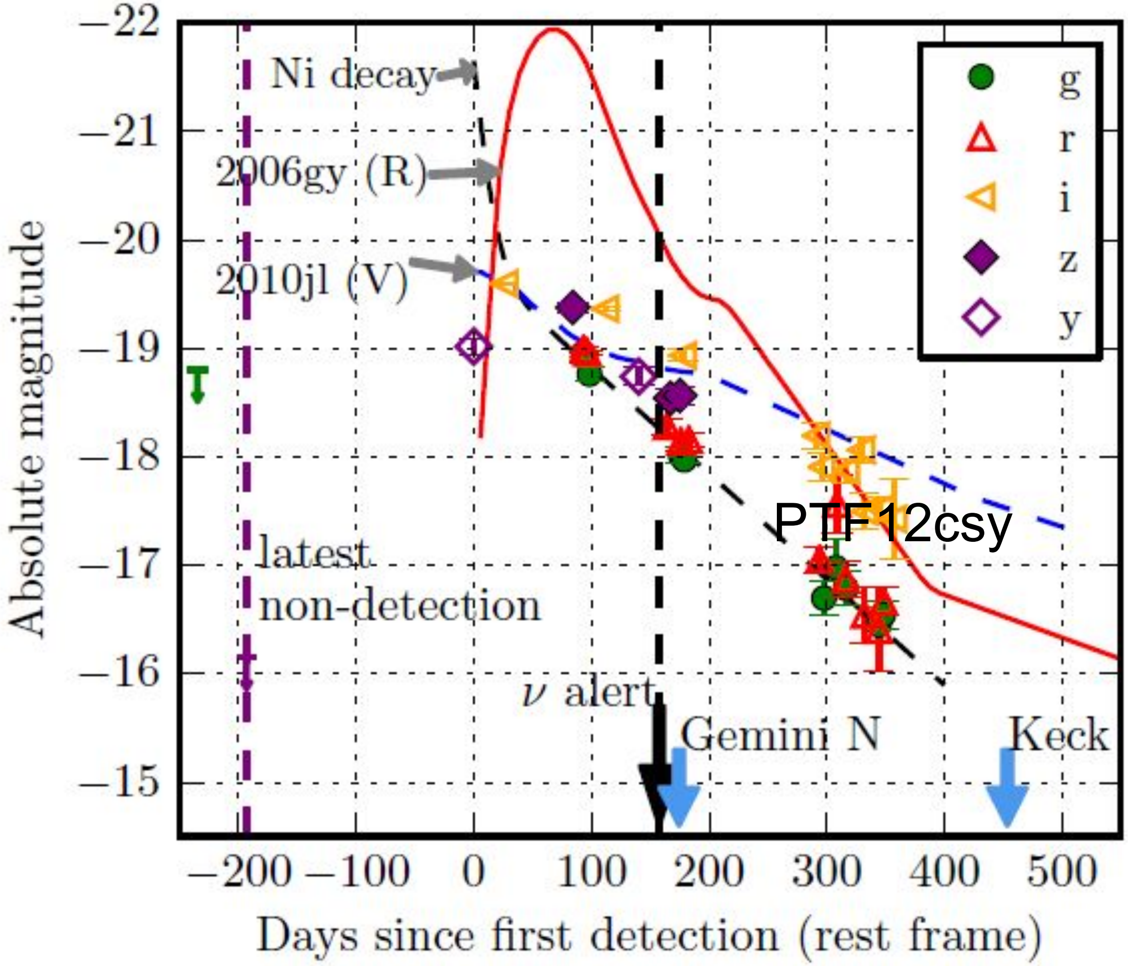
An IceCube neutrino alert triggers the discovery of a supernova(2015-06-11)





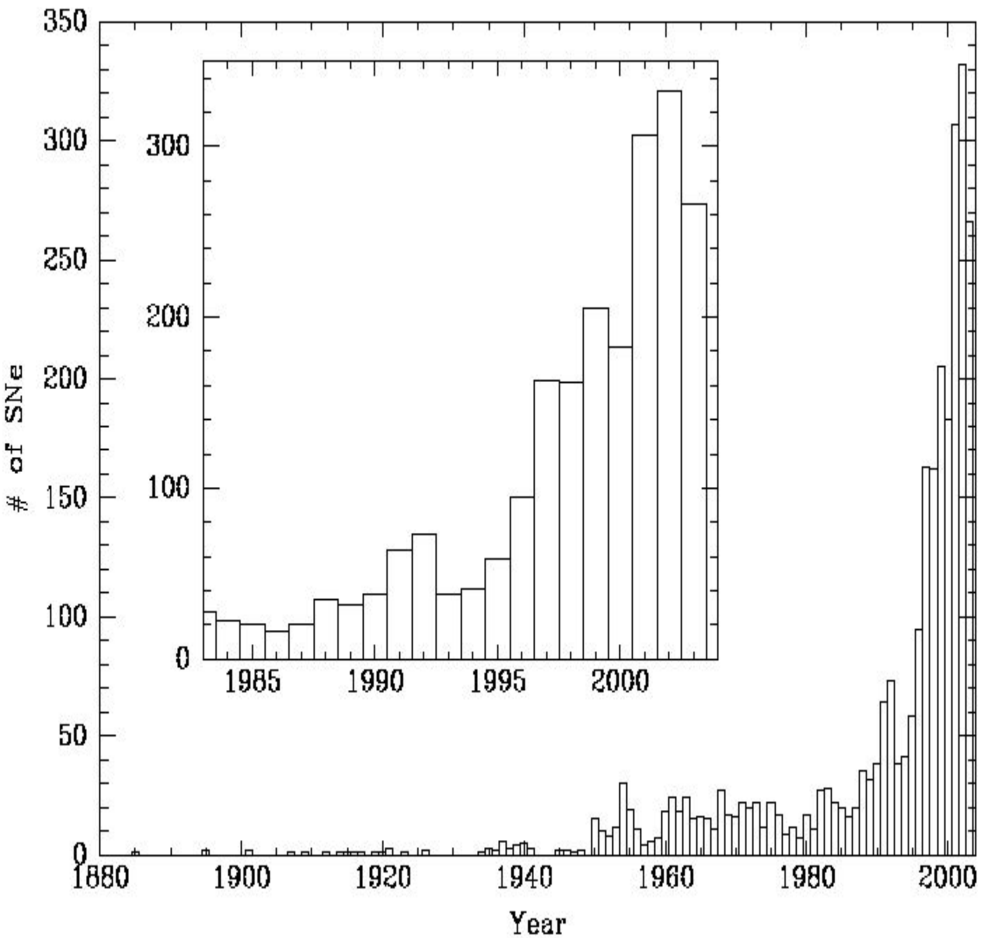
AARSTEN et al. 2015

IceCube-trigered supernova (z=0.0684)



AARSTEN et al. 2015

Supernovae discovered since 1885



1885 -- 1949:	0-6
1950 -- 1980:	20
1980 -- 1990:	30
1991 -- 1996:	70
1997 -- 2000:	180
2001 -- 2010:	300-500
2011 -- :	> 1000

A New Generation of Telescopes

Radio — Optical — Gamma-ray

Radio

LOFAR
MWA
LWA

ATA
EVLA
ALMA
SKA
FAST

Optical

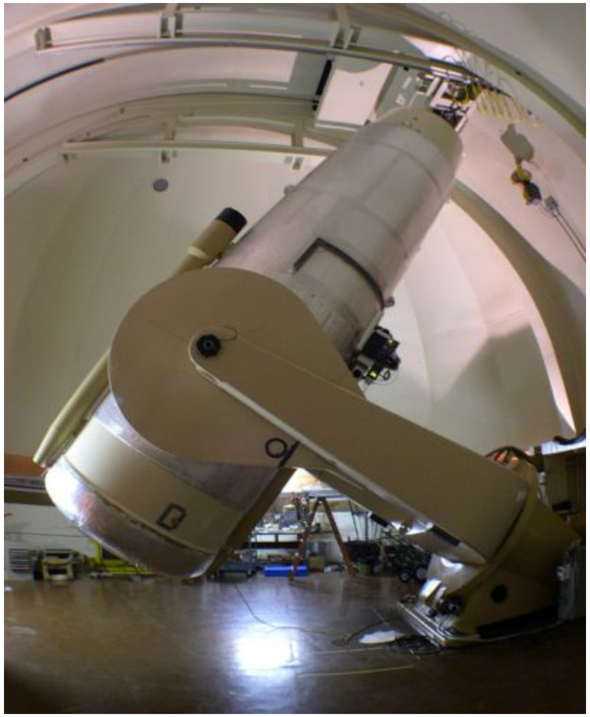
Pan Starrs
DES
LSST
KDUST

PTF,iPTF
La-Silla
Skymapper
TNTS1,TNTS2
ASAS,
AST3
TMT

Gamma-ray

Swift
GLAST
HXMT
SVOM

“Current” Optical Surveys



PTF

Telescope: Caltech 1.2-m
CCD: **0.1 G pixels**
FOV: 7.8 square degrees
Mag: 21.0

Panstarrs

Telescope: 1.8 m
CCD: 1**.4 G pixels**
FOV: 9.0 square degrees
Mag: 24.0 mag

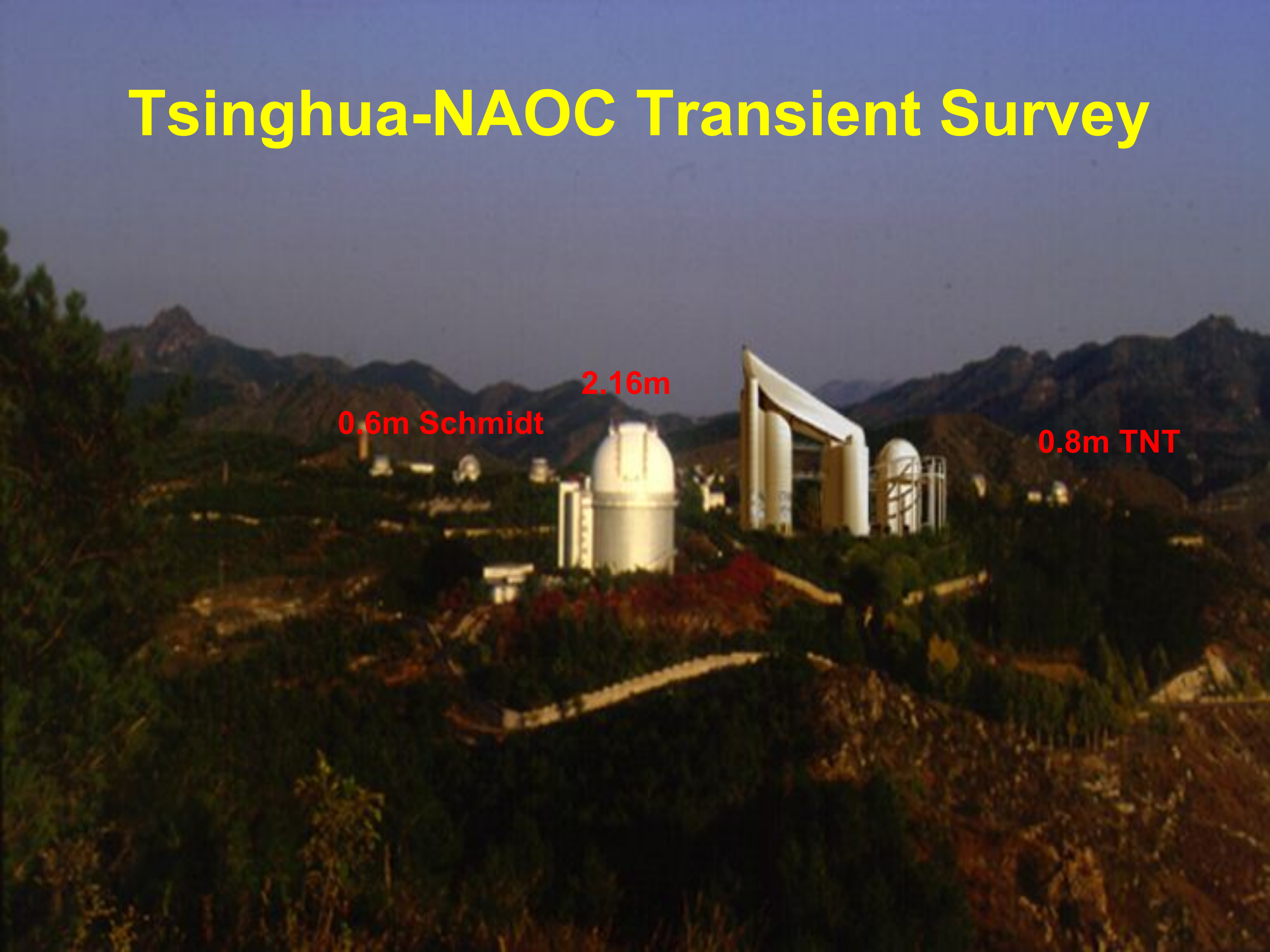
La-Silla Quest

Telescope: ESO 1.0-m
CCD: **0.16G pixels**
FOV: 9 square degrees
Mag:24.0 mag

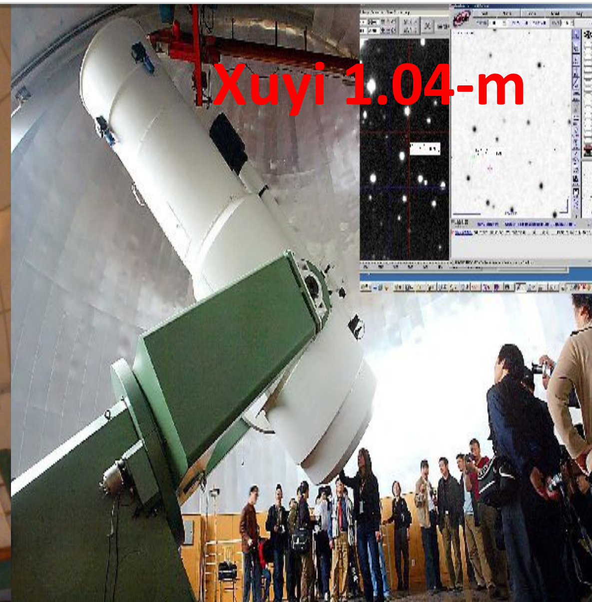
AST3-1 and AST3-2

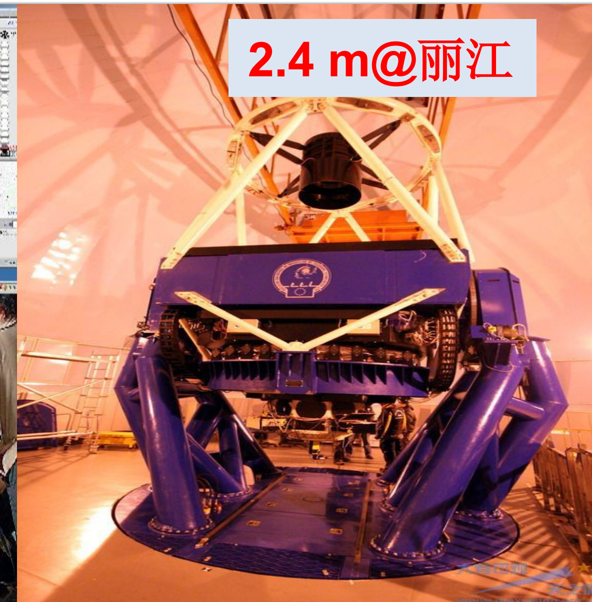
- Telescope: AST3 0.5m
- CCD: **0.1 G pixels**
- FOV: 4.3-8.6 square degrees
- Mag: ~20.0 mag

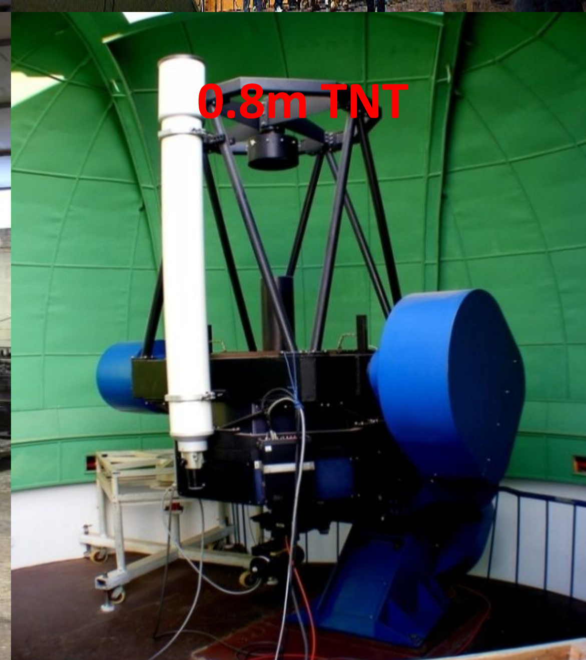
Tsinghua-NAOC Transient Survey

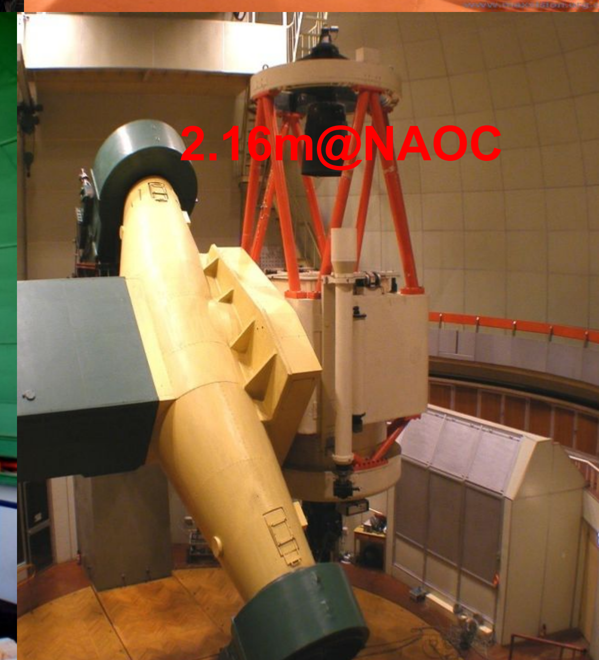


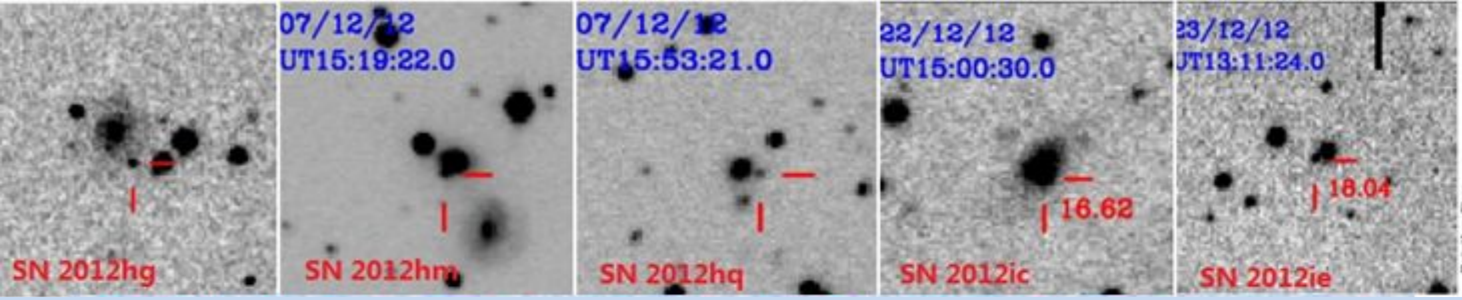
Wide-field telescopes and follow-up facilities in China



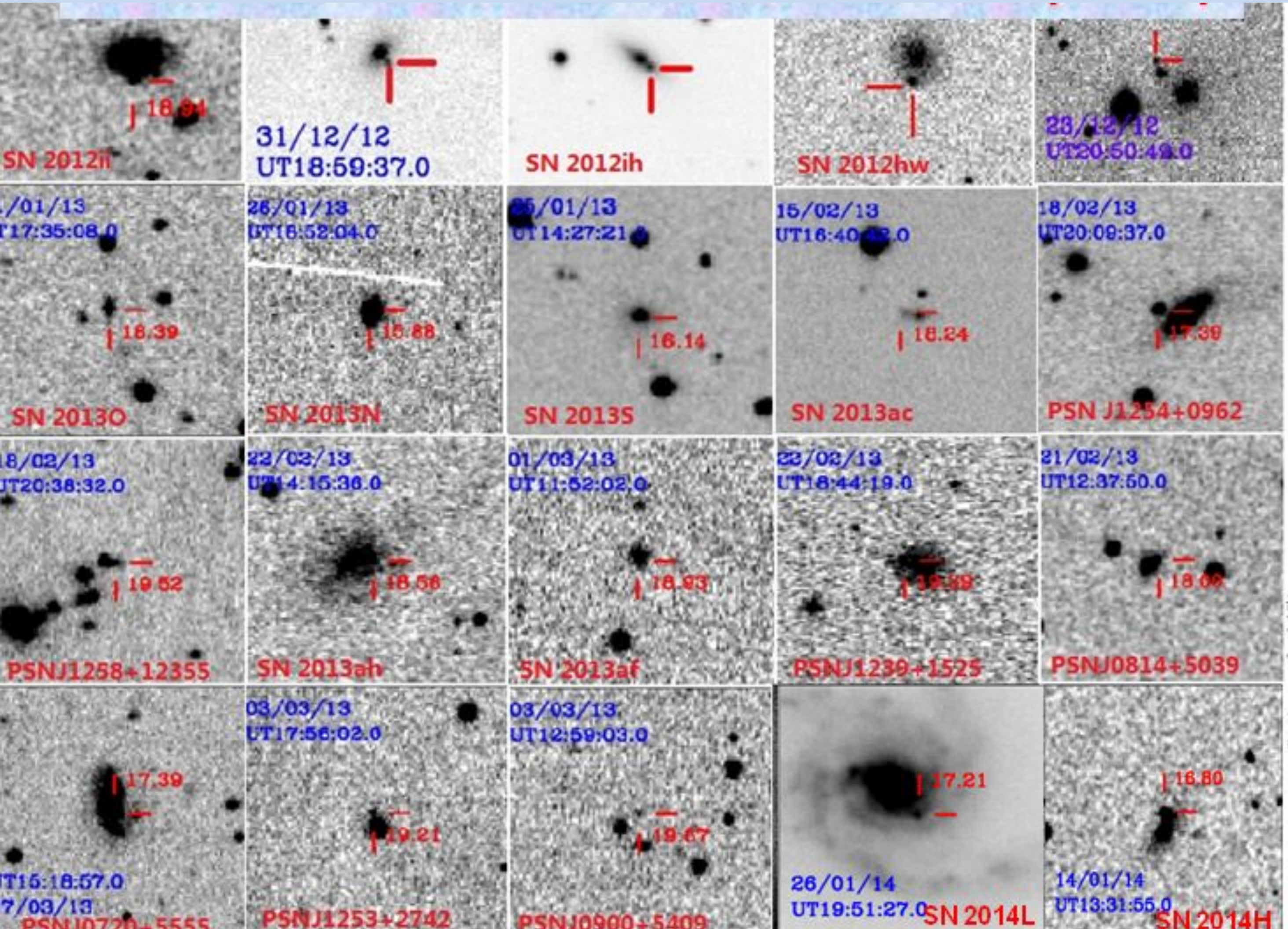


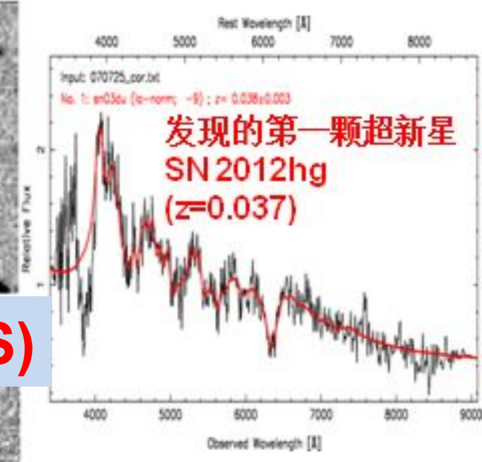


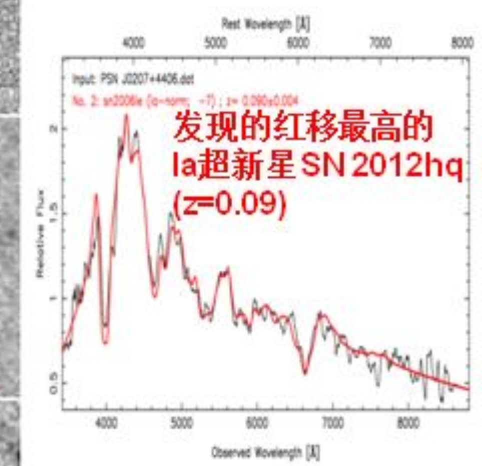


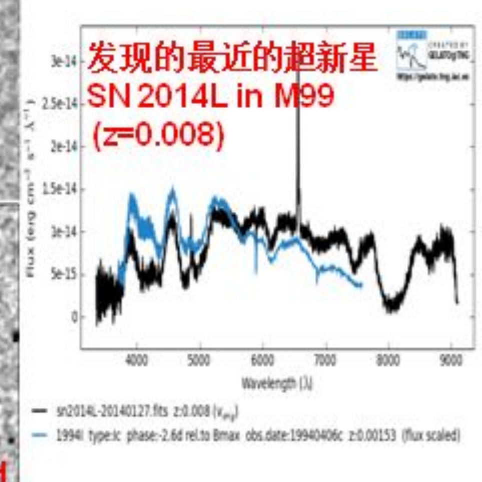


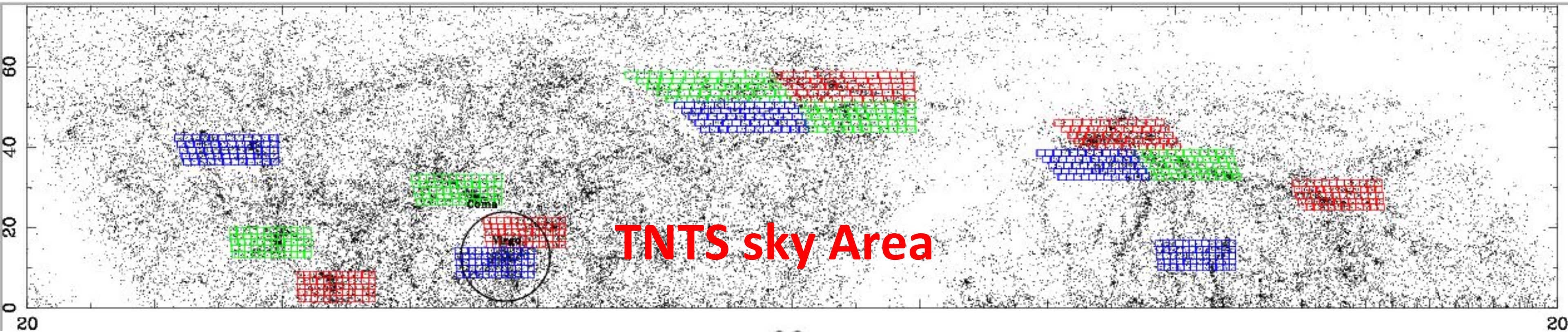
Tsinghua University-NAOC Transient Survey (TNTS)

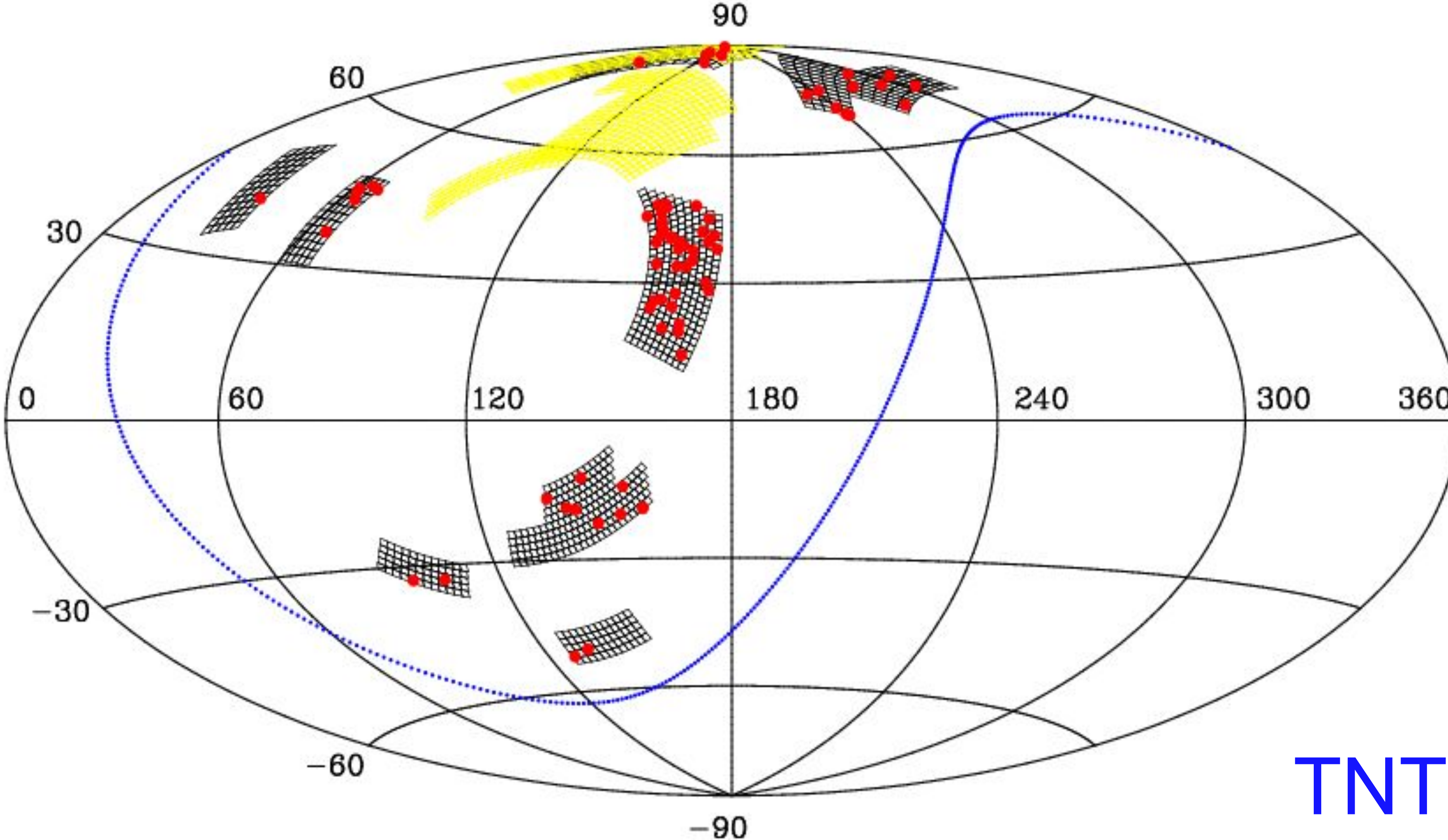






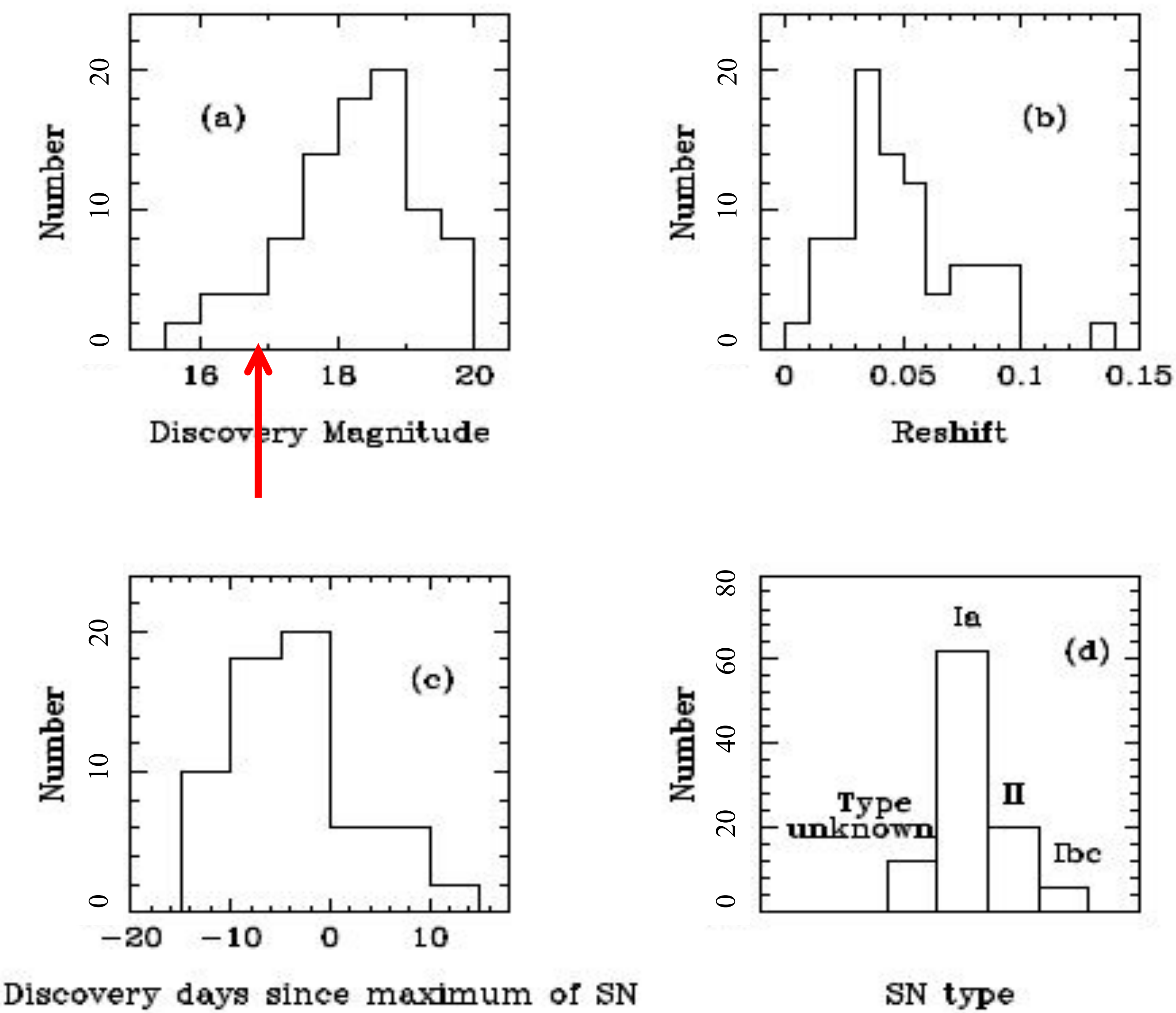



TNTS sky Area
Coma
60
40
20
0
20
20


90
60
30
0
60
120
180
240
300
360
−30
−60
−90

TNTS

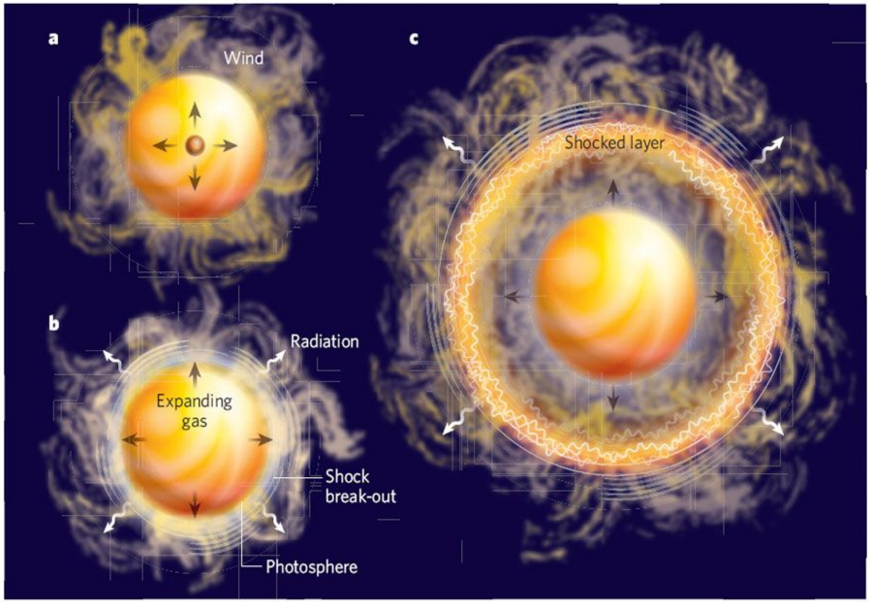
SN Sample from TNTS (N>120 since Nov. 2012)

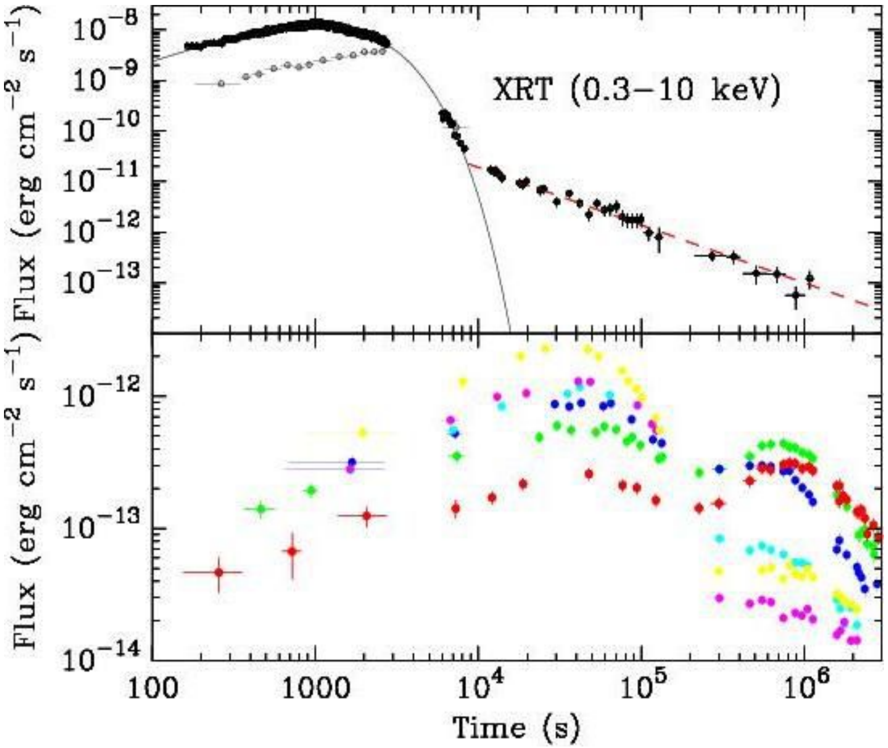


Zhang, Wang et al. 2015, RAA

Neutrino Alert for Supernova Detection

Early discovery is important for Shock breakout detection

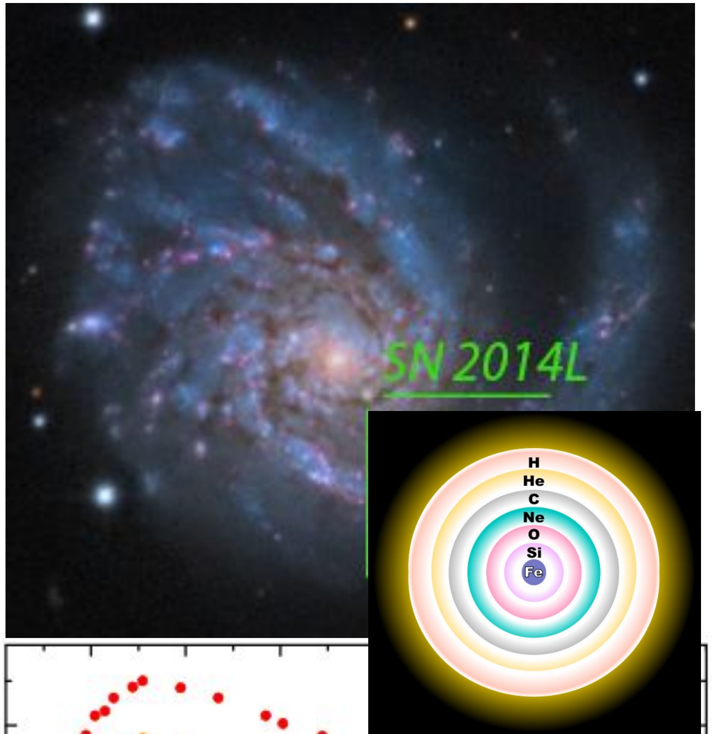


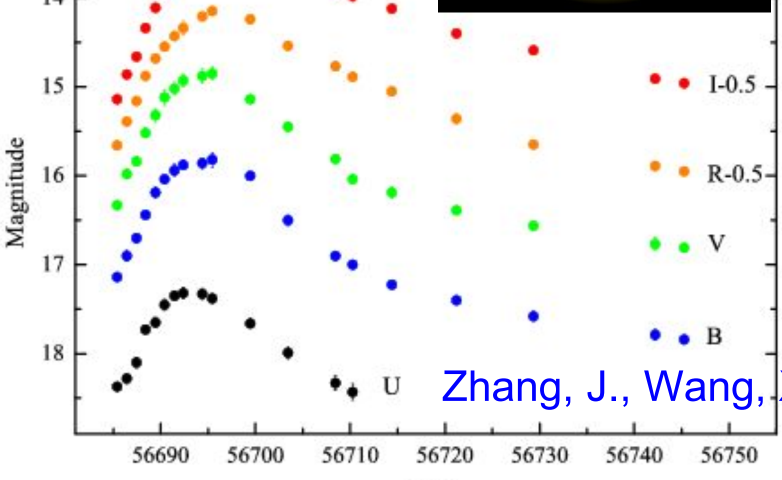


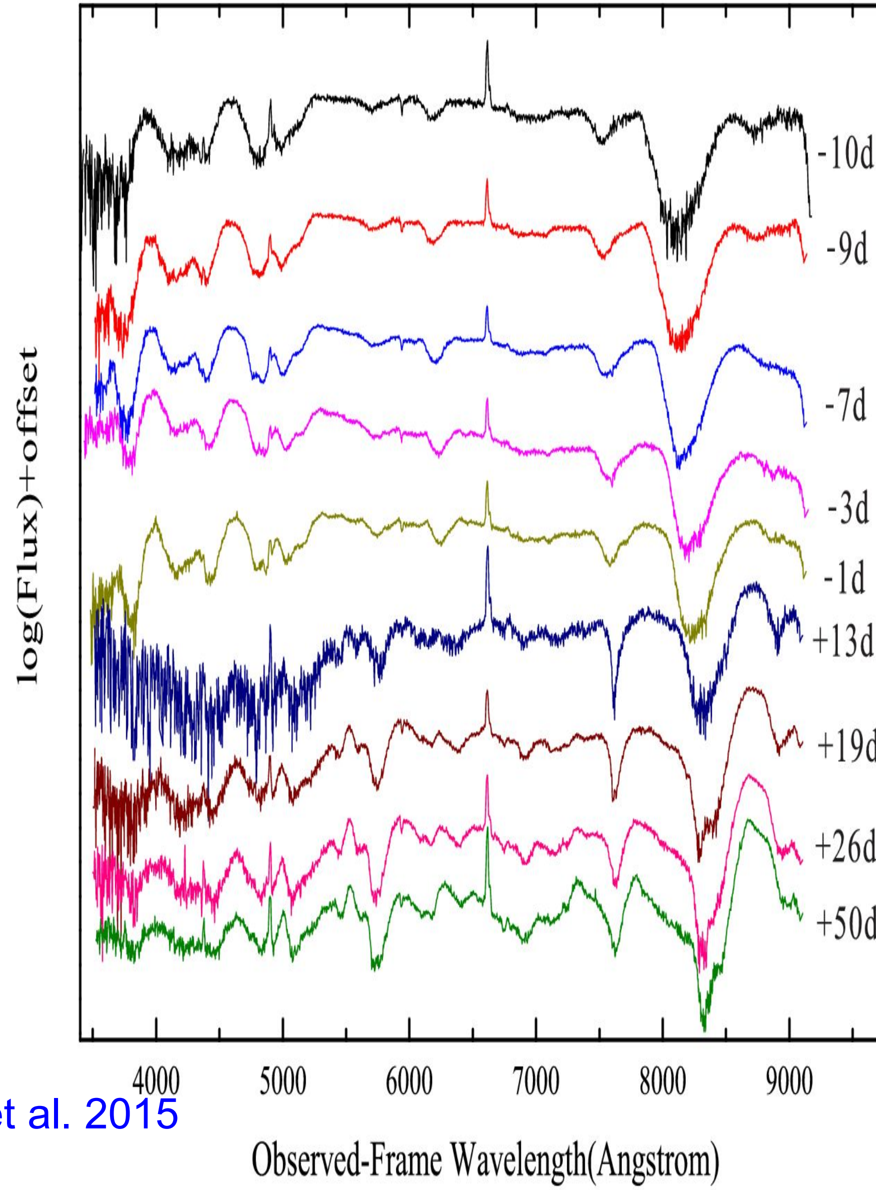
Soderberg et al. 2008, Nature **453**, 469

激波爆的探测对于验证恒星演化理论和限制前身星性质具有非常重要的物理意义。

SN 2014L in M99 (D=13-14 Mpc)

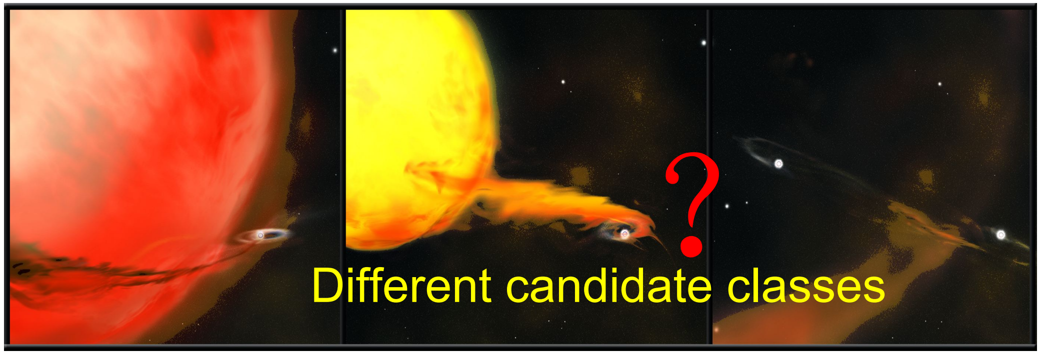


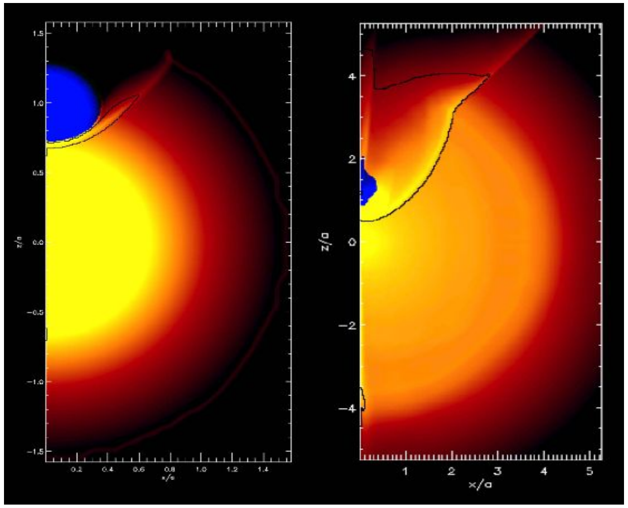




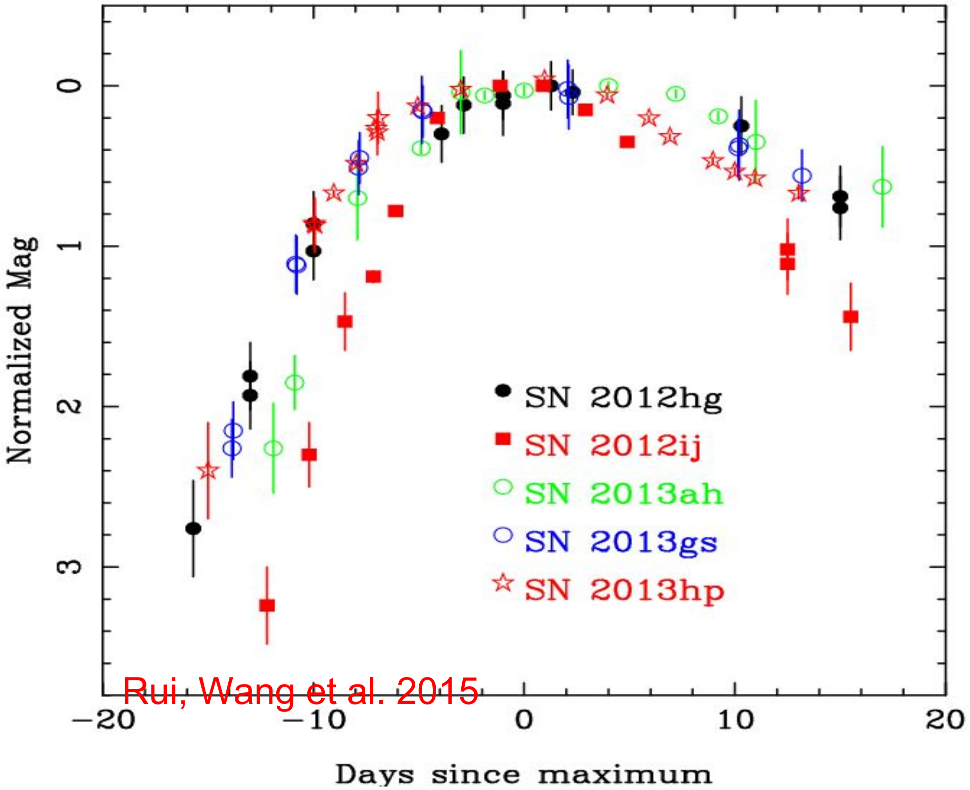
Zhang, J., Wang, X. et al. 2015

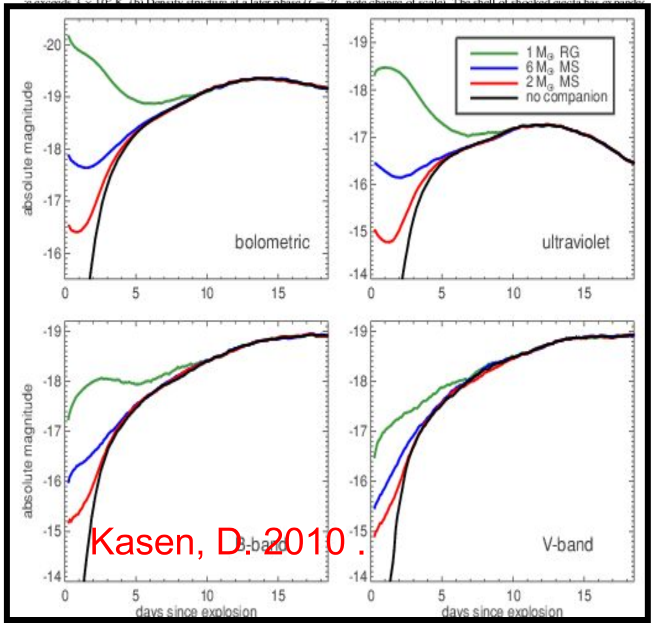
Important for Constraining SN Ia Progenitors

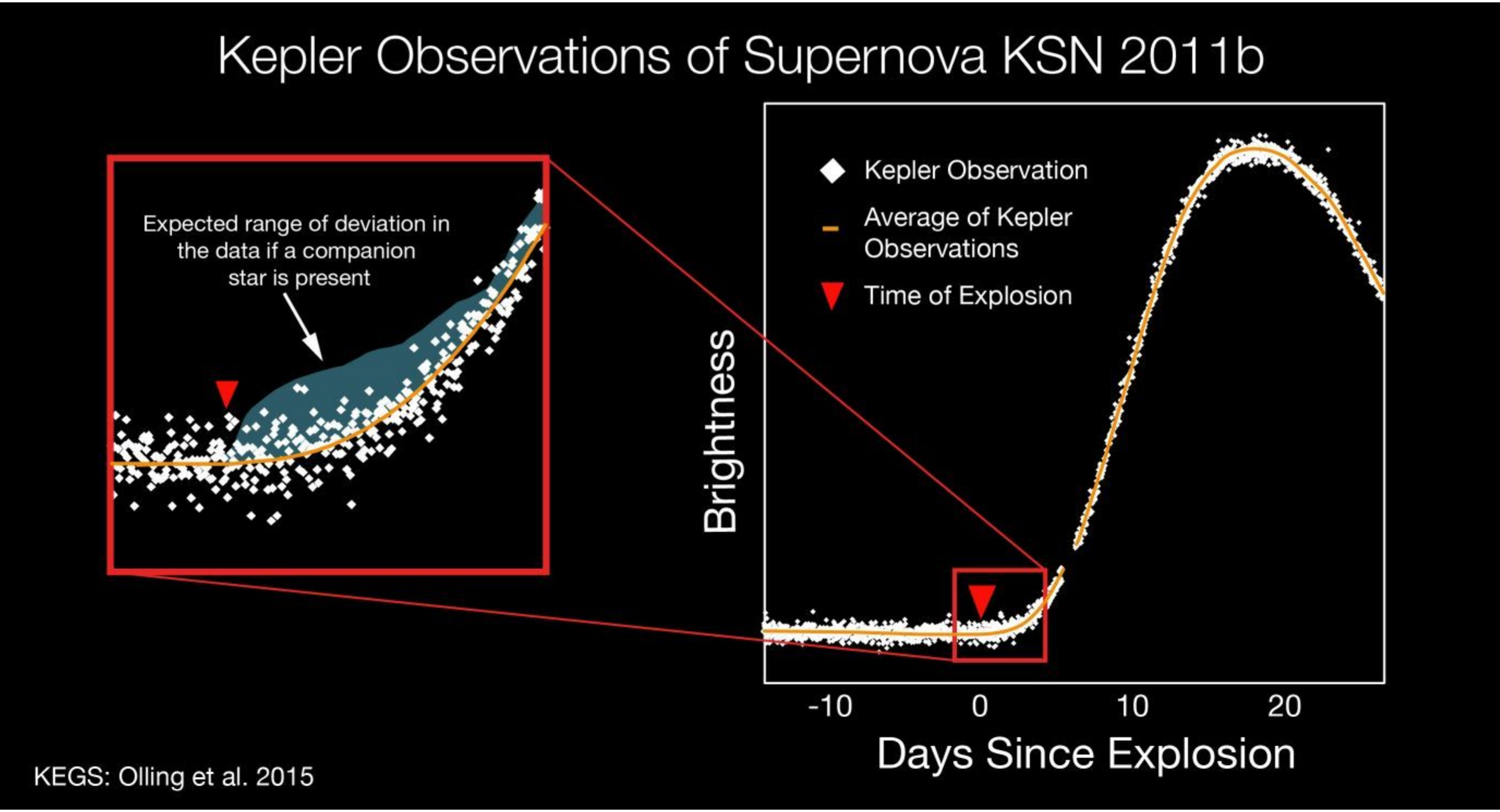




ynamic calculation of a Type Ia supernova colliding with a red giant star ($R_* = 10^{13}$ cm, $a = 2.5 \times 10^{13}$ cm). (a) Density structure
$= t_1/2$). The companion star (drawn in blue) diverts the flow and carves a hole in the ejecta. The black contour shows the region w



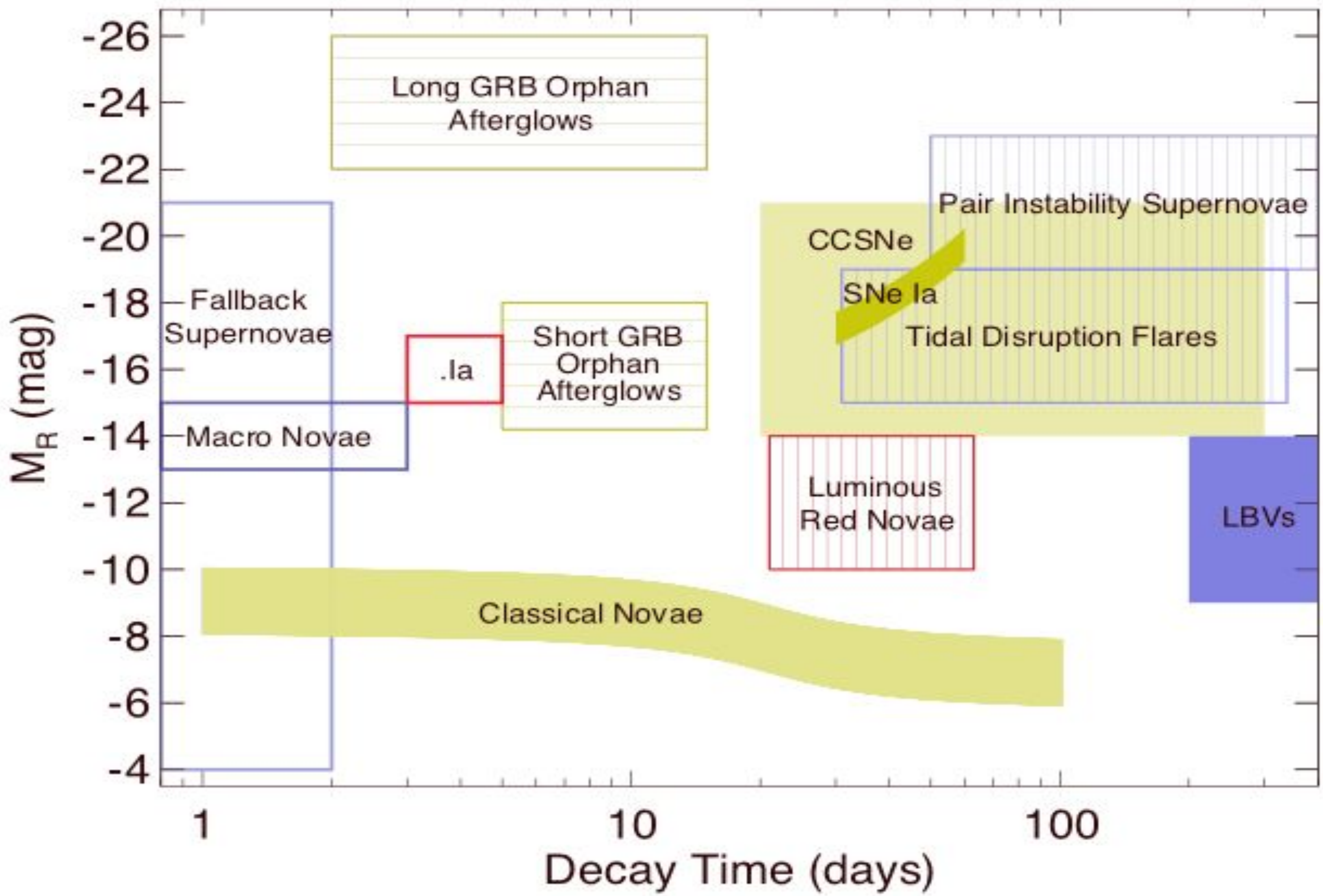




RP Olling *et al.* *Nature* **521**, 332-335 (2015) doi:10.1038/nature14455

nature

Neutrinos from Other Transients?



Star that may explode soon