Supernova Light

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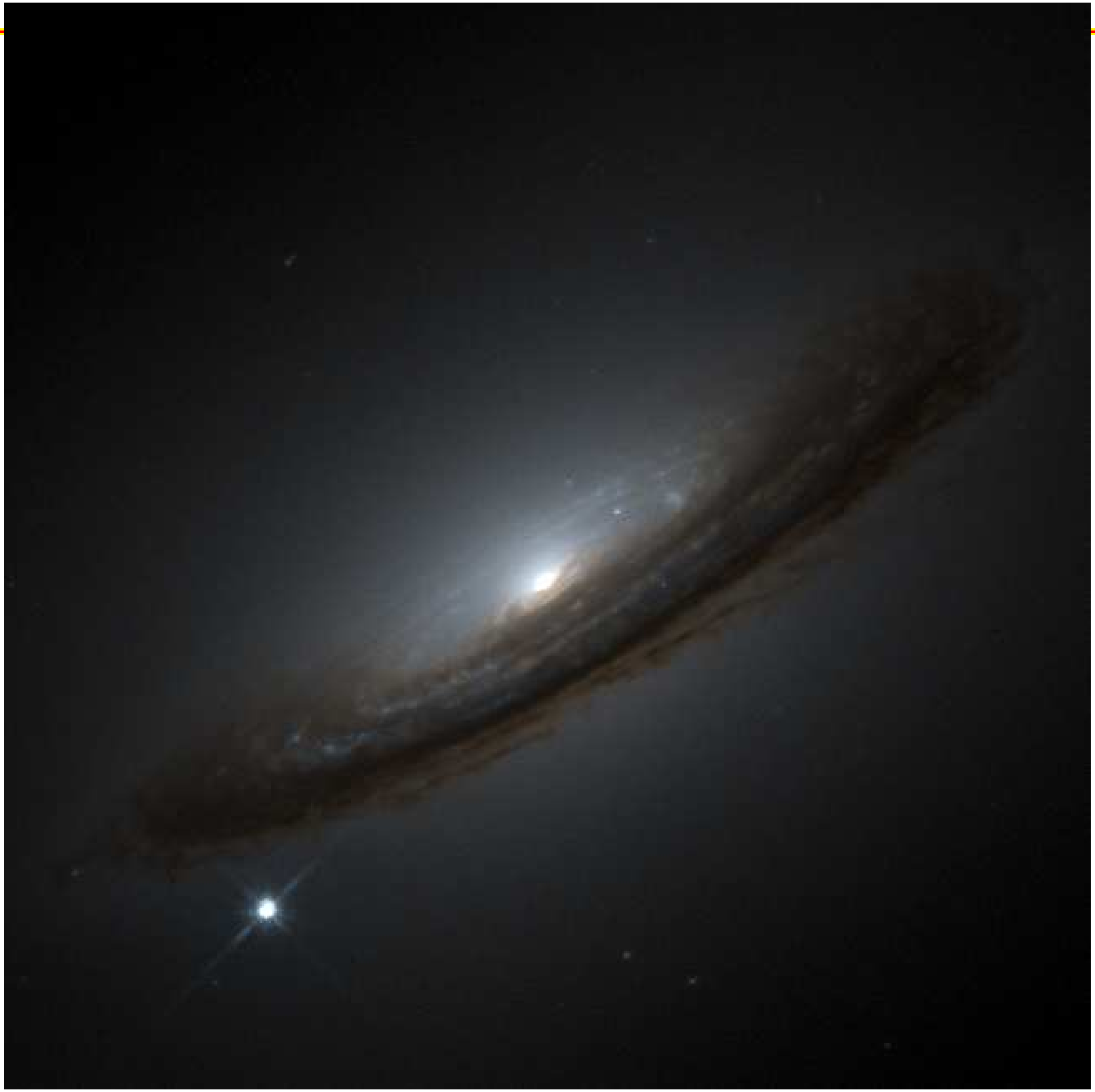
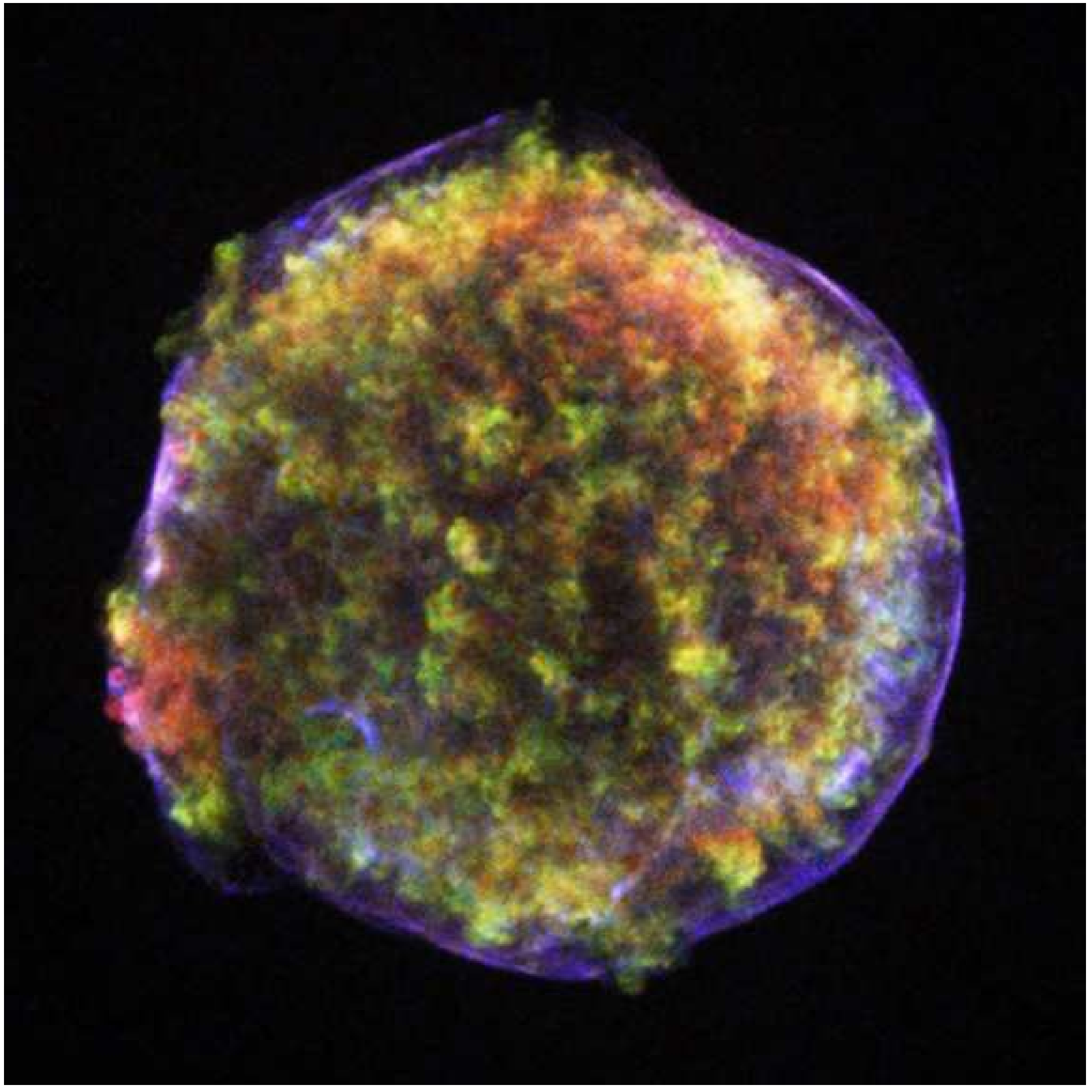
SN1994D type Ia in NGC4526



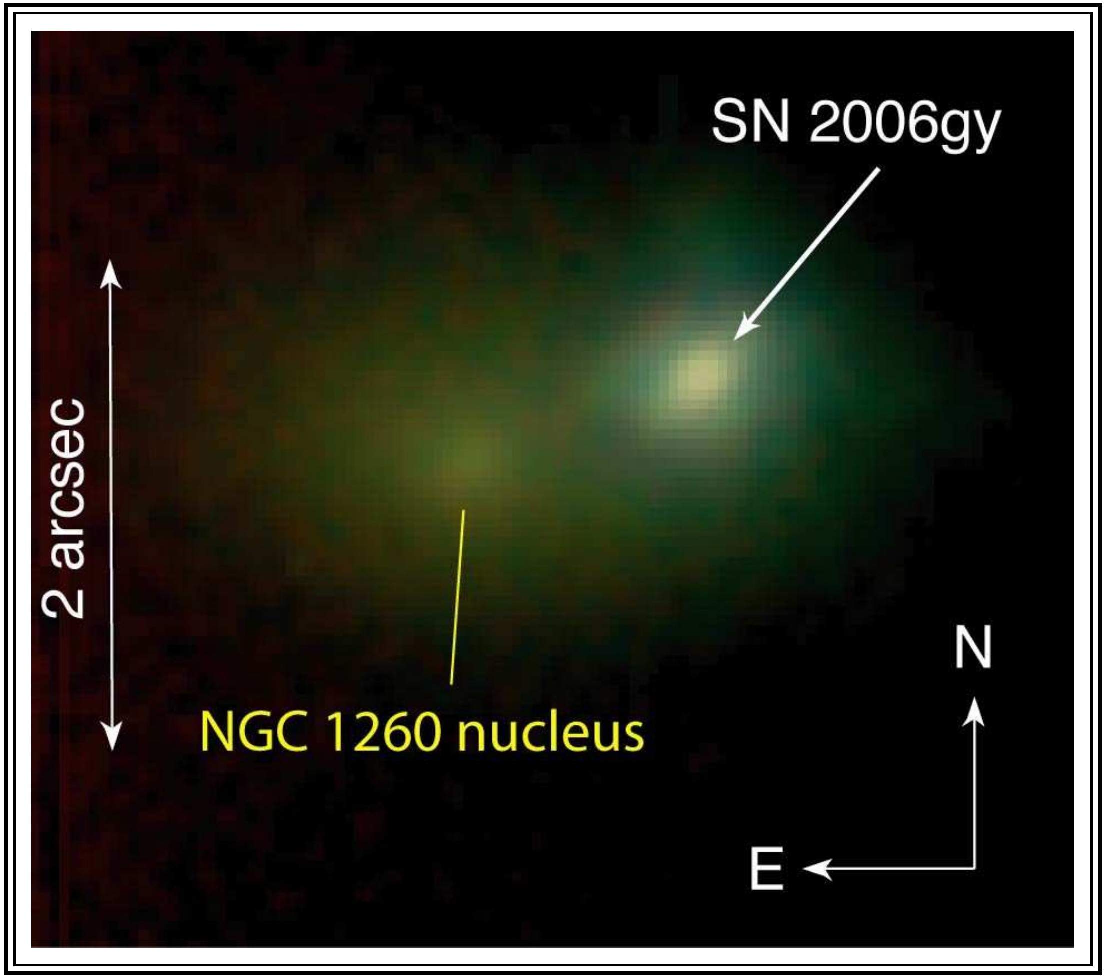
SNR Tycho in X-rays (Chandra)



SN 2006gy

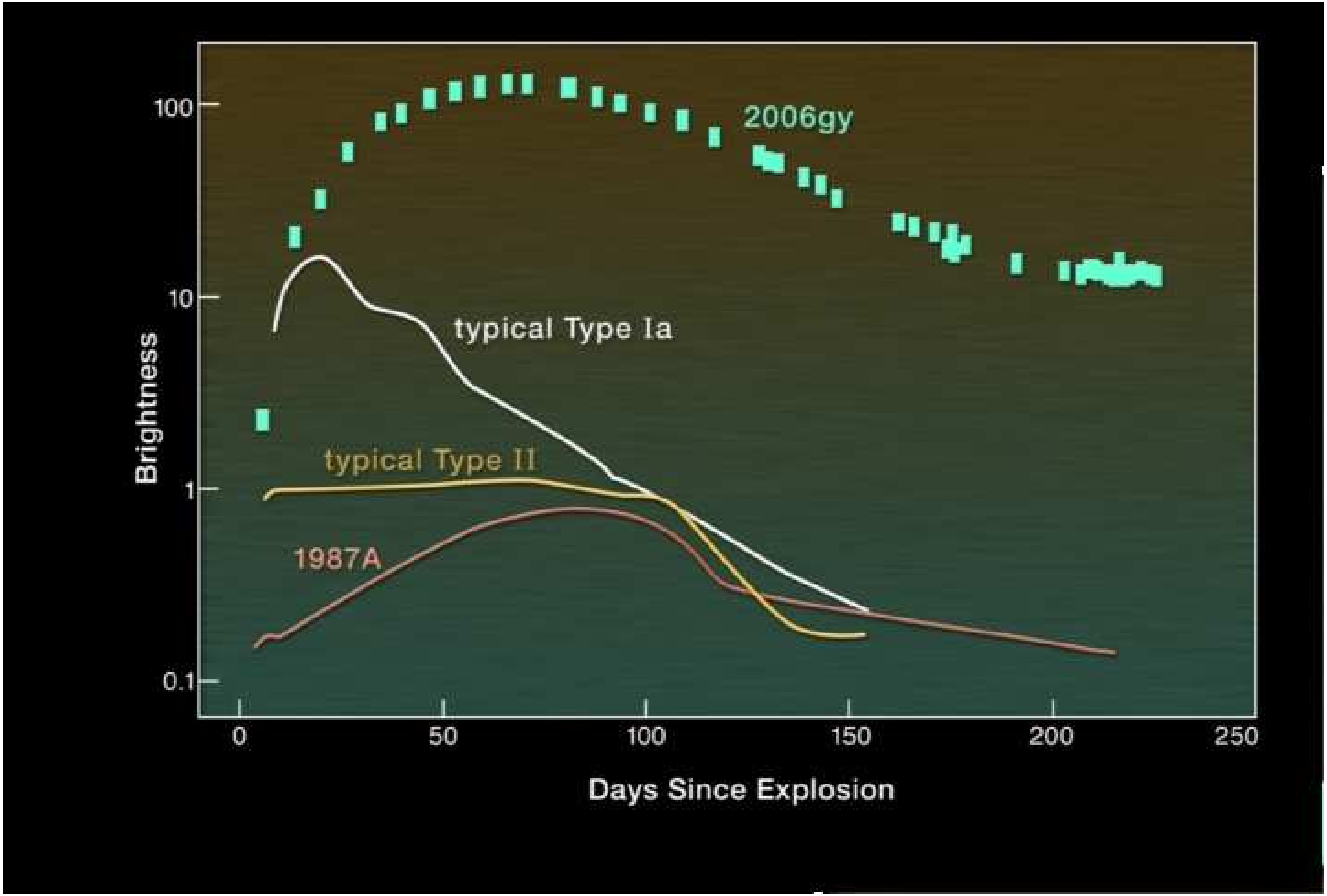
Ofek et al. 2007, ApJL, astro-ph/0612408)

Smith et al. 2007, Sep. 10 ApJ, astro-ph/0612617)

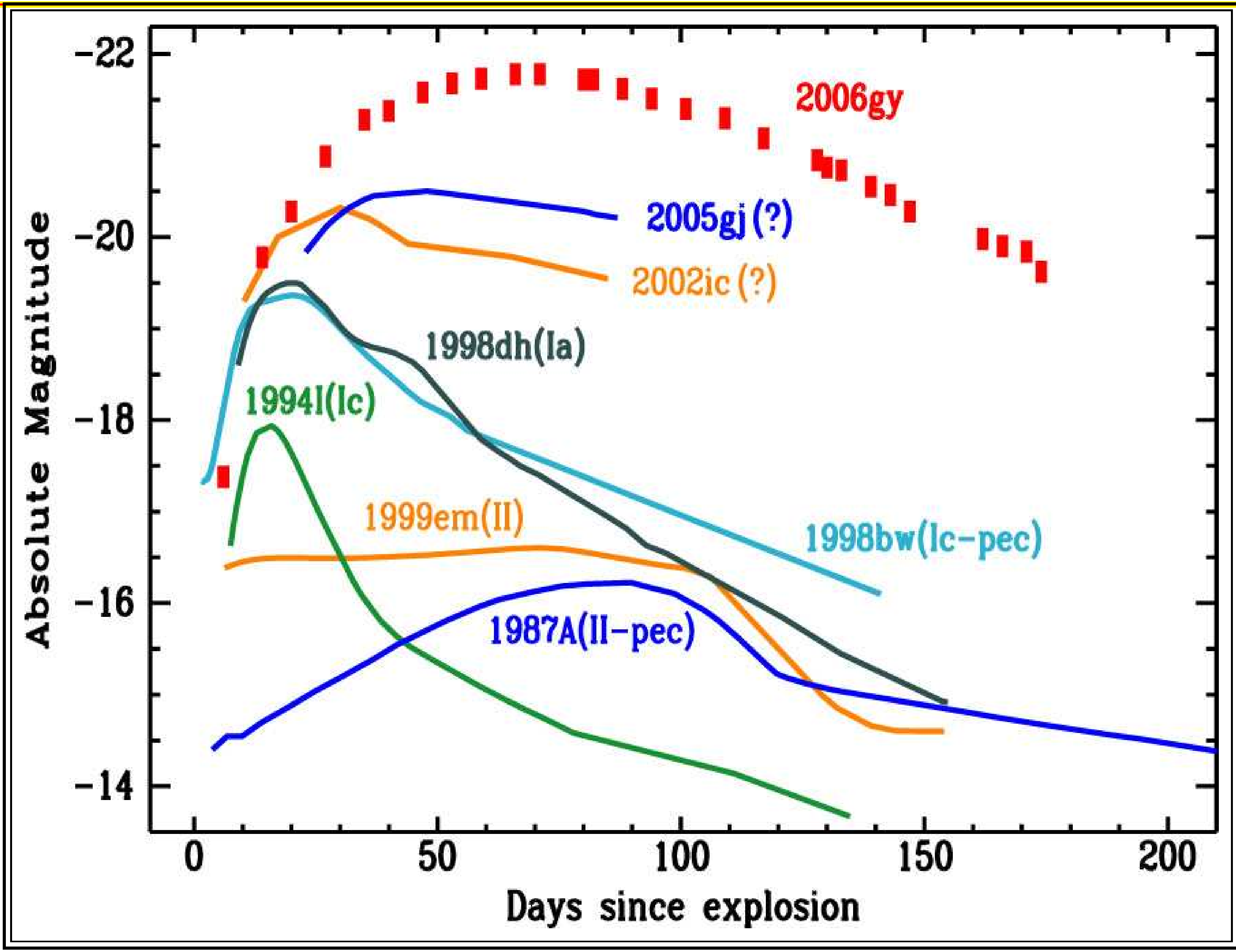


Brightest. Supernova. Ever

by N.Smith



Most Luminous SN ever



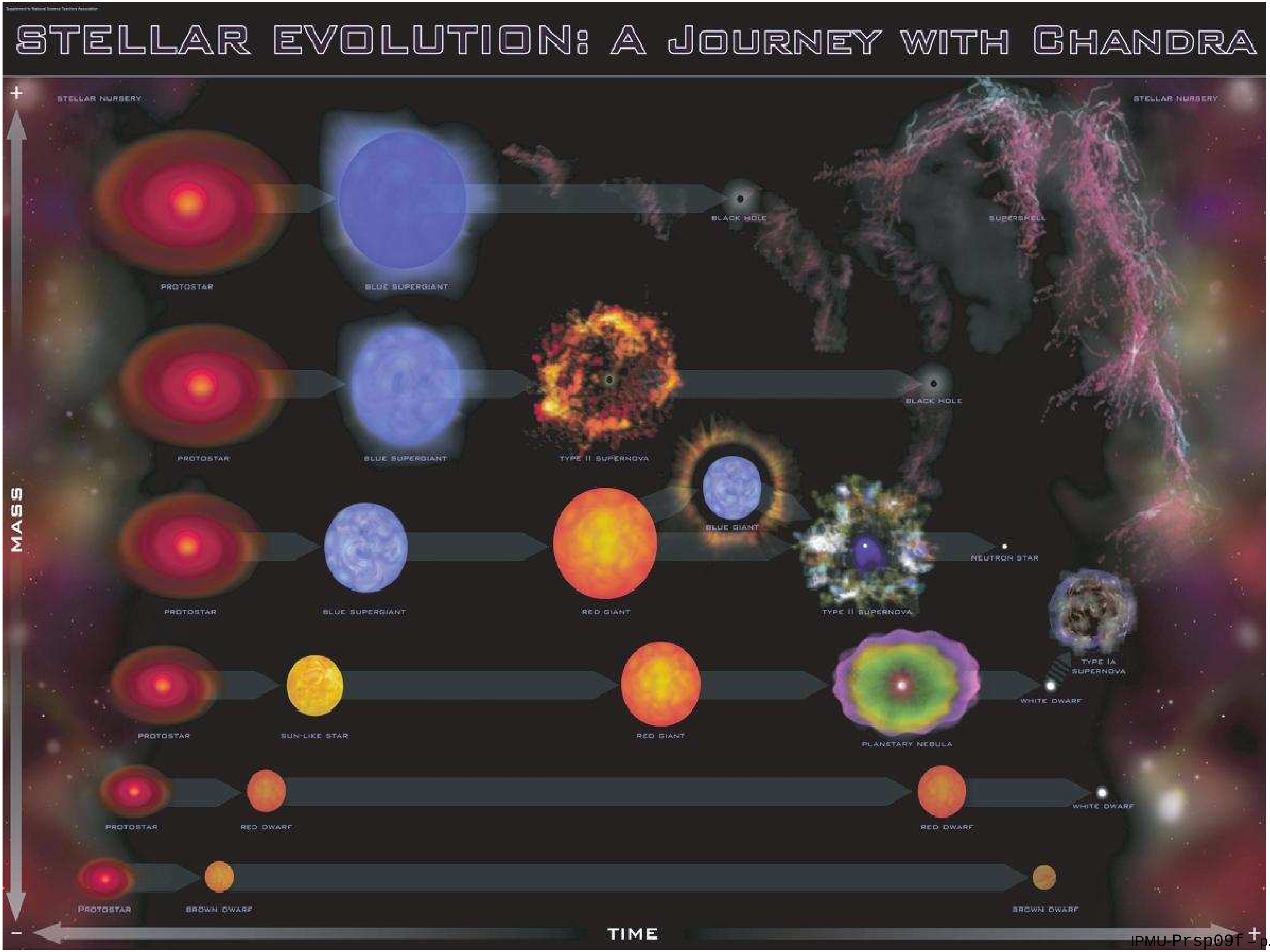
Luminous SN: too many photons?

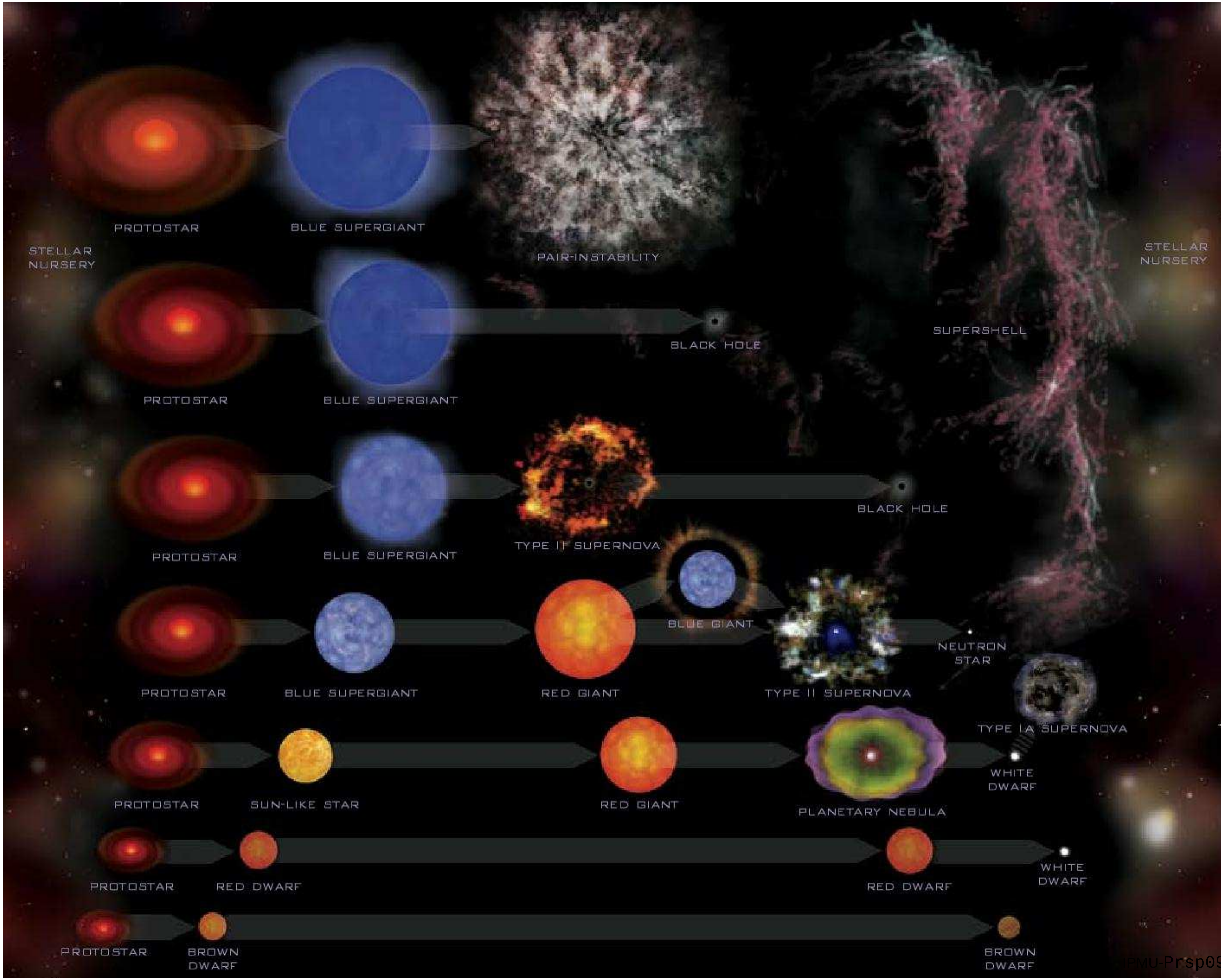
Now we know a few other SNe with peak luminosity even higher than SN 2006gy.

Total light 10^{51} ergs: 2 orders of mag higher than normal core collapsing SN and 1 order more than brightest thermonuclear SN

To explain this light we inevitably involve large stellar masses.

I'll try to explain why the evolution of stars with $M > 10M_\odot$ is quite different from low mass stars, and what happens at $M \sim 100M_\odot$


STELLAR EVOLUTION: A JOURNEY WITH CHANDRA
STELLAR NURSERY
STELLAR NURSERY
PROTOSTAR
BLUE SUPERGIANT
BLACK HOLE
SUPERSHELL
PROTOSTAR
BLUE SUPERGIANT
TYPE II SUPERNOVA
BLACK HOLE
BLUE GIANT
PROTOSTAR
BLUE SUPERGIANT
RED GIANT
TYPE II SUPERNOVA
NEUTRON STAR
TYPE IA SUPERNOVA
PROTOSTAR
SUN-LIKE STAR
RED GIANT
PLANETARY NEBULA
WHITE DWARF
PROTOSTAR
RED DWARF
RED DWARF
WHITE DWARF
PROTOSTAR
BROWN DWARF
BROWN DWARF
MASS
TIME
+
-
+


STELLAR
NURSERY
PROTOSTAR
BLUE SUPERGIANT
PAIR-INSTABILITY
STELLAR
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DWARF

SN light production

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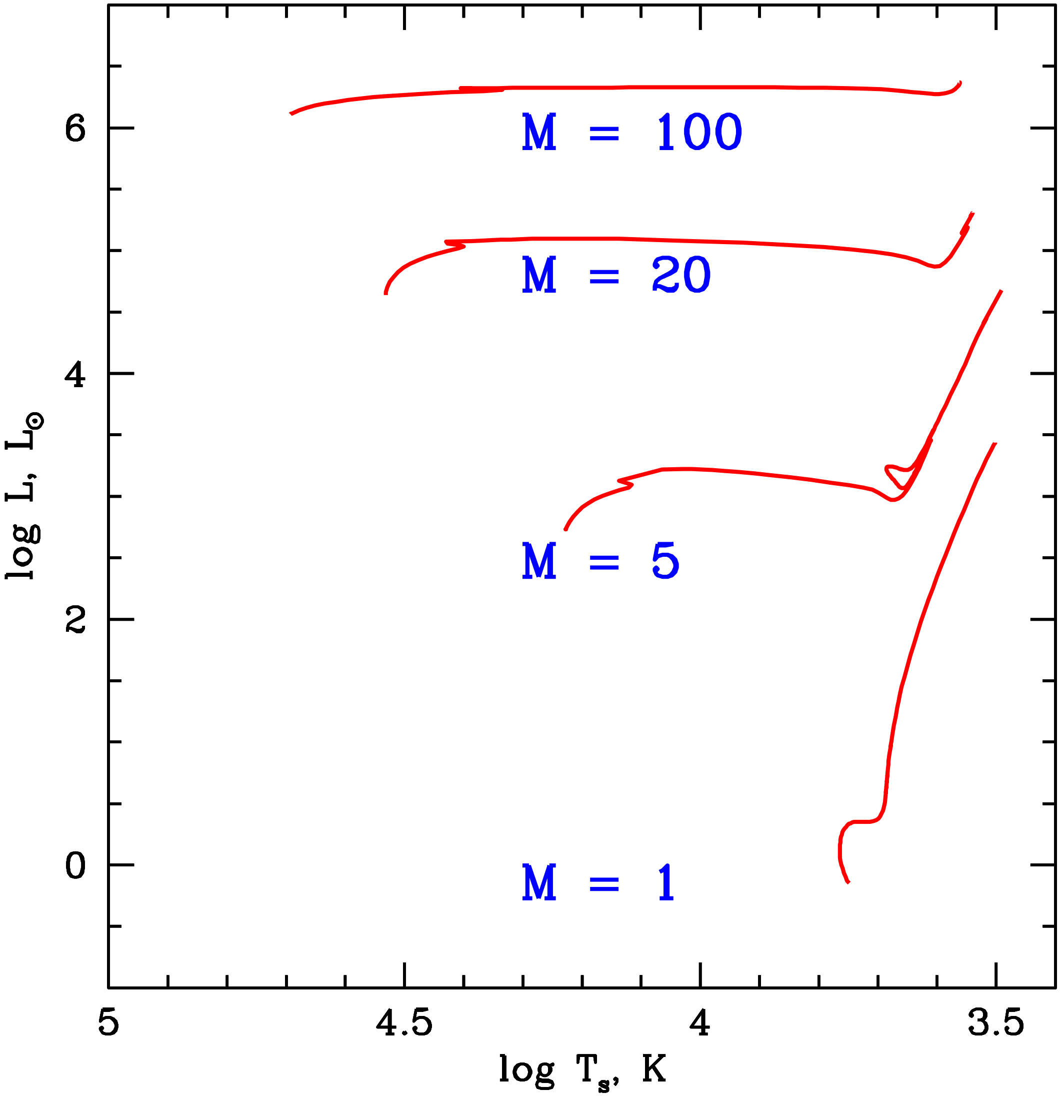
- Radiation-dominated shocks and tenacious myths on X-rays from SN shocks

Stellar evolution

HR ($L - T_{\rm eff}$) diagram needed for comparison with observations



Compression in center

even if $R_{\rm out}$ grows

massive than about $2.25M_\odot$ approach a common path, as is shown in Figure 4 (from Iben 1973a). This is a consequence of the fact that the density and pressure distributions in the inner parts of the hydrogen-exhausted core and the rate of energy

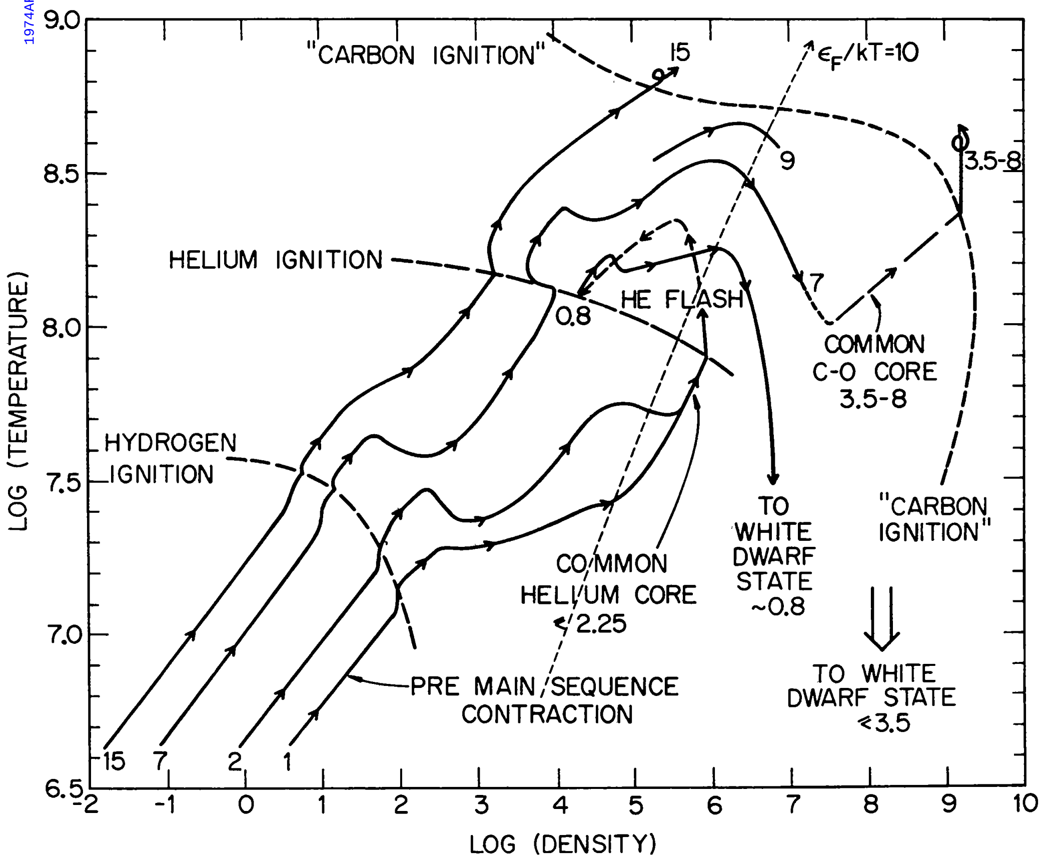


Figure 4 Tracks in the ρ-T plane traced out by the centers of stars of various masses (Iben 1973a).

Virial theorem

From Baz', Zeldovich, Perelomov...

$$\delta E_{\text{tot}} \equiv \delta\mathcal{E} = \delta\langle H\rangle = 0$$

in the first order of perturbation $\delta\psi$ – the variational principle in quantum case.
Let us take a perturbation of the form:

$$\psi + \delta\psi = \alpha^{3N/2}\psi(\{\alpha\vec{r_i}\}), \quad i = 1, \dots, N,$$

so the wave function is uniformly changed for all $3N$ space coordinates. The coefficient $\alpha^{3N/2}$ is from normalization to unity. Note, that $\alpha > 1$ here corresponds to the *compression* of the whole system.

We have

$$\langle H \rangle = \langle E_{\rm kin} \rangle + \langle U \rangle.$$

Now

$$\langle E_{\rm kin} \rangle \to \alpha^2 \langle E_{\rm kin} \rangle$$

because for non-relativistic (NR) particles, $E_{\rm kin} \propto p^2 \propto 1/\lambda^2$
The variation of U depends on the law of interaction. For Coulomb (and Newton!) interactions

$$\langle U \rangle \propto \int \sum_{i \neq k} \psi^* \frac{1}{r_{ik}} \psi \, d^N \vec{r} \to \alpha \langle U \rangle.$$

Thus

$$\langle H \rangle \to \alpha^2 \langle E_{\rm kin} \rangle + \alpha \langle U \rangle,$$

and variation of this gives

$$\delta \langle H \rangle = 2\alpha\delta\alpha \langle E_{\rm kin} \rangle + \delta\alpha \langle U \rangle = 0,$$

so with $\alpha = 1$ for unperturbed state we find

$$2\langle E_{\rm kin} \rangle + \langle U \rangle = 0.$$

This is the virial theorem for atomic Coulomb potential (and for globular stellar clusters as well! See the use of Schrödinger Eq. for stellar dynamics in Widrow & Kaser, 1993)

For all those systems (NR atoms or plasma, NR stars and stellar clusters)

$$\mathcal{E} = \langle E_{\mathrm{kin}} \rangle + \langle U \rangle = -\langle E_{\mathrm{kin}} \rangle$$

so the loss of total energy $\mathcal{E}$ corresponds to the *growth* of the kinetic energy $\langle E_{\mathrm{kin}} \rangle$. The same is true for the internal energy of matter if it is in the form of kinetic energy of particles.

One can do $U \propto r^k$, but more important for us is extremely relativistic (ER) case: $E_{\mathrm{kin}} \propto p \propto 1/\lambda$, then

$$\langle E_{\mathrm{kin}} \rangle + \langle U \rangle = 0.$$

Pressure

For NR:

$$P = \frac{2}{3}\varepsilon$$

and

$$E_{\rm kin} = E_{\rm thermal} = \frac{3}{2}\int PdV$$

For ER:

$$P = \frac{1}{3}\varepsilon$$

and

$$E_{\rm kin} = E_{\rm thermal} = 3\int PdV$$

and always

$$3\int PdV + \langle U\rangle = 0$$

Central Pressure

Now, for $U \sim -G_{\rm N} M^2/R$, omitting all coefficients of order unity, pressure and density in the center are:

$$P_c \simeq \frac{G_{\rm N} M^2}{R^4}, \; \rho_c \simeq \frac{M}{R^3}.$$

and we find

$$P_c \simeq G_{\rm N} M^{\frac{2}{3}} \rho_c^{4/3}.$$

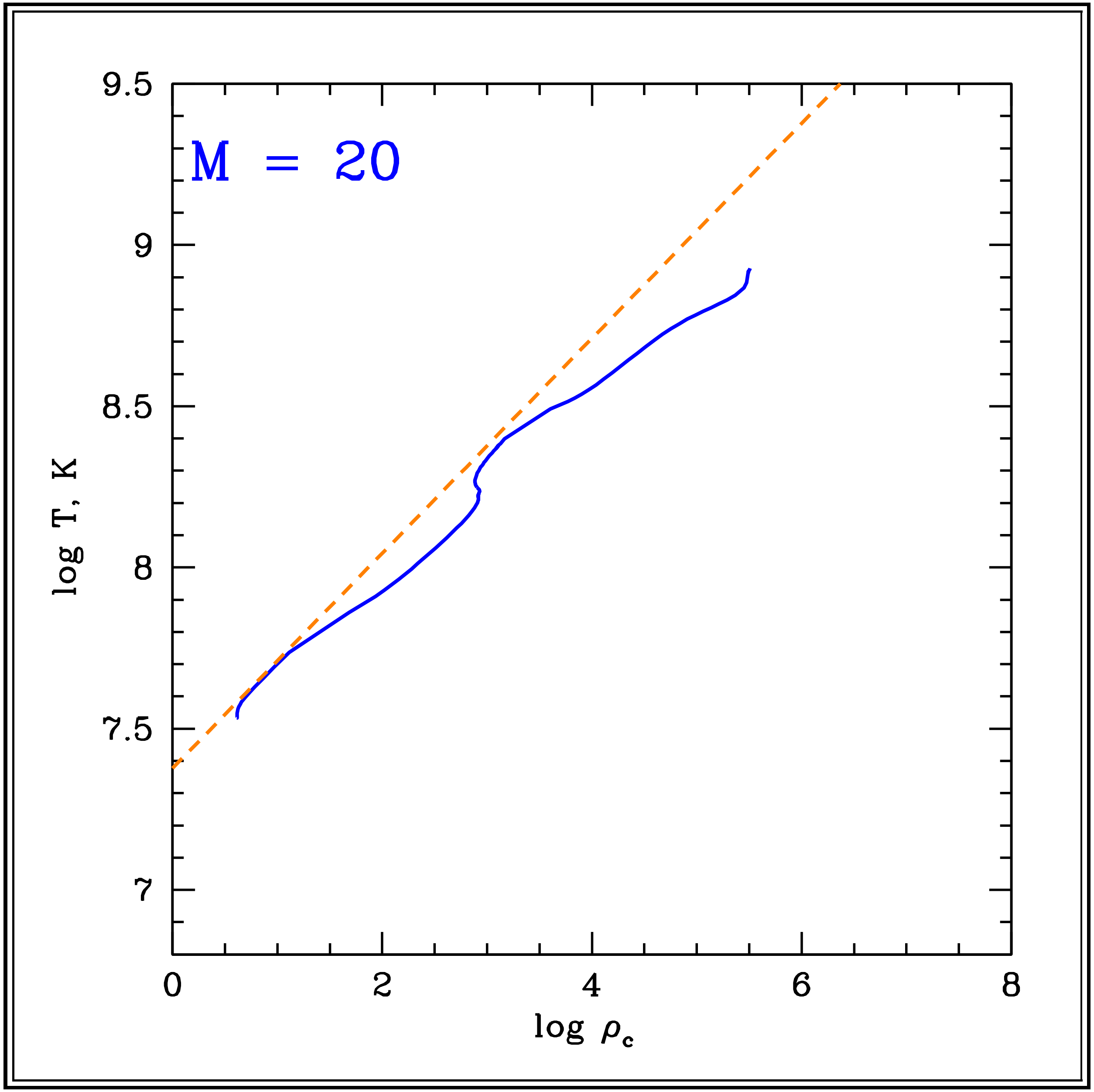
$T_c \propto M^{2/3}\rho_c^{1/3}$ in ND stars

So if we have a classical ideal plasma with $P = \mathcal{R}\rho T/\mu$, where $\mathcal{R}$ is the universal gas constant, and μ – mean molecular mass,

$$T_c \simeq \frac{G_{\rm N} M^{2/3}\rho_c^{1/3}\mu}{\mathcal{R}}.$$

With $\mu \simeq 1$ for H-He fully ionized plasma we get for the Sun $T_c \simeq 10^7$ K $\simeq 1$ keV. This is OK for "virial" velocity $v_{\rm vir}^2 \sim \varphi \sim r_g/R_\odot \sim 10^{-6}$ (although $\sqrt{2}$ less than for neutrals!). May be called "virial" $T_{\rm vir}$ for ions, but not for electrons.

Now check: $T_c \propto M^{2/3} \rho_c^{1/3}$



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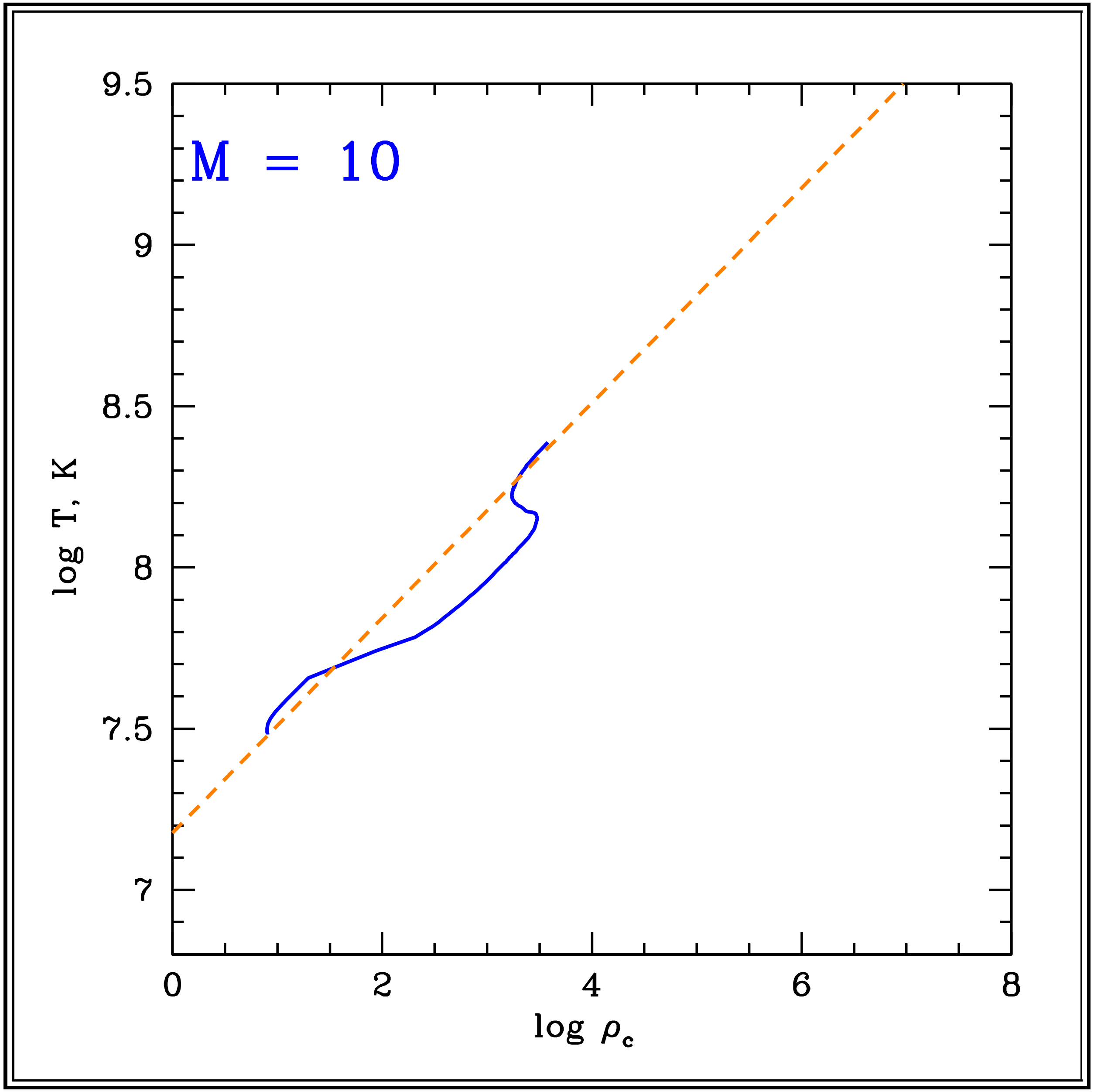
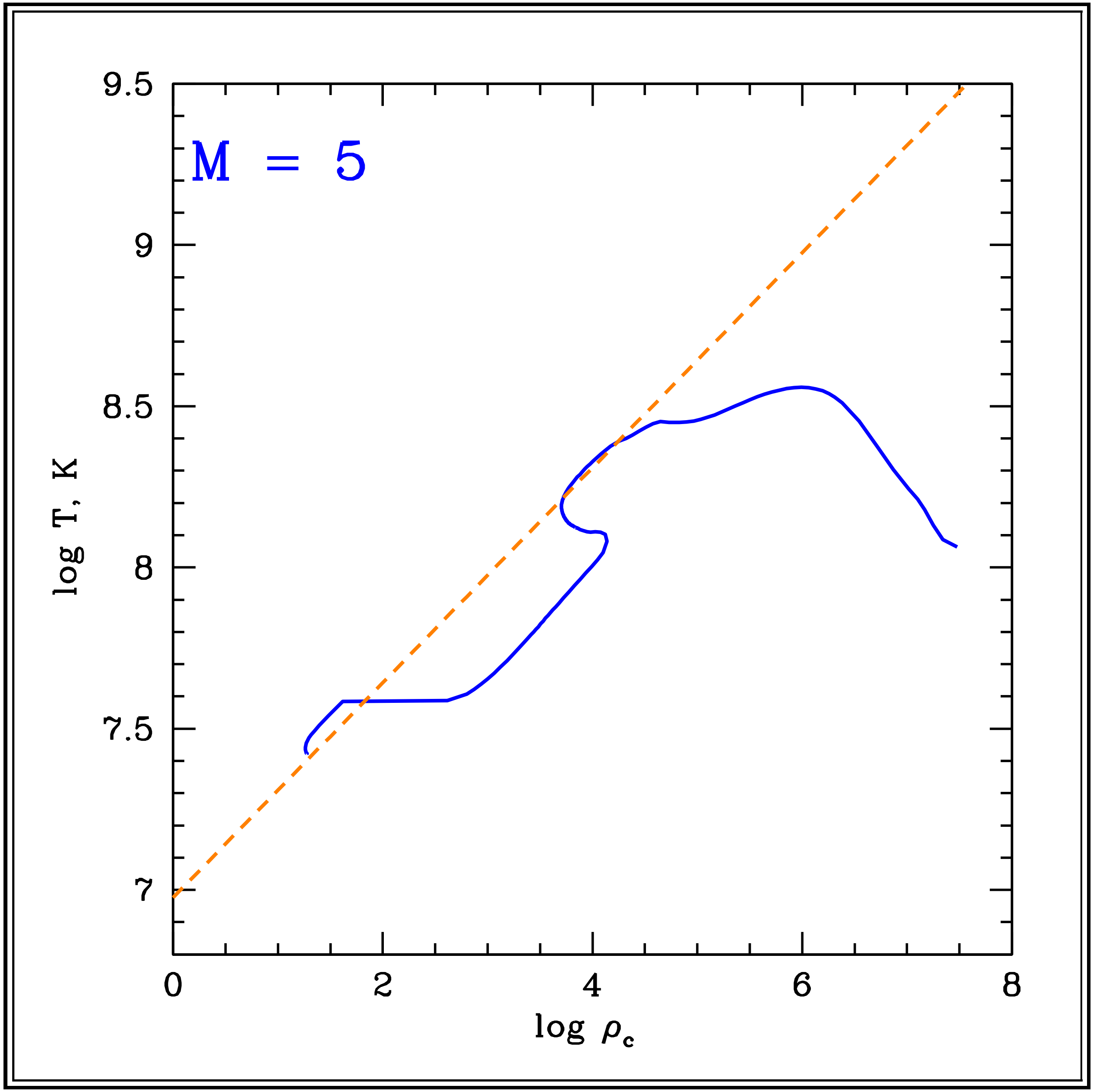
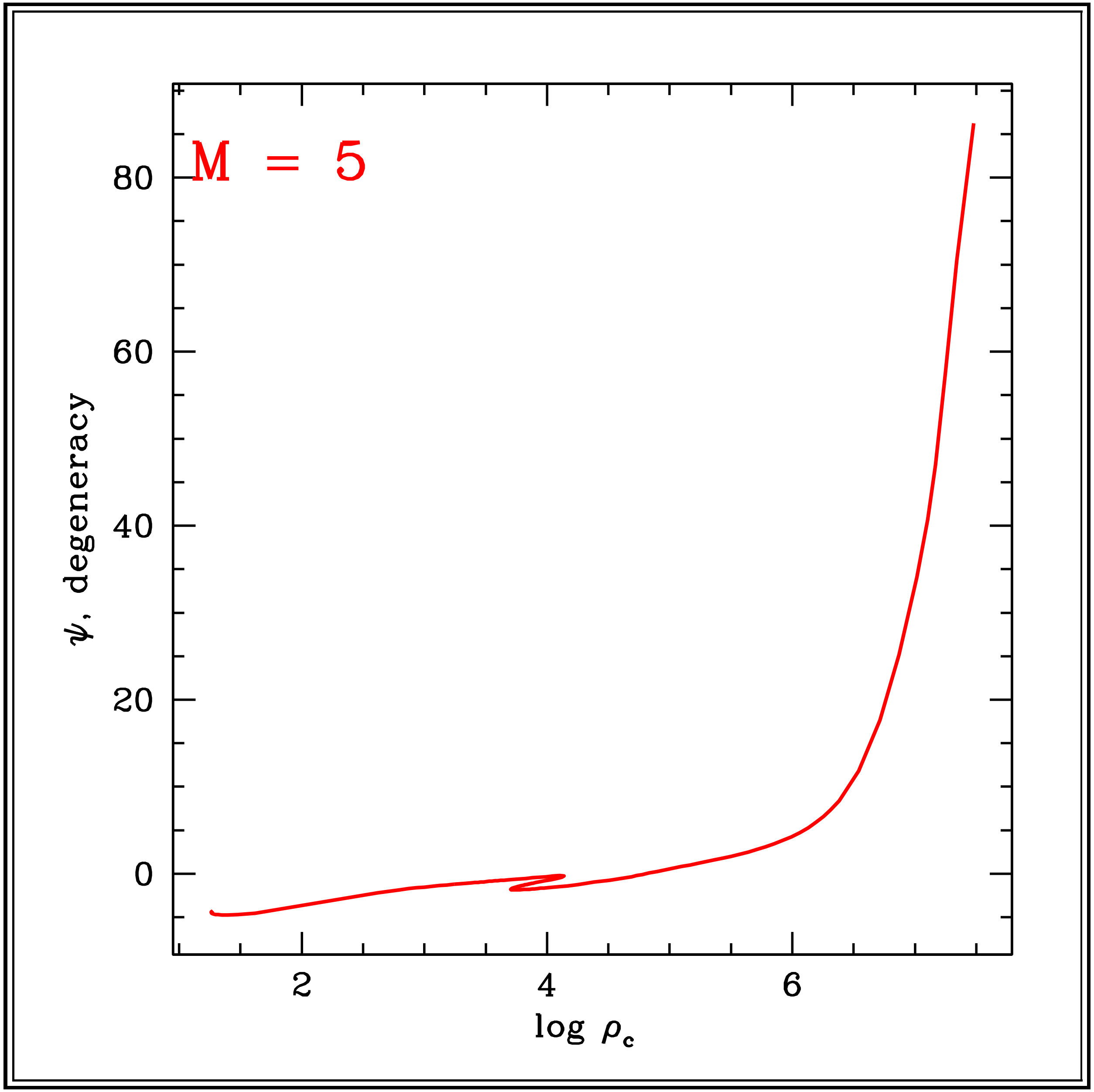


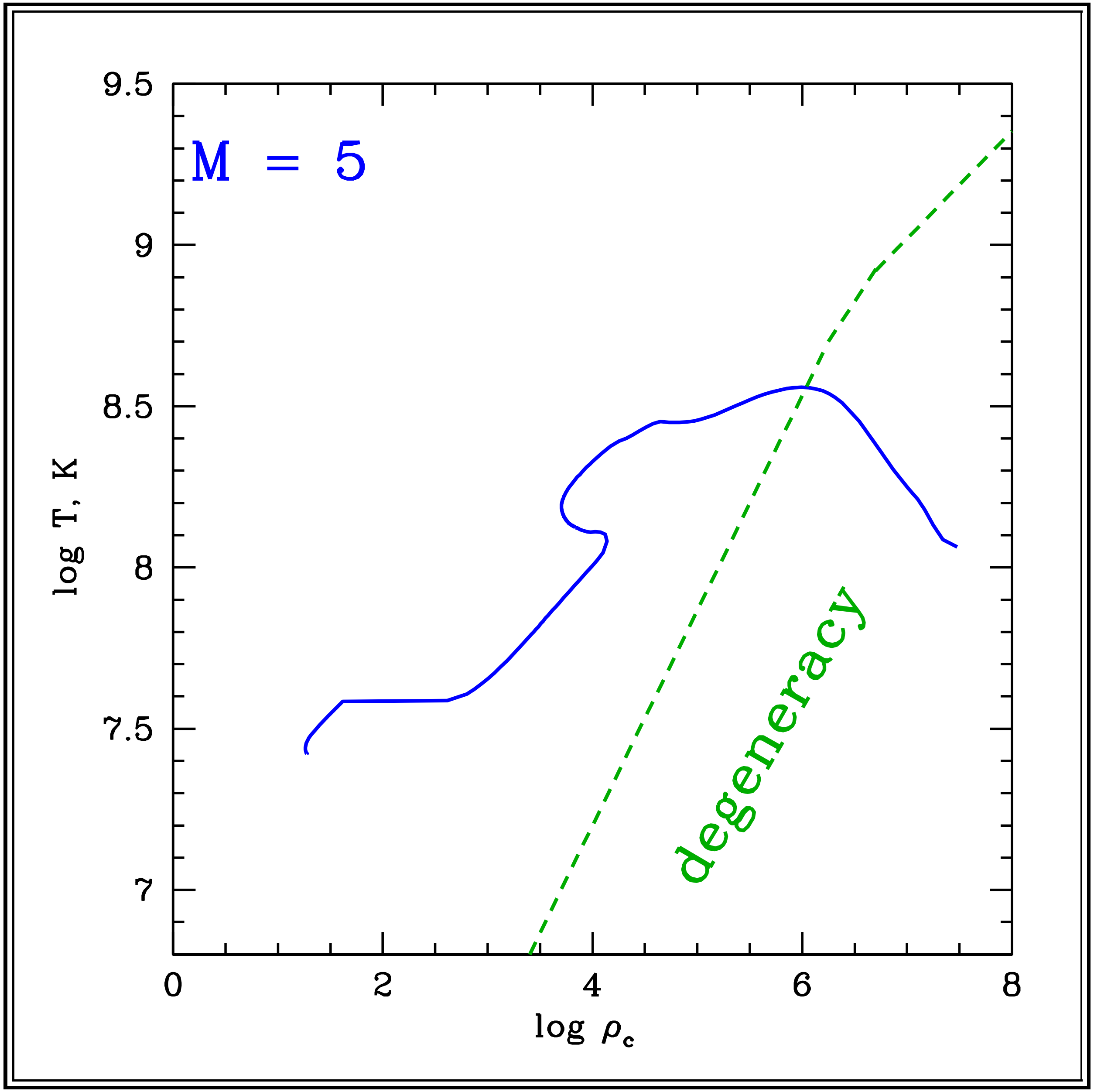
Not so for lower masses



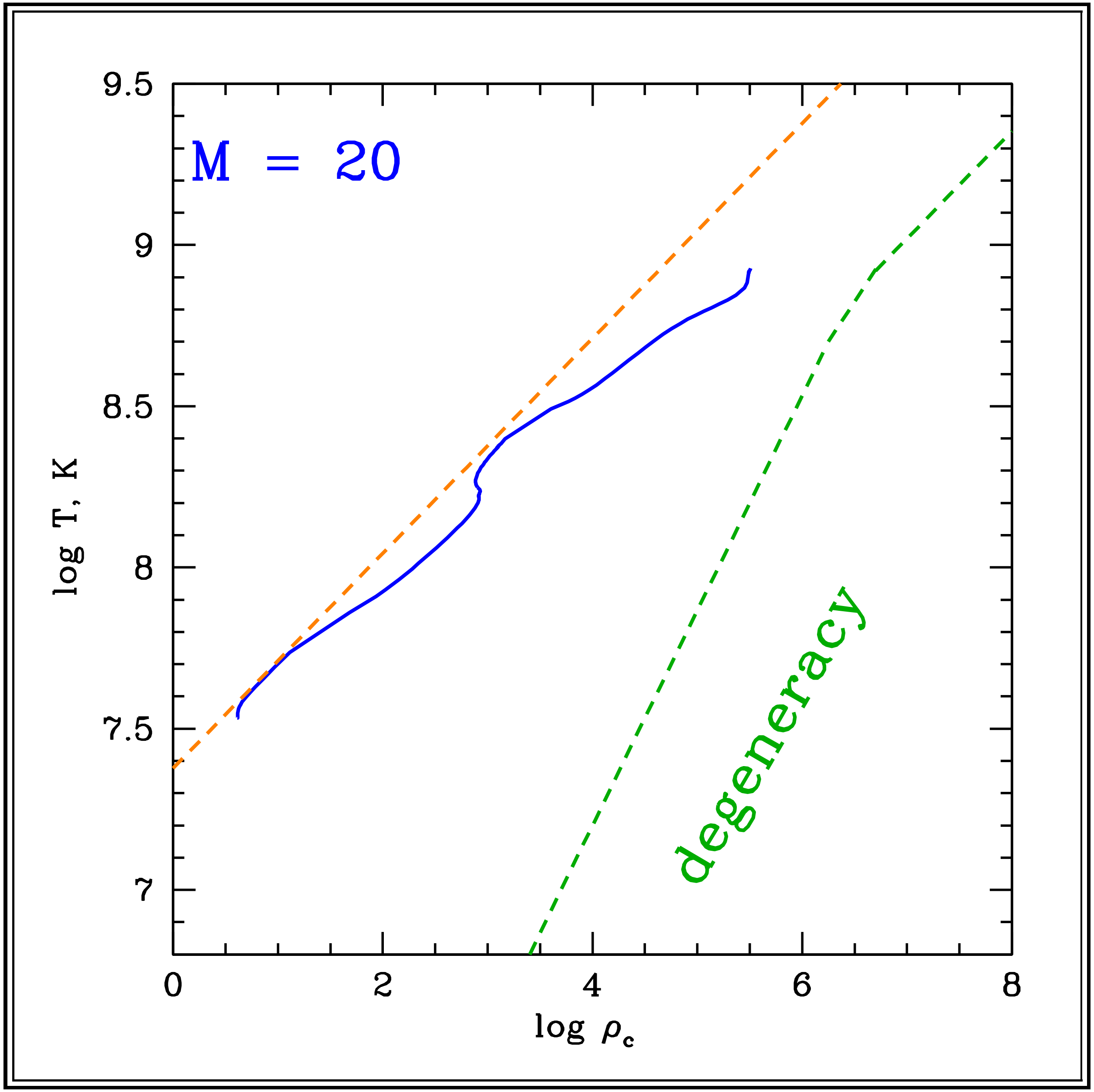
Degeneracy of electrons



Degeneracy of electrons



$M > 10 M_\odot$ never degenerate



Compare with old Iben's results

massive than about $2.25M_{\odot}$ approach a common path, as is shown in Figure 4 (from Iben 1973a). This is a consequence of the fact that the density and pressure distributions in the inner parts of the hydrogen-exhausted core and the rate of energy

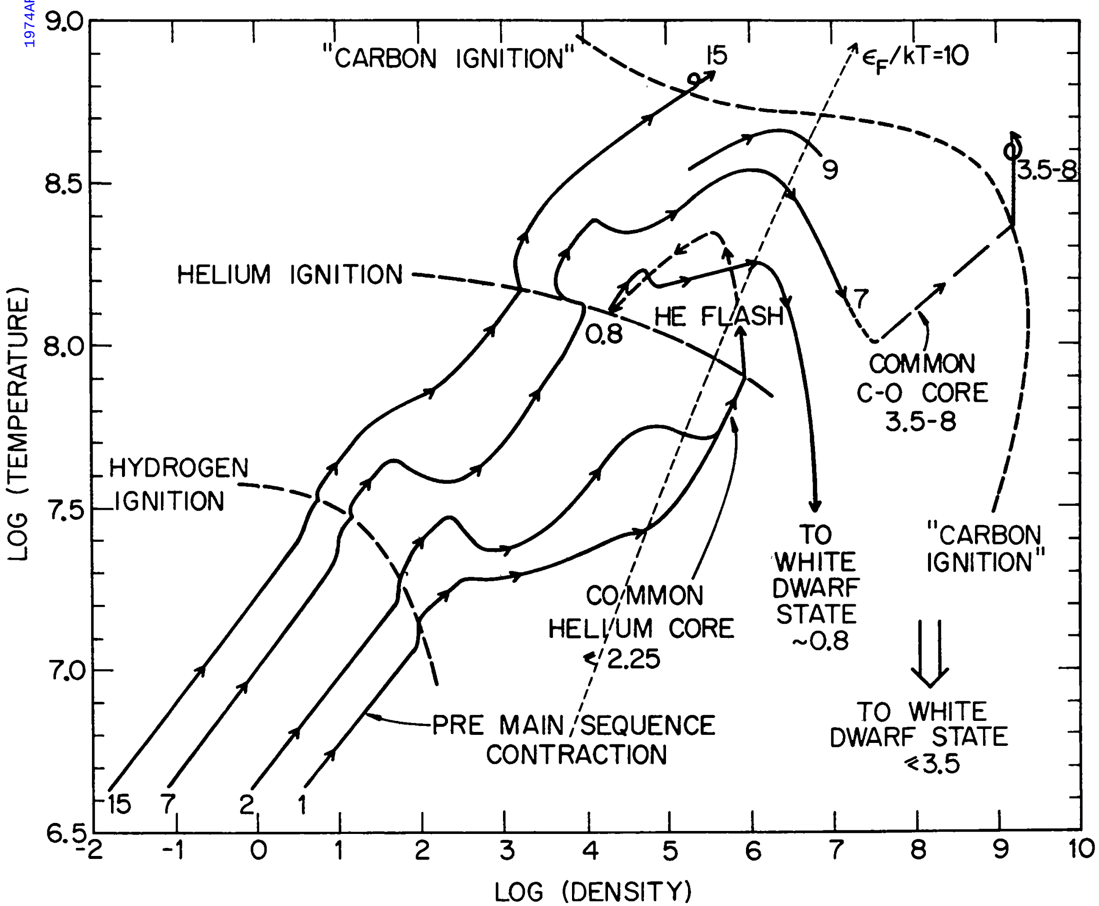


Figure 4 Tracks in the ρ-T plane traced out by the centers of stars of various masses (Iben 1973a).

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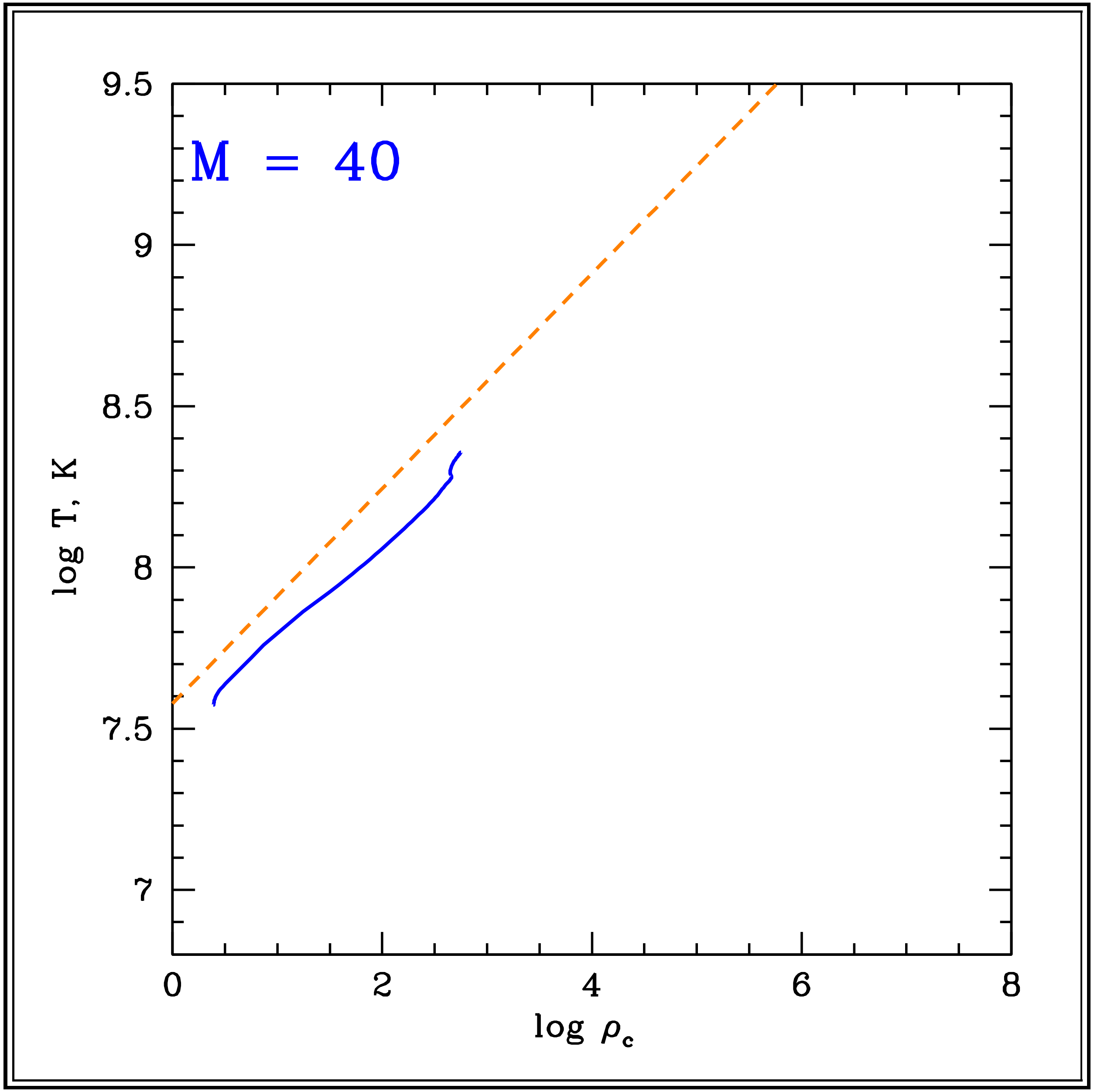

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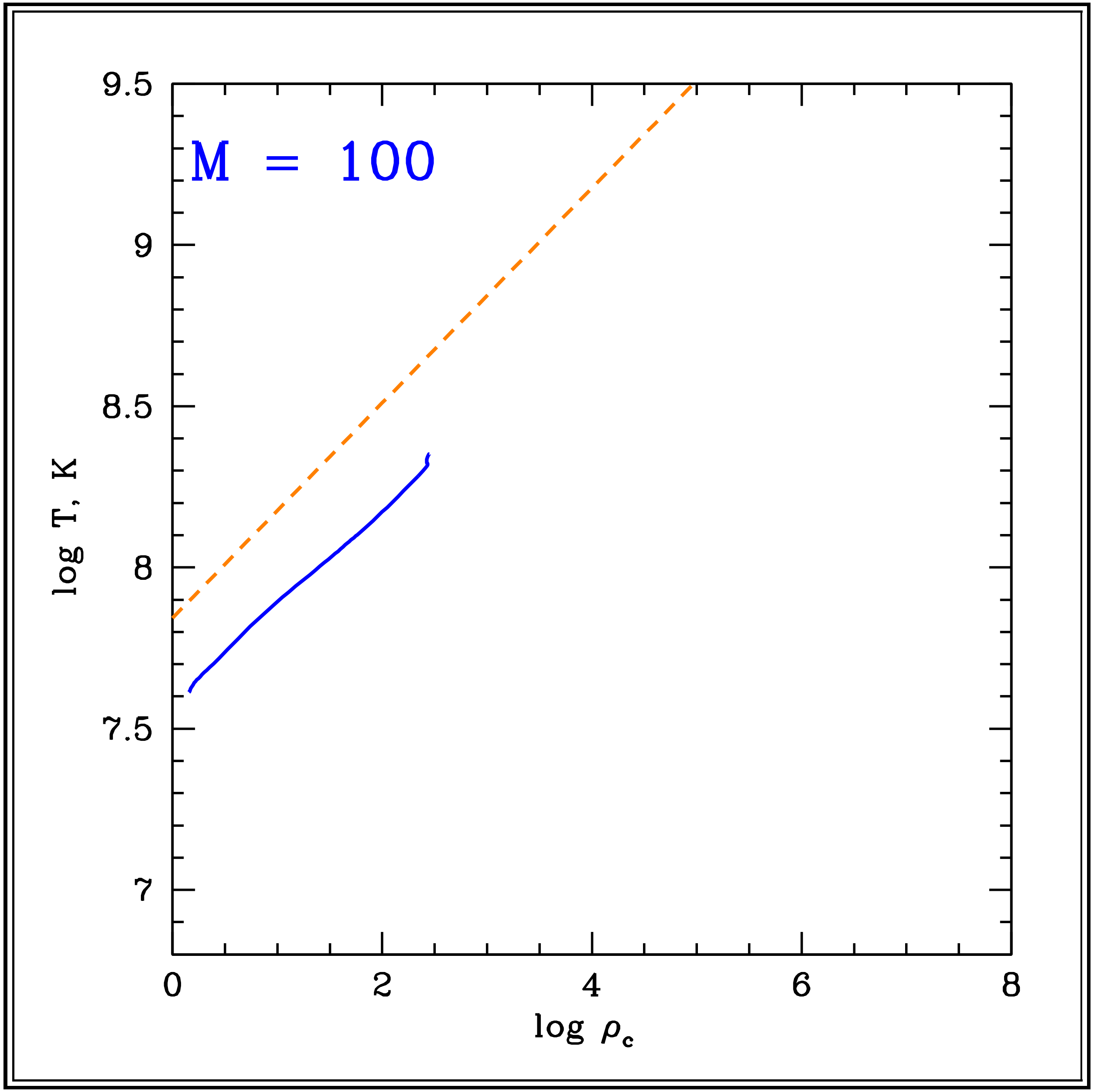
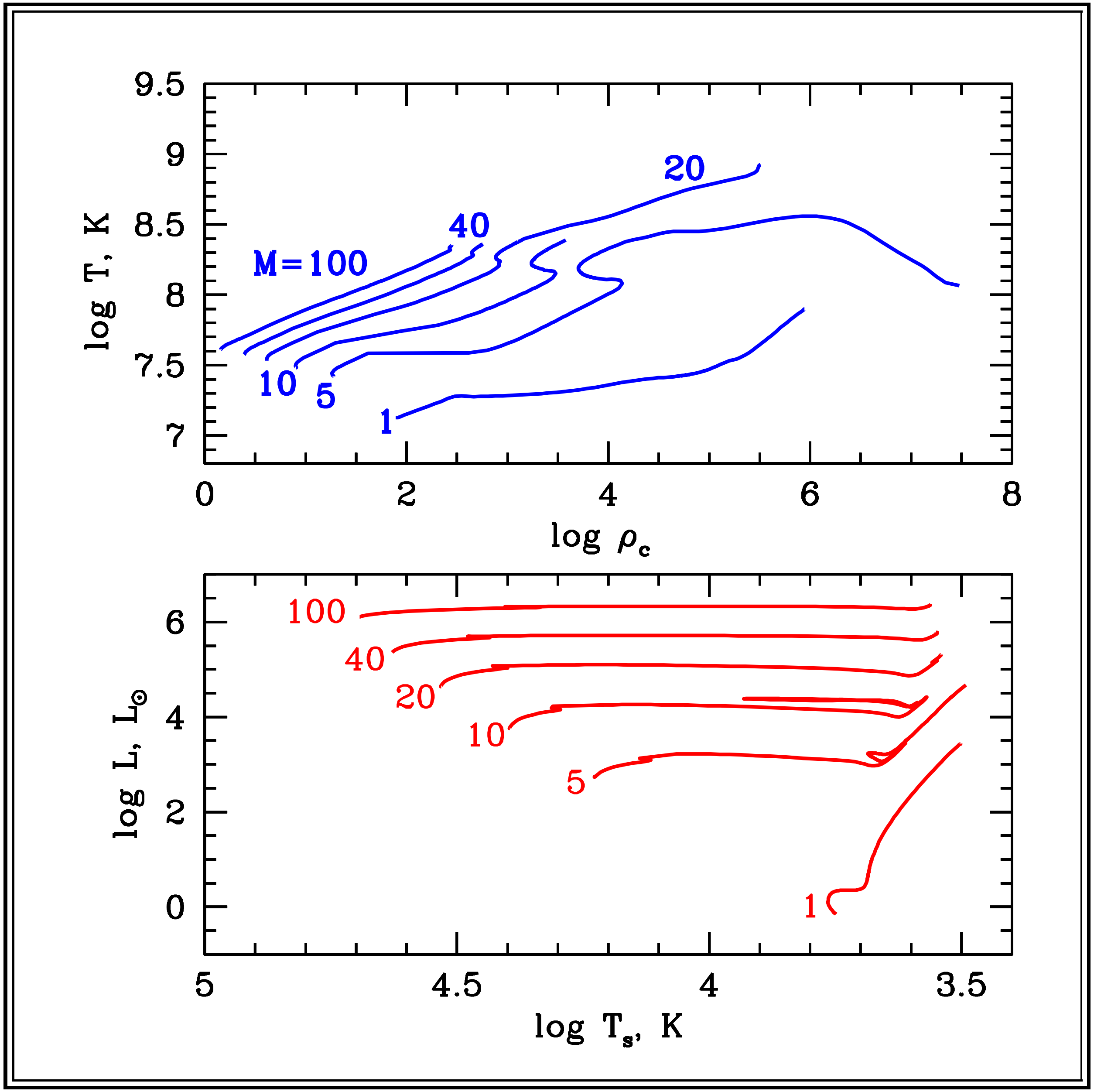


If radiation dominates in P

When plasma is radiation-dominated (for massive stars), then, $P \propto T^4$, and

$$T_c \propto M^{1/6} \rho_c^{1/3}.$$

HR and $T_c - \rho_c$ evolution



Compute stars yourself

Computational Astrophysics:

`http://rainman.astro.uiuc.edu/ddr/`

The Digital Demo Room

10000 stars evolve together – find on this site

7 stars of masses $20M_\odot < M < 80$ evolve in a combined run

and explode as SNe – produced on this site – click here

The carbon-oxygen cores of low mass stars turn out to be degenerate at the moment when the carbon burning begins. The temperature of their interiors is also strongly affected by the neutrino energy losses. Should the carbon burning only begin in degenerate conditions, it acquires a violent, explosive nature giving rise to the explosion of Type Ia supernovae.

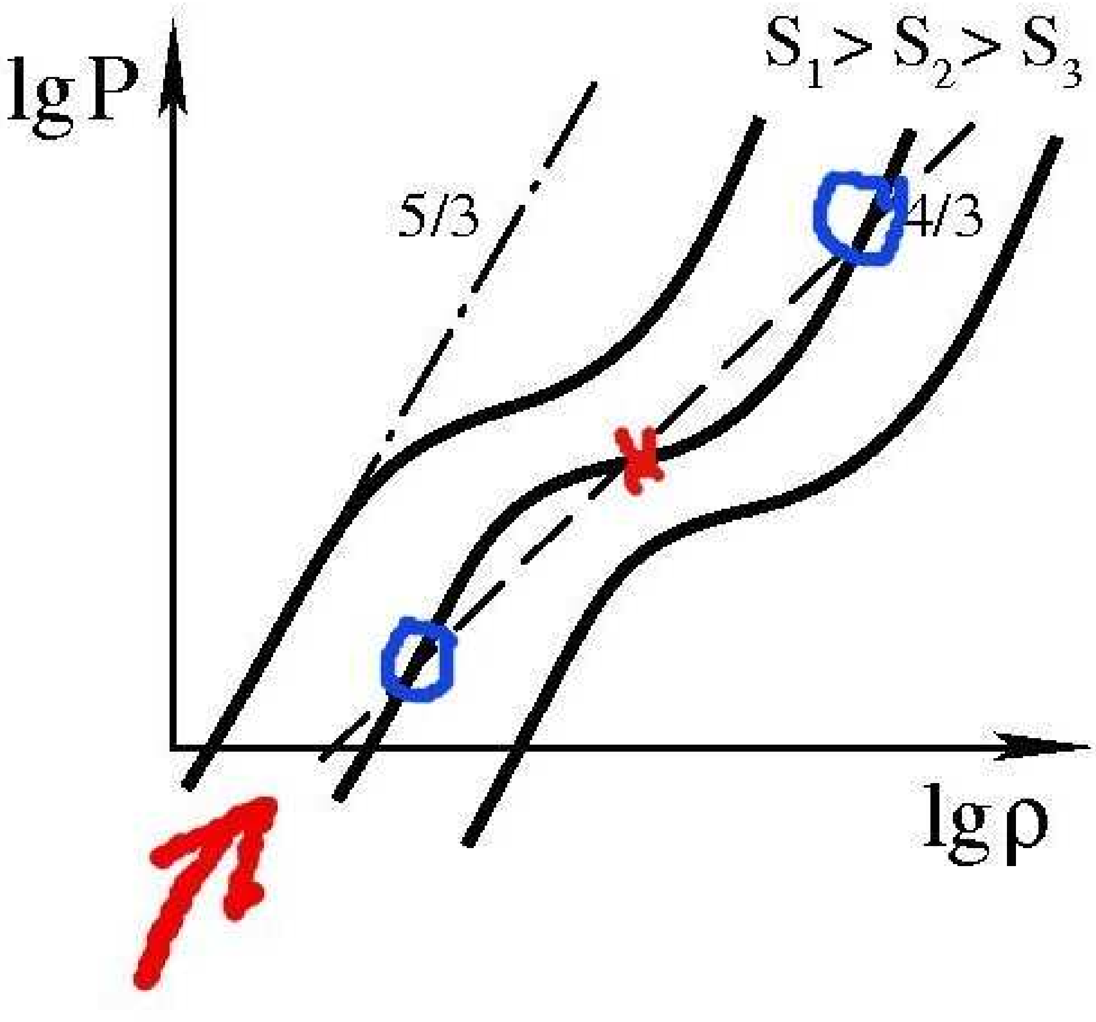
On hydrodynamical instability

Equilibrium requires (in Newtonian gravity):

$$P_c \simeq G_{\mathrm{N}} M^{2/3} \rho_c^{4/3}.$$

This implies that adiabatic exponent $\gamma < 4/3$ may lead to a hydrodynamic instability.

Mechanical stability



M=const

Relativistic particles

lead to $\gamma \to 4/3$

We have $\gamma \sim 4/3$ due to high entropy S (photons and e^+e^- pairs).
At low $S \to 0$ we have $\gamma \to 4/3$ due to high Fermi energy of degenerate electrons at high density ρ.

Causes for a collapse: pairs

For very massive stars the radiation pressure $aT^4/3$ must be much larger than $\mathcal{R}\rho T$.
Here per gram

$$E_{\rm th} = aT^4/\rho$$

and from

$$TS = E_{\rm th} + P/\rho \quad \text{for} \quad \mu = 0,$$

we find per unit mass

$$S = \frac{4}{3}\frac{aT^3}{\rho}.$$

Photons and ...

$$T = \left(\frac{3}{4}\frac{S\rho}{a}\right)^{1/3}, \quad P = \frac{1}{3}aT^4 = \frac{a}{3}\left(\frac{3}{4}\frac{S\rho}{a}\right)^{4/3},$$

i.e. $P \propto \rho^{4/3}$ for constant S, and $\gamma = 4/3$. When $T \gtrsim 0.1 m_e c^2$ for small μ in non-degenerate gas the pairs (e^+e^-) are born intensively, so for $T \gg m_e c^2$ the total thermal energy

$$E_{\mathrm{th}}\rho = aT^4 + \frac{7}{4}aT^4 = \frac{11}{4}aT^4,$$

$(7a/8)$ is added per each polarization of fermions.
Exact formulae see, e.g., SB,Dunina-Barkovskaya,DKN, 1996, ApJS.

. . . and e^+e^- pairs

pressure

$$P = \frac{11}{12} a T^4,$$

and entropy per gram

$$S = \frac{11}{3} \frac{aT^3}{\rho}.$$

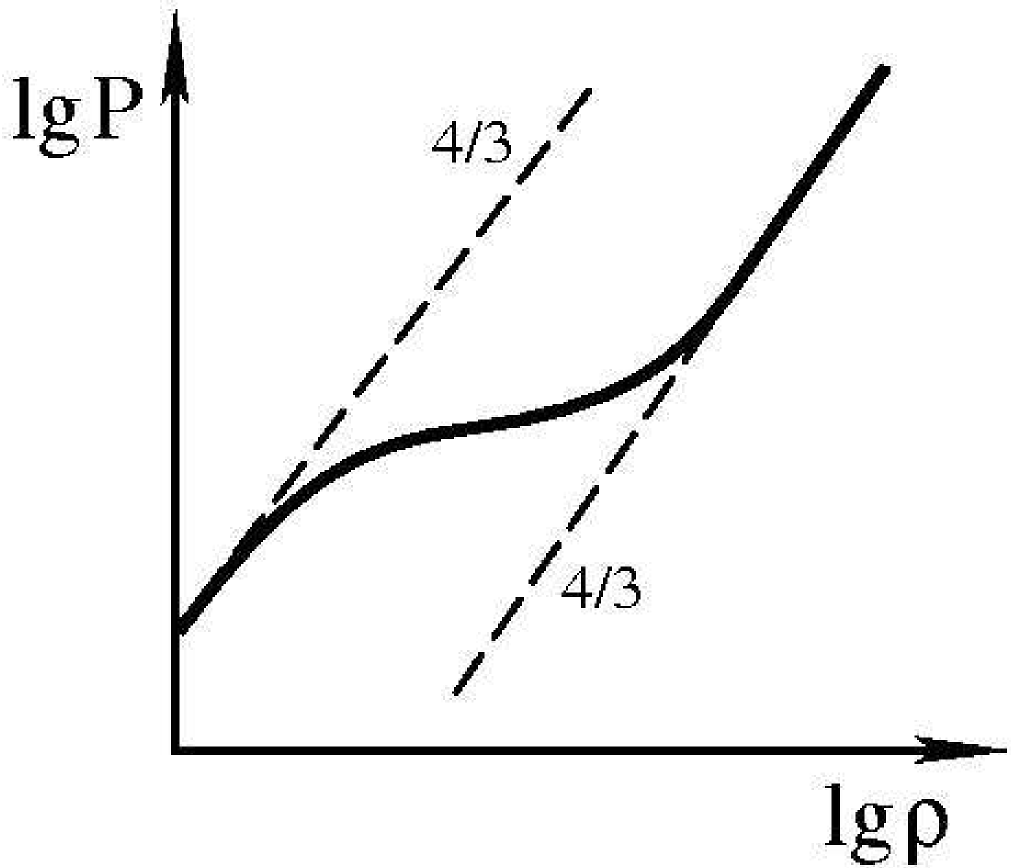
Thus for $T \gg m_e c^2$ again $P \sim \rho^{4/3}$, but the coefficient is smaller

$$P = \frac{11}{12} a T^4 = \frac{11a}{12} \left(\frac{3}{11} \frac{S\rho}{a} \right)^{4/3},$$

so in between the slope $\log P$ – $\log \rho$ must be less than $4/3$.

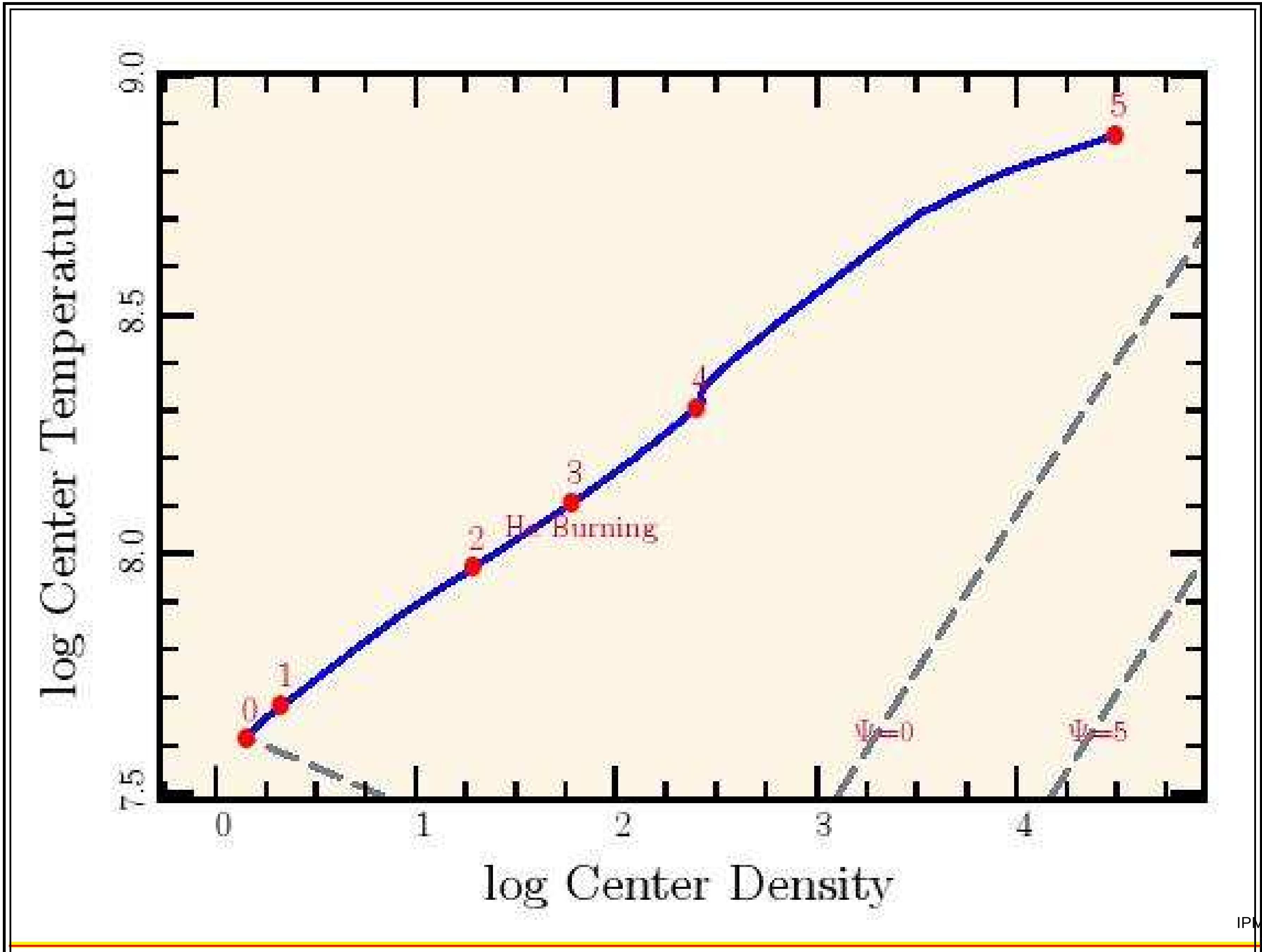
Pair instability

A radiation dominated star was already at the verge of the loss of the stability ($P \propto \rho^{4/3}$), and now it is unstable if ($\gamma < 4/3$).



Higher mass means higher T_c

for the same ρ, hence pair creation



Open evolution code

Previous plot is taken from here

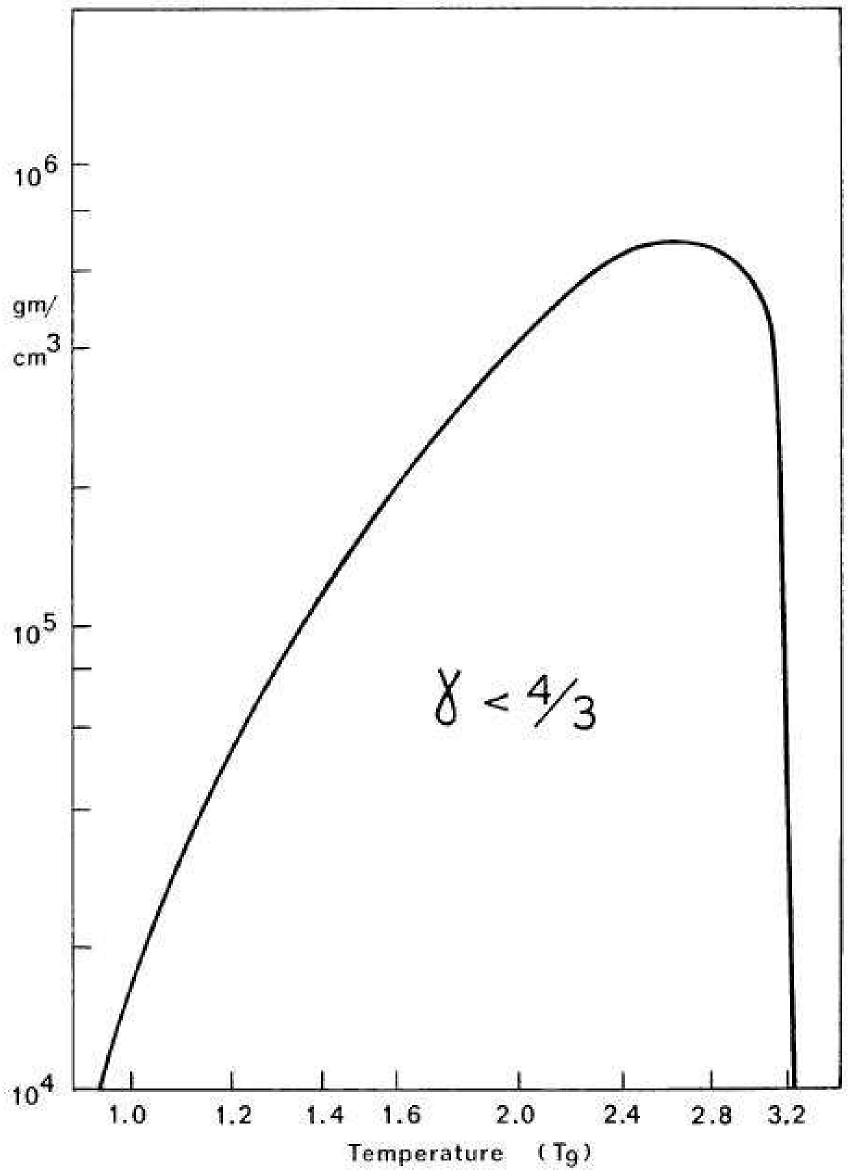
$\boxed{\text{Paxton: P.Eggleton evolution code}}$

Centre Temperature-Density Tracks for Metallicity Z = 0.02. The “He” symbols show where the net of power from nuclear reactions beyond hydrogen burning minus neutrino losses from all sources reaches the break-even point.

Adiabatic γ for pairs

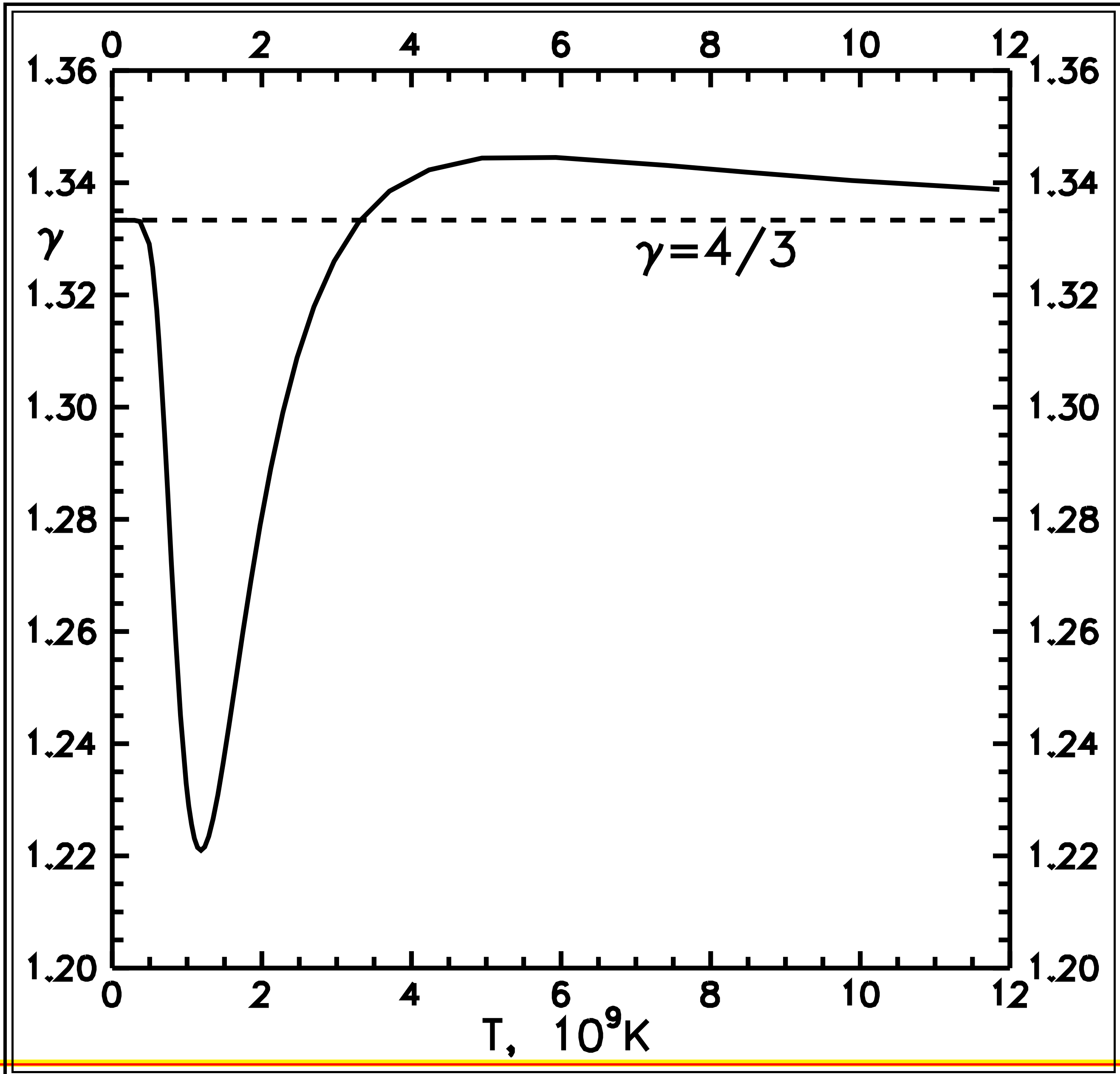
Gary S. Fraley 1968. Pair-instability SNe

SUPERNOVAE EXPLOSIONS INDUCED BY PAIR-PRODUCTION INSTABILITY

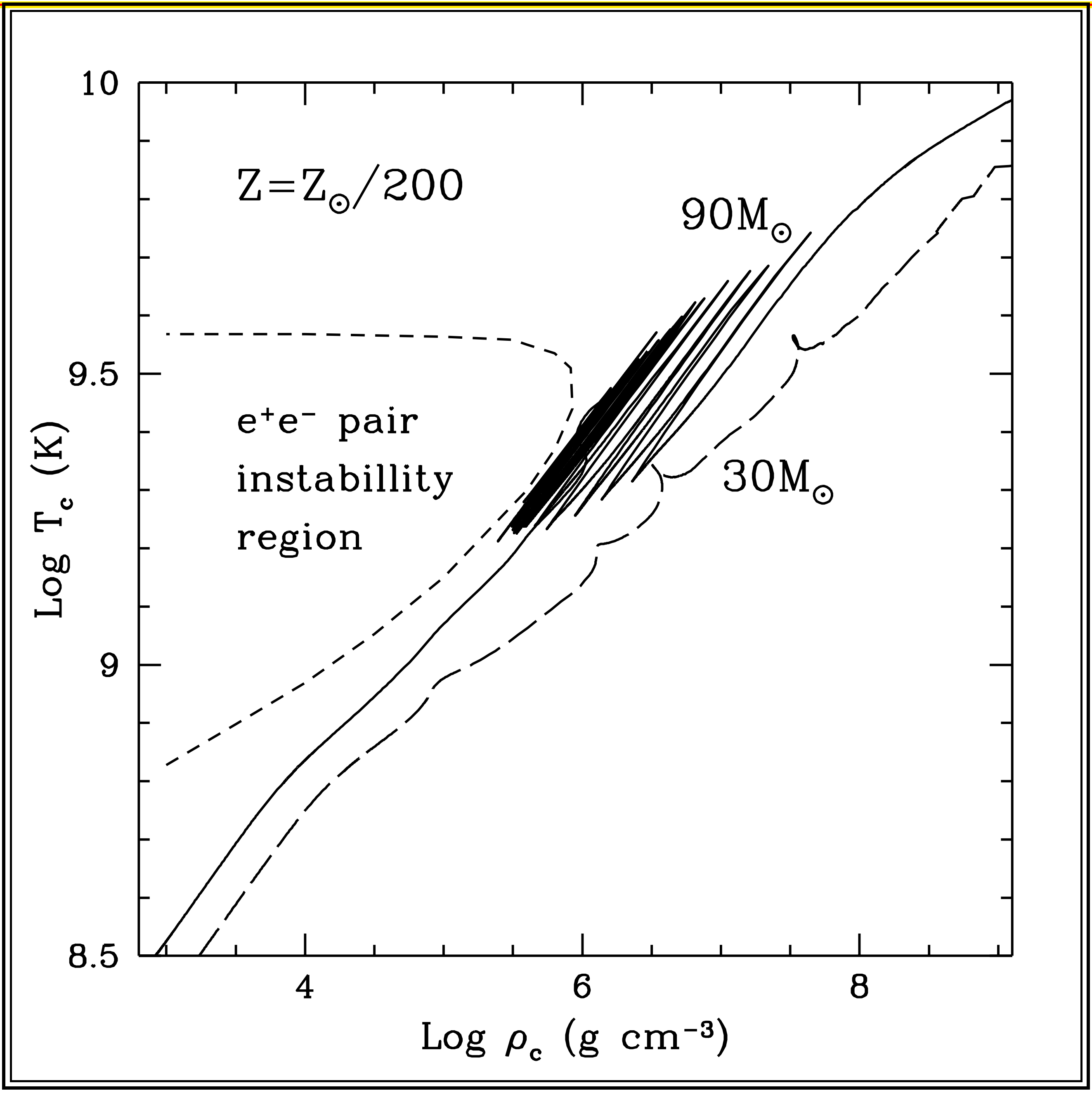


Adiabatic γ for pairs

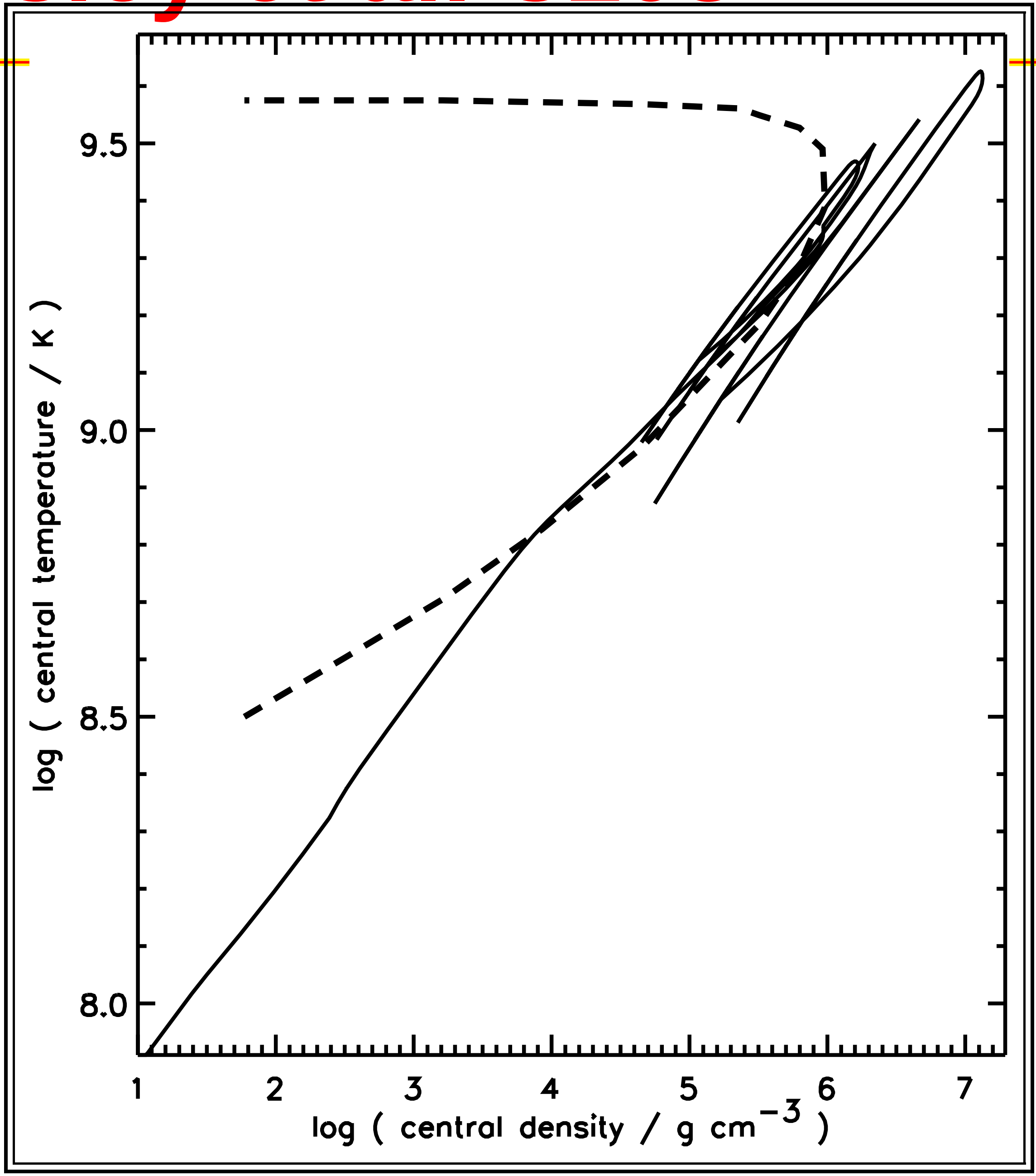
D.K.Nadyozhin 1974, see SB,Dunina-Barkovskaya,DKN, 1996, ApJS



Umeda and Nomoto 2007



Woosley et al. s103



This gives the Most Luminous Supernovae!

SN light production in shocks

- Radiation-dominated shocks and tenacious myths on X-rays from SN shocks

SN light production in shocks

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- Shock propagation and entropy creation inside a star

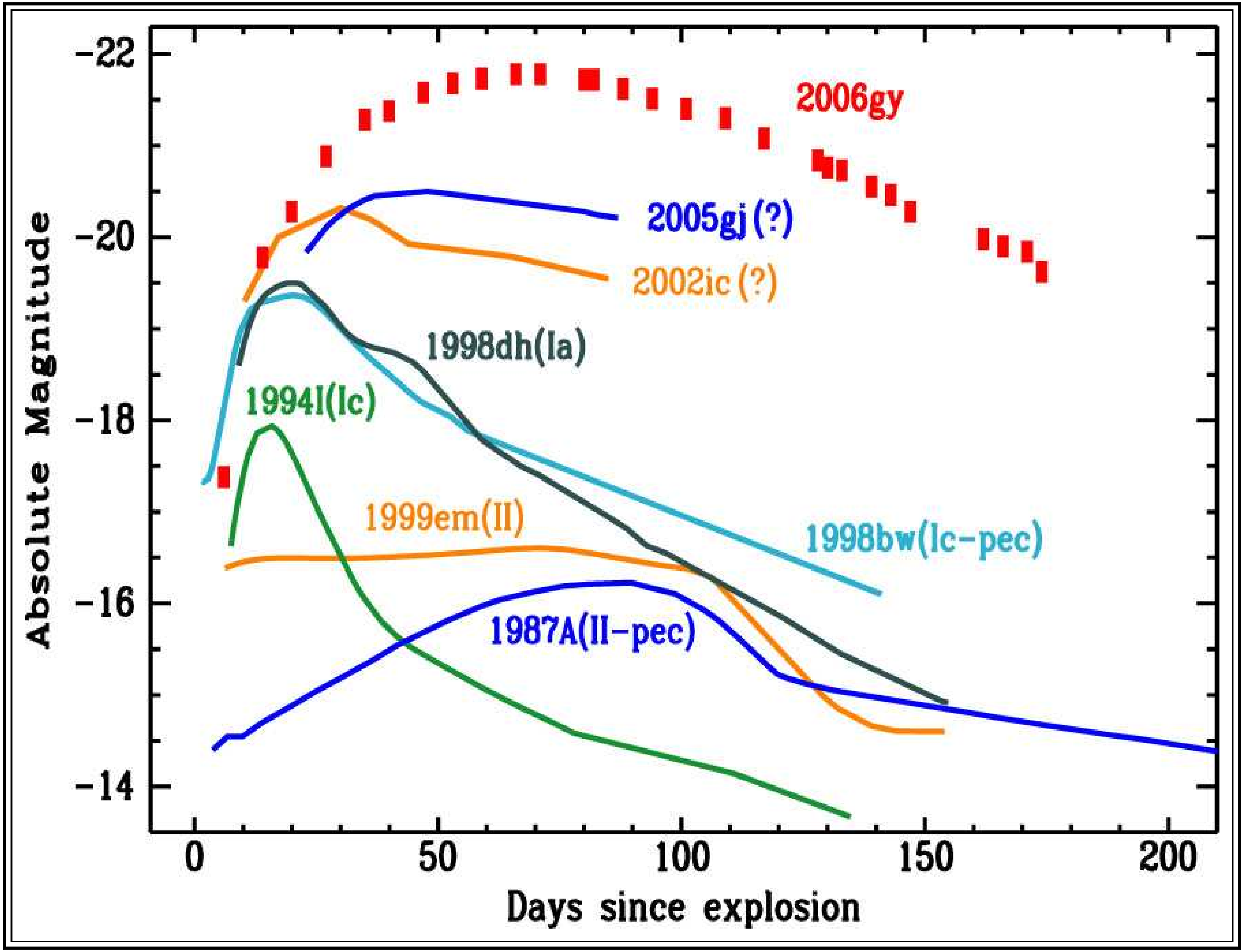
SN light production in shocks

- Radiation-dominated shocks and tenacious myths on X-rays from SN shocks
- Shock propagation and entropy creation inside a star
- Shock breakout, if any

SN light production in shocks

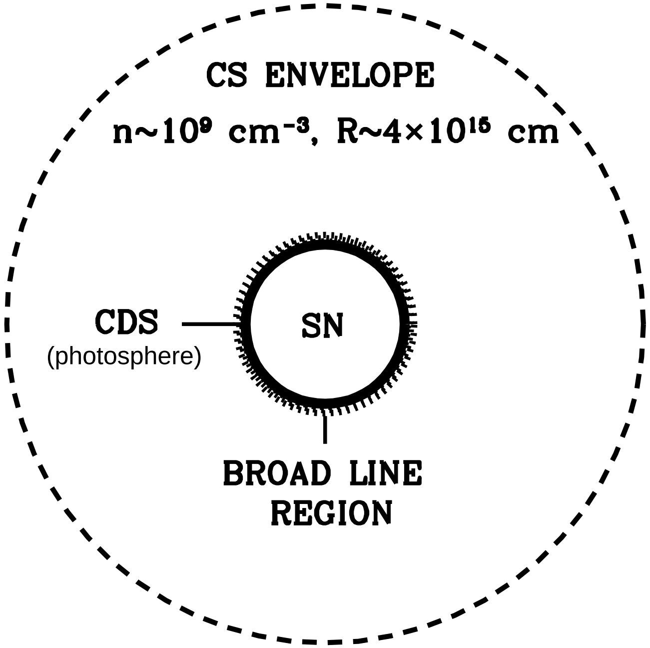
- Radiation-dominated shocks and tenacious myths on X-rays from SN shocks
- Shock propagation and entropy creation inside a star
- Shock breakout, if any
- Diffusion of photons and cooling of ejecta

Models for powerful light



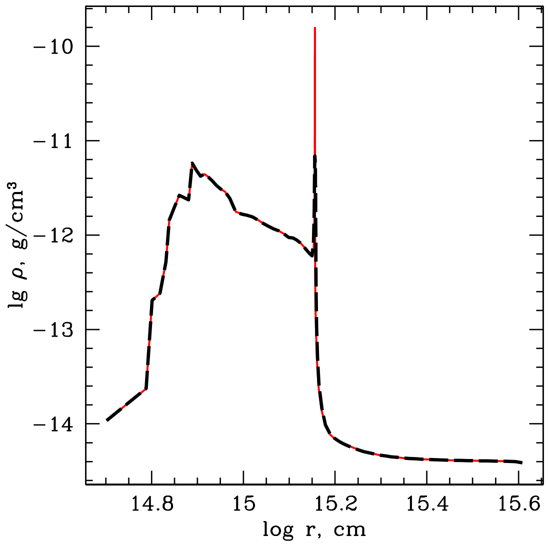
Models for powerful light

Radiative shock, Chugai, Blinnikov ea'04, Woosley ea'07 ...



Models for powerful light

Dense shell Chugai, Blinnikov ea'04



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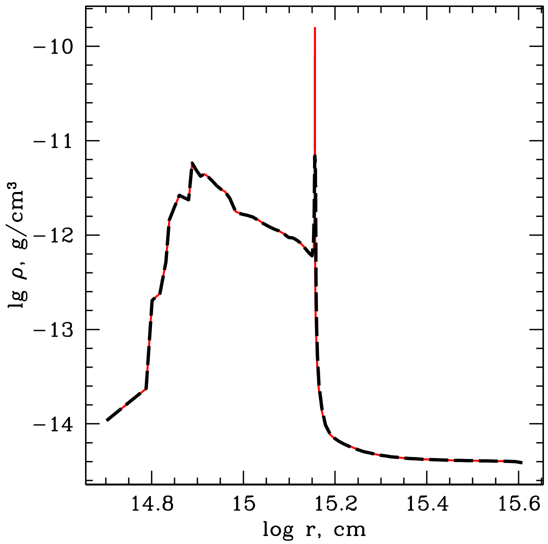
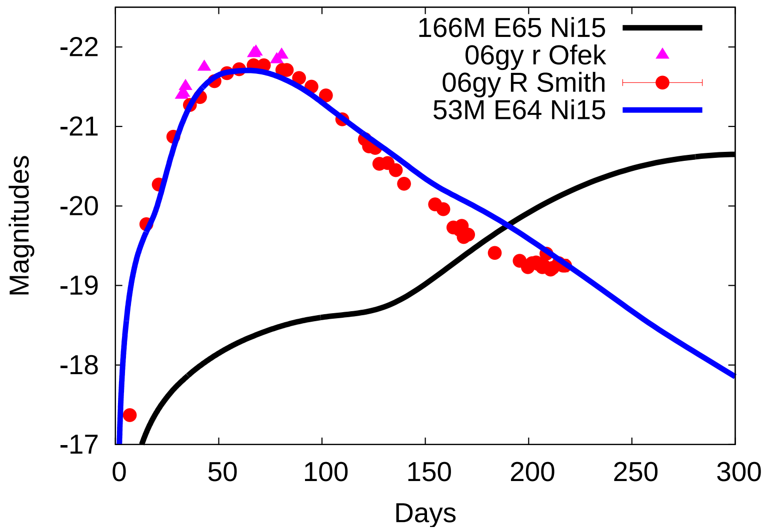


Radioactive, Nomoto, Tominaga ea'07



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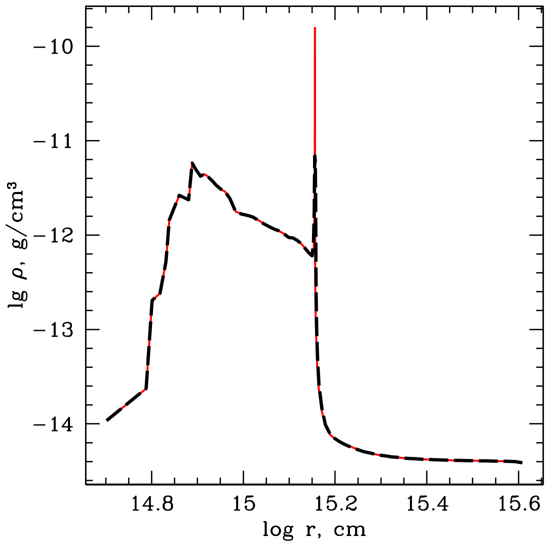

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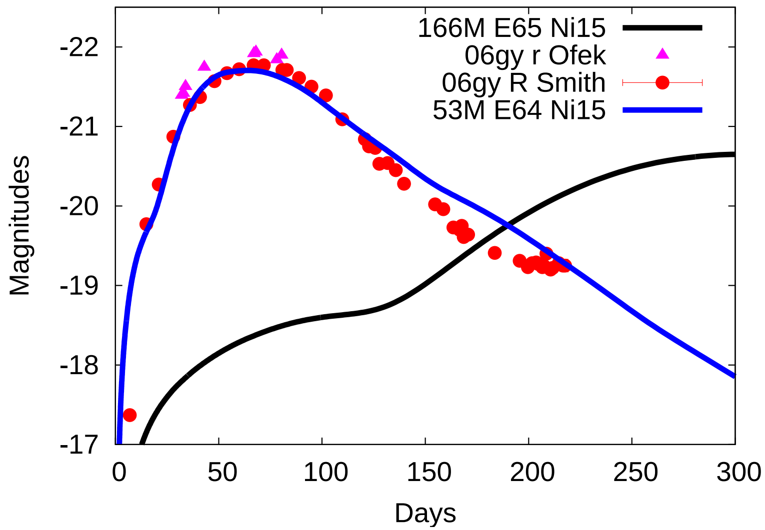
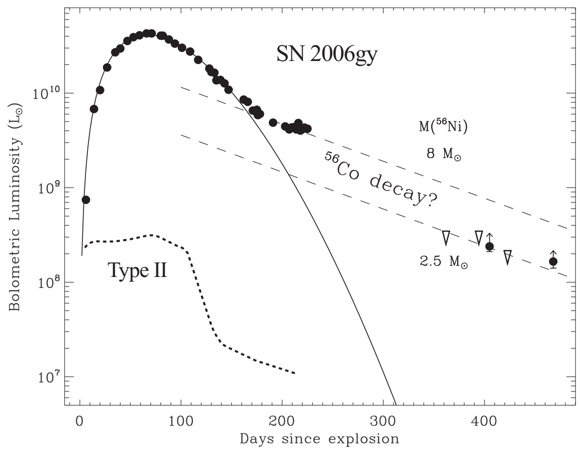


Diffusion, McCray, Smith'07



Models for powerful light

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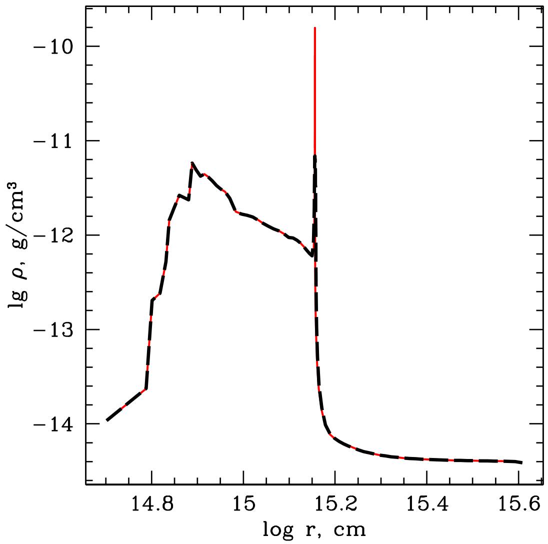

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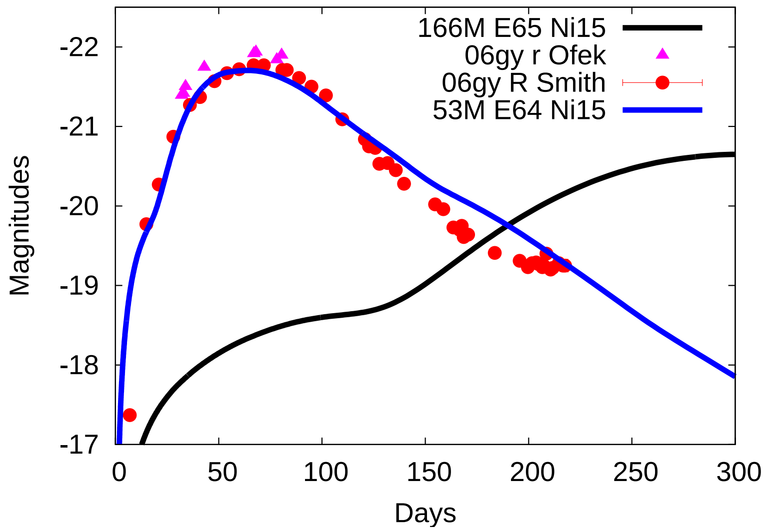

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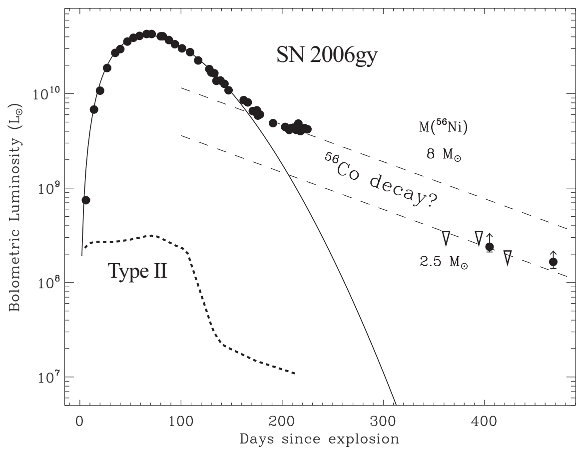
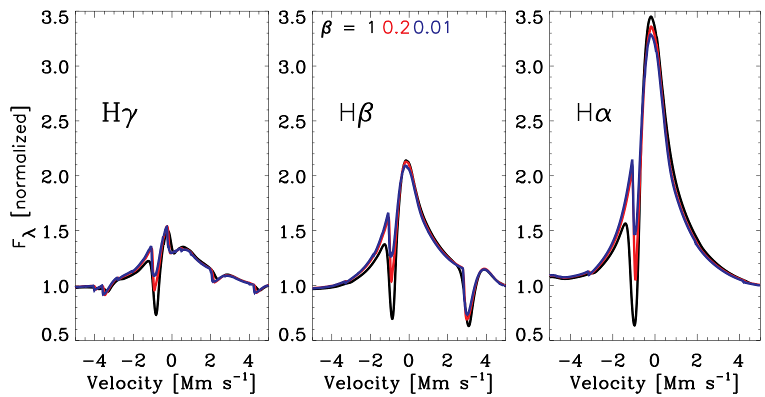


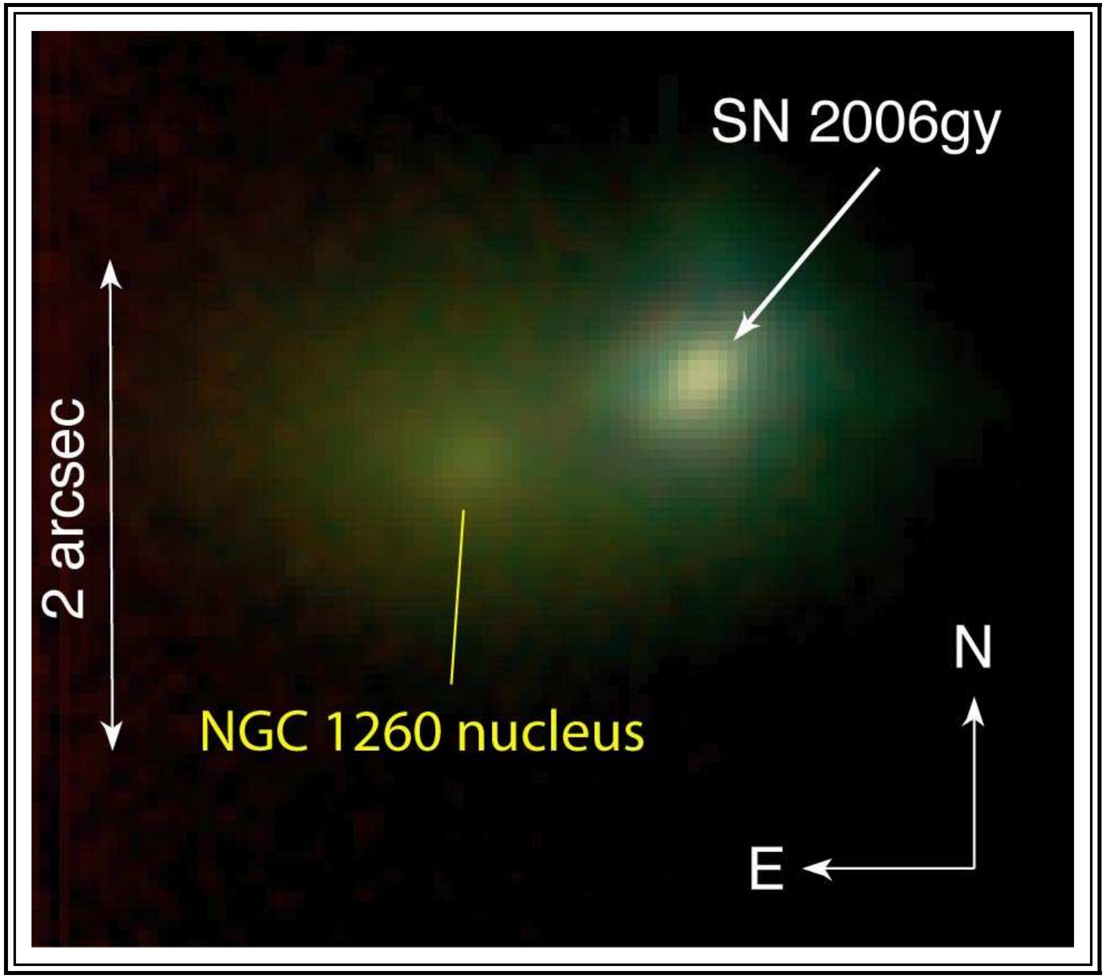
Atmospheric, Dessart ea'08



SN 2006gy

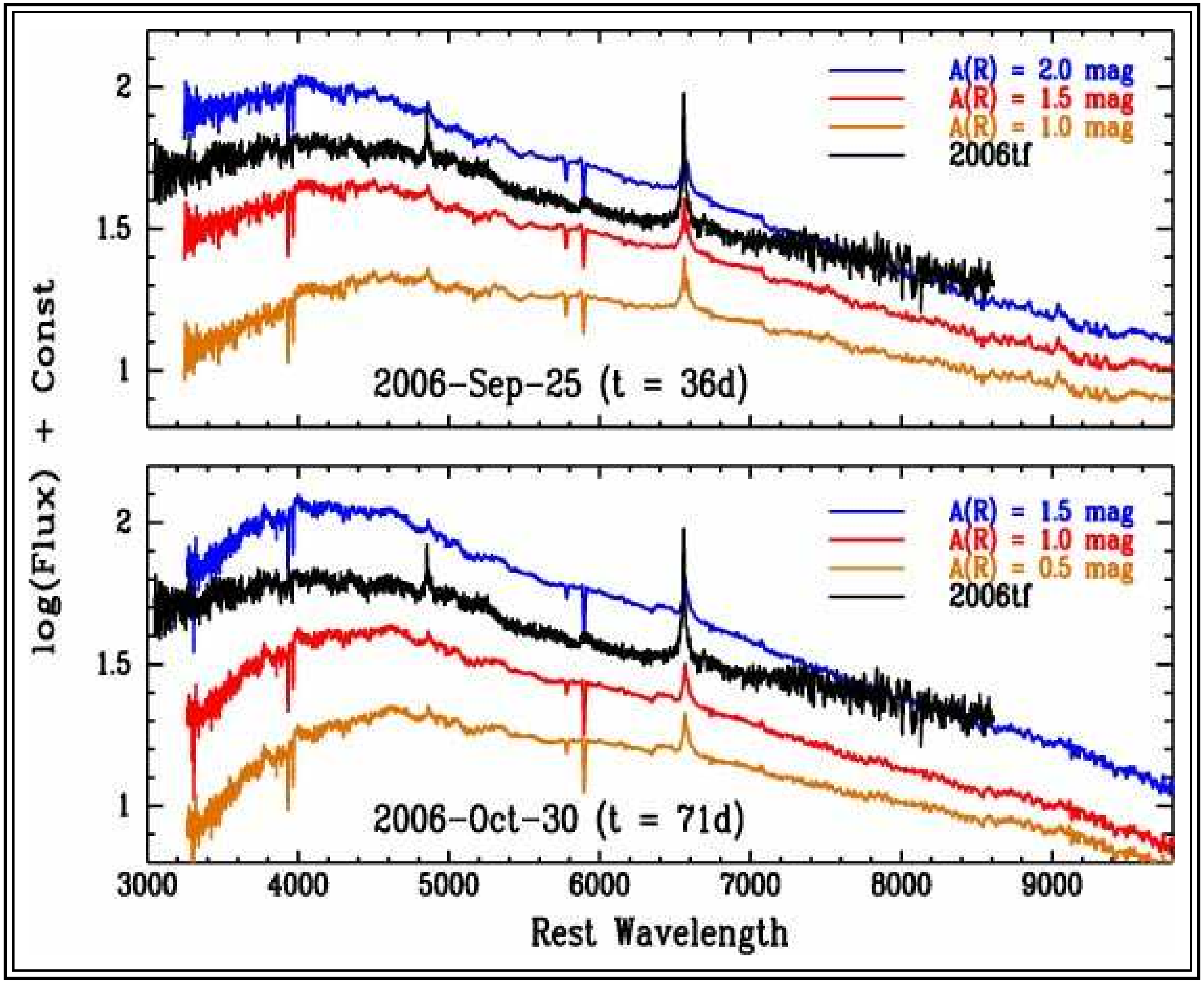
Ofek et al. 2007, ApJL, astro-ph/0612408)

Smith et al. 2007, Sep. 10 ApJ, astro-ph/0612617)

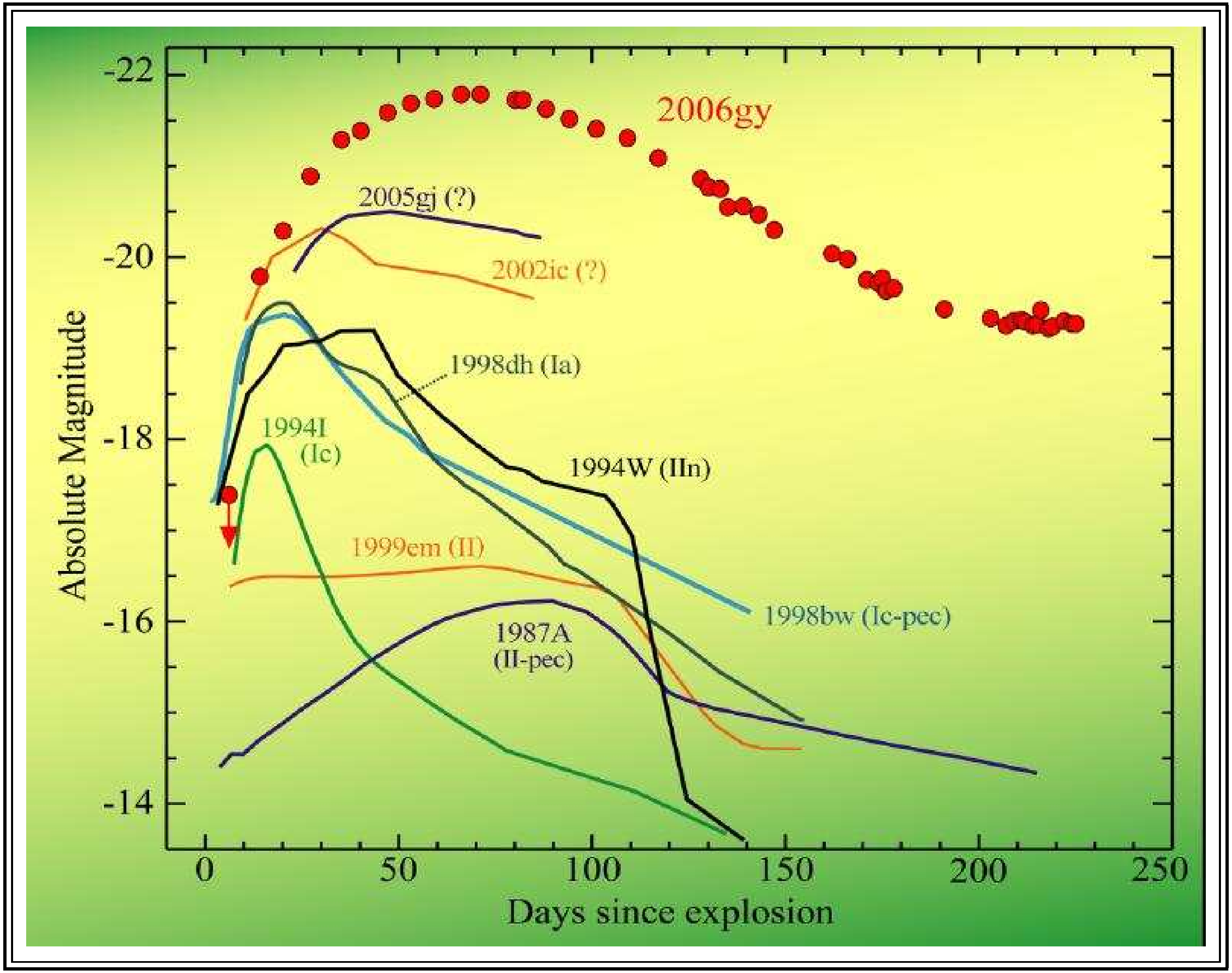


Smith et al. SN06gy spectra

Narrow lines: SNIIn



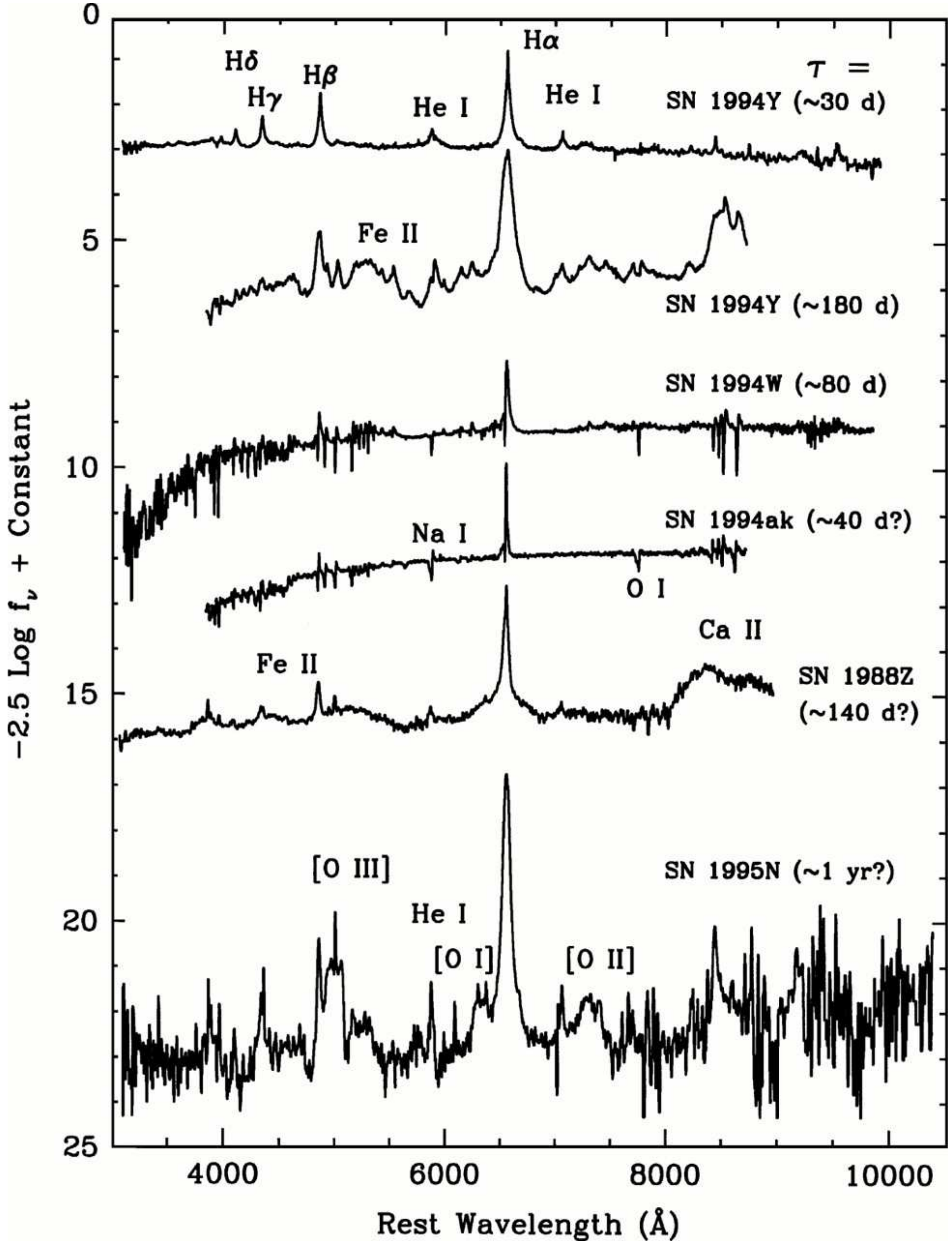
Another LC set with SN IIn



Problems posed by SN2006gy

- Total light 10^{51} ergs: 2 orders of mag higher than normal SN II
- If the source is radioactive material, then huge amount, high explosion energy
- If the source is a shock wave, why X-ray was weak
- What evolution leads to any of those outcomes?

Spectra of SNe IIn



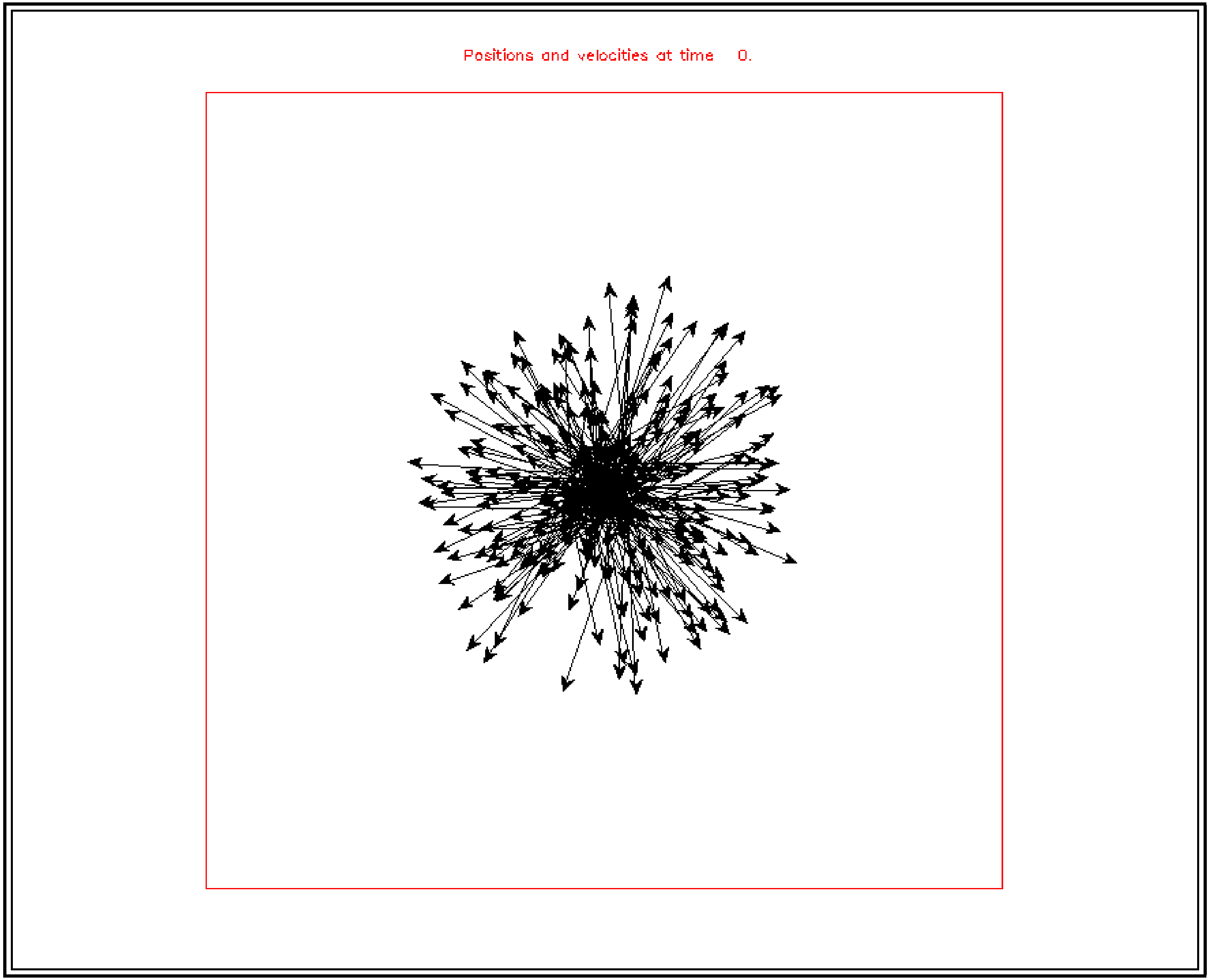
SN light

Many photons $\Rightarrow$ high entropy: $S \sim n_\gamma / n_b$.

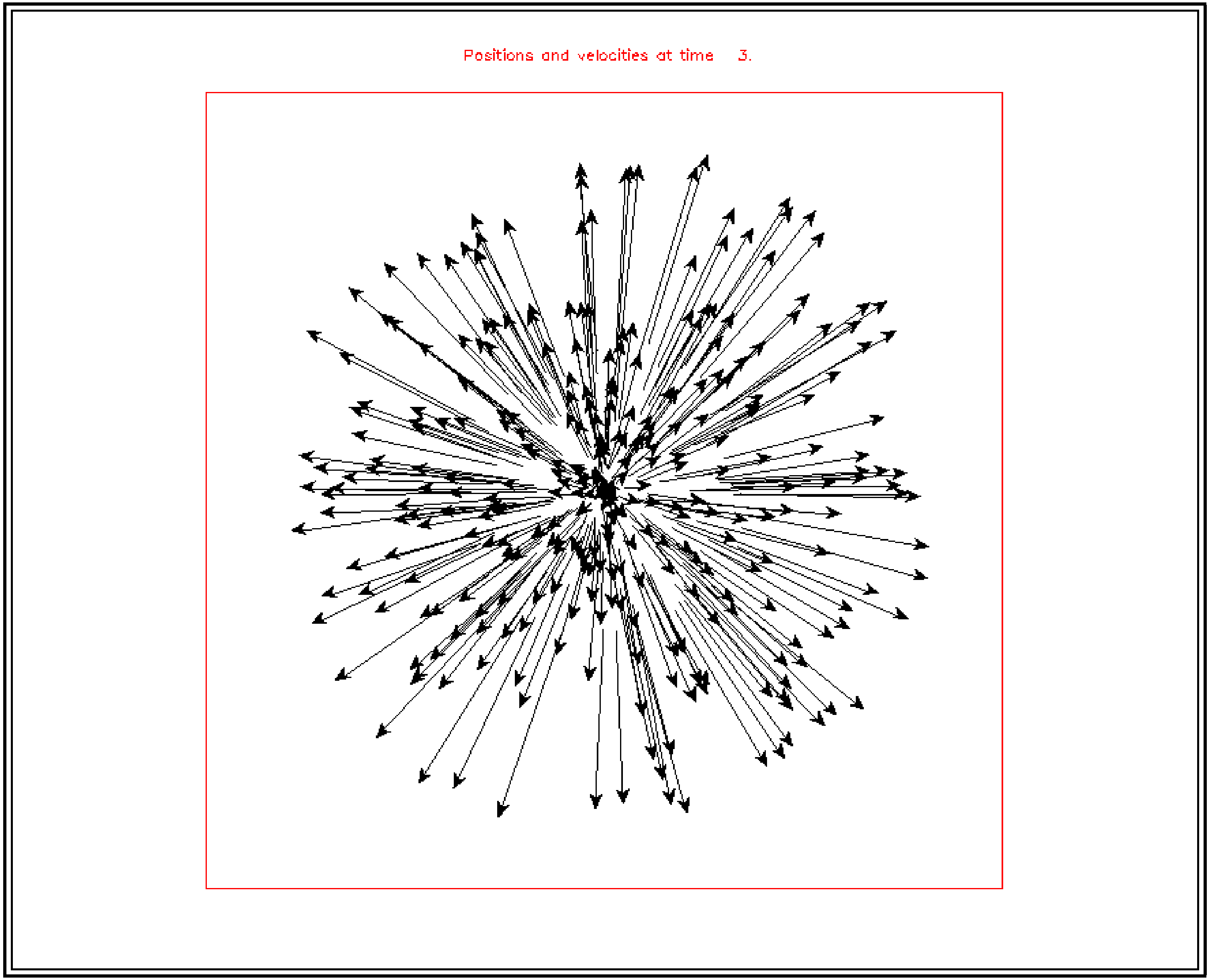
Thus a source of S is needed for luminous

SNe: either radioactivity or shocks.

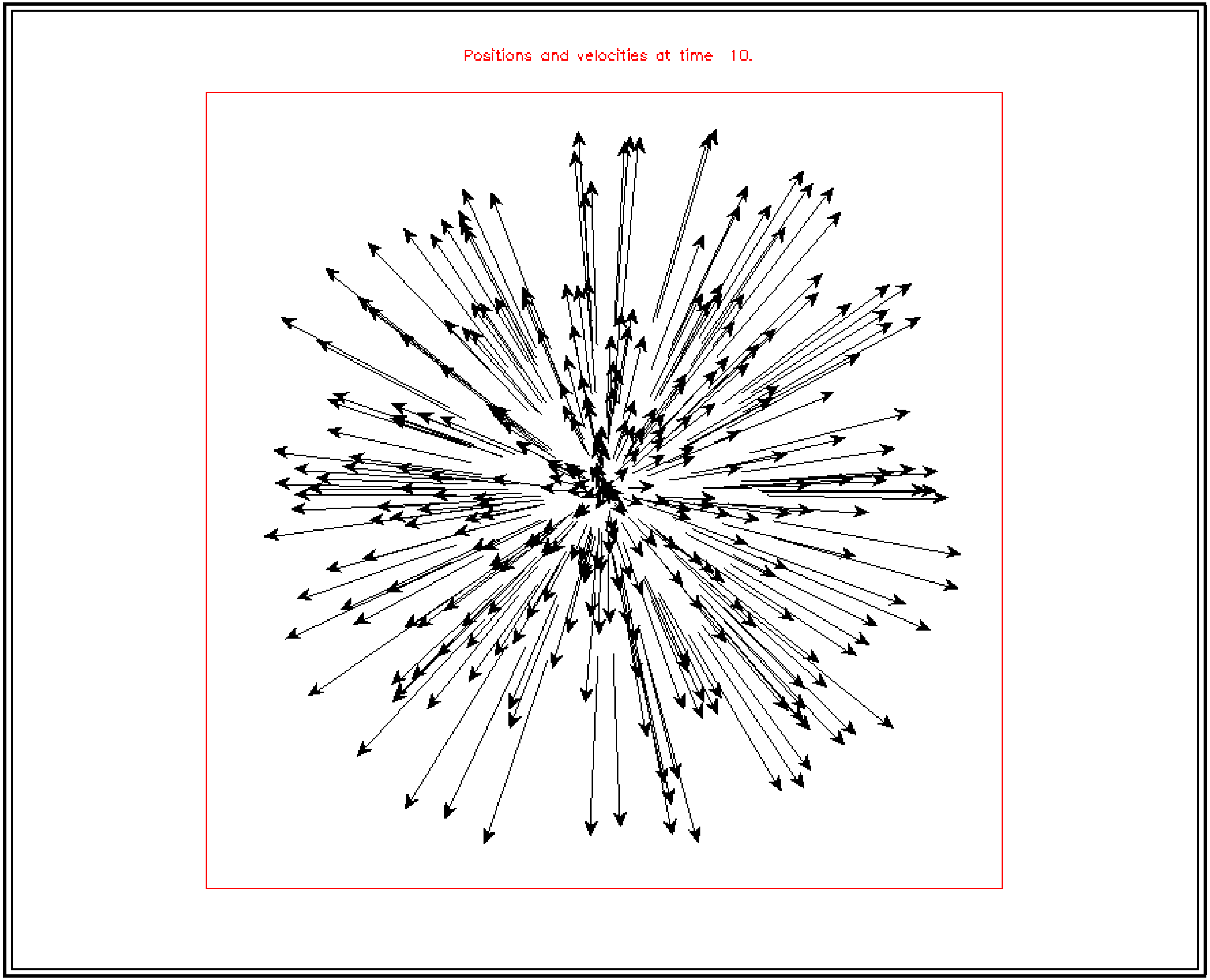
Chaos ⇒ Order in expansion: 0



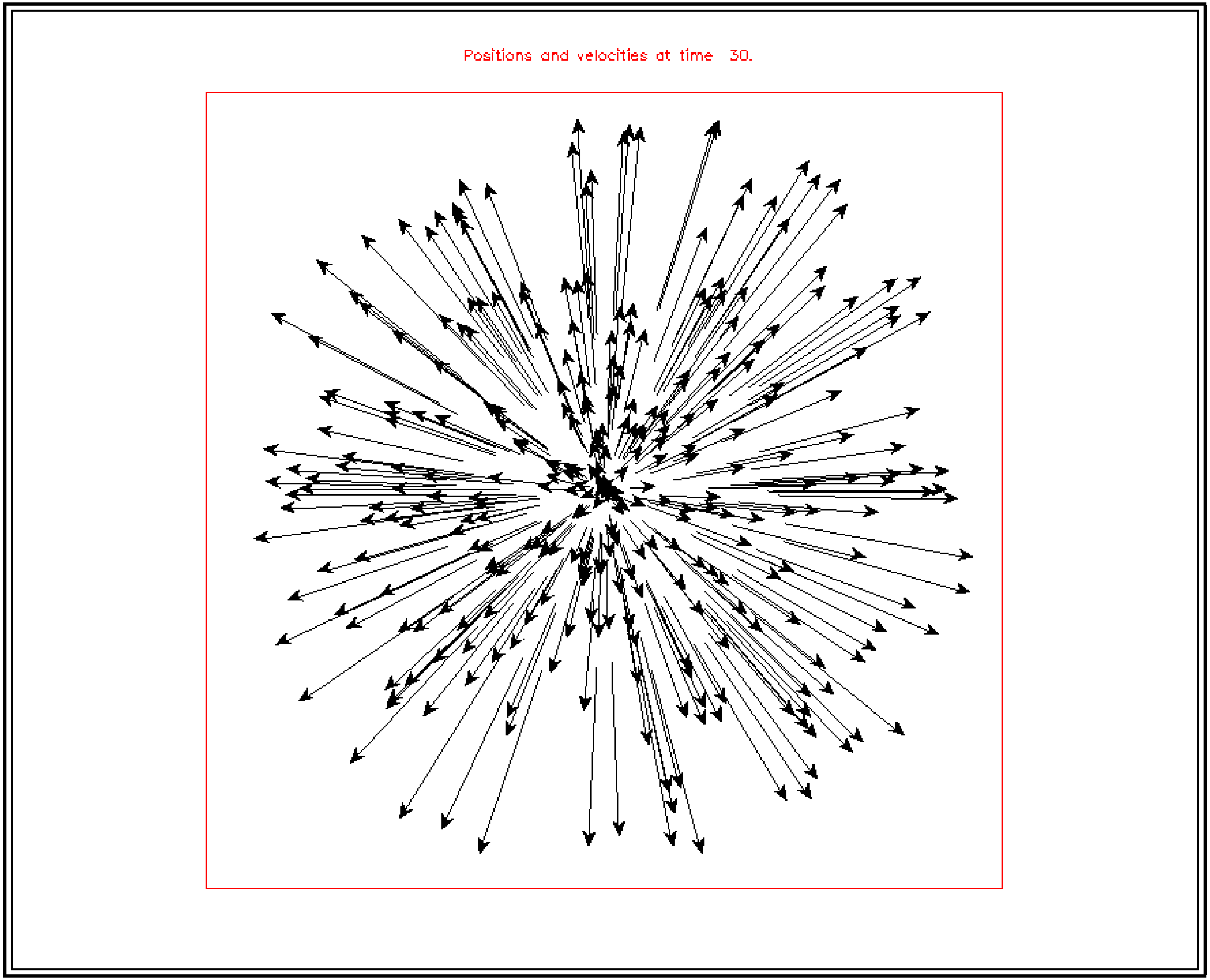
Chaos ⇒ Order in expansion: 3



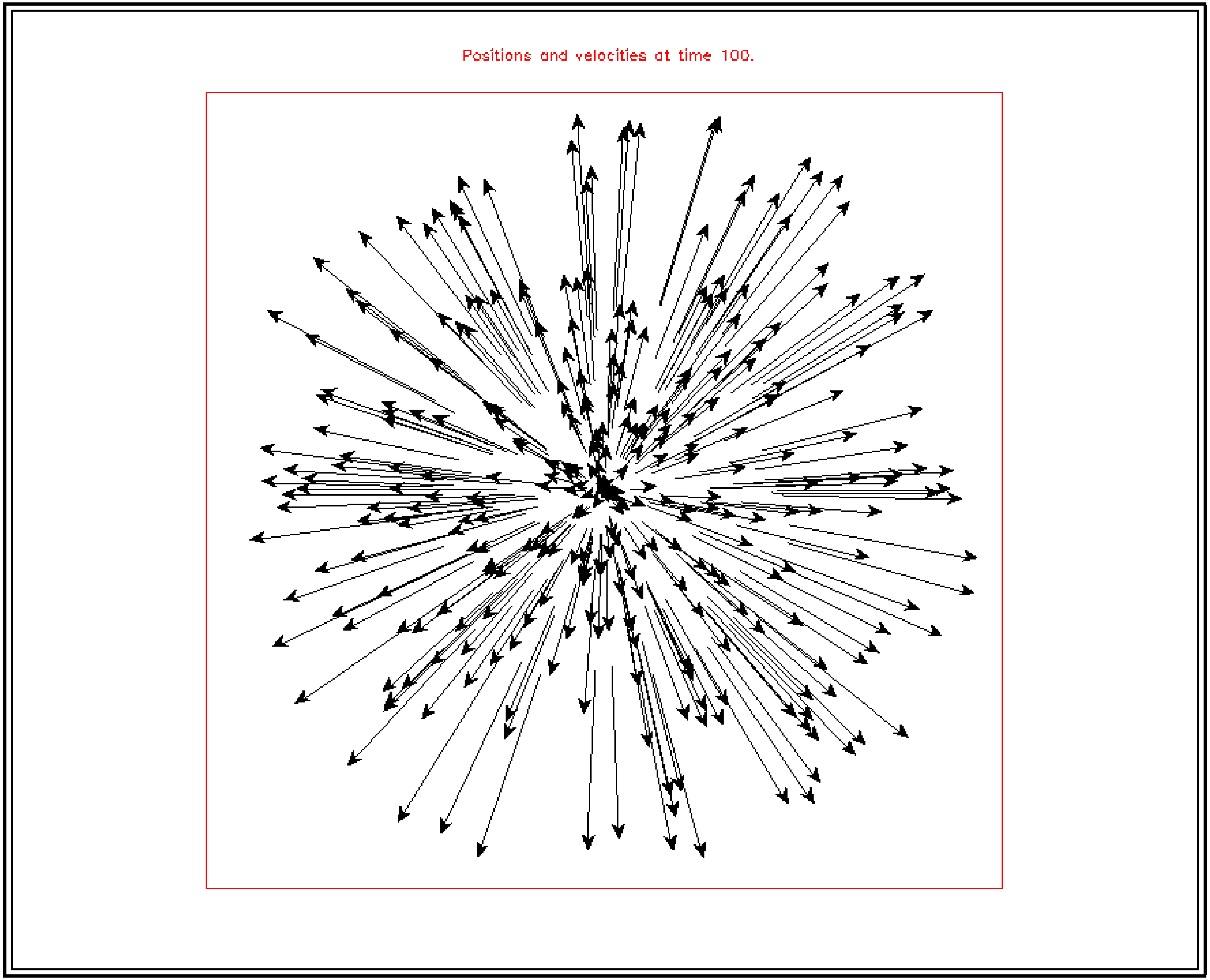
Chaos $\Rightarrow$ Order in expansion: 10



Chaos ⇒ Order in expansion: 30

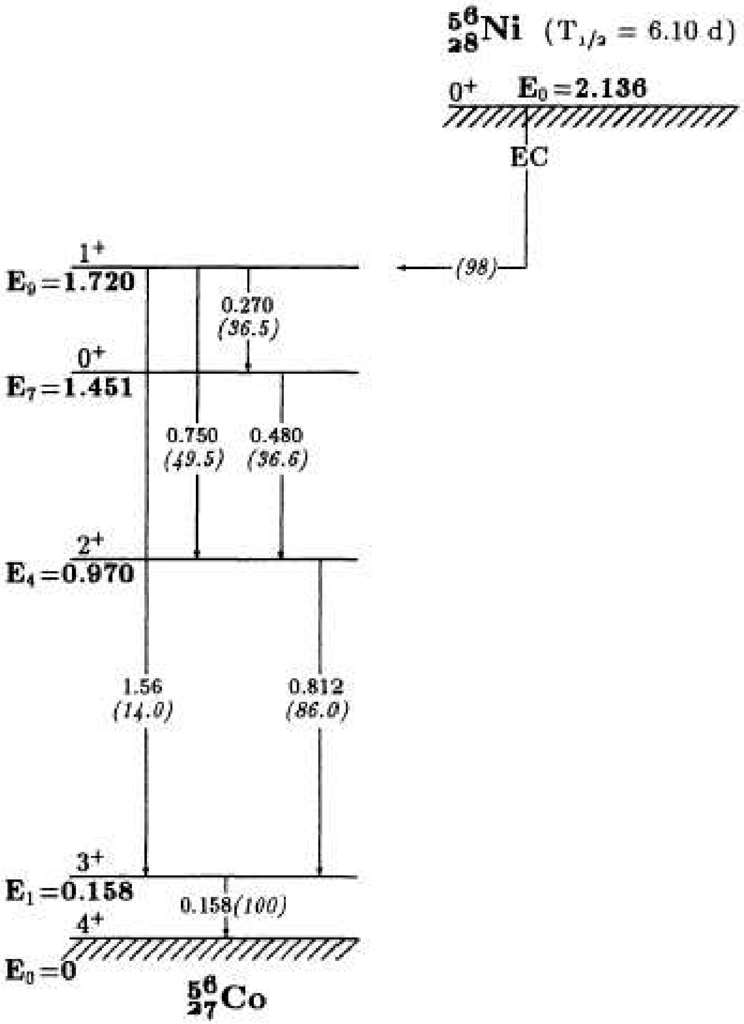


Chaos ⇒ Order in expansion: 100



Sources of photons in SN I

radioactive decays ^{56}Ni$\rightarrow$ ^{56}Co (following Nadyozhin)



Sources of photons in SN I

radioactive decays ^{56}Co$\rightarrow$ ^{56}Fe

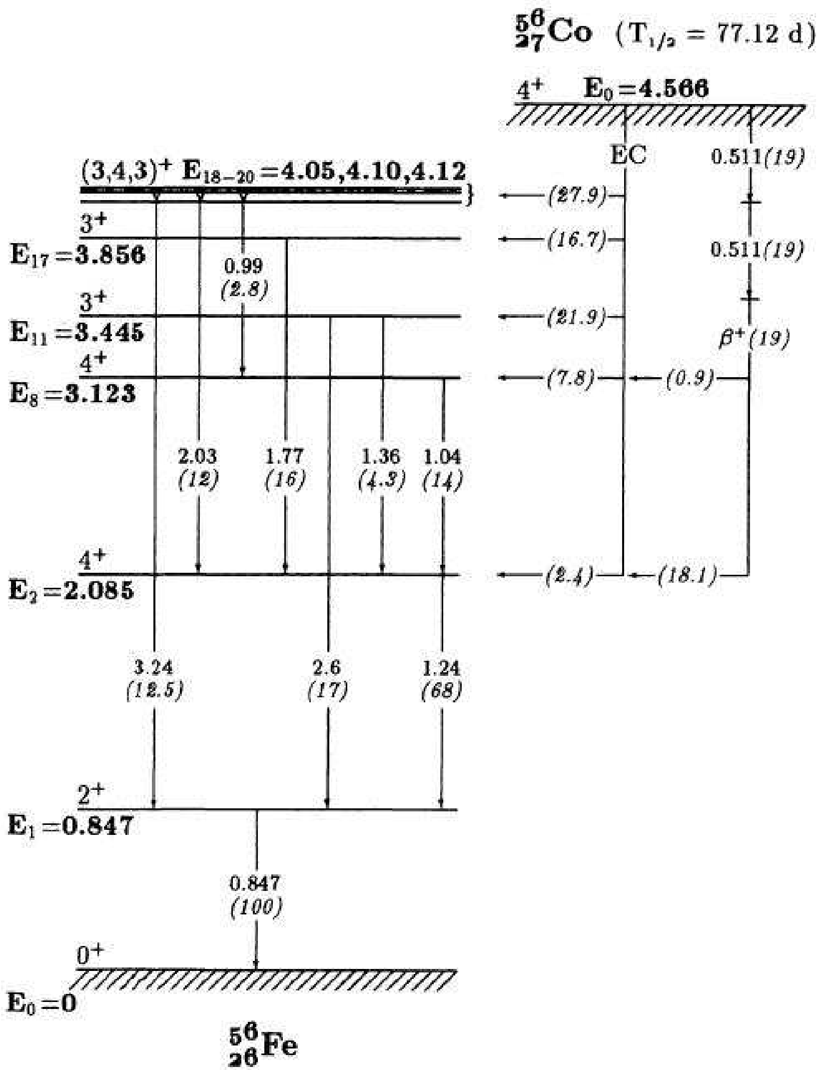


FIG. 2.—Simplified ^{56}Co → ^{56}Fe decay scheme

Sources of entropy in SN II: Shocks

Shock inside the star remains in adiabatic phase while optical depth,

$$\frac{\delta R}{l} > \frac{c}{D},$$

where δR is the distance from the shock to the photosphere (Ohyama 1963, also Imshennik V.S., Morozov Yu.I. 1964)

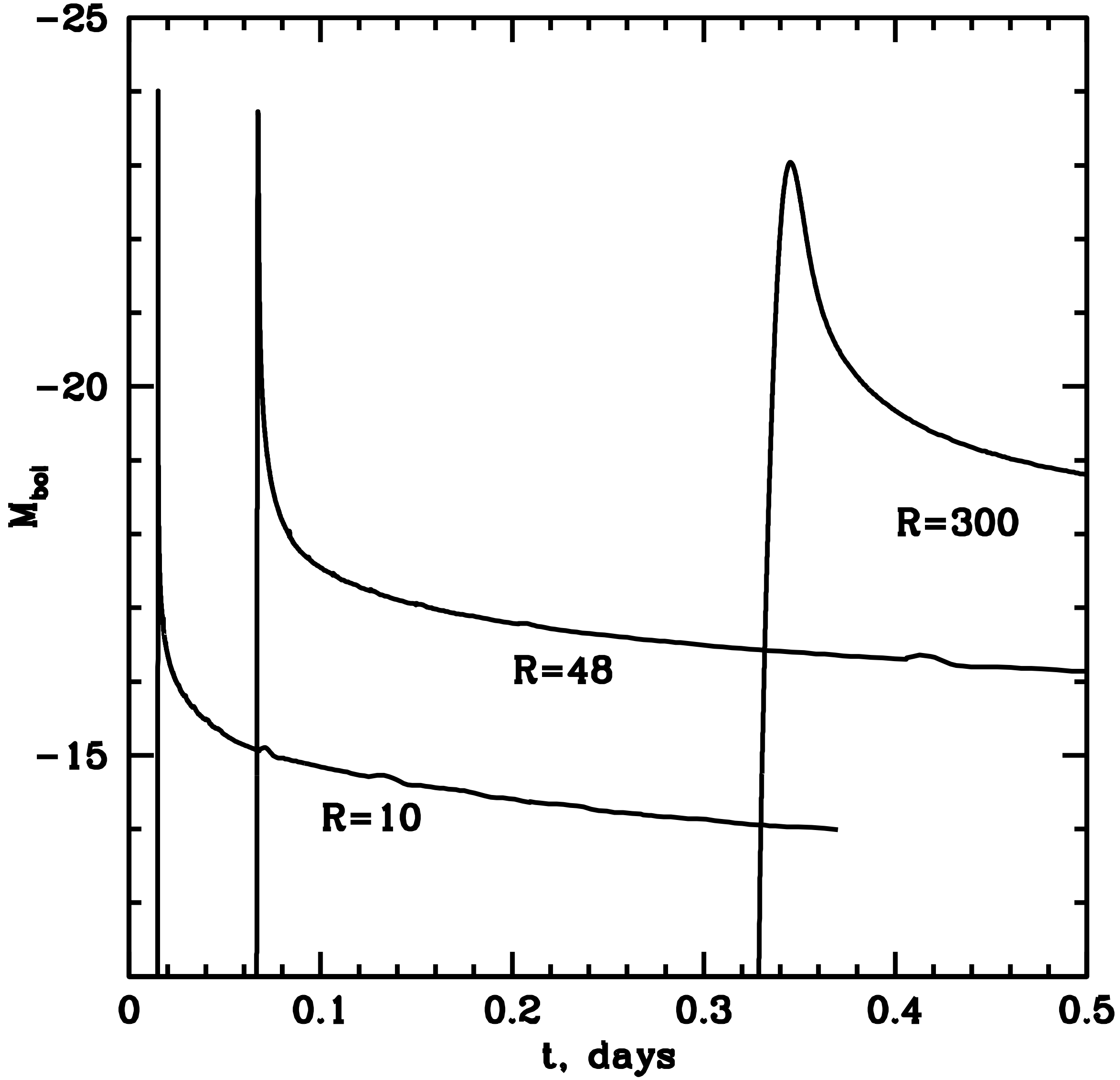
When

$$\frac{\delta R}{l} \lesssim \frac{c}{D},$$

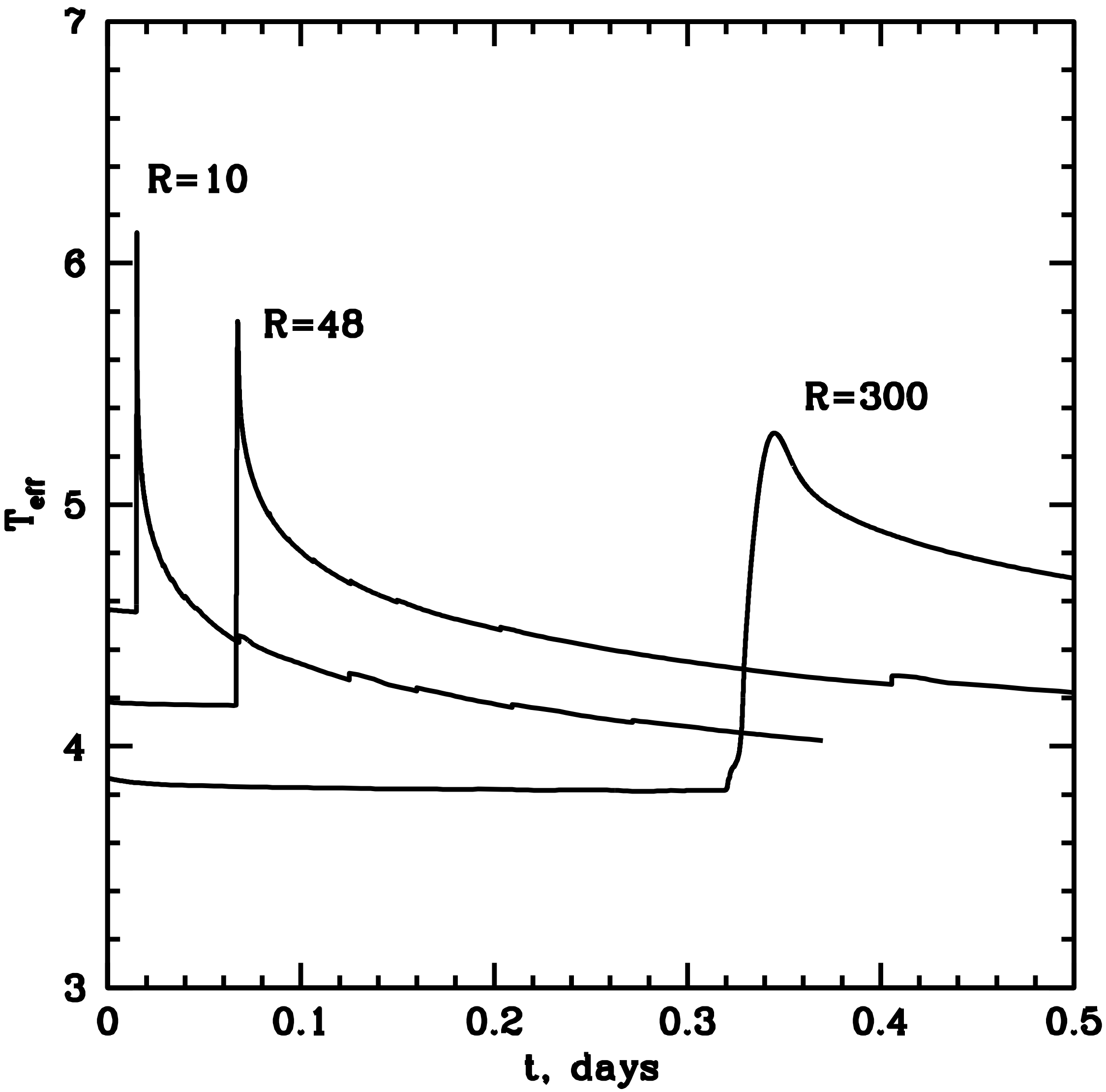
the burst of photon luminosity begins: shock break-out. The shock is highly non-adiabatic then and a density peak is built up similar to the old SNRs.

Shock Luminosity in SN II

Shocks:
Different radii at shock-breakout epoch



Shock $\lg T$ in SN II



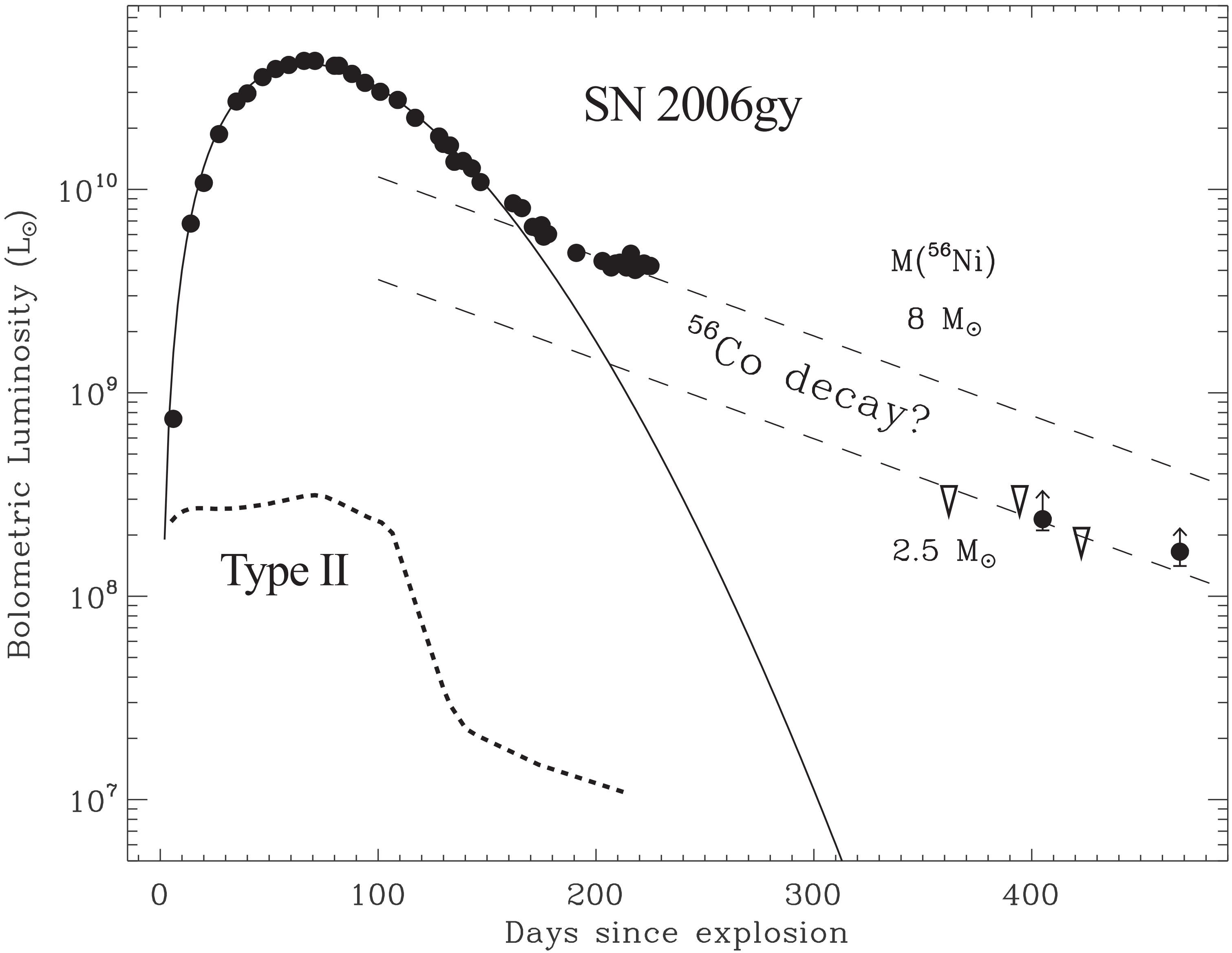
Pure diffusion models for SNIIn

The entropy produced by shock in a cloud may be used as a reservoir of photons.

If the cloud is large in radius and in mass, then high luminosity may be achieved

N.Smith: SN06gy data

Model by N.Smith & R.McCray is shown



SN II LC Theory

Imshennik, Nadyozhin & Grasberg (1964-1971)

ON THE THEORY OF THE LIGHT CURVES OF SUPERNOVAE*

E. K. GRASSBERG

Radioastronomical Observatory, Academy of Sciences Latvian S.S.R., Riga, U.S.S.R.

and

V. S. IMSHENNIK and D. K. NADYOZHIN

Institute of Applied Mathematics U.S.S.R. Academy of Sciences, Moscow, U.S.S.R.

(Received 1 June, 1970)

Huge PreSN LC

Imshennik and Nadyozhin, 1964).

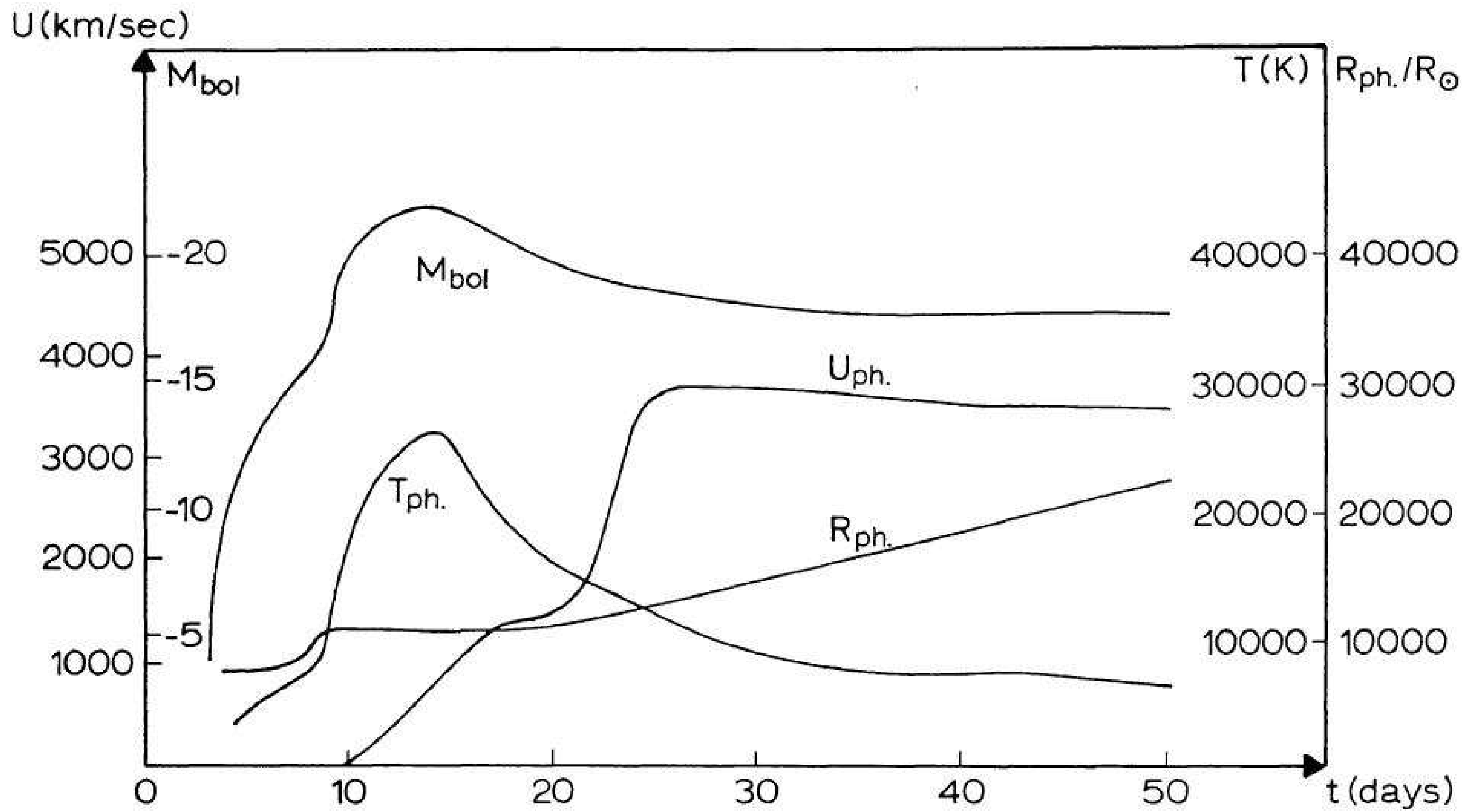


Fig. 10. The extensive Model No. 5, $R_0 = 10000\ R_{\odot}$, $M_0 = 30.9\ M_{\odot}$.

Blinnikov & Popov 1993

advancing Arnett's analytical theory

Astron. Astrophys. 274, 775–784 (1993)

Analytic models for low-mass supernovae of type II

S.I. Blinnikov[1,2] **and D.V. Popov**[1]

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E-mail: blinnikov at vxitep.itep.msk.su and dvpopov at vxitep.itep.msk.su
[2] Max-Planck-Institut für Astrophysik, Karl-Schwarzschild-Strasse 1, W-8046 Garching b. München, Germany

Received August 11, accepted December 20, 1992

Blinnikov & Popov 1993

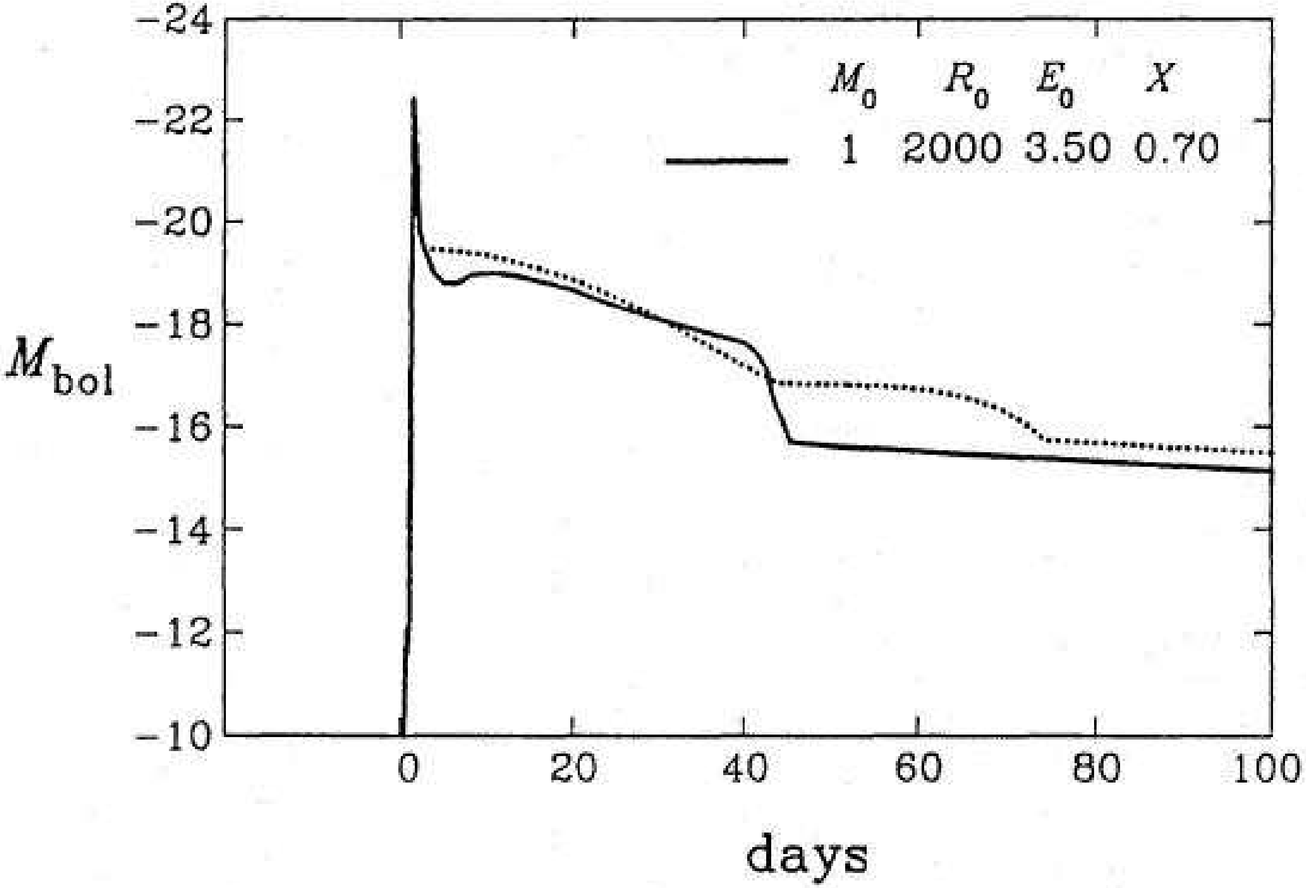
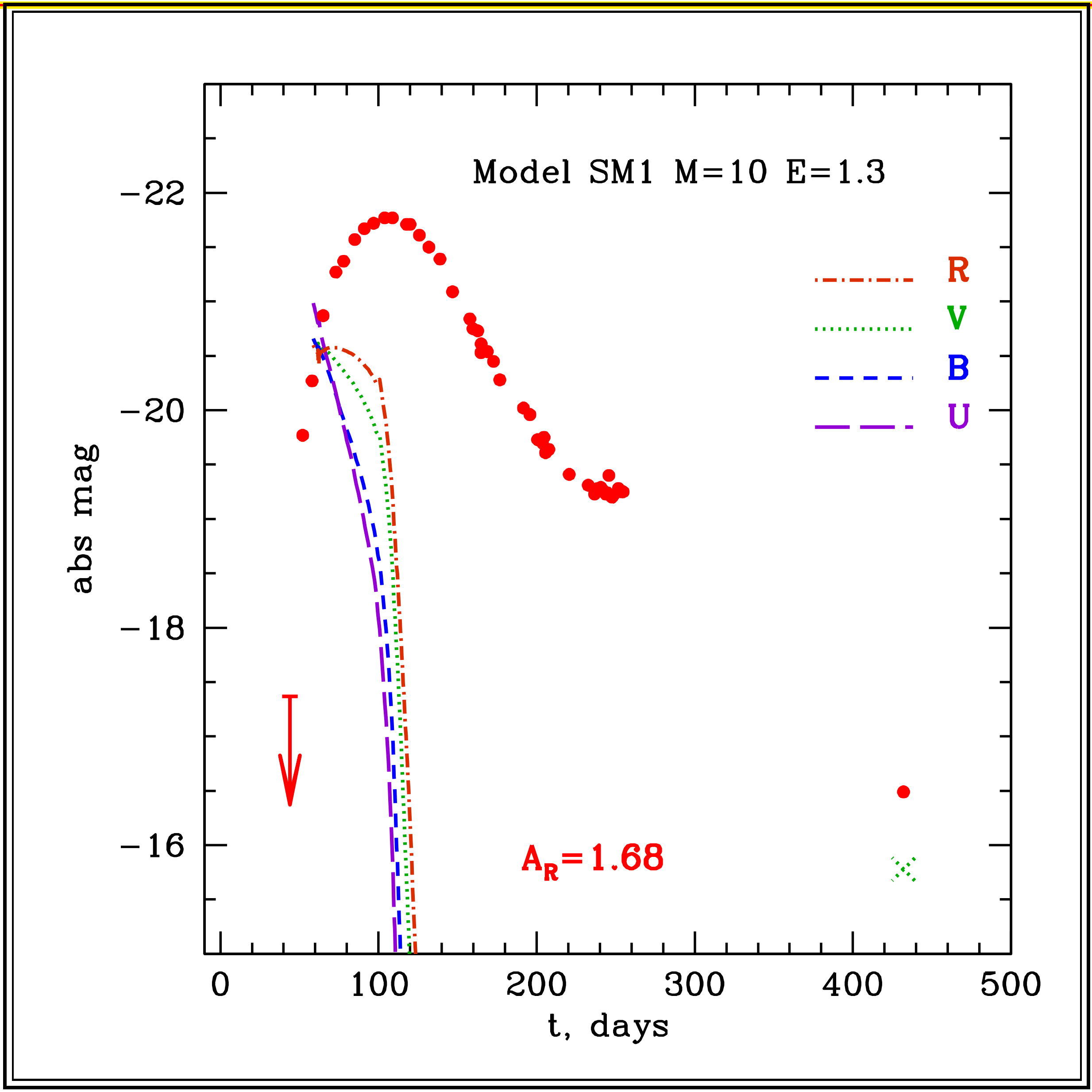
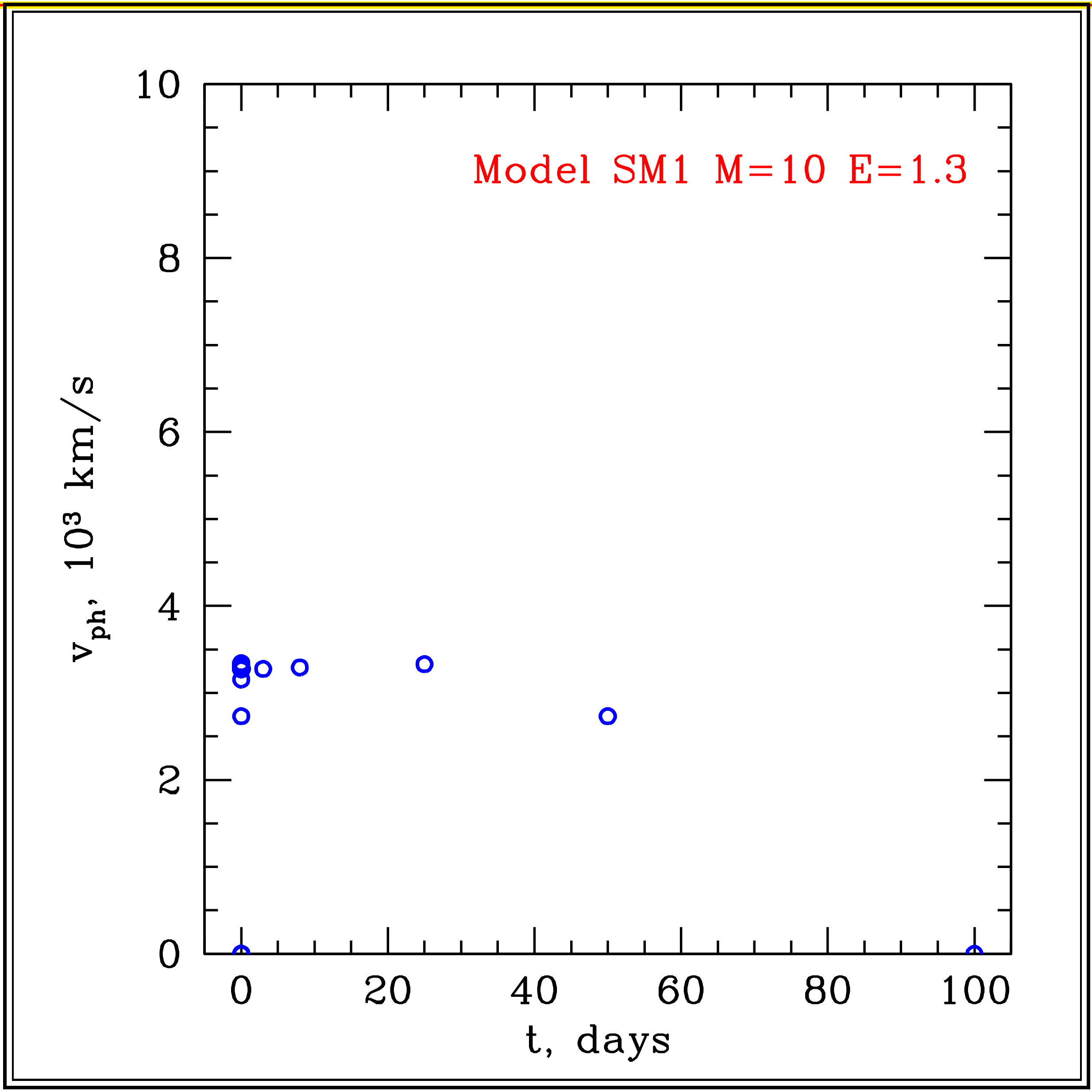


Fig. 5. Comparison of $M_{\rm bol}(t)$ from analytic (dots) and numerical (solid line) solutions: with the mass of ^{56}Ni equal to 0.078 $M_\odot$ in the same model as in Fig. 4

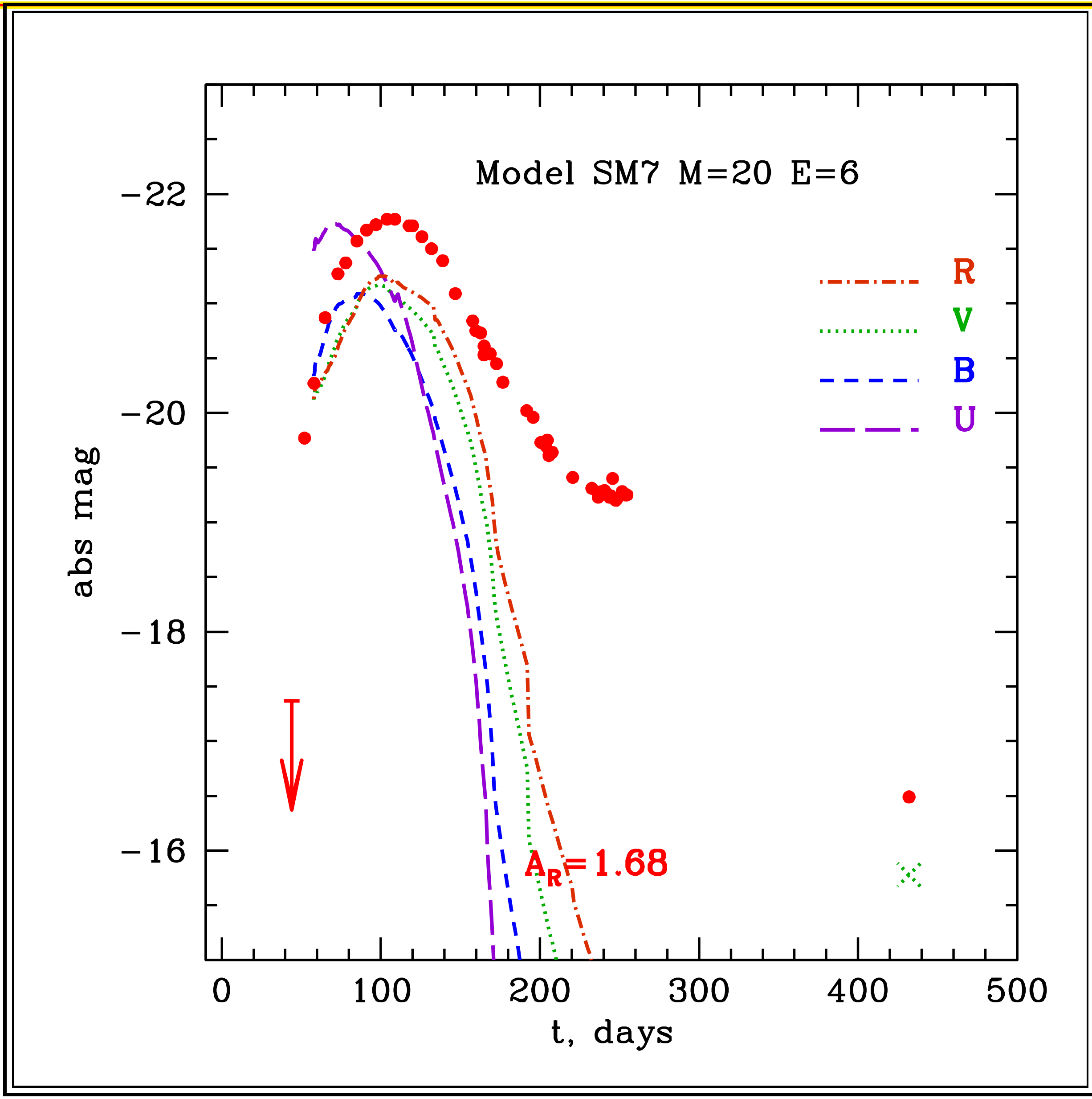
Light Curve Smith McCray 1



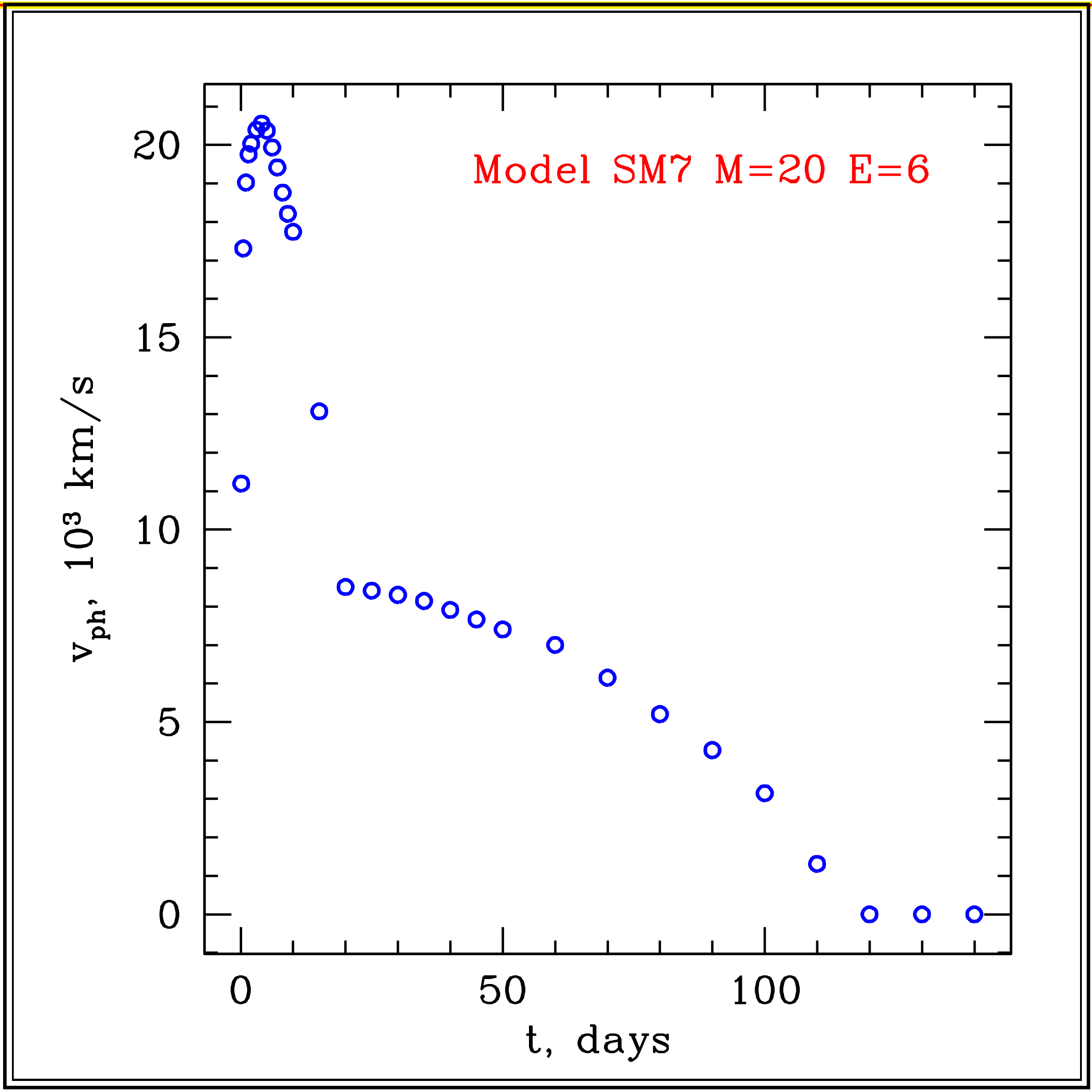
Photoph. speed SM 1



Light Curve Smith McCray 7



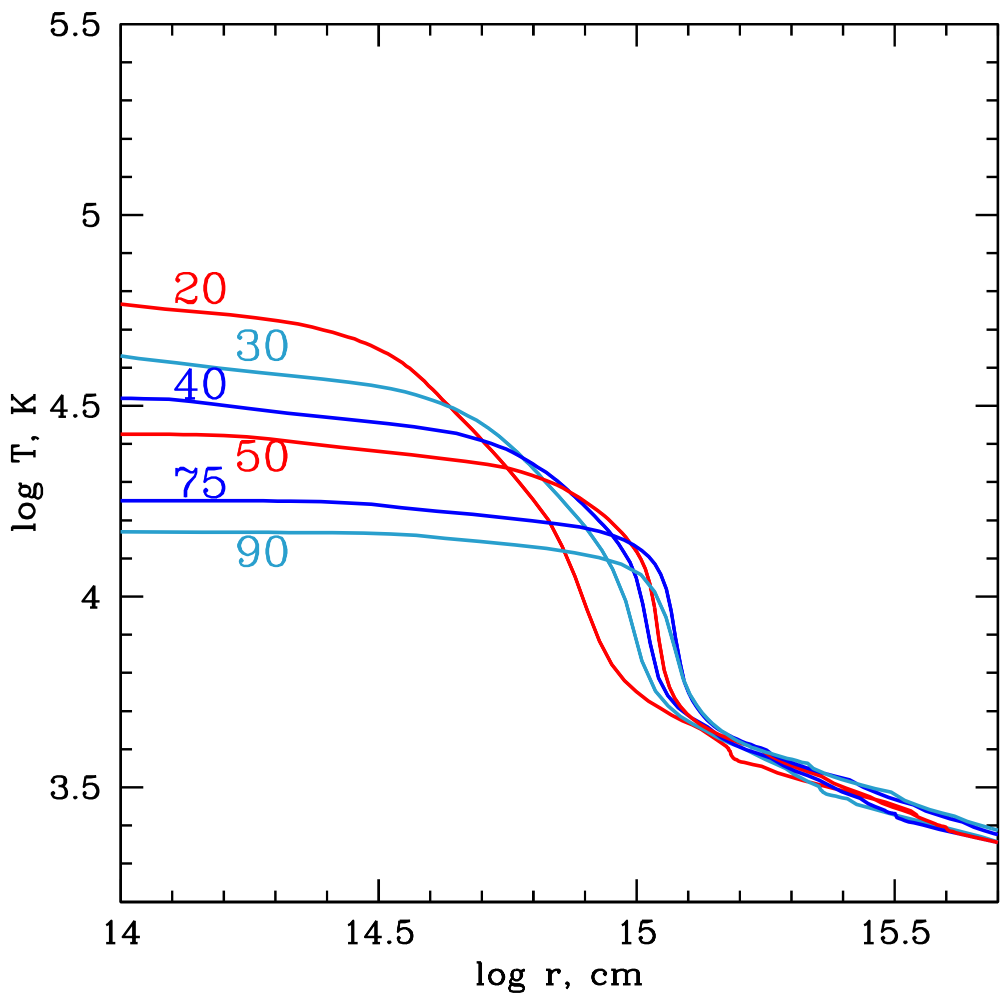
Photoph. speed SM 7



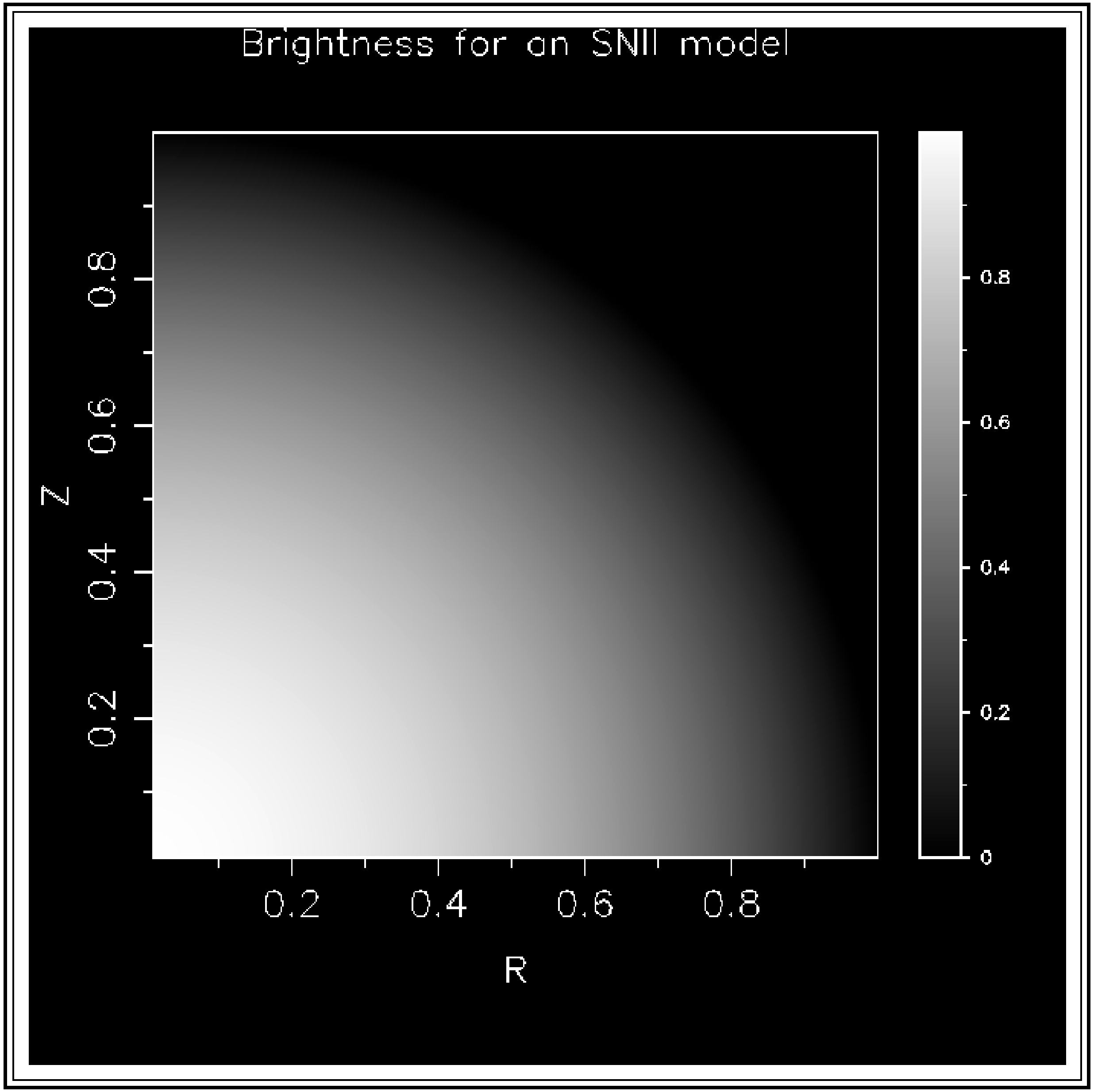
Type IIP photosphere

almost at rest - not much expanding in R

Recombination front moving inside in M_r



‘Visible’ disk of SN IIP

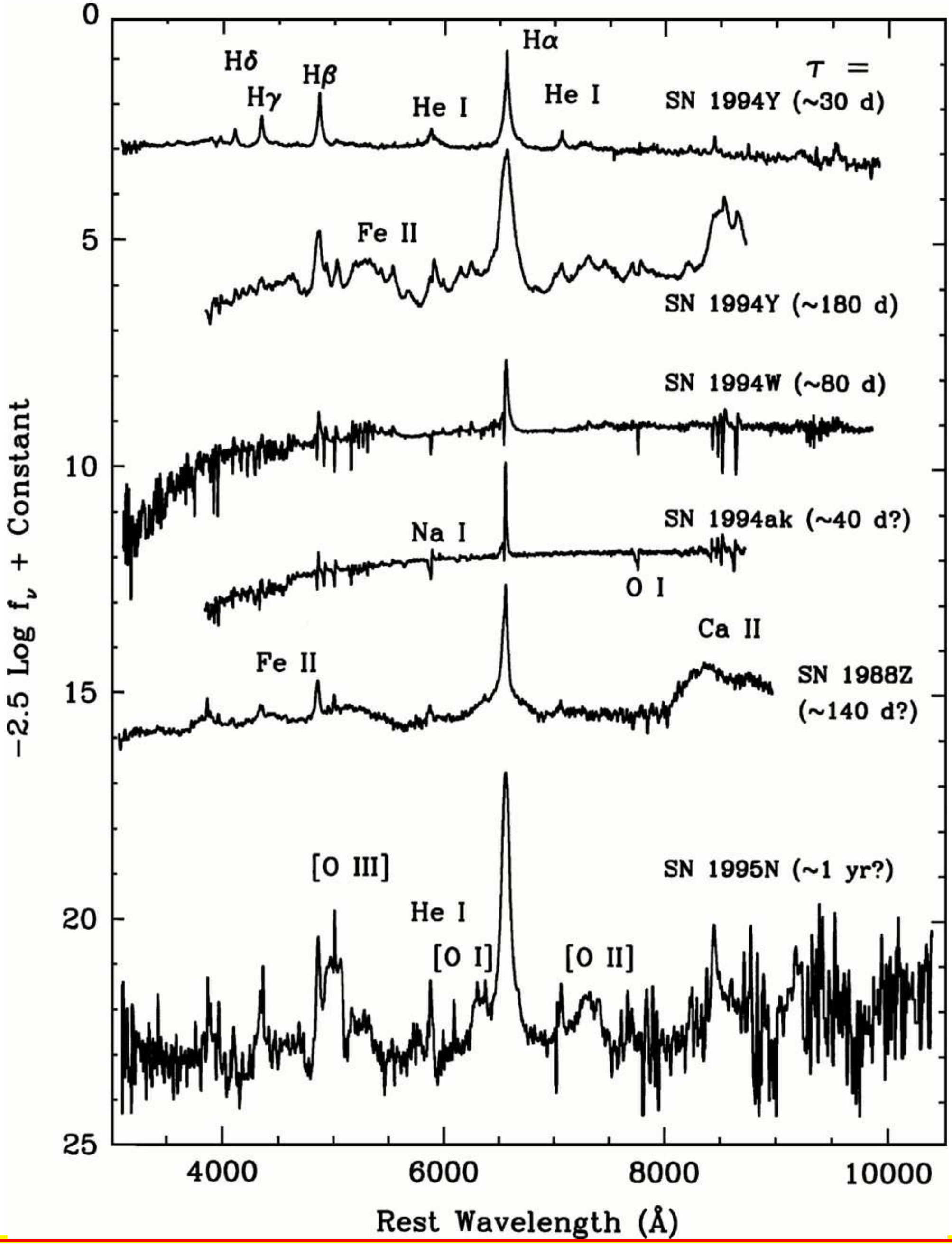


Difficulties of diffusion models

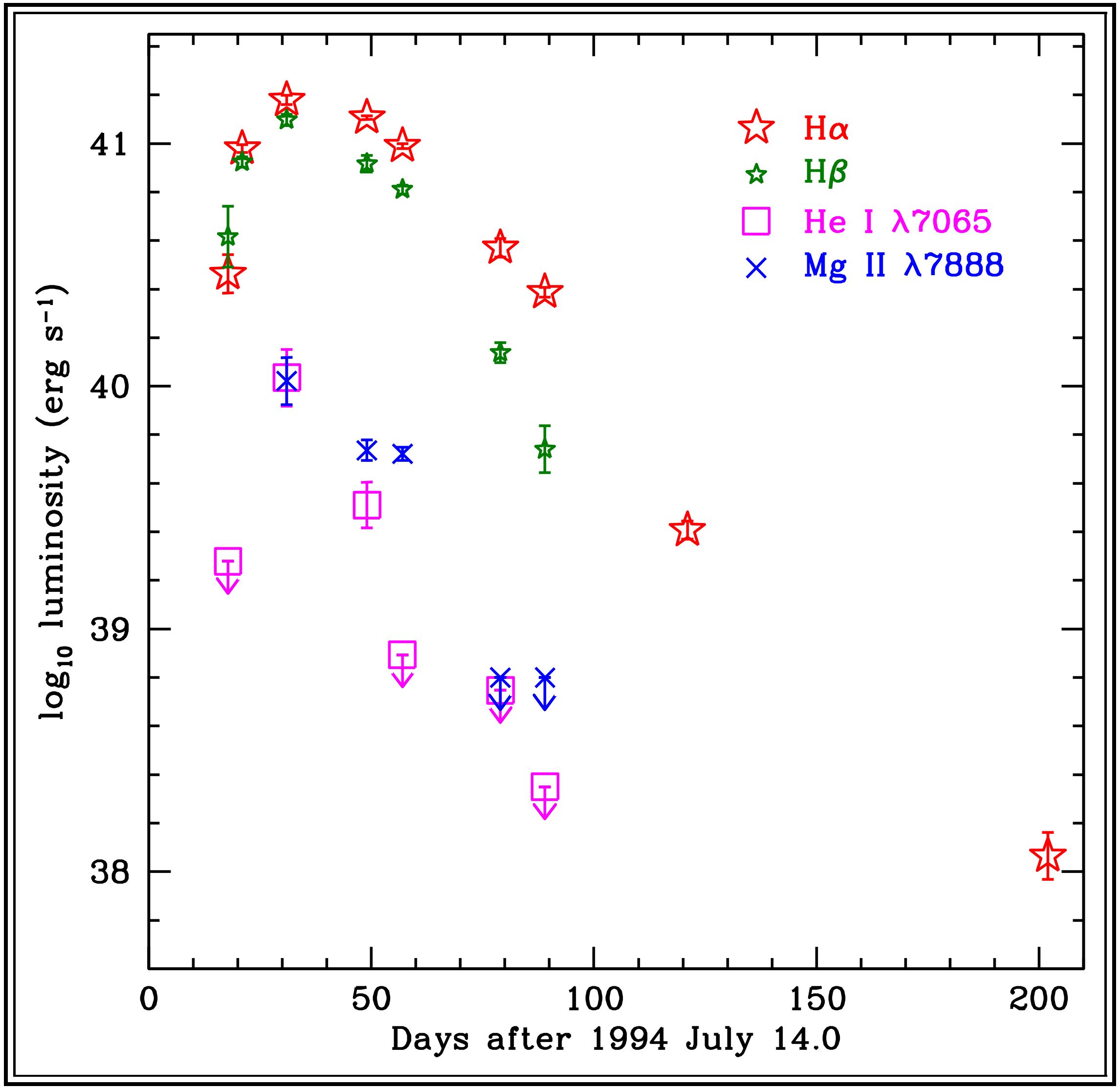
High luminosity leads to a cooling wave – the evolution of light and photospheric velocity is too fast for SN 2006gy.

If the cloud is large in radius and in mass, a strong shock is radiative and degenerates into a thin shell: initial heating must be done by a mysterious source of heating uniformly distributed throughout the cloud

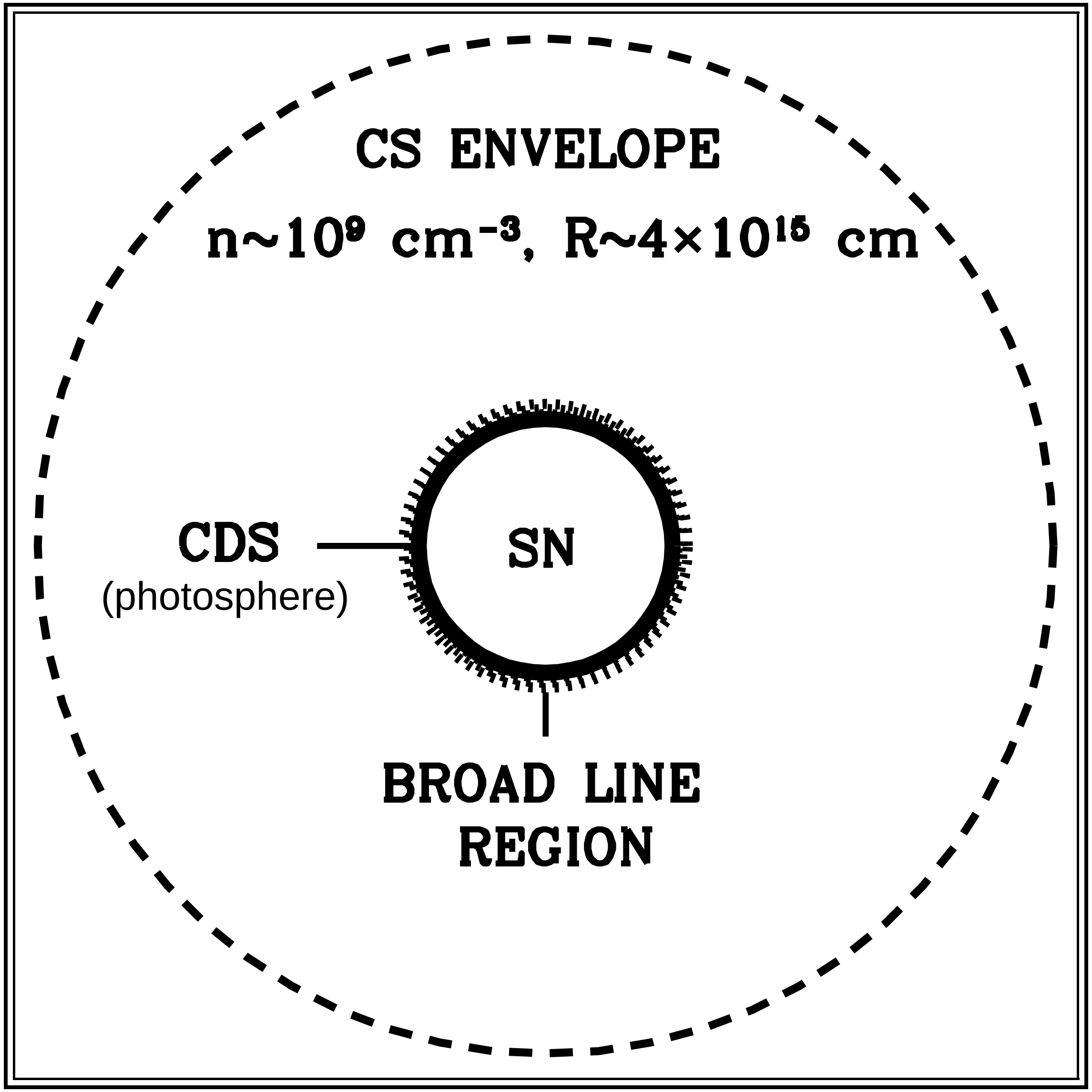
SN IIn: the brightest light



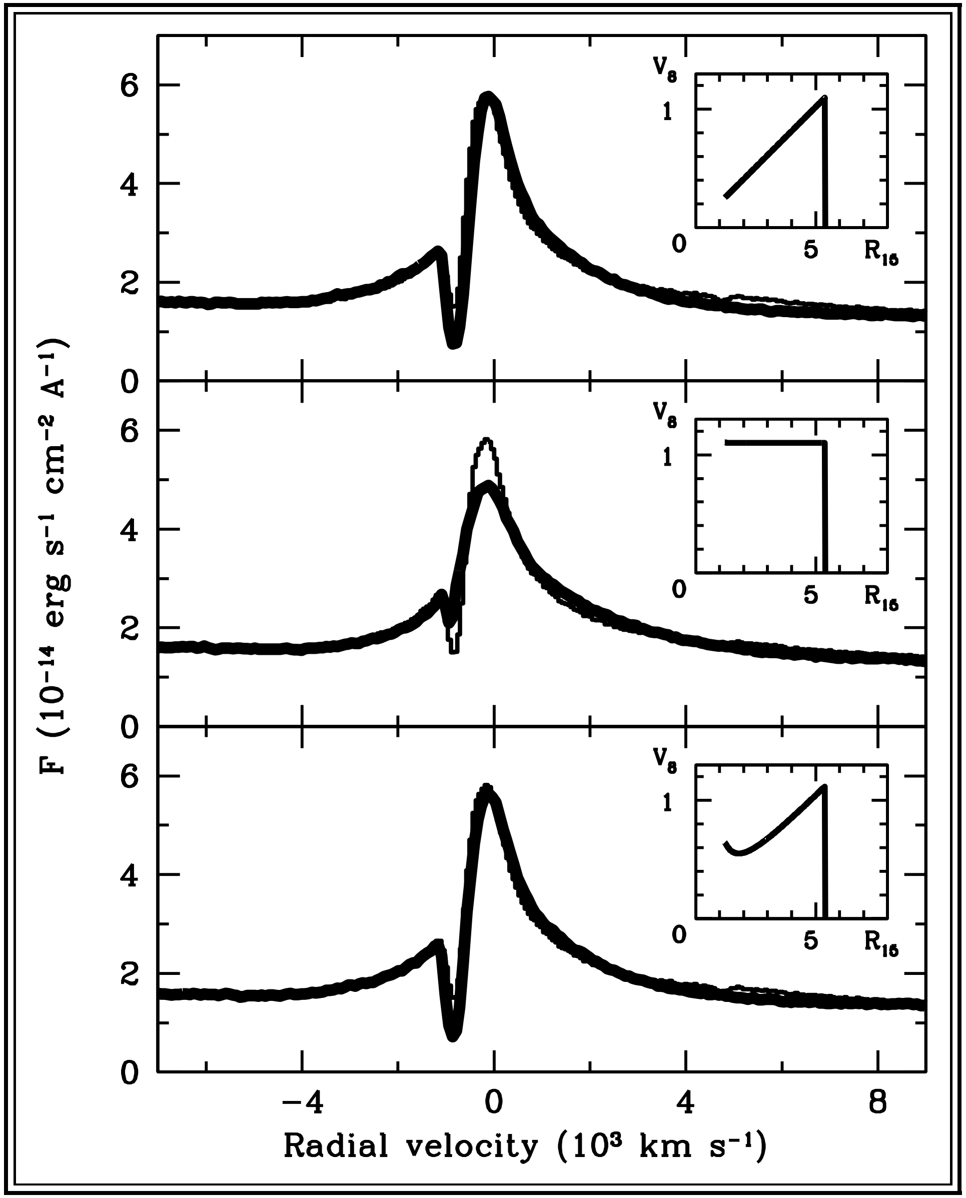
SN 1994W line power



SN1994W & SN2006gy structure

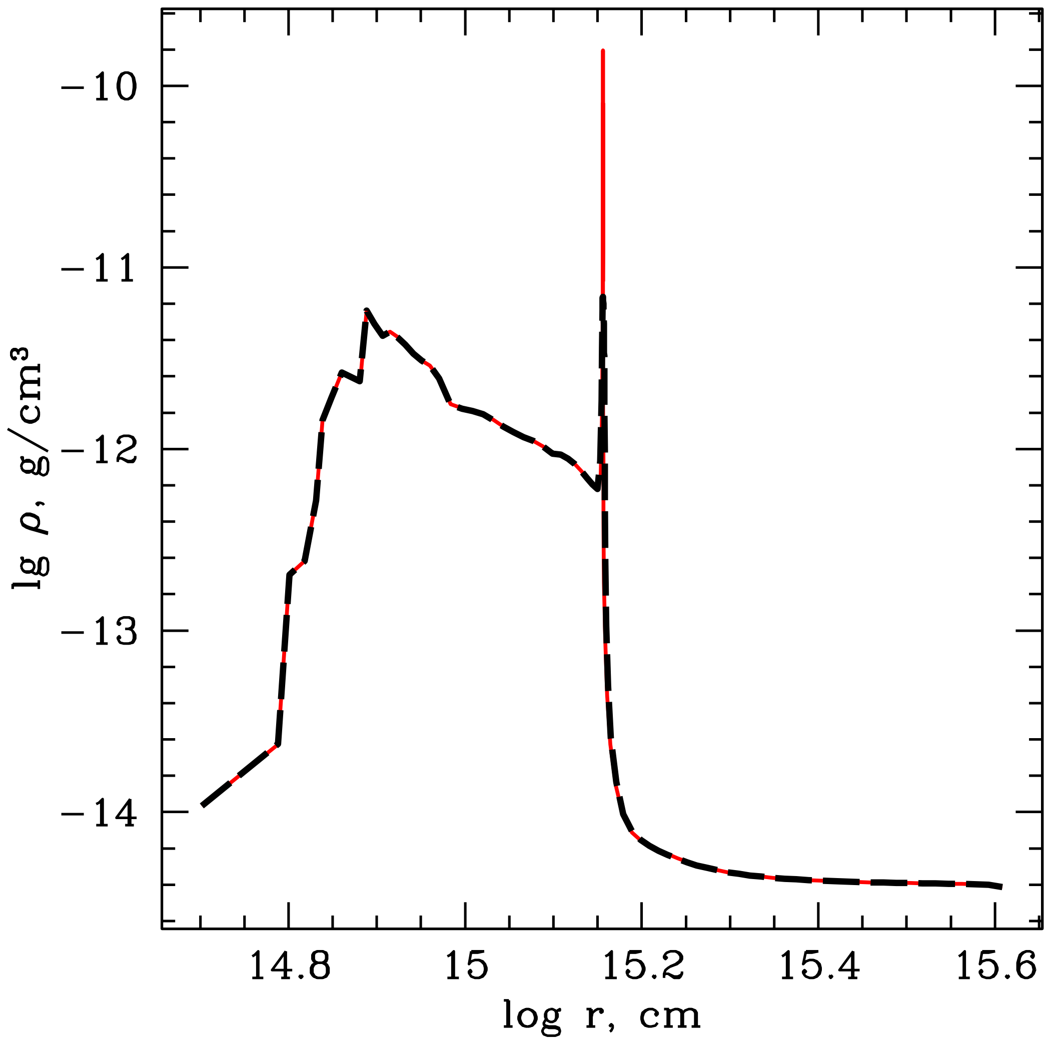


SN 1994W line profile models



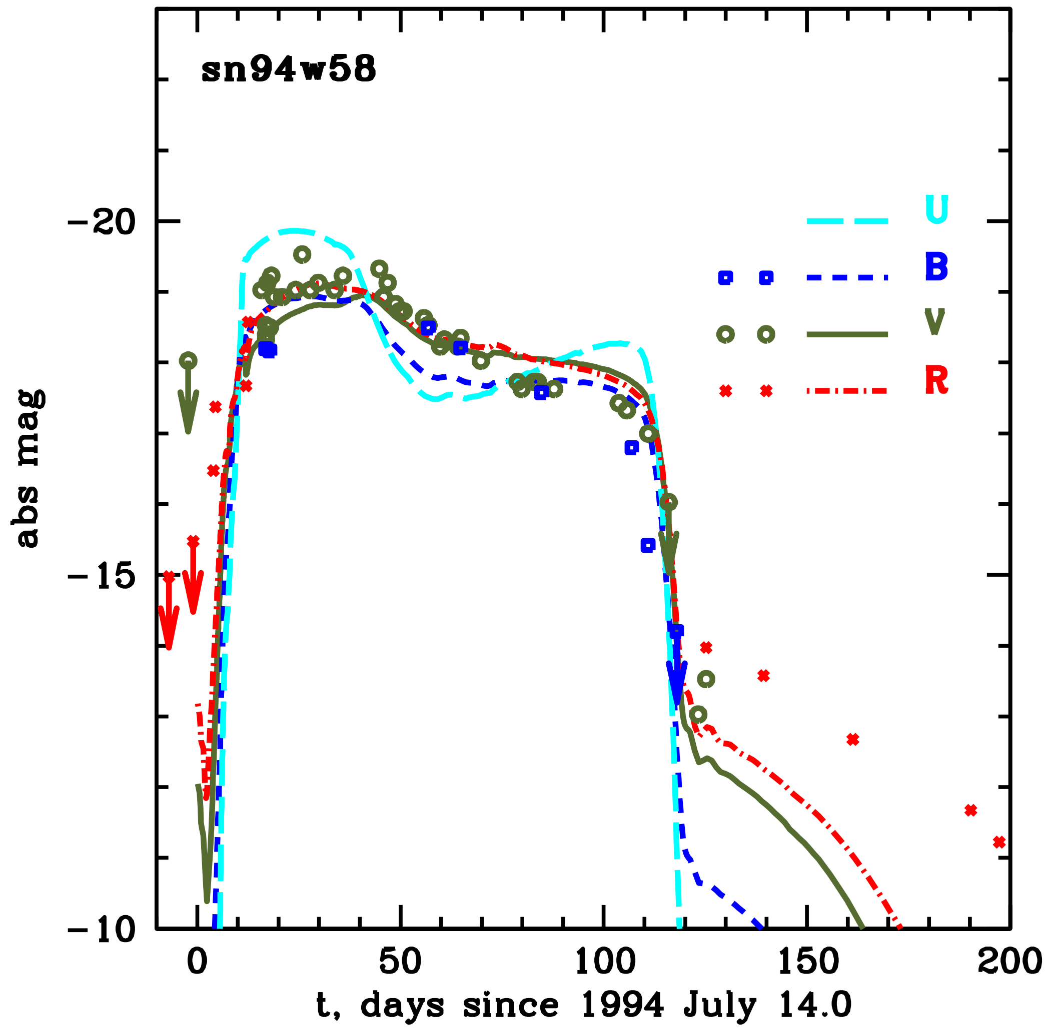
Shocks in SNe IIn

A long living shock: an example of SN1994w of type IIn. Density as a function of the radius r in two models at day 30. The structure tends to an isothermal shock wave.



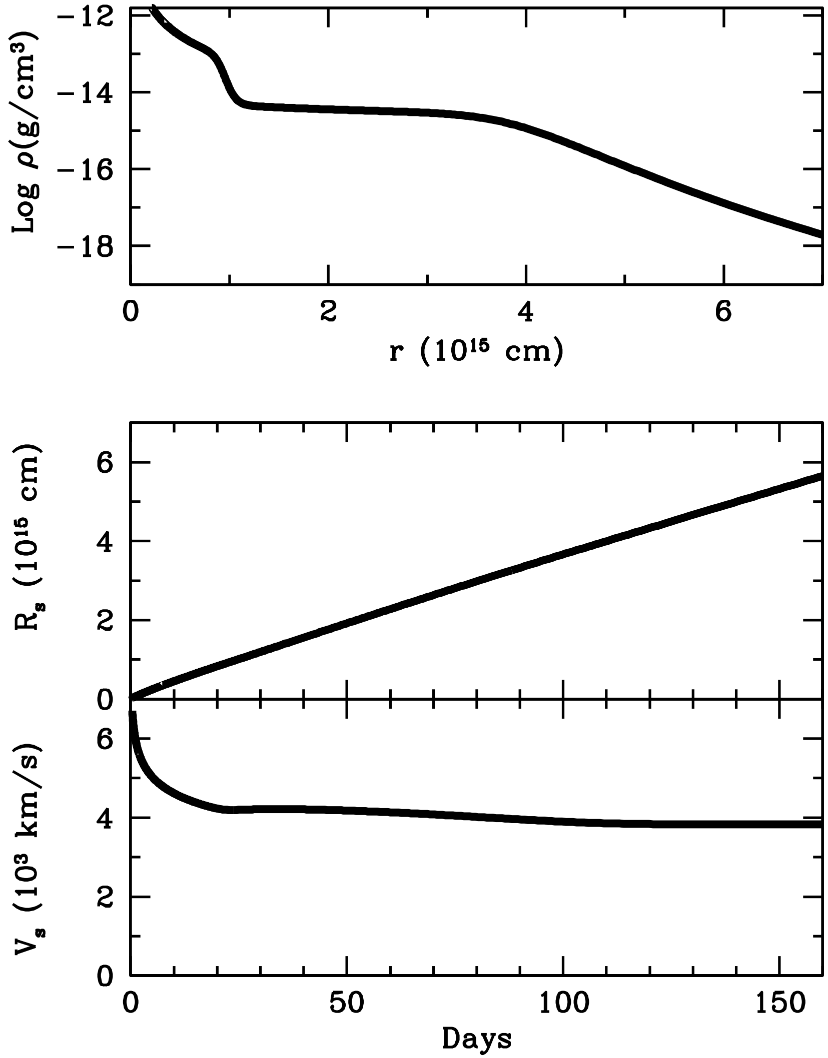
Light Curve SN 1994W

Light curves for the run sn94w58. Fluxes in BV filters converge - contrary to SN II, a good feature to distinguish SN IIn before spectroscopic observations.

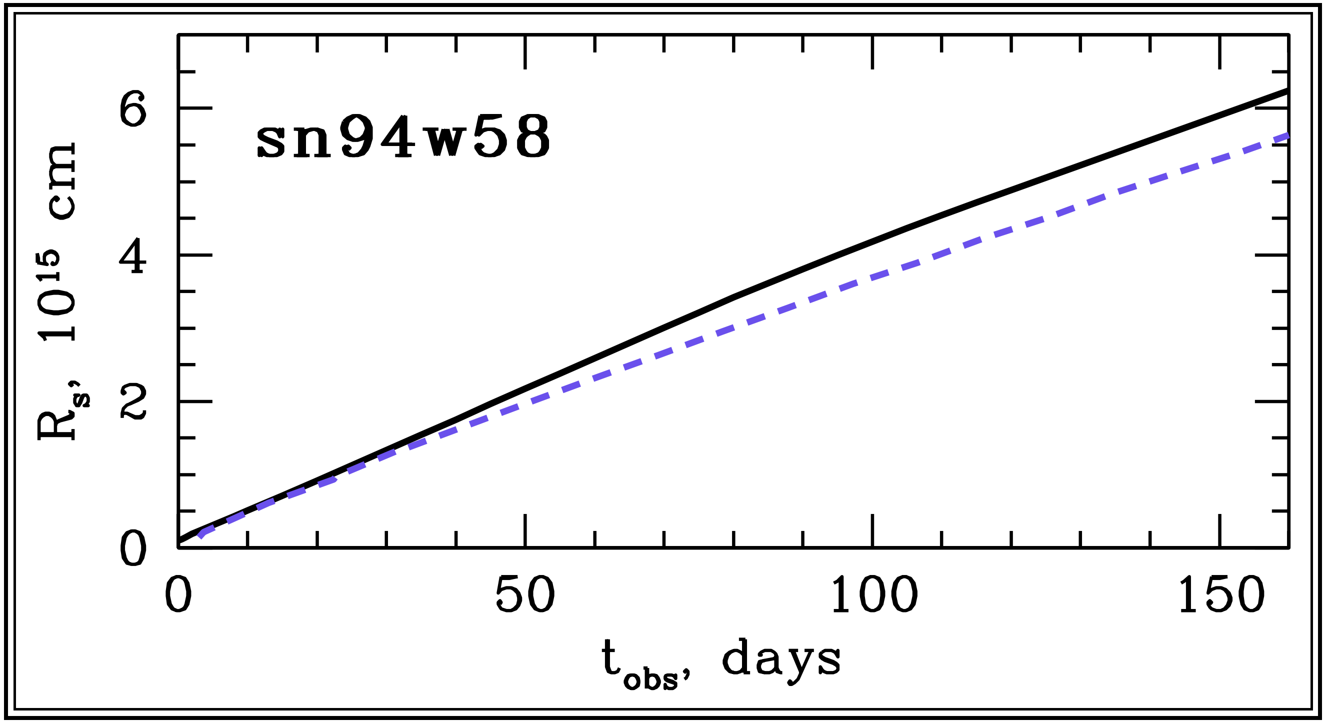


Spectrum modeling $R(t)$

Chugai's kinematic model The CS density (*top panel*) and evolution of the radius and velocity of the cool dense shell (*two bottom panels*)

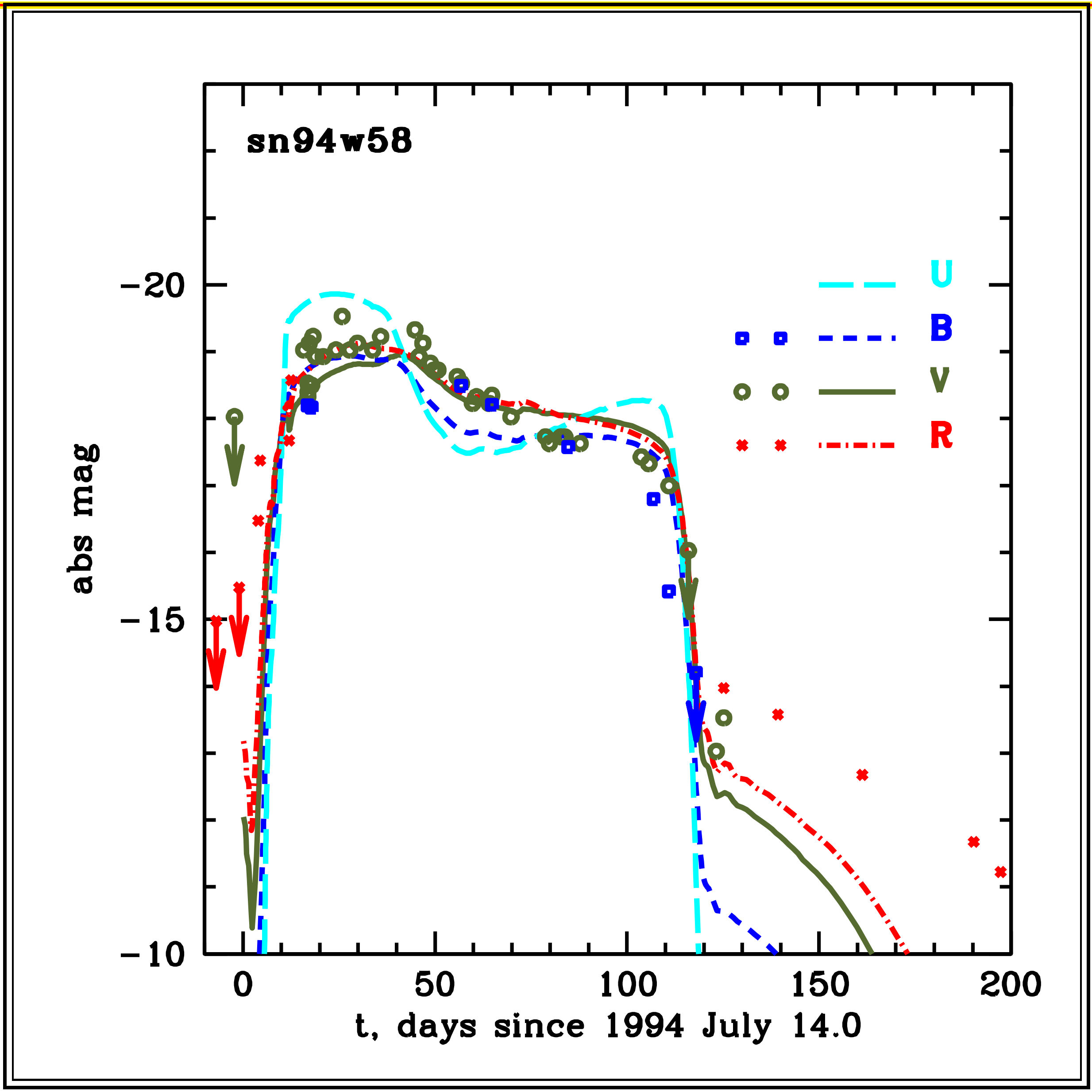


On the same plot

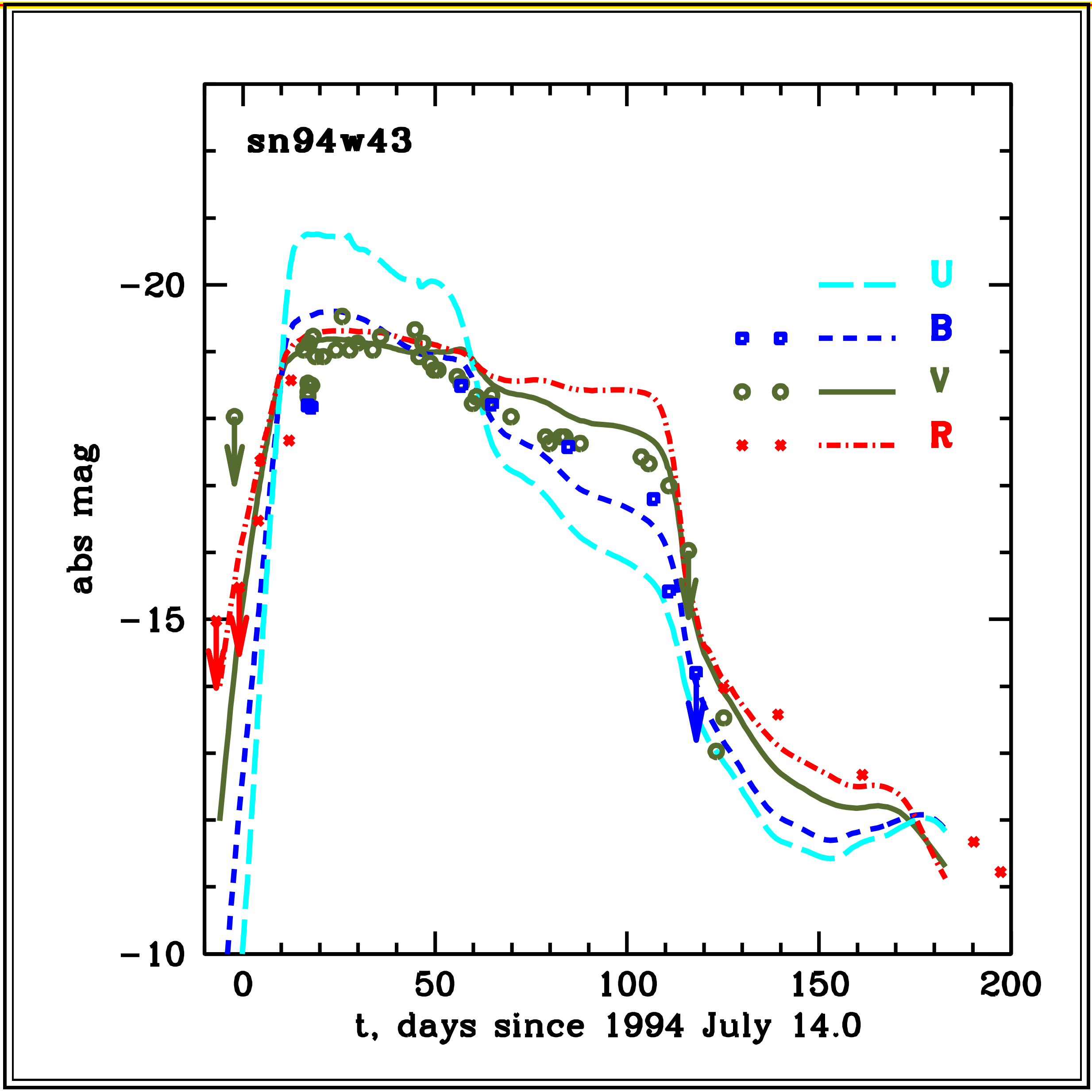


Broken line is from spectra, solid – from hydro LC model.

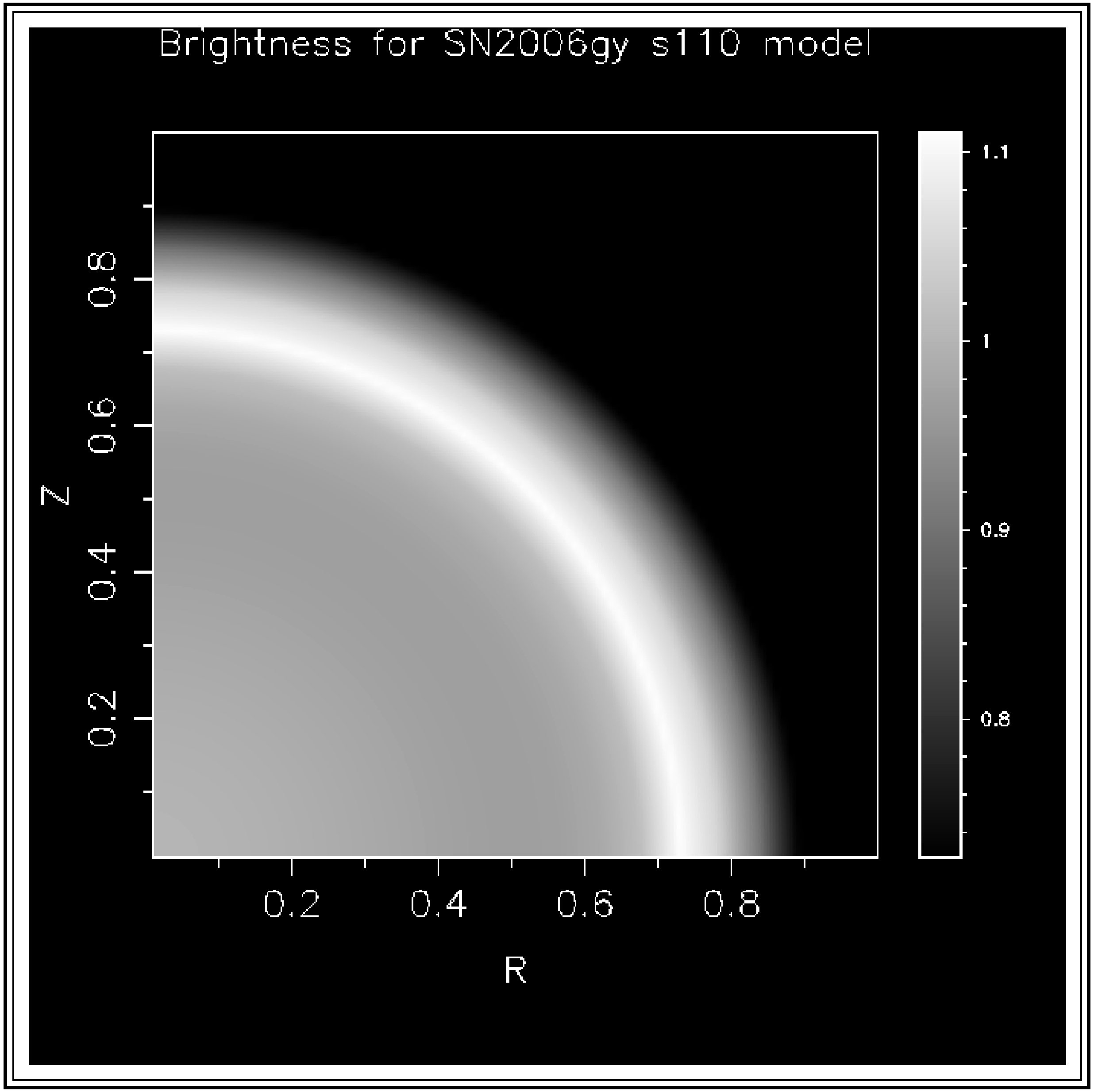
Light Curve SN 1994W



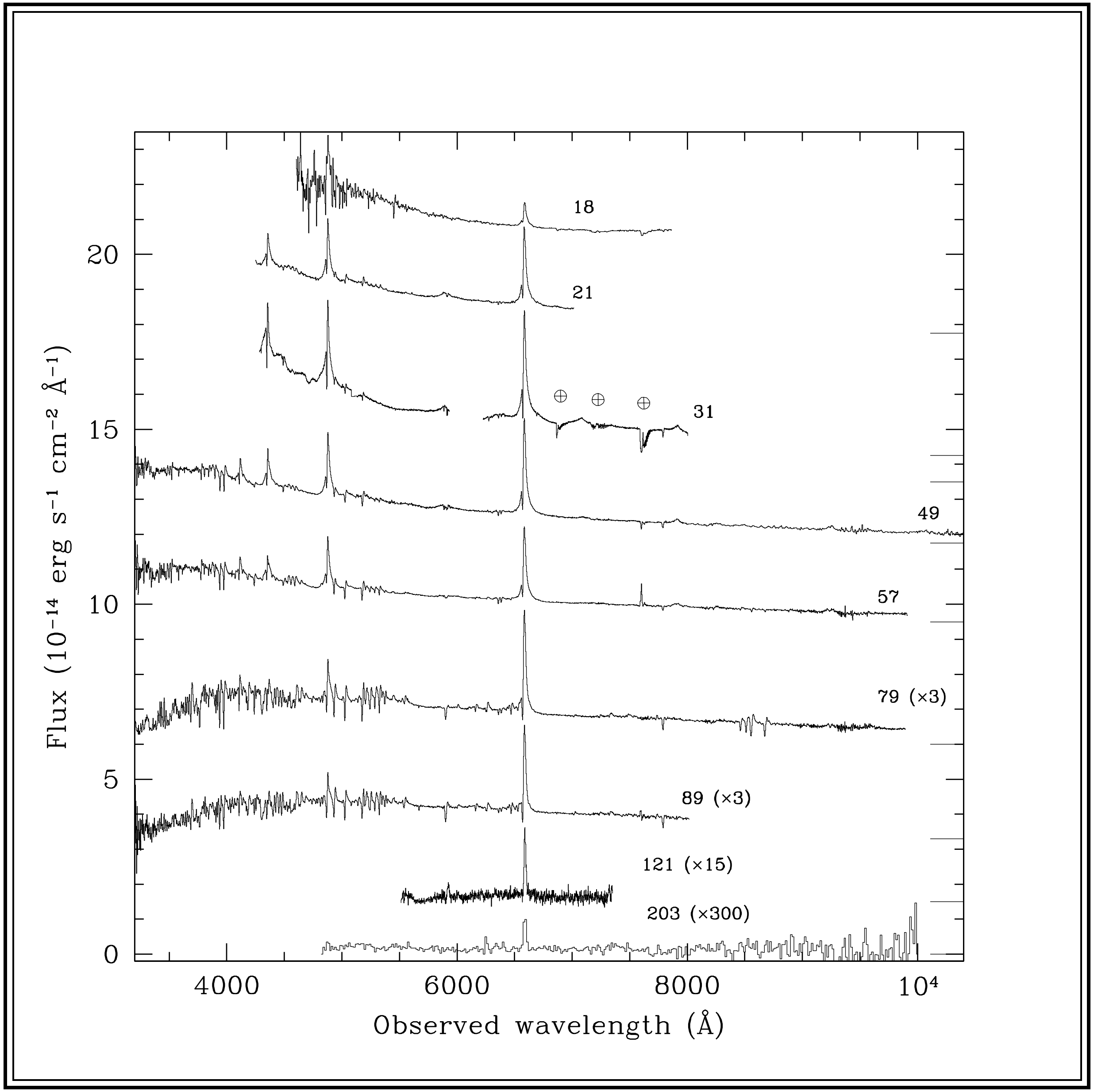
Light Curve b SN 1994W



‘Visible’ disk of SN IIn



Observed spectrum of SN 1994W

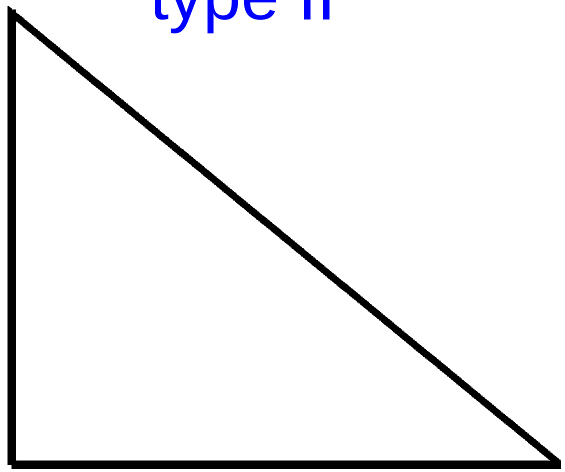


SN Light Source

Cooling

type II

no source of S



Permanent heating

by shock

type IIn

Fading heating

by radioactivity

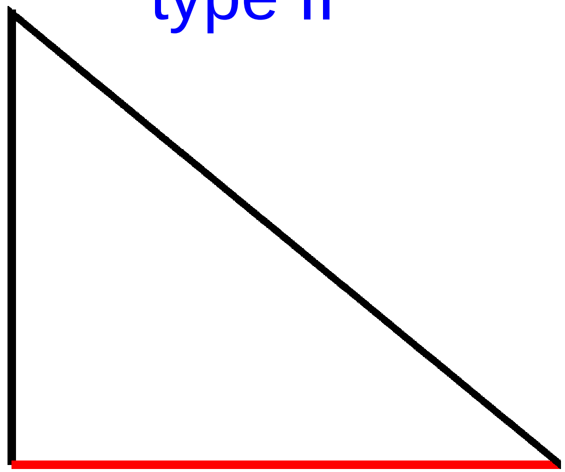
type Ia, Ib/c

SN Light Source

Cooling

no source of S

type II



Permanent heating

by shock

type IIn

Fading heating

by radioactivity

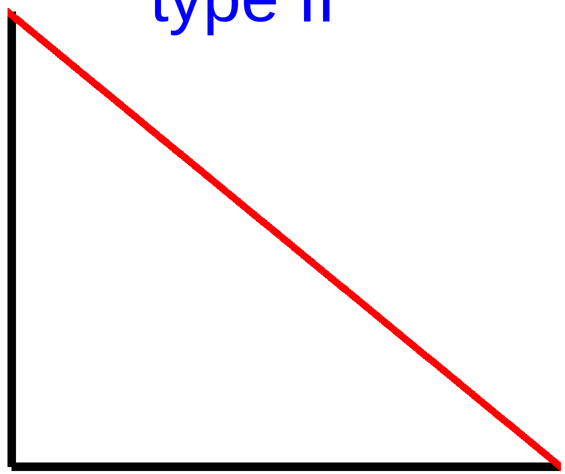
type Ia, Ib/c

SN Light Source

Cooling

no source of S

type II



Permanent heating

by shock

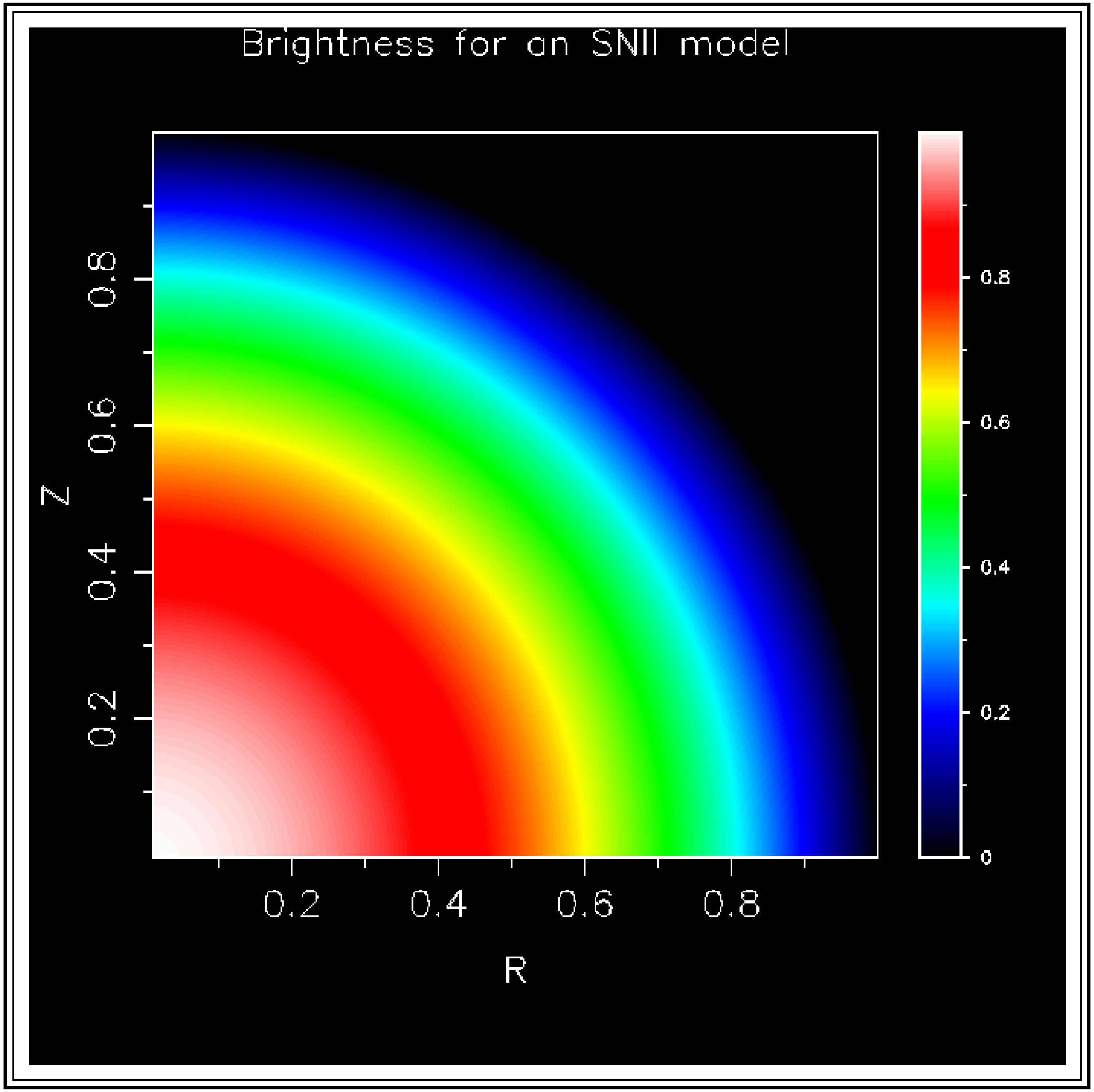
type IIn

Fading heating

by radioactivity

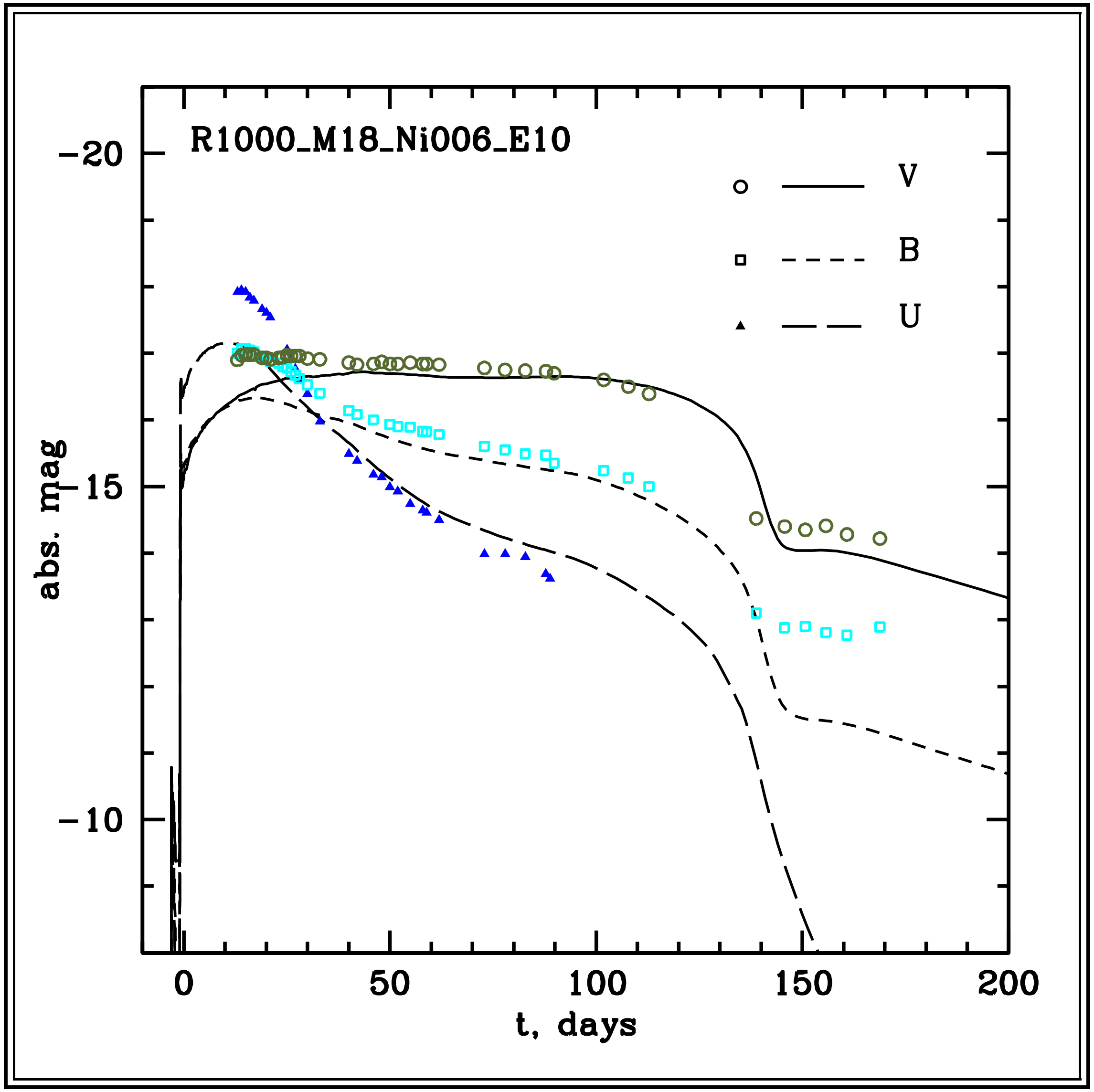
type Ia, Ib/c

‘Visible’ of SN IIP c

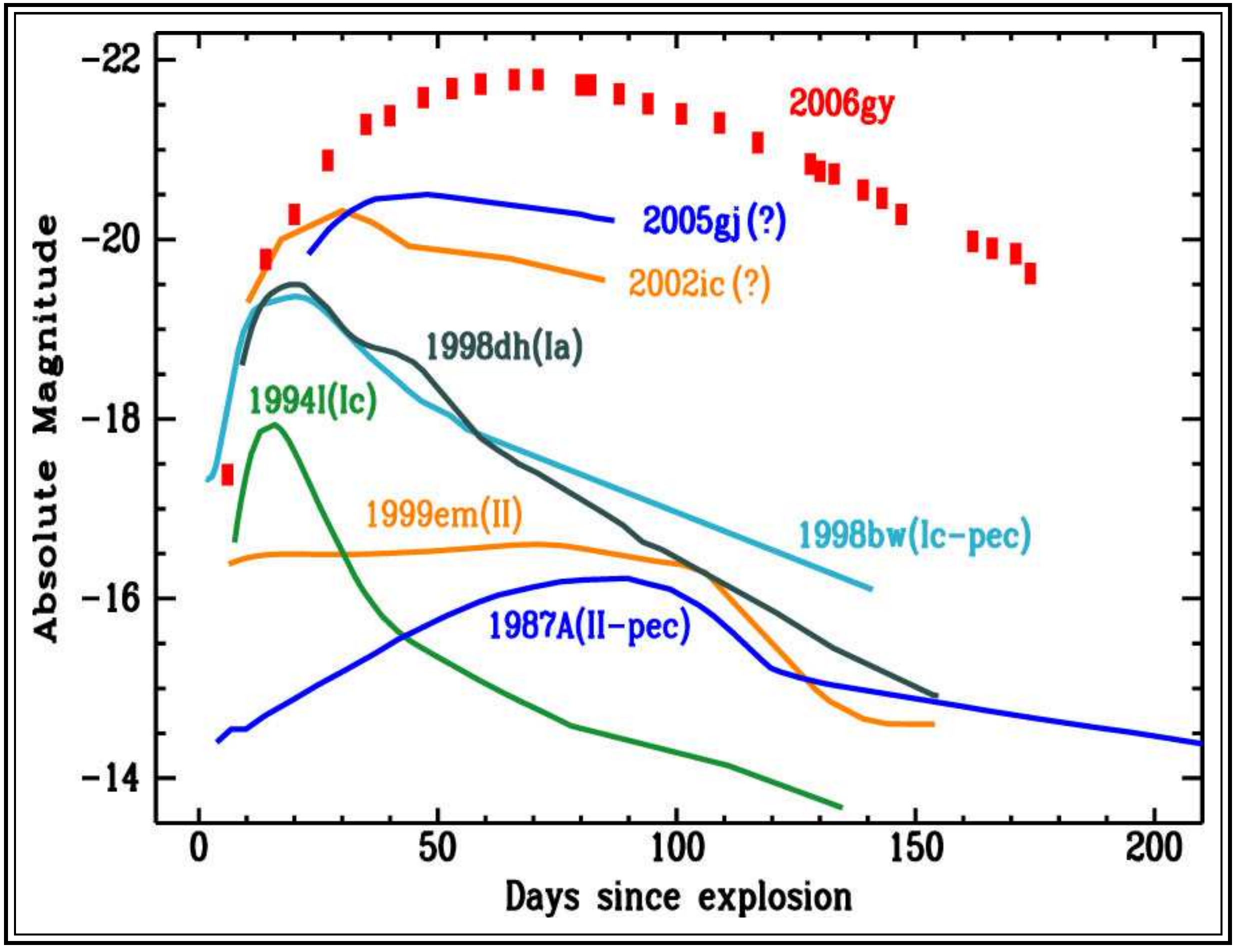


Baklanov et al. (2005)

SN 1999em D= 12.38 Mpc



Type IIP too weak for SN06gy



A huge $1000R_\odot$ RSG produces a rather weak SN II. Is it feasible for radioactivity? Yes, but for tens of $M_\odot$ in ^{56}Ni.

One has to go to VERY massive stars.

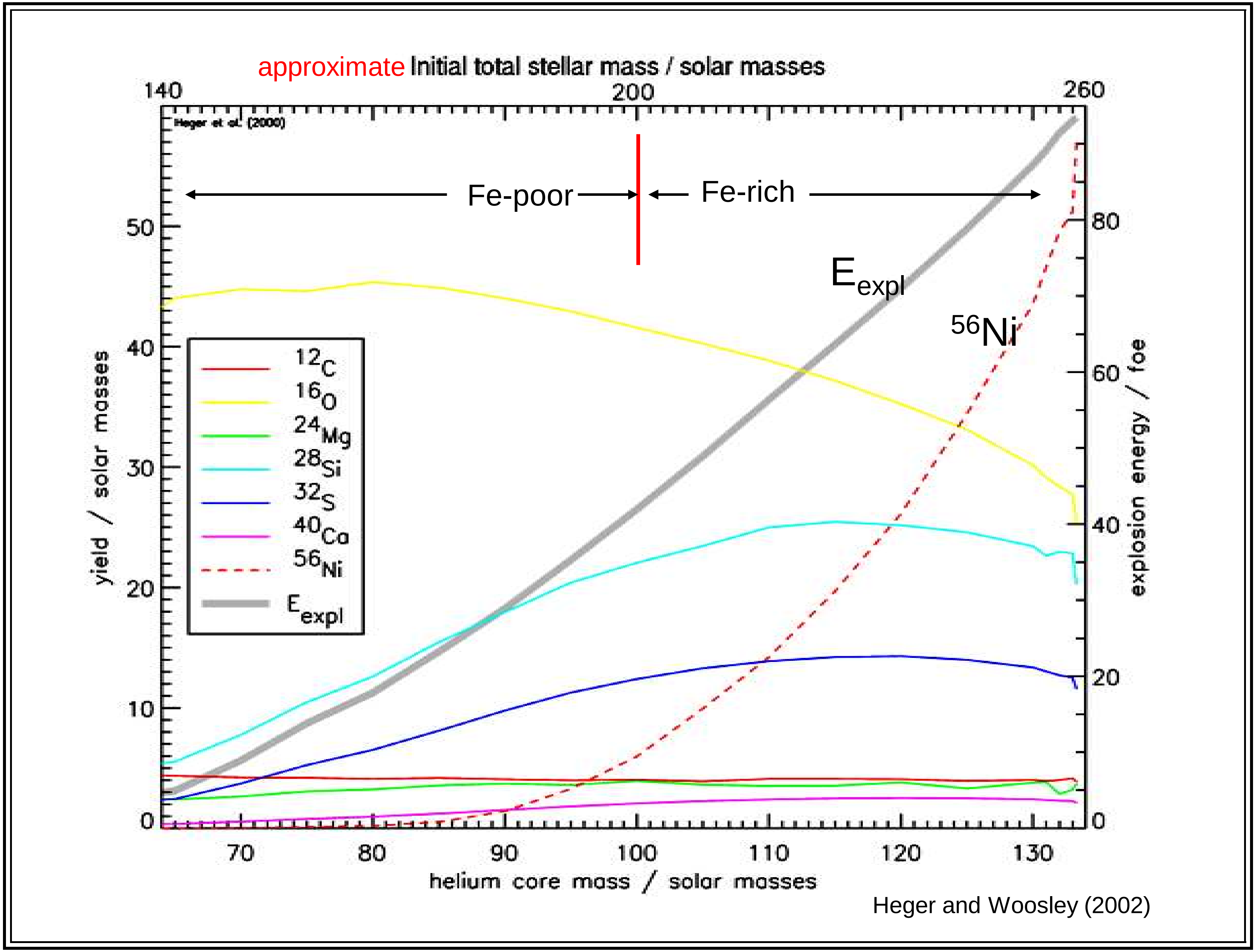
Very Massive Stars

Four kinds of deaths

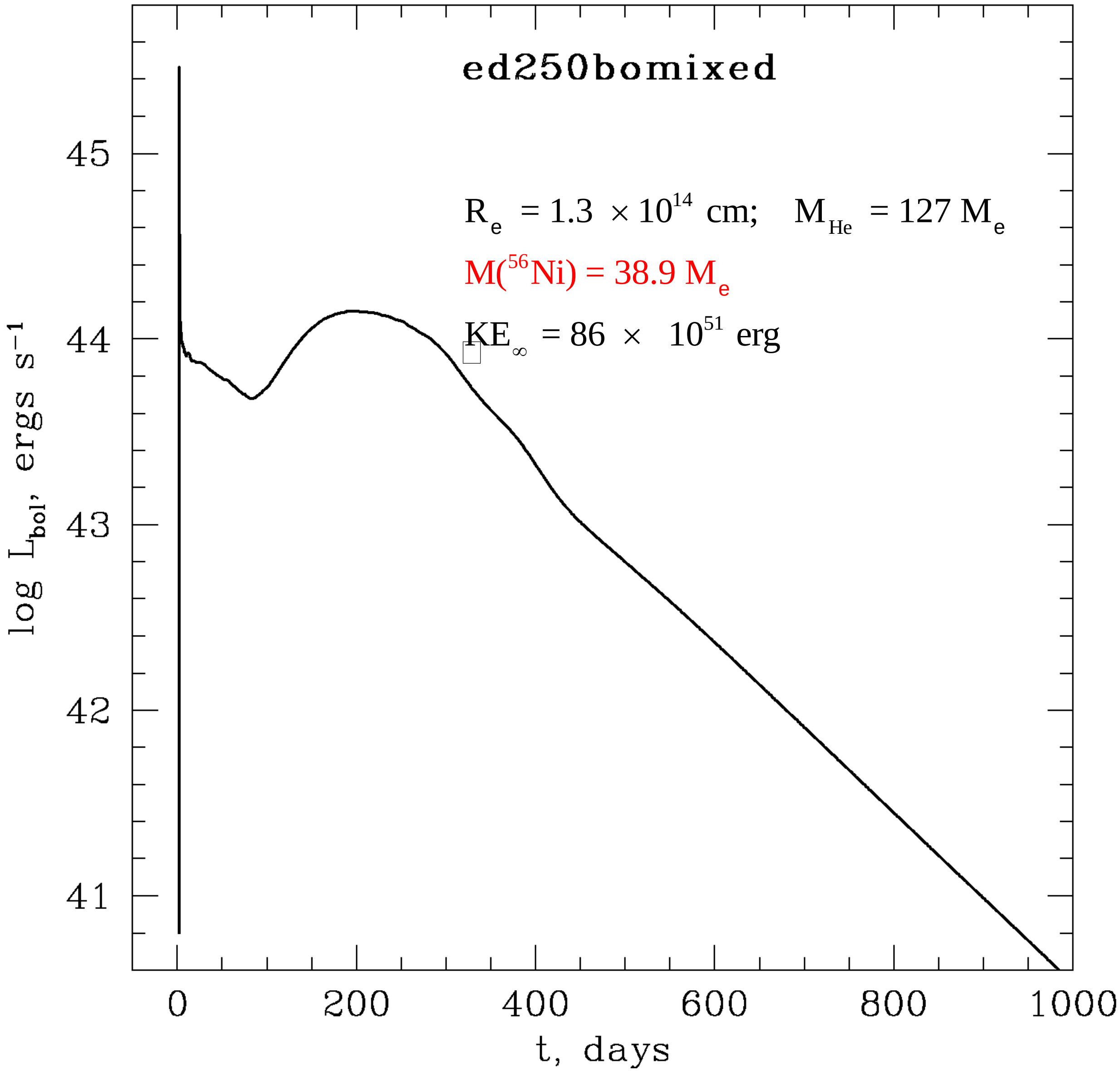
With some uncertainty about exact demarcations, one can delineate four kinds of deaths for non-rotating helium stars. (For rotation decrease main sequence mass 10 - 20%)

He Core	Main Seq. Mass	Supernova Mechanism
$2 \le M \le 40$	$10 \le M \le 95$	Fe core collapse to neutron star or a black hole
$40 \le M \le 60$	$95 \le M \le 130$	Pulsational pair instability followed by Fe core collapse
$60 \le M \le 137$	$130 \le M \le 260$	Pair instability supernova
$M \ge 137$	$M \ge 260$	Black hole. Possible GRB

Very Massive Stars



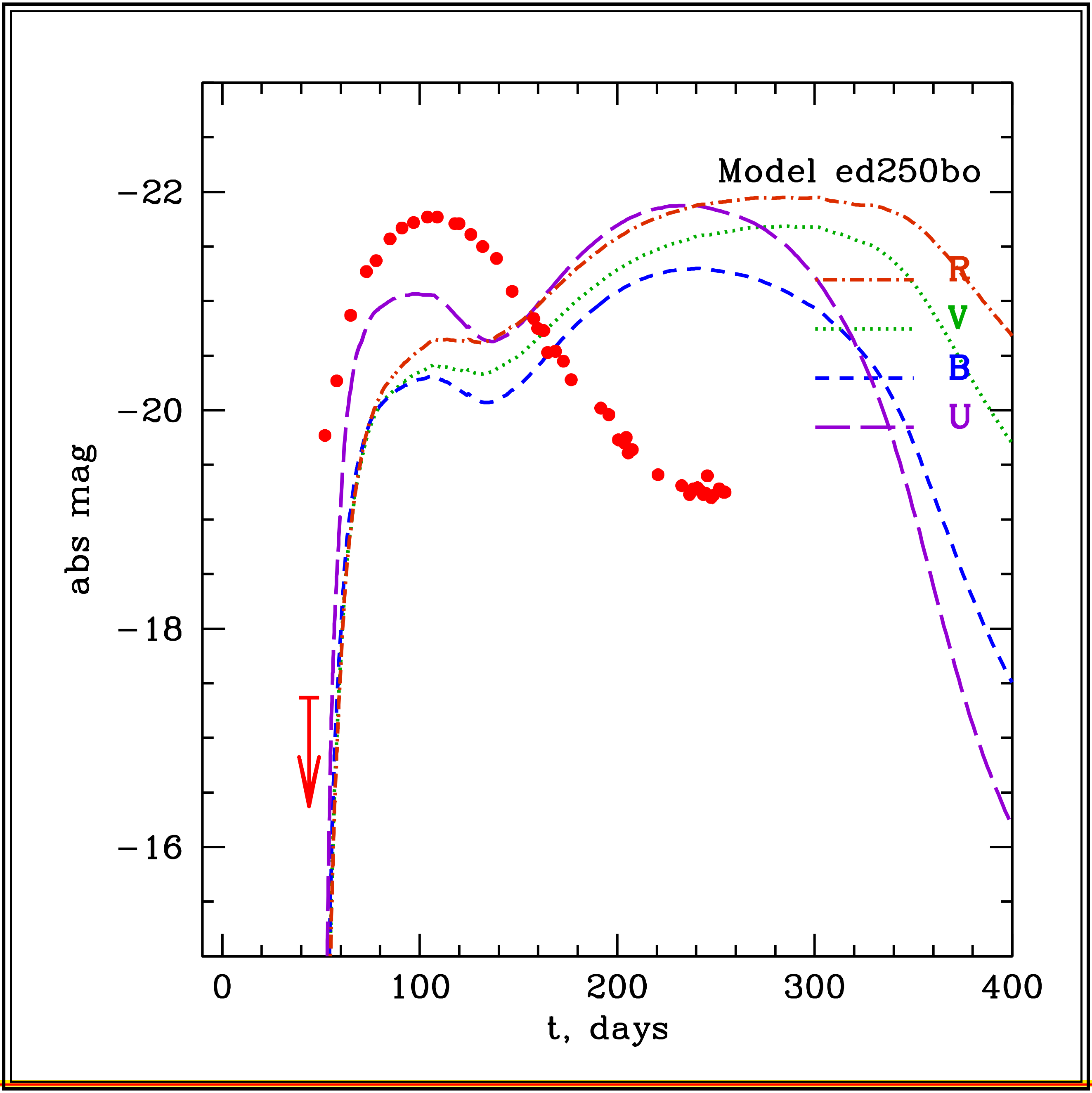
Bolometric for ed250



Brighter still are the bigger explosions that make lots of ^{56}Ni

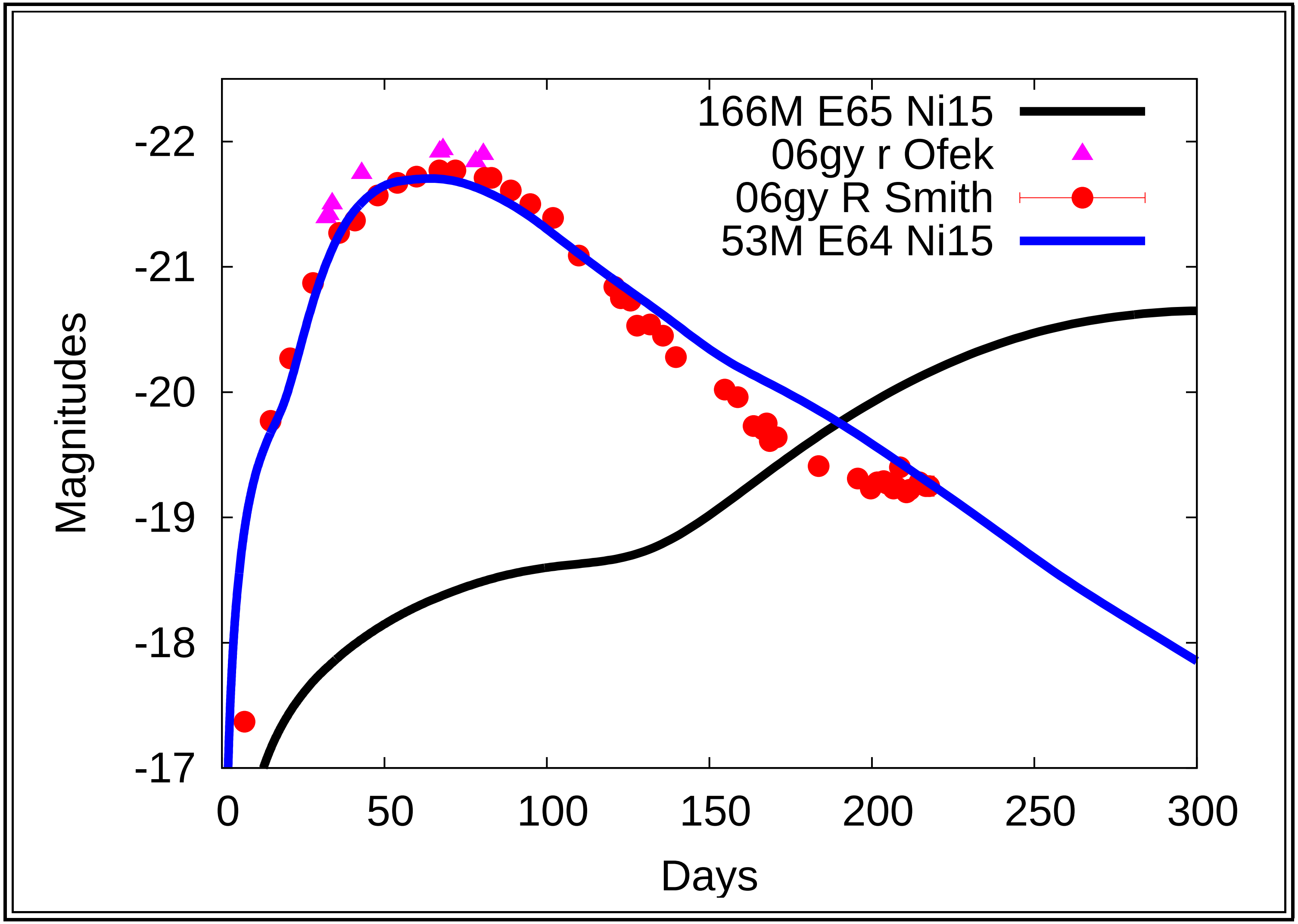
Calculations by Sergei Blinnikov

UBVR for ed250 and SN06gy



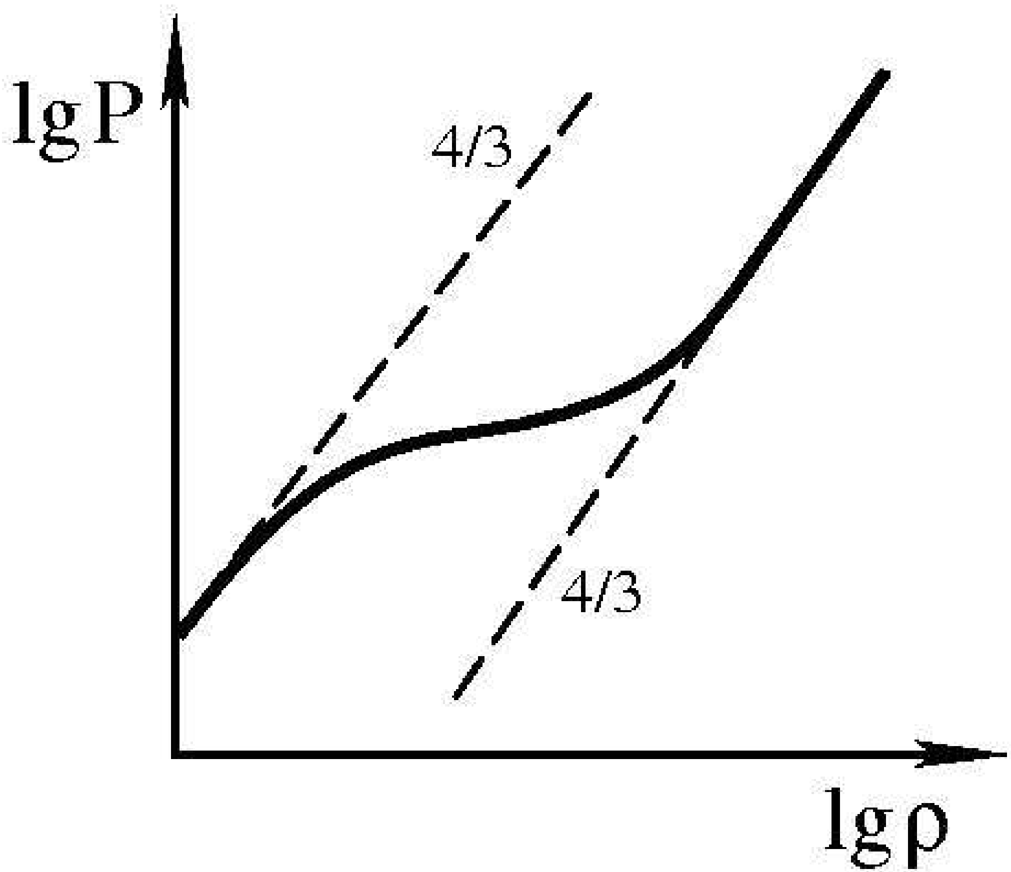
K. Nomoto, N. Tominaga,

M. Tanaka,K. Maeda,H. Umeda, 2007

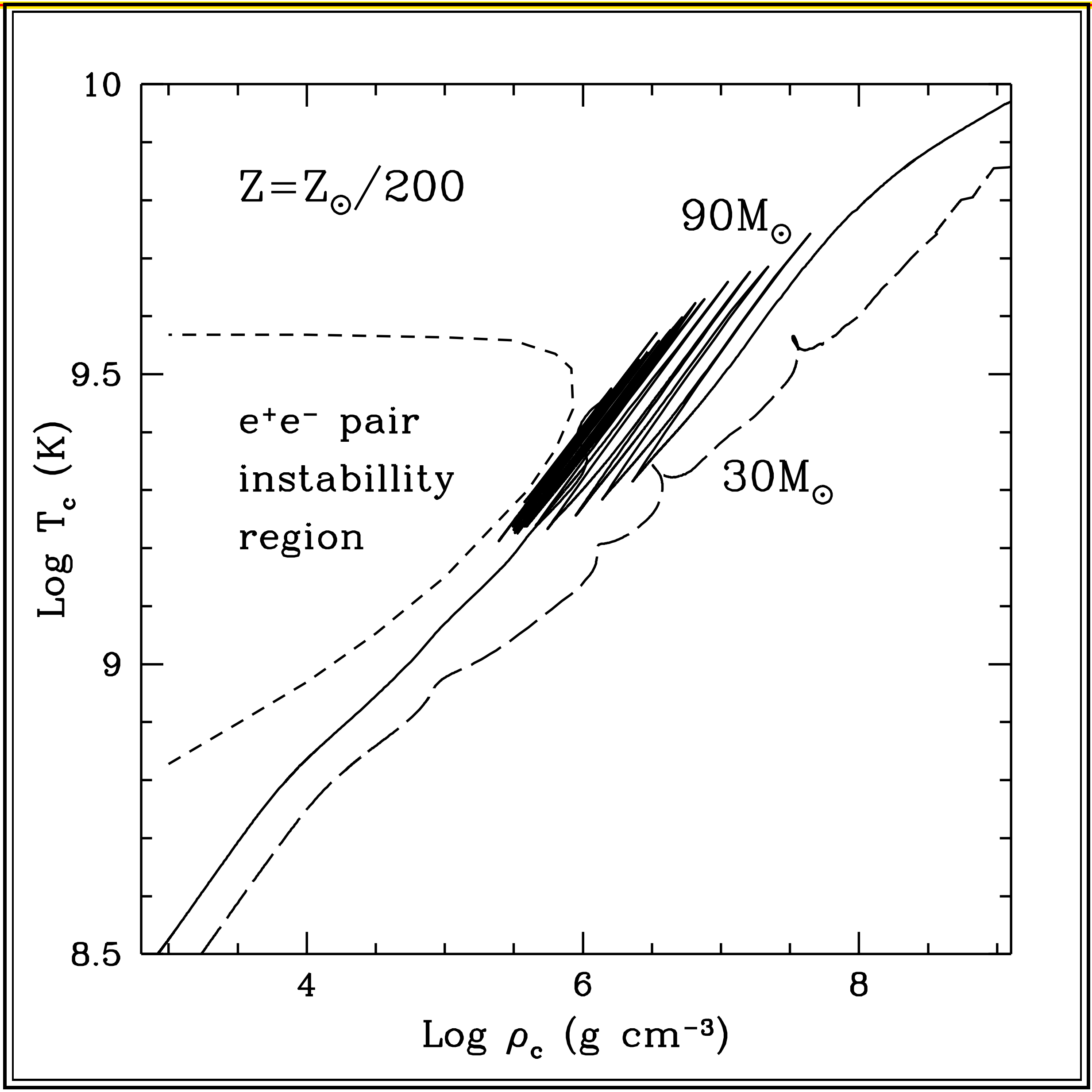


Pair instability

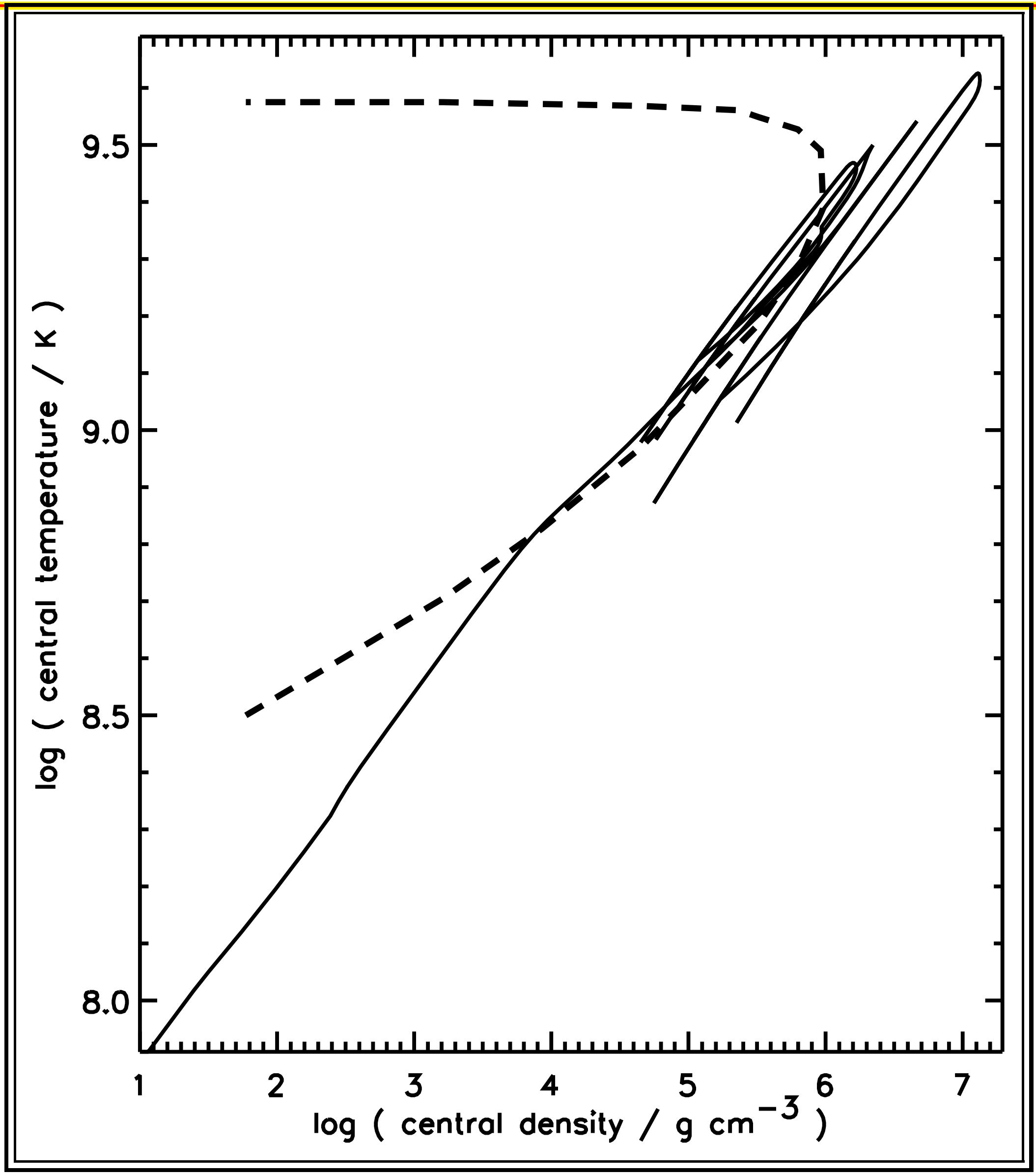
A radiation dominated star was already at the verge of the loss of the stability ($P \propto \rho^{4/3}$), and now it is unstable if ($\gamma < 4/3$).



Umeda and Nomoto 2007

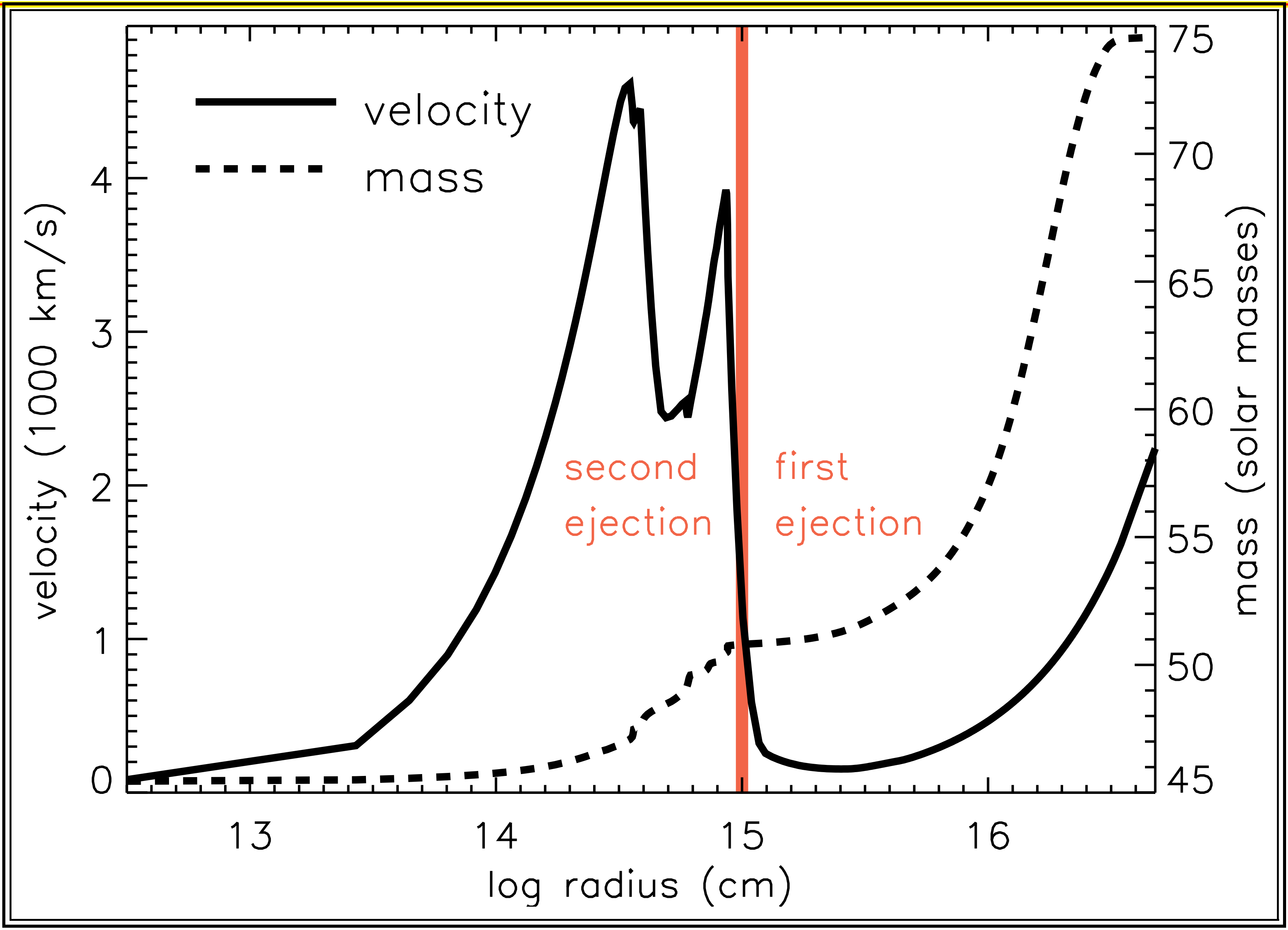


Woosley et al. s103

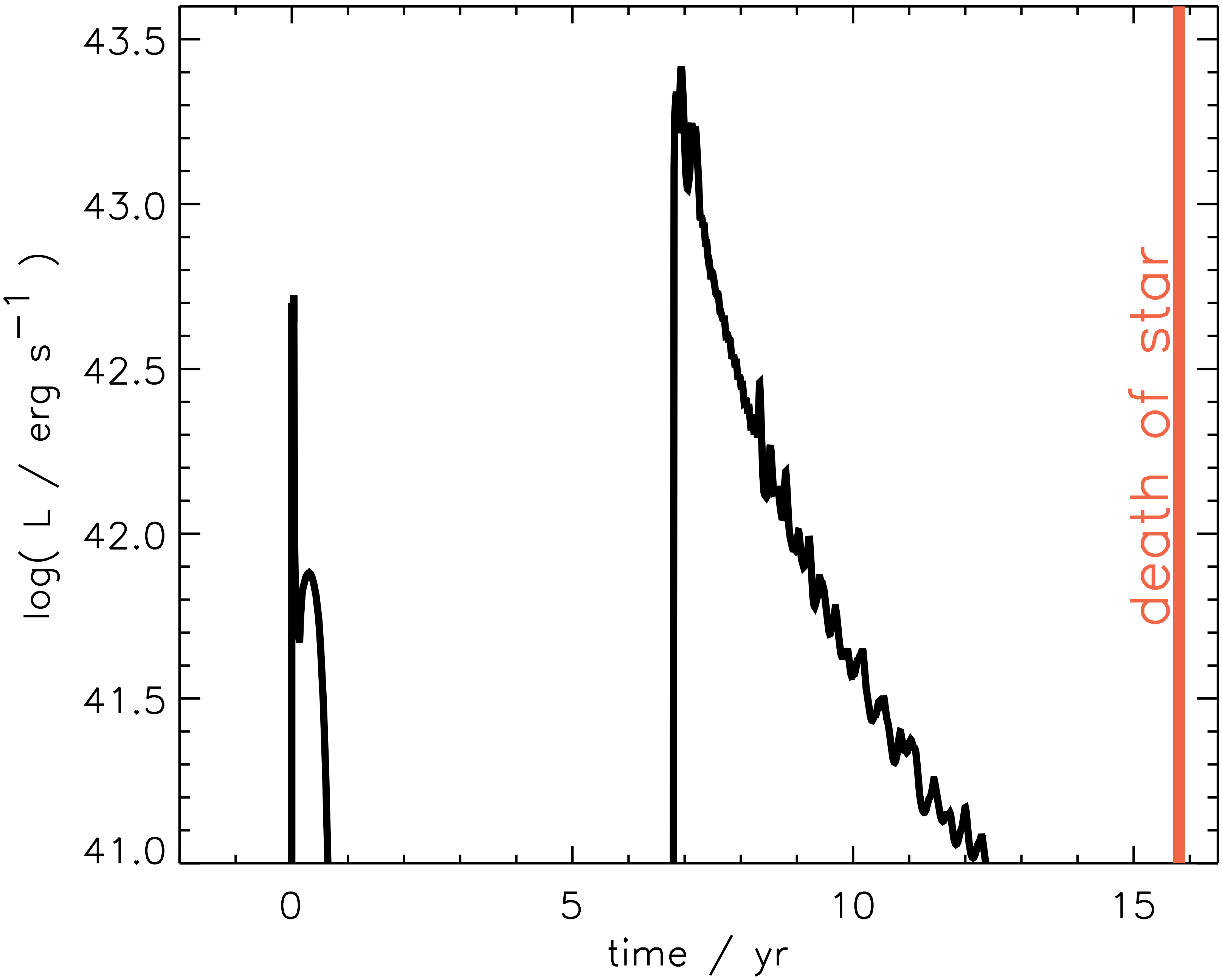


This gives the Most Luminous Supernovae!

SN-repeaters



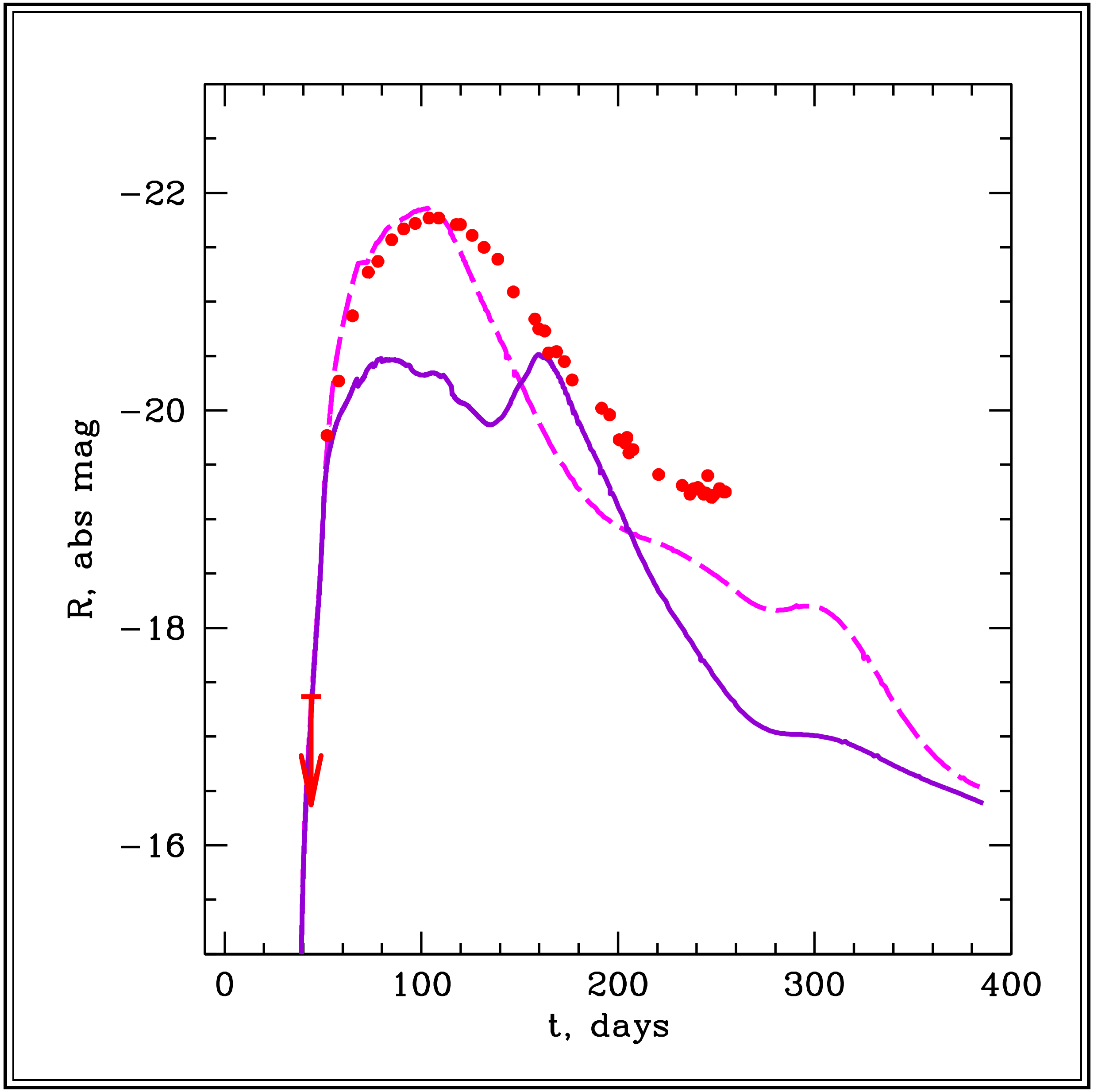
SN-repeaters2



SN-repeaters3

He Mass ($M_\odot$)	Pulse	KE_1 (10^{50} erg)	ΔM ($M_\odot$)	T_c (10^9 K)	ρ_c (10^5 g cm^{-3})	interval (sec)
48	1	0.048	0.11	1.48	1.68	7.34(5)
	2	0.92	0.57	1.57	2.02	4.31(5)
	3	2.20	1.19	1.31	1.34	2.77(6)
	4	3.09	1.64	1.38	3.00	2.02(6)
	5	4.41	1.84	1.32	3.40	8.33(6)
	6	3.02	2.42	1.86	28.6	7.43(5)
52	1	0.85	1.13	1.01	0.40	6.32(7)
	2	1.46	0.94	1.57	5.02	4.58(5)
	3	4.27	1.90	1.16	2.74	8.10(6)
	4	7.29	3.12	1.09	2.68	9.56(7)
58	1	13.3	9.39	0.24	0.0072	1.24(11)
	2	4.00	2.39	1.46	6.08	2.10(6)
	3	7.78	3.06	1.07	3.31	1.61(8)

Stella: LCs for SN2006gy



Double explosion: old idea

Grasberg & Nadyozhin (1986)

Type II supernovae: two successive explosions?

É. K. Grasberg and D. K. Nadëzhin

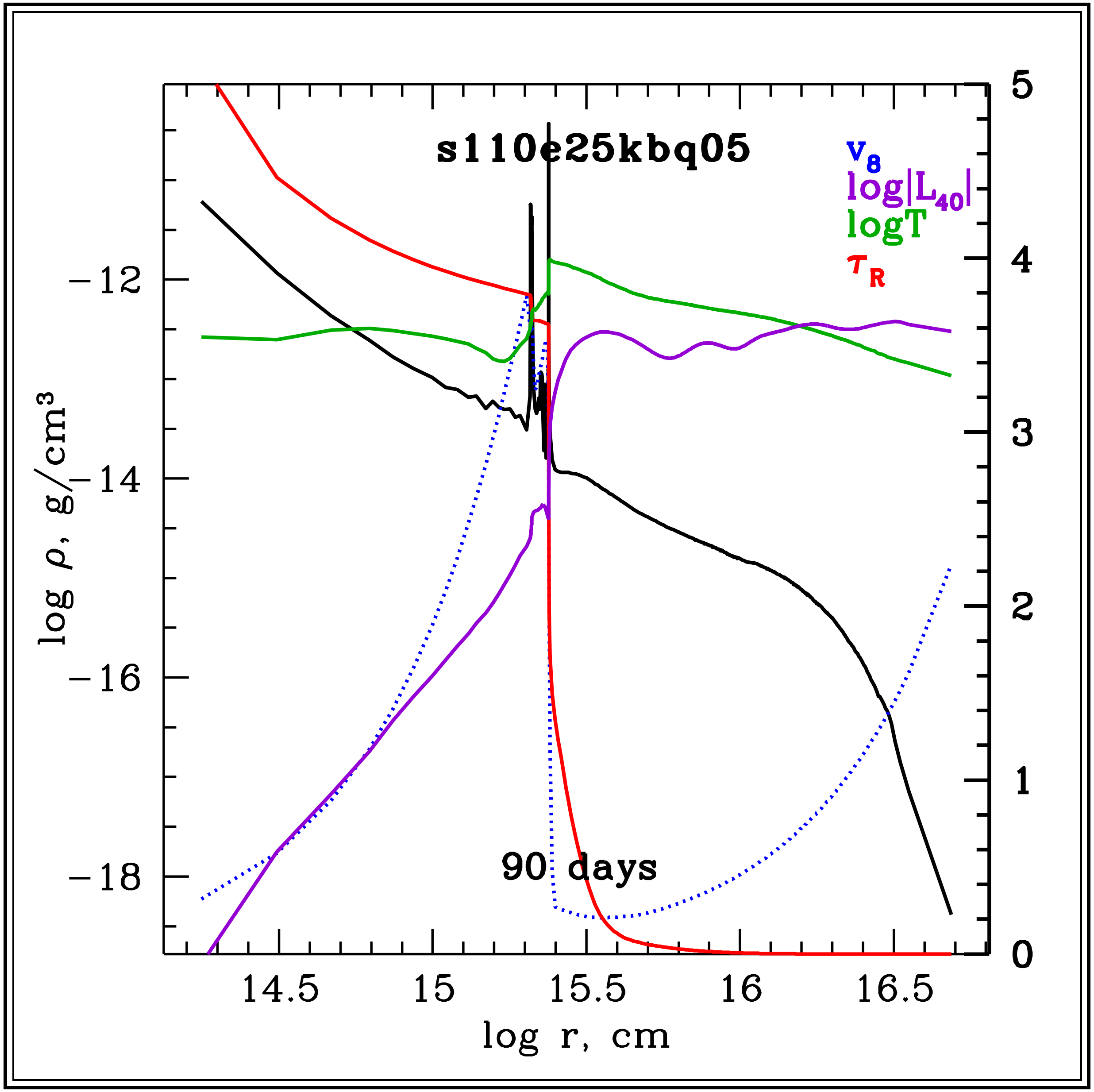
Radio Astrophysical Observatory, Latvian Academy of Sciences, Riga
and Institute of Theoretical and Experimental Physics, Moscow

(Submitted September 5, 1985)

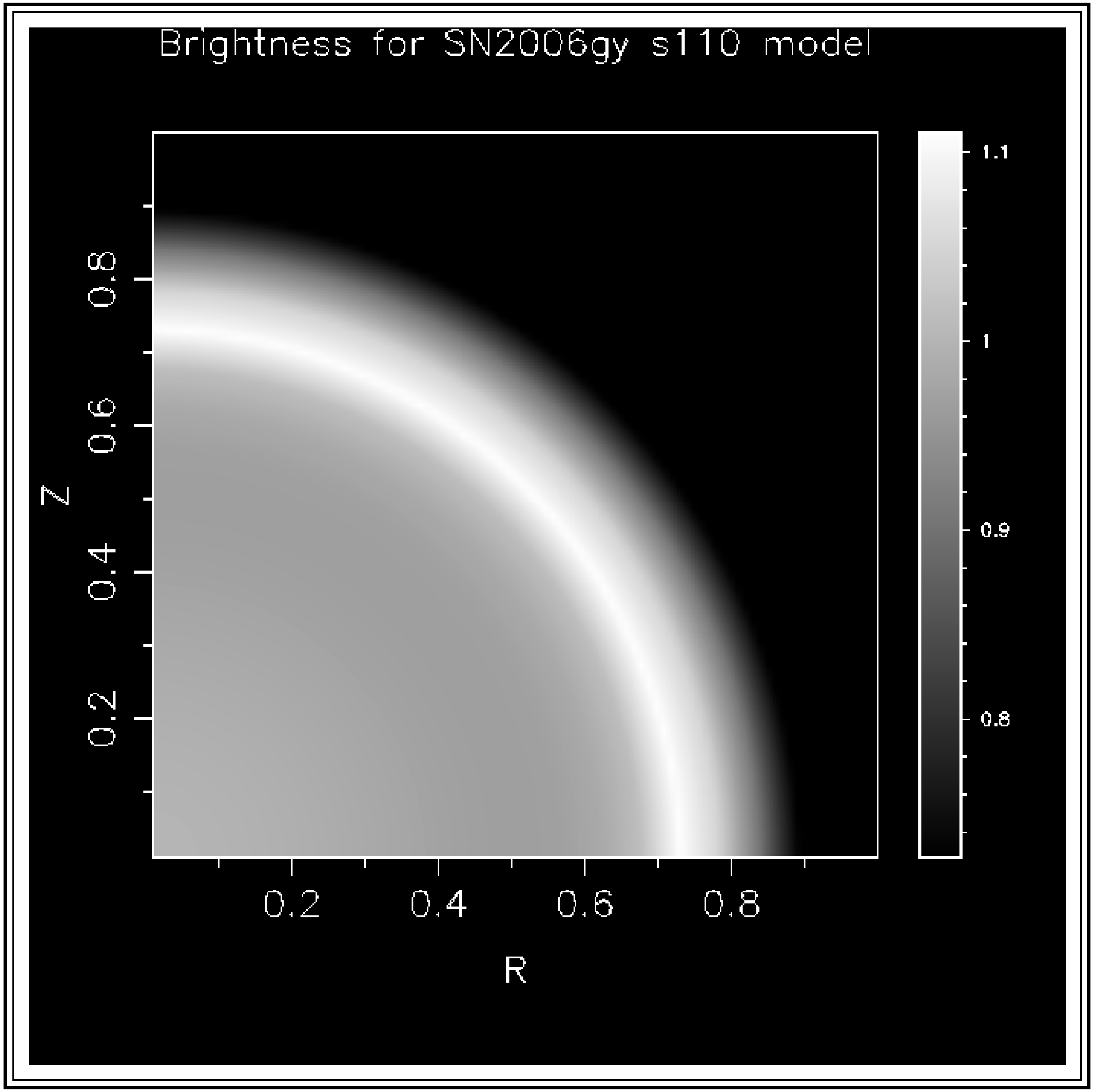
Pis'ma Astron. Zh. **12**, 168–175 (February 1986)

A type II supernovae model wherein a weak explosion precedes a much stronger one can explain the behavior of the narrow-line systems observed in some type II spectra. For SN 1983k in NGC 4699, the two outbursts would have been separated by 1–2 months. Core gravitational collapse generating a relatively weak shock as the presupernova reorganizes itself might trigger the first explosion, while the second would occur when the newborn neutron star transfers energy to the envelope that has failed to collapse.

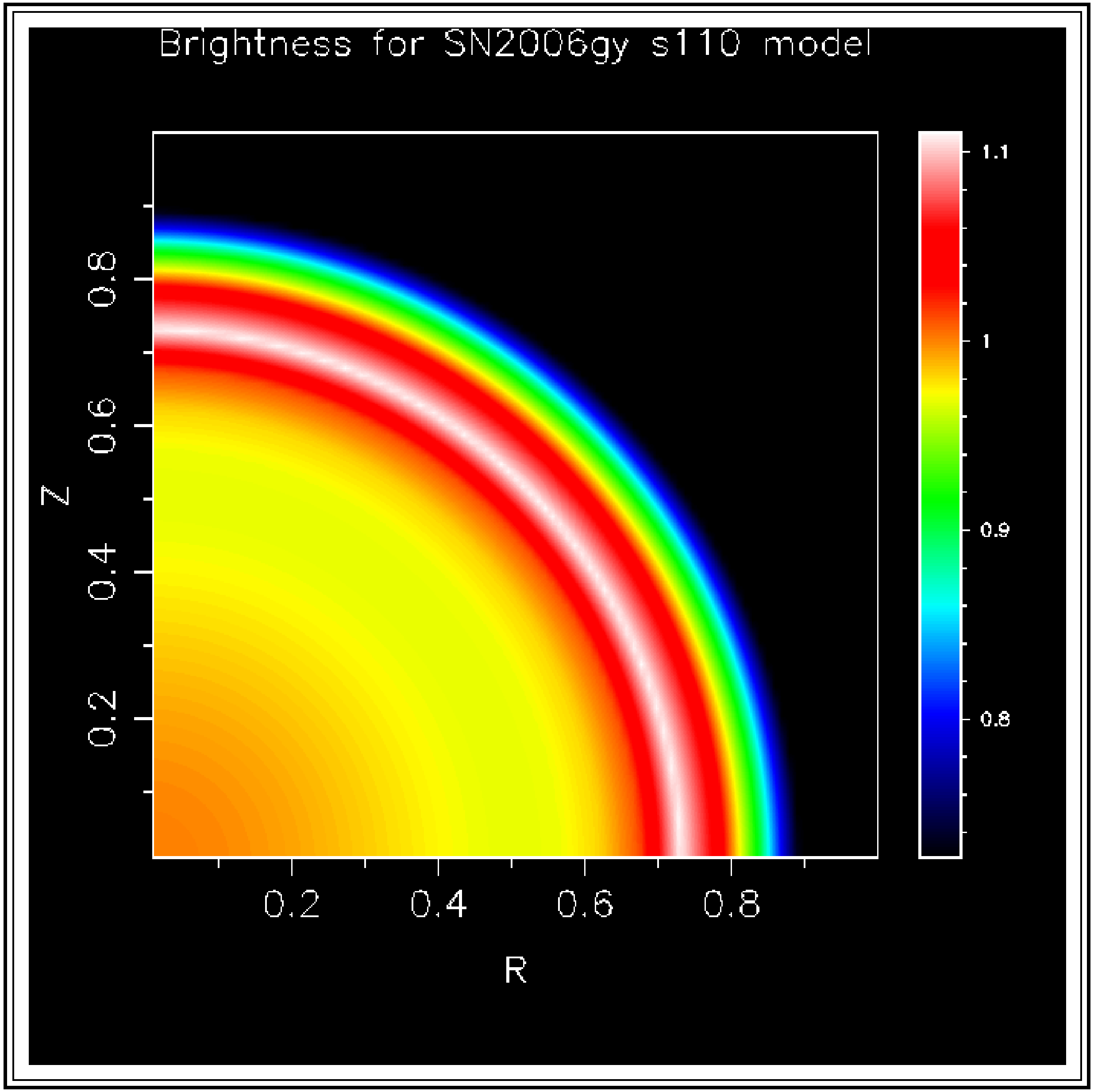
Hydro structure 90 d



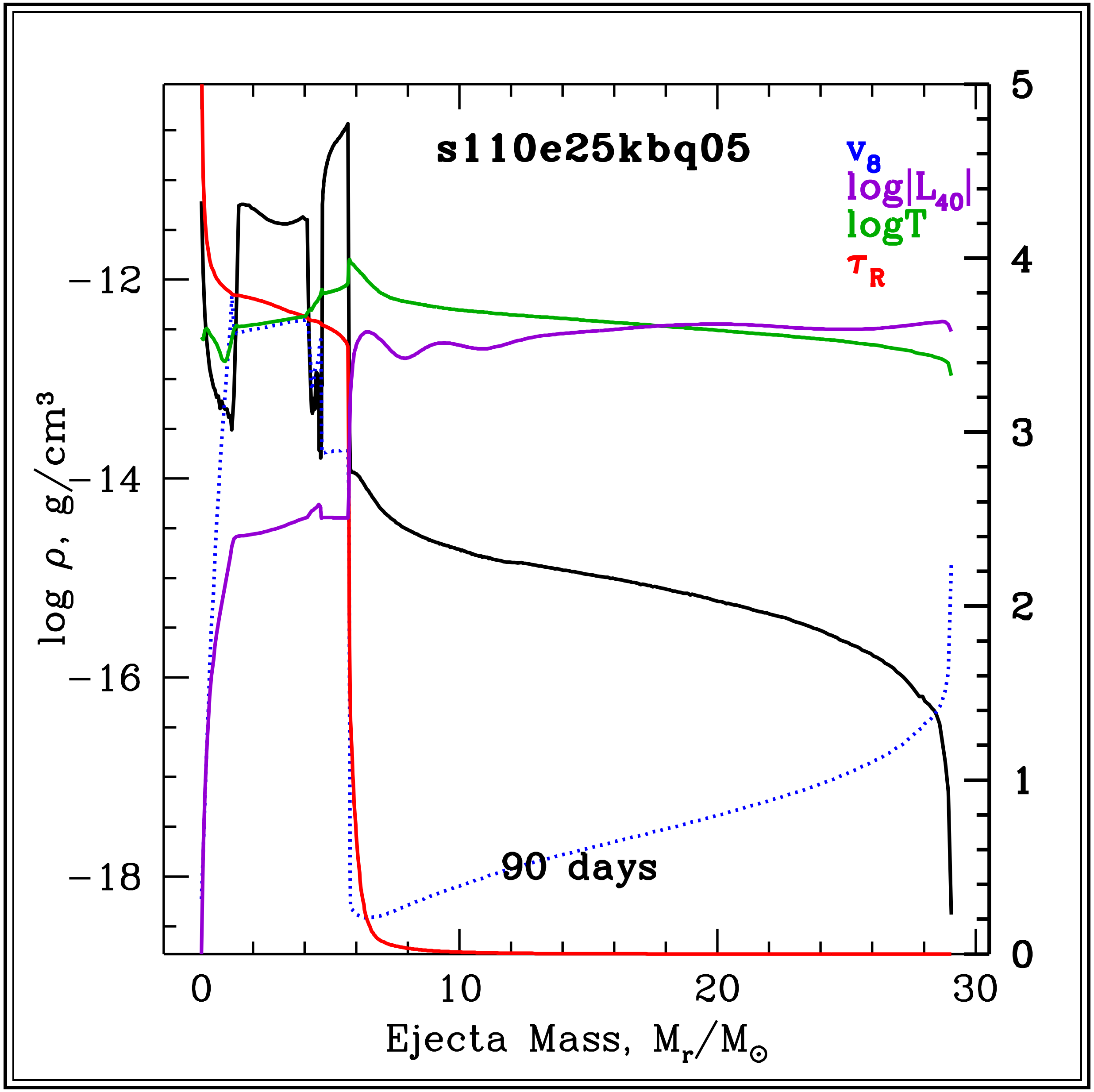
‘Visible’ disk of SN 2006gy



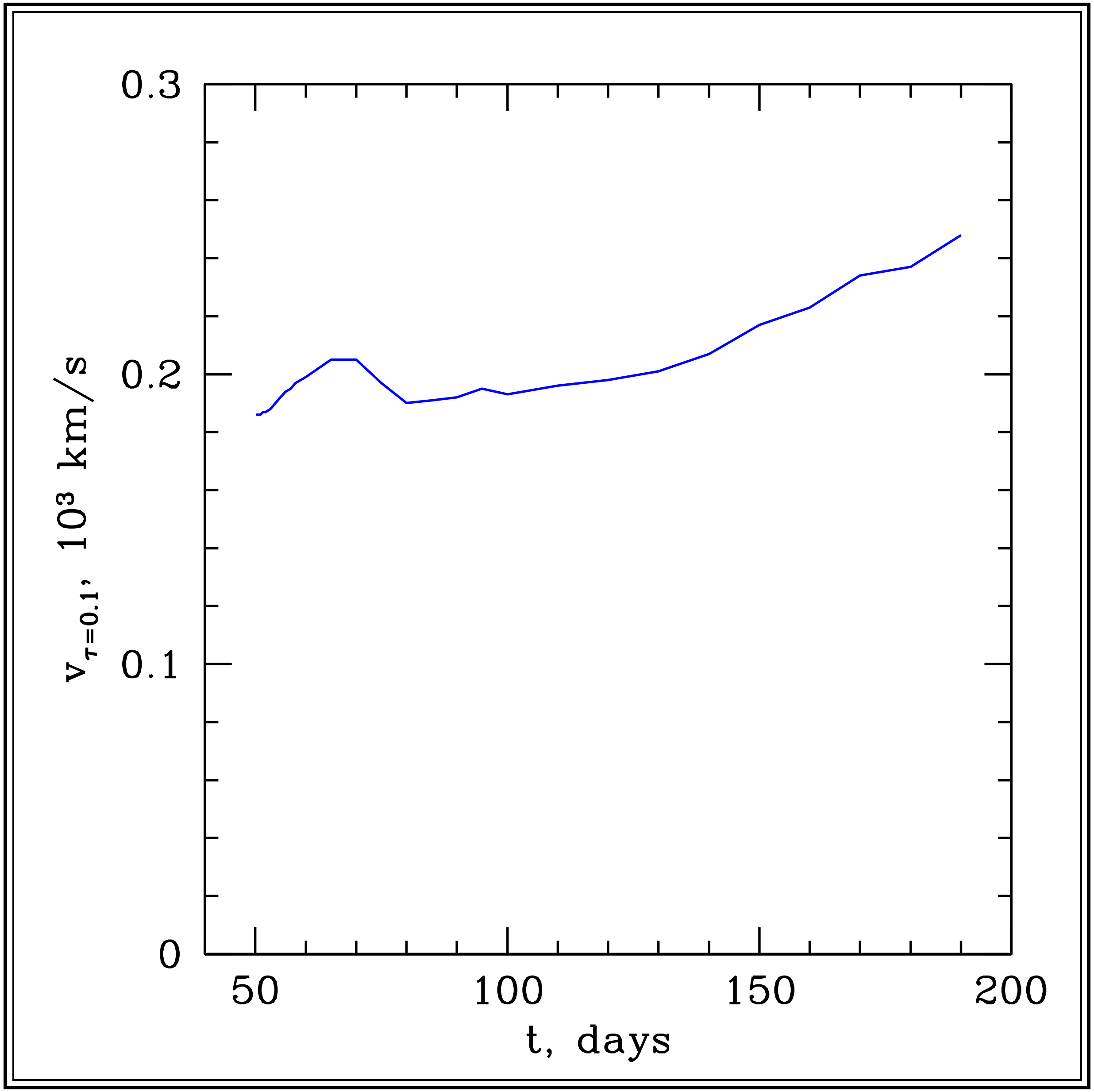
‘Visible’ disk of SN 2006gy c



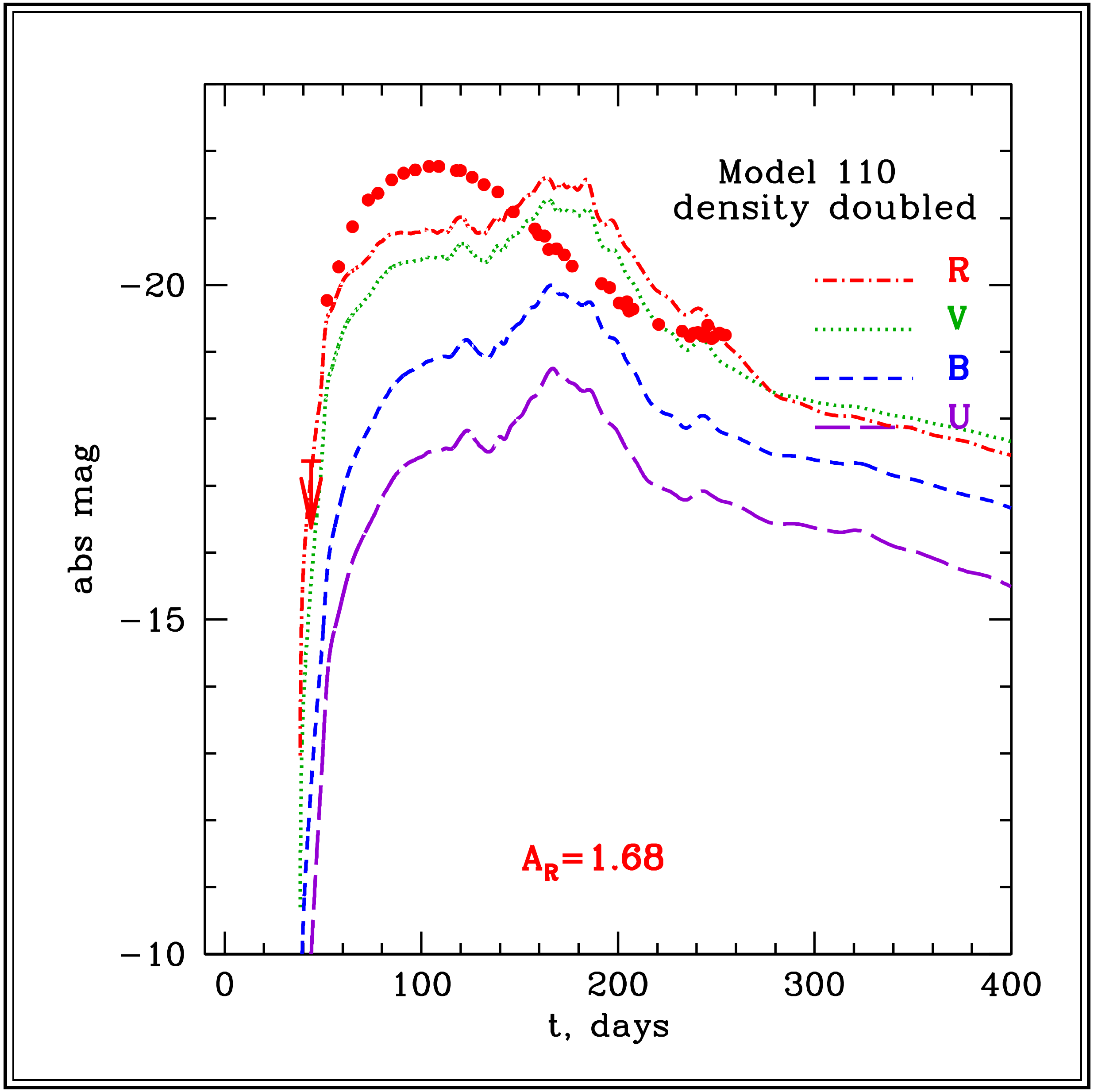
90 d, mass coordinate



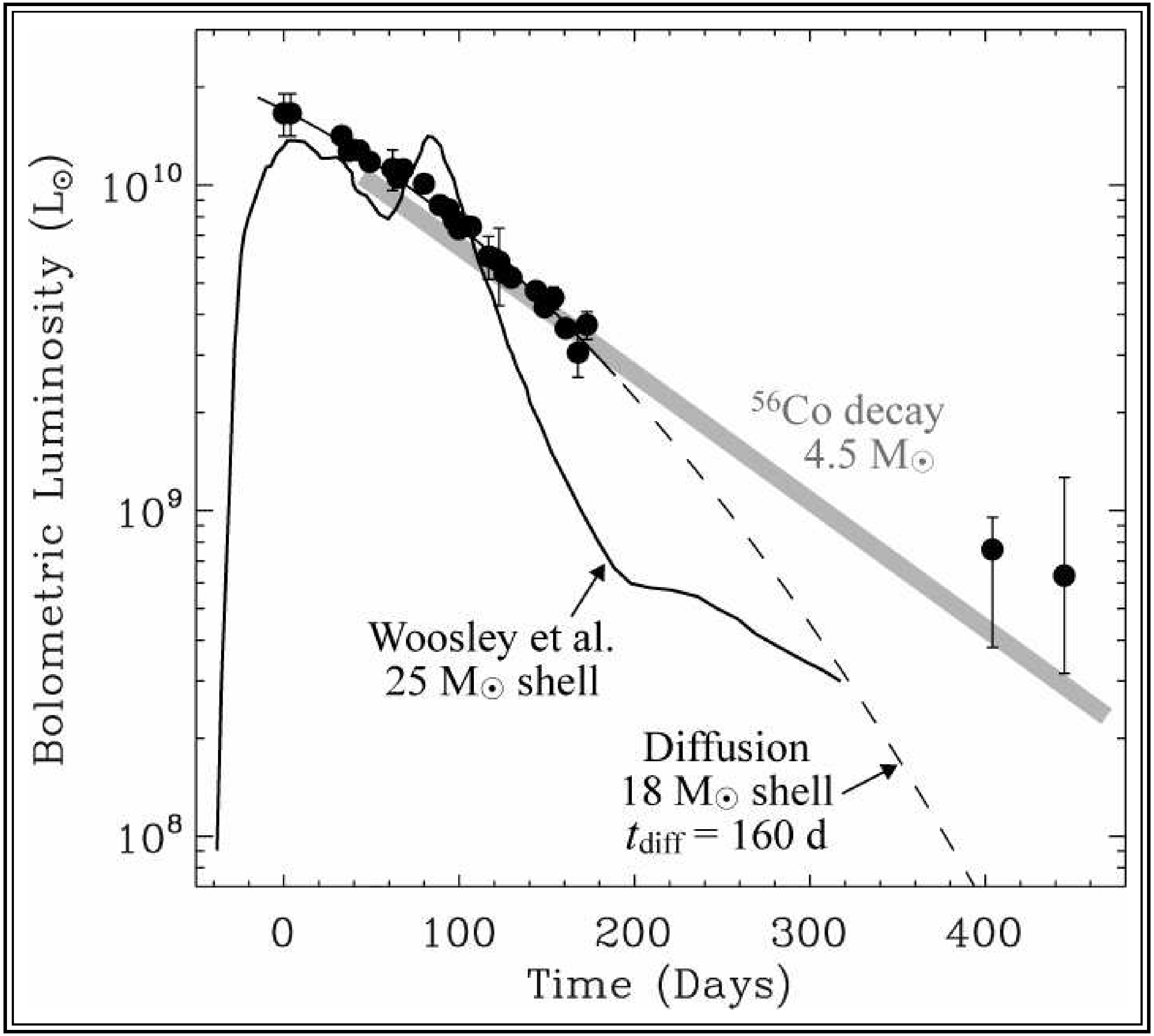
Velocity at $\tau = 0.1$



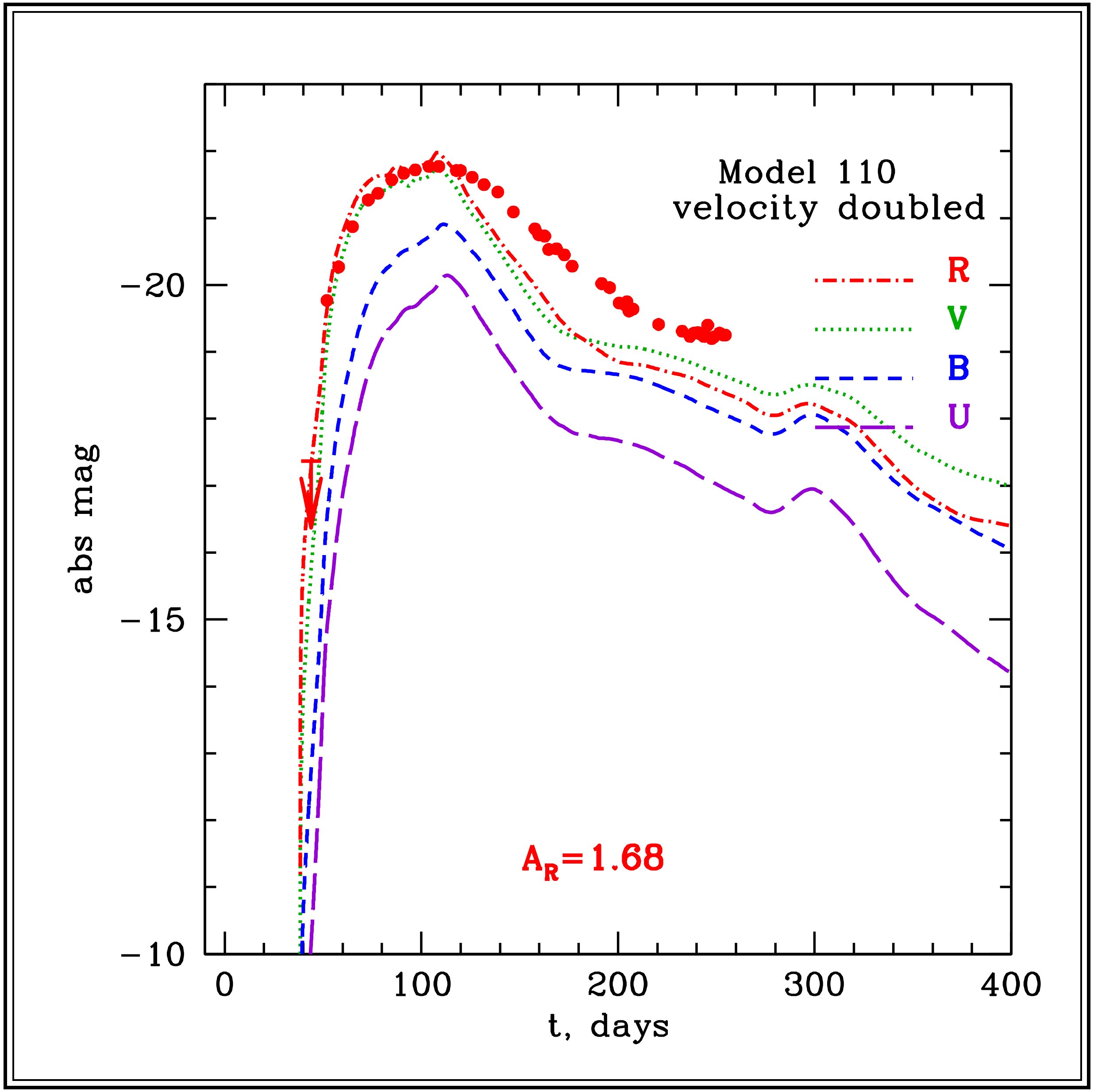
LCs for doubled ρ



SN 2006tf and models

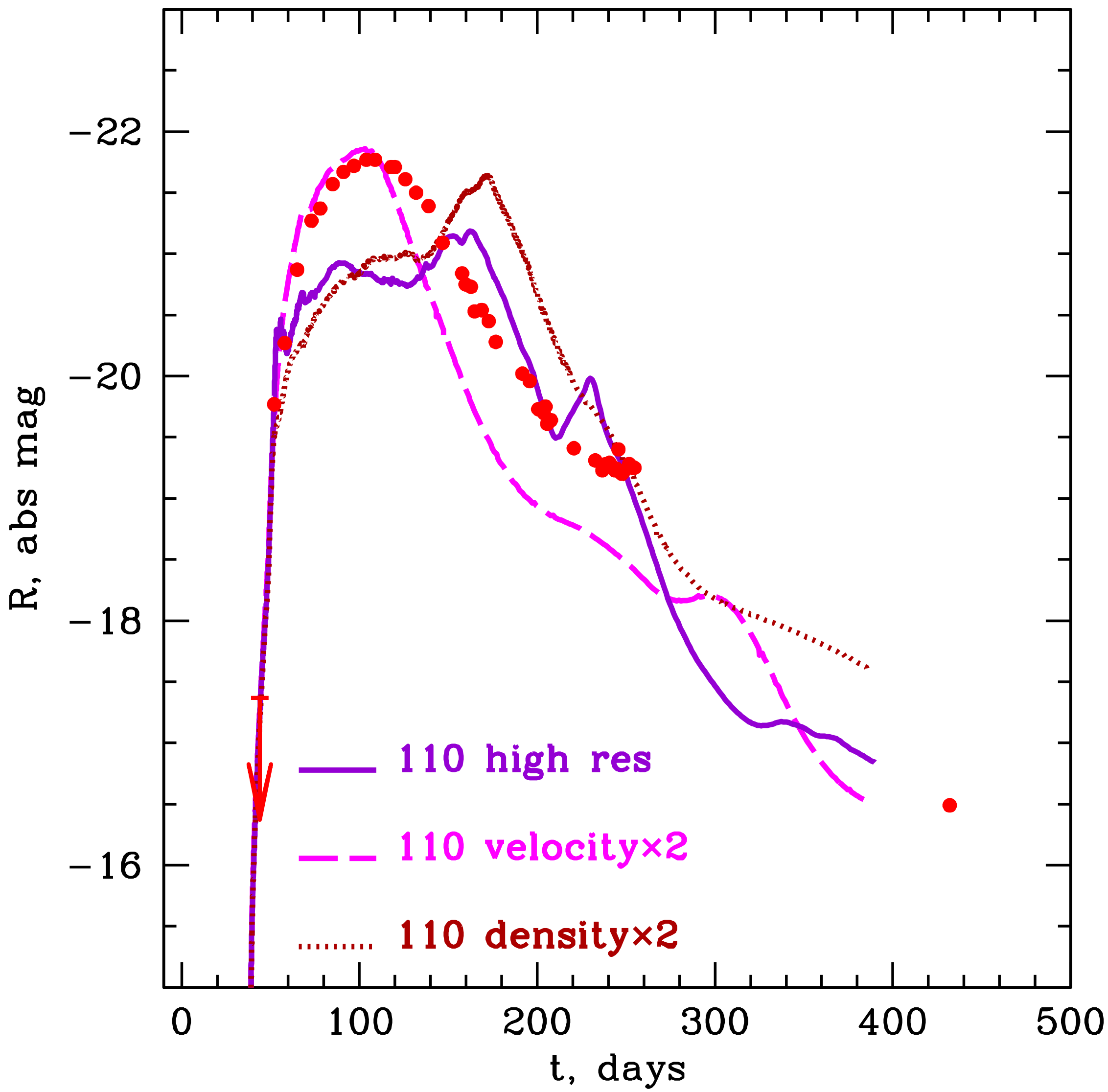


LCs for doubled velocity

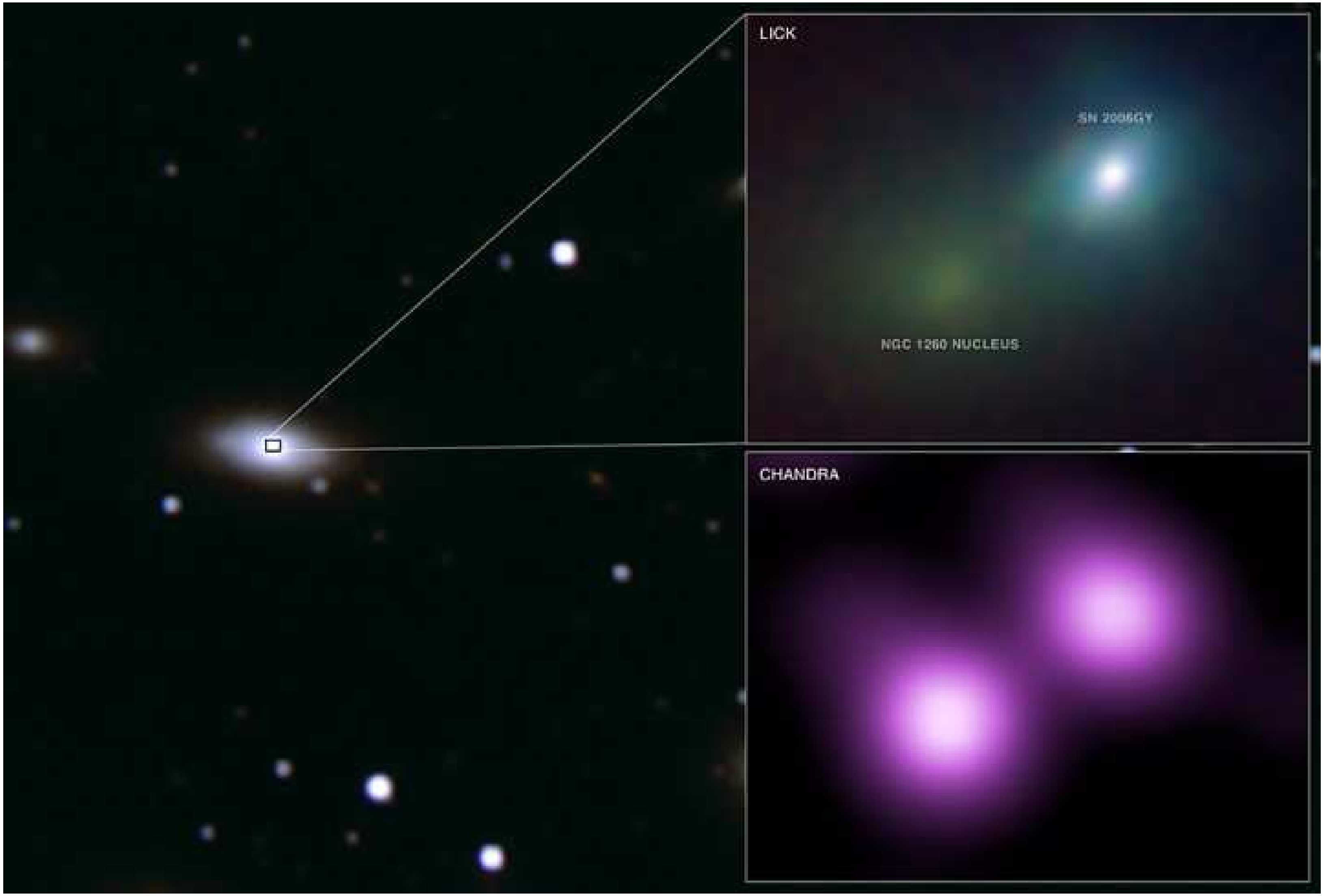


Higher res., tail observed

K. Kawabata, et al. (2008), ApJ subm., Courtesy M.Tanaka



Soft X-ray from SN06gy?



Postshock temperature

T_2 behind a strong shock, constant γ, small losses/gains Q, for ideal gas, neglecting radiation, is

$$T_2 = \frac{2(\gamma-1)u_1^2\mu}{(\gamma+1)^2\mathcal{R}} = \frac{3u_1^2\mu}{16\mathcal{R}} \quad \text{for } \gamma = 5/3\ .$$

If we put here $D_8 = u_1/10^8$cm/s, then D_8 is the shock speed in thousand km/s and we get

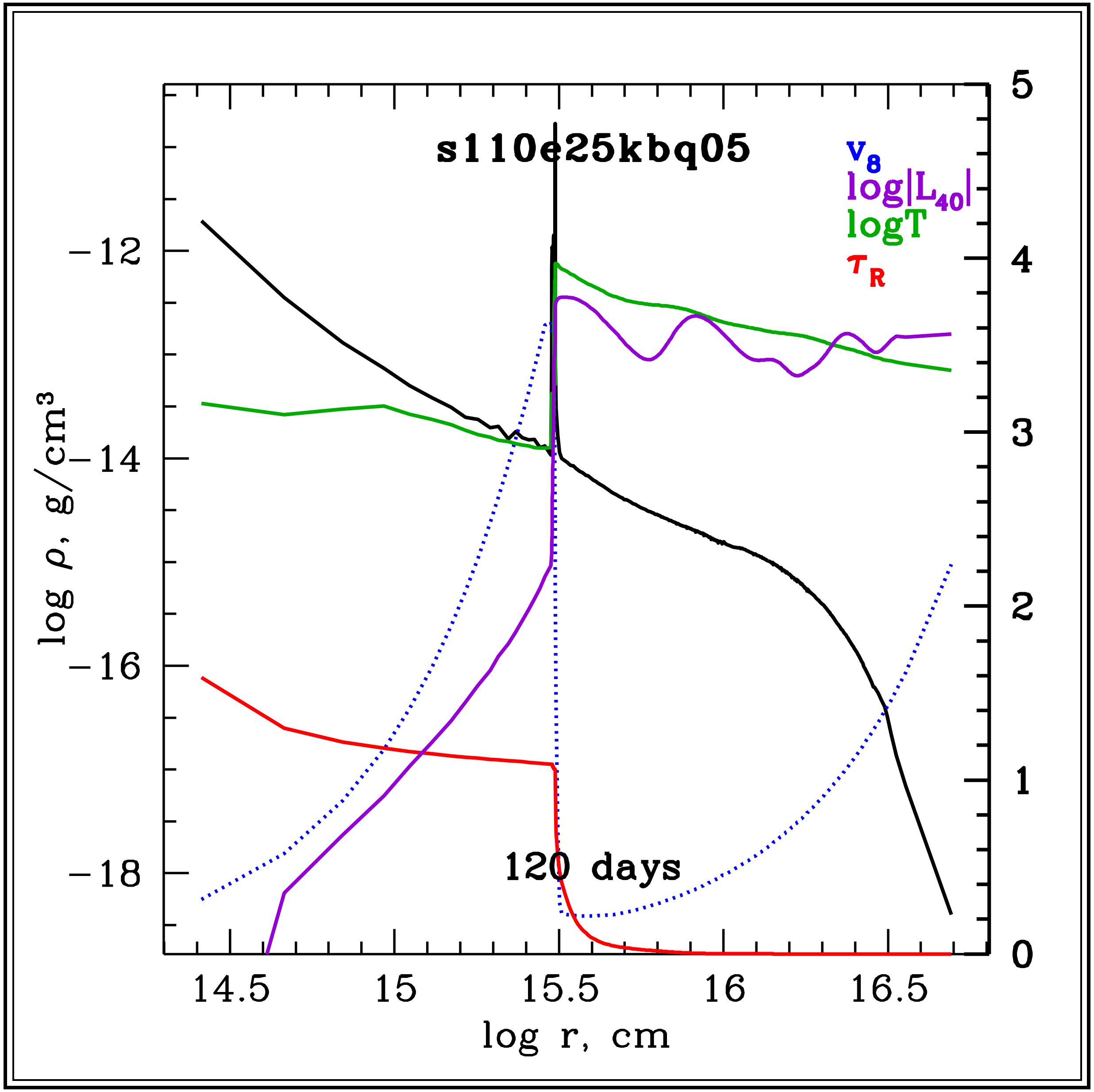
$$T_2 = 2.25 \times 10^7 \mu D_8^2$$

in K or

$$T_2(\text{keV}) = 1.94\mu D_8^2$$

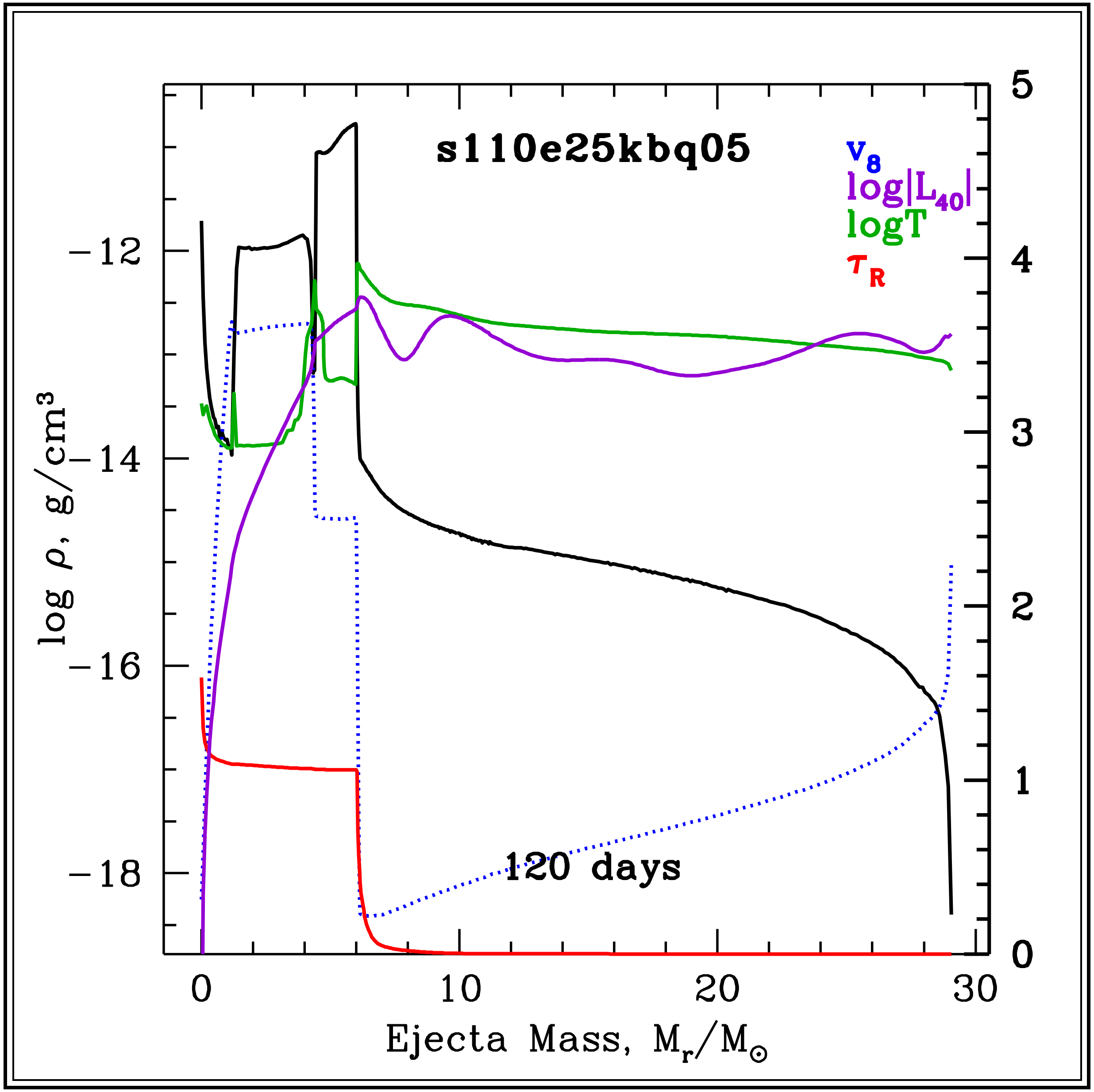
in keV. Here $\mu = A/(1+Z)$ for plasma (since $n = n_{\rm baryon}/\mu = n_{\rm ion}A/\mu = n_{\rm ion} + n_e = n_{\rm ion} + Zn_{\rm ion}$).

Hydro structure 120 d



X-rays from the shock cannot go out yet, the matter is too dense.

120 d, mass coordinate

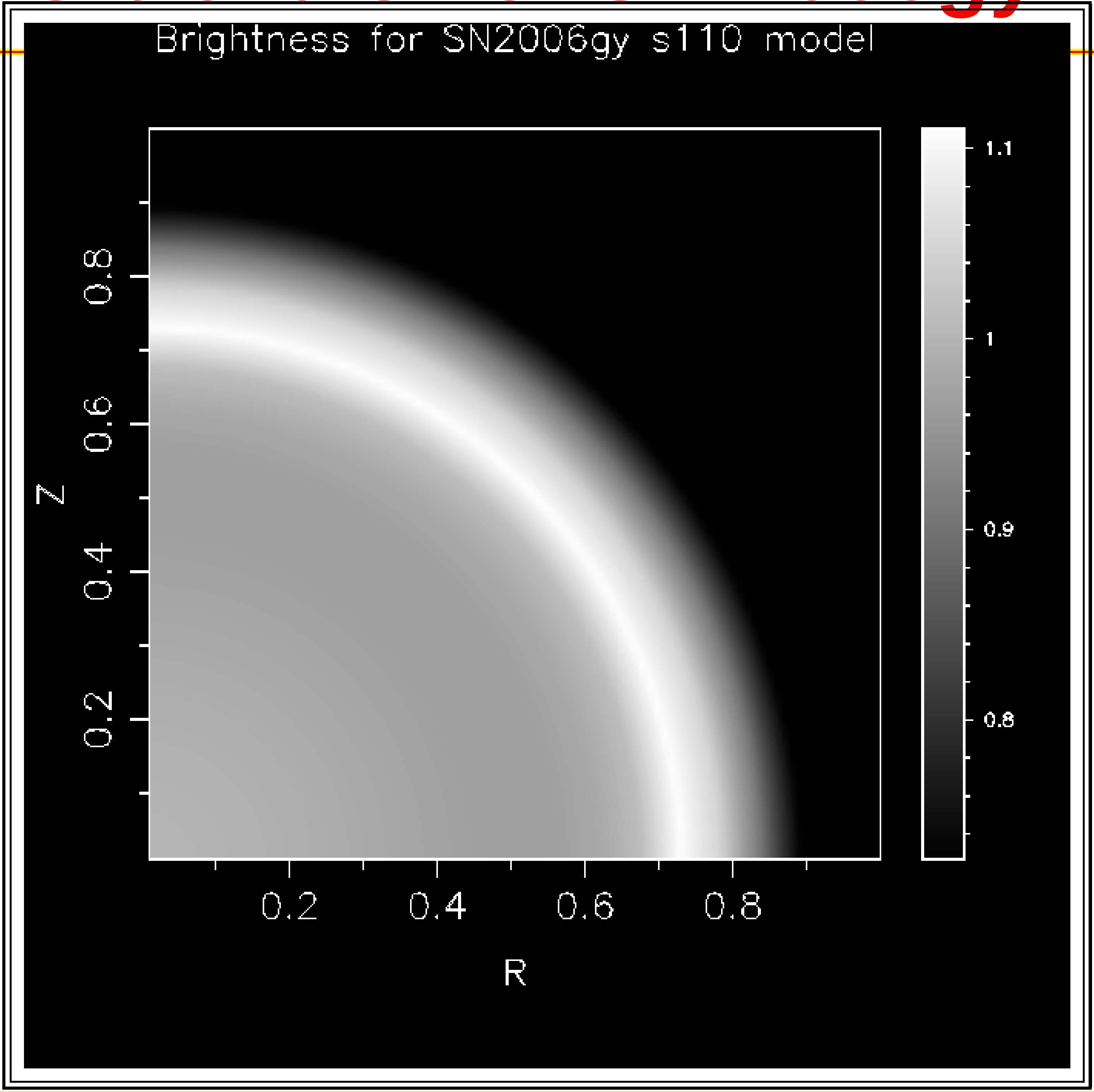


Other X-ray SNe IIn

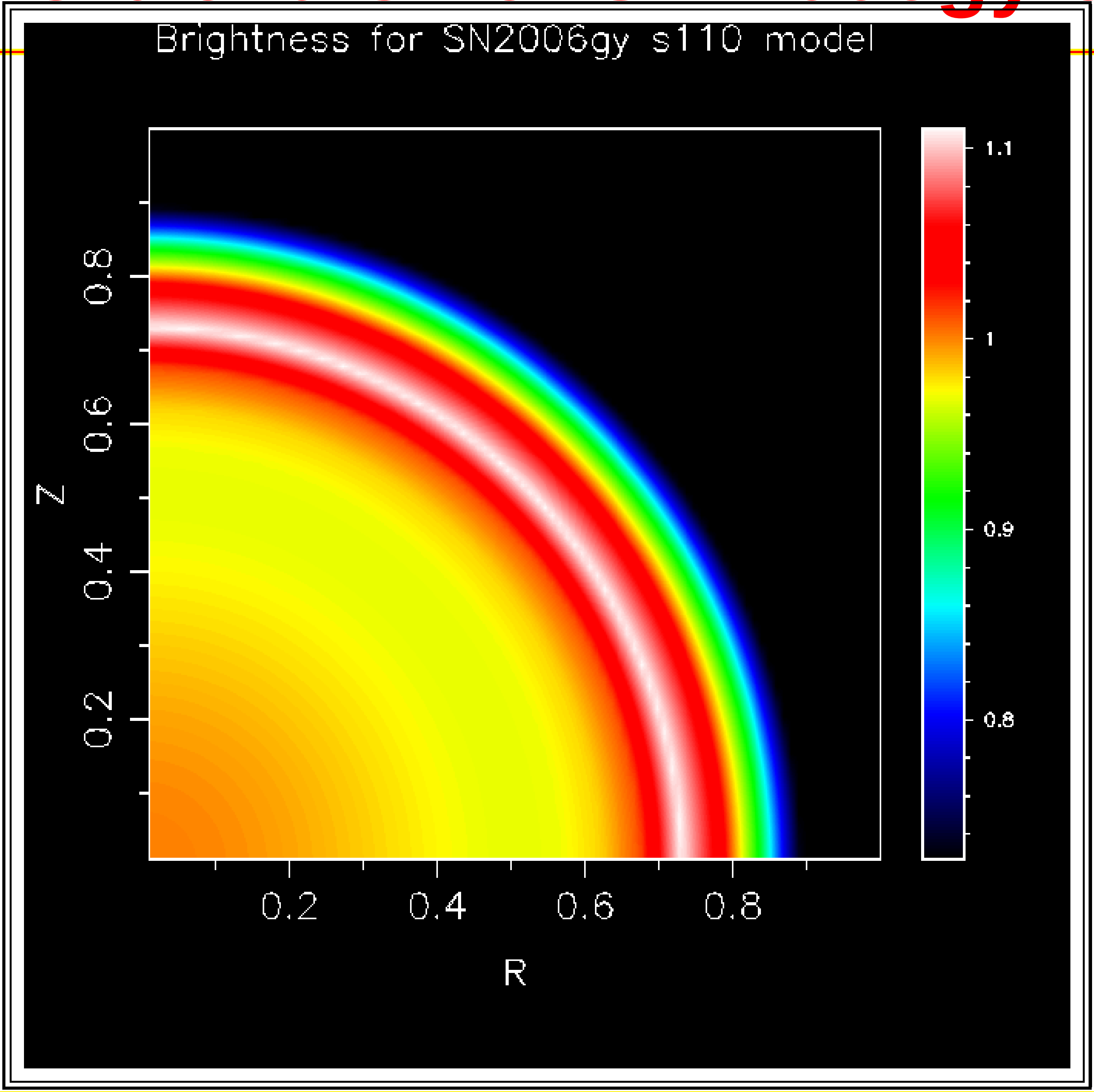
SN	galaxy	dist. Mpc	discovery day
1986J	NGC 891	9.6	3,300
1988Z	+03-28-022	89	2,370
1994W	NGC 4041	25	1,180
1995N	-2-38-017	24	440
1998S	NGC 3877	17	678
2005ip	NGC 2096	30	490
2005kd	PGC14370	64	450

All SN IIn discovered late in X-ray!

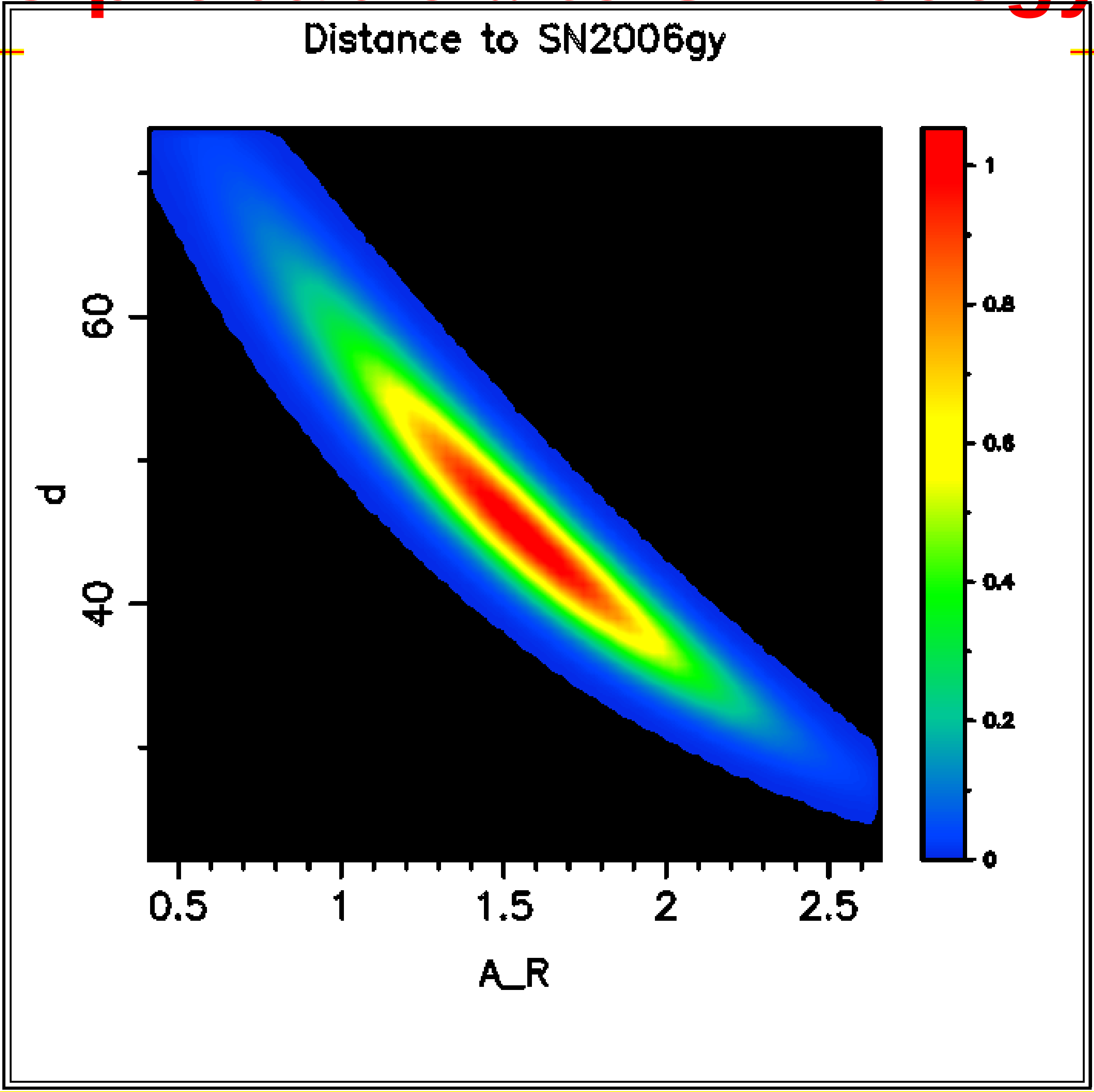
‘Visible’ disk of SN 2006gy



‘Visible’ disk of SN 2006gy c

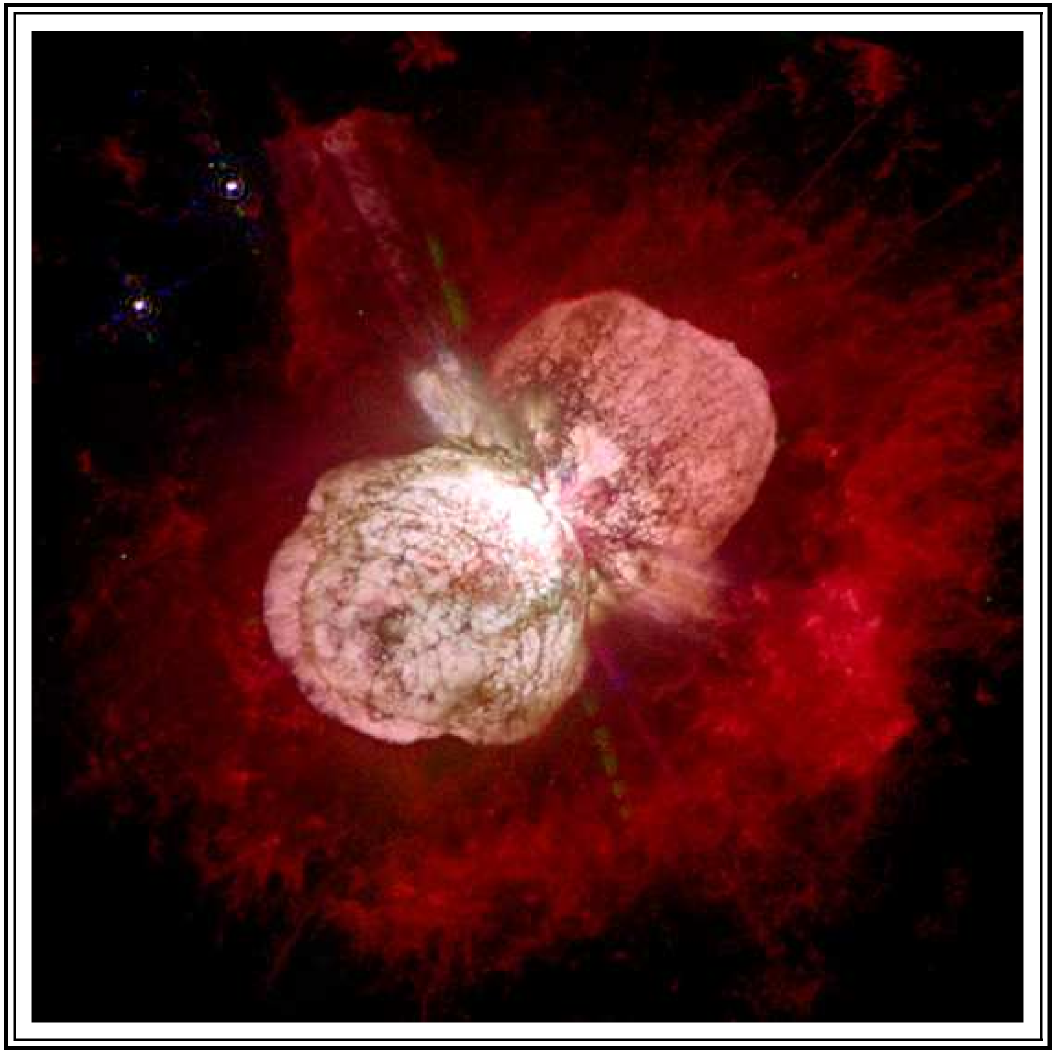


MC probable d to SN 2006gy



Multi-D is a must

for next steps in theoretical modeling



Conclusions

- Radiating shocks are most probable sources of light in most luminous supernovae like SN2006gy.
- The medium for the shining shock to propagate is naturally produced in massive star evolution due to violent non-linear pulsations when e^-e^+ pairs become appreciable in the pressure in their interiors.
- The supercritical radiative shock may be well below X-ray T for a long time.
- Most luminous SN 2006gy events may be observed at high z [for years due to $(1+z)$] and may be useful as direct distance indicators in cosmology.