Superluminous Supernovae and their Emission Mechanisms

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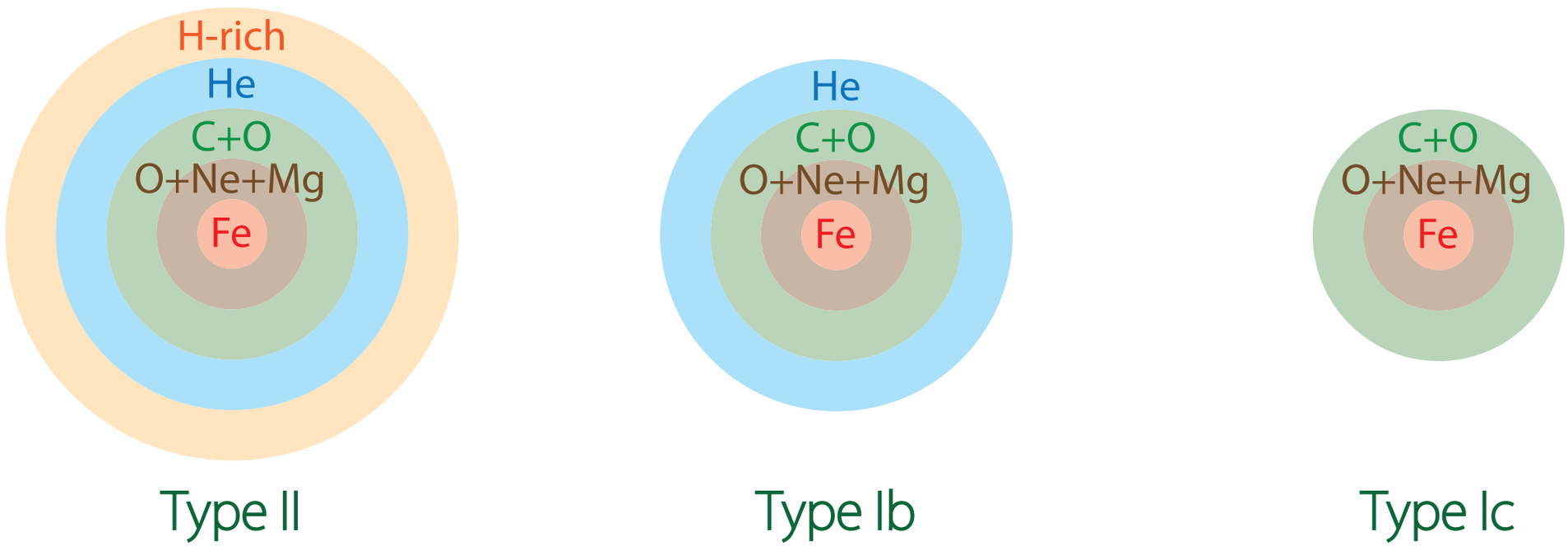
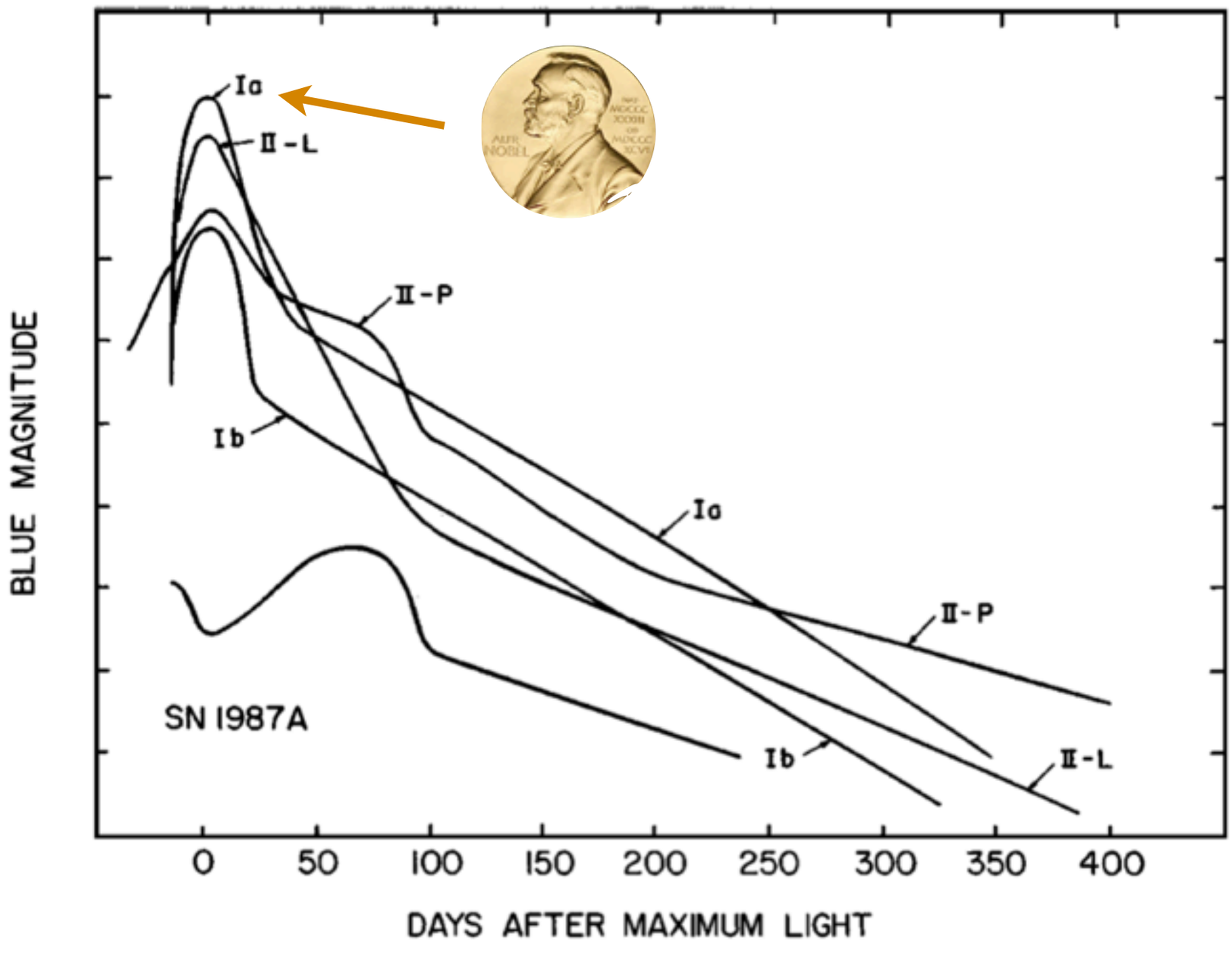
Supernovae

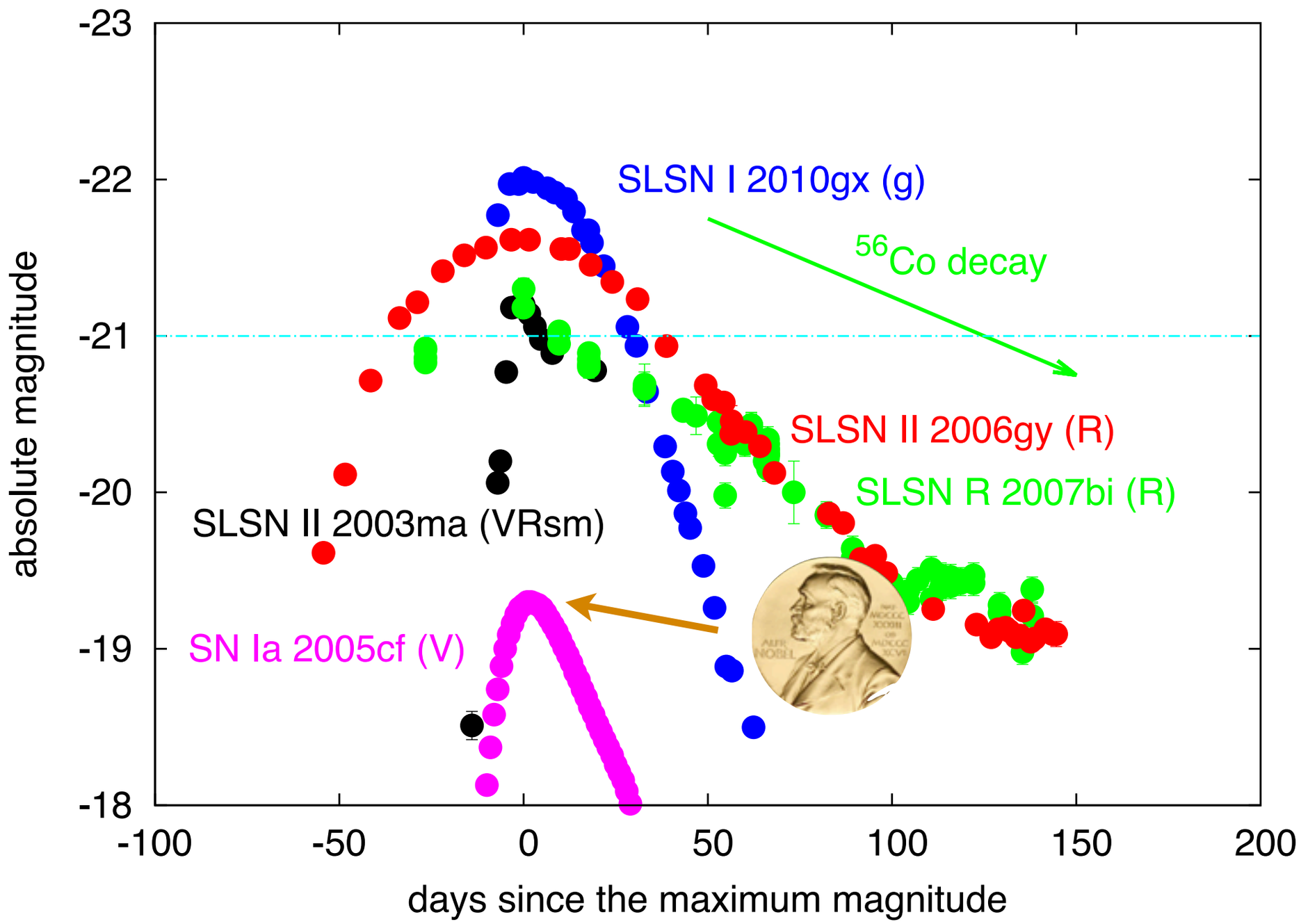
- Explosions of stars
  - Type Ia Supernovae -- white dwarfs in binary systems 
  - Core-collapse Supernovae -- massive stars above ~ 10 Msun



Supernova Light Curves



Superluminous Supernovae



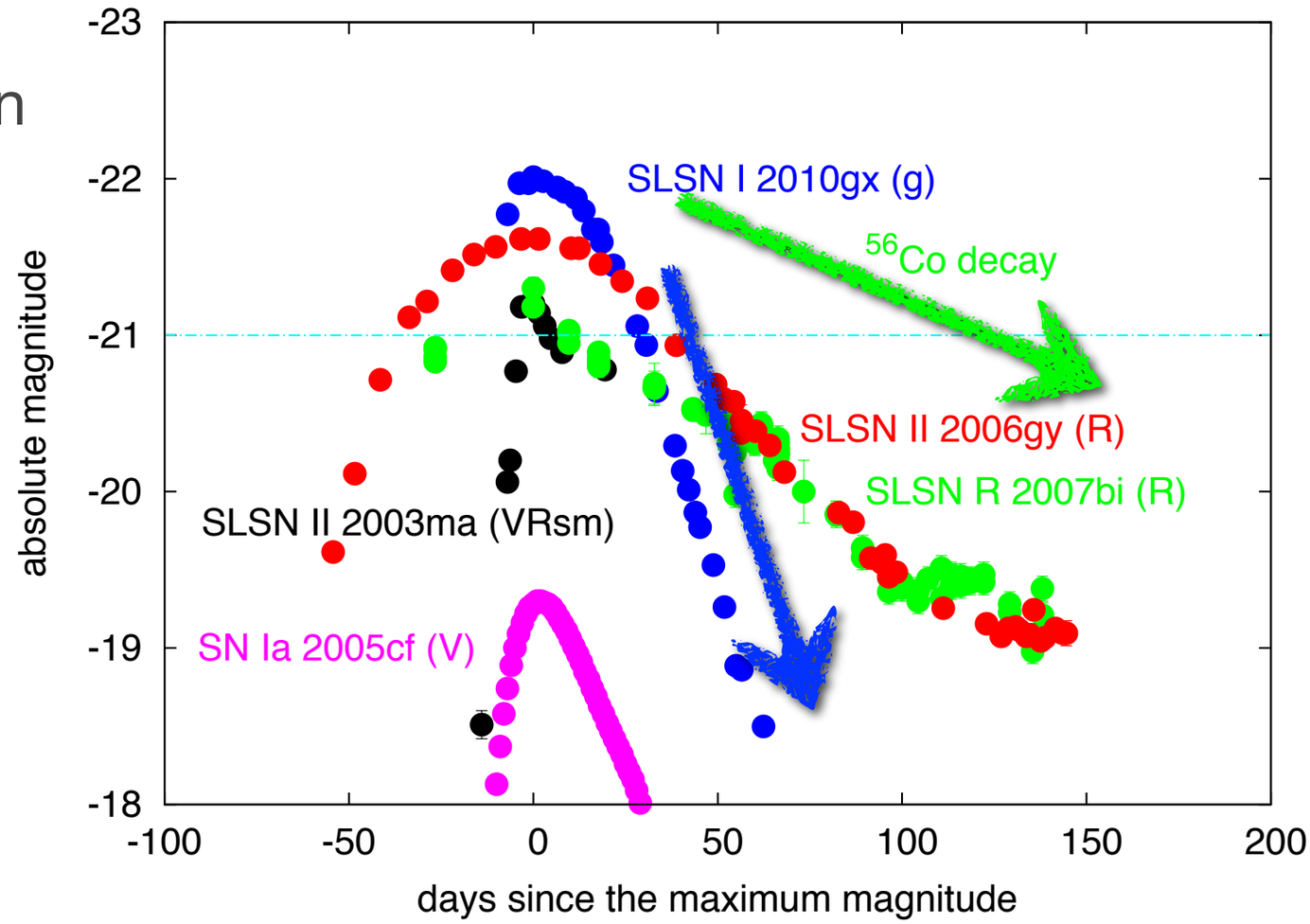
Superluminous Supernovae -- Radiation Energy

Supernova	Redshift	Absolute peak (mag)	Radiated energy (ergs)
SLSN-R			
SN 2007bi	0.1289	−21.35	1 to 2 × 10^{51}
SN 1999as	0.12	−21.4	
SLSN-II			
CSS100217	0.147	−23.07	1.3 × 10^{52}
SN 2008fz	0.133	−22.34	1.4 × 10^{51}
SN 2008am	0.2338	−22.39	2 × 10^{51}
SN 2008es	0.205	−22.21	1.1 × 10^{51}
SN 2006gy	0.019	−22.0	2.3 to 2.5 × 10^{51}
SN 2003ma	0.289	−21.52	4 × 10^{51}
SN 2006tf	0.074	< −20.7	7 × 10^{50}
SLSN-I			
SN 2005ap	0.2832	−22.73	1.2 × 10^{51}
SCP 06F6	1.189	−22.53	1.7 × 10^{51}
PS1-10ky	0.956	−22.53	0.9 to 1.4 × 10^{51}
PS1-10awh	0.908	−22.53	0.9 to 1.4 × 10^{51}
PTF09atu	0.501	−22.03	
PTF09cnd	0.258	−22.03	1.2 × 10^{51}
SN 2009jh	0.349	−22.03	
SN 2006oz	0.376	−21.53	
SN 2010gx	0.230	−21.23	6 × 10^{50}

(Gal-Yam 2012)

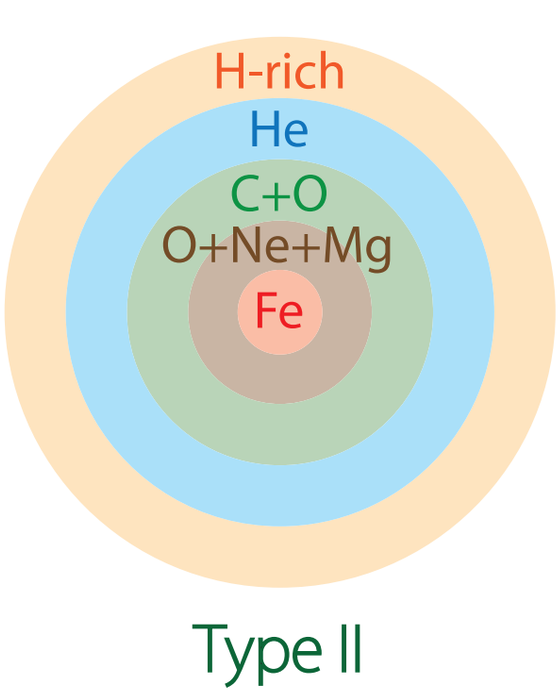
Diversities of Superluminous Supernovae

- SLSN II
  - with H line -- mostly Type IIn (only one exception)
- SLSN R
  - without H line, slow LC evolution
    - 56Ni heating?
- SLSN I
  - without H line, fast LC evolution

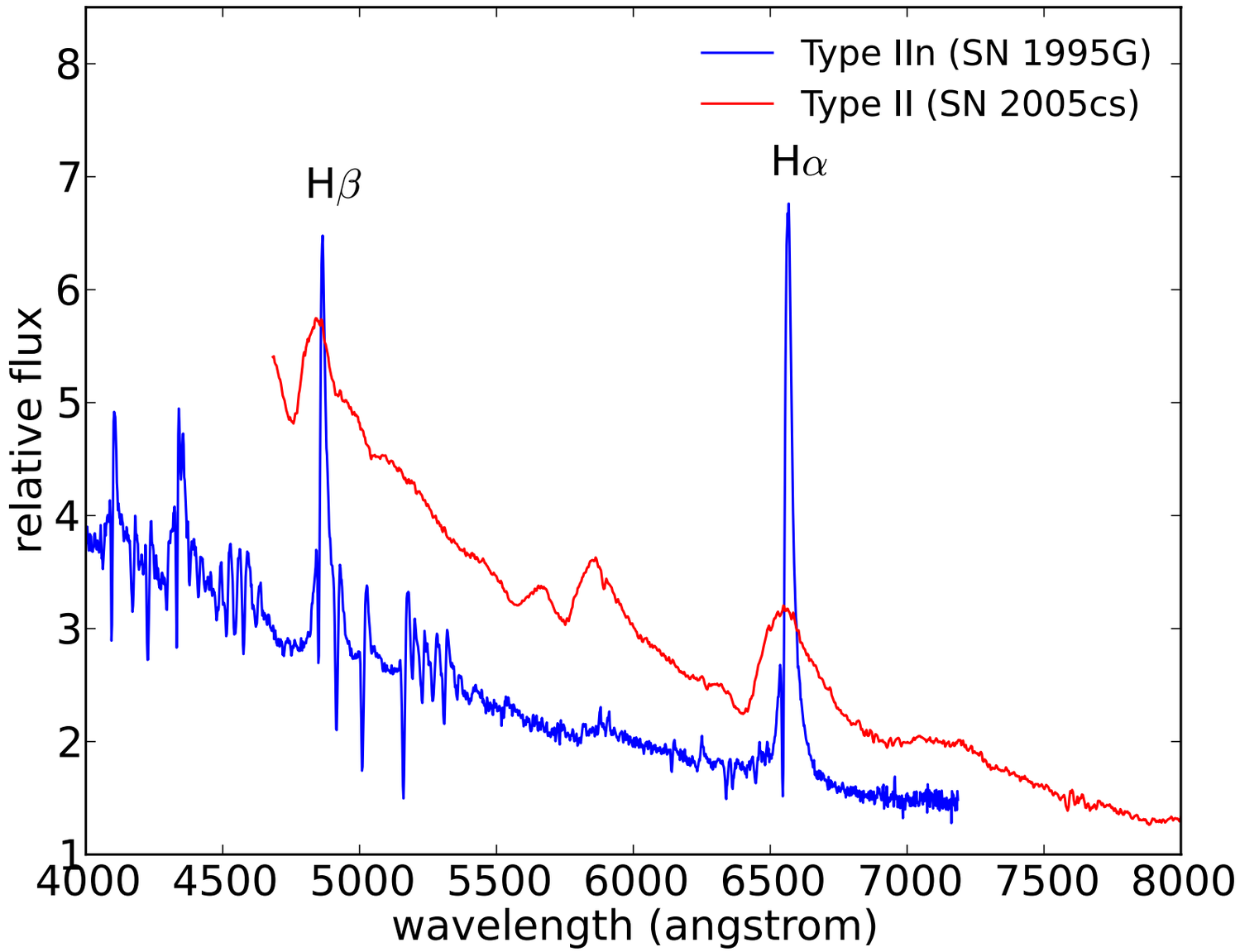


Type IIn Supernovae

- H lines + narrow emission lines



Type II



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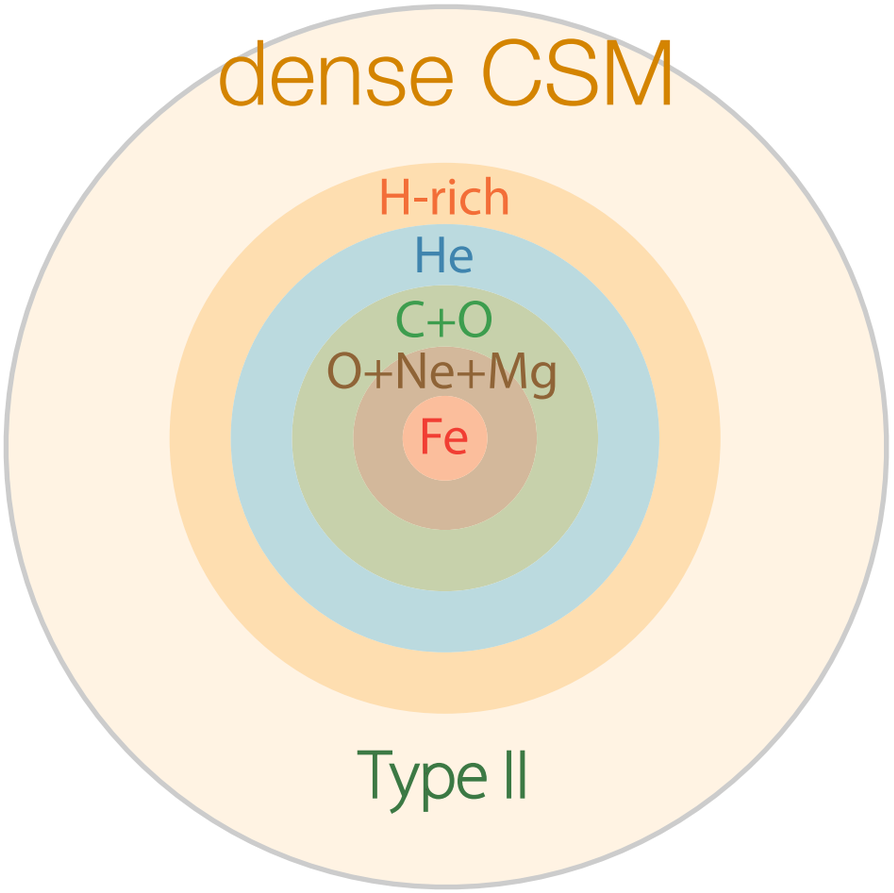
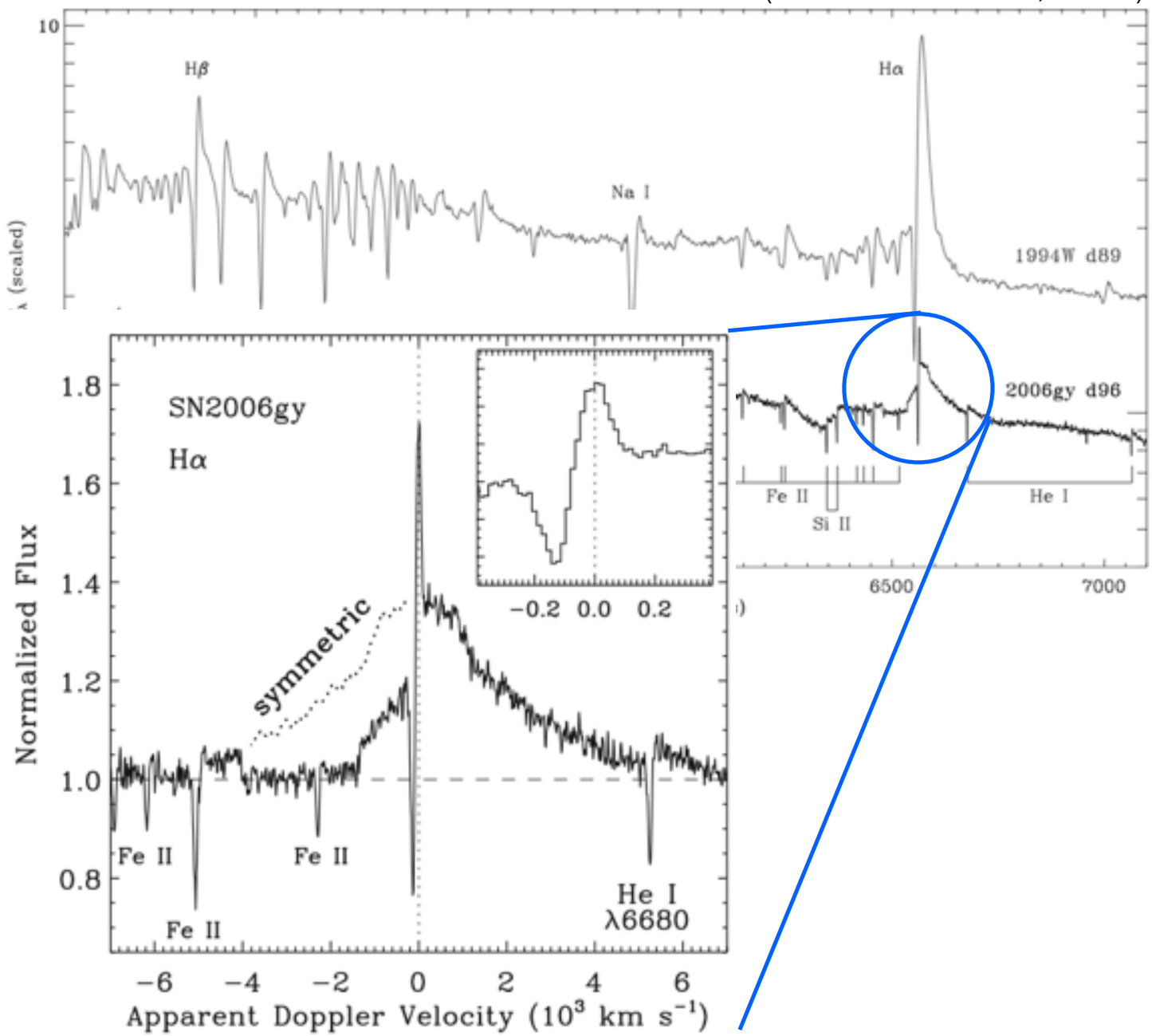
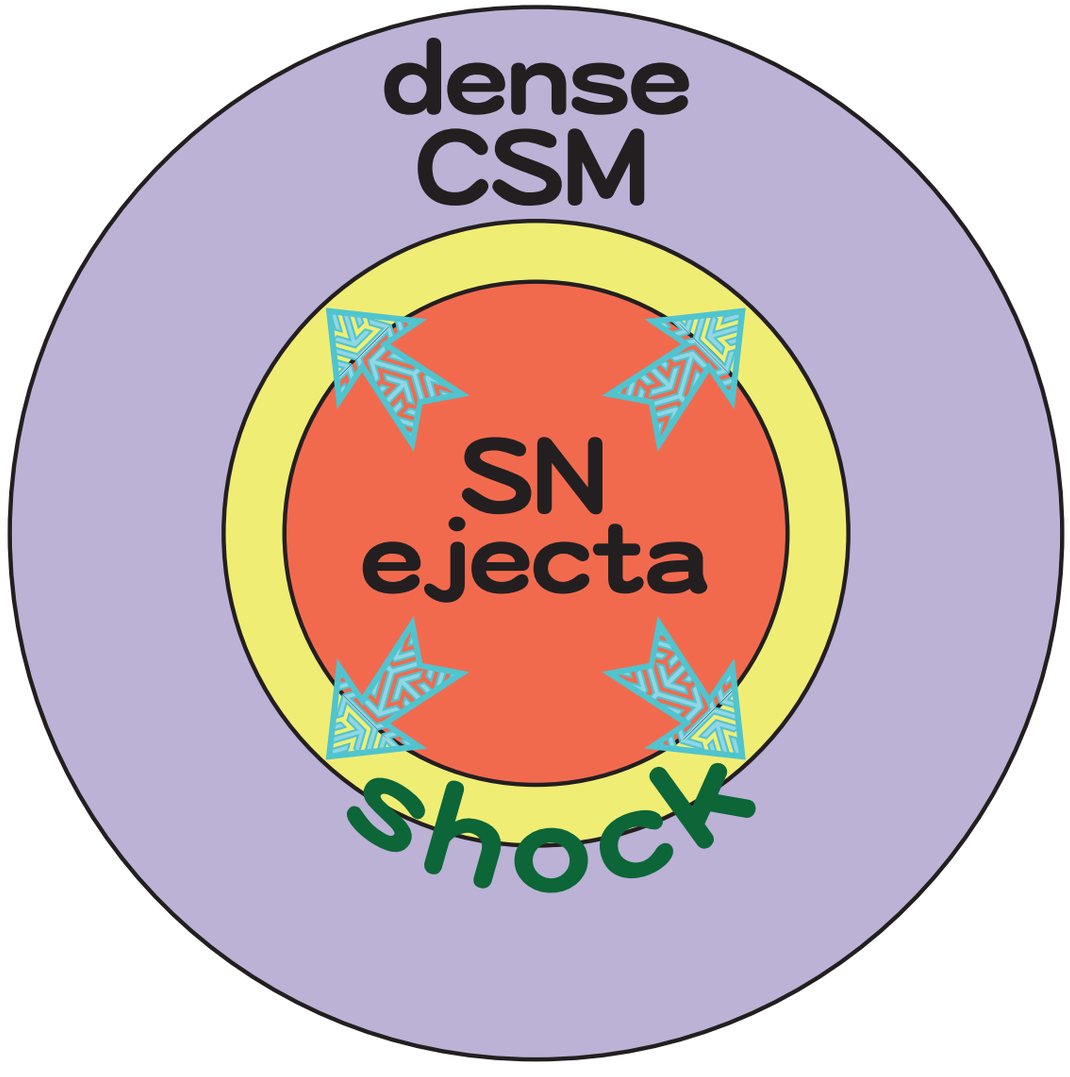


(Smith et al. 2007, 2010)



Interaction between SN Ejecta and Dense CSM

- Deceleration of SN ejecta by dense CSM
  - kinetic energy -> thermal energy -> radiation energy

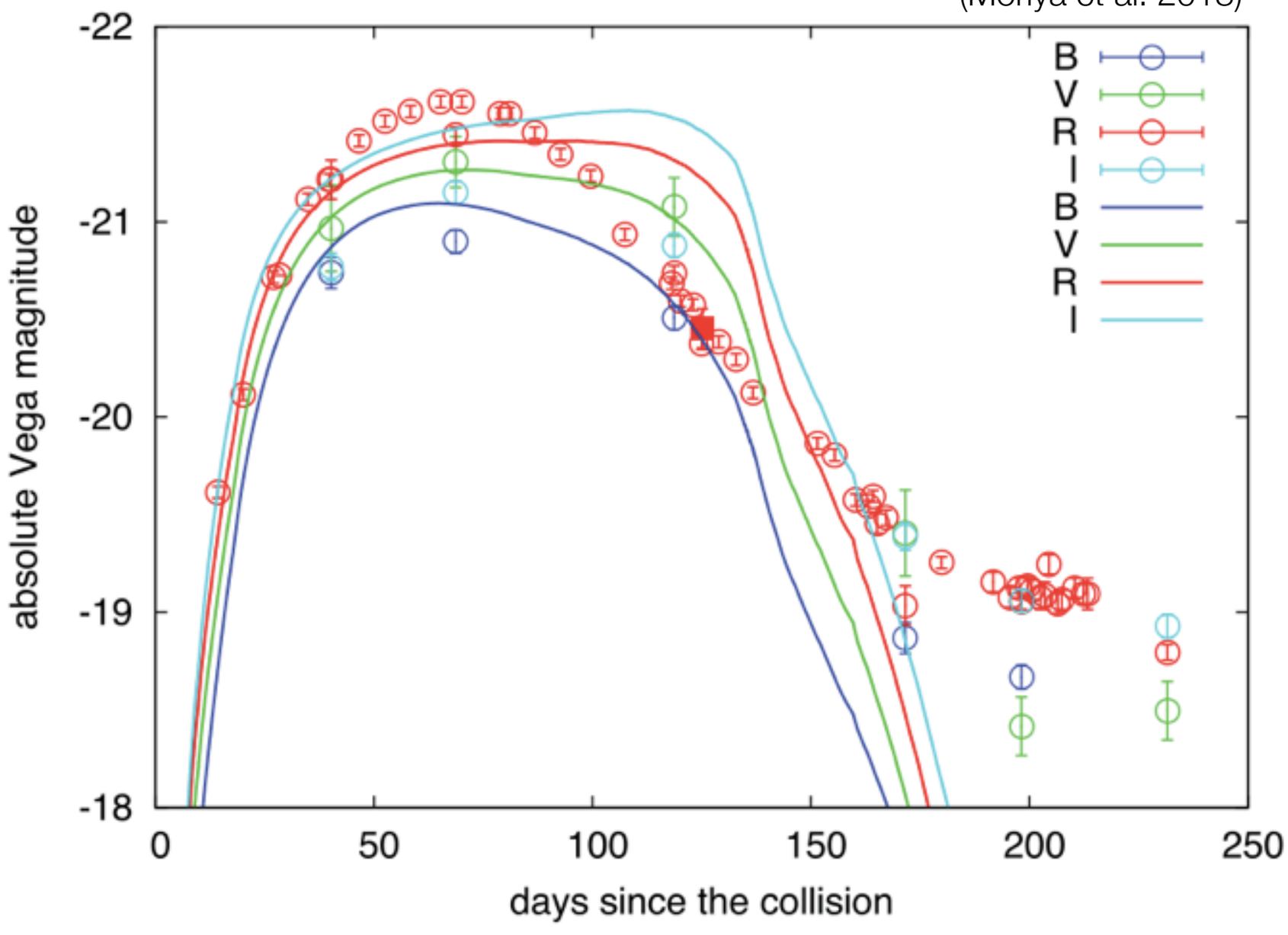


Numerical Simulations of the Collisions

- Radiation hydrodynamics code STELLA (e.g., Blinnikov et al. 2006)

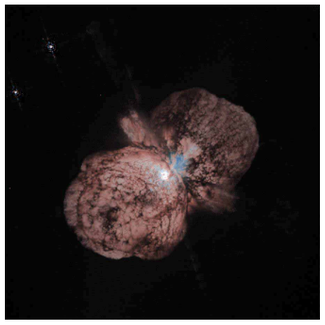
Numerical Simulations of the Collisions

(Moriya et al. 2013)

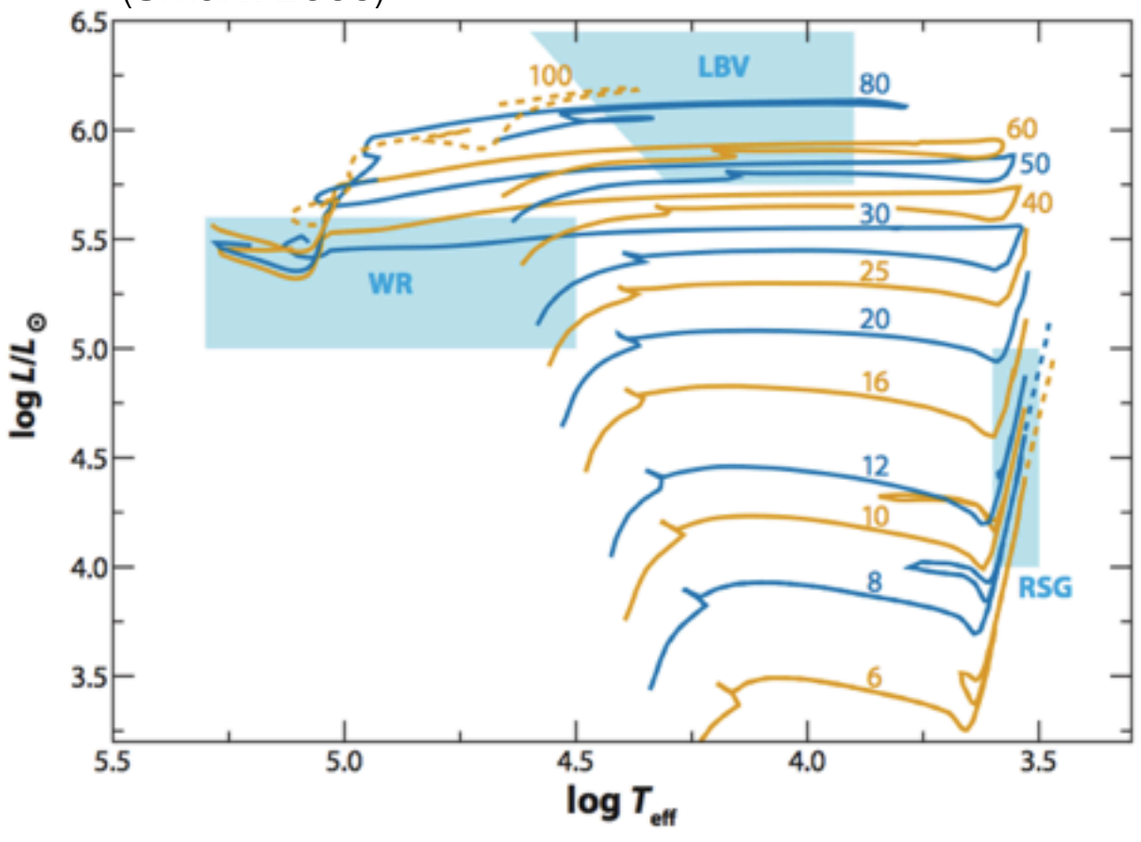


Many remaining mysteries...

- How can we obtain such dense CSM?
  - luminous blue variables (LBVs) have such dense CSM
    - eta Carinae
  - LBVs as SN progenitors?



(Smartt 2009)



20 Msun, 2e52 erg

15 Msun within 1e16 cm

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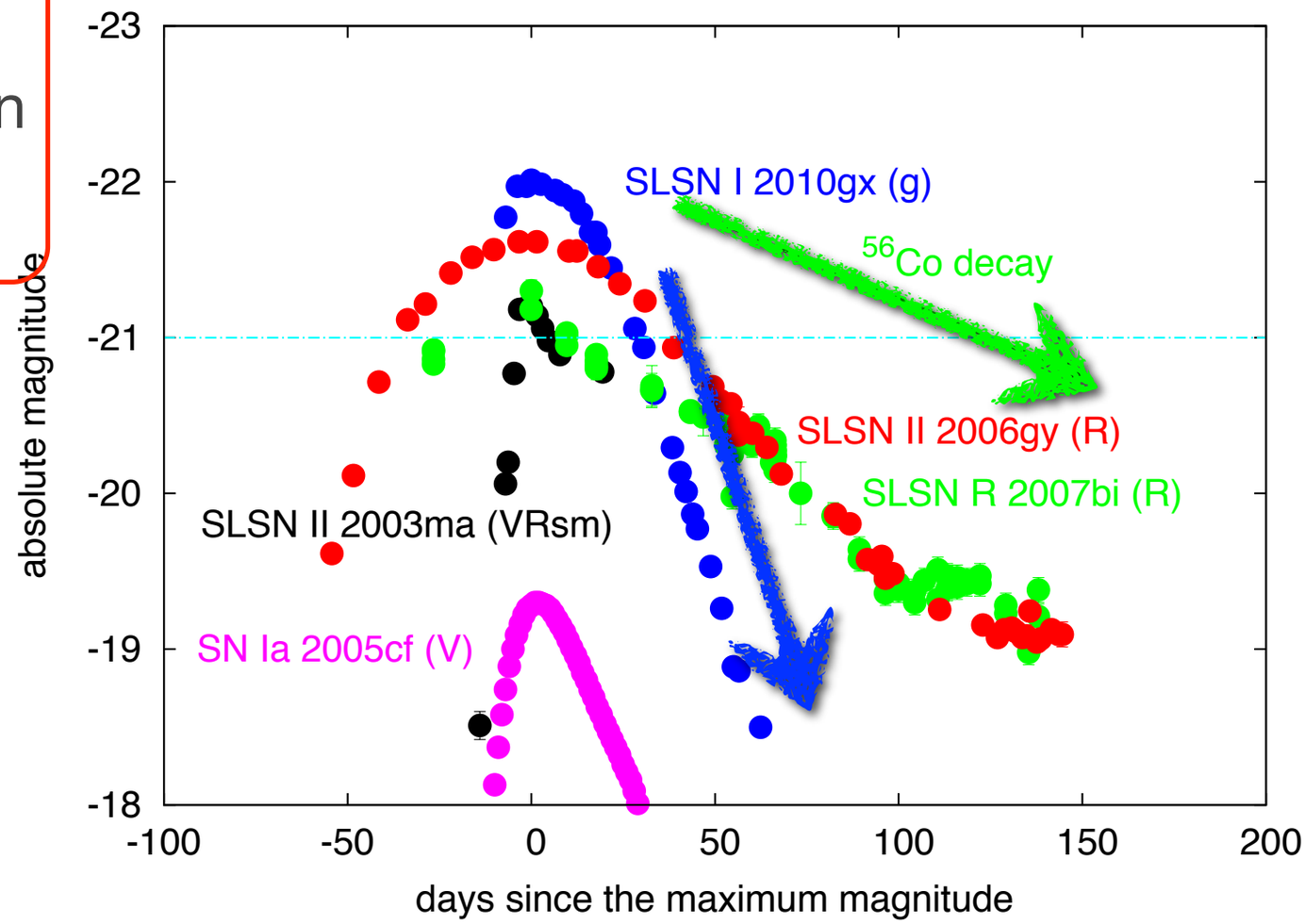
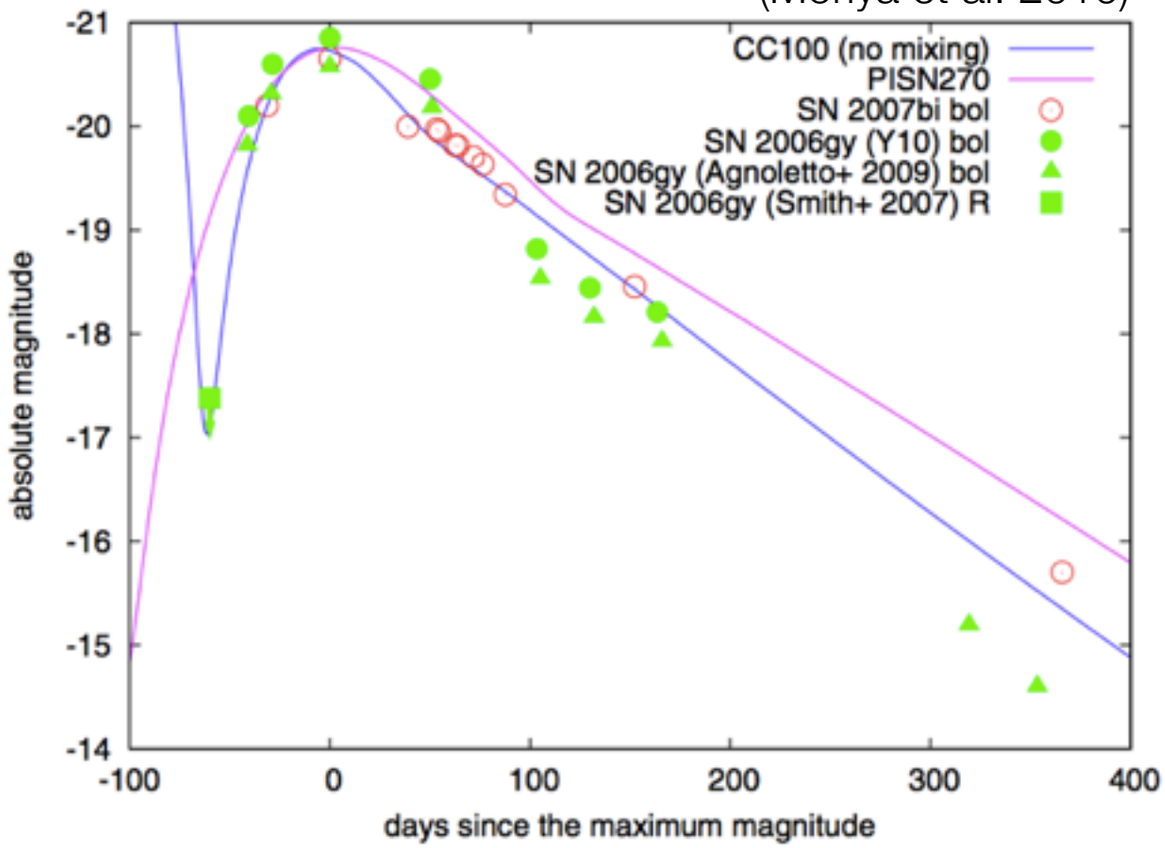


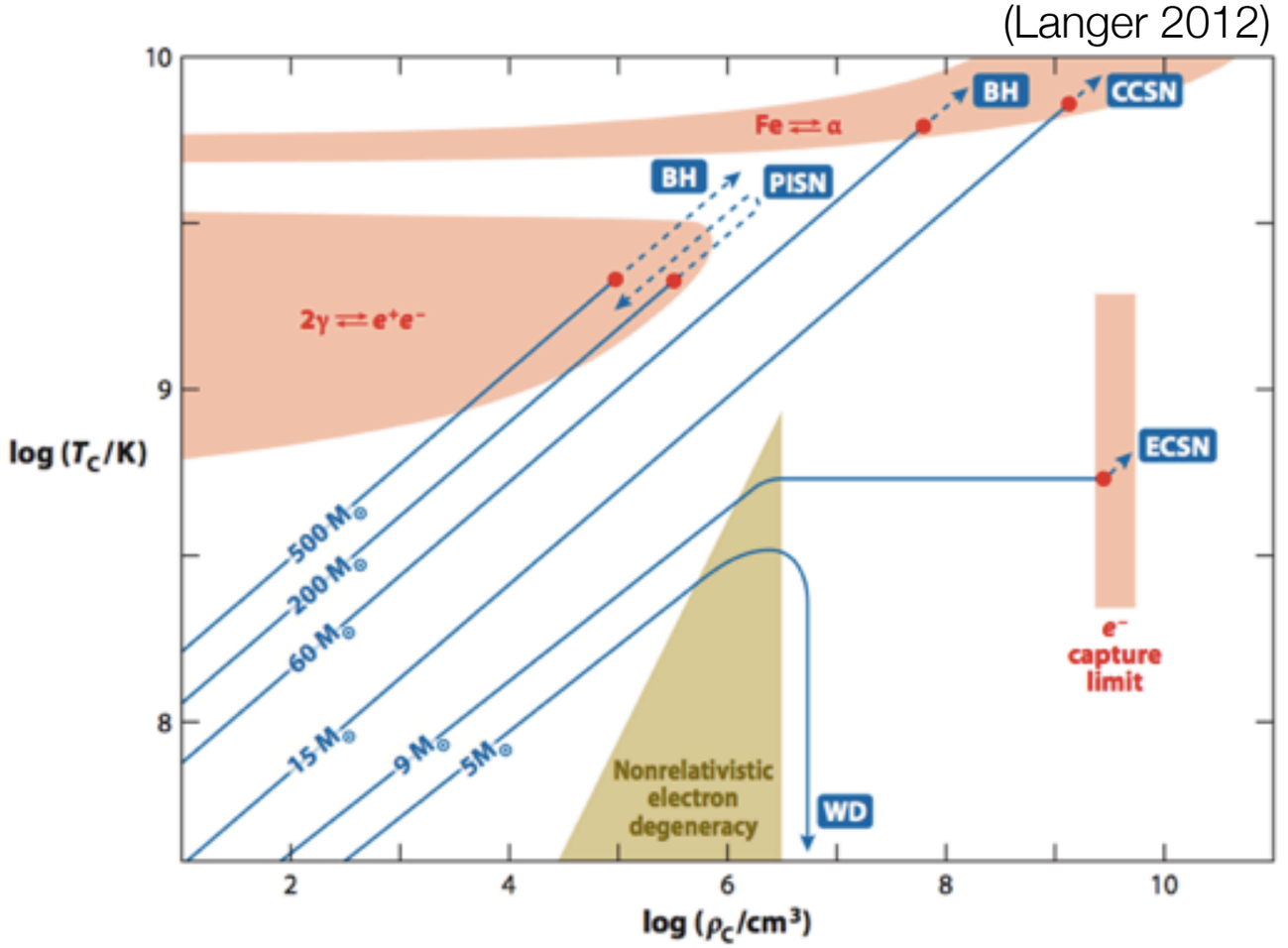
SLSN R

- LCs are consistent with 56Ni
  - more than 5 Msun(!!) is required (SN Ia: ~ 0.6 Msun)
  - How to make such huge amount of 56Ni?
    - pair-instability SN?
    - energetic core-collapse SN?

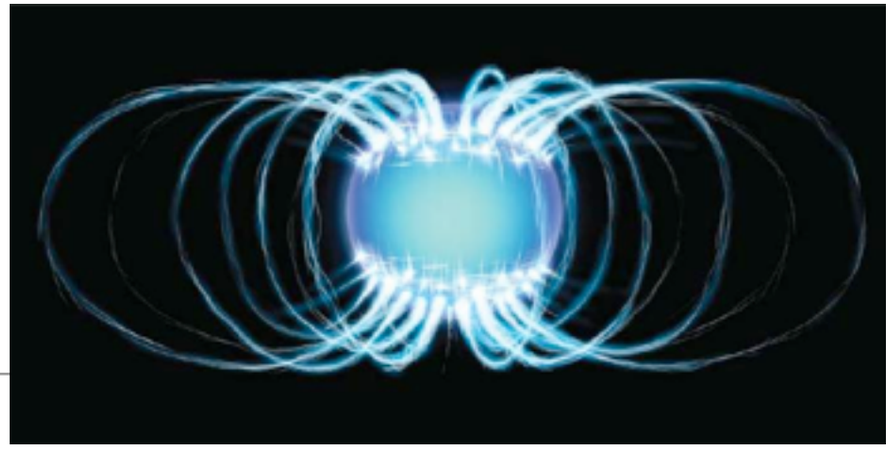
(Moriya et al. 2010)



(Langer 2012)

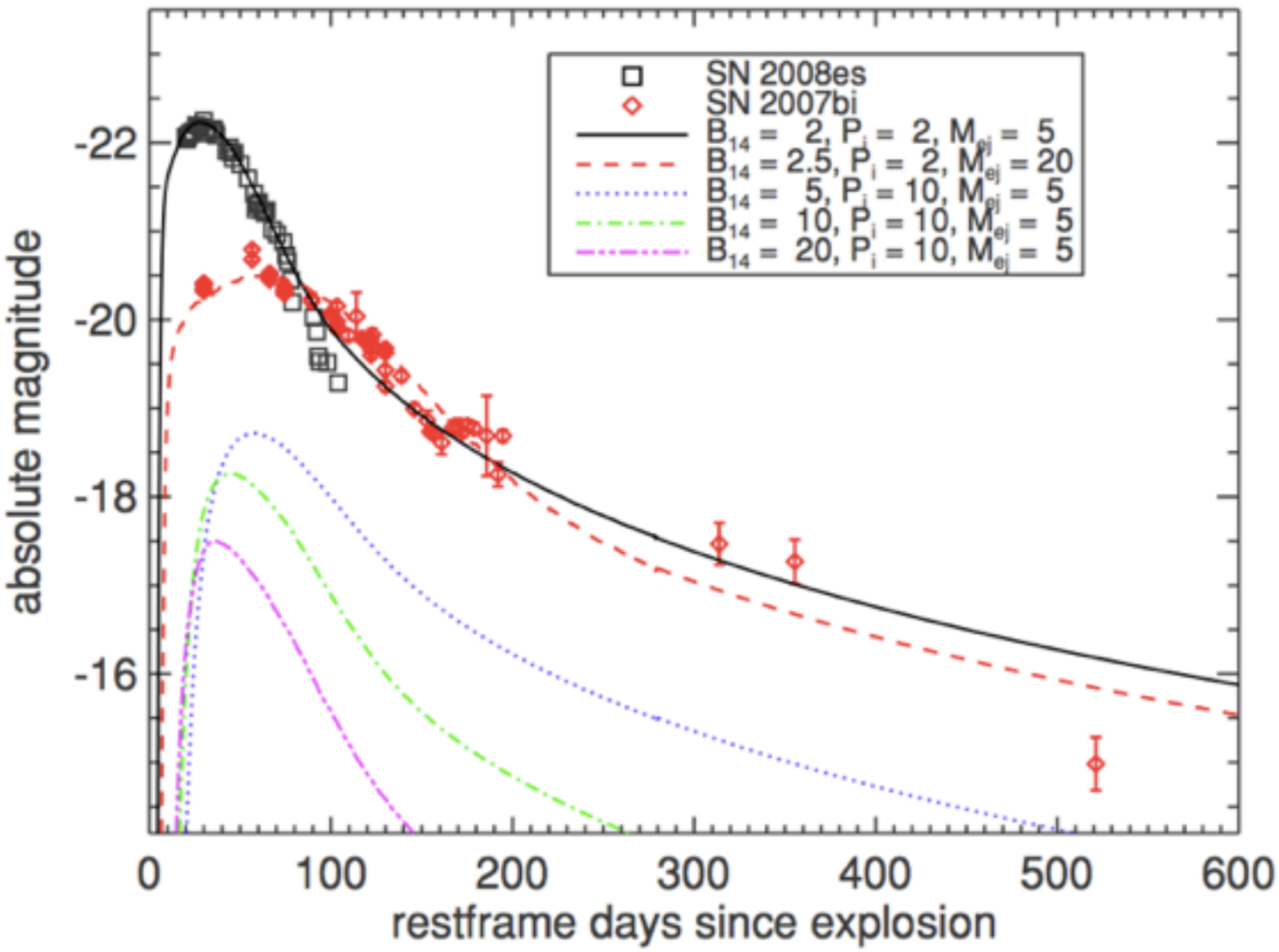


SLSN R



- Spectra are inconsistent with 56Ni heating? (Dessart et al. 2012)
  - 56Ni heating cannot make the blue spectra (~10,000 K) of SLSN I
  - another possibility: magnetars

(Kasen & Bildsten 2010)



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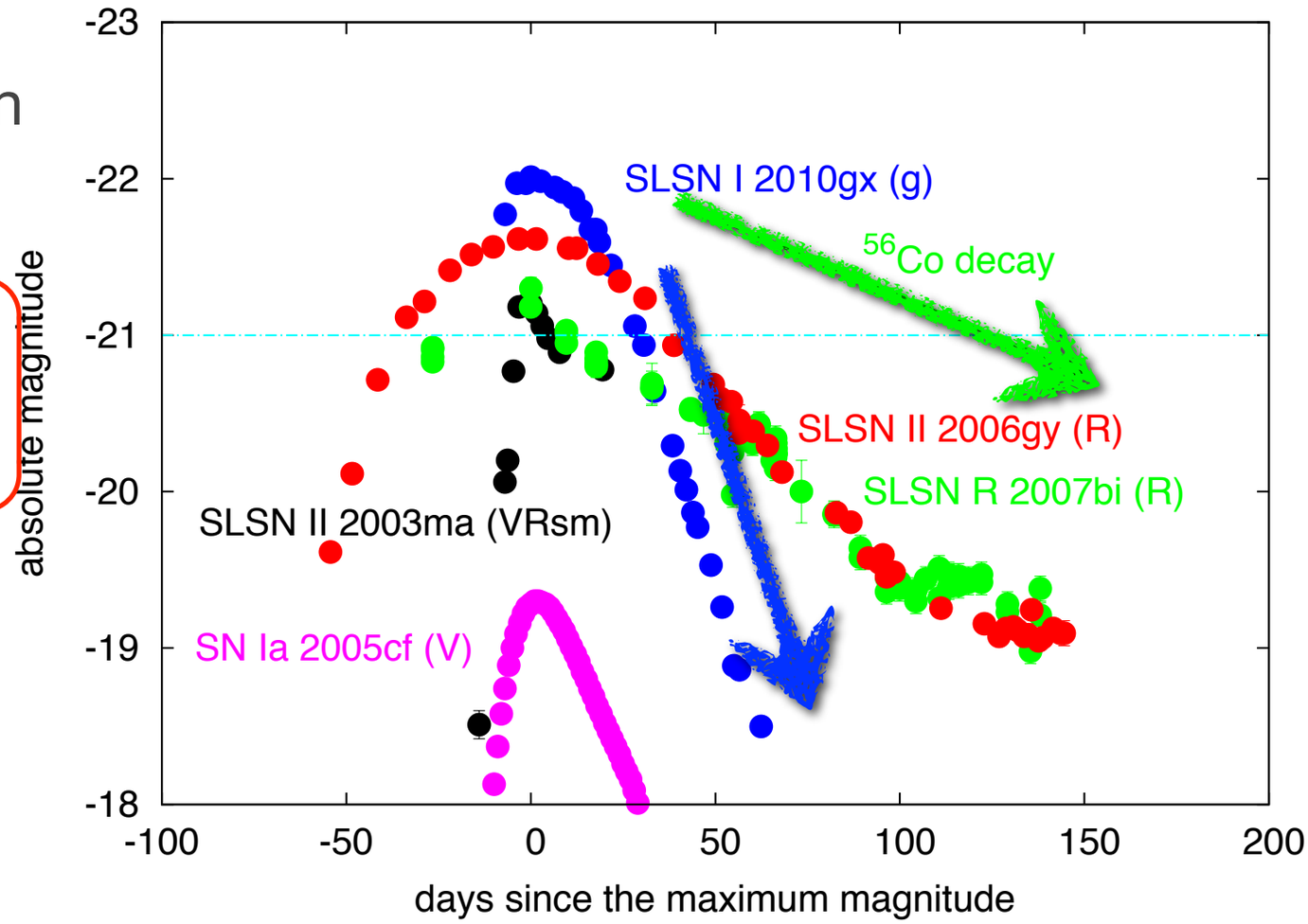
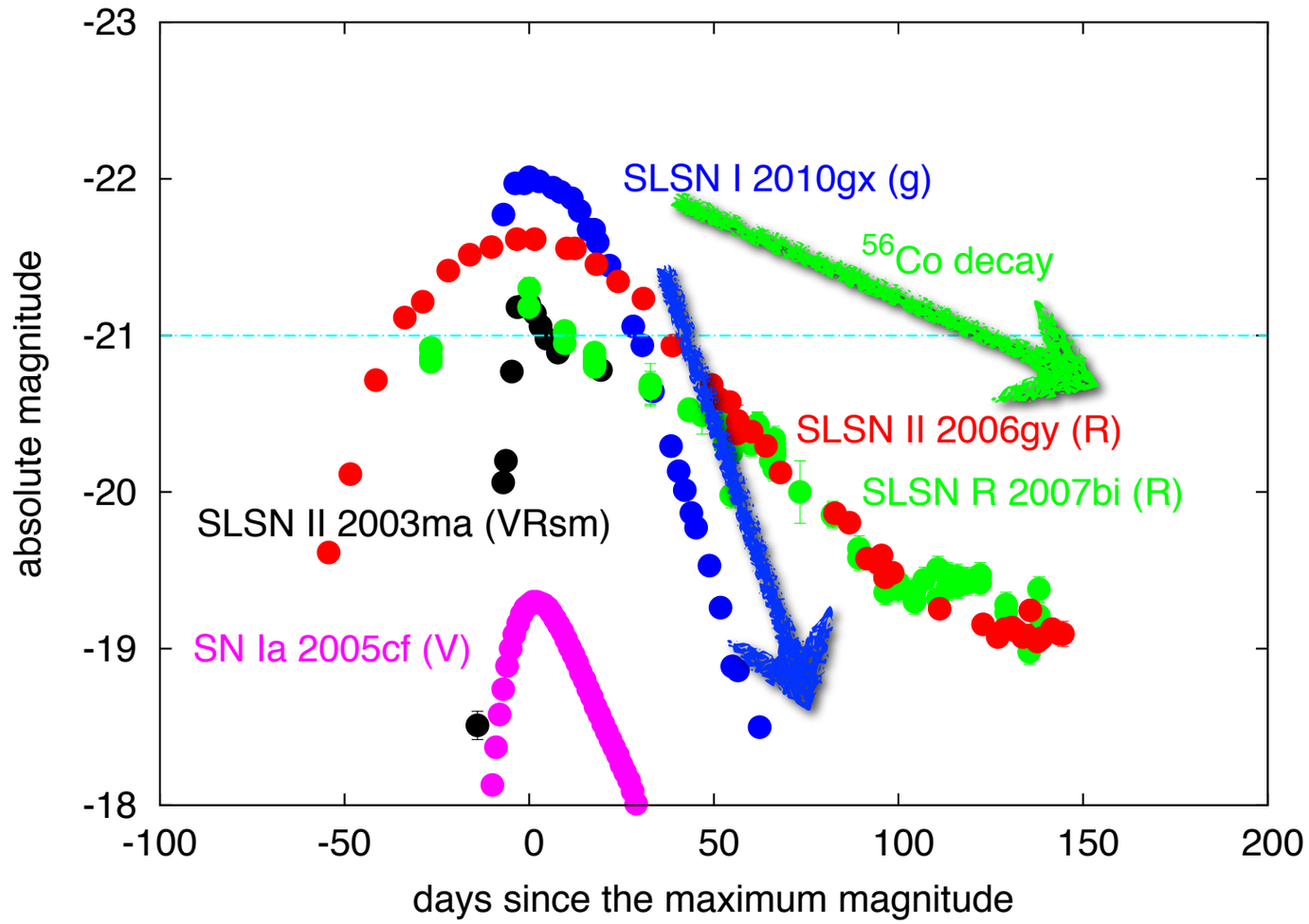


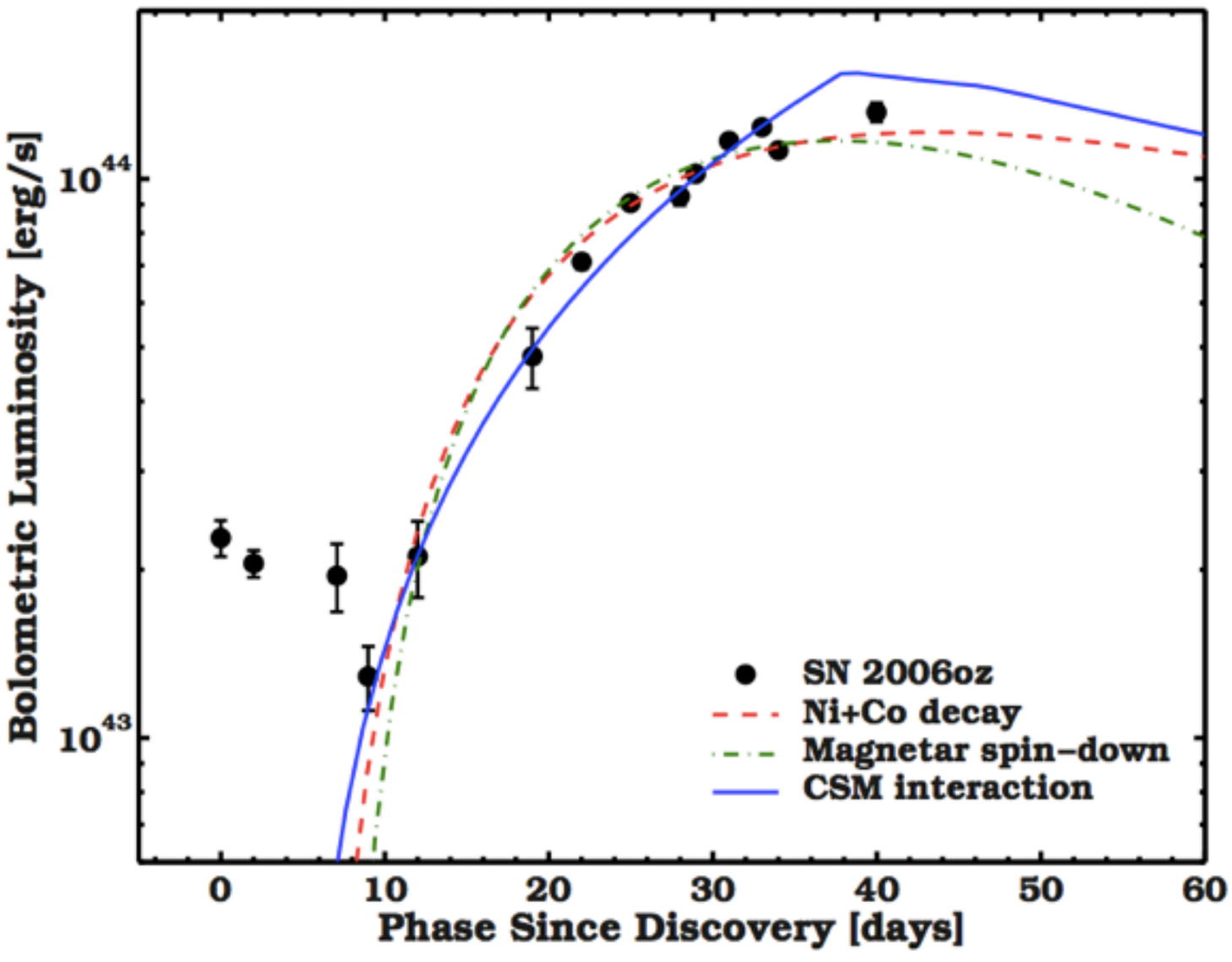
SLSN I

- 56Ni is impossible
  - declines too fast
- magnetars?
- interaction?
  - ~ 10 Msun H-poor CSM
- other ways?

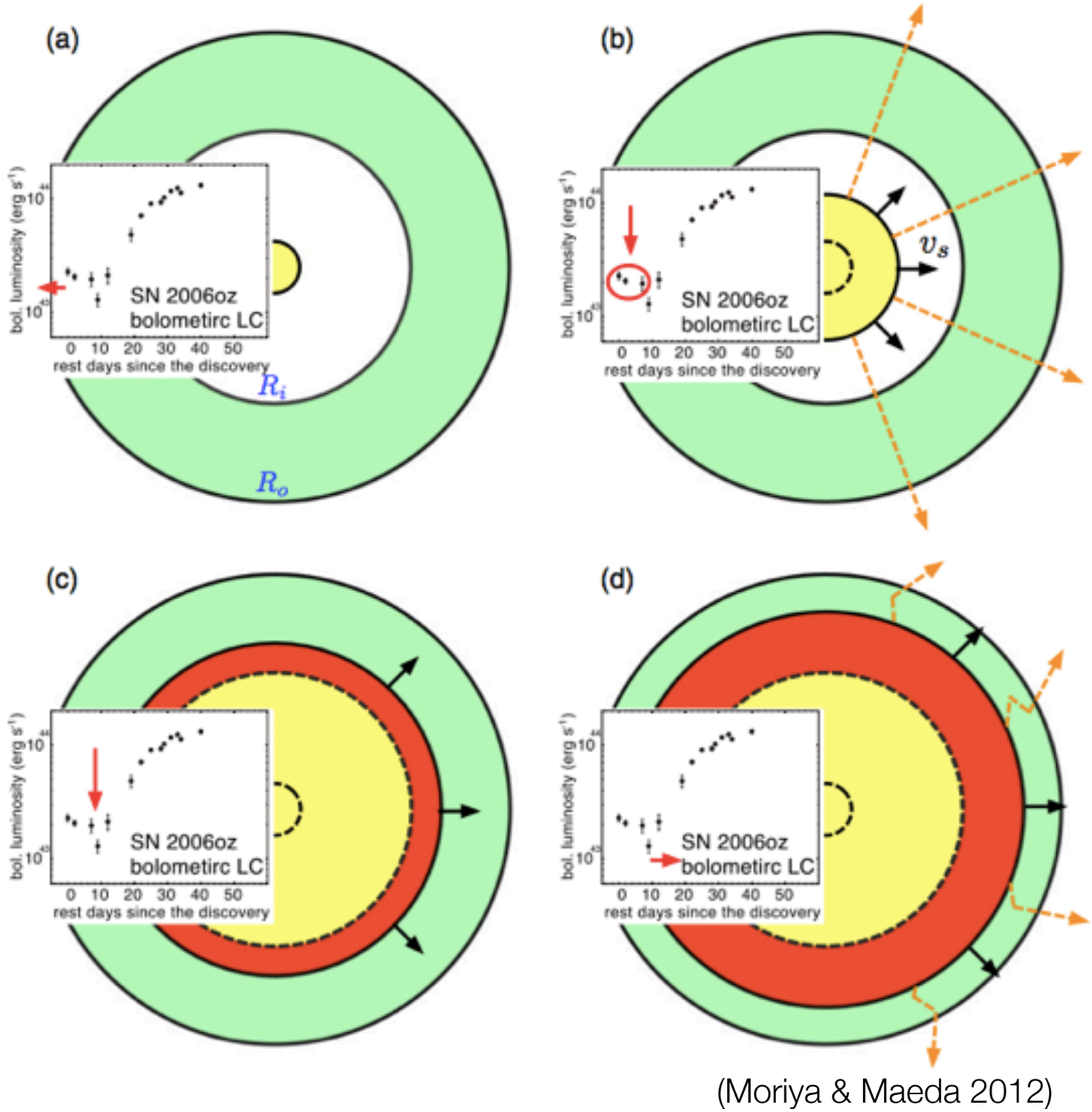


Precursor of SLSN I 2006oz

(Leloudas et al. 2012)



Precursor of SLSN I 2006oz

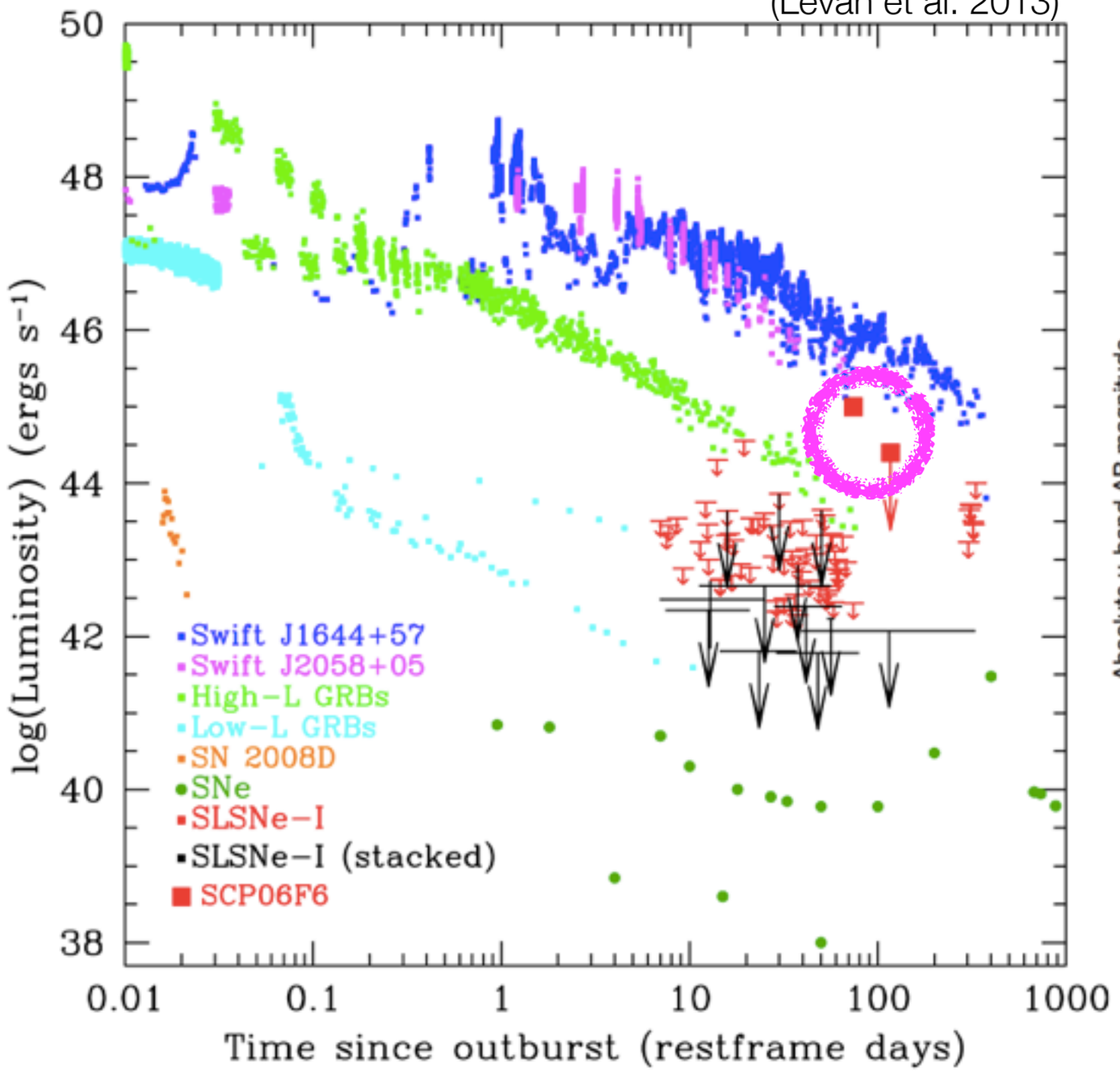


(Moriya & Maeda 2012)

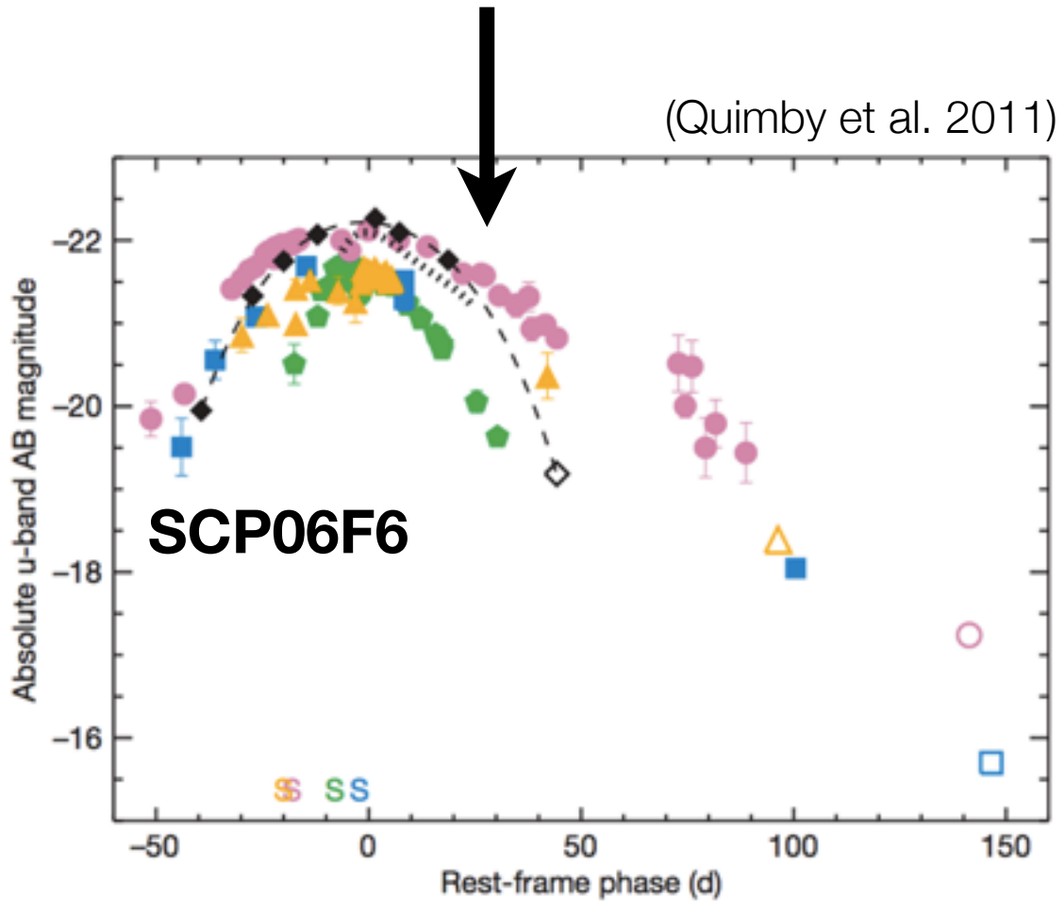
X-rays from SLSN I?

- Expected from both interaction and magnetars

(Levan et al. 2013)



(Quimby et al. 2011)



Summary

- Superluminous supernovae
  - peak optical luminosity exceeds -21 mag
  - total radiated energy exceeds 1e51 erg
- Emission mechanisms
  - interaction between SN ejecta and dense CSM (SLSN II, SLSN I)
  - magnetars (SLSN R, SLSN I)
  - large amount of 56Ni (SLSN R)
  - others?
- Progenitors are still unclear
  - large mass ejection immediately before the explosion

Спасибо!