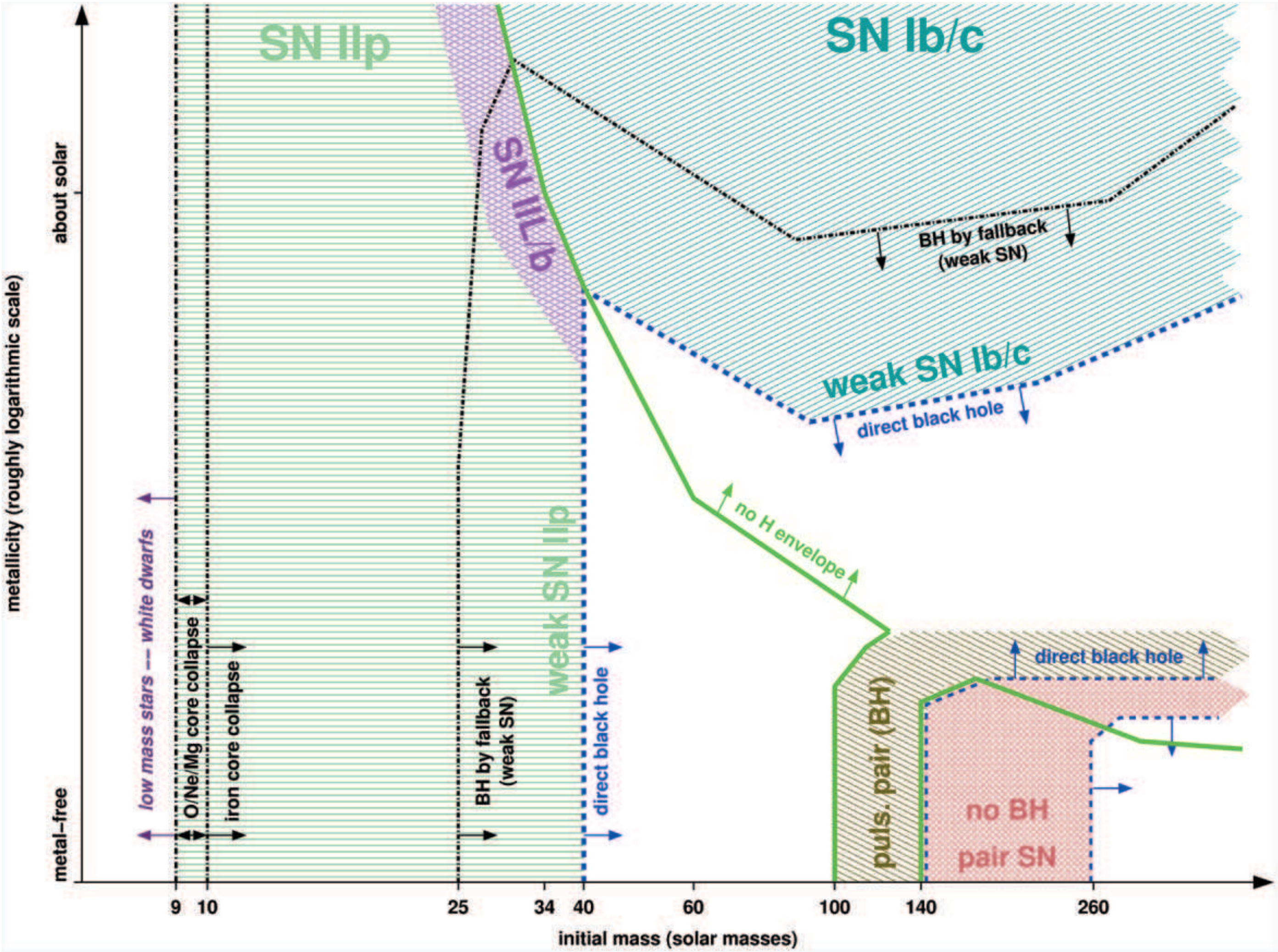
Supernova 2005cs and the Origin of Type IIP Supernovae

Victor Utrobin
ITEP, Moscow

with Nikolai Chugai (INASAN, Moscow)

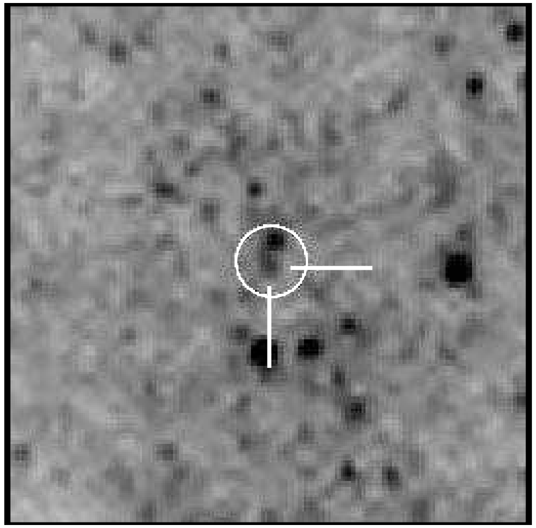
Conference on "Physics of Neutron Stars - 2008"
St. Petersburg, Russia
June 24 – 27, 2008

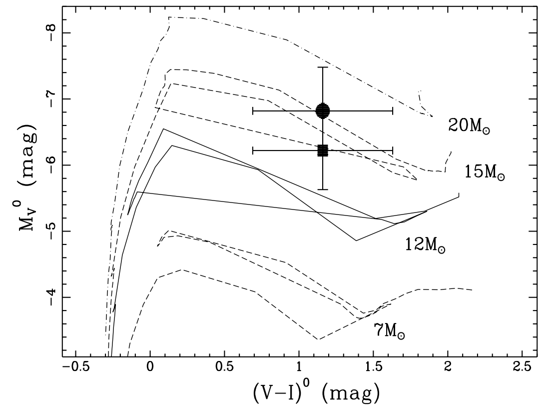
Death of Massive Stars



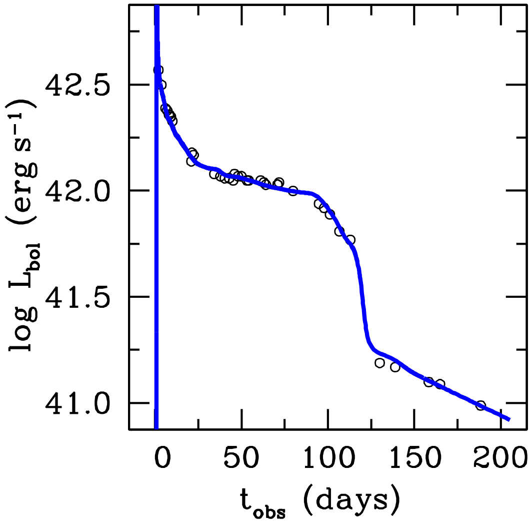
Type IIP SNe originate presumably from $9 - 25 M_{\odot}$ main-sequence stars (Heger et al. 2003).

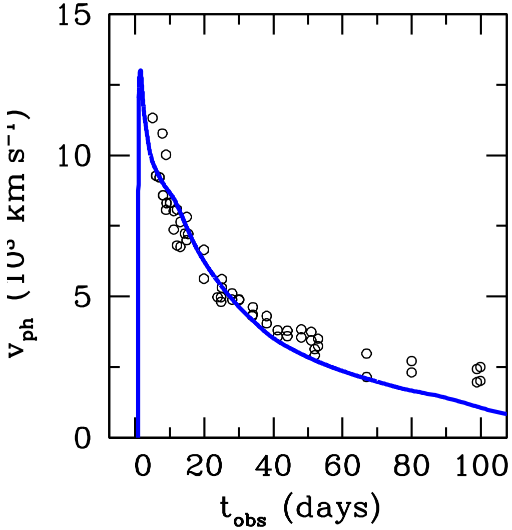
Two Methods to Estimate Mass of the Progenitor





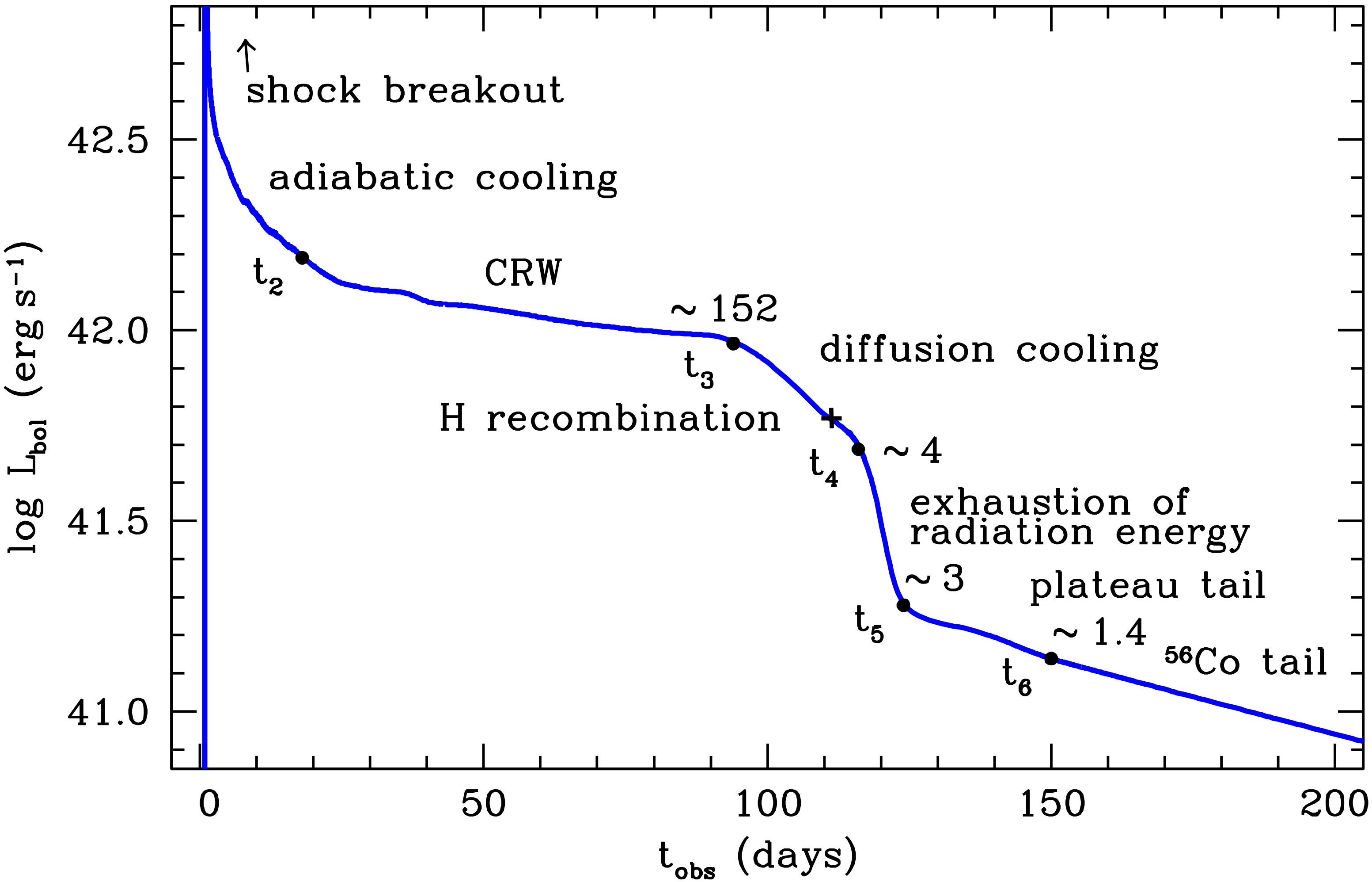
"Evolutionary mass"
The flux and the color index of detected pre-SN can be converted into stellar mass using the stellar evolution models. Evolutionary mass is measured for 8 pre-SNe, and for 6 pre-SNe the upper limits are estimated (Li et al. 2007).





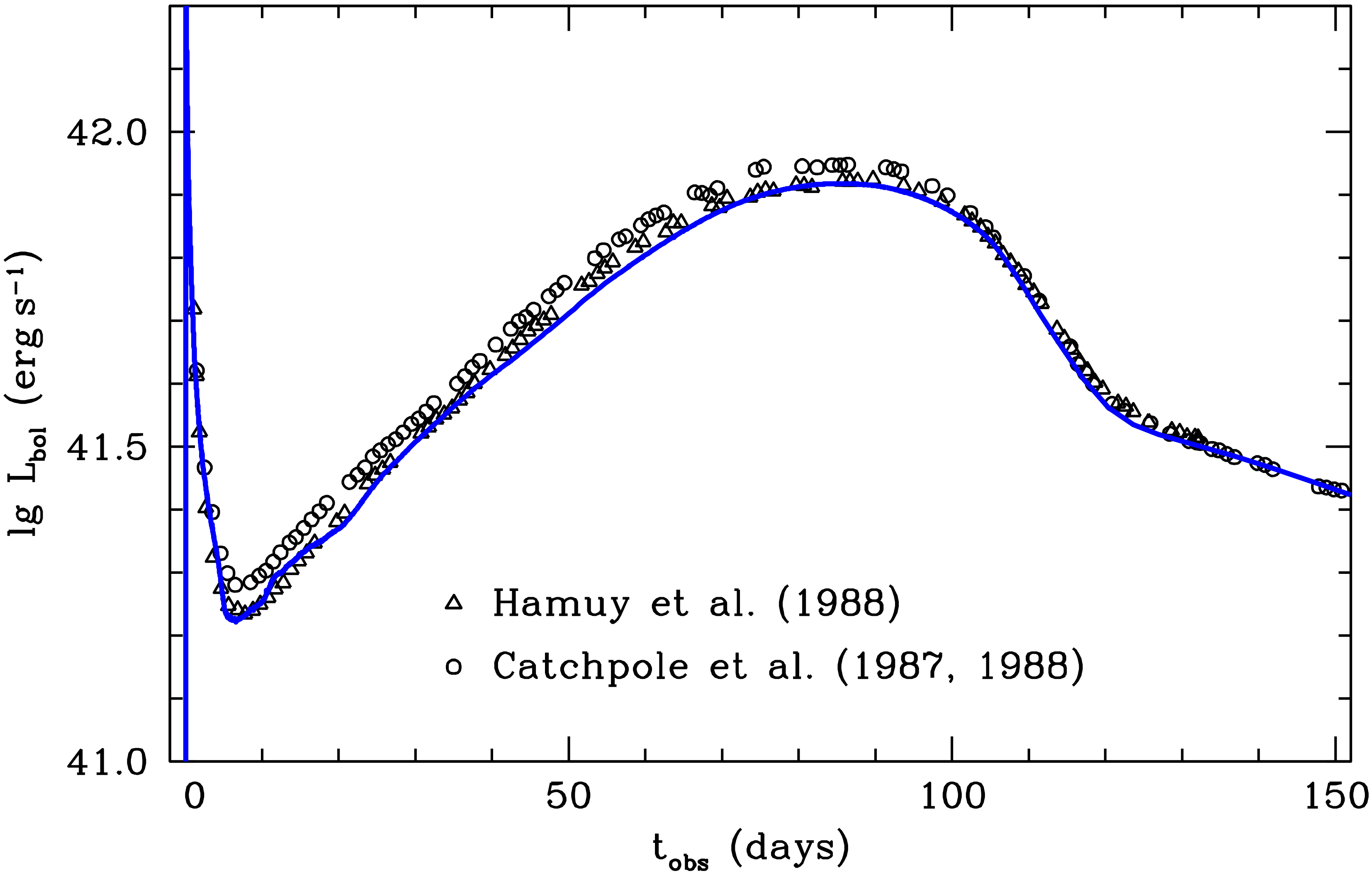
"Hydrodynamic mass"
Hydrodynamic modeling recovers the ejecta mass which, combined with the mass of neutron star and the mass lost by the stelar wind, gives the mass estimate of main-sequence star. Hydrodynamic mass is measured only for three type IIP SNe.

Physics of the Light Curve



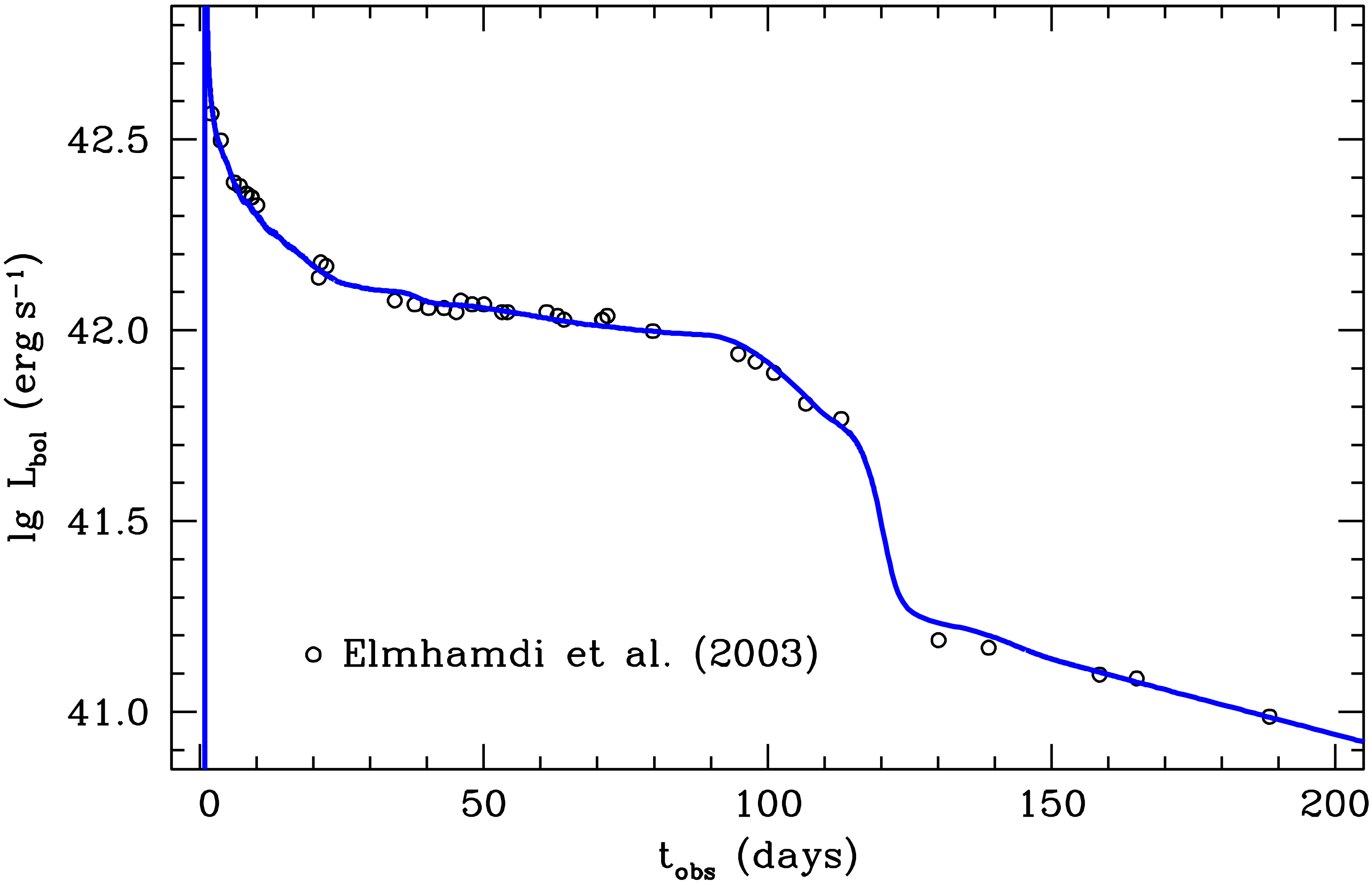
There are a few type IIP SNe that have complete photometry and good quality spectra.

The Peculiar Type IIP SN 1987A



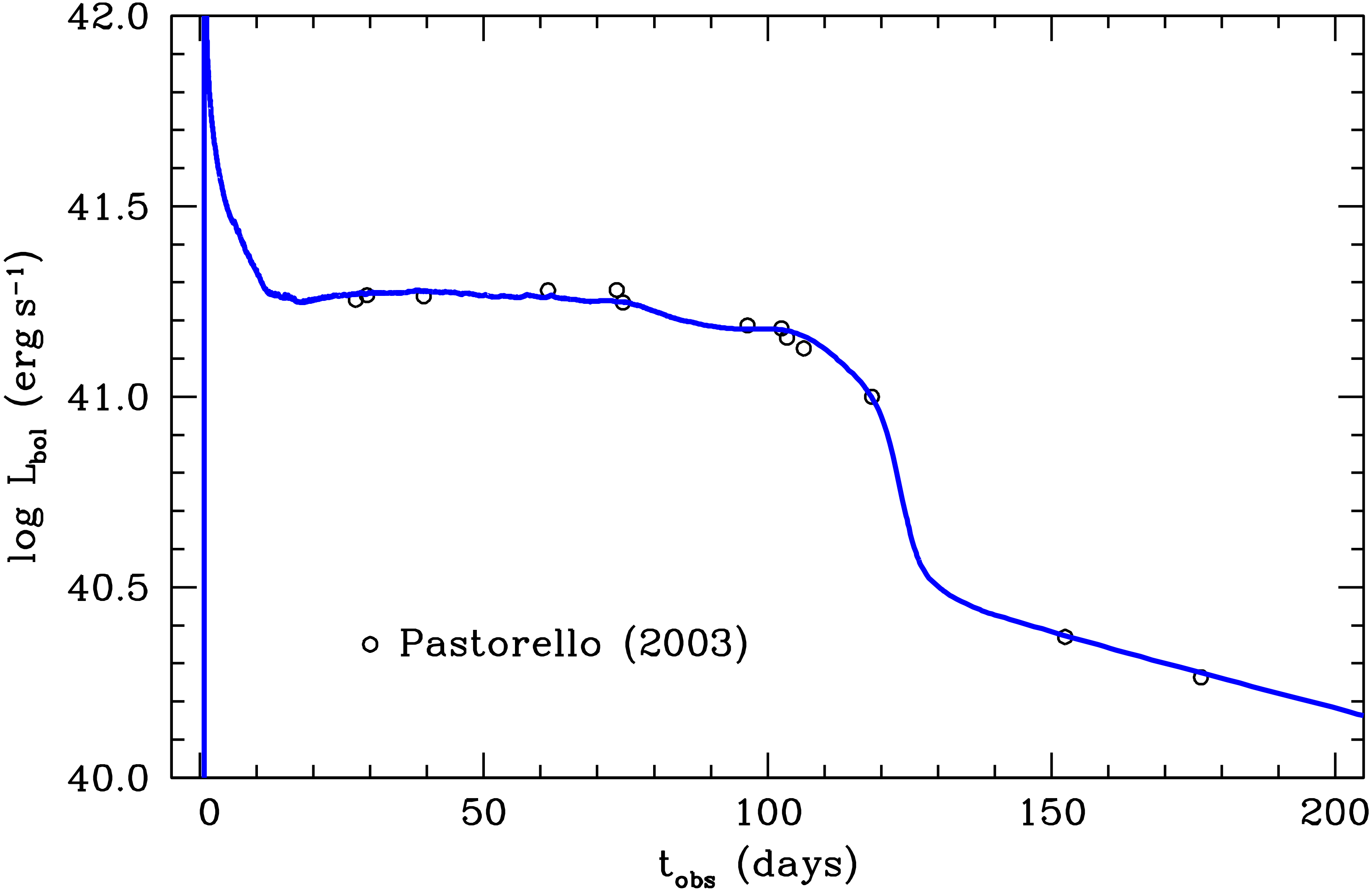
$R_0 = 35R_\odot$, $M_{env} = 18M_\odot$, $E = 1.5 \times 10^{51}$ erg, $M_{\rm Ni} = 0.0765M_\odot$ (Utrobin 2005)

The Normal Type IIP SN 1999em



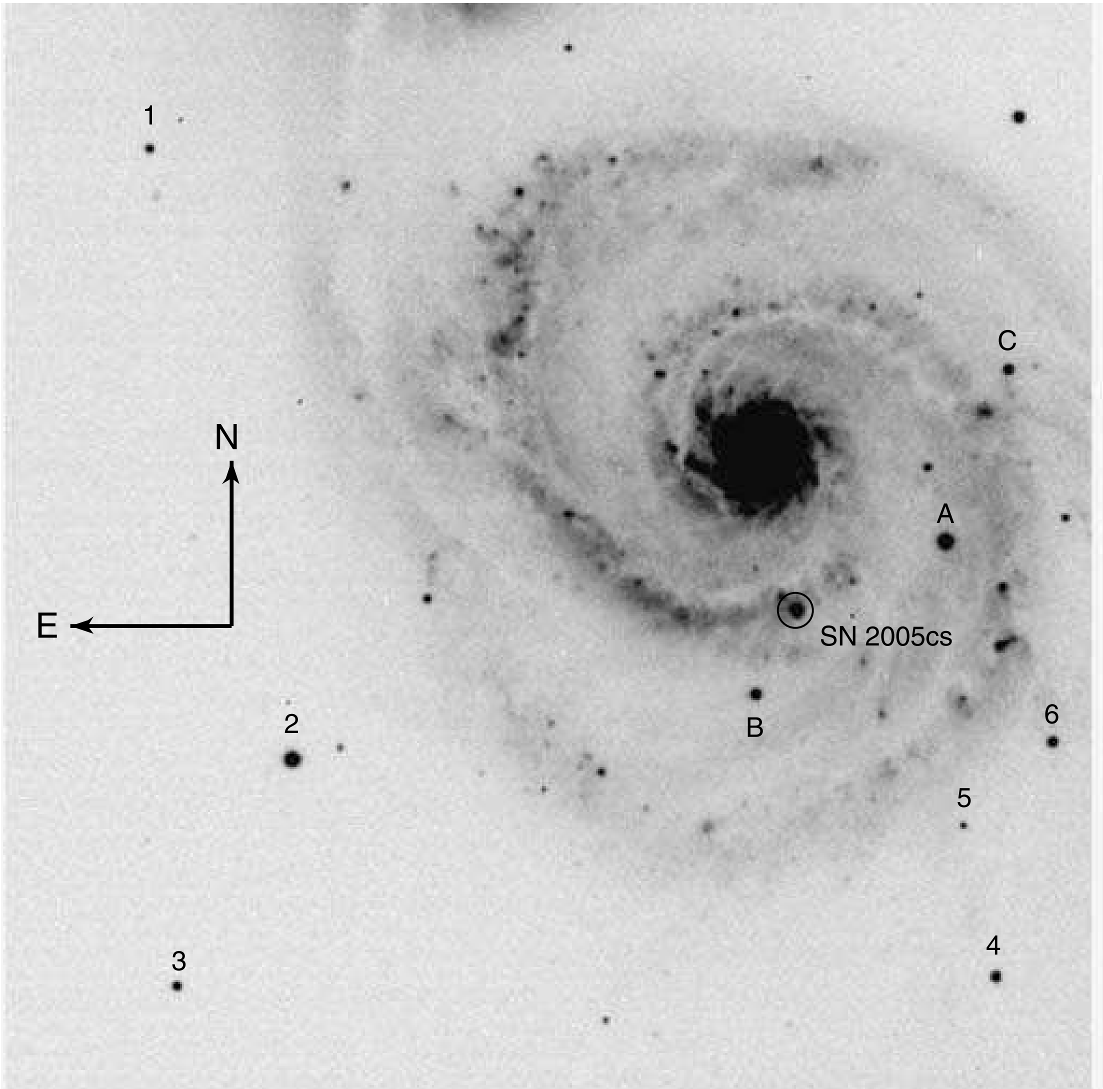
$R_0 = 500 R_\odot$, $M_{env} = 19 M_\odot$, $E = 1.3 \times 10^{51}$ erg, $M_{\rm Ni} = 0.036 M_\odot$ (Utrobin 2007)

The Low-Luminosity Type IIP SN 2003Z



$R_0 = 230 R_\odot$, $M_{env} = 14 M_\odot$, $E = 2.45 \times 10^{50}$ erg, $M_{\rm Ni} = 0.0063 M_\odot$
(Utrobin et al. 2007)

The Sub-Luminous Type IIP Supernova 2005cs in M51



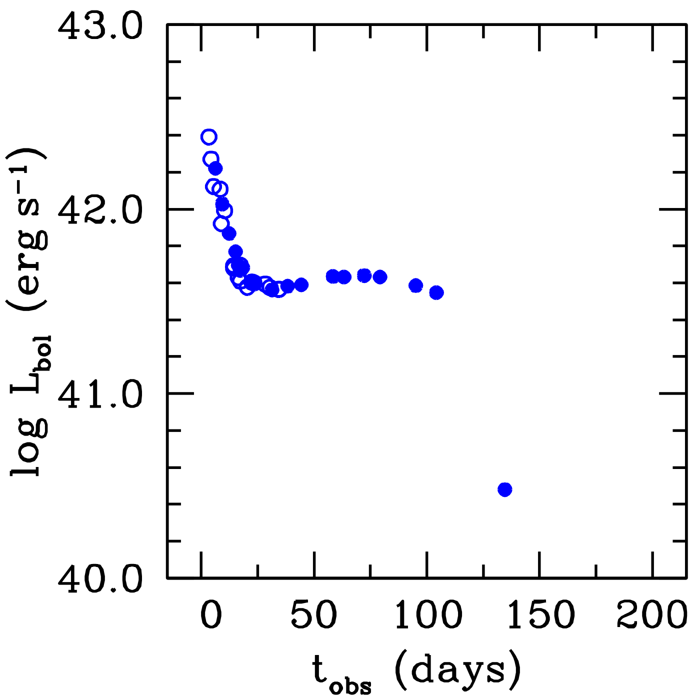
Discovered by amateur Wolfgang Kloehr (Germany)

t_0=JD 2453549±1
D=8.4 Mpc
(Pastorello et al. 2006)

E_{B-V} = 0.12±0.08
(Li et al. 2006)

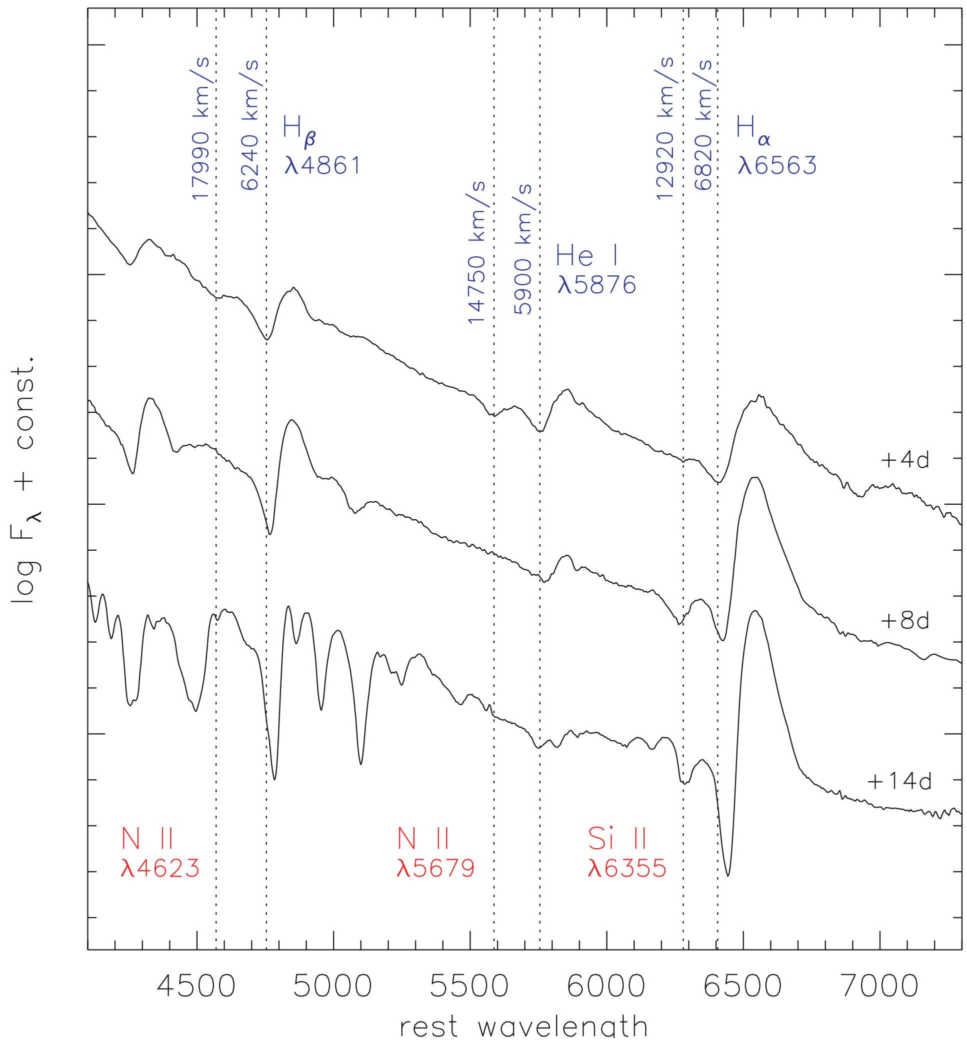
V-band image obtained on 2005 July 1 (Pastorello et al. 2006).

Supernova 2005cs: Bolometric Light Curve and Spectra



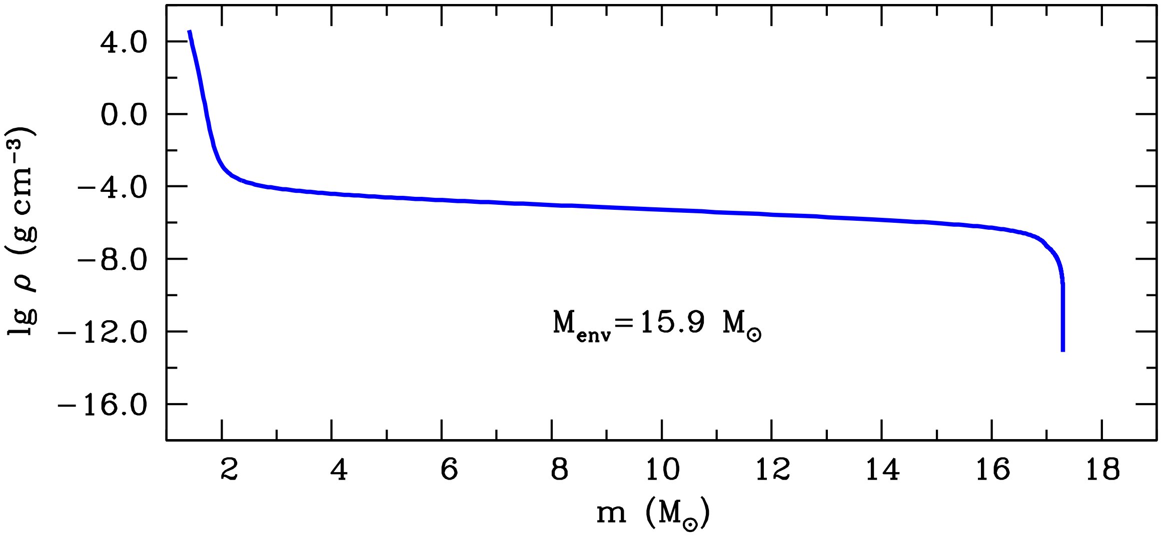
The observed bolometric light curve is recovered from $UBVRI$ photometry of Pastorello et al. (2006) and Tsvetkov et al. (2006).

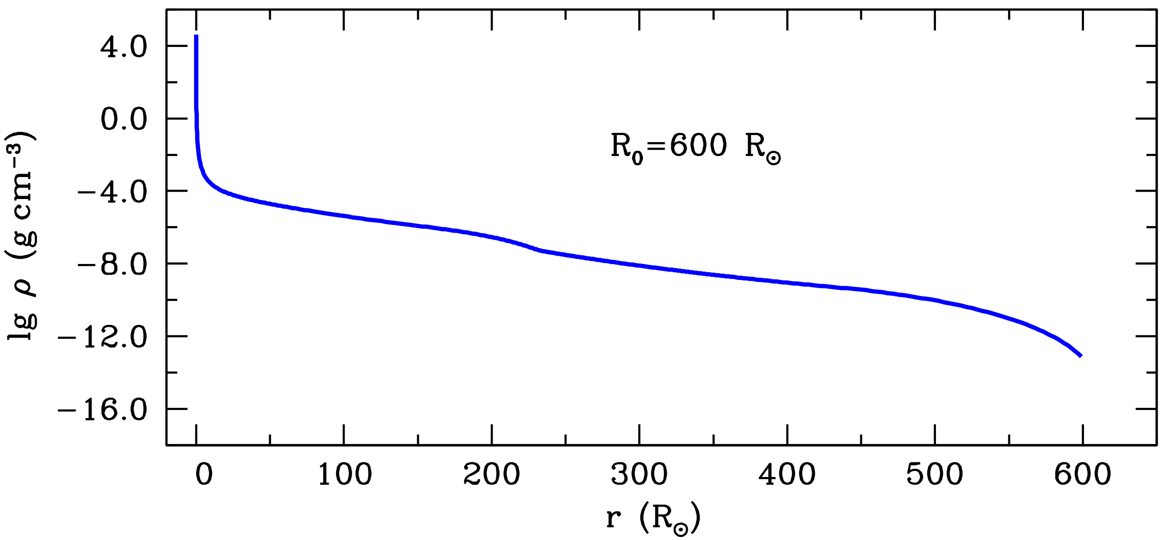
$M_{\rm Ni} = 0.0082 M_\odot$ from R-luminosity compared to that of SN 1987A



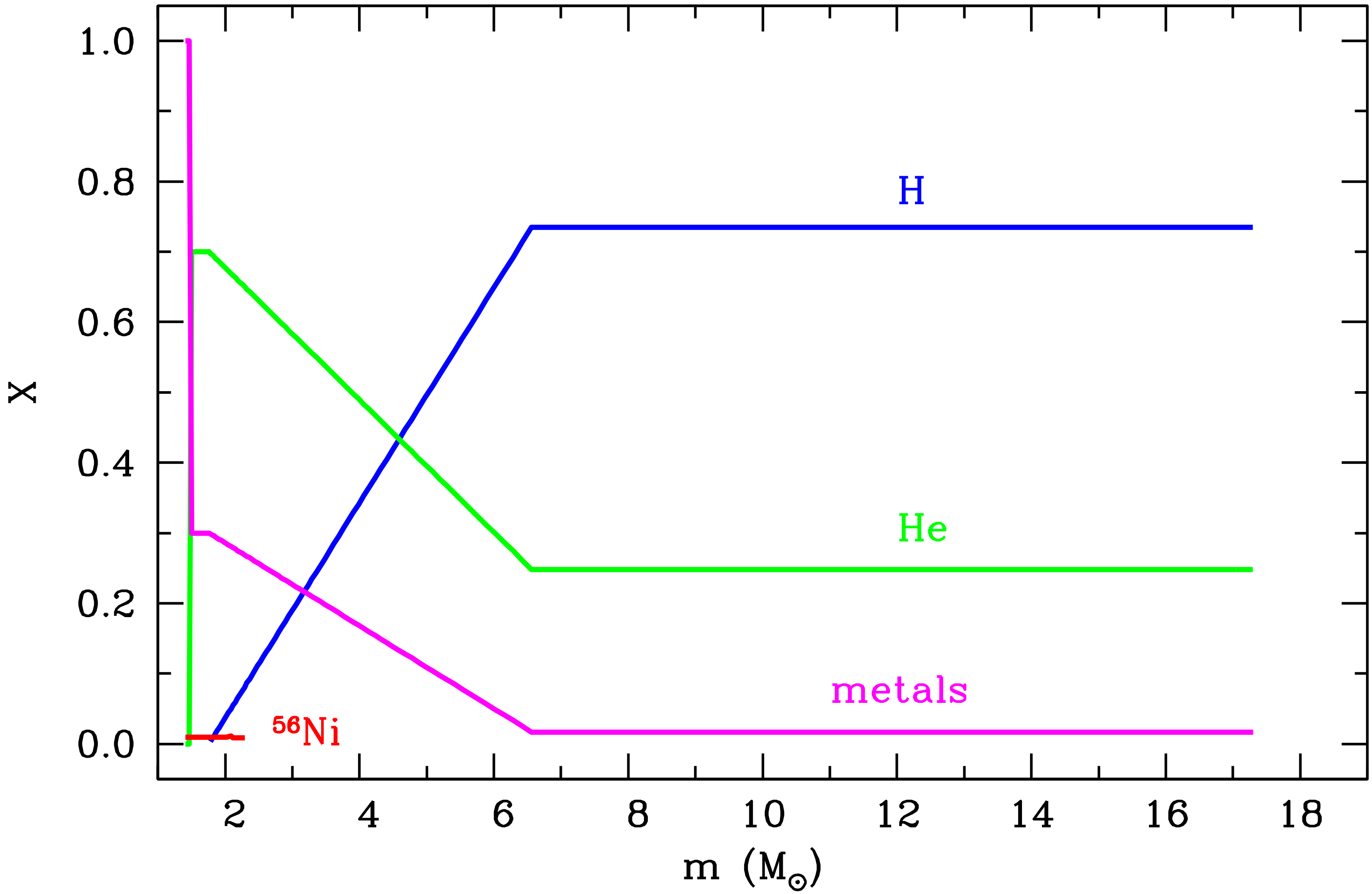
$v_{max} = 10000$ km s^{-1} (Pastorello et al. 2006)

Hydrodynamic Model: Presupernova Structure



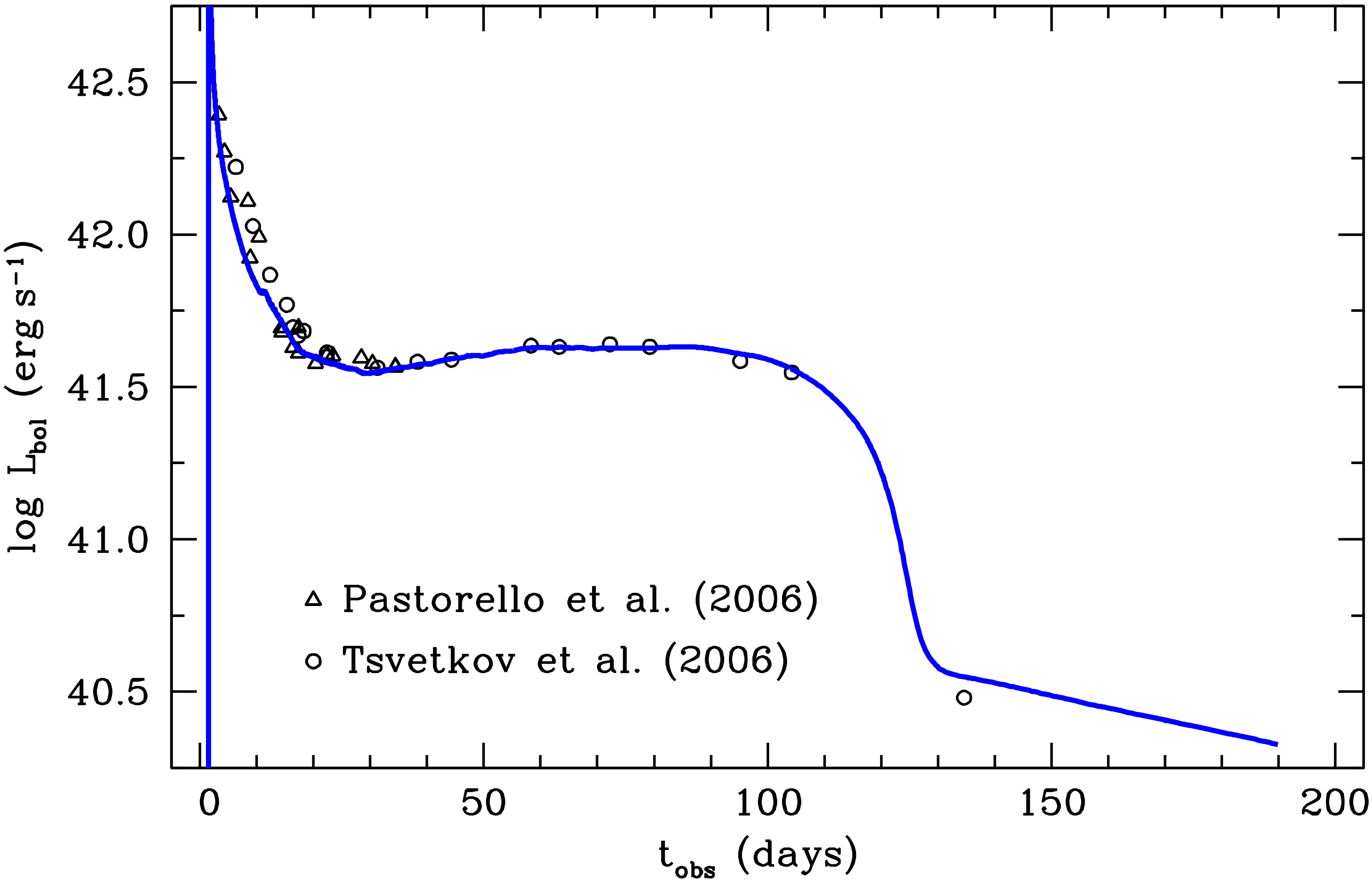


Hydrodynamic Model: Chemical Composition



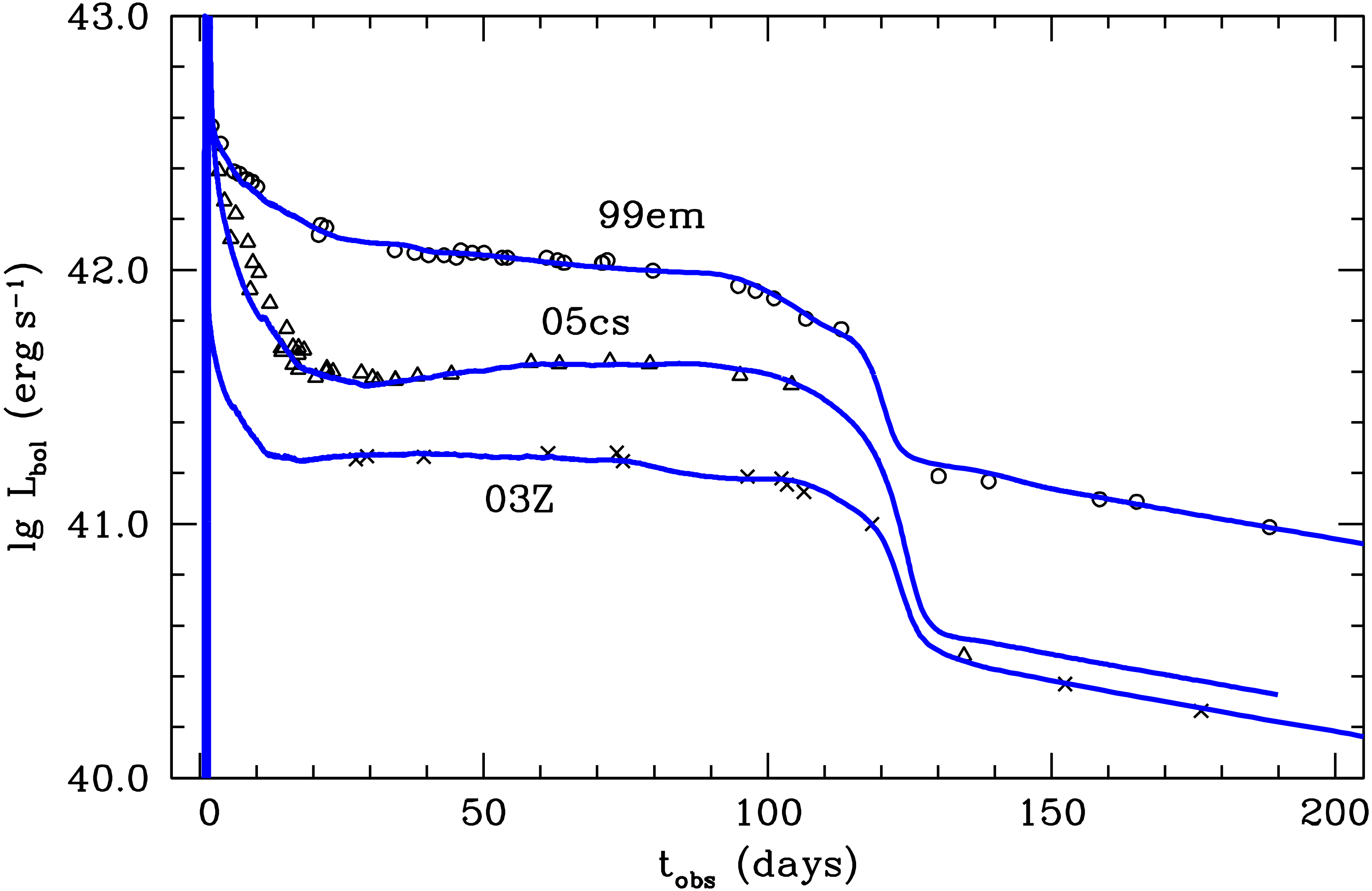
$M_{\rm He}^{core} = 4.2 M_{\odot}$, $v_{\rm Ni}^{max} = 610$ km s^{-1}, $v_{\rm H}^{min} = 300$ km s^{-1}

Hydrodynamic Model: Bolometric Light Curve



$R_0 = 600 R_\odot$, $M_{env} = 15.9 M_\odot$, $E = 4.1 \times 10^{50}$ erg, $M_{\rm Ni} = 0.0082 M_\odot$

Bolometric Light Curves of Type IIP Supernovae



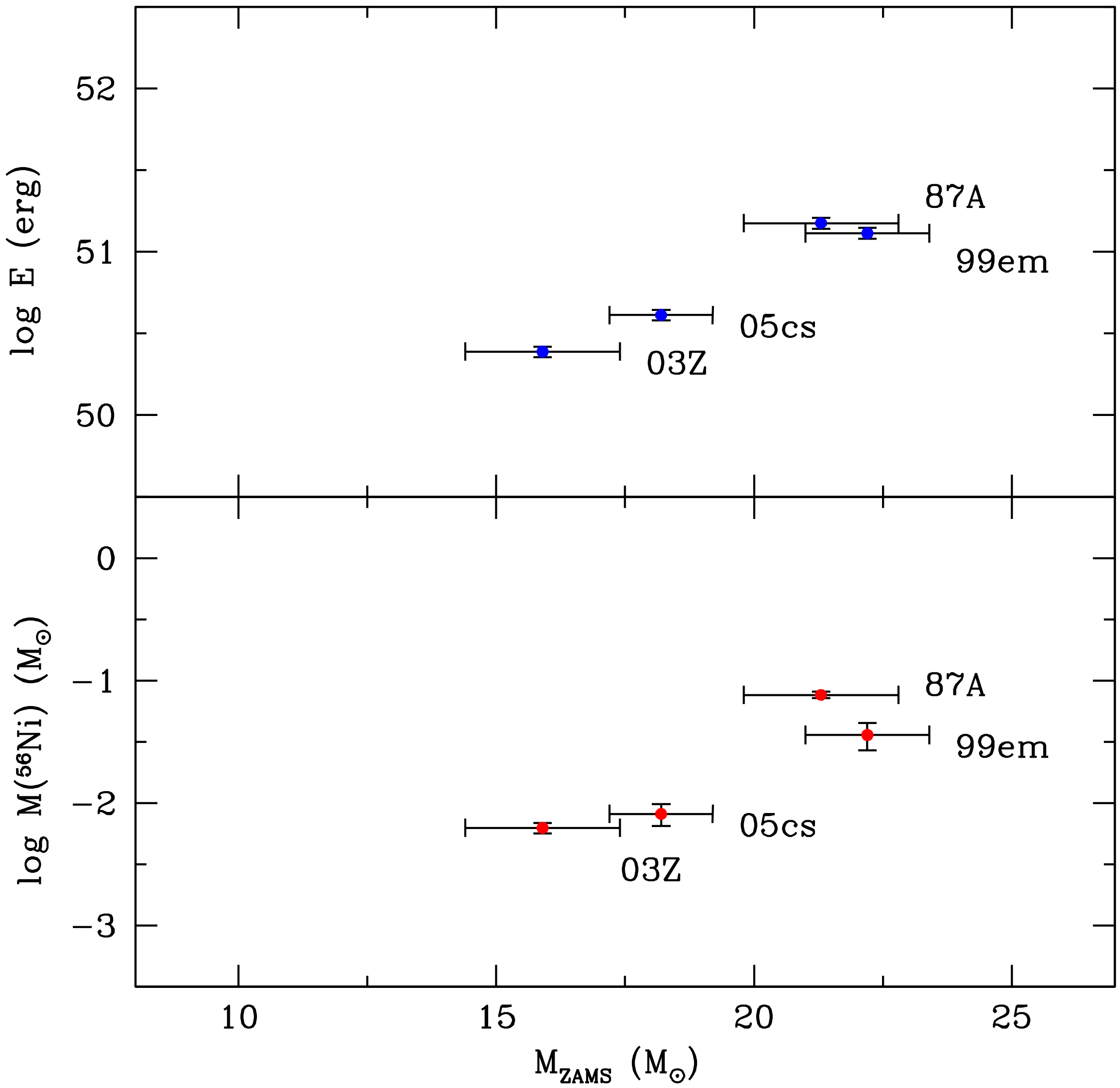
The initial peak of SN 2005cs is more prominent than those of other type IIP SNe.

Hydrodynamic Models for Type IIP Supernovae

SN	R_0 ($R_\odot$)	M_{env} ($M_\odot$)	E (10^{51} erg)	$M_{\rm Ni}$ ($10^{-2} M_\odot$)	$v_{\rm Ni}^{max}$ (km s^{-1})	$v_{\rm H}^{min}$ (km s^{-1})
SN 1987A	35	18	1.5	7.65	3000	600
SN 1999em	500	19	1.3	3.60	660	700
SN 2003Z	230	14	0.245	0.63	535	360
SN 2005cs	600	15.9	0.41	0.82	610	300

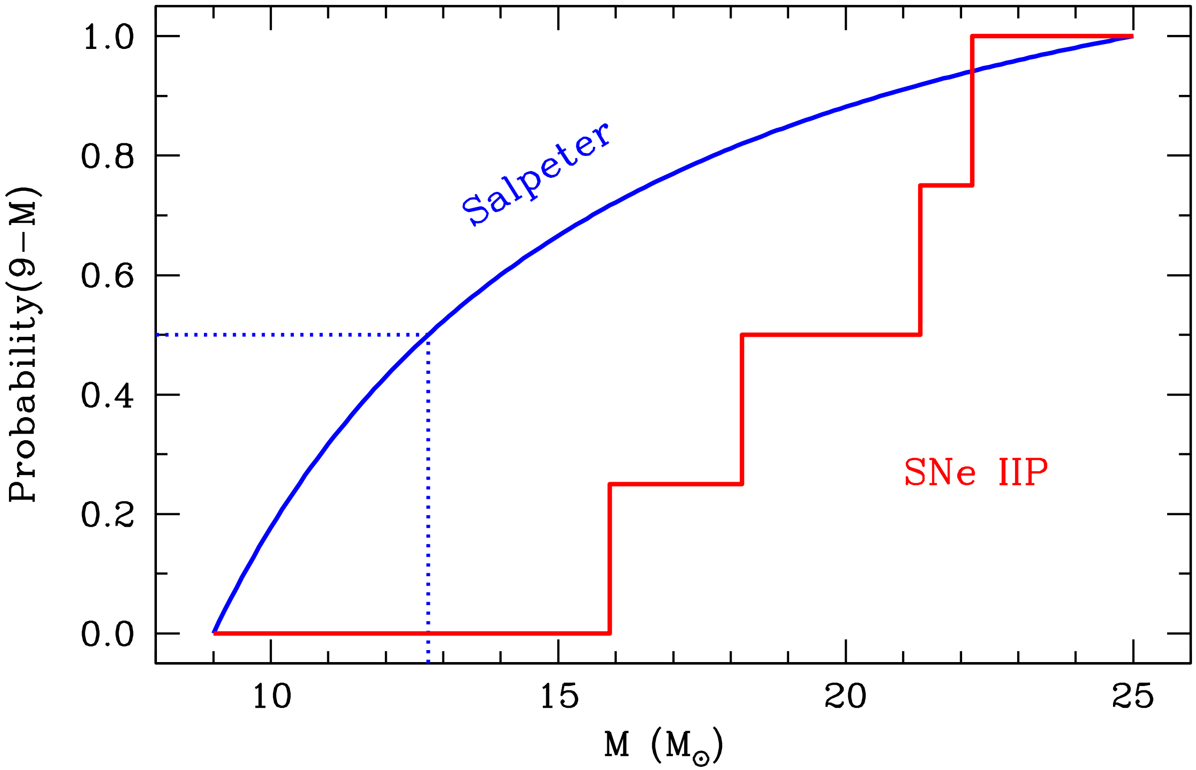
- The basic parameters of the sub-luminous type IIP SN 2005cs are intermediate between those of low-luminosity and normal type IIP SNe.
- In the case of SN 1987A, a relative compactness of the pre-SN is a major factor that determines the peculiar properties of this phenomenon.
- The optimal model for SN 1987A is characterized by a moderate ^{56}Ni mixing up to ~ 3000 km s^{-1} compared to a weaker ^{56}Ni mixing up to ~ 600 km s^{-1} in other type IIP SNe, hydrogen being mixed deeply downward to $360 - 700$ km s^{-1}.
- The total ^{56}Ni mass correlates with the explosion energy. This dependence is consistent with the empirical correlation found by Nadyozhin (2003).

Explosion Energy and ^{56}Ni Mass Versus Progenitor Mass



The explosion energy and the ^{56}Ni mass decrease towards a lower progenitor mass.

Cumulative "Salpeter" and "Observed" Distributions



Significance: a random realization of four SNe has a little probability of ~ 0.01.

What happens with main-sequence stars from the $9 - 15\ M_\odot$ mass range?
Selection effect: SNe II from the $9 - 15\ M_\odot$ stars are intrinsically faint.
Silent collapse: core collapse in the $9 - 15\ M_\odot$ range does not produce any SN II, but a black hole up to $\sim 15\ M_\odot$ as the outcome.

Conclusions

- The basic parameters of the sub-luminous type IIP supernova 2005cs are intermediate between those of low-luminosity and normal type IIP SNe: $M_{env} = 15.9 M_{\odot}$, $E = 4.1 \times 10^{50}$ erg, $M_{\rm Ni} = 0.0082 M_{\odot}$, and $M_{\rm ZAMS} = 18.2 M_{\odot}$.
- The fate of the $9 - 15\ M_{\odot}$ main-sequence stars might be:
  1) these stars produce very faint yet undetectable SNe IIP;
  2) a core collapse of stars from this mass range does not produce SN event at all.