Early UV/Optical supernova emission

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Early UV/Optical observations of supernova

- X-ray triggering has produced detection of the early stages of type Ib/c SN (e.g. 2008D, 2006aj).
- Combination of UV observations with GALEX and a ground based SN survey[1] produced early observations of two Type IIp SN.
- New high cadence optical surveys with follow up by Swift[2] will produce new observations.
- Source: cooling of shock heated outer $10^{-3}M_\odot$ shell of the envelope.

[1] Gezari et al.(2008)
[2] Ofek E. et al.(in prep.)

A simple description of shock propagation

- Presupernova envelope density $\rho_0(r) = \rho_{1/2}\delta^n, \quad \delta \equiv (1 - r/R)$ ($n = 3, 3/2$ for radiative (BSG) and convective (RSG))

- Shock velocity (interpolating[3] ST-Sakuri)

$$v_s(\delta) \approx 0.8 \left(\frac{E}{M}\right)^{1/2} \delta^{-0.19n}$$

  M - ejecta mass, E - explosion energy

- The pressure behind the shock $\quad p = \frac{aT_0^4}{3} = \frac{6}{7}\rho_0 v_s^2$

- The approximation breaks at $\tau_0 = c/v_{\mathsf{SB}} \to \delta M_{\mathsf{SB}}$

- Final velocity: $\quad v_f \approx 2v_s$

[3] [Matzner & McKee 99]

Early UV/Optical emission

- Freely expanding and adiabatically cooled ejecta, diffusion is neglected, photosphere propagates inward.

- For $t \gtrsim R/v_{\mathrm{SB}}$

$$\delta M_{\mathrm{photo.}}/M \approx 10^{-2.5} \frac{(\sigma_T/m_p\kappa)^{0.8} E_{51}^{0.8}}{(M/M_\odot)^{1.6}} t_{\mathrm{day}}^{1.6};$$

$$T_{\mathrm{eff.}} \approx 1\,(\sigma_T/m_p\kappa)^{0.27} R_{12}^{1/4} t_{\mathrm{day}}^{-1/2} \mathrm{eV};$$

$$T_{\mathrm{therm.\text{-}depth}}/T_{\mathrm{eff.}} \approx 1.2(\kappa_{\mathrm{abs.}}/\kappa_{\mathrm{abs.\ OP}})^{-1/8};$$

$$L_{\mathrm{bol.}} = 10^{42}(\sigma_T/m_p\kappa)^{-0.8} \frac{E_{51}^{0.9}}{(M/M_\odot)^{0.7}} R_{12} t_{\mathrm{day}}^{-1/3} \mathrm{erg/s};$$

$E = E_{51}\,10^{51}\mathrm{erg},\ R = R_{12}\,10^{12}\mathrm{cm}$

- Measure R (from T), E/M (@ $\delta M \sim 0.003 M_\odot$)

Early UV/Optical emission (cont'd)

- The model holds for $\delta M_{\text{photo.}} > \delta M_{\text{SB}}$

$$t > t_{\text{BO}} = 10^2 (\sigma_T/m_p\kappa)^{-0.2} \frac{(M/M_\odot)^{0.6}}{E_{51}^{0.9}} R_{12}^{1.4}\,\text{s}$$

- The bolometric luminosity when diffusion is included[4] (for $n = 3$)

$$L_c = 8.9 \times 10^{41} (\sigma_T/m_p\kappa)^{-0.82} \frac{E_{51}^{0.91} R_{12}}{(M/M_\odot)^{0.74}} t_5^{-0.35} \text{ erg}\,\text{s}^{-1},$$

compared to the luminosity of our model

$$L = 9.1 \times 10^{41} (\sigma_T/m_p\kappa)^{-0.85} \frac{E_{51}^{0.85} R_{12}}{(M/M_\odot)^{0.69}} t_5^{-0.35} \text{ erg}\,\text{s}^{-1}$$

$\Rightarrow$ Diffusion not important.

[4] Chevalier (1992)

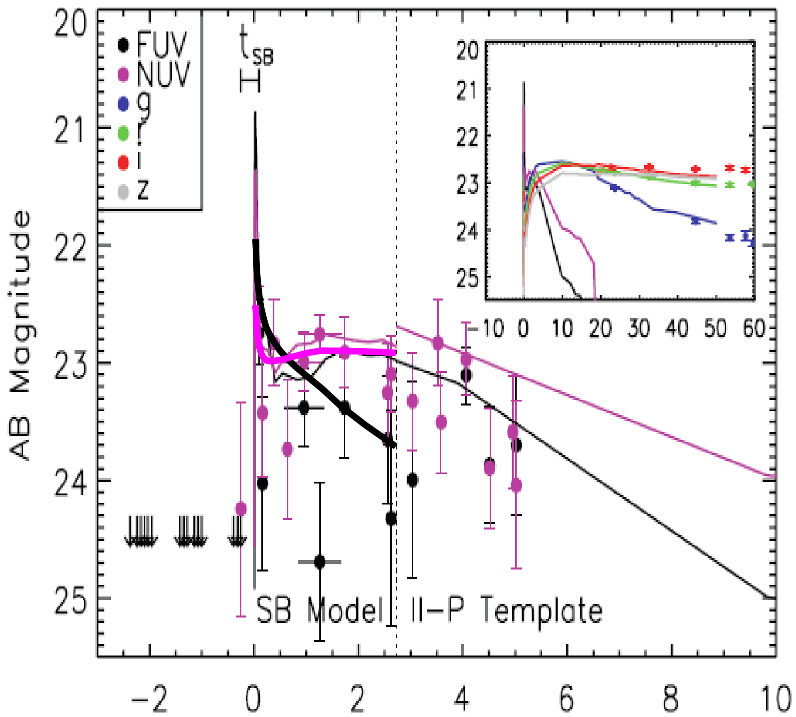
Related work

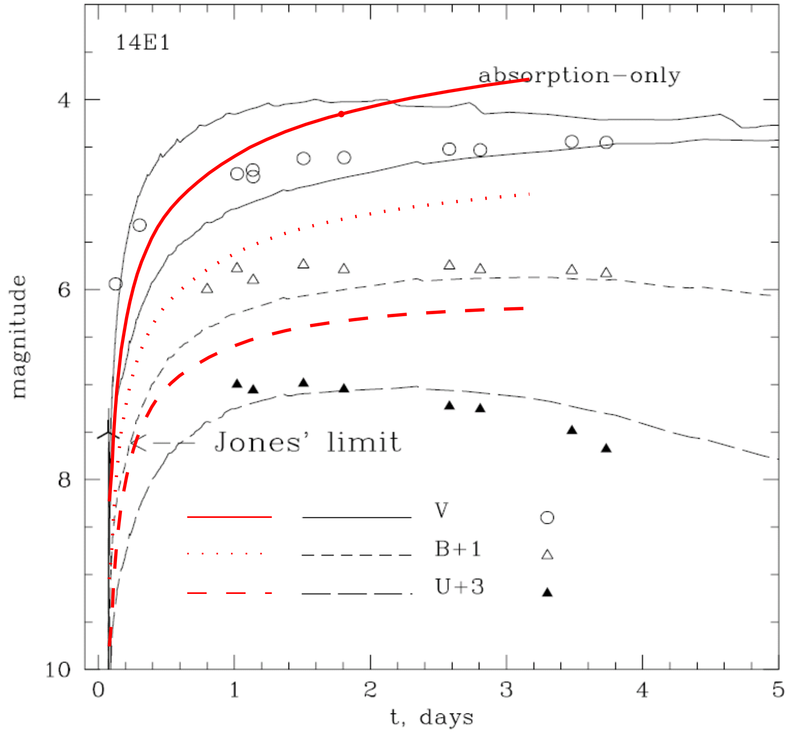
- Chevalier (1992): $L_{\text{bol.}}$ from diffusion - same as our simple model.
  [Erroneous scaling in Chevalier (1992) corrected in Chevalier et. al. (2008)]

- Piro et. al. (2010): $L_{\text{bol.}}$ from diffusion for SN Ia.

- Nakar & Sari (2010): $L_{\text{bol.}}$ from diffusion - same as our simple model.
  Their T_{col} is larger than ours by a factor ~ 1.5, because they take $\kappa_{\text{abs.}} = \kappa_{\text{f.f.}}$

Comparison to simulations/Observations





SNLS04D2dc obs. and models[4] RSG, $R = 865R_{\odot}, M = 11.13M_{\odot}, E_{51} = 1.2$

SN1987A obs. and models[5] BSG, $R_{*} = 48.5R_{\odot}, M = 14.67M_{\odot}, E_{51} = 1$

- Our simple model approximately reproduces results of detailed simulation.

[5]Gezari et al.(2008)

[6]Blinnikov et al.(2000)

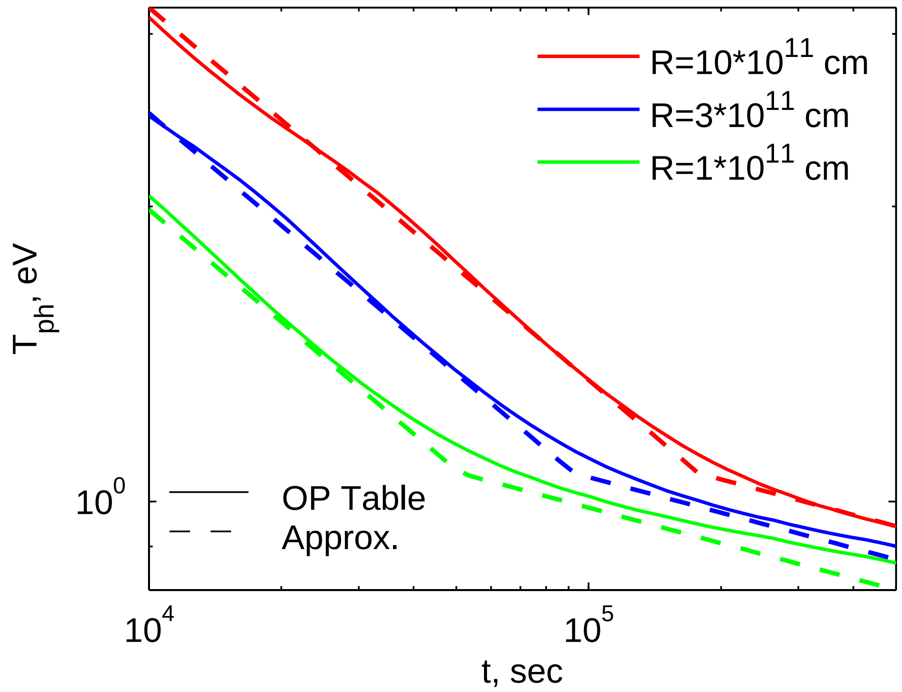
Complications

- Extinction
- Simple model limited by simplified opacity (λ dependence)
- Smaller progenitors:

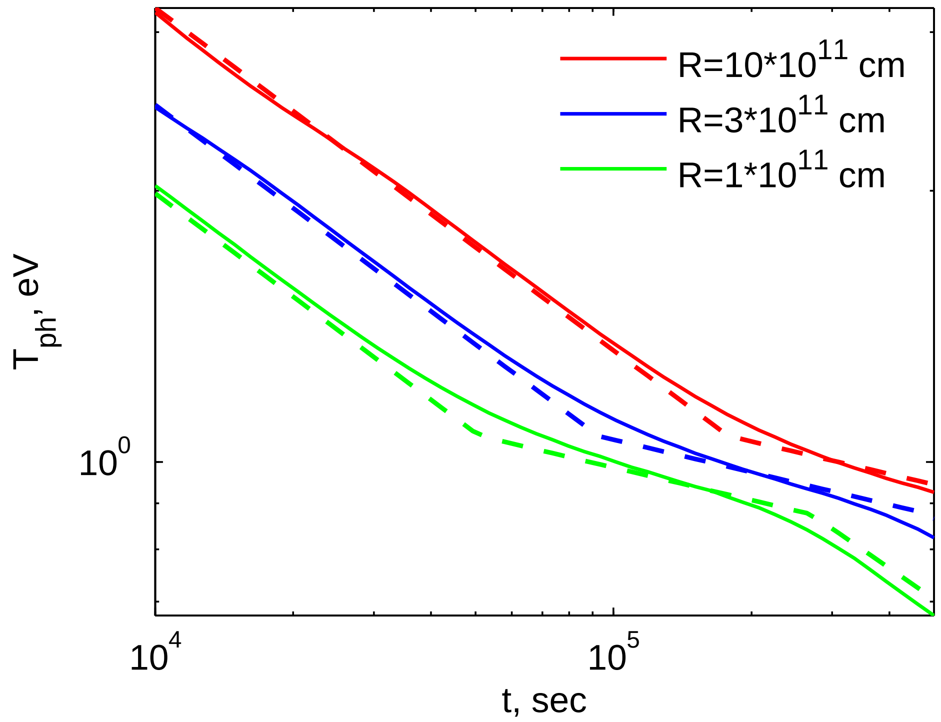
Lower T (~ 1 eV @ $\sim$1 day)
Absence of H
$\rightarrow$ modification of opacity (e.g. recombination)

Note: $R \sim T_{\text{eff.}}^4 \kappa^{-1}$
$T_{\text{col.}}$: distorted by extinction.

Analytic model including realistic opacity



$X_{\text{He}} = 0.98$

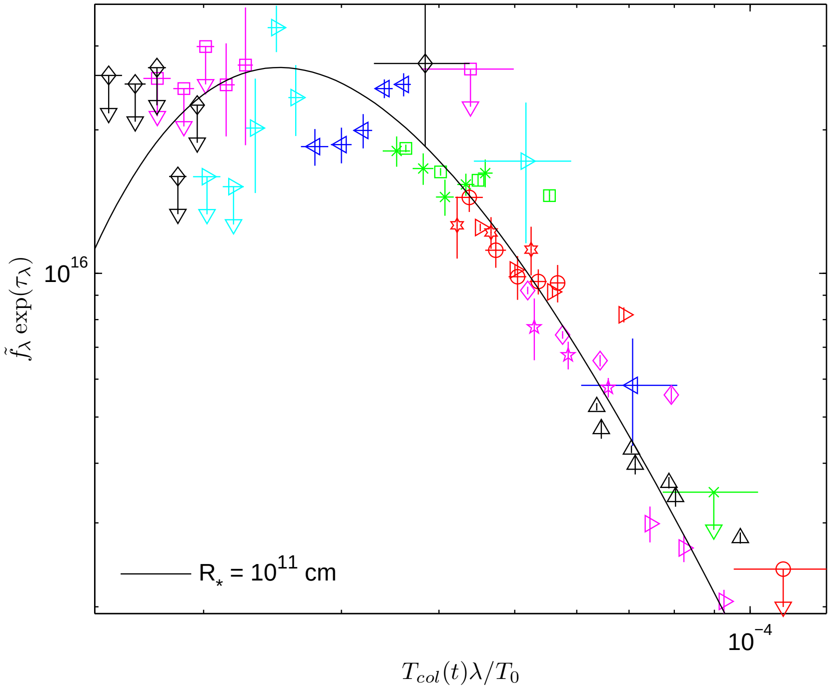


$X_{\text{He}} = 0.7, \quad X_{\text{CO}} = 0.3$

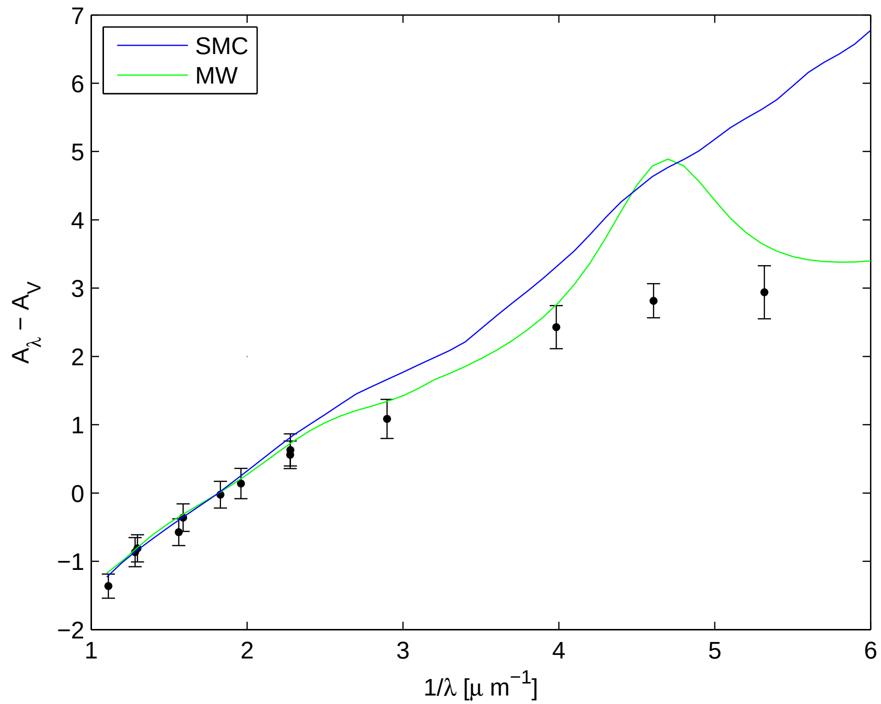
- Taking realistic κ affects the decline of T.

Removing reddening (SN2008D)

For the correct R & comp., scaling brings all $f_\lambda(t)$ to a universal form.



Norm ⇒ relative extinction



- R & comp. ⇒ relative extinction ⇒ extinction curve ⇒ E/M

Summary

- Early UV/O : determine R, envelope comp., Extinction, E/M.

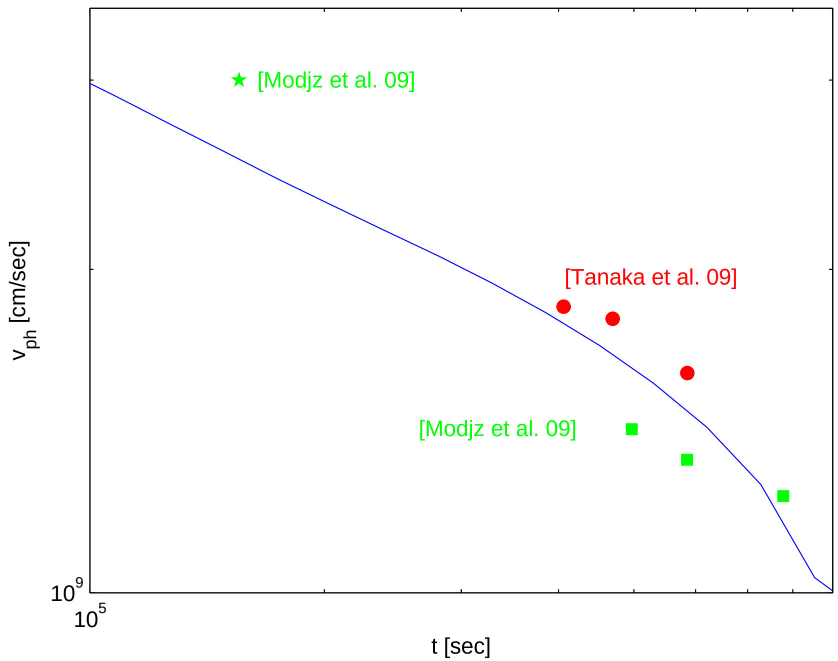
- SN2008D : $R = 10^{11}$ cm,
  He with C/O,
  Relative extinction curve, E(B-V)=0.6,
  $E_{51}/(M/M_{\odot}) \sim 0.8$ (assuming A_V E(B-V)).

Compare with[7,8]:

$0.8 < E_{51}/(M/M_{\odot}) < 1.3$
30% C at 20,000 km/s
$0.4 < E(B-V) < 0.8$

Progenitor models[8]:

$0.9 < R/10^{11}\text{cm} < 1.5$



[7] Soderberg et al. (2006), Mazzali et al. (2008)
[8] Tanaka et al. (2009)