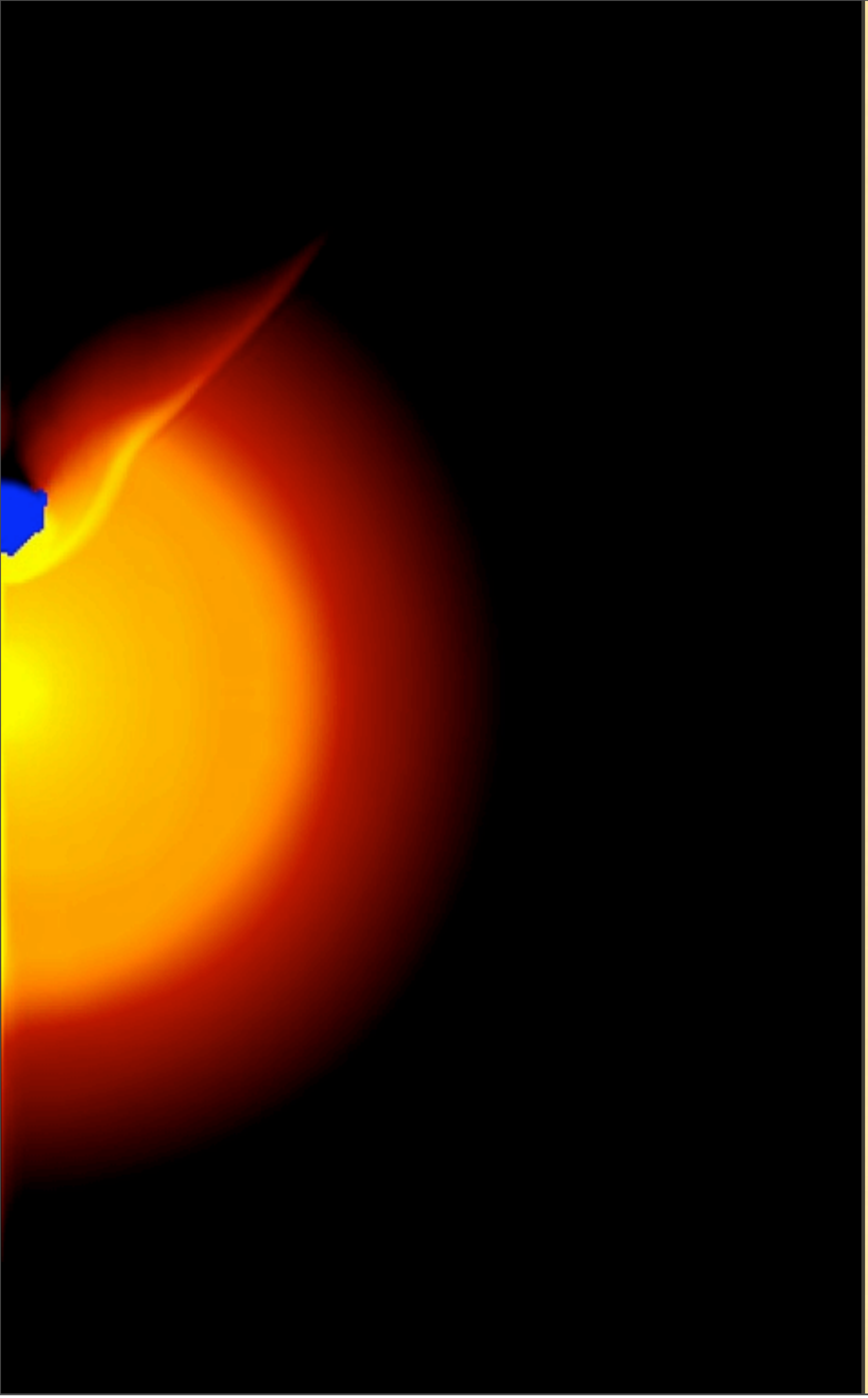
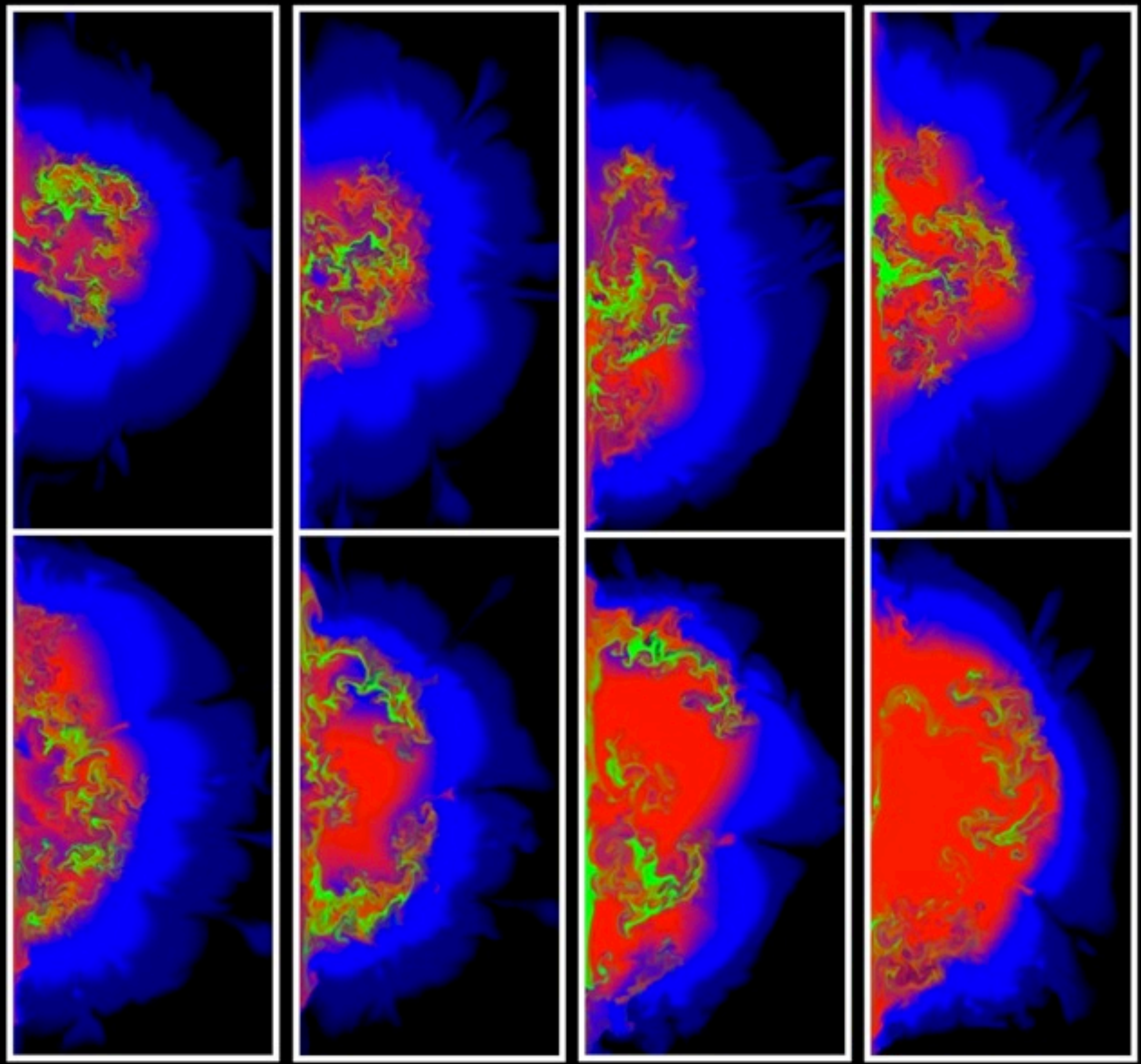


light curves of type Ia supernovae from different progenitor scenarios

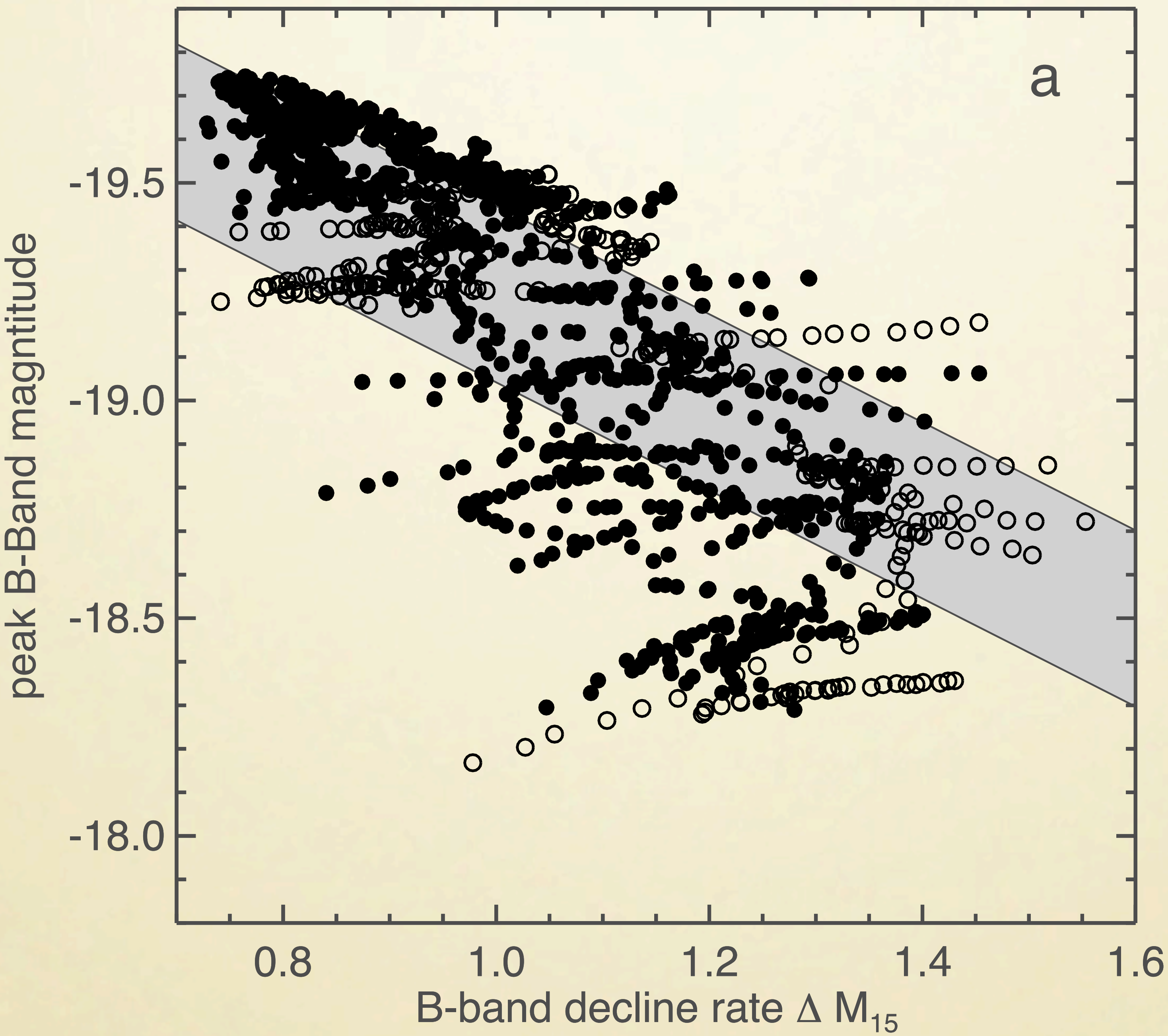
daniel kasen
UC Santa Cruz

2-D delayed detonation models



kasen, röpke, and woosley; nature (2009)

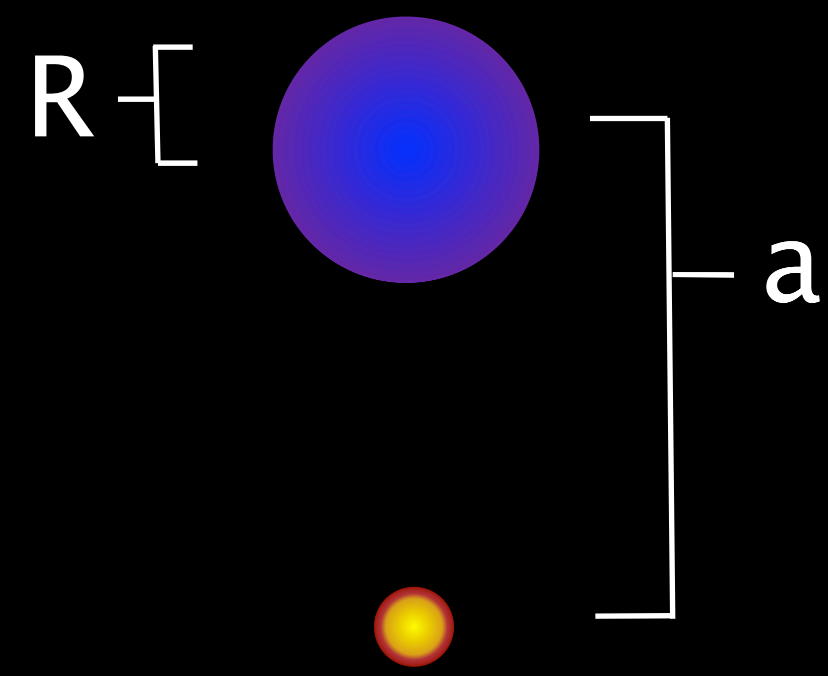
width-luminosity relations for 2-dimensional delayed detonation models



44 models
30 viewing angles each

kasen, röpke, and woosley; nature (2009)

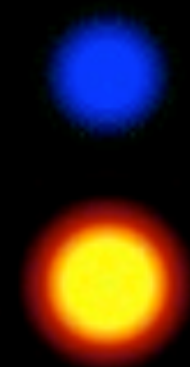
single degenerate progenitor system



R @10^{11}–10^{12} cm (main sequence, M = 1–6 M_{sun})

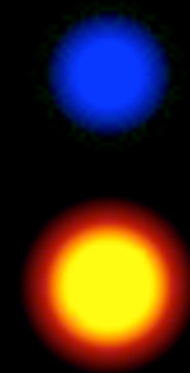
R @10^{13} cm (red giant; M @ 1 M_{sun})

a/R = 2–3 in Roche lobe overflow



supernova companion interaction

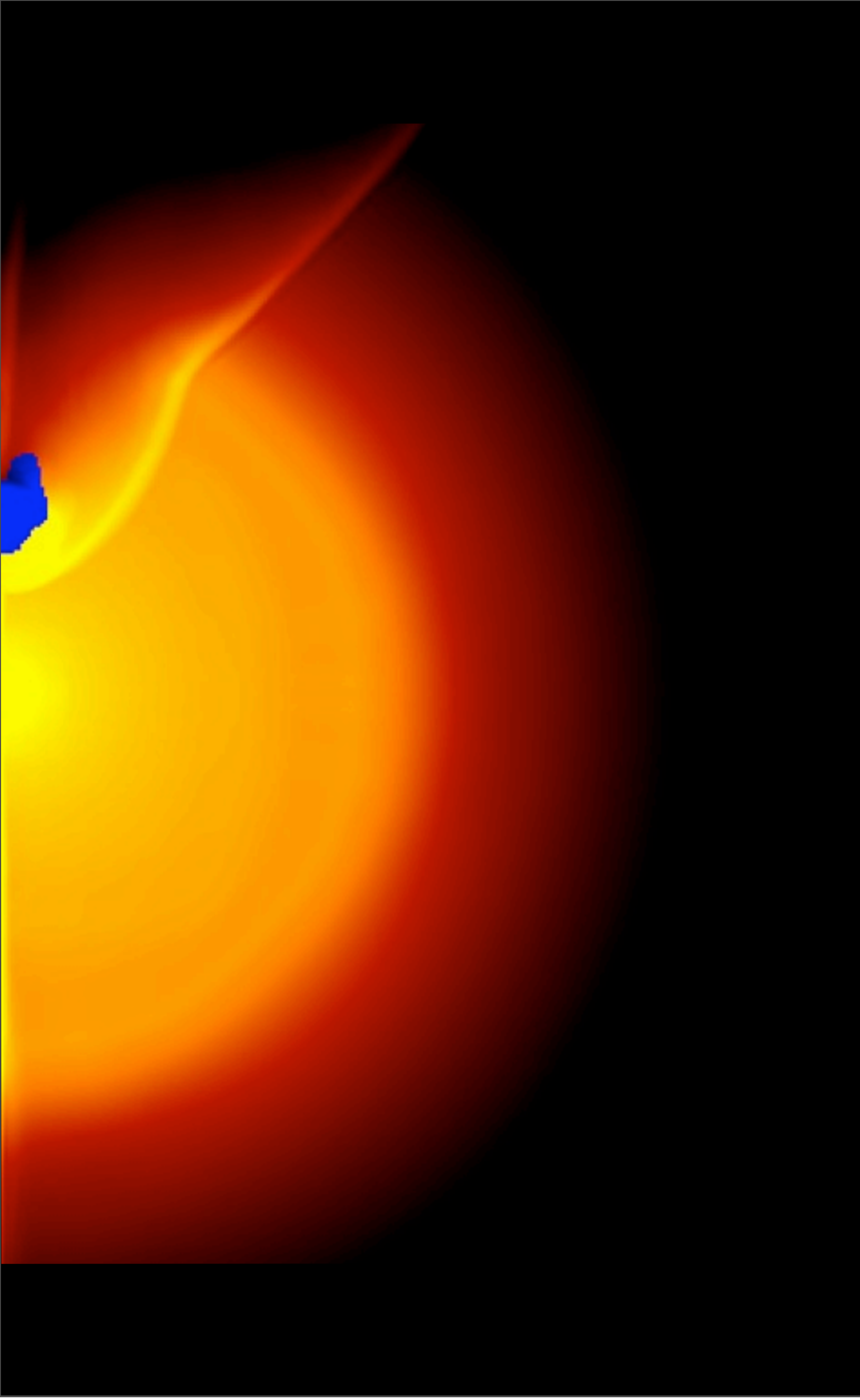
Wheeler et al. (1975); Fryxell & Arnett (1981); Livne et al. (1992); Marietta et al. (2000); Pakmor et al. (2008).



density plot

red giant @

$a = 2.5 \times 10^{13}$ cm



signatures of companion interaction

search for tycho's companion

ruiz-lapuente et al (2004)

kerzendorf (2009)

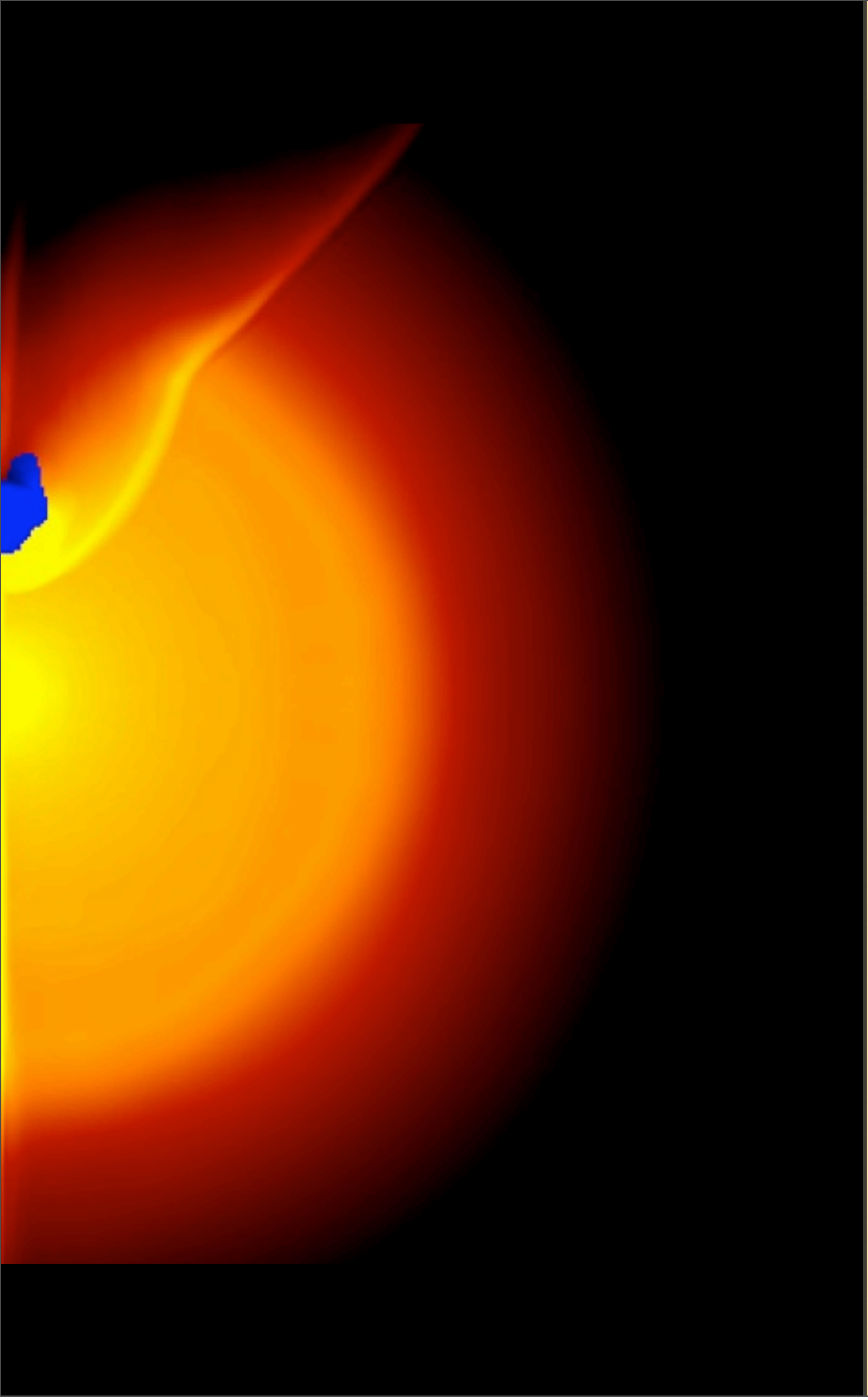
search for stripped hydrogen

mattila al al., (2005)

leonard et al., (2007)

supernova polarization

kasen et al., (2004)



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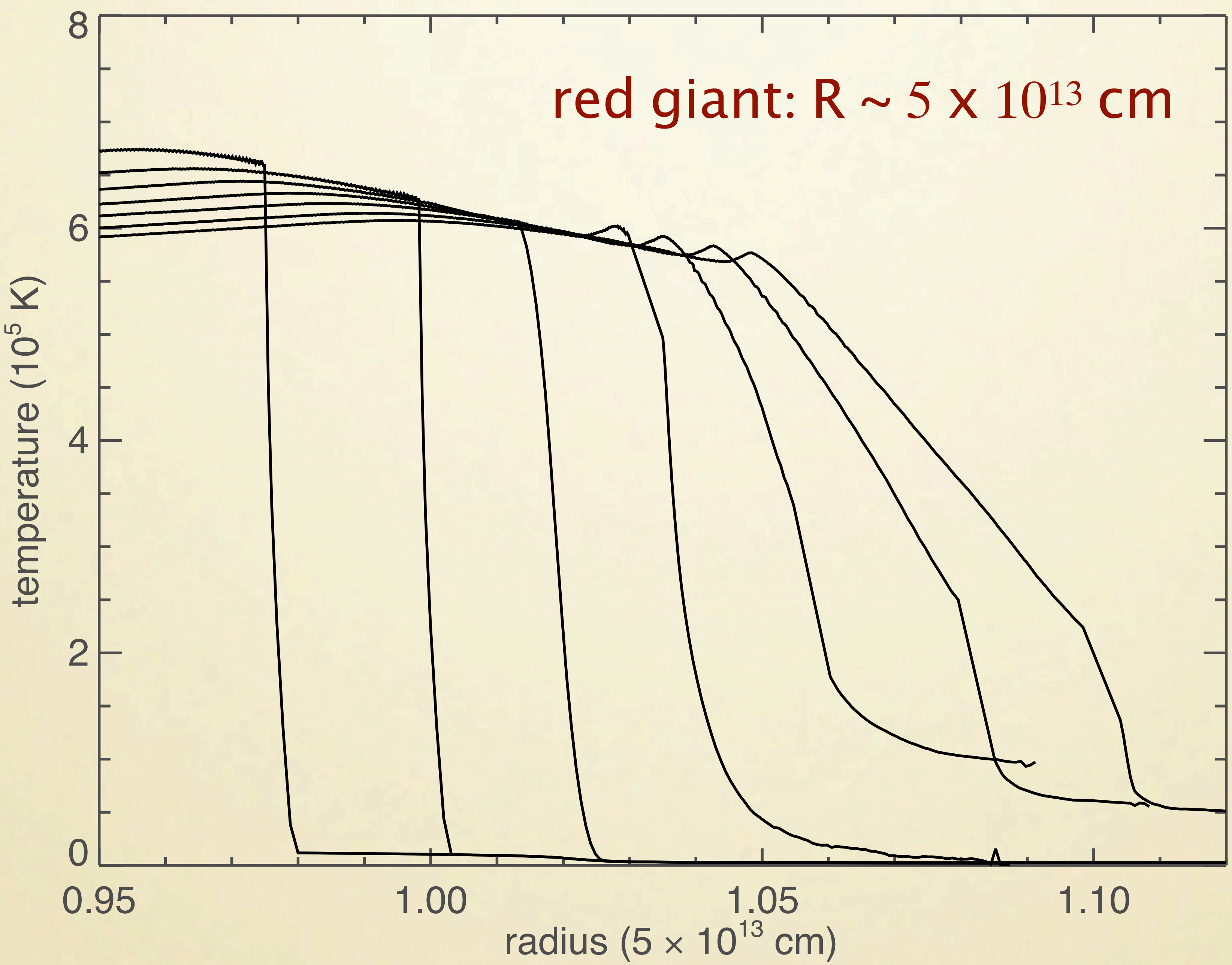
kasen et al., (2004)

could we see the collision itself?

kasen, (2009)

SHOCK BREAKOUT IN SNIIP

photons escape when diffusion time @ dynamical time

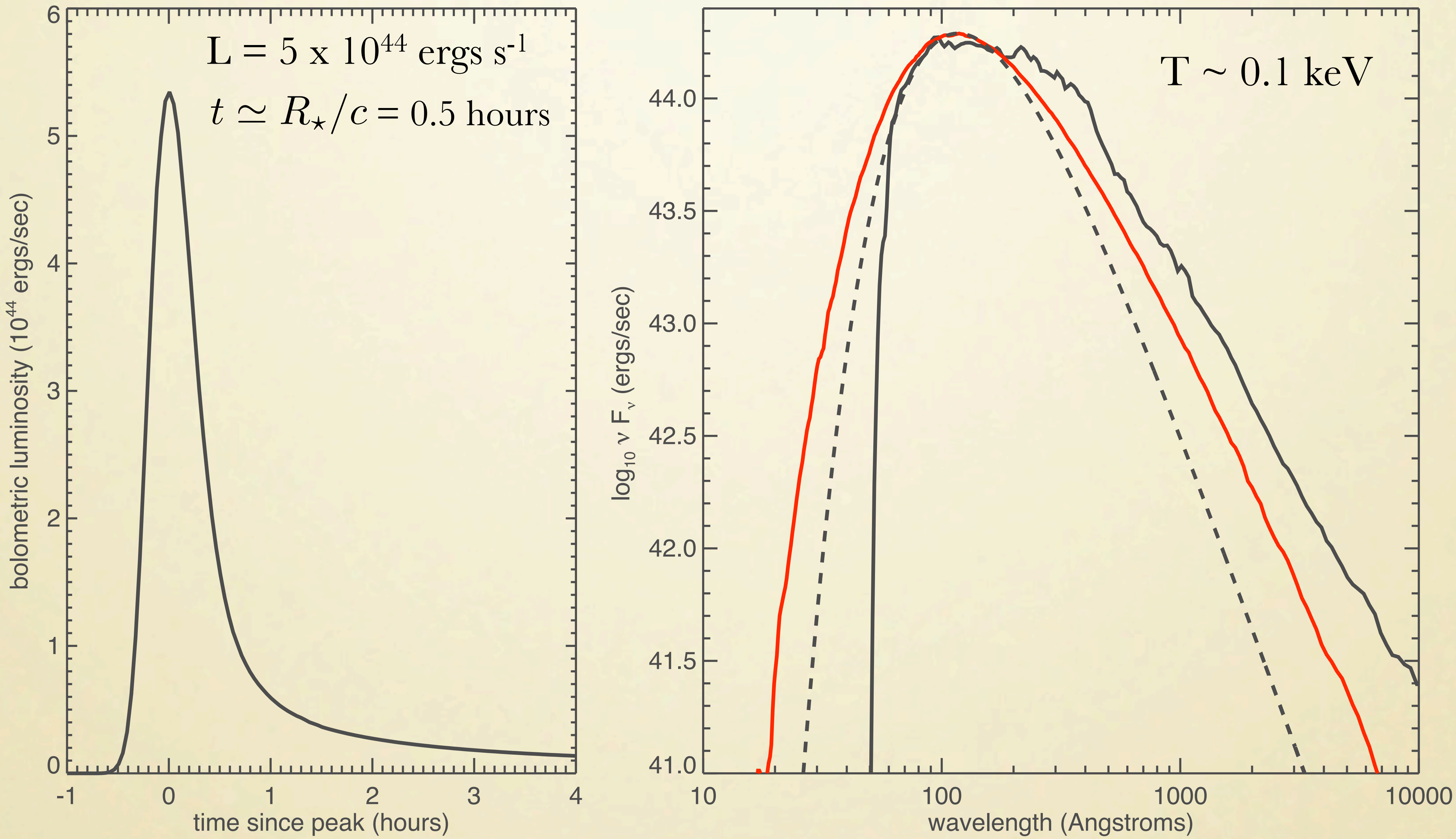


kasen & woosley (2009 in prep)

SHOCK BREAKOUT IN SNIIP

implicit monte carlo radiation hydrodynamics

kasen & woosley (2009 in prep)

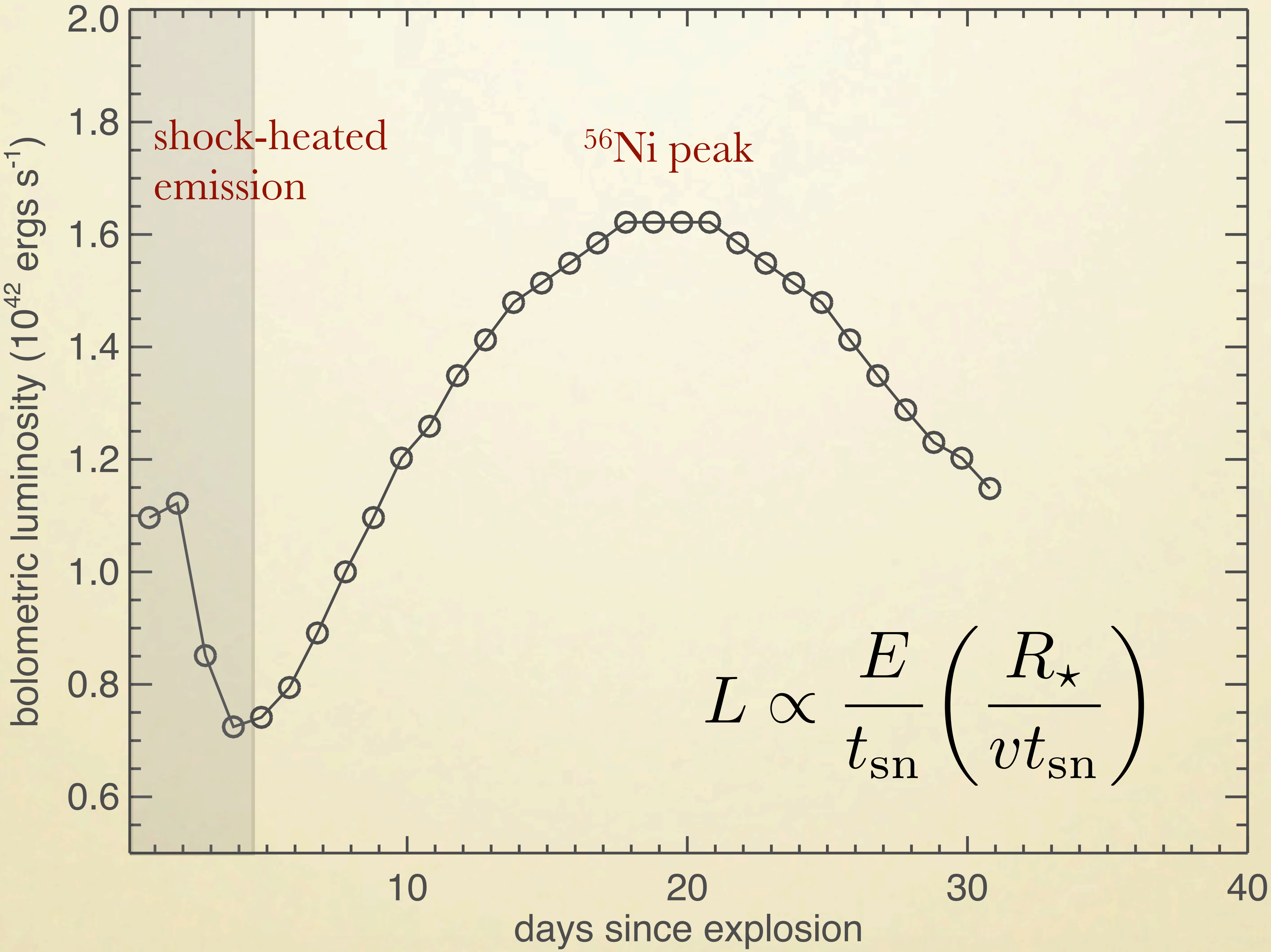


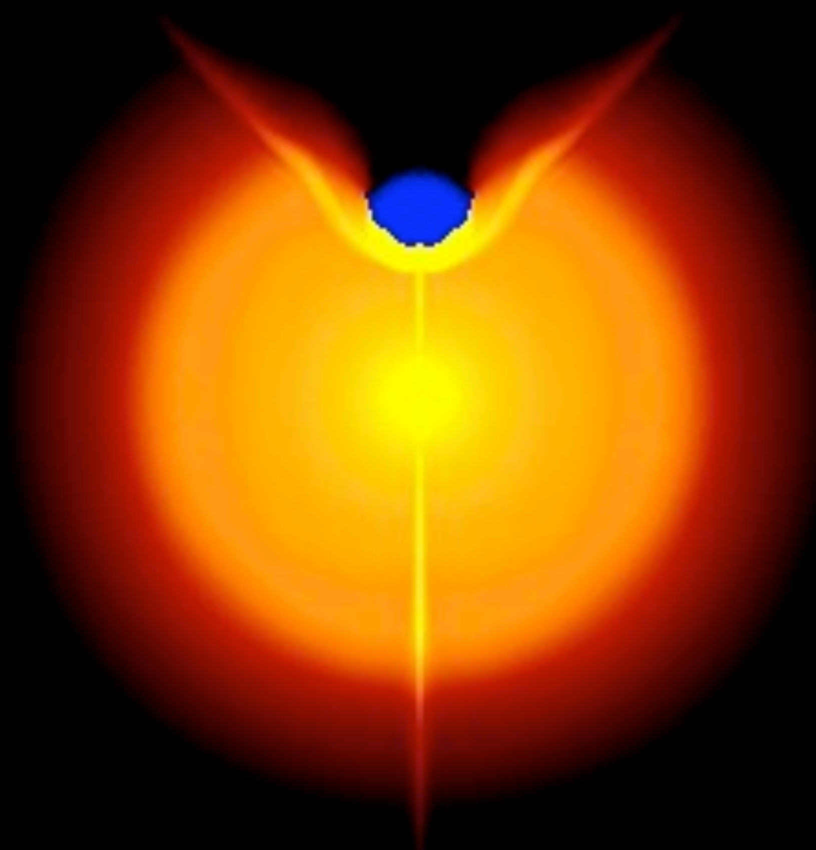
sn2008d: soderberg et al (2008), modjaz et al (2009)

snls-06D2dc: gezari et al (2008), schawinski (2008)

EARLY LUMINOSITY

SN 2008D (from Modjaz et al. 2009)



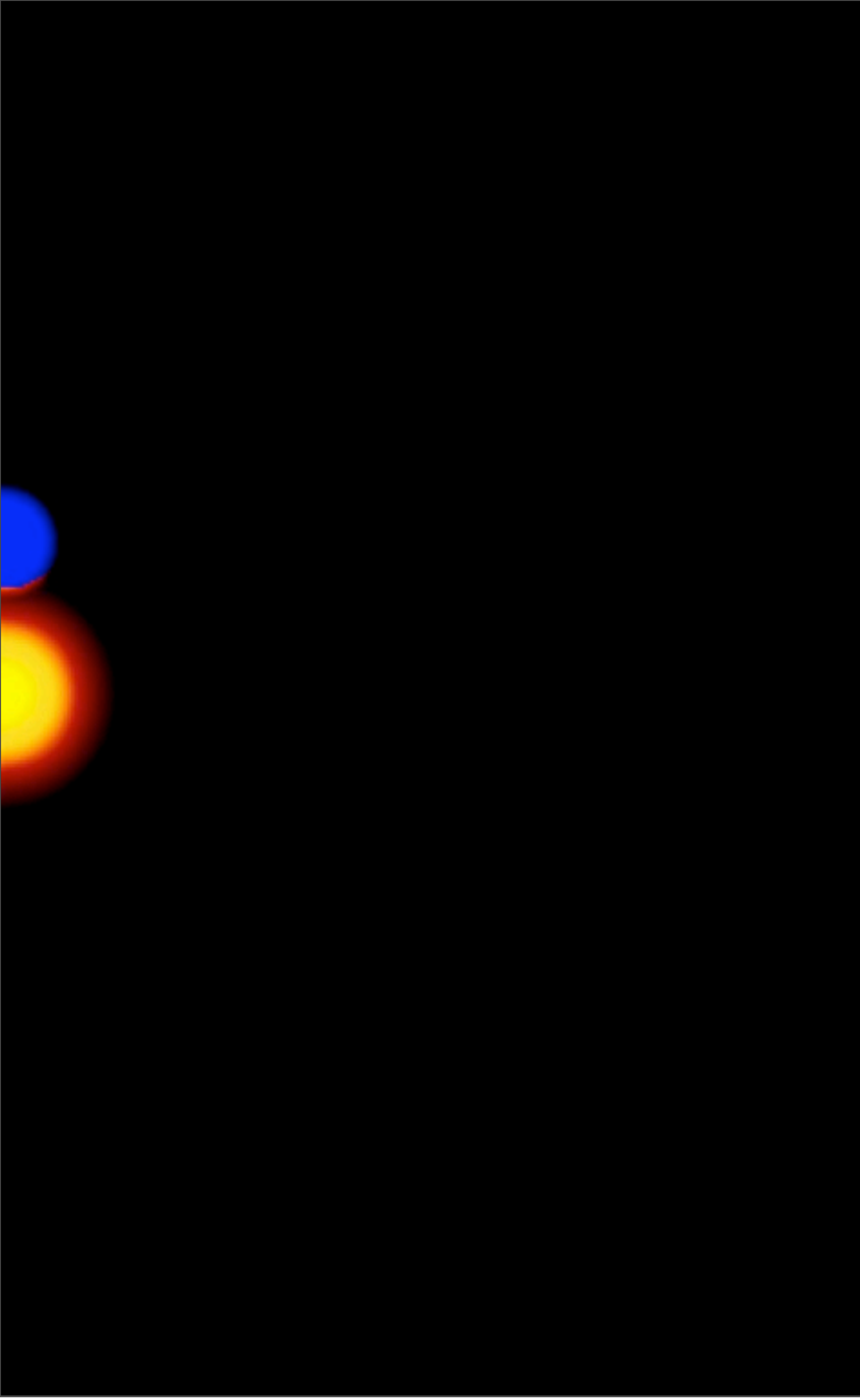


$a \sim 10^{11}$–10^{13} cm

comparable length scale, velocities and temperatures
as in core-collapse shock breakout

so does the collision produce an x-ray burst, followed
by early UV/optical emission?

kasen 2009 apj submitted (astro-ph soon) analytic + some simulation



expansion

interaction timescale

$$t_i = a/v$$
$$\simeq 3 - 8 \text{ hours} \quad \text{for RG}$$
$$\simeq 5 - 20 \text{ mins} \quad \text{for MS}$$

shock conditions

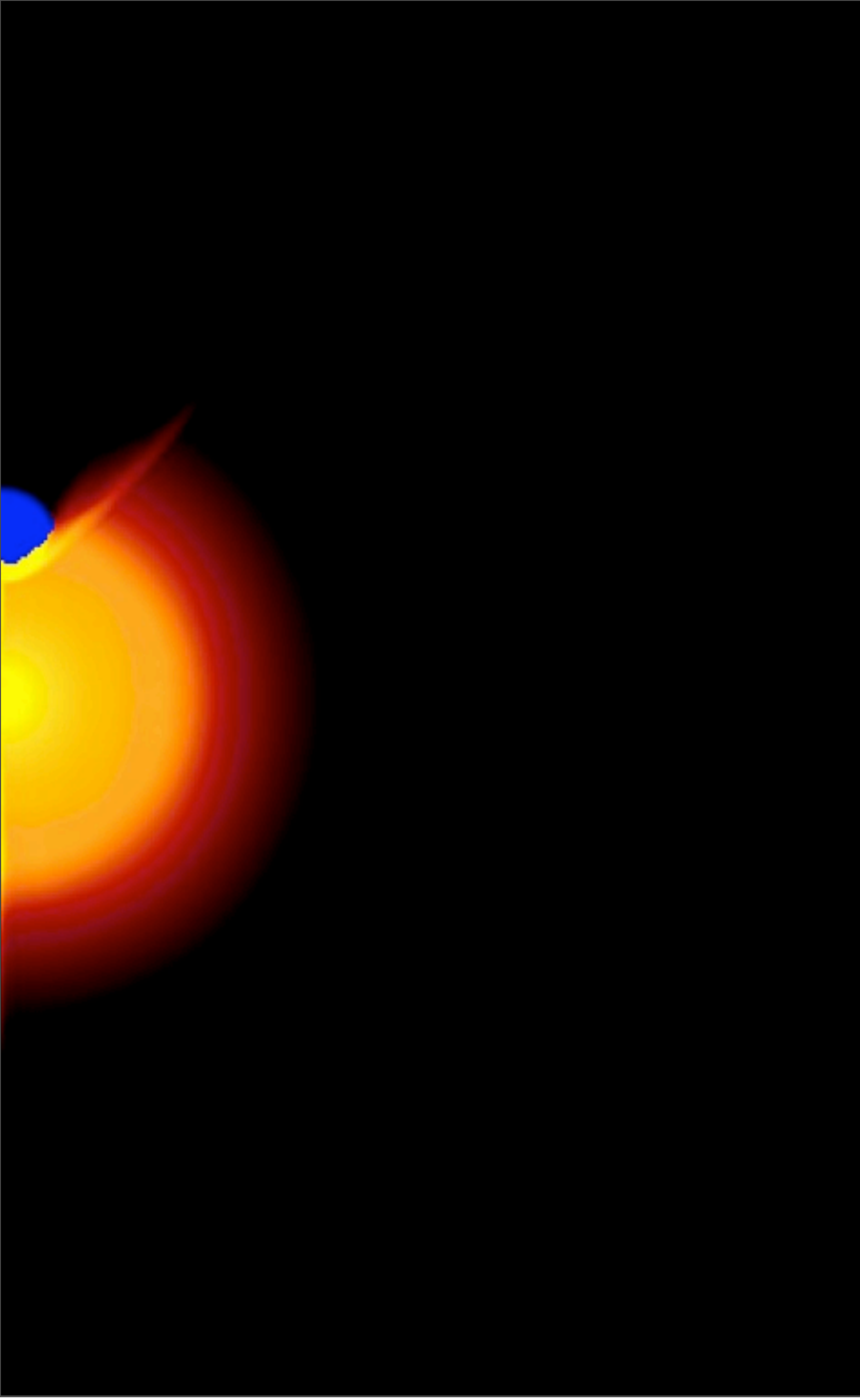
$\gamma = 4/3$ (radiation dominated gas)

$$\rho_s = \frac{\gamma+1}{\gamma-1} = 7\rho_0$$

$$p_s = \frac{2}{1+\gamma}\,\rho_0 v^2 \sin^2\chi$$

$$p_s = \frac{a_R T^4}{3}$$

$$T_s = 2.8\times 10^6 \left(\frac{a}{10^{13}\ \mathrm{cm}}\right)^{-3/4}\ \mathrm{K}$$



carving a hole

half opening angle

$$\theta_h = 30^\circ - 40^\circ$$

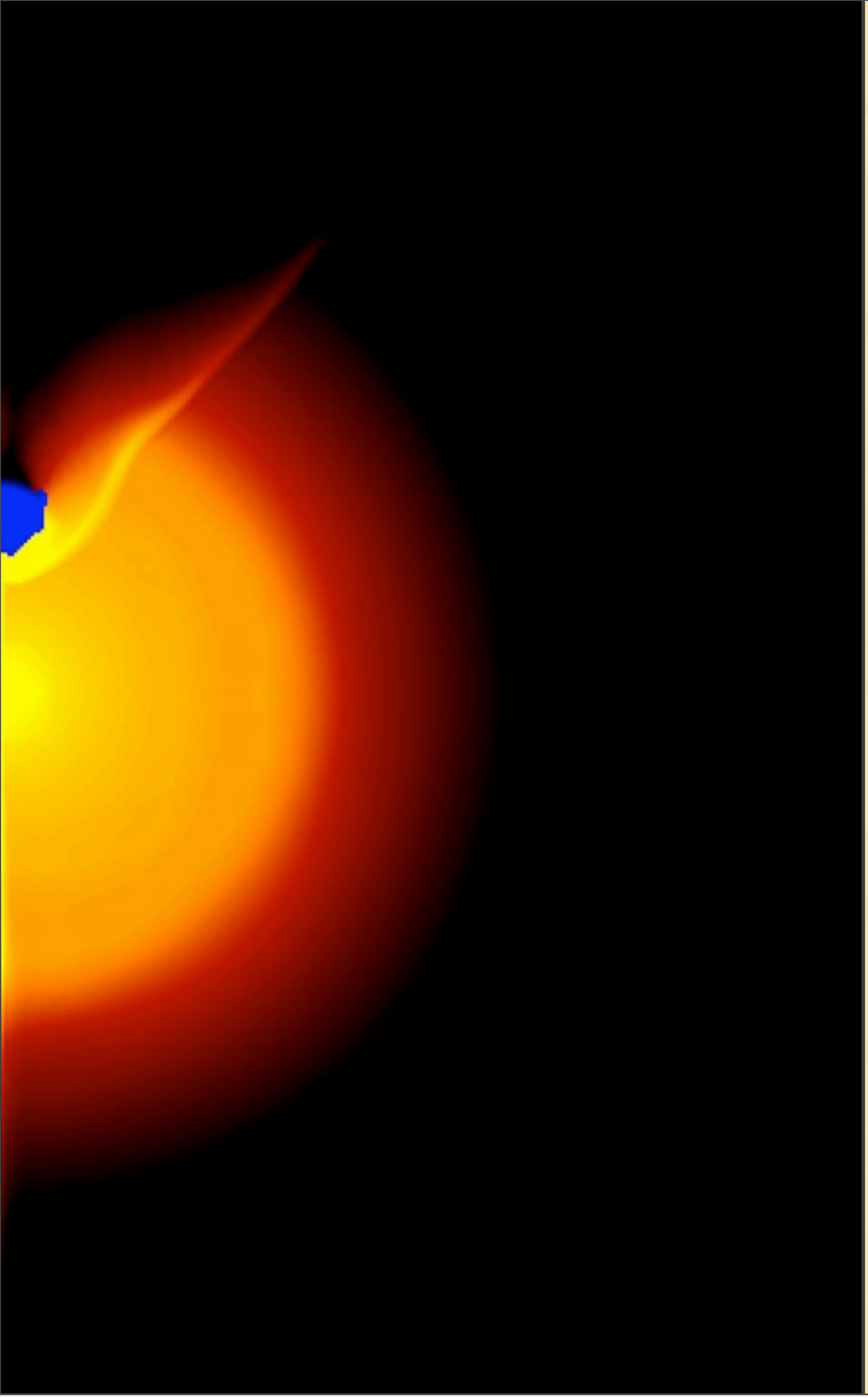
solid angle of shadowcone

$$\frac{\Omega_h}{4\pi} \approx \frac{1}{10}$$

thickness of shell from mass conservation

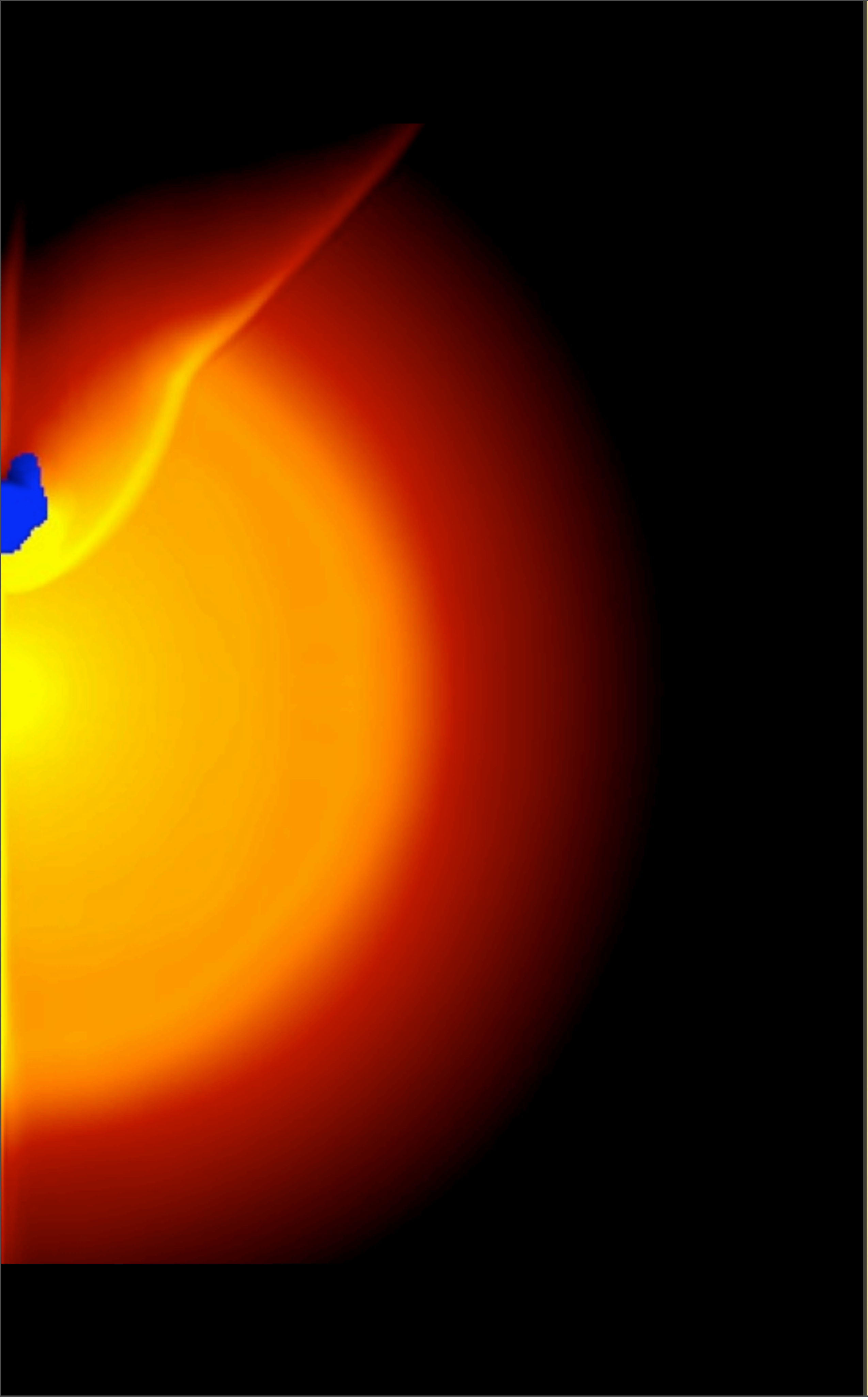
$$\rho_0 V_h = \rho_\mathrm{s} V_\mathrm{sh}$$

$$\frac{l_\mathrm{sh}}{a} = \frac{\Omega_\mathrm{h}}{4\pi}\frac{2\rho_0}{\rho_s} \approx \frac{1}{35}$$



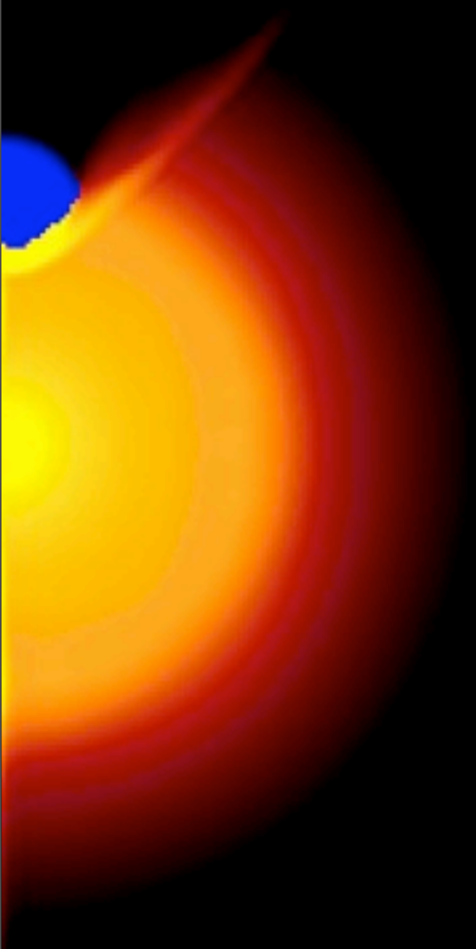
reclosing

lateral expansion to refill
the hole on roughly
the interaction timescale
$t \sim a / v$



engulfed

the bulk of the ejecta remains
very optically thick
at these phase



prompt burst

diffusion time = dynamical time

$$\frac{l_d^2 \kappa \rho_s}{3c} = a/v$$

$$\frac{l_d}{l_{\rm sh}} \approx 3 \frac{a}{v_{\rm t} t_{\rm sn}} \left(\frac{4\pi}{\Omega_{\rm h}} \right)$$

$$\approx 1/3 \qquad \text{for RG}$$

$$\approx 0.1 - 0.01 \quad \text{for MS}$$

PROMPT X-RAY BURST

ANALYTICAL ESTIMATES

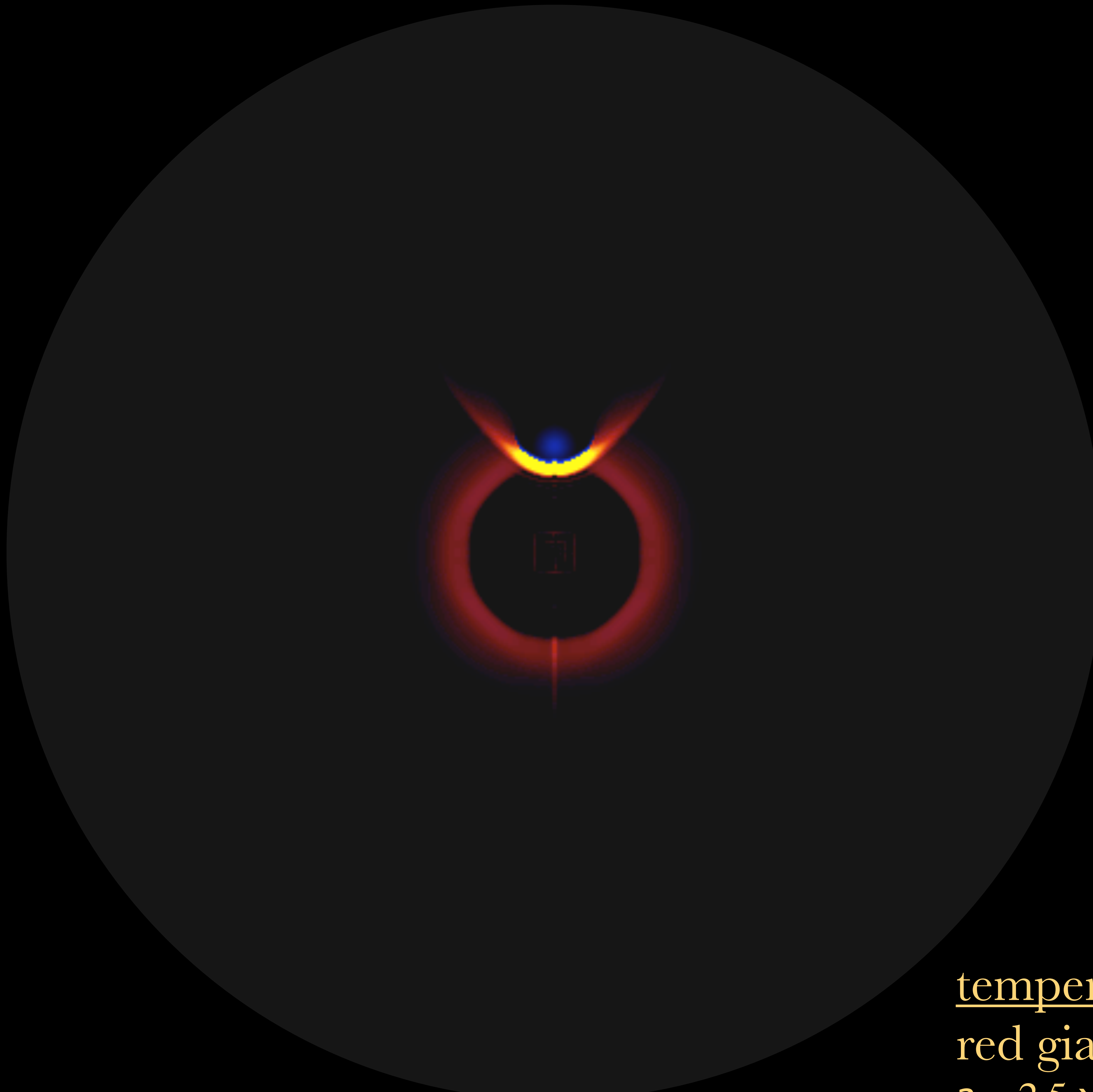
isotropic equivalent luminosity

$$L_{\rm x} = 5 \times 10^{44} \; M_c^{1/2} v_9^{5/2} \kappa_e^{-1/2} \text{ ergs s}^{-1}$$

visible from $\theta < \theta_h$ or $\Omega_h / 4\pi = 10\%$ of the time

red giant	main sequence
$t_i \simeq 3 - 8$ hours	$t_i \simeq 5 - 20$ mins
$T_s \simeq 0.1 - 0.2$ keV	$T_s \simeq 1 - 5$ keV

non-equilibrium, non-thermal effects
line fluorescence emission
sub-structure and variability



<u>temperature plot</u>

red giant

$a = 2.5 \times 10^{13}$ cm

Early Luminosity

analytical estimates

self-similar diffusion wave analysis (ala Chevalier 1992)

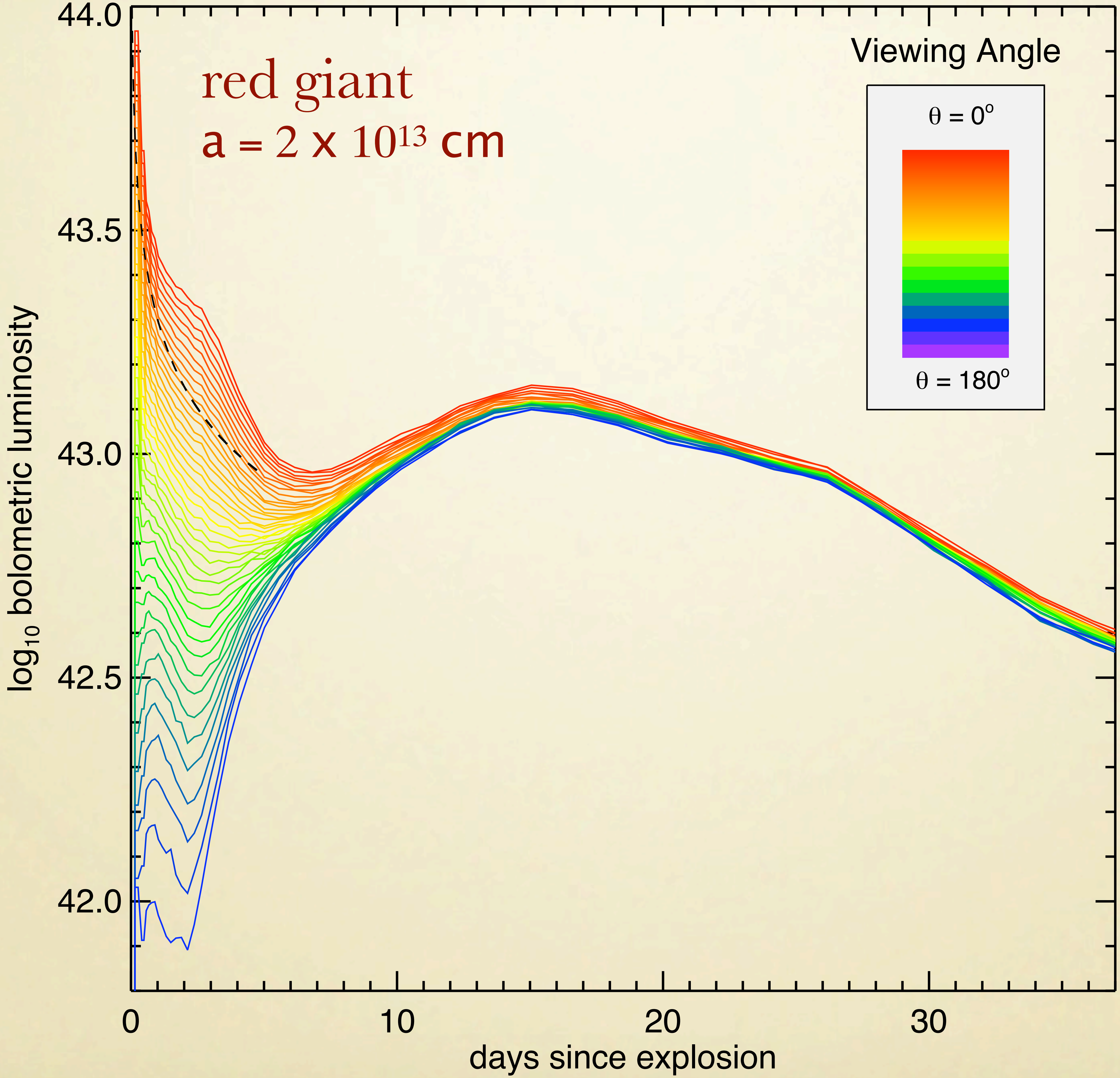
$$L_c = C \frac{M v_{\rm t}^2}{t_{\rm sn}} \left(\frac{a}{v t_{\rm sn}}\right) \left(\frac{t}{t_{\rm sn}}\right)^{-4/(n-2)}$$

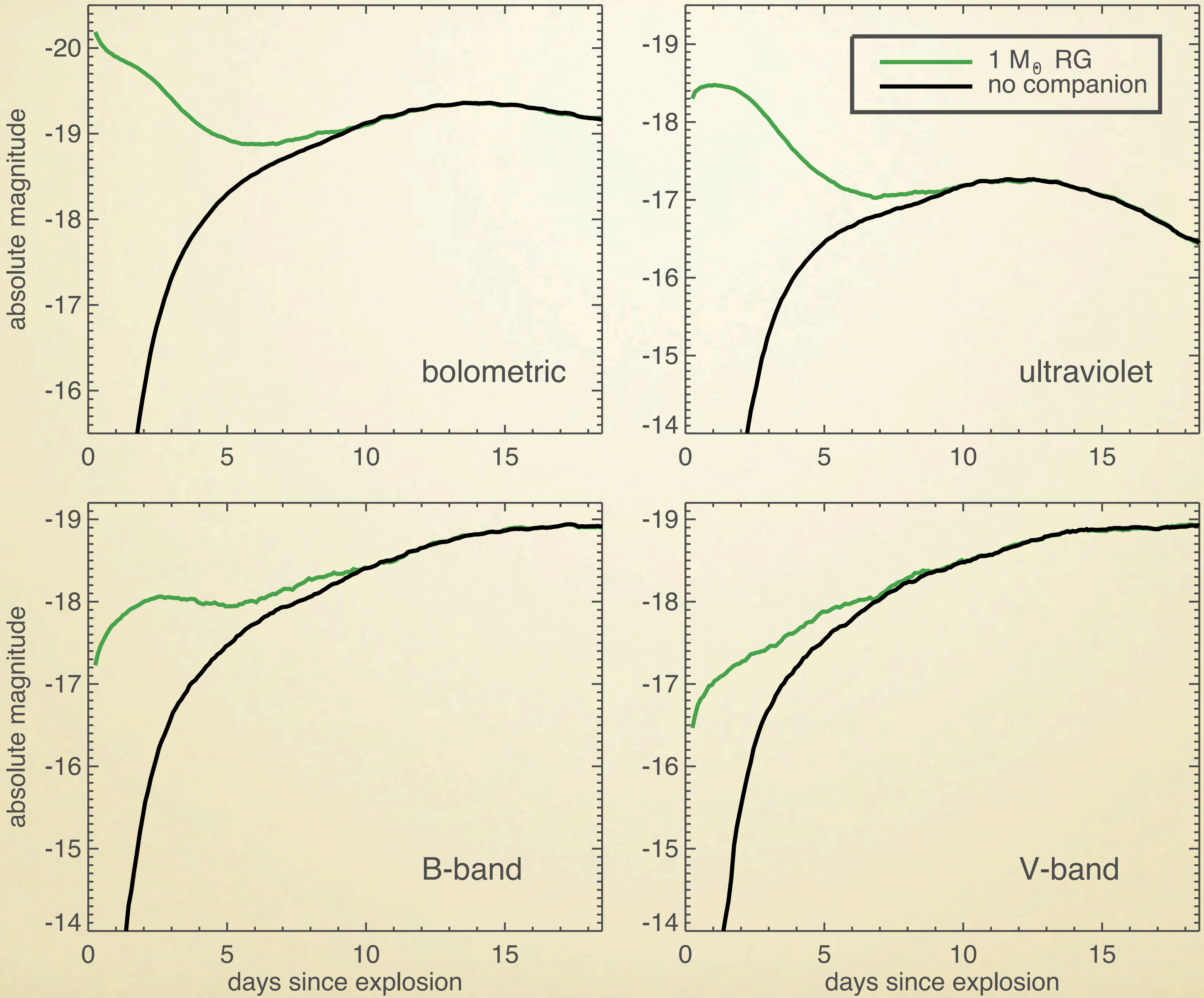
(isotropic equivalent comoving frame luminosity)

for density profile exponent n = 10

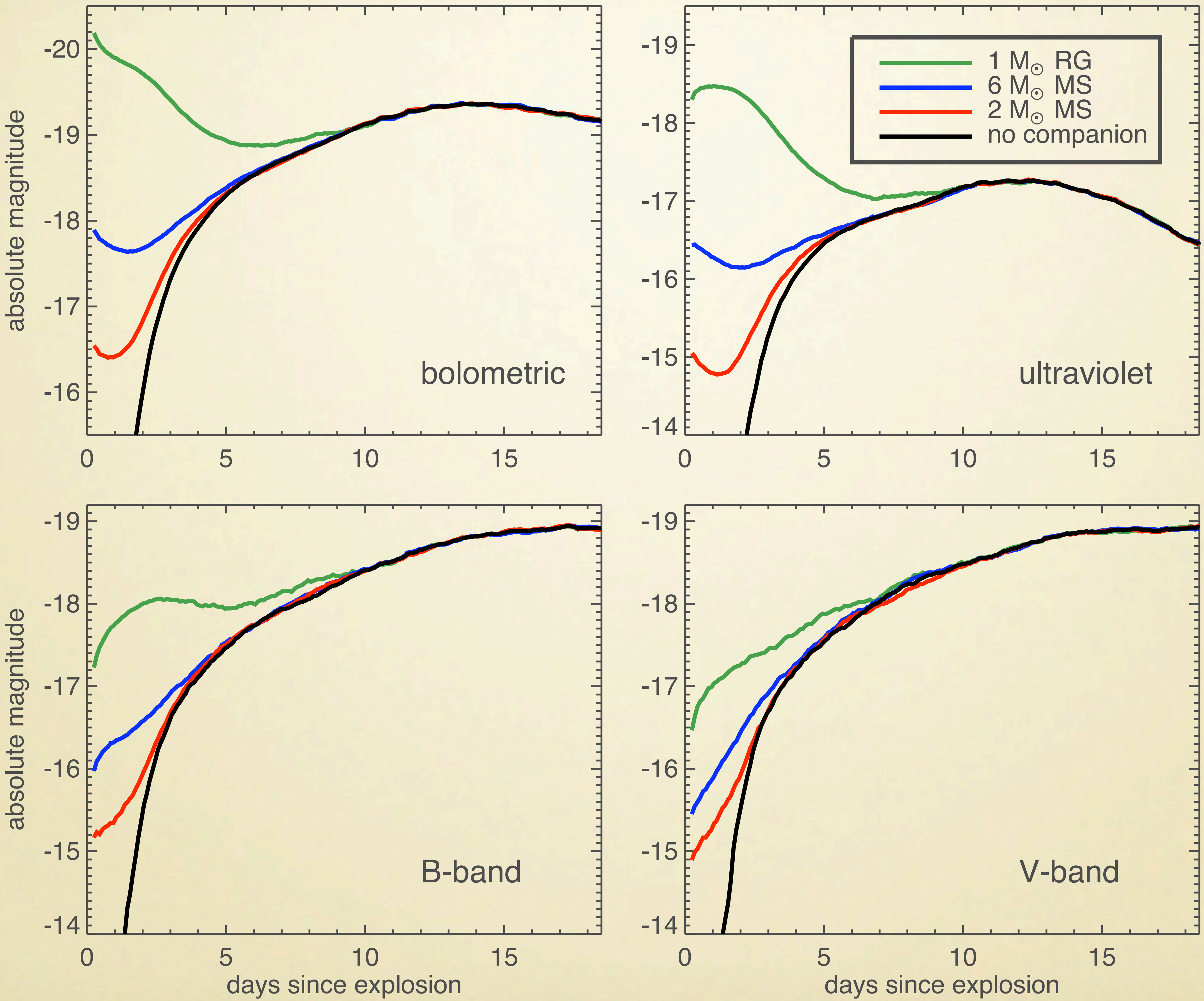
$$L_c = 10^{43} \left(\frac{a}{10^{13}\ {\rm cm}}\right) t_{\rm day}^{-1/2}\ {\rm ergs\ s}^{-1}$$

$$T_{\rm eff} = 2.5 \times 10^4 \left(\frac{a}{10^{13}\ {\rm cm}}\right)^{1/4} t_{\rm day}^{-37/72}\ {\rm K}$$ (l @ 1000 A)


red giant
a = 2 x 10^13 cm
Viewing Angle
θ = 0°
θ = 180°
log10 bolometric luminosity
days since explosion
44.0
43.5
43.0
42.5
42.0
0
10
20
30



absolute magnitude
-20
-19
-18
-17
-16
0
5
10
15
bolometric
-19
-18
-17
-16
-15
-14
1 $M_{\odot}$ RG
no companion
ultraviolet
B-band
V-band
days since explosion


1 M⊙ RG
6 M⊙ MS
2 M⊙ MS
no companion
bolometric
ultraviolet
B-band
V-band
absolute magnitude
absolute magnitude
days since explosion
days since explosion
-20
-19
-18
-17
-16
-19
-18
-17
-16
-15
-14
-19
-18
-17
-16
-15
-14
-19
-18
-17
-16
-15
-14
0
5
10
15

Supernova Collision Emission

observational prospects

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tests for the presence of a companion star appear within our observational grasp (x-ray bursts and early optical/UV luminosity)

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the properties of the collision emission provide a straightforward measure of the separation distance

$$t_{\rm xray} \approx a/v \qquad T_{\rm xray} \propto a^{-3/4} \qquad L(1 \text{ day}) \propto a$$

and hence the companion radius, assuming a/R = 2-3

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providing an *empirical* means of determining how the parameters of the progenitor system influence the supernova explosion