Light Curve Modeling of Super-Luminous Supernovae and Dense CSM around their Progenitors

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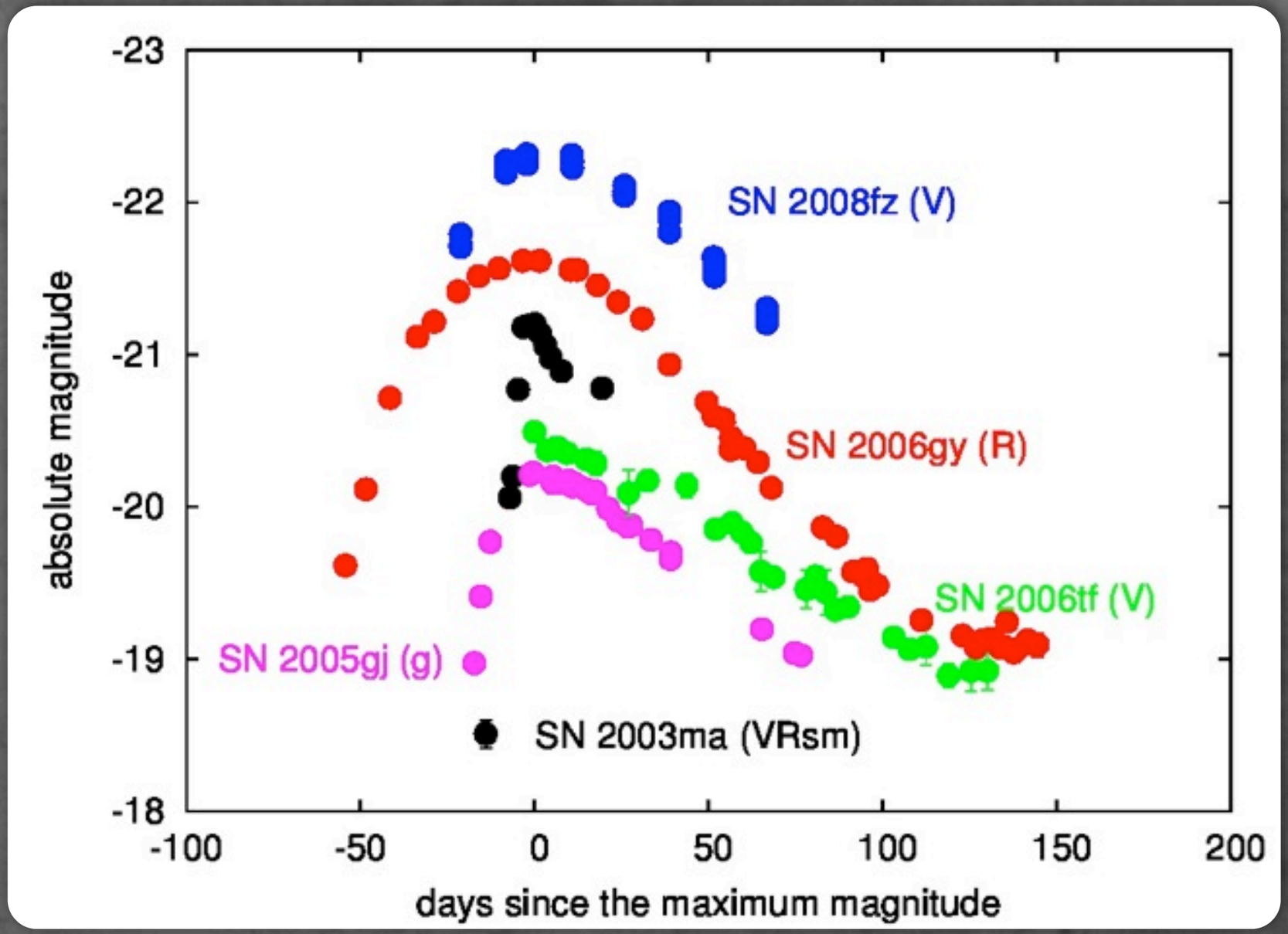
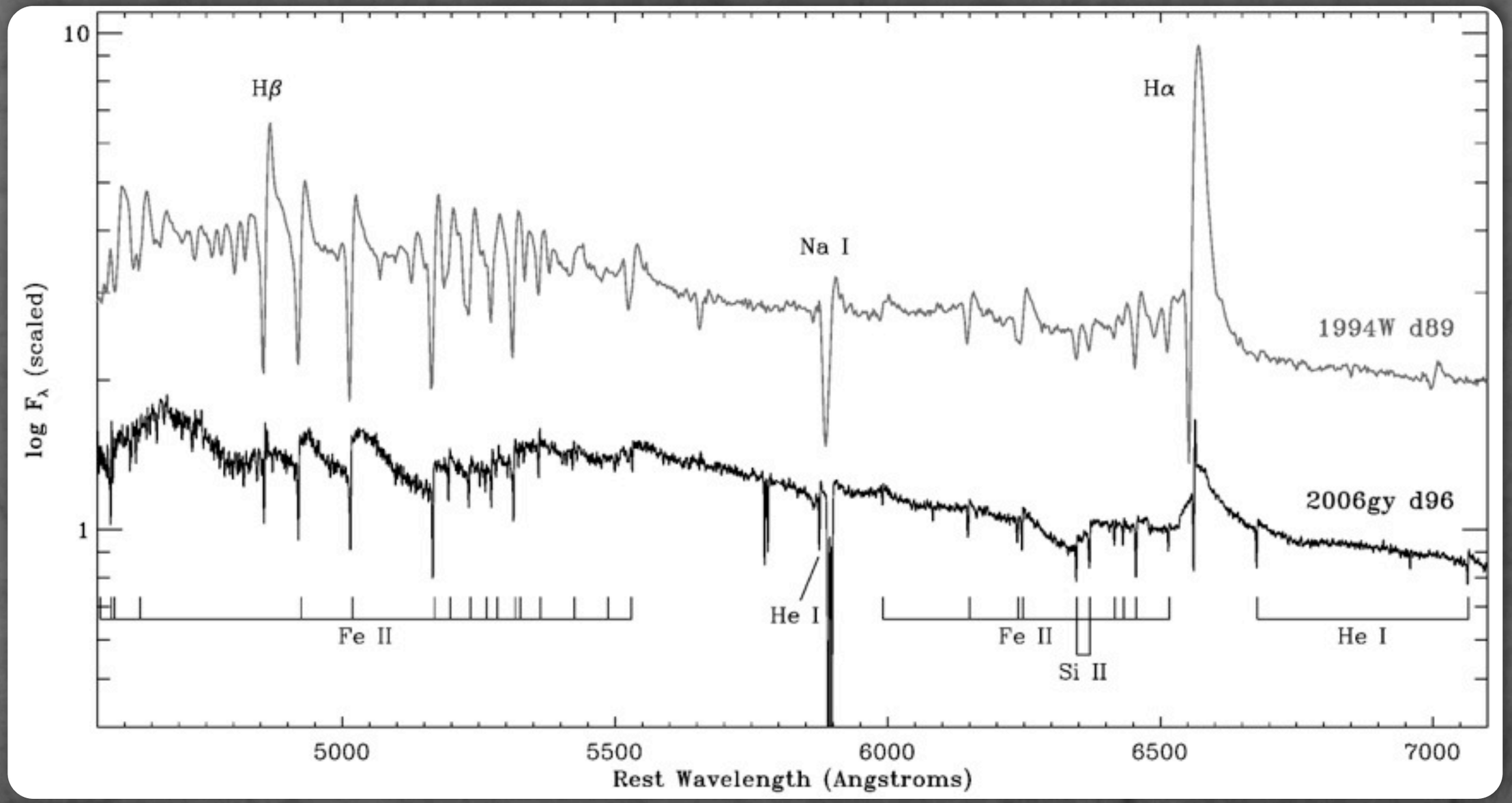
Contents

- H-rich super-luminous supernovae
  - shock breakout in dense CSM
- H-poor super-luminous supernovae
  - an evidence of the C+O-rich dense CSM

Super-Luminous Supernovae

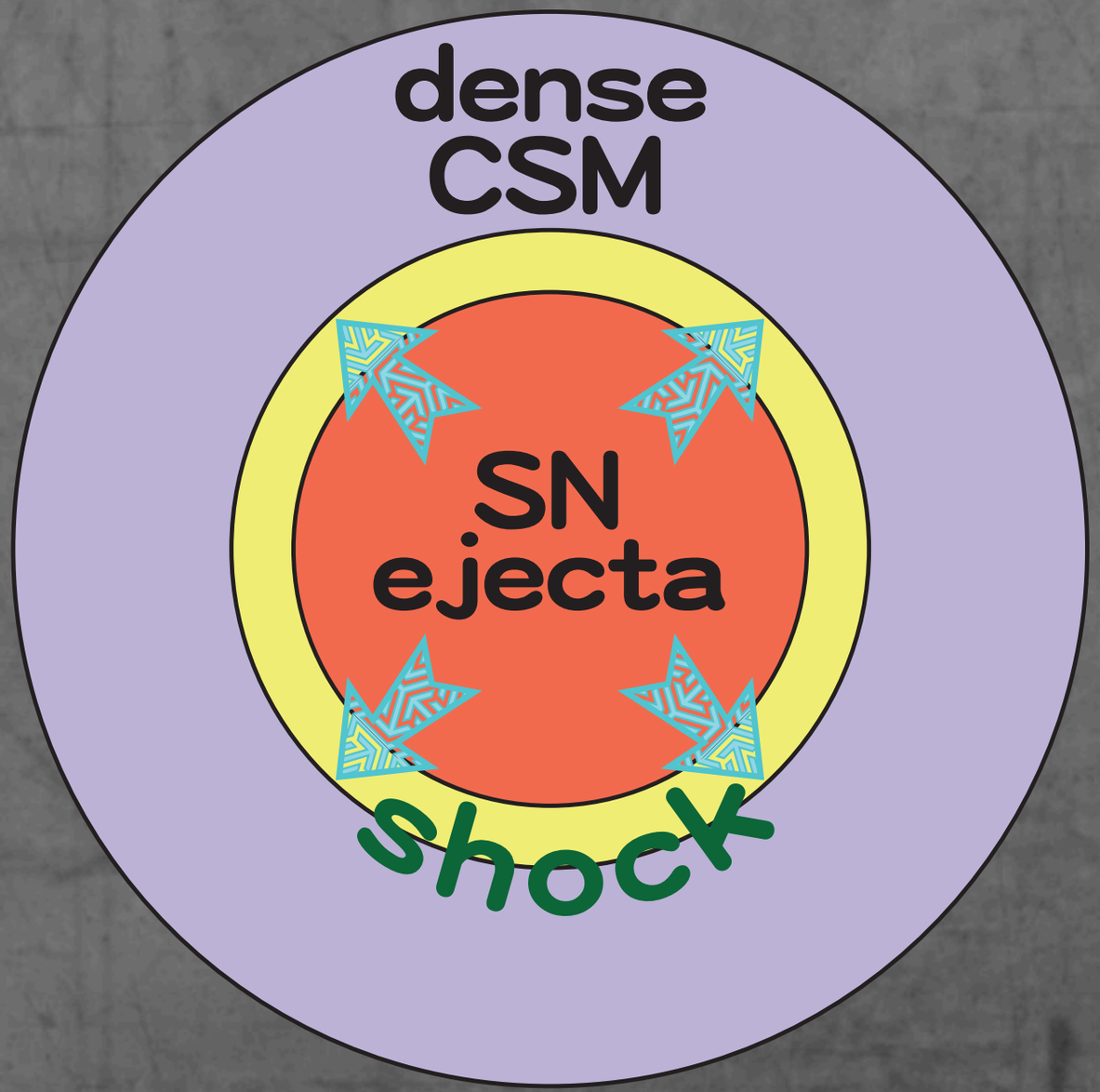


Type IIn SLSNe

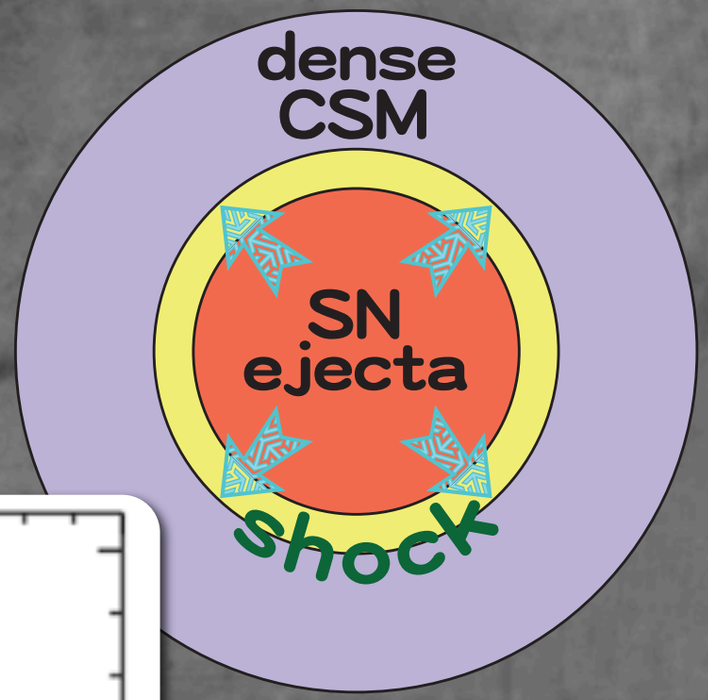


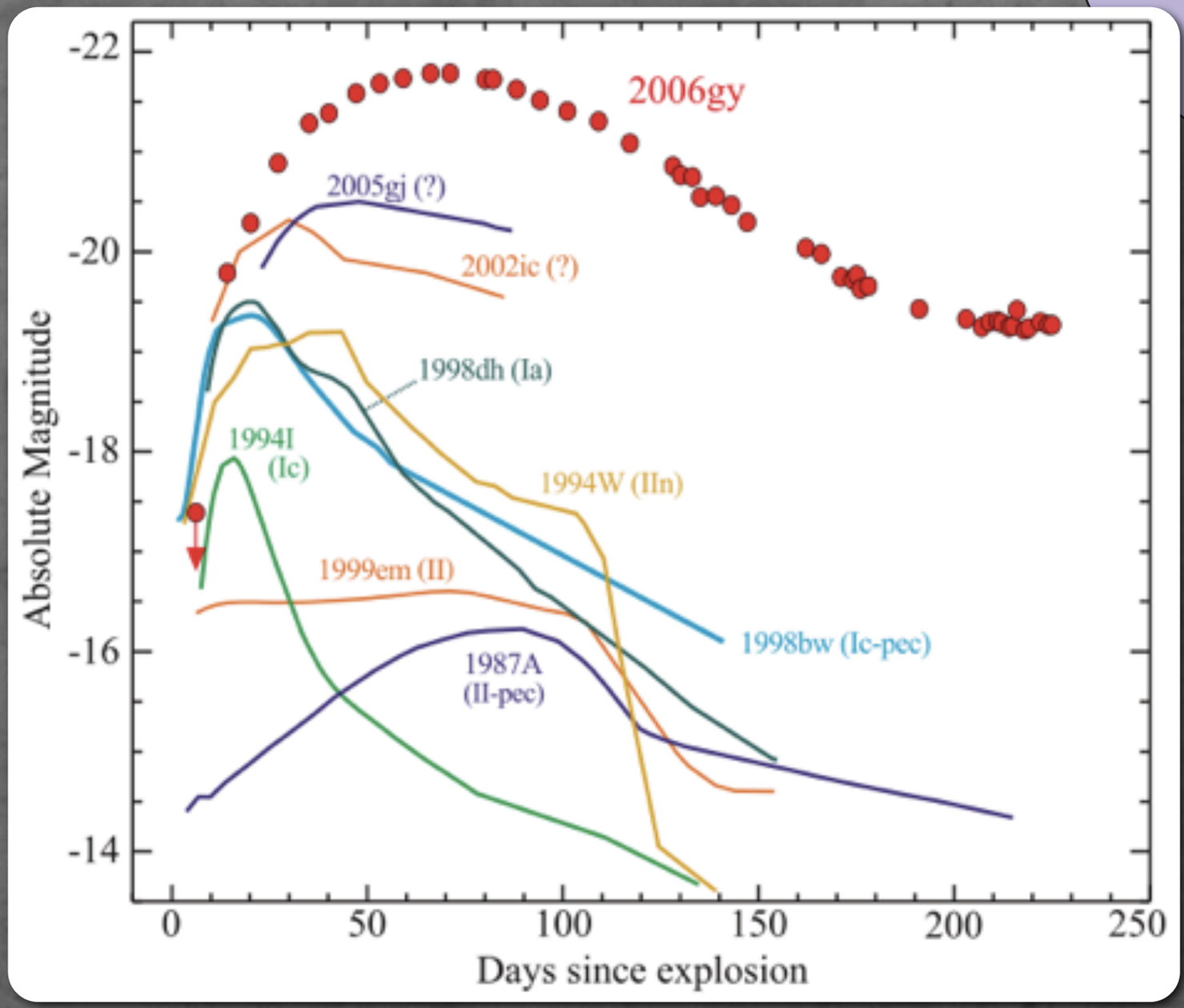
Smith et al. (2010)

Dense CSM and SN ejecta



SN 2006gy

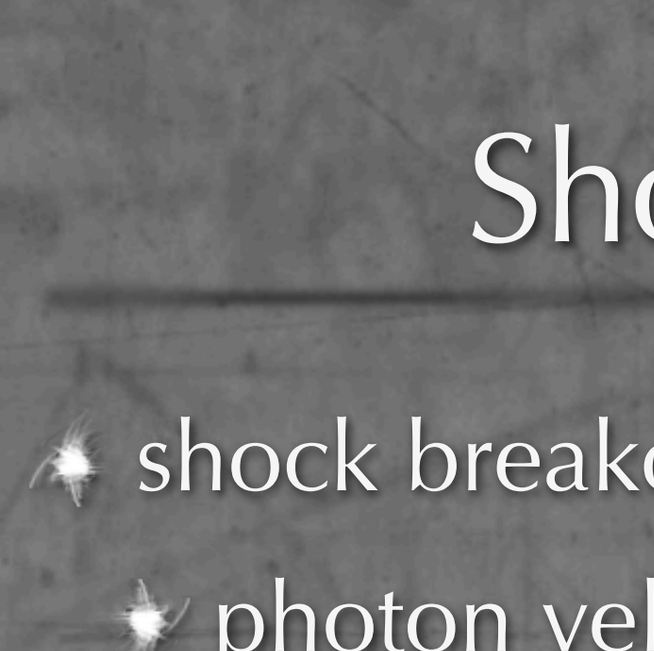


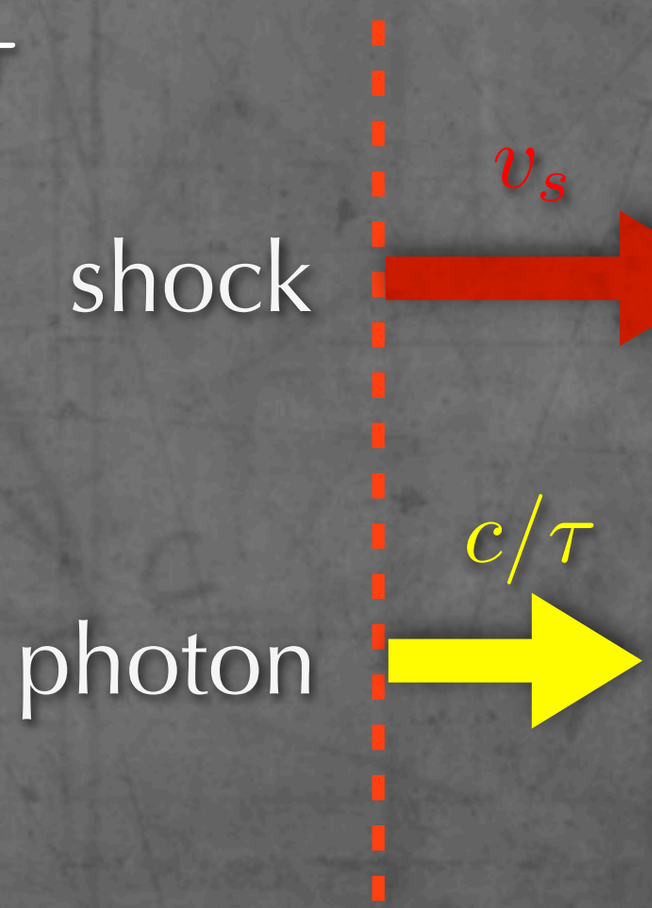


Smith et al. (2007)

Shock Breakout in CSM

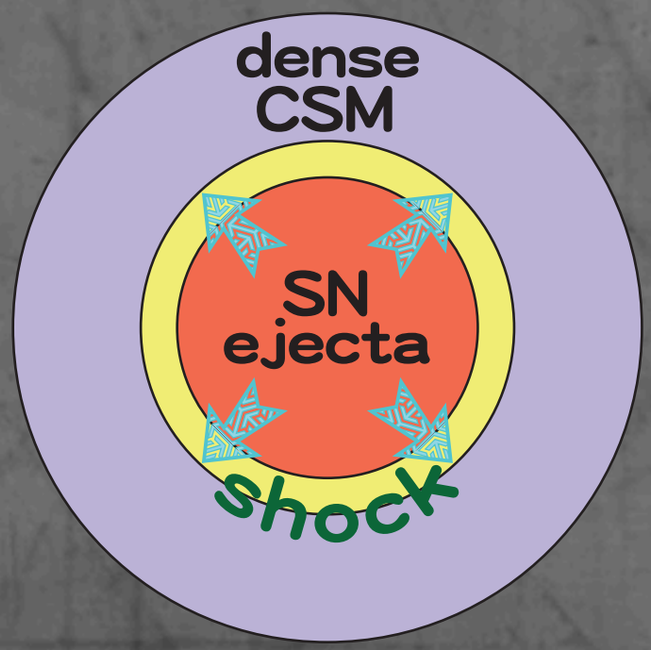
- shock breakout
  - photon velocity in optically thick environment: c/τ
    - $v_s > c/\tau$

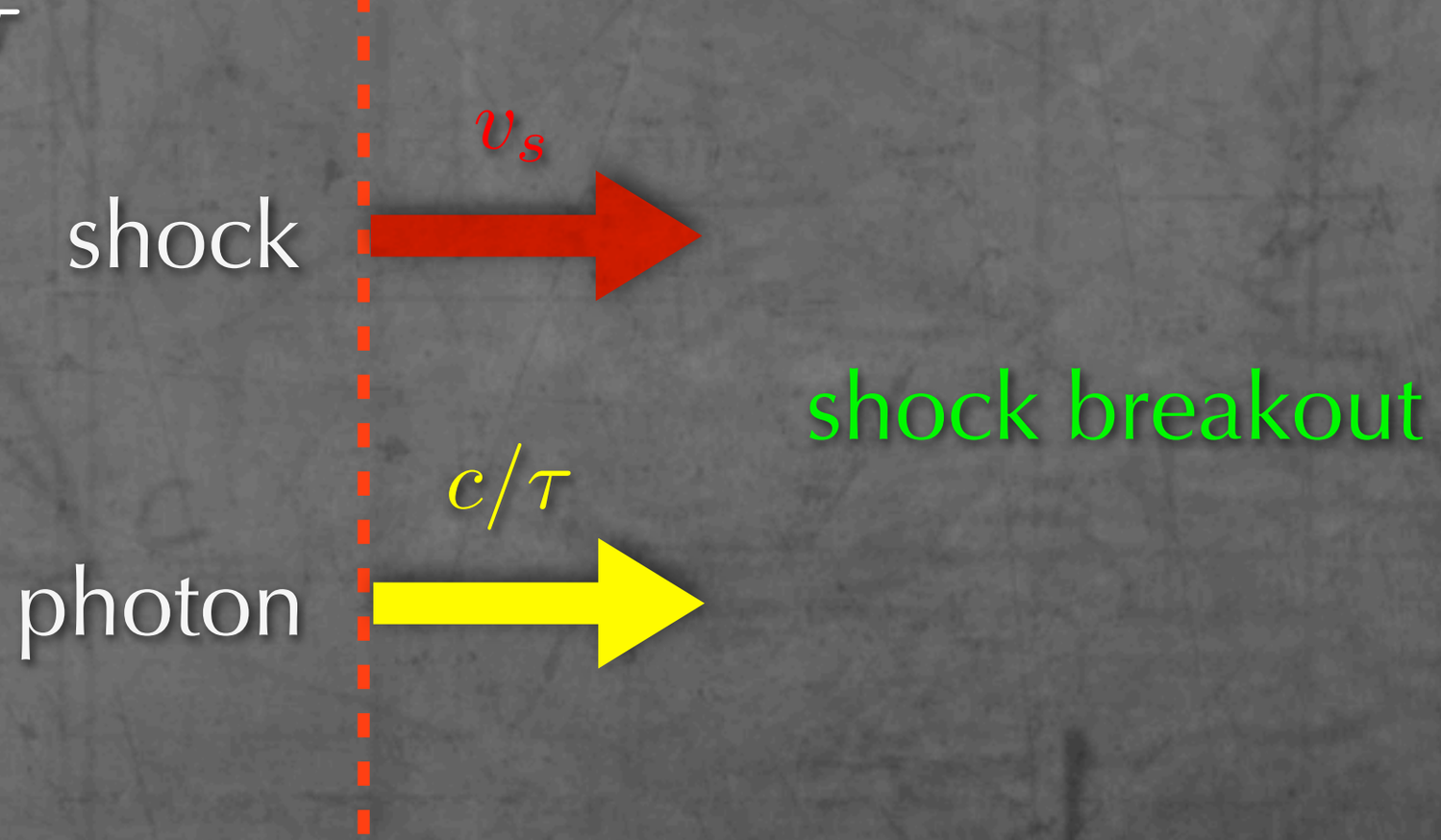




Shock Breakout in CSM

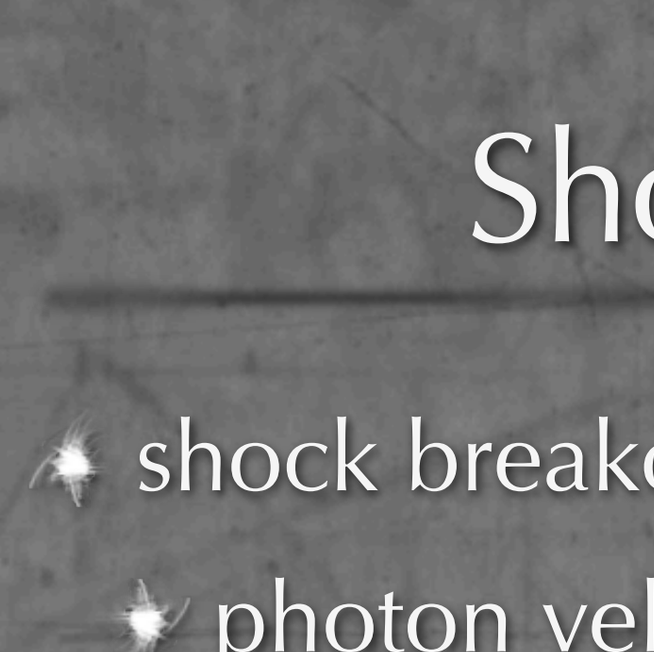
- shock breakout
  - photon velocity in optically thick environment: c/τ
    - $v_s \simeq c/\tau$

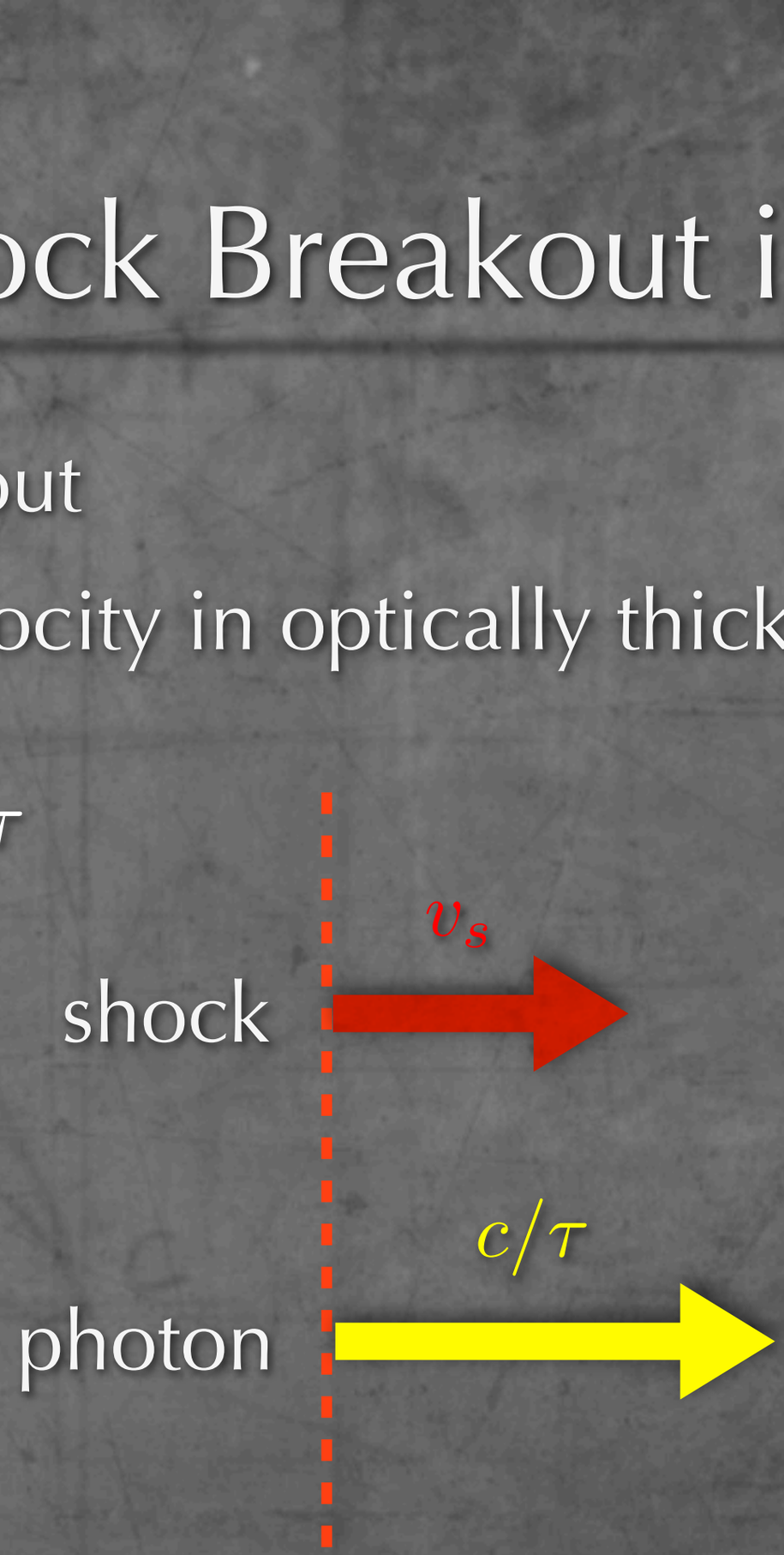




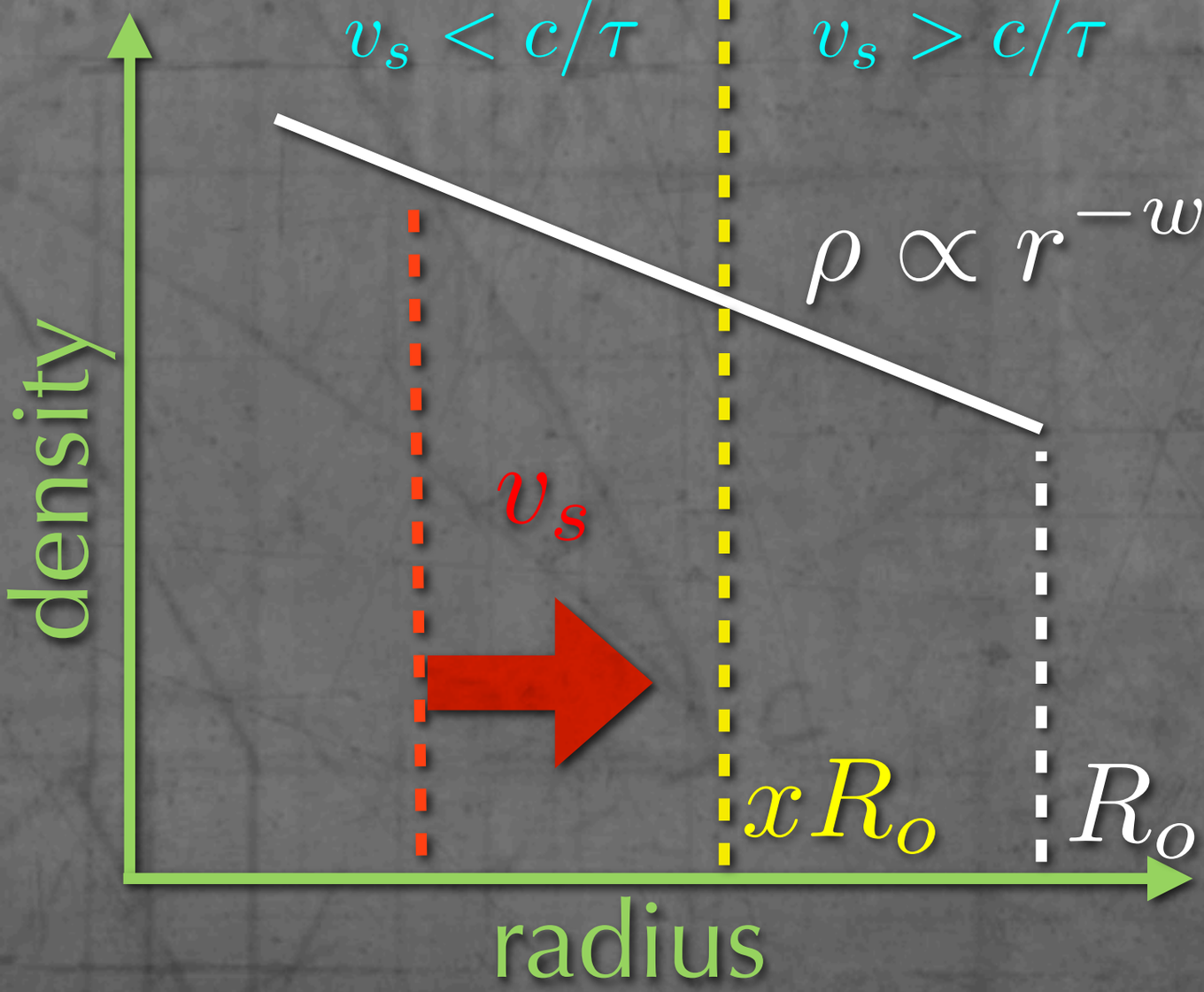
Shock Breakout in CSM

- shock breakout
  - photon velocity in optically thick environment: c/τ
    - $v_s < c/\tau$





Shock Breakout in CSM



rising time of LC:

$$t_d \simeq \begin{cases} \frac{R_o}{v_s}\left[\left(\frac{c/v_s+x^{1-w}}{c/v_s+1}\right)^{\frac{1}{1-w}} - x\right] & (w \neq 1), \\ \frac{R_o}{v_s}\left(x^{\frac{1}{1+c/v_s}} - x\right) & (w = 1), \end{cases}$$

time to pass entire CSM:

$$t_s \simeq \frac{R_o - xR_o}{v_s}.$$

Moriya & Tominaga (2012)

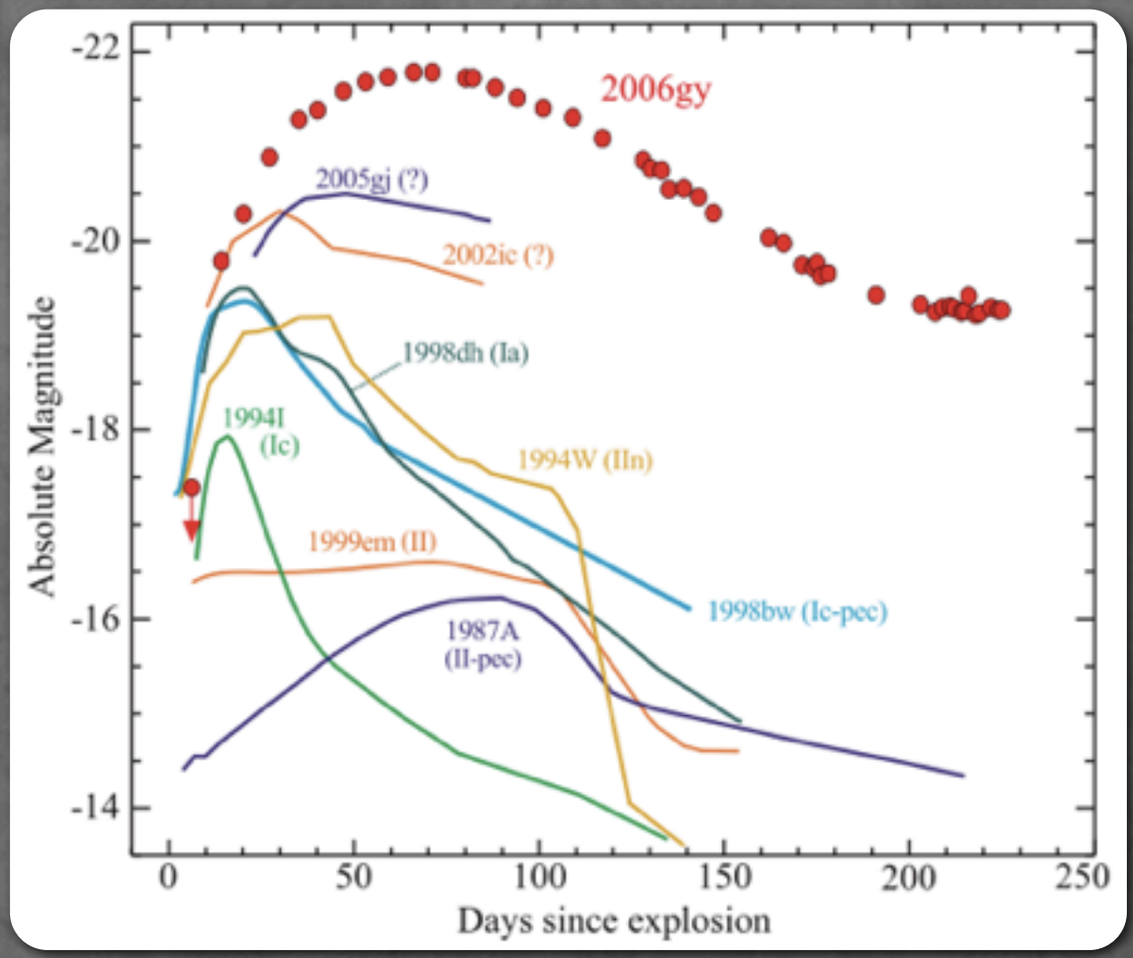
SN 2006gy

- Light Curve

  $t_d \simeq 70$ days

- Spectra

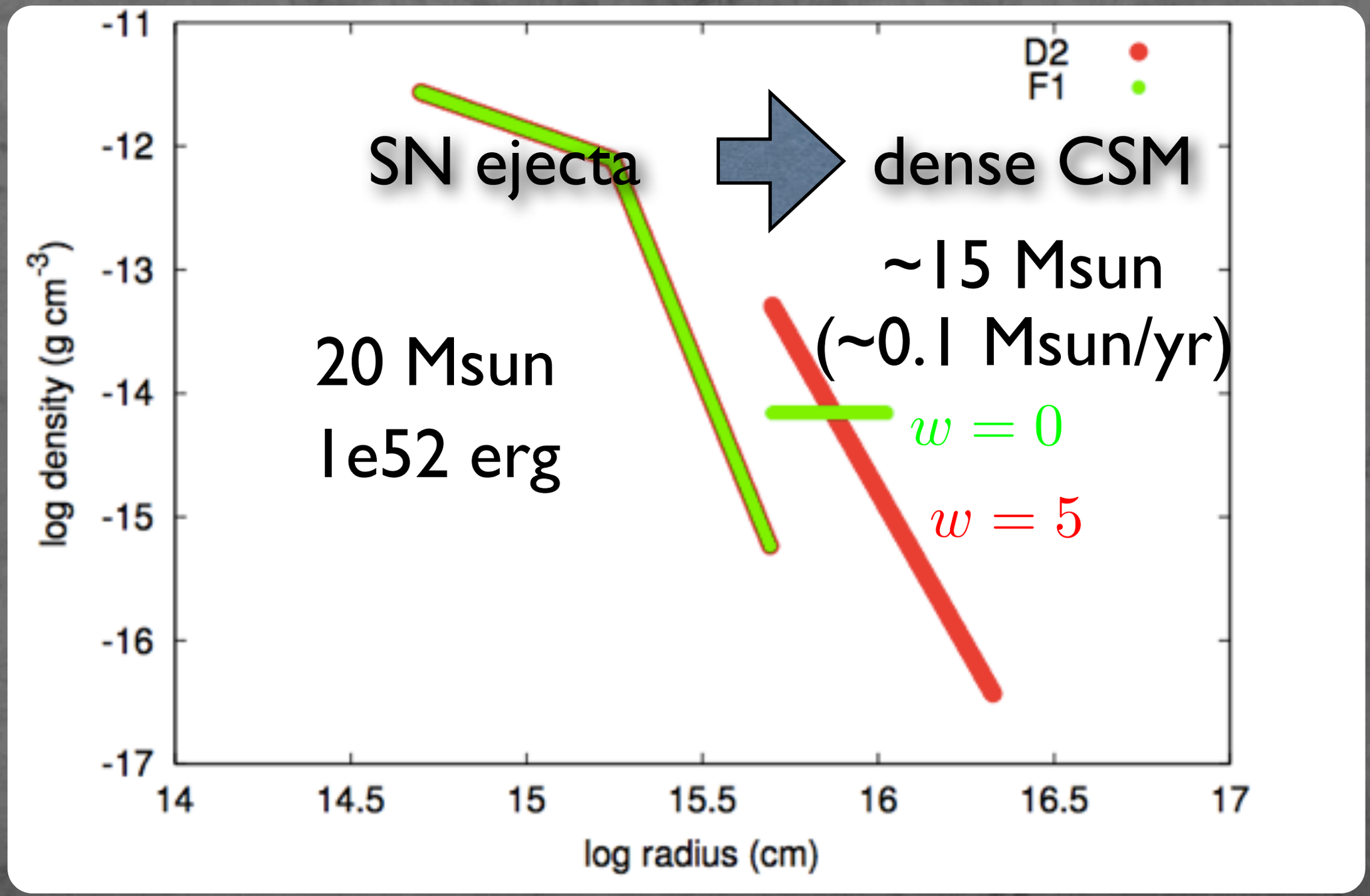
  $t_s \simeq 200$ days



Smith et al. (2007)

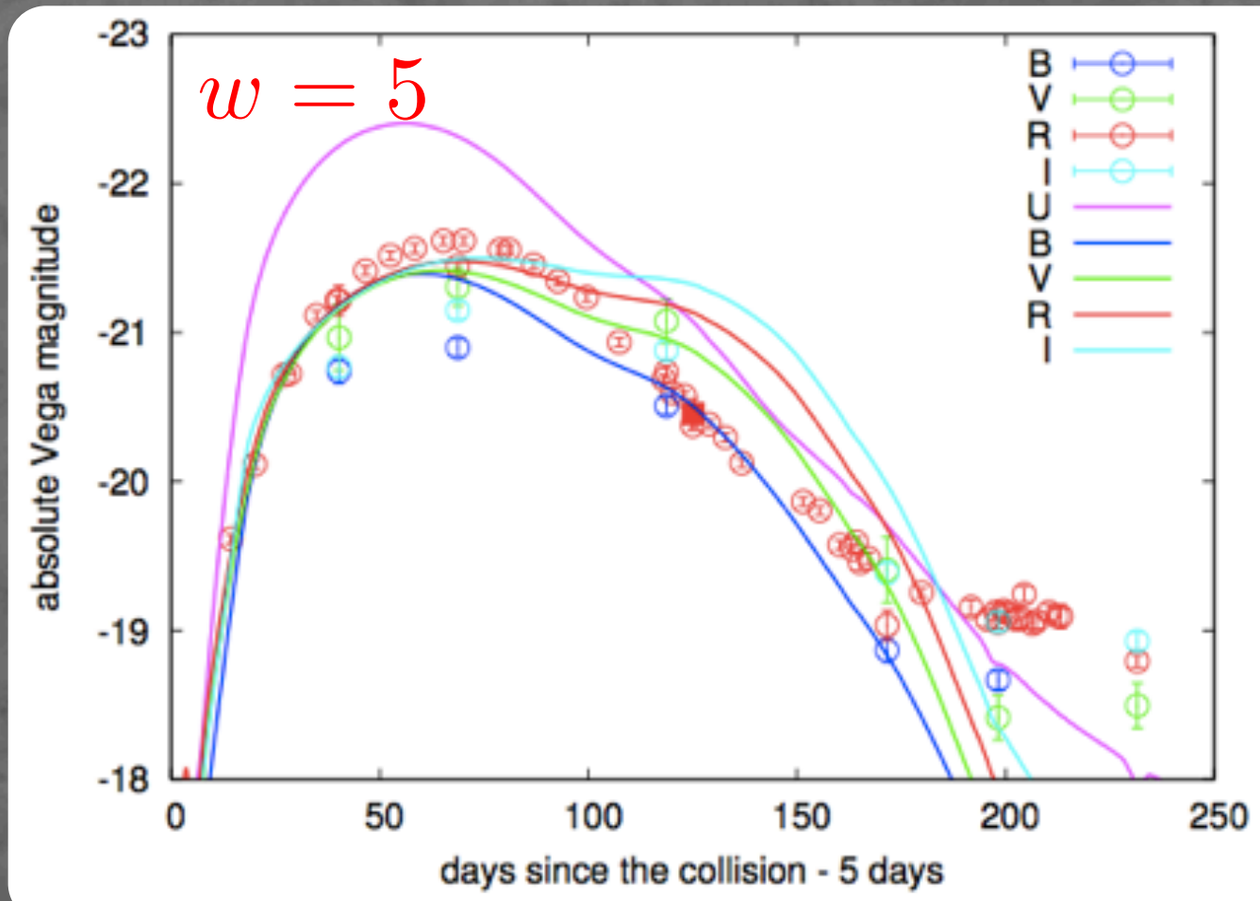
- STELLA code (Blinnikov et al.)
  - 1D multi-group radiation hydrodynamics

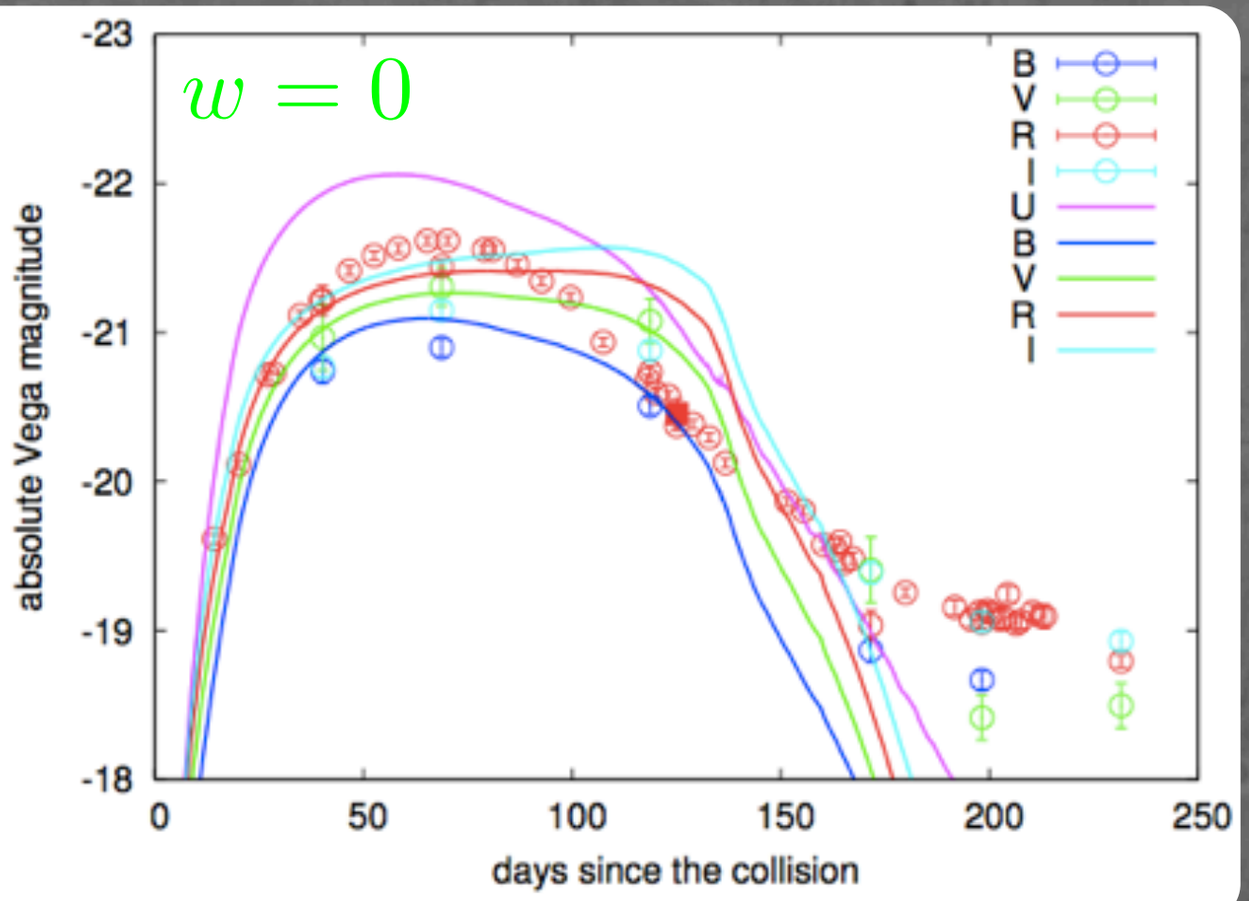
Initial Condition



dense CSM: 100 km/s, $\rho \propto r^{-w}$

Light Curve Models

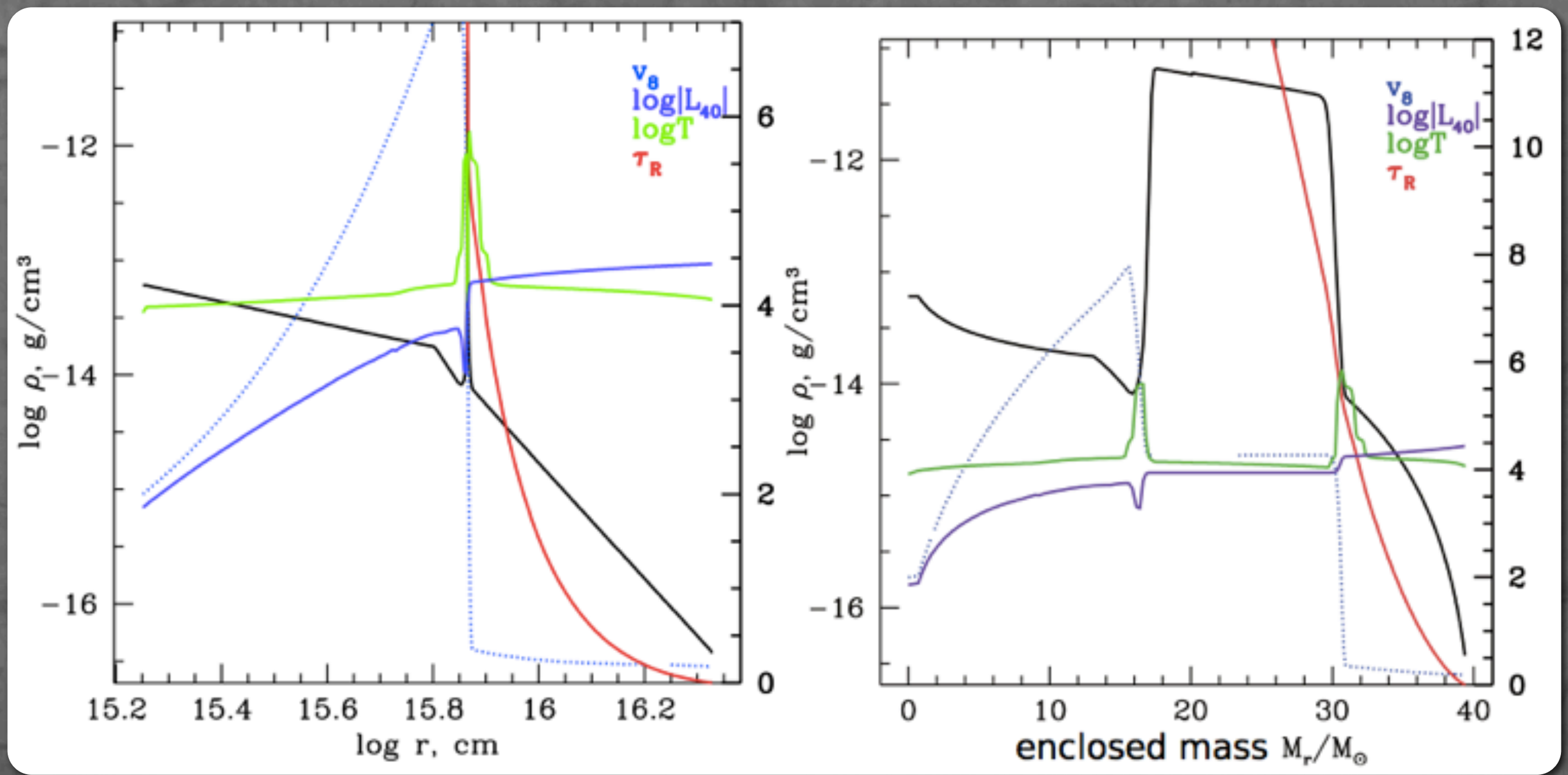




Moriya et al. in prep.

Dynamical Structure

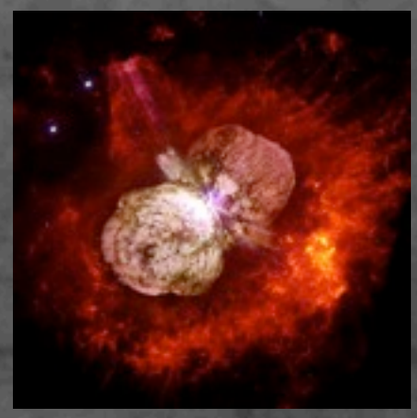
- structures around the peak of the w=5 model



Moriya et al. in prep.

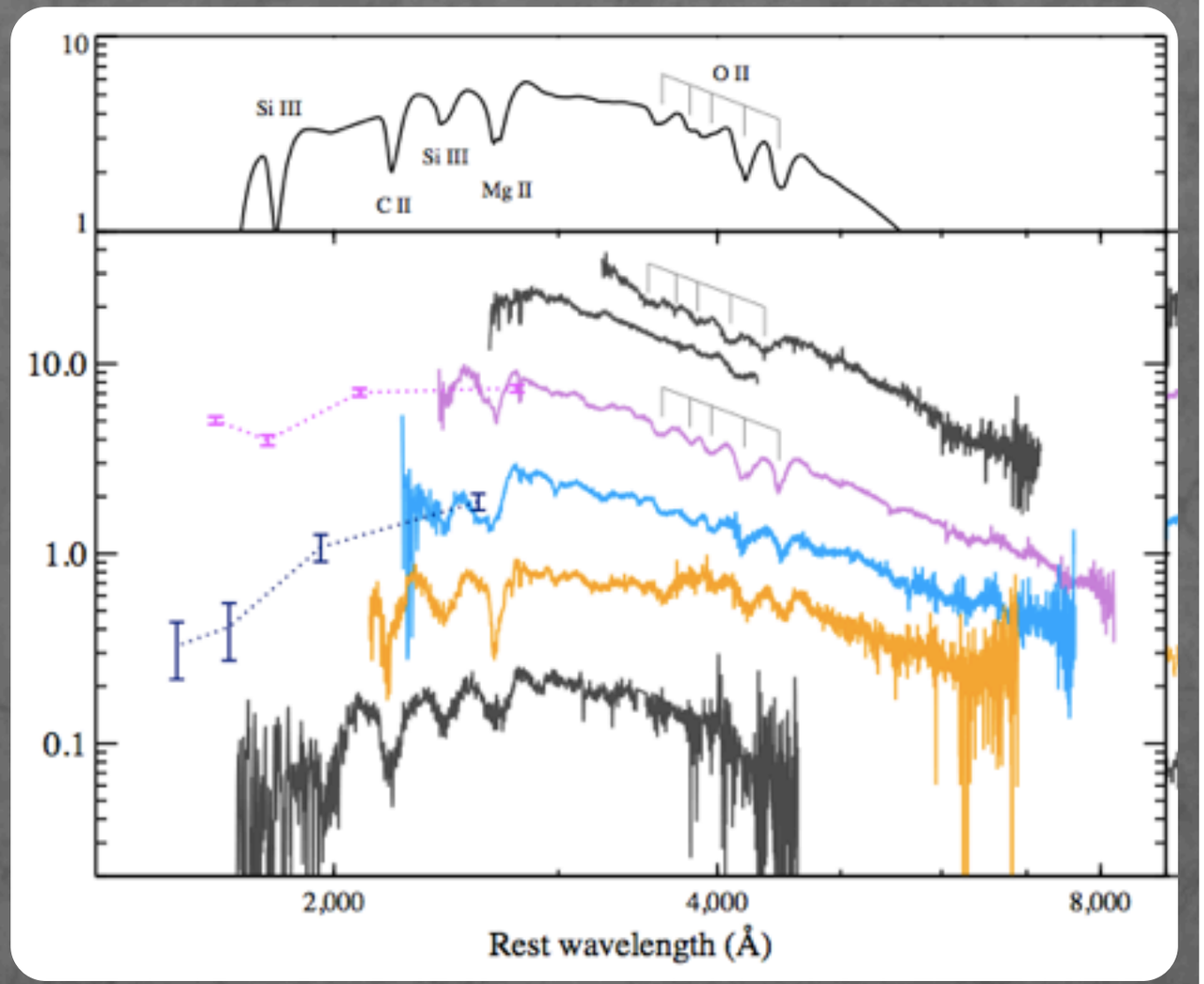
Implications for H-rich SLSNe

- SN ejecta + CSM interaction model works
  - CSM is dense enough to cause shock breakout
    - ~ 15 Msun (~0.1 Msun/yr by a 100 km/s wind)
- Progenitors should be very massive
  - RSGs may be difficult to have the required CSM
  - Luminous blue variables?

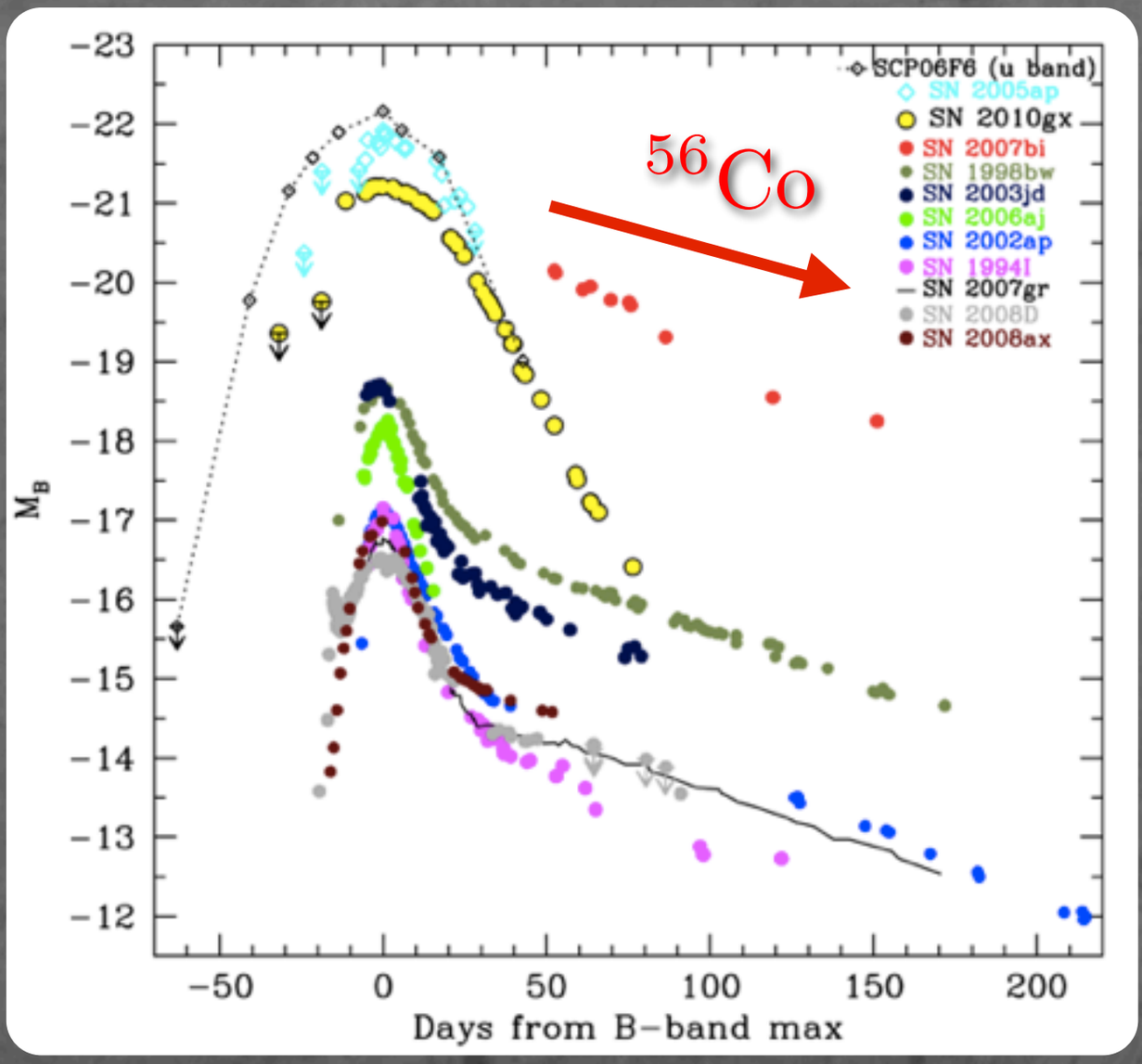


η Car

H-poor SLSNe



Quimby et al. (2011)



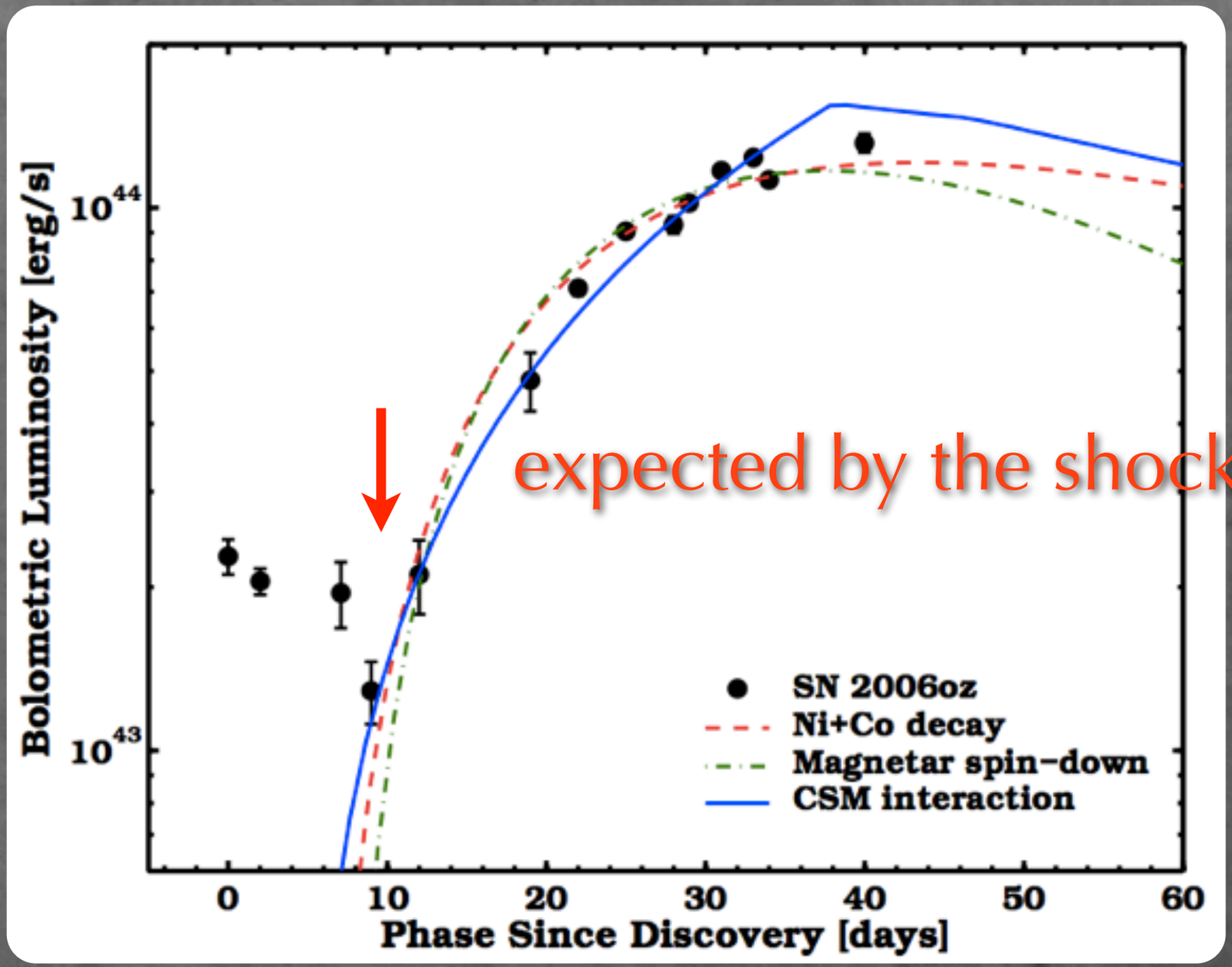
Pastorello et al. (2010)

H-poor SLSNe w/o 56Ni

- How they get bright?
  - Interaction of SN ejecta and C+O-rich CSM?
  - Magnetars inside?
  - Quark novae?
  - ...

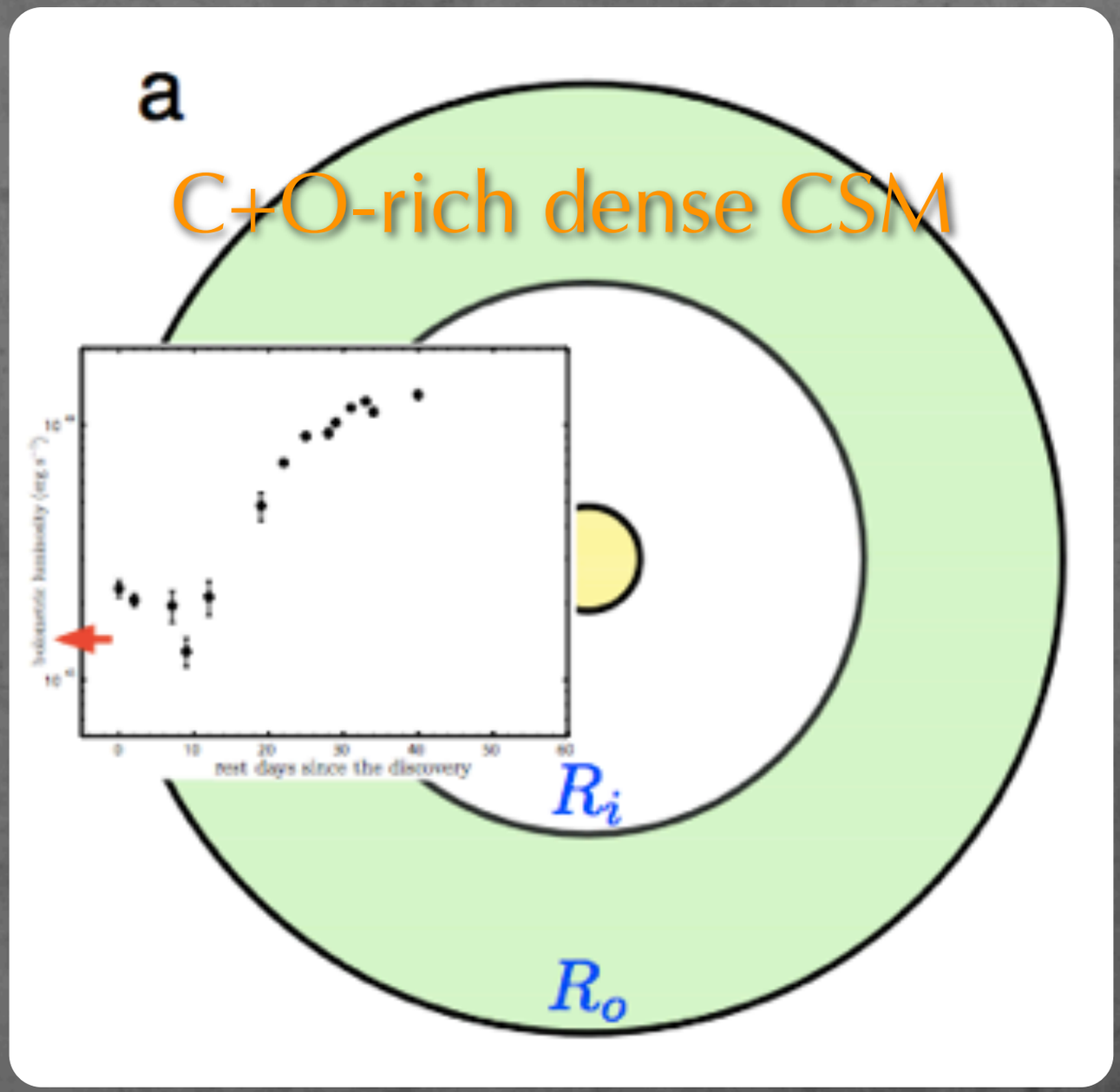
No observational evidence so far

Dip after the Precursor



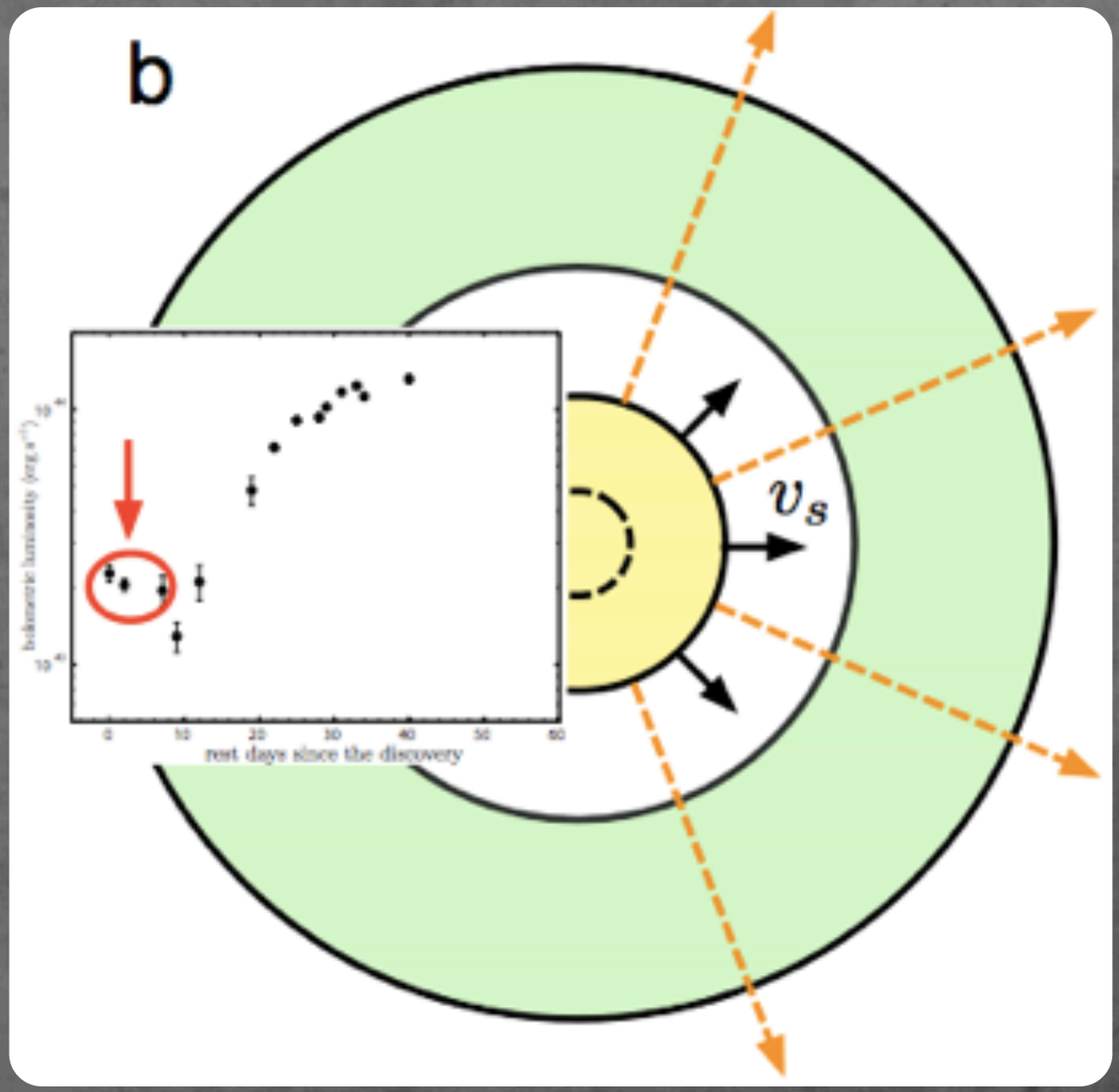
Leloudas et al. (2012)

Dip from Shock Breakout



Moriya & Maeda (2012), on arXiv tomorrow

Dip from Shock Breakout



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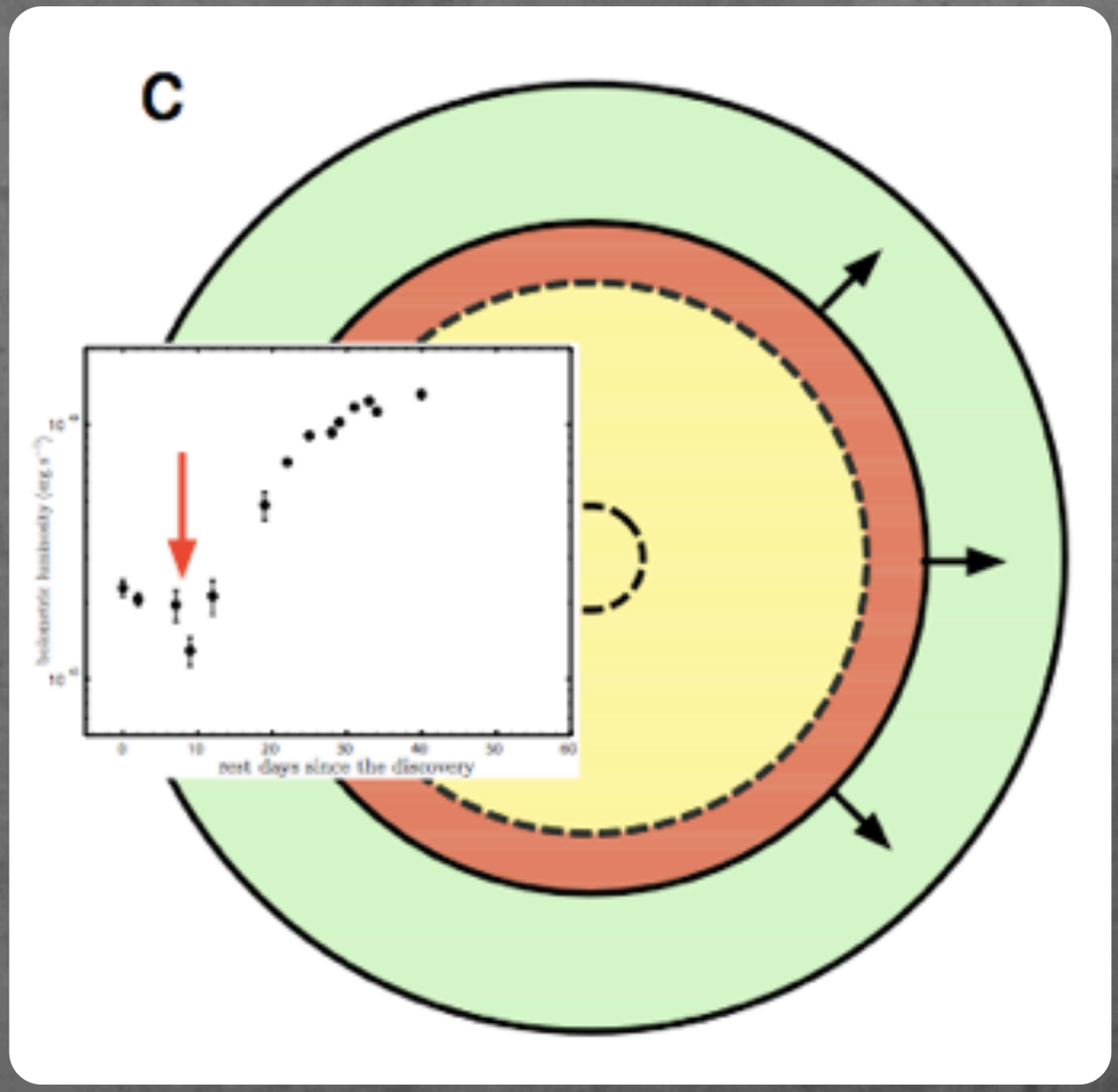
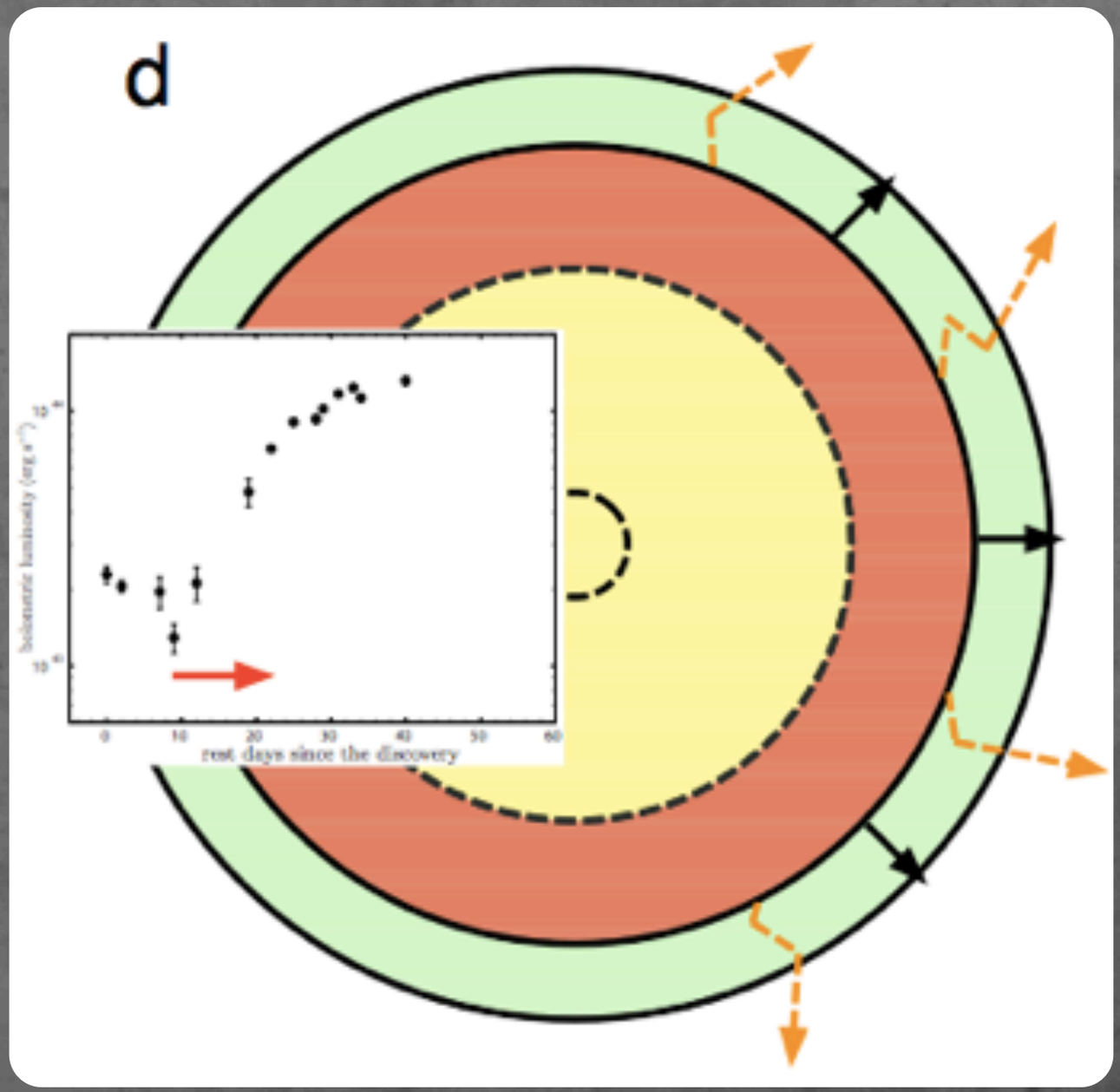


Moriya & Maeda (2012), on arXiv tomorrow

Dip from Shock Breakout



Moriya & Maeda (2012), on arXiv tomorrow

H-poor SLSNe w/o 56Ni

- Dip after the precursor in SN 2006oz
- an evidence of the shock breakout in a C+O-rich dense CSM!
- Simple estimate of the CSM density
- 30 days rising time, Rbb evolution

$R_i = 10^{15}$ cm $R_o = 2.5 \times 10^{15}$ cm 10^{-12} g cm^{-3}

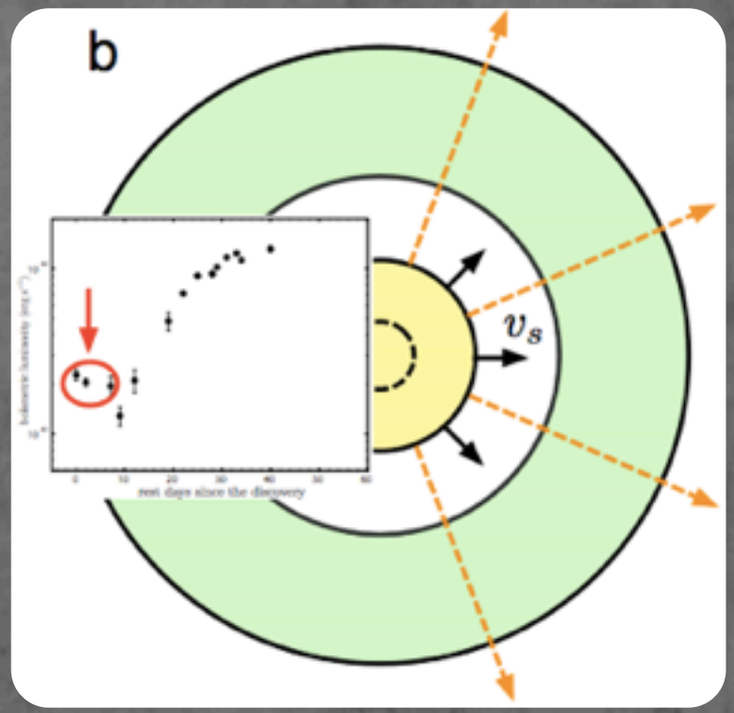
35 $M_\odot$ C+O-rich CSM => $\sim 1\ M_\odot$ yr^{-1}

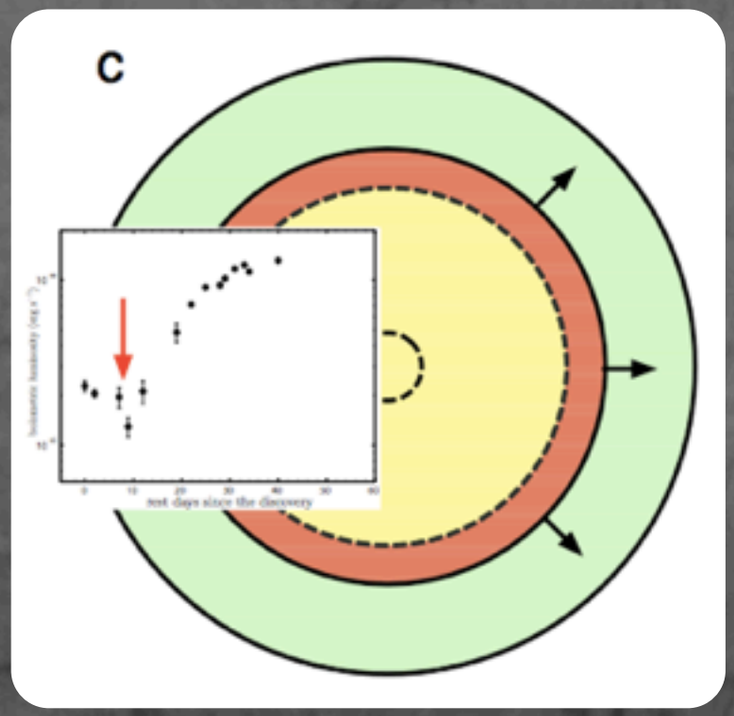
(from WR stars?)

Moriya & Maeda (2012), on arXiv tomorrow

Origin of the Precursor

- 56Ni?
  - ~ 1 Msun 56Ni
    - rising time may be too short
    - less dense CSM within Ri
      - ~ 0.1 Msun CSM (Moriya+ ’10)
    - ...





Summary

- H-rich SLSNe
  - SN 2006gy: ~ 15 Msun dense CSM
  - both w=0 and w=5 models work
  - progenitors: luminous blue variables?
- H-poor SLSNe
  - ‘dip’ after the precursor indicates shock breakout
  - SN 2006oz: ~ 10 Msun C+O-rich CSM
  - progenitors: WR stars? binary? collision?