Models of SNe IIn for cosmology: problems to solve

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Kyoto, 31st of October 2013

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Sources

- Work on SN light curves with E.Sorokina, P.Baklanov, M.Potashov, A.Tolstov, A.Dolgov, K.Nomoto, N.Tominaga, M.Tanaka, T.Moriya, Y.Kamiya
- Observations of SN2006gy, 2009ip, 2010jl...
- Theory of SNIIn (Nadyozhin,Grasberg,Chugai,SB, Woosley,Heger...)
- Recent papers: Blinnikov e'a 2012, Baklanov e'a 2013 (JETPL), Potashov e'a 2013 (MNRAS)

SNe as distance indicators

Nobel prize in physics 2011
"for the discovery of the accelerating expansion of the Universe through observations of distant supernovae"

Secondary

SNe Ia

S.Perlmutter

A.Riess

B.Schmidt

Nobel prize in physics 2011

Actually, neither acceleration, nor the expansion itself of the Universe are directly observable!

This is hard because decades of accurate observations are $\sim 10^{-9}$ the age of the Universe. Accuracy of observations for distances and angles in large scale is much much worse.

What is measured: distance and redshift

Photometric distance:

$$d_{\rm ph}^2 = \frac{L(\text{emitted, ergs/s})}{4\pi F(\text{observed, ergs/s/cm}^2)}$$

Dependence on redshift z

$$d_{\rm ph}(z)(\Omega_m, \Omega_{DE}, w(z))|_{\text{theory}}$$

is determined by cosmology.
Comparison with

$$d_{\rm ph}(z)(\text{observed})$$

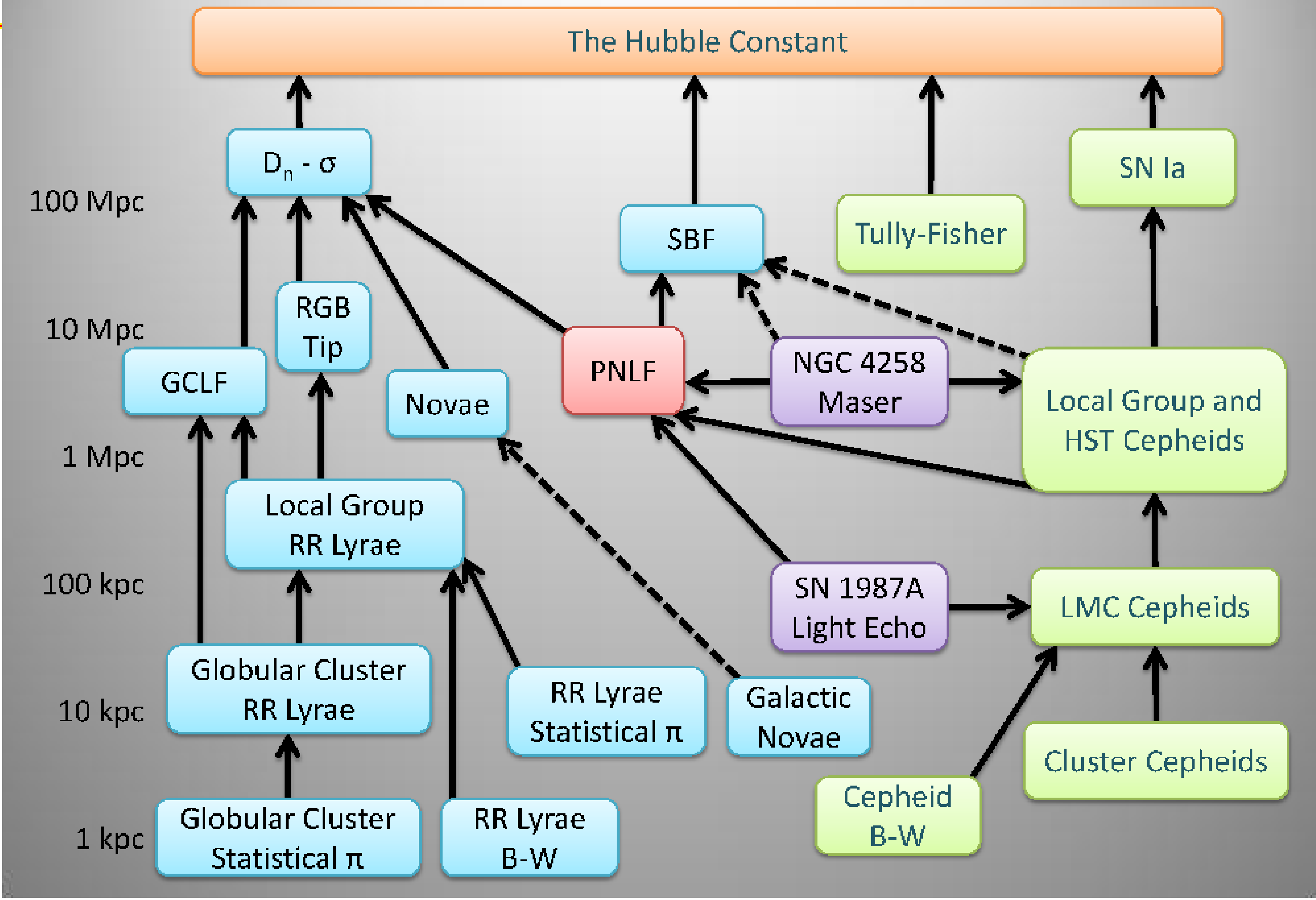
allows one to find $\Omega_m, \Omega_{DE}, w(z)$, etc.

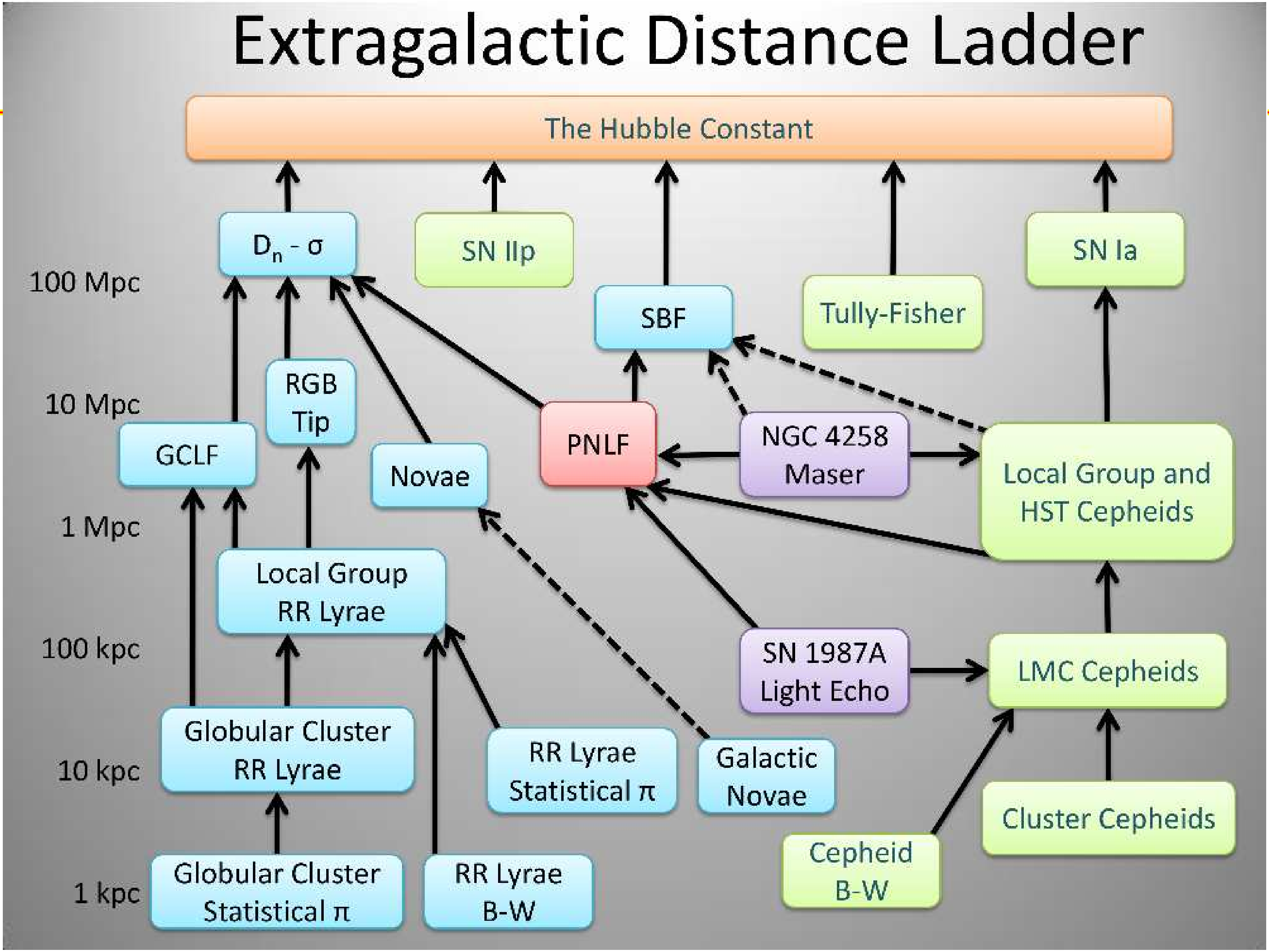
There are models without expansion producing similar relations, e.g. Wetterich, arXiv:1303.6878

Distance indicators

Primary	Secondary
↓	↓
SNe IIP	SNe Ia

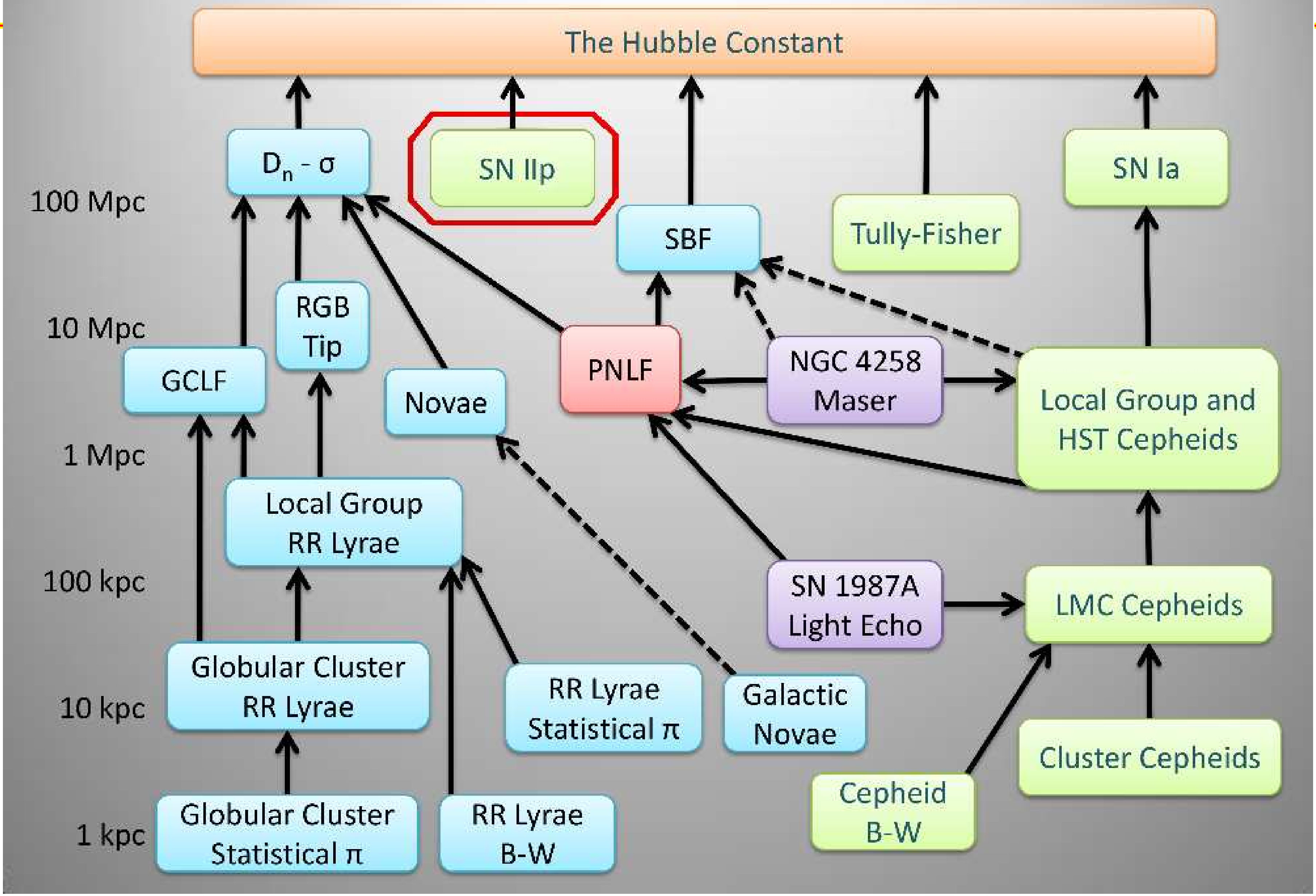
Extragalactic Distance Ladder





Extragalactic Distance Ladder
The Hubble Constant
Dn - σ
SN IIp
SBF
Tully-Fisher
SN Ia
100 Mpc
10 Mpc
1 Mpc
100 kpc
10 kpc
1 kpc
RGB Tip
GCLF
Novae
PNLF
NGC 4258 Maser
Local Group and HST Cepheids
Local Group RR Lyrae
SN 1987A Light Echo
LMC Cepheids
Globular Cluster RR Lyrae
RR Lyrae Statistical π
Galactic Novae
Cluster Cepheids
Globular Cluster Statistical π
RR Lyrae B-W
Cepheid B-W

Extragalactic Distance Ladder



Distance indicators

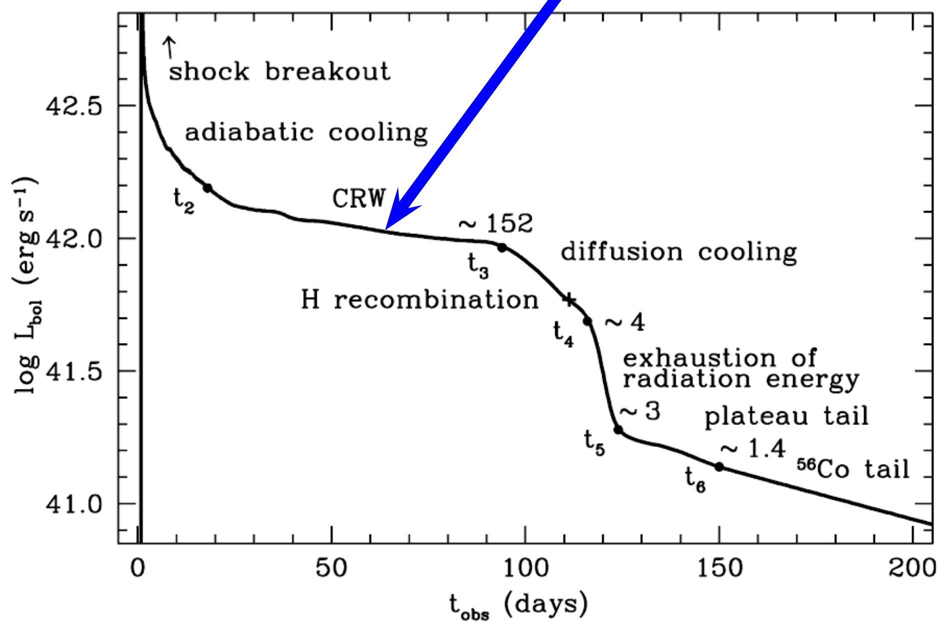
Primary

SNe IIP

V. Utrobin A&A
461, 233 (2007)

SN 1999em LC

Plateau phase



Distance indicators

Primary → SNe IIP → Expanding photosphere method (EPM)

Secondary → SNe Ia

R. P. Kirshner and J. Kwan, Astrophys. J. 193, 27 (1974)

Expanding Photosphere Method (EPM)

Cf. Baade(1926)-Wesselink(1946) method for Cepheids . Measuring color and flux at two different times, t_1 and t_2, one finds the ratio of the star's radii, R_2/R_1 (or from interferometry).

Using weak lines which are believed to be formed near the photosphere one can measure the photospheric speed $v_{\rm ph}$.

Then $\int_{t_1}^{t_2} v_{\rm ph} dt$ would give $\Delta R_{\rm ph} = R_2 - R_1$.

Knowing R_2/R_1 and $R_2 - R_1$, it is easy to solve for the radii. The ratio of fluxes gives

$$\frac{D^2}{R^2} = \frac{F_\nu(\text{emitted})}{F_\nu(\text{observed})} ,$$

hence the distance D.

Problems with BW

But this idea does not work for supernovae (as a rule)!

Velocity of matter at the photosphere $v_{\rm ph}$ is not at all $\dot{R}_{\rm ph} \equiv dR_{\rm ph}/dt$.

Velocity $v_{\rm ph}$ and $\dot{R}_{\rm ph}$ may even have opposite signs!

Kirshner & Kwan, 1974

The main idea of EPM for SNe is different from BW!
(Kirshner & Kwan were the first to point this out.)

Using weak lines one can measure the matter velocity on photospheric level, $v_{\rm ph}$, and then one finds,

$$R_{\rm ph} = v_{\rm ph} t \ .$$

This is based on the assumption of free expansion,

$$v = r/t \propto r \ ,$$

– like a Hubble law. Velocity is not assumed to be $dR_{\rm ph}/dt$.

Distance from EPM

Now the distance D to the supernova is

$$D = R_{\rm ph}\sqrt{\frac{F_\nu(\rm model)}{F_\nu(\rm observed)}}$$

if a reliable model flux $F_\nu(\rm model)$ at the SN photosphere is compared with the detected flux $F_\nu(\rm observed)$.

Great Success of EPM

B.Schmidt et al.(1994), R.Eastman et al.(1996) found $H_0 = 73 \pm 6$ based on EPM for a set of SNe II.

Distance indicators

Primary

SNe IIP

Secondary

SNe Ia

EPM

Spectral-fitting expanding atmosphere method (SEAM)

E. Baron, et al. Astrophys. J. Lett. 616, L91 (2004)

Distance indicators

Primary

SNe IIP

Secondary

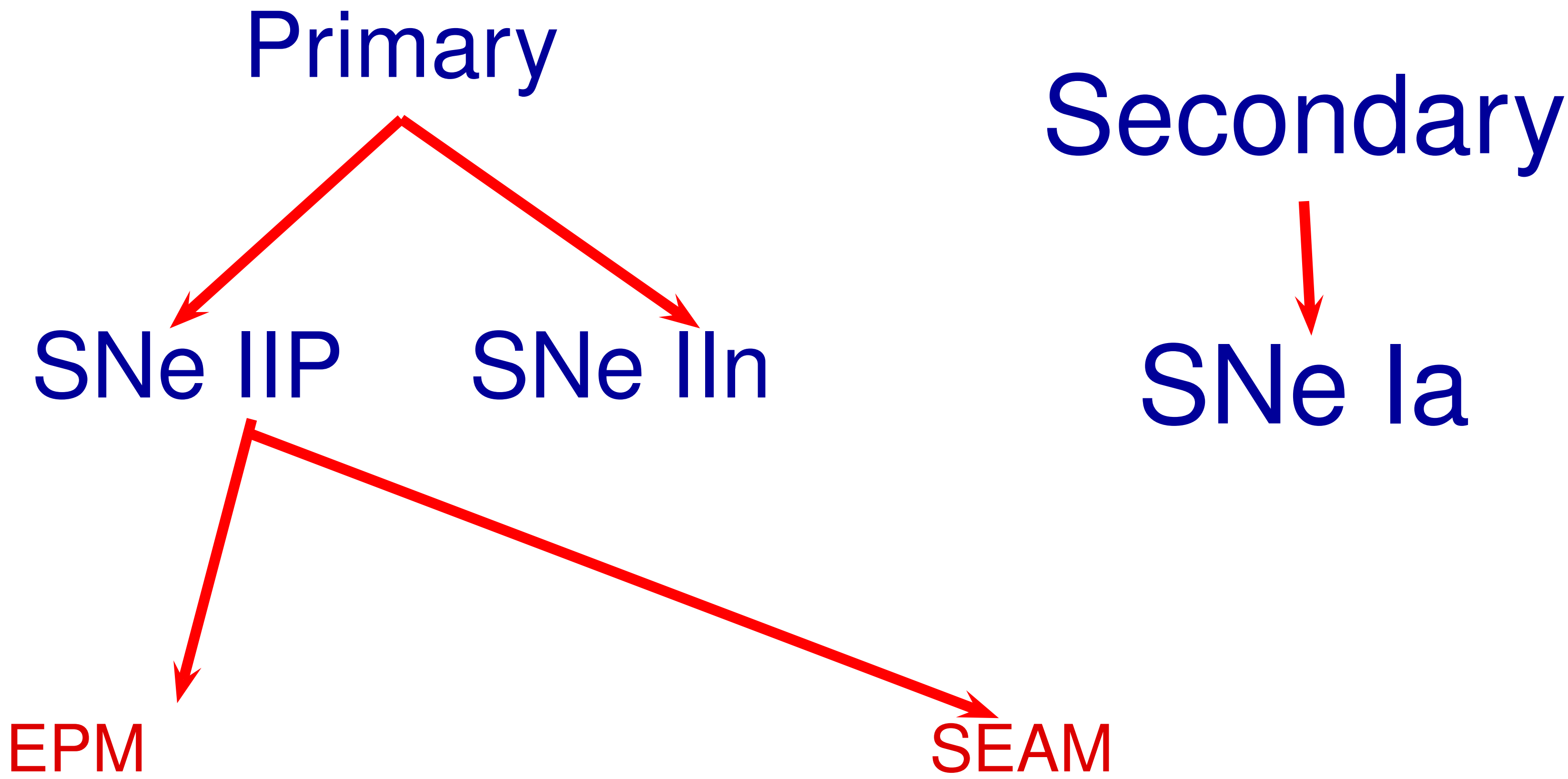
SNe Ia

EPM

SEAM

Free expansion $v = \frac{r}{t}$ is assumed!

Distance indicators



Distance indicators

Primary

SNe IIP   SNe IIn

Secondary

SNe Ia

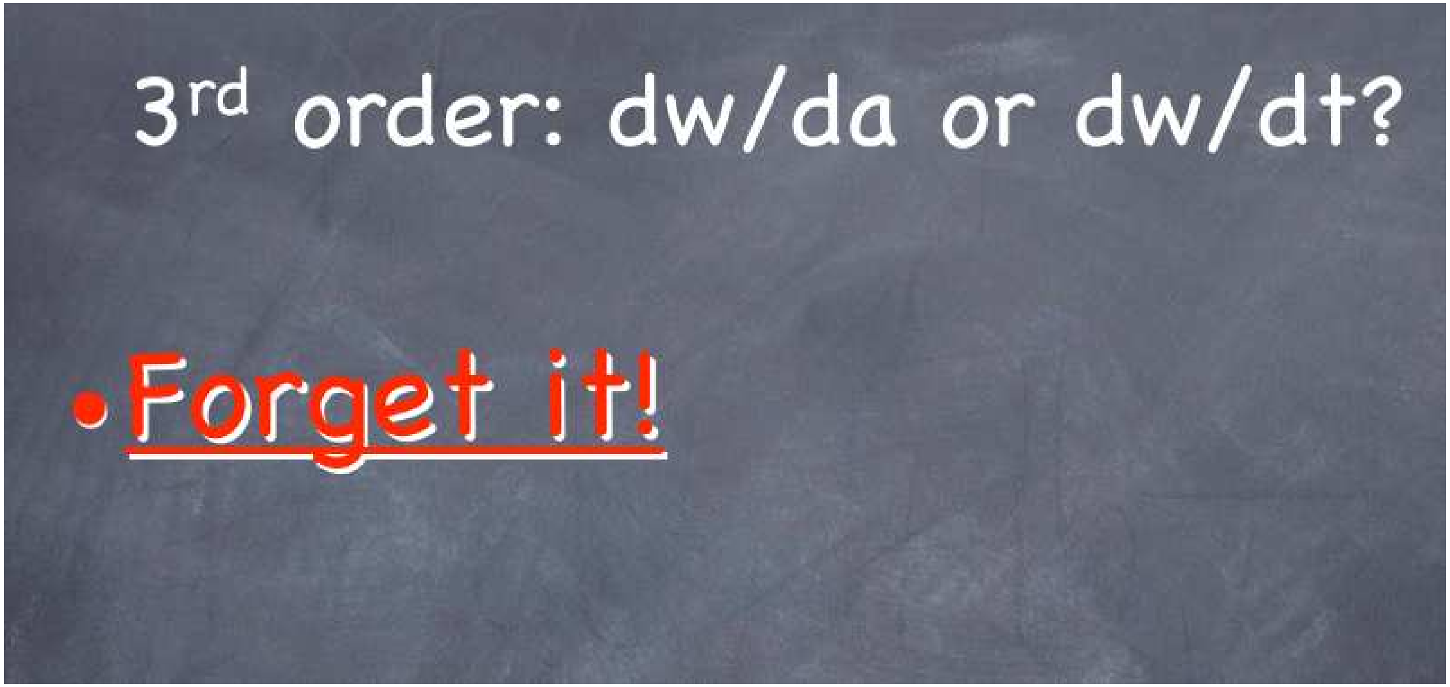
Dense Shell Method (DSM)

No free expansion, back to Baade!

S. Blinnikov, et al. JETP Letters 96, 153 (2012); M. Potashov, et al. MNRAS 431, 98 (2013)

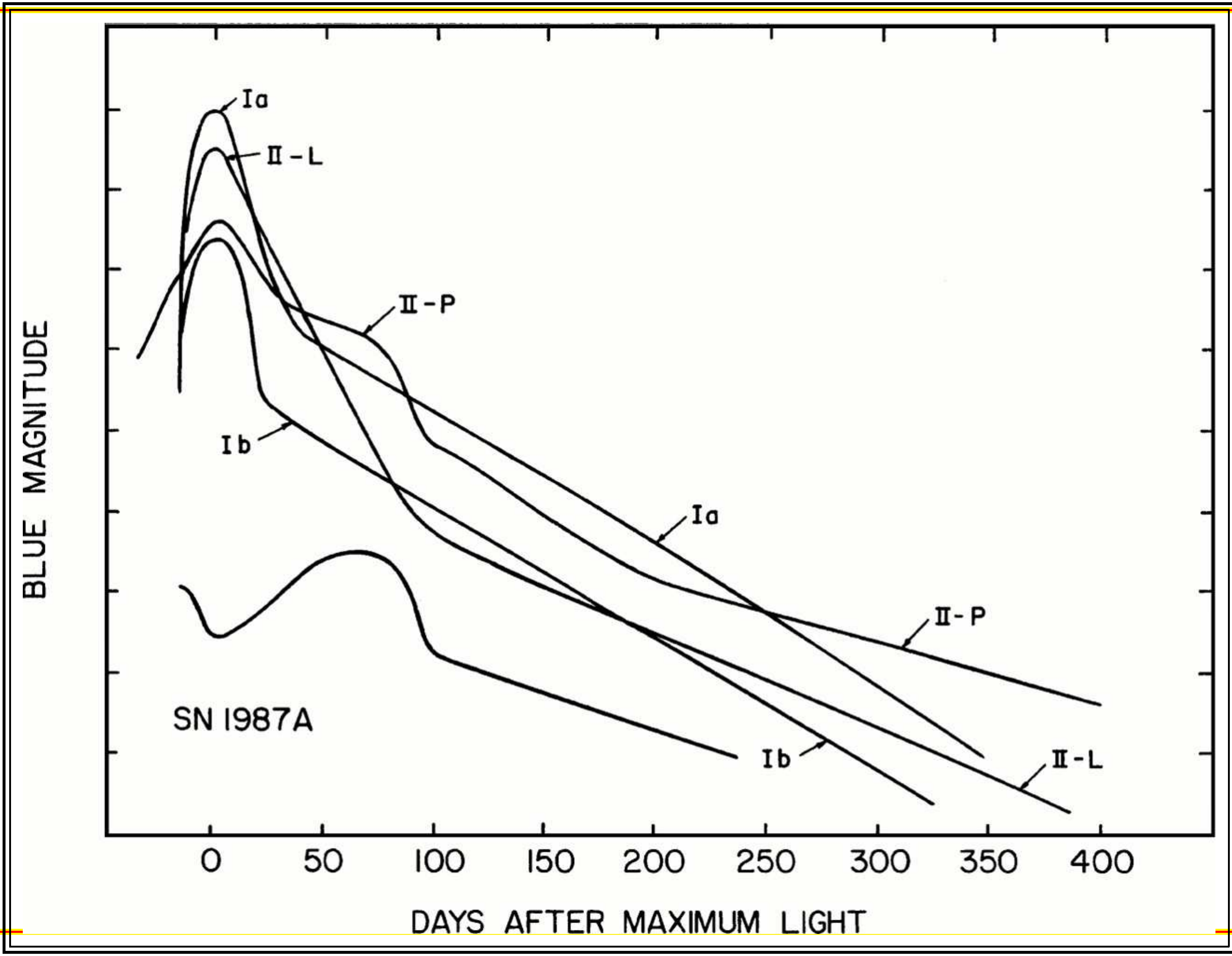
Why we need this?

Nick Suntzeff:

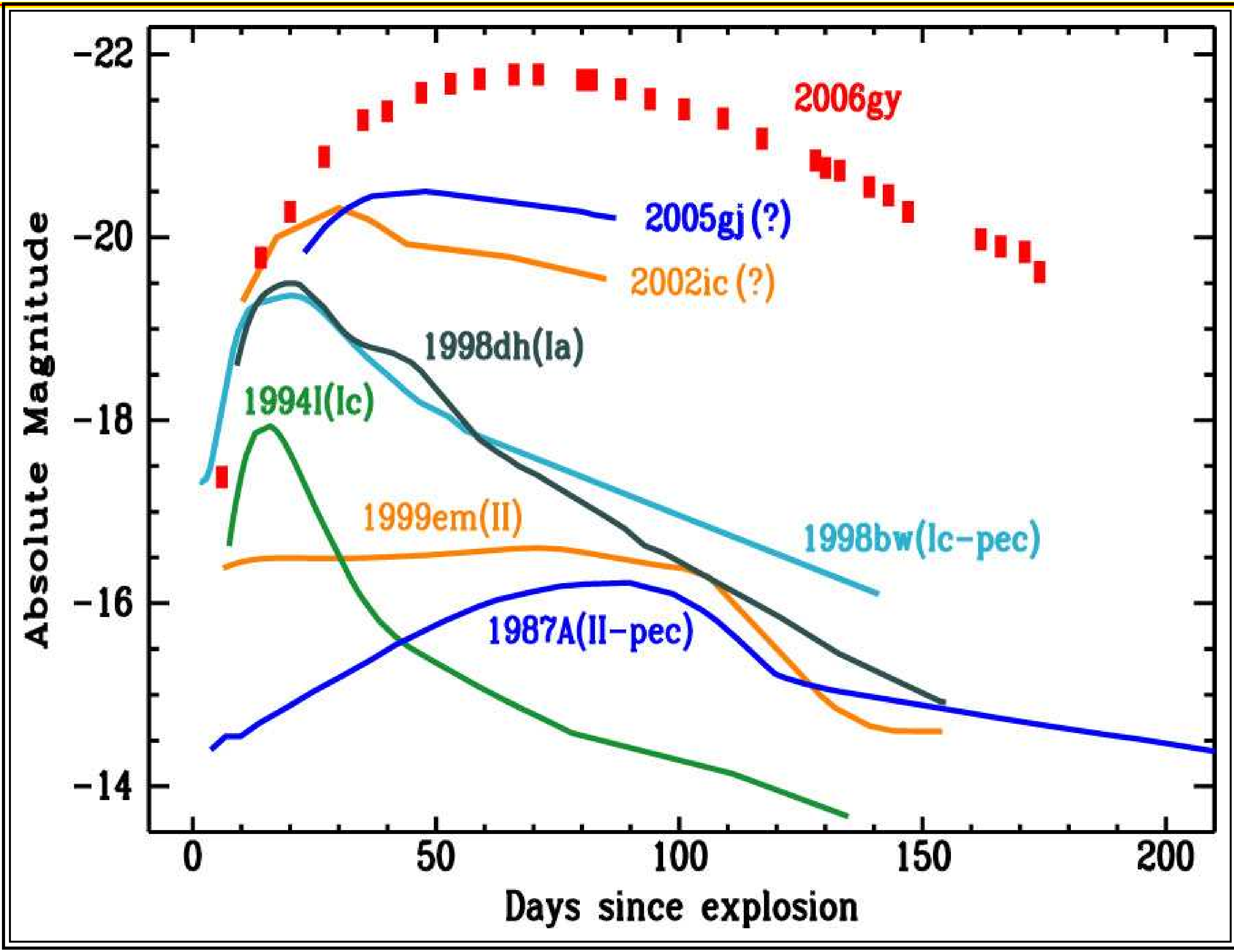


Forget it, when using SNe Ia. Other tools may help.

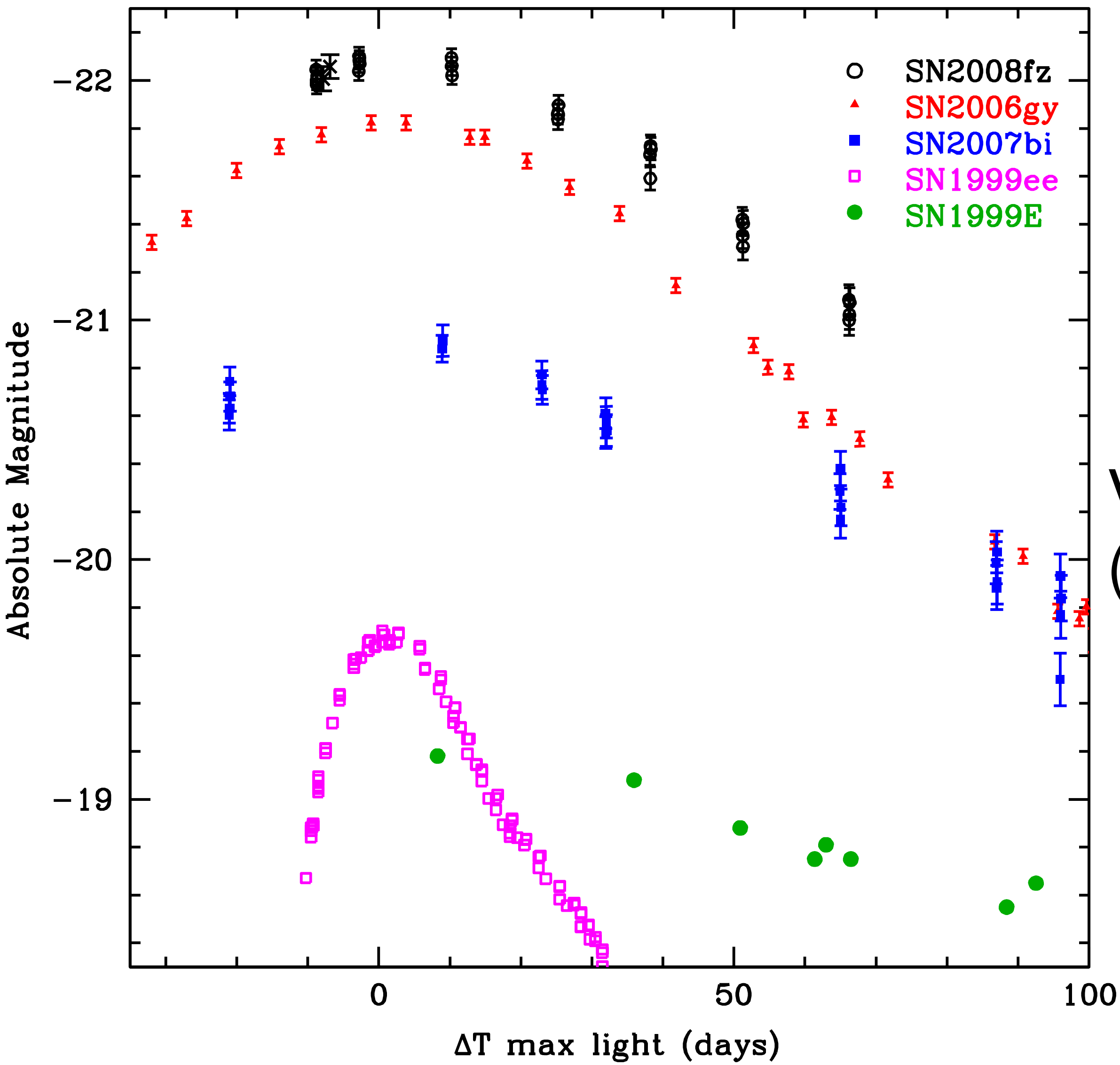
SN Light Curves A.Filippenko in ARAA



Most Luminous SNe N.Smith ea'07



Extremely luminous Type IIn SNe

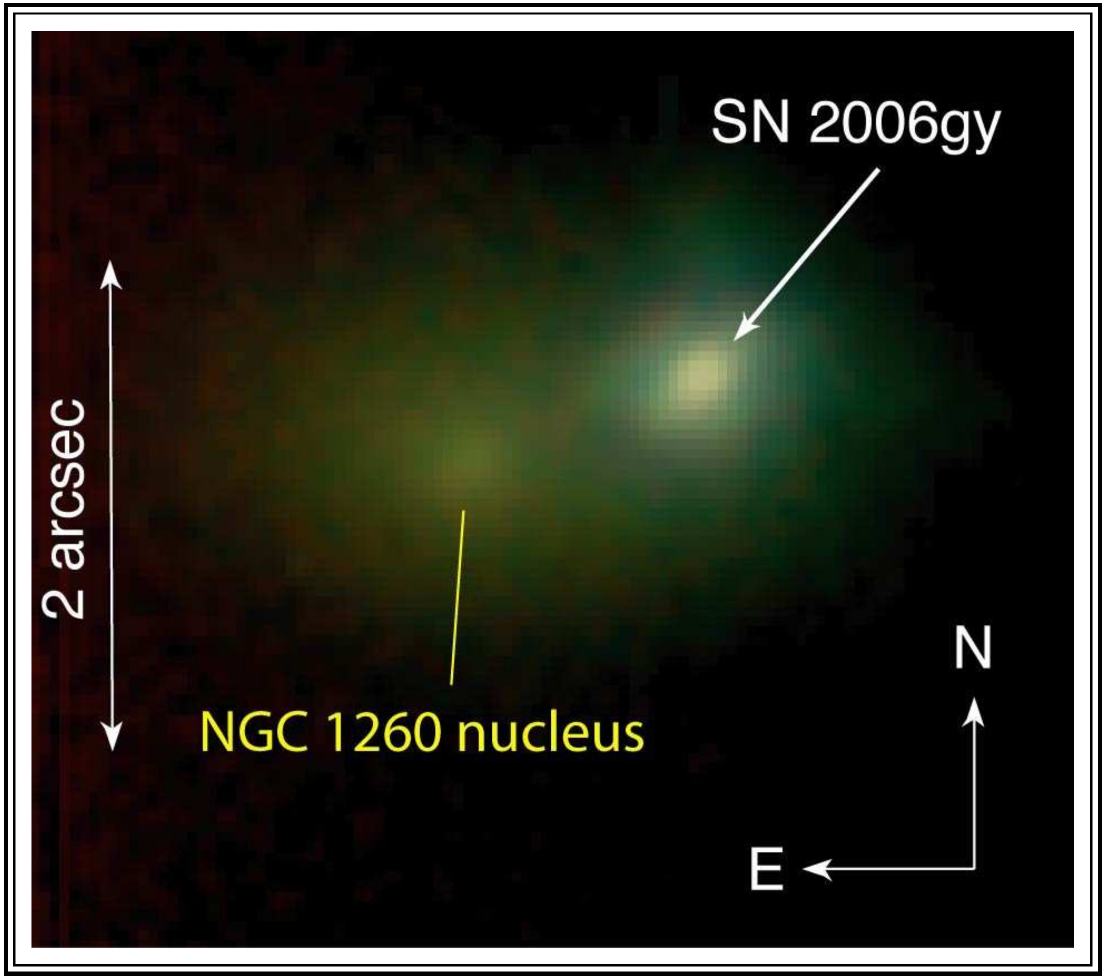


V-band
(Drake et al. 2010)

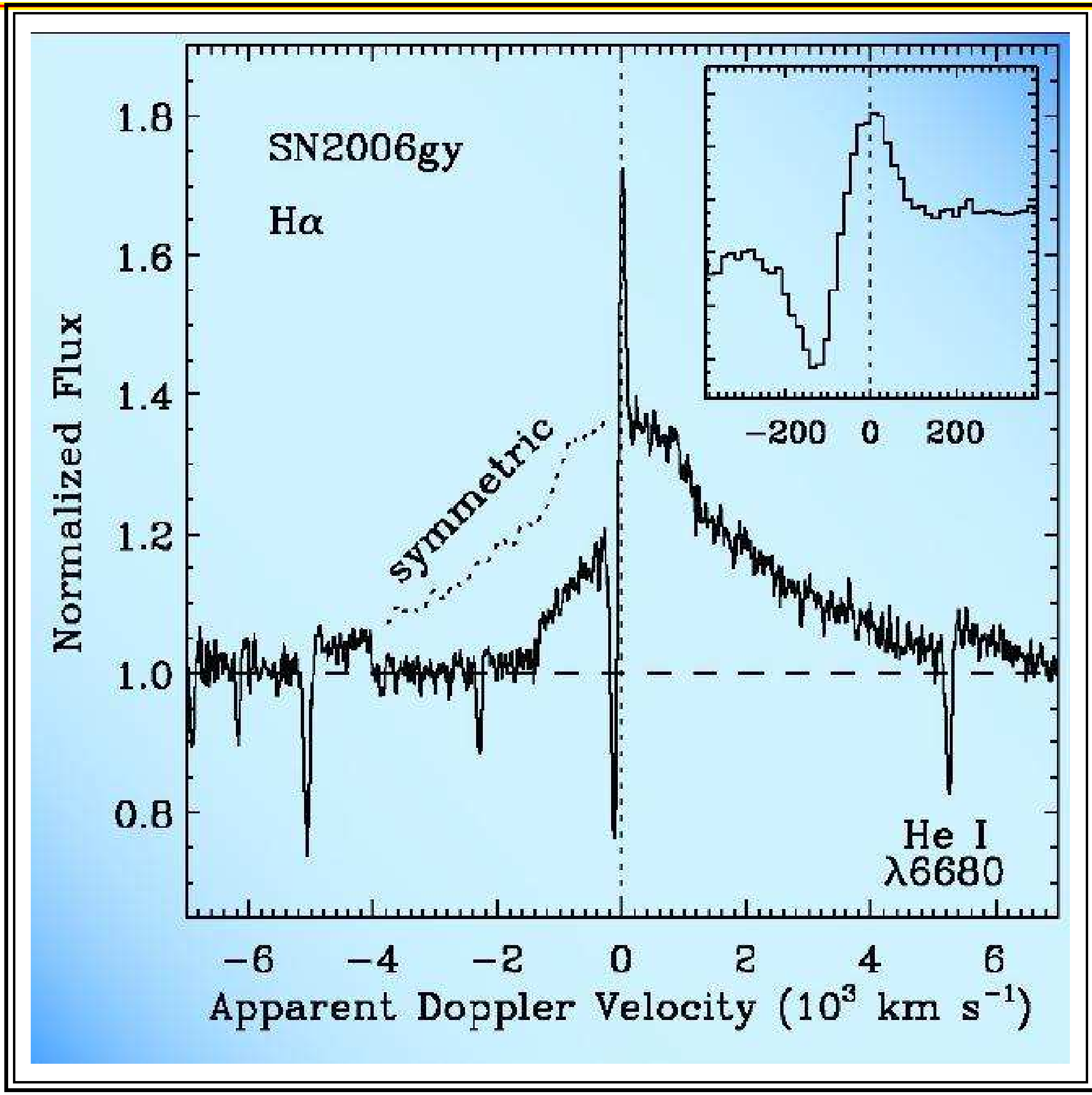
SN 2006gy, type IIn

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

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

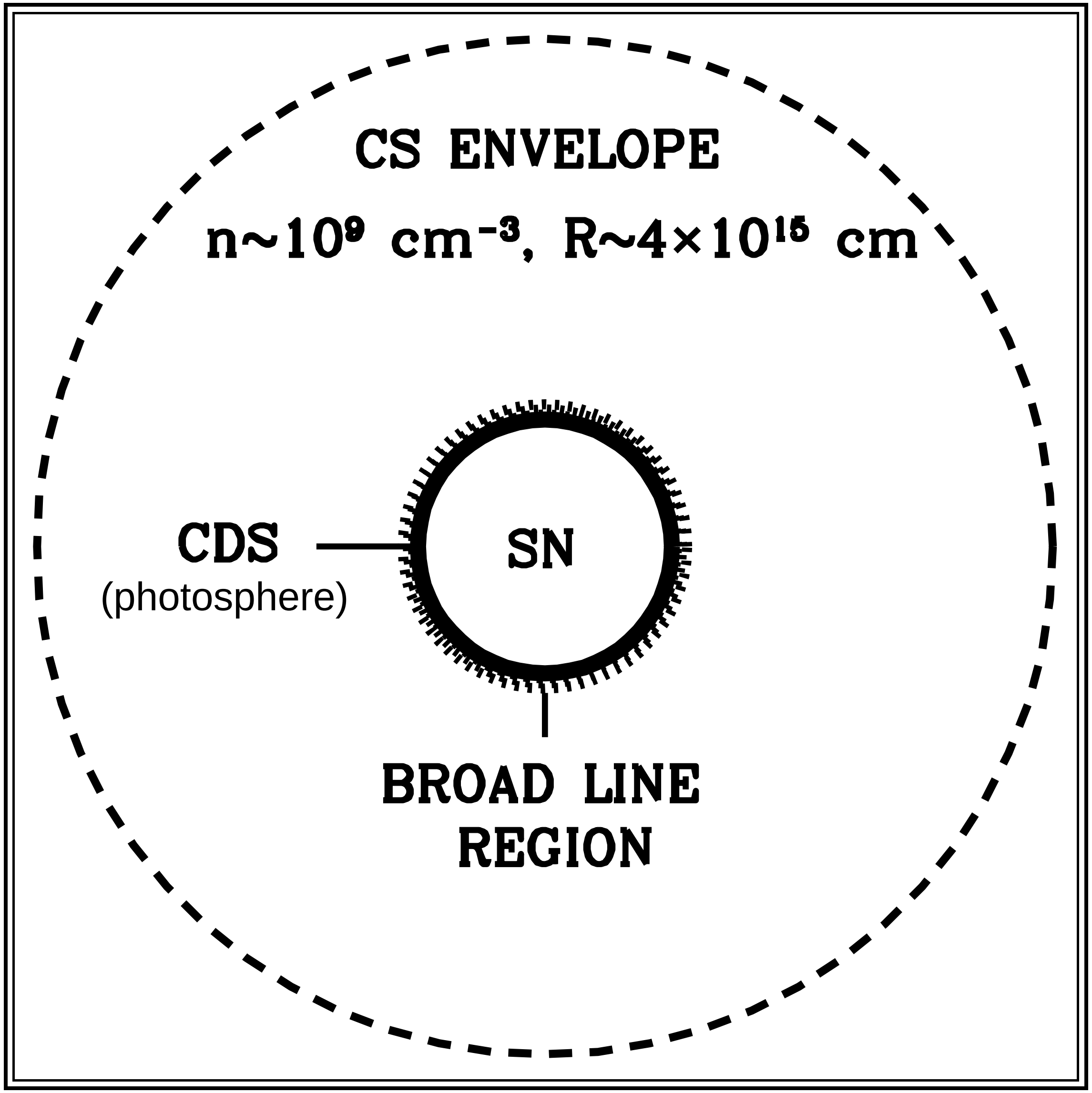


Smith et al. SN 2006gy, H_α profile

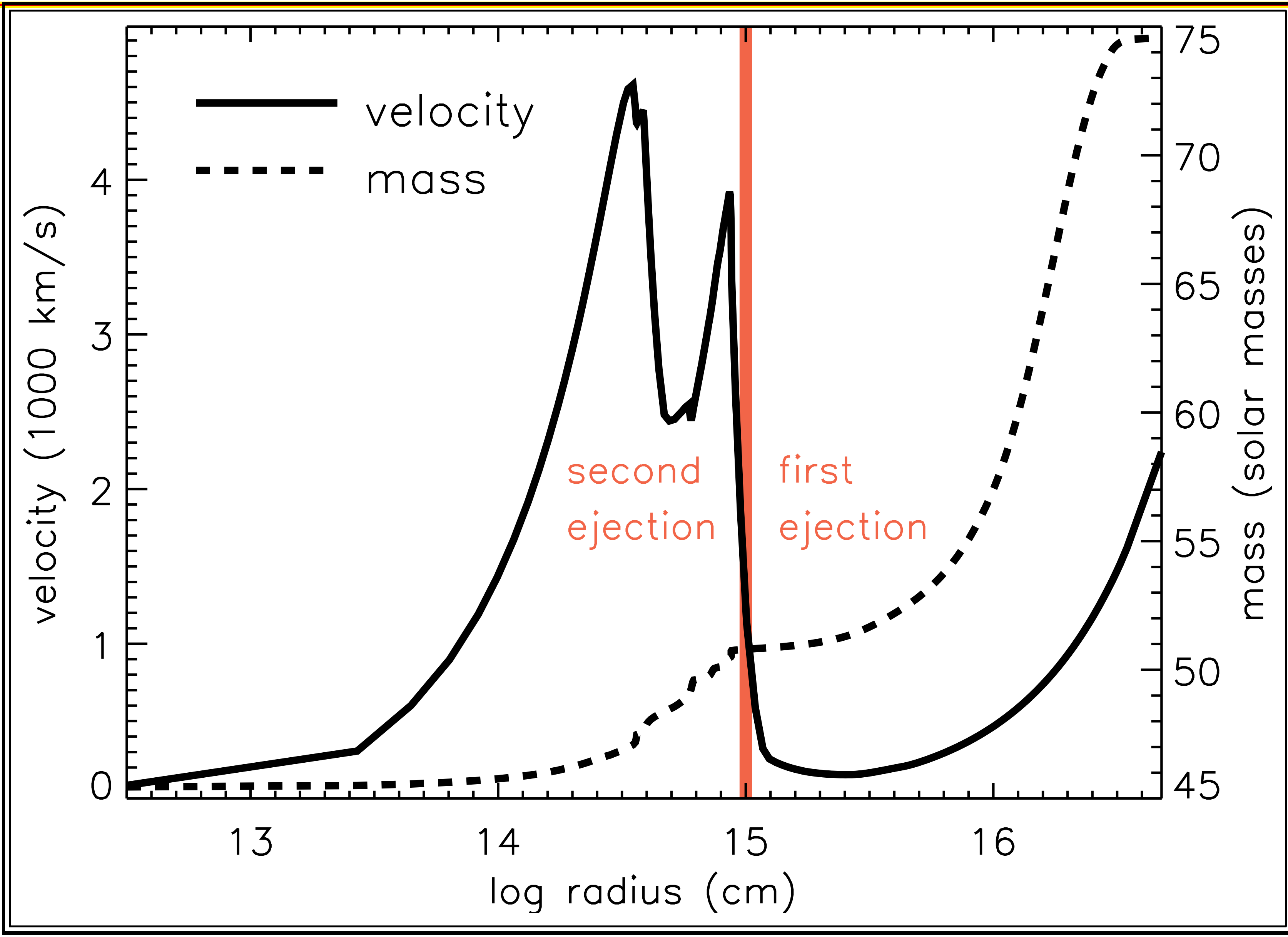


Narrow component ~ 200 km/s, wide ~ 5000 km/s.

SN IIn structure, Chugai, SB ea'04



Two mass ejections Woosley e'a 2007



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

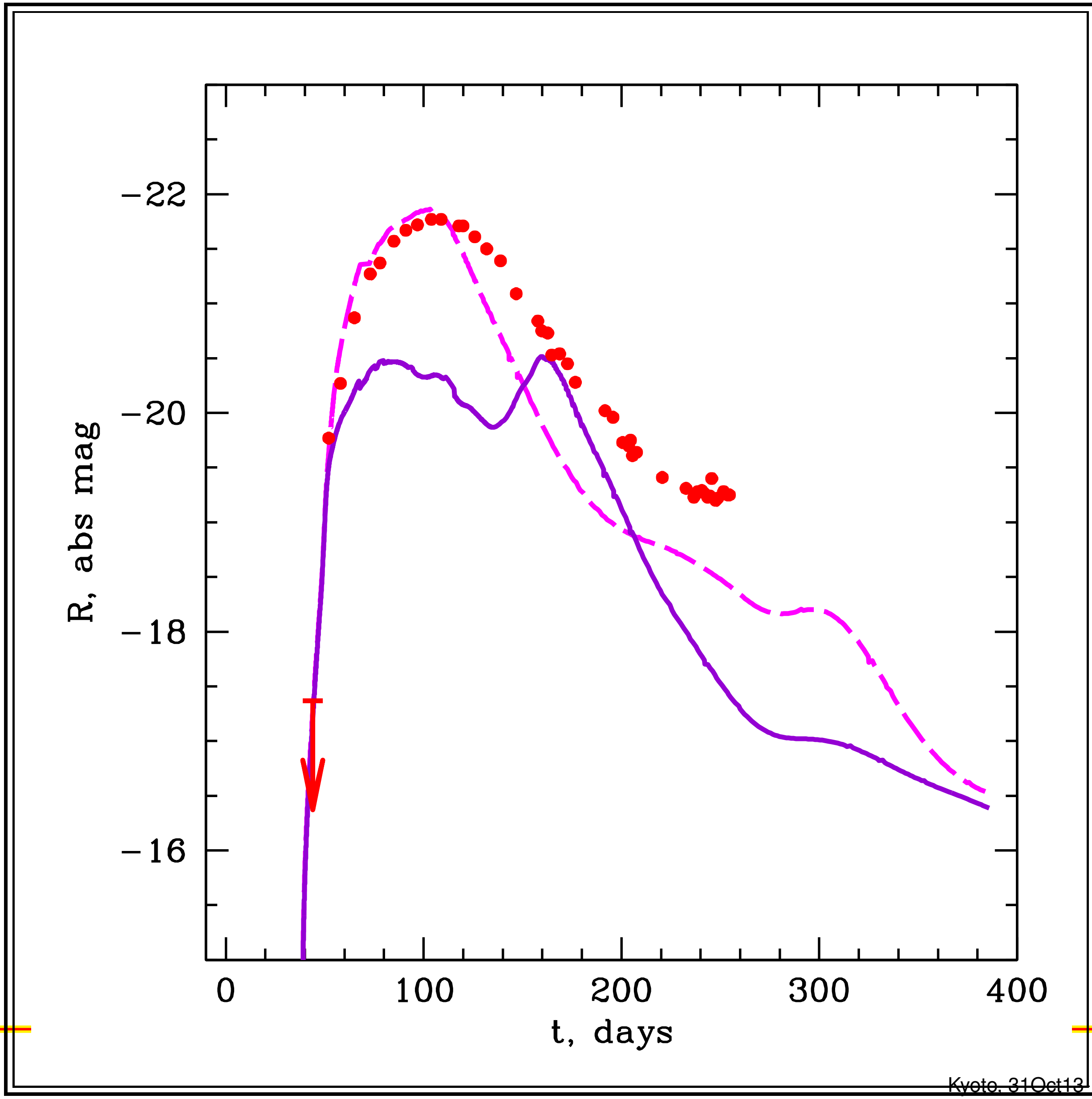
(Submitted September 5, 1985)

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

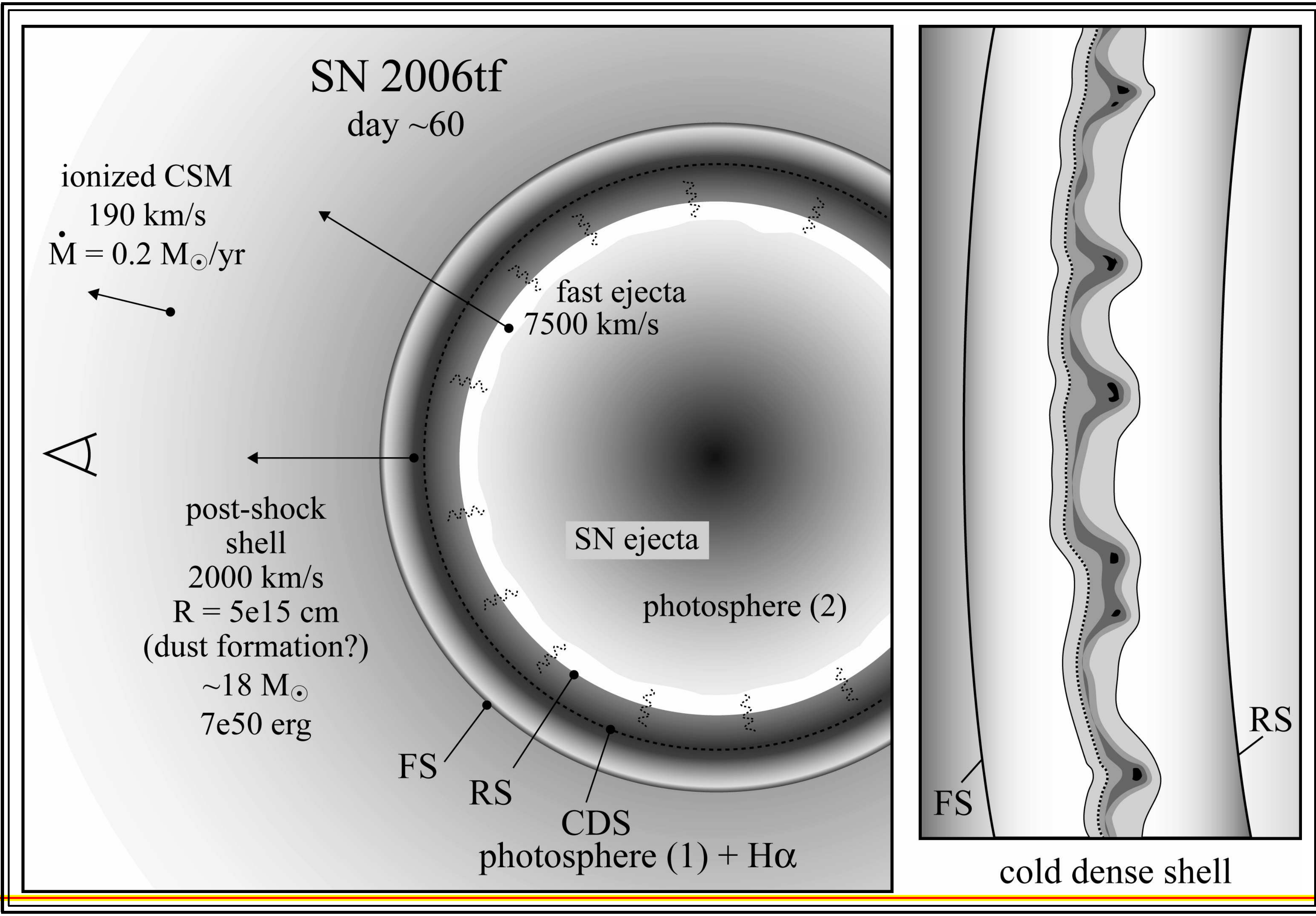
A type II supernovae model wherein a weak explosion precedes a much stronger one can explain the behavior of the narrow-line systems observed in some type II spectra. For SN 1983k in NGC 4699, the two outbursts would have been separated by 1–2 months. Core gravitational collapse generating a relatively 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.

Light curve for SN2006gy

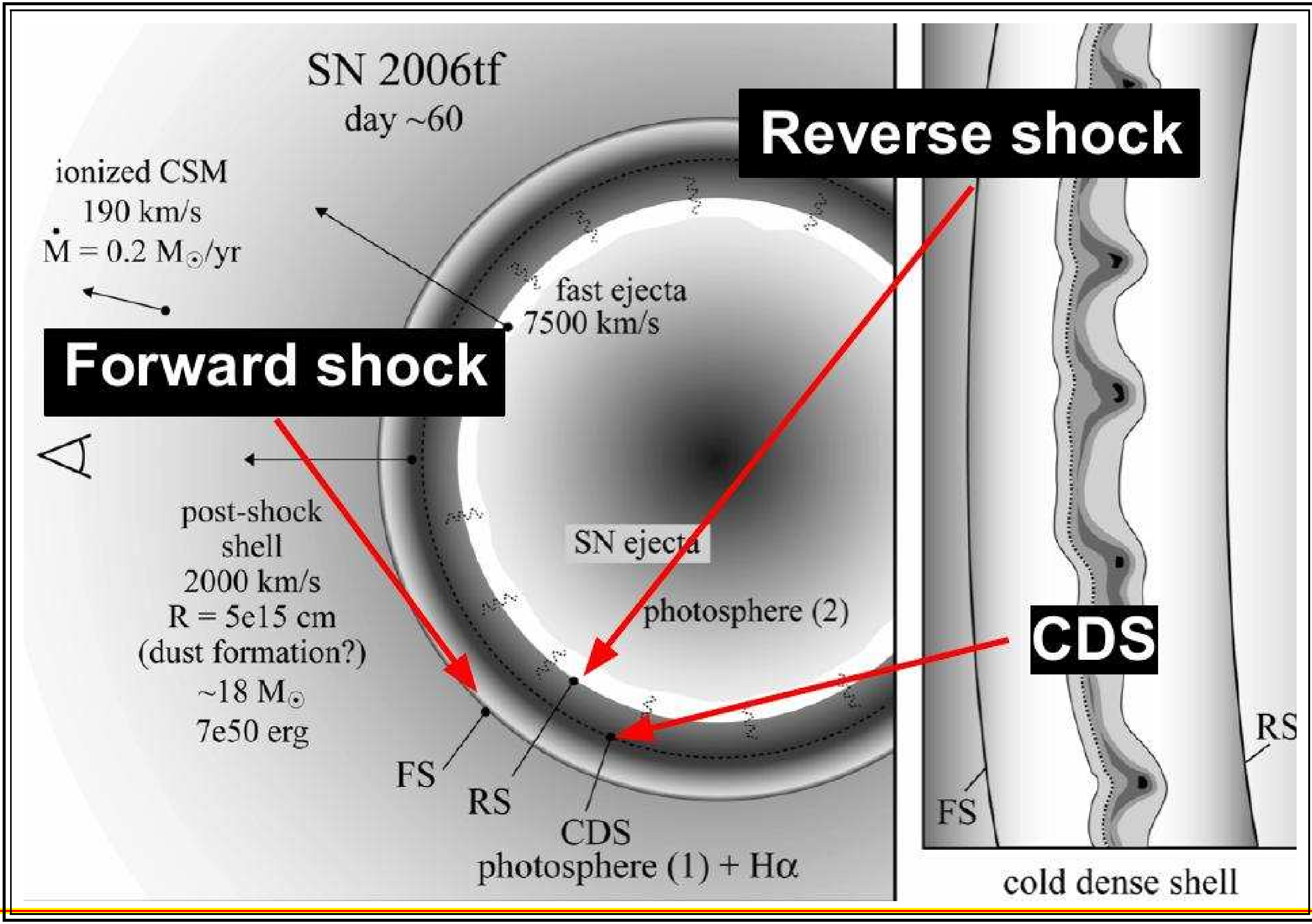
from Woosley, SB, Heger (2007)



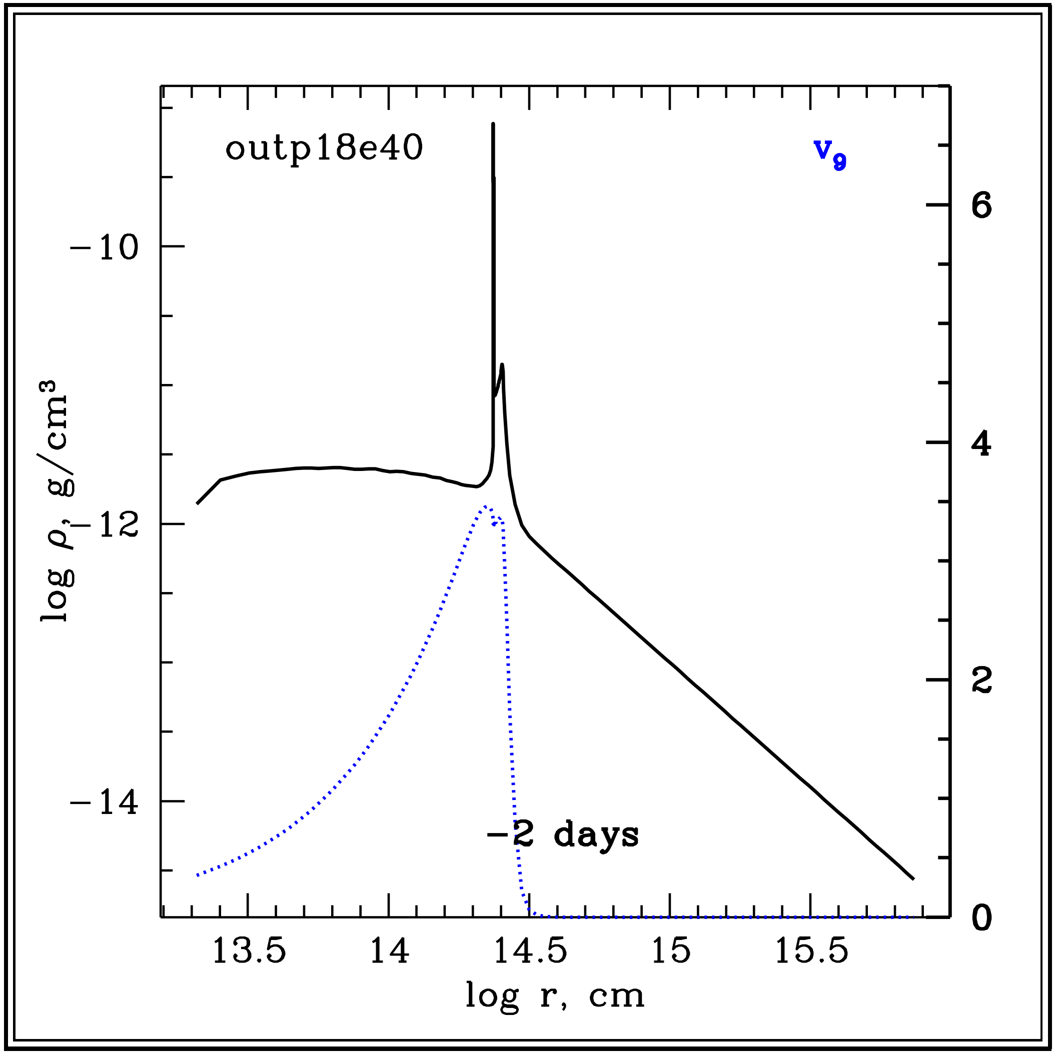
Smith,Chornock ea cartoon, 06tf



Cold Dense Shell

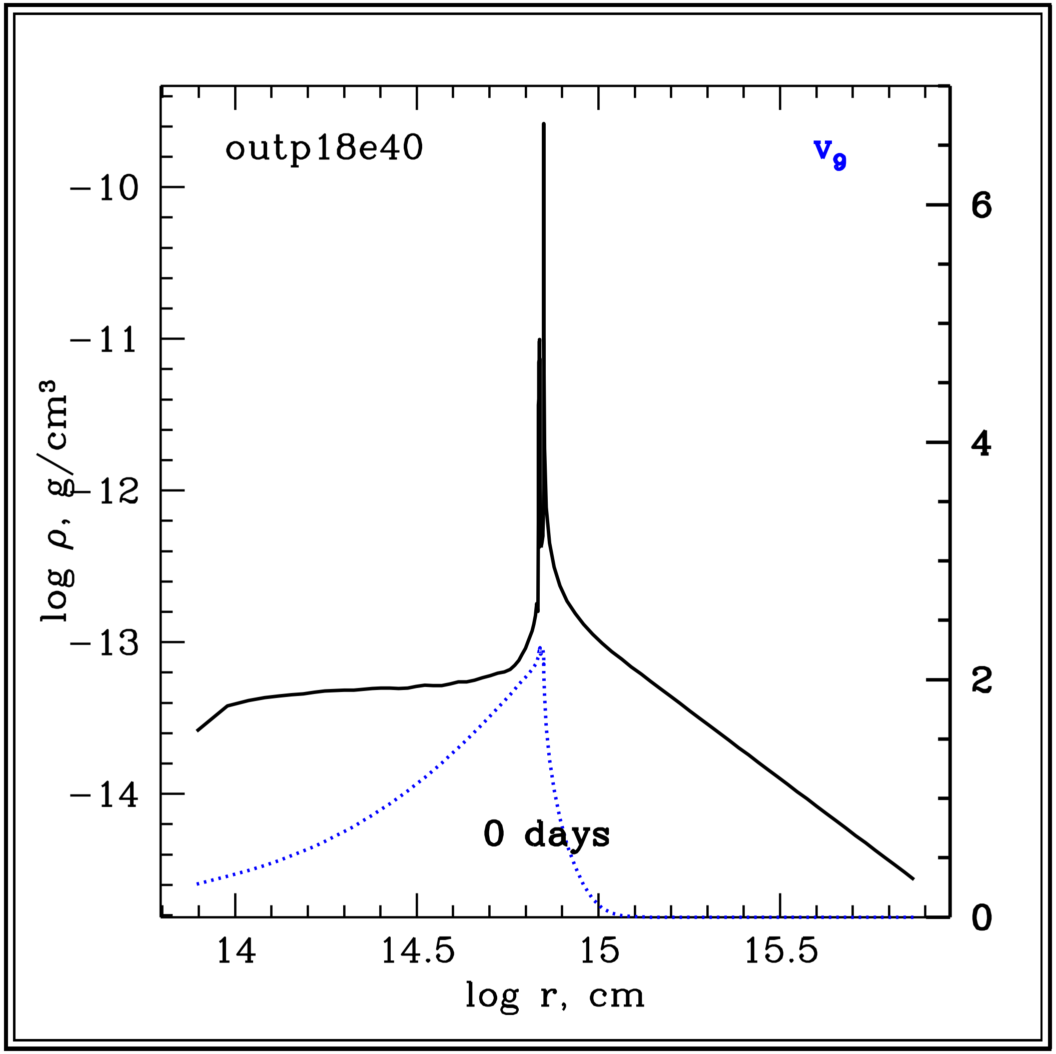


Long Living Dense shells-1 Sorokina et al.



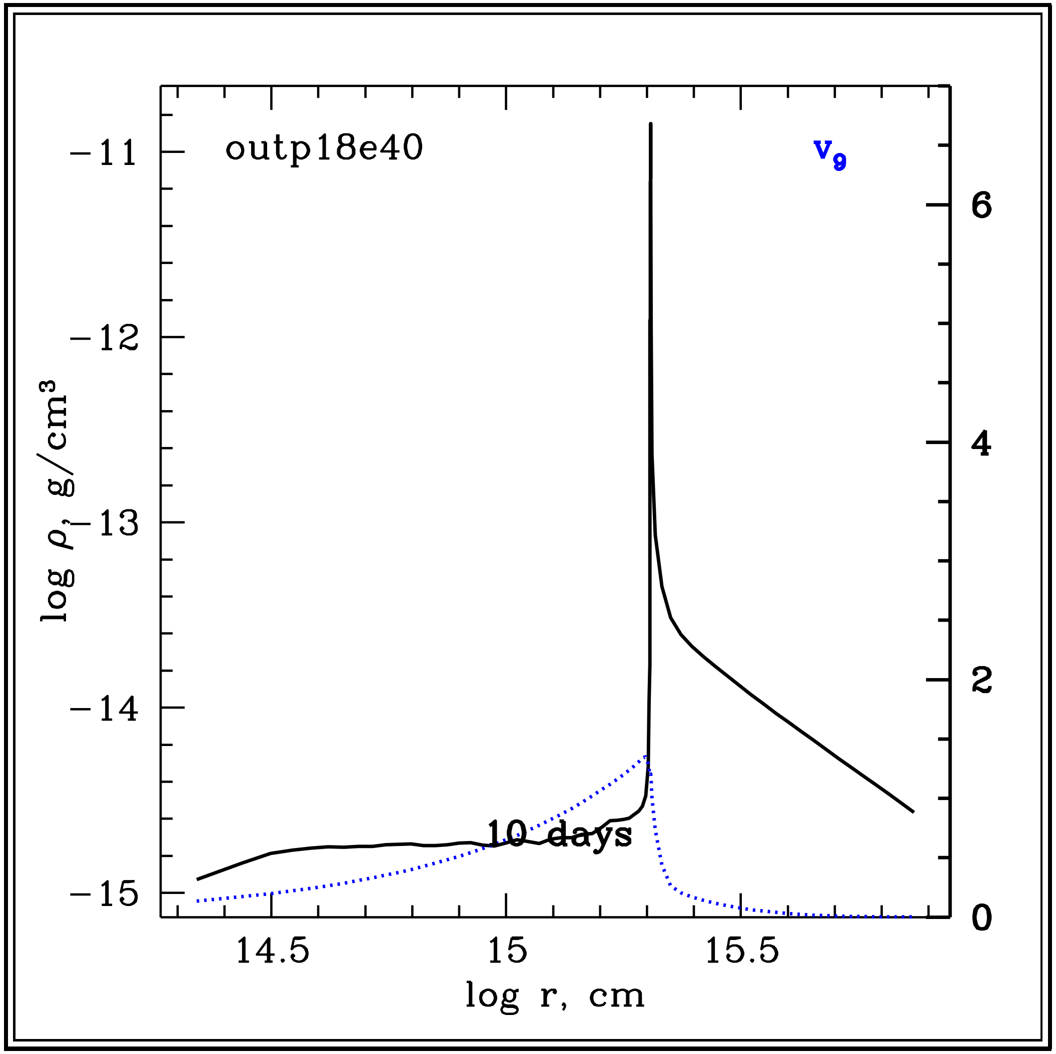
See Poster 16

Long Living Dense shells-2 Sorokina et al.



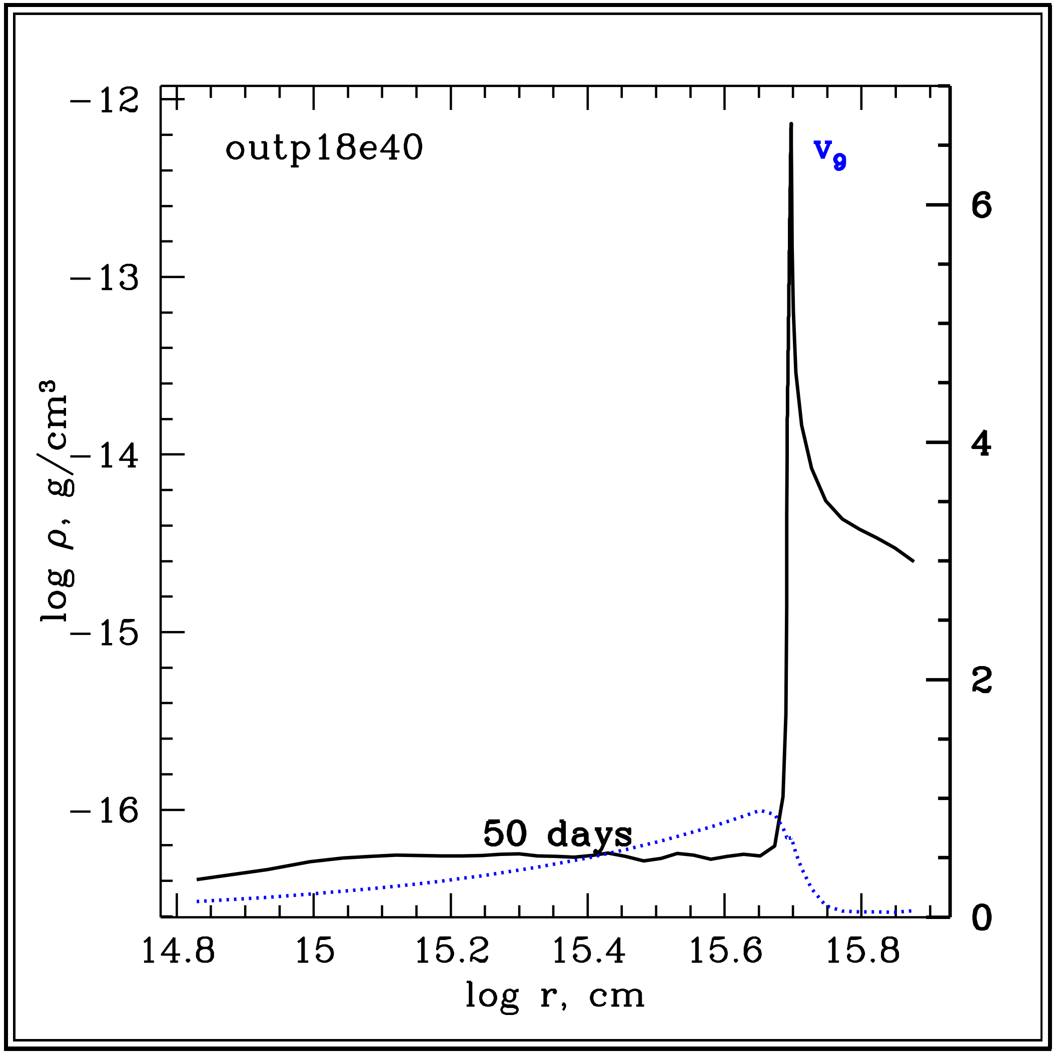
See Poster 16

Long Living Dense shells-3 Sorokina et al.



See Poster 16

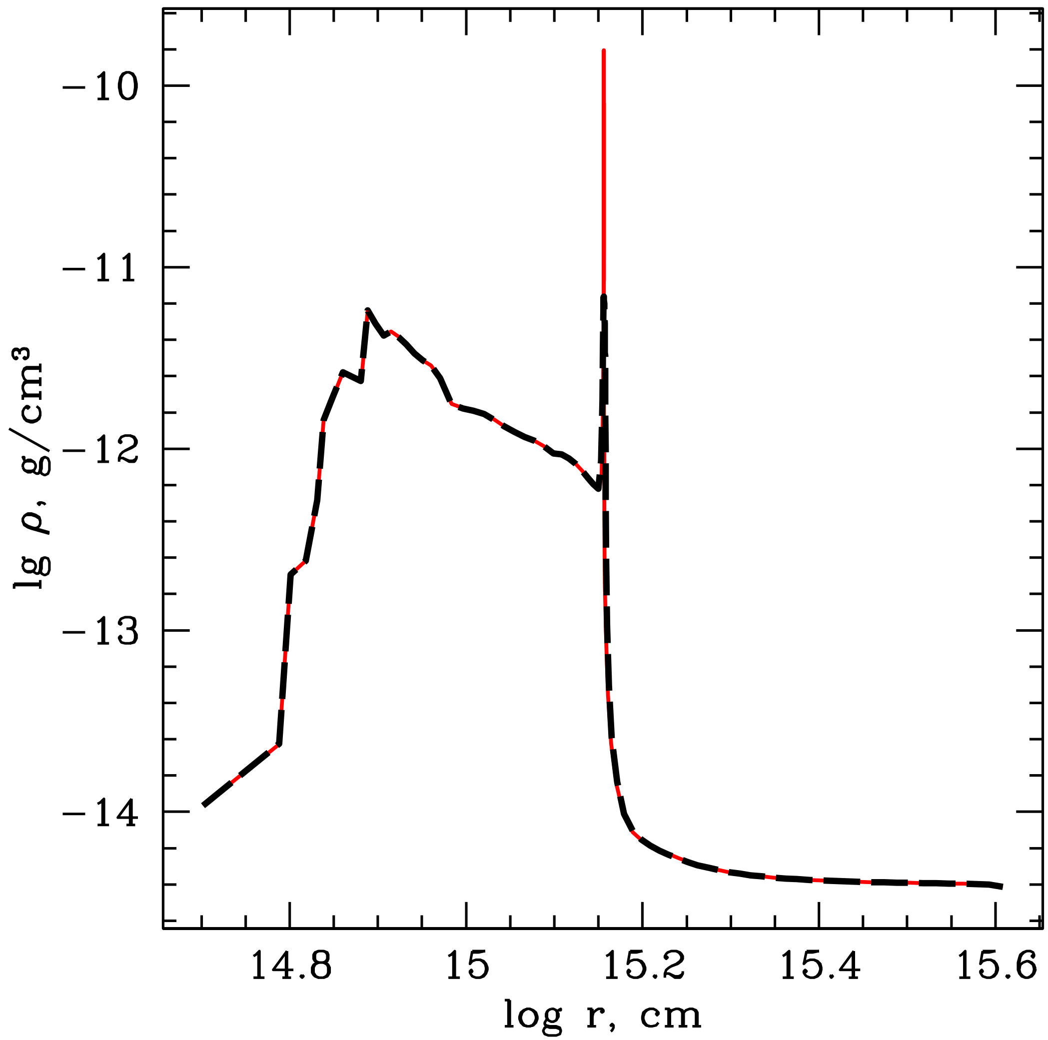
Long Living Dense shells-4 Sorokina et al.



See Poster 16

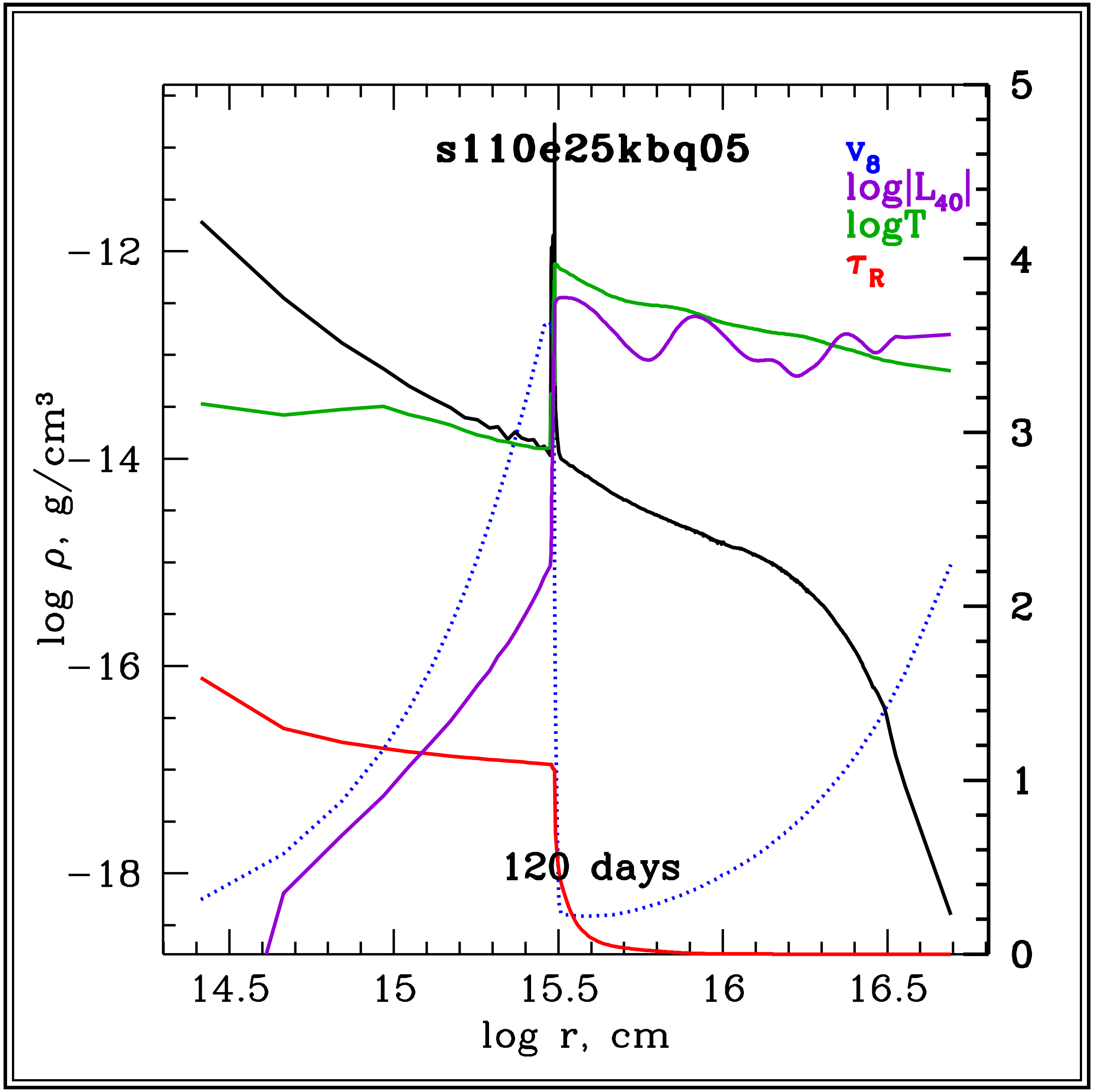
Shocks in SNe IIn

A long living shock: an example for 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.



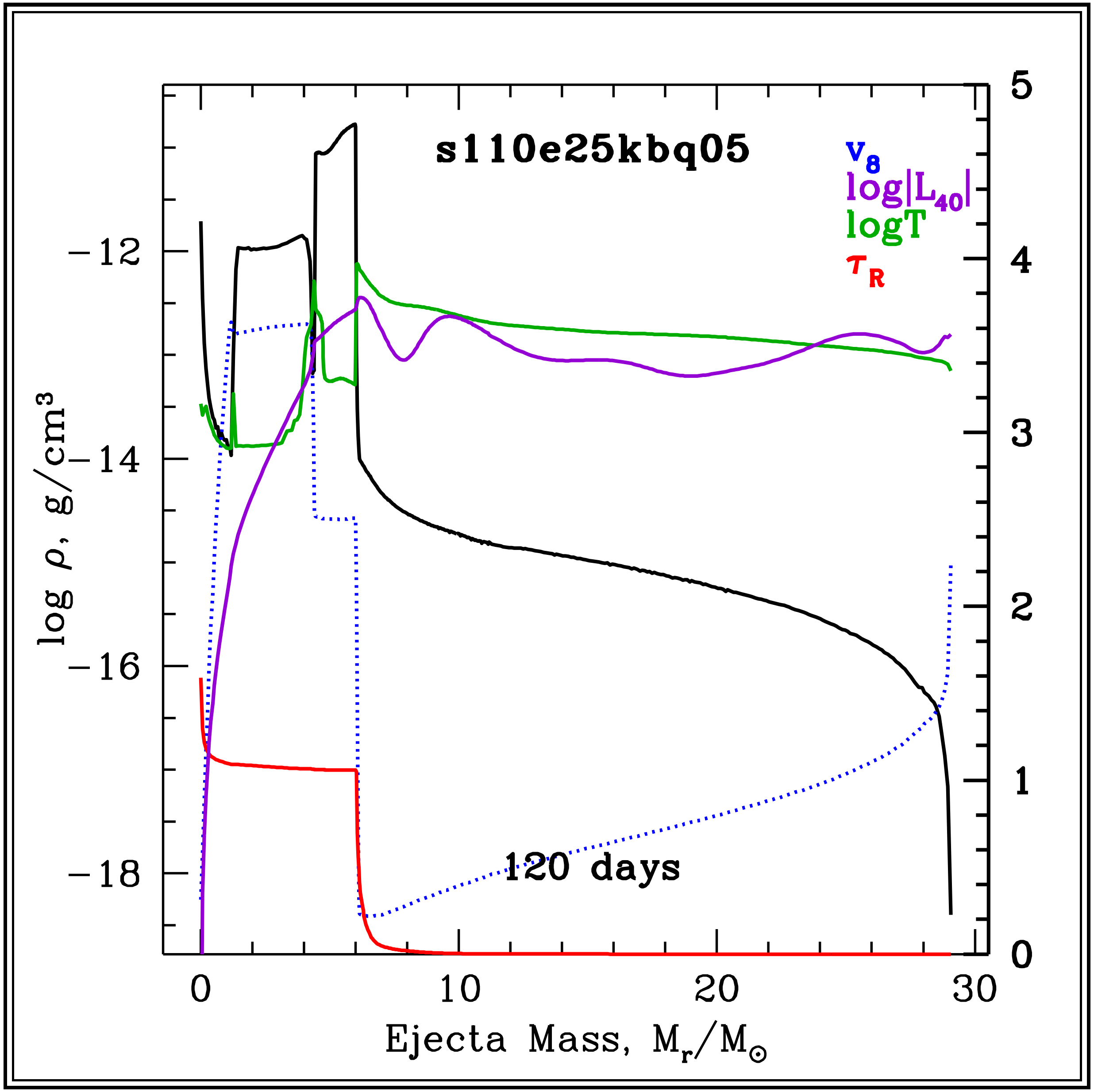
Where are forward and reverese shocks?

SN06gy Hydro structure 120 d

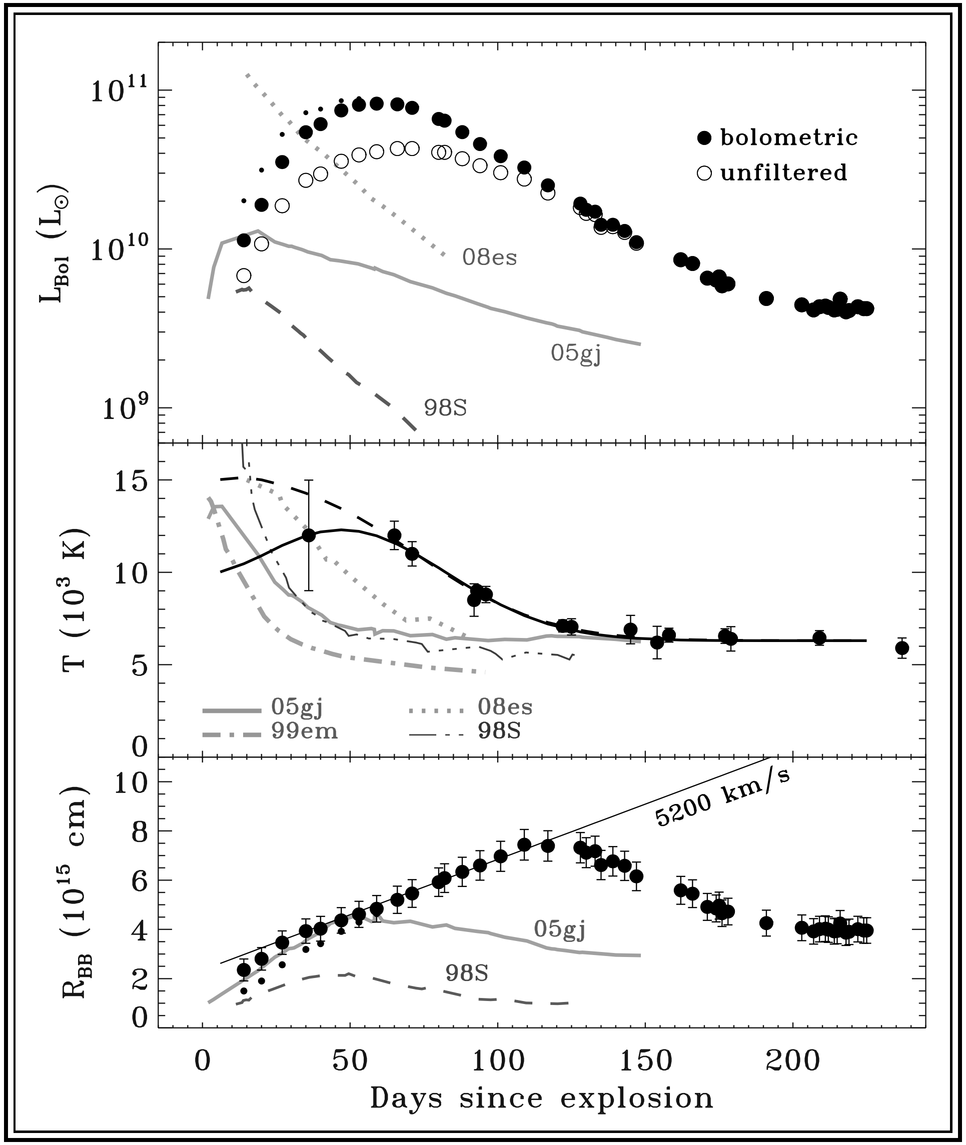


X-rays from the shock cannot go out yet, the matter is too dense.

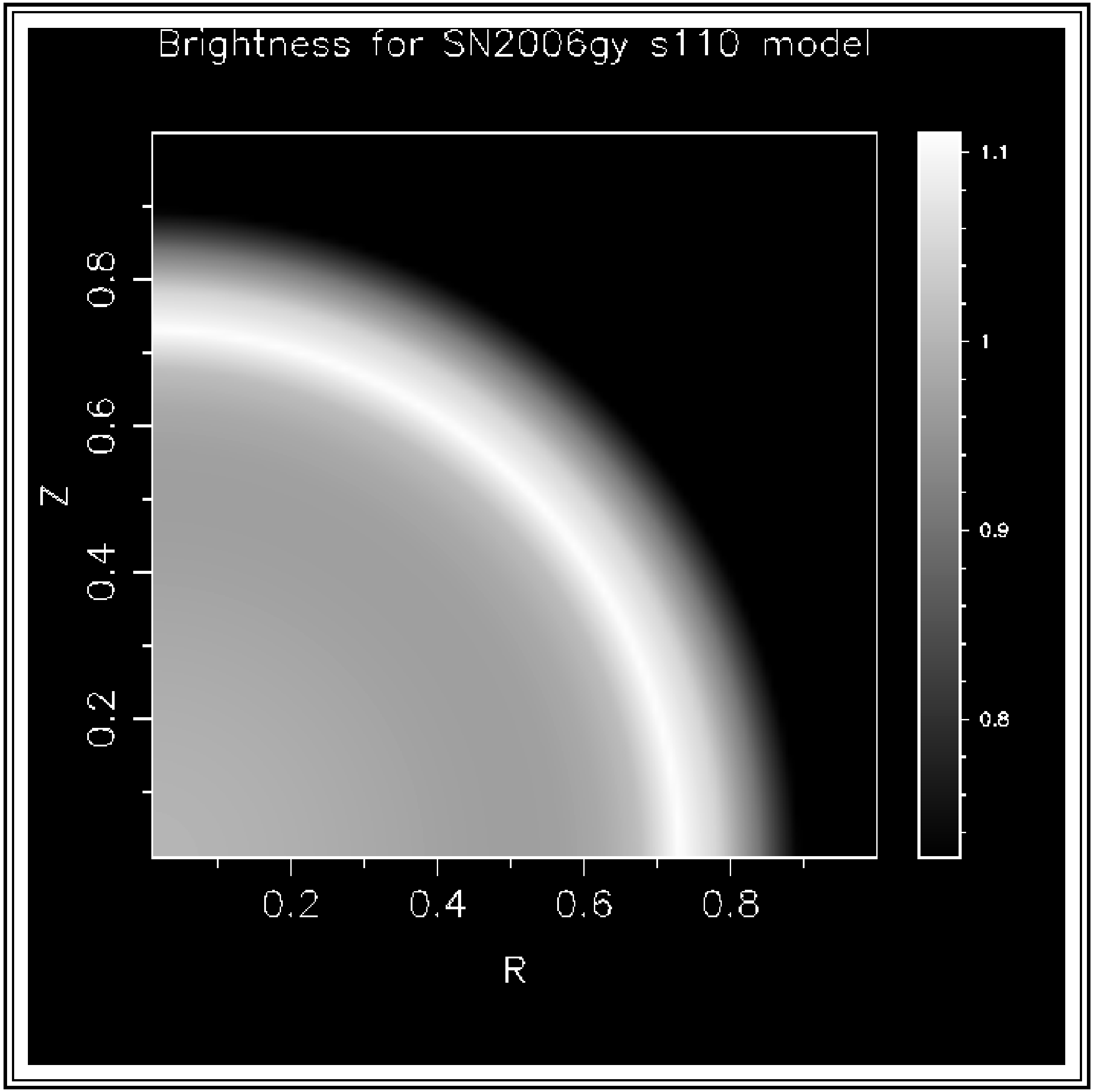
SN06gy 120 d, mass coordinate



Observed $L, T, R(t)$ of SN2006gy



‘Visible’ disk of SN 2006gy



New DSM for SNe IIn

- Measure narrow line components to estimate the properties of CS envelope (may be done crudely).
- Measure wide line components to find the photospheric speed v_{ph} (as accurately as possible).
- Build a best fitting model for broad band photometry and the speed v_{ph}.

New DSM for SNe IIn

- Although the “Hubble”-law $v = r/t$ is not applicable, $v_{\rm ph}$ now measures true velocity of the photospheric radius (not only the matter flow speed, as in type II-P).
- Now the original Baade’s idea works for measuring the radius by integrating $v_{\rm ph}$ (of course, with due account of scattering, limb darkening/brightnening etc in a time-dependent spectral modeling of emerging light). This must be used when iterating the best fitting model.
- The observed flux then gives the distance.

Dense Shell Method, DSM

$$dR = v_{\rm ph} dt$$

$R_0 =$ Initial shell radius, unknown!

$$R_i \equiv R_0 + \Delta R_i$$

$$i = 1, 2, 3 \ldots$$

Dense Shell Method, DSM

$$\zeta_{\nu i}(R_0 + \Delta R_i)\sqrt{\pi B_\nu(T_{\nu i})} = 10^{0.2A_\nu} D\sqrt{F_{\nu i}}$$

Model: $\zeta_{\nu i}$ – correction factor

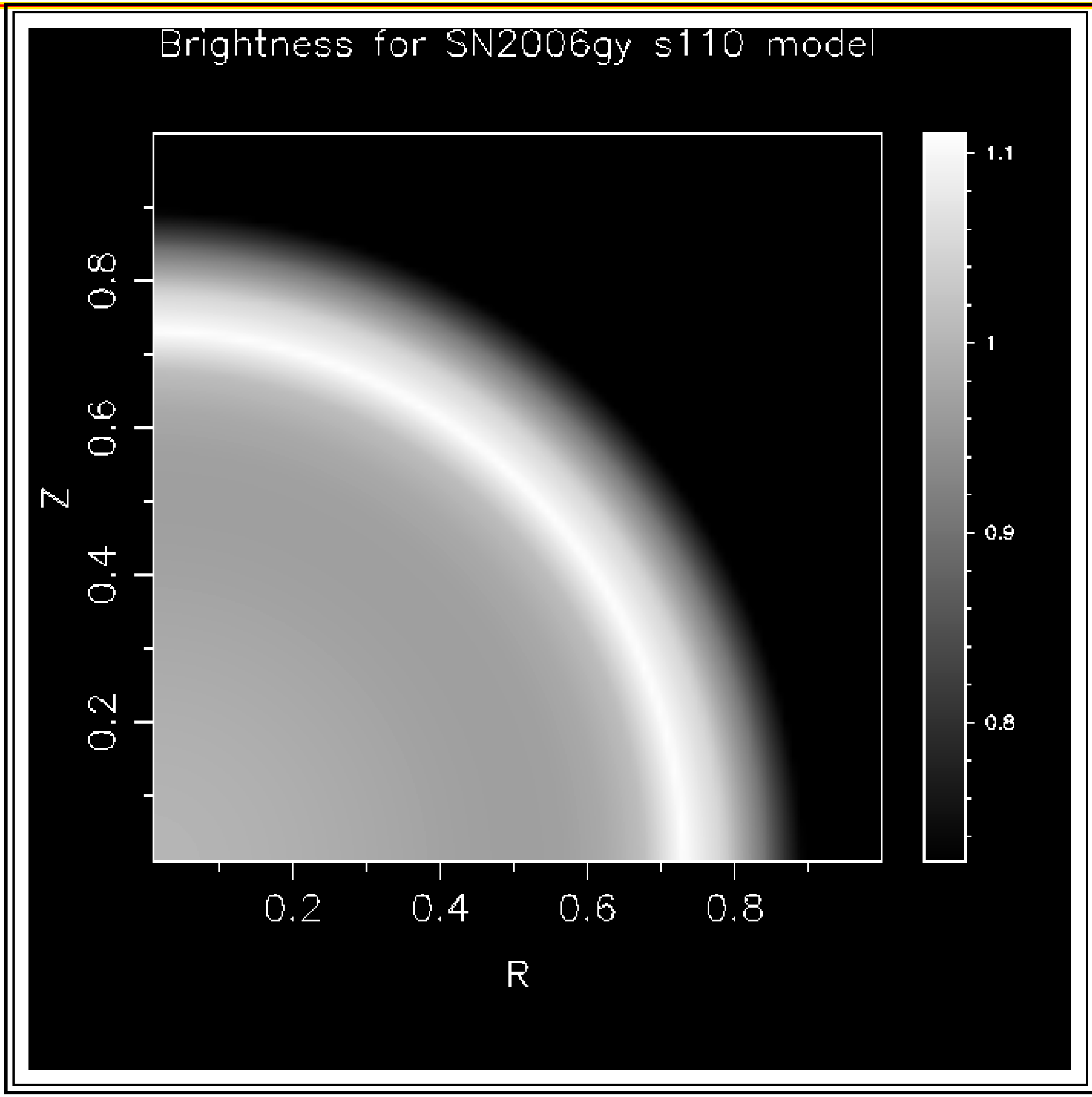
Observations+model: $T_{\nu i},\ \Delta R_i$

Observations: $F_{\nu i},\ A_\nu$ – extinction

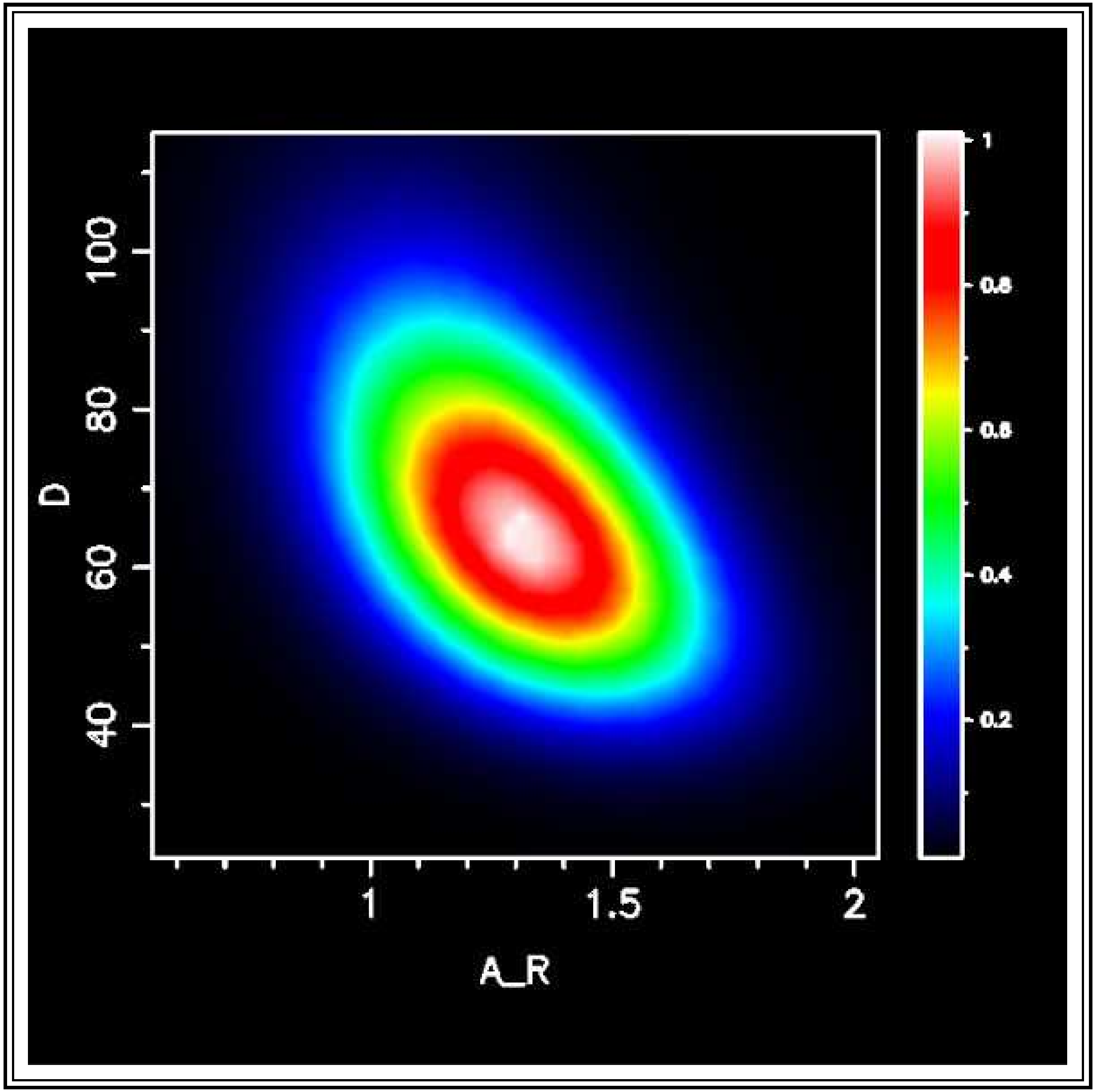
All quantities are defined for the frequency ν.

And finally, D is the sought-for distance to the star.

'Visible' disk of SN 2006gy for ζ



MC probable D to SN 2006gy

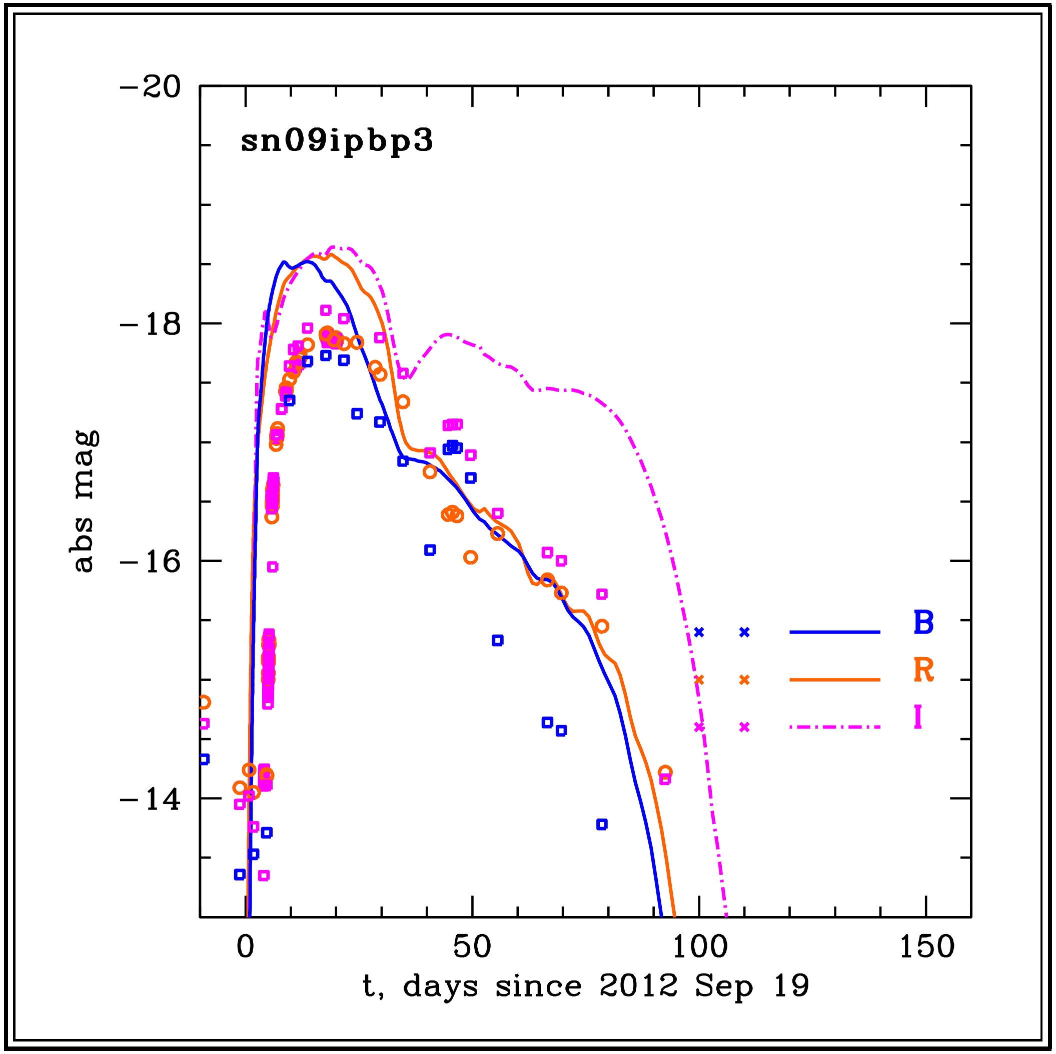


D to SN 2006gy

$$D \approx 68^{+19}_{-15}\,(68\%\ \text{CL})\ \text{Mpc}$$

Large error due to uncertainty in extinction

A better example of SN 2009ip



– almost no extinction.

Real explosion September 2012

D to SN 2006gy and SN 2009ip

$$D \approx 68^{+19}_{-15} \; (68\% \text{ CL}) \text{ Mpc}$$

for SN 2006gy

Standard value around 71 Mpc

$$D \approx 20.1 \pm 0.8 \; (68\% \text{ CL}) \text{ Mpc}$$

for SN 2009ip

Standard value around 20.4 Mpc

Hubble parameter

SN 2006gy gives

$$H_0 \approx 79^{+23}_{-17} \text{ km/s/Mpc.}$$

Recent SNIa result

A. Riess, et al. ApJ 730, 119 (2011)

$$H_0 \approx 73 \pm 2.4 \text{ km/s/Mpc.}$$

Latest PLANCK value

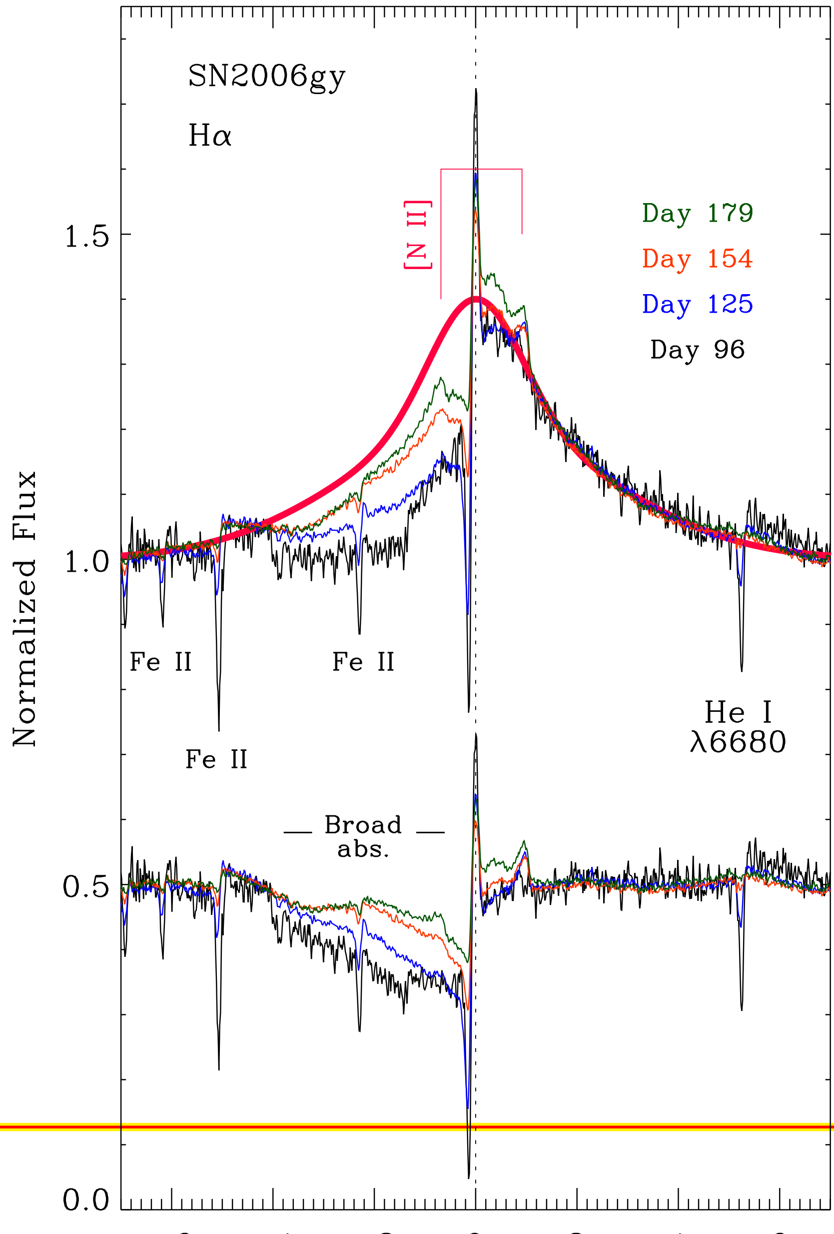
$$H_0 \approx 67.3 \pm 1.2 \text{ km/s/Mpc.}$$

Problems to Solve

- Extracting v_{ph} from spectra
- NLTE effects
- Multi-D

Extracting $v_{\rm ph}$ from spectra

Observed lines of SN2006gy

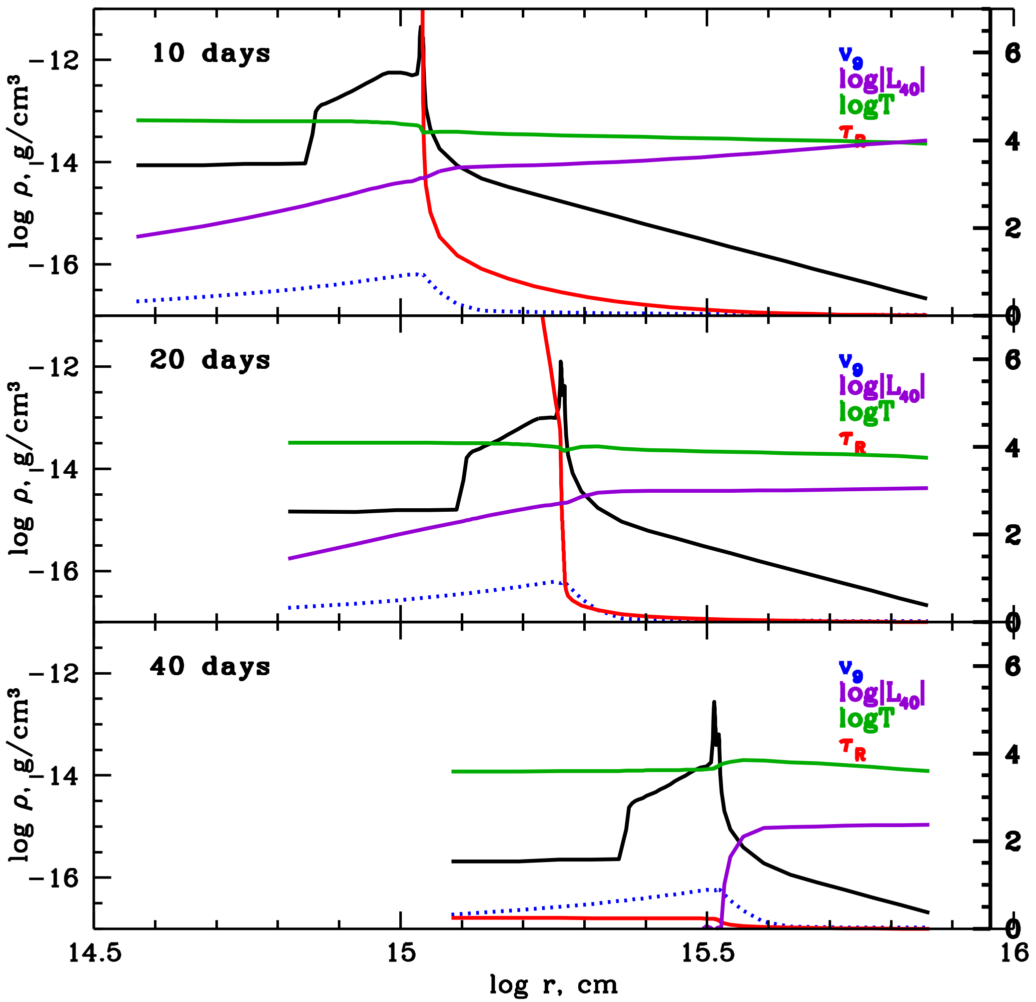


Care of wide wings due to scattering (Chugai; Dessart & Hillier)

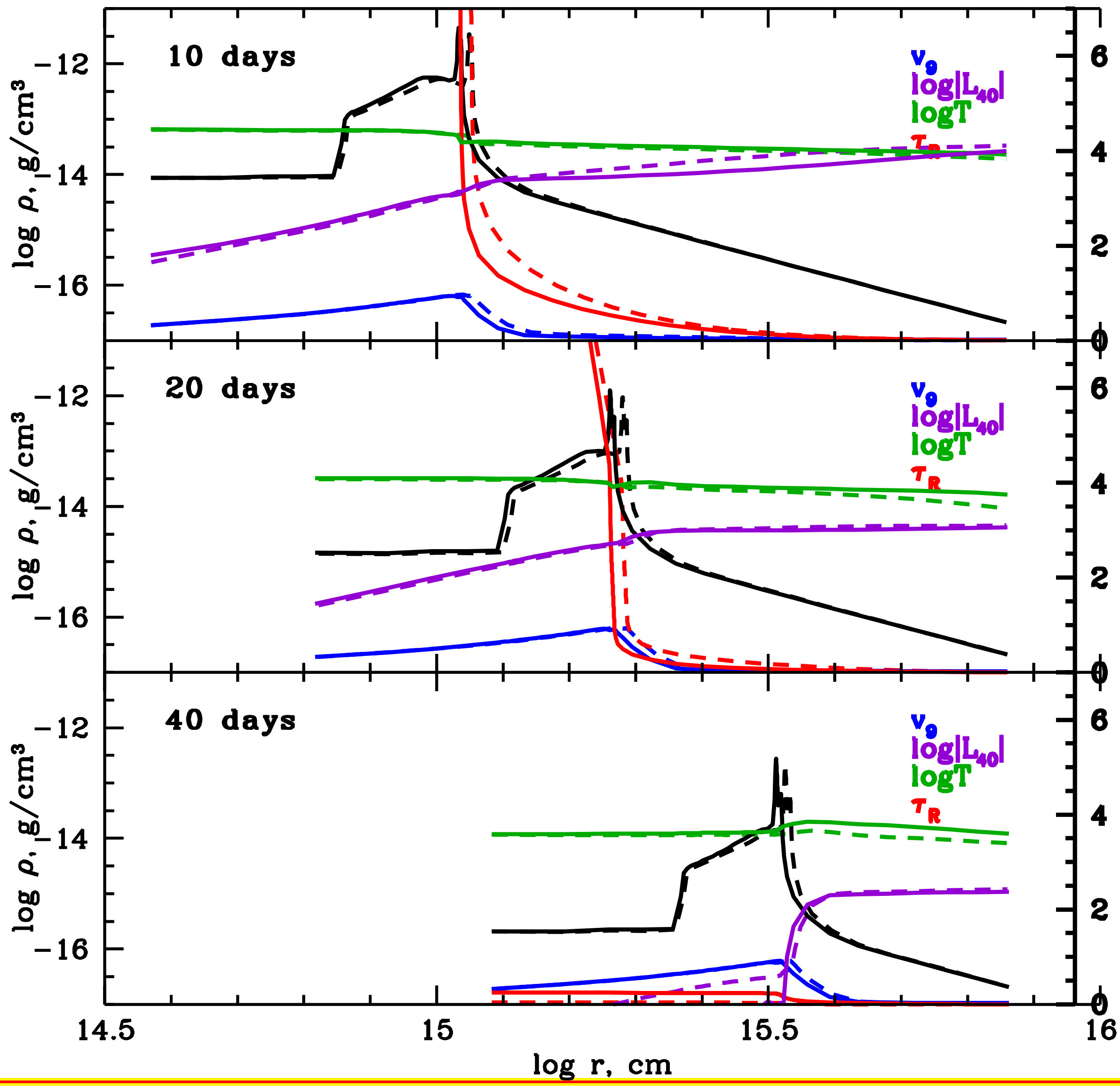
NLTE effects Baklanov et al. 2013

Using approach similar to Lucy, Mazzali, Sim..., but for hydro simulations

Evolution of model sn09ipbp3 in LTE

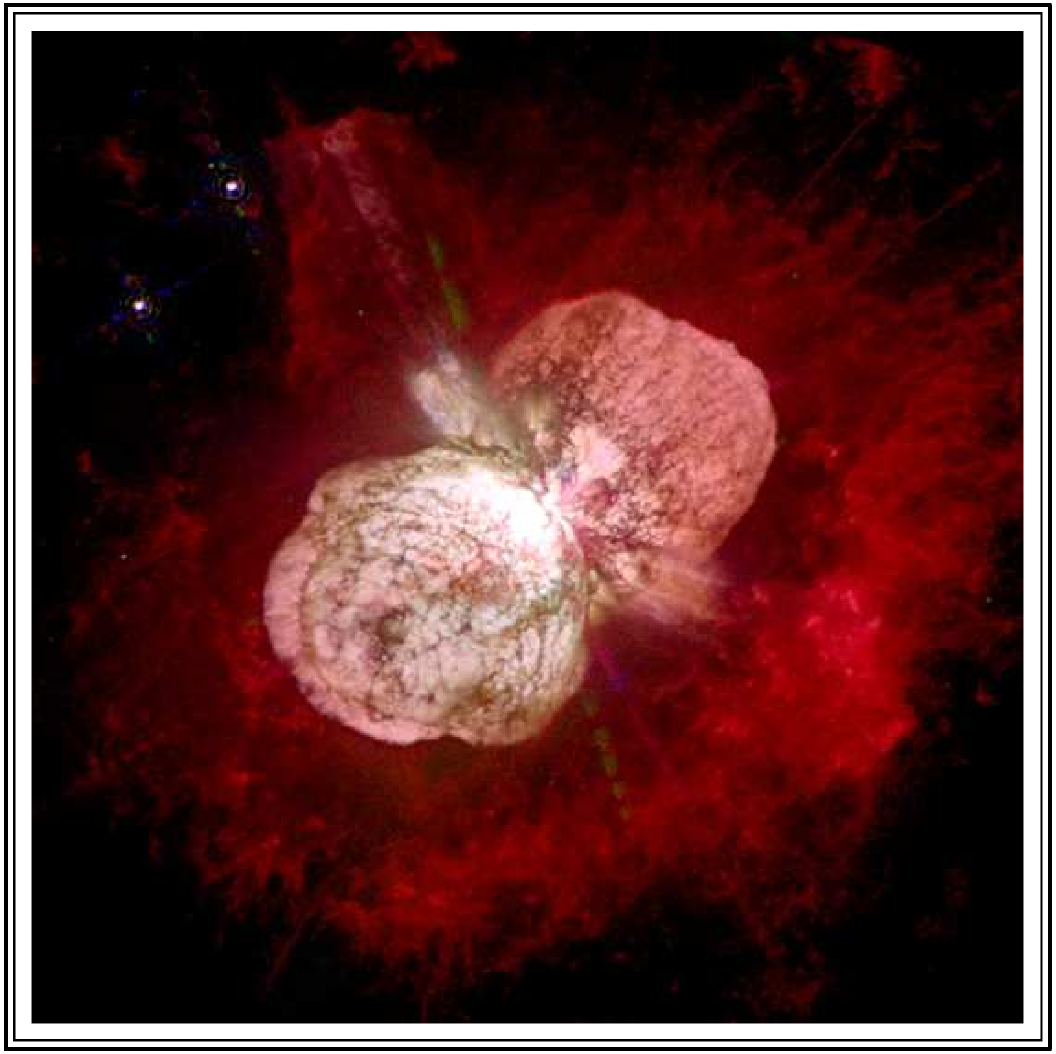


LTE(solid) vs Non-LTE(dashed)



Next step will be Multi-D

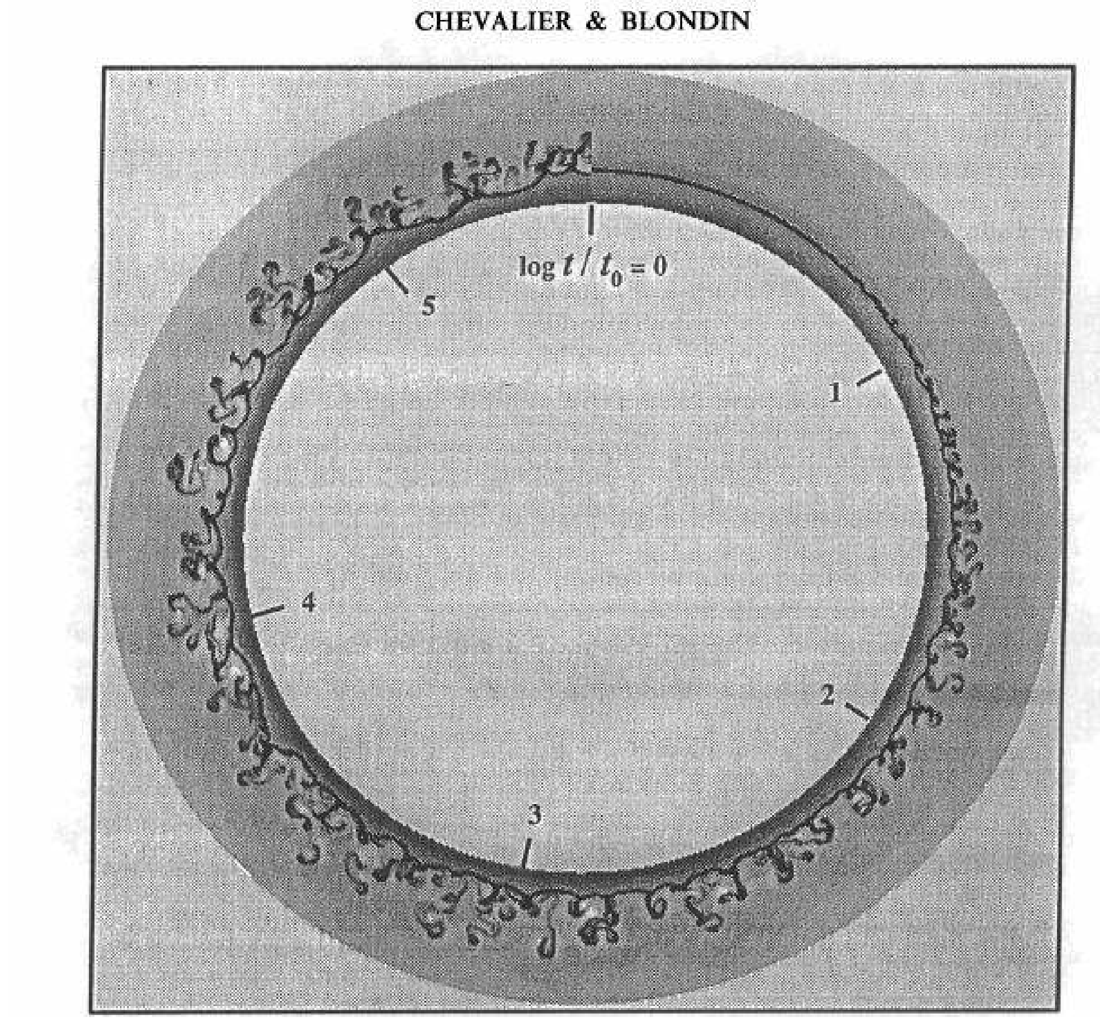
in theoretical modeling



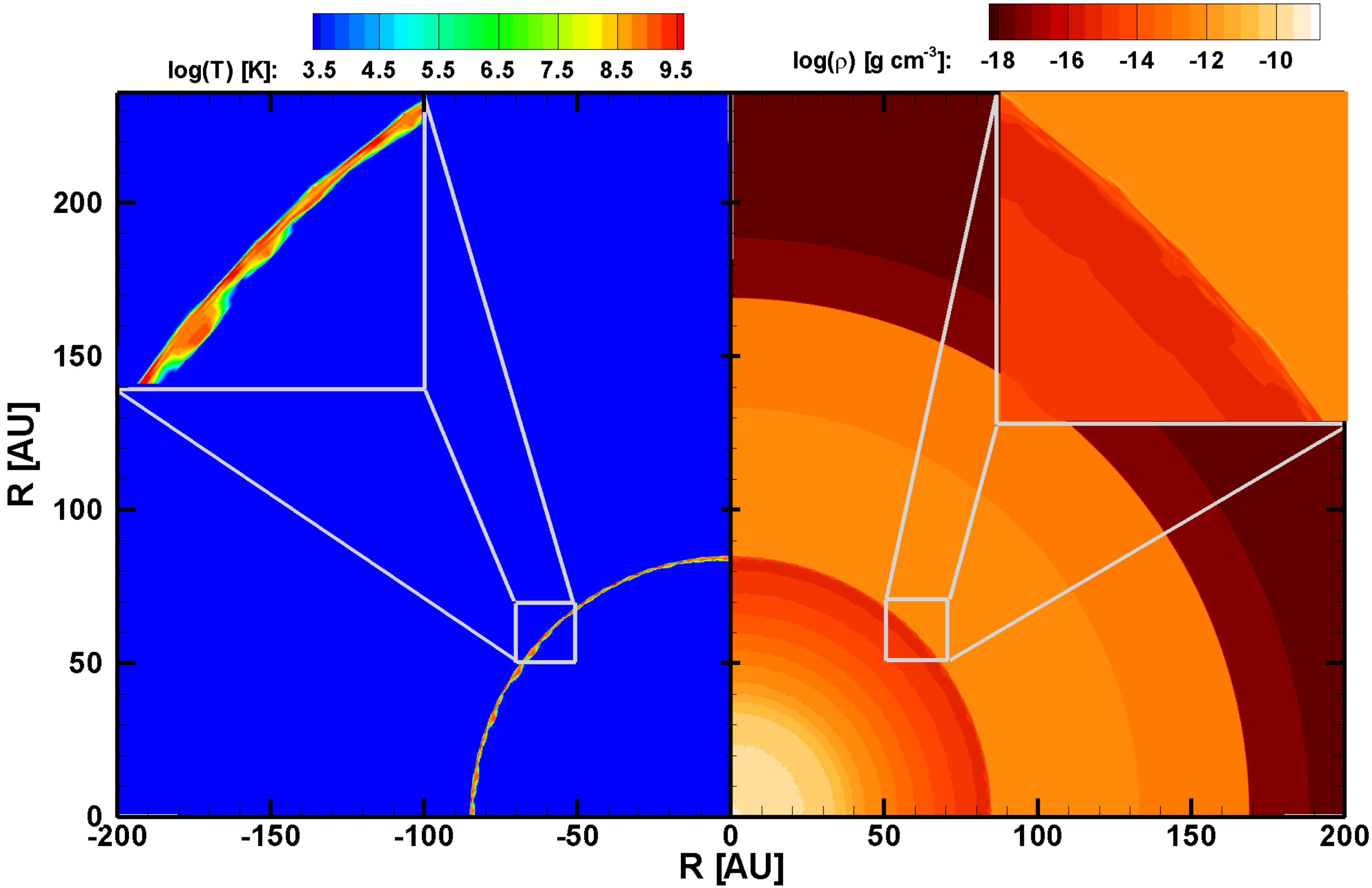
Multi-D

We begin with our open source code FRONT3D `dau.itep.ru/sn` (Semyon Glazyrin) and adopting SHDOM radiative transfer (Nozomu Tominaga)

Chevalier & Blondin 1995

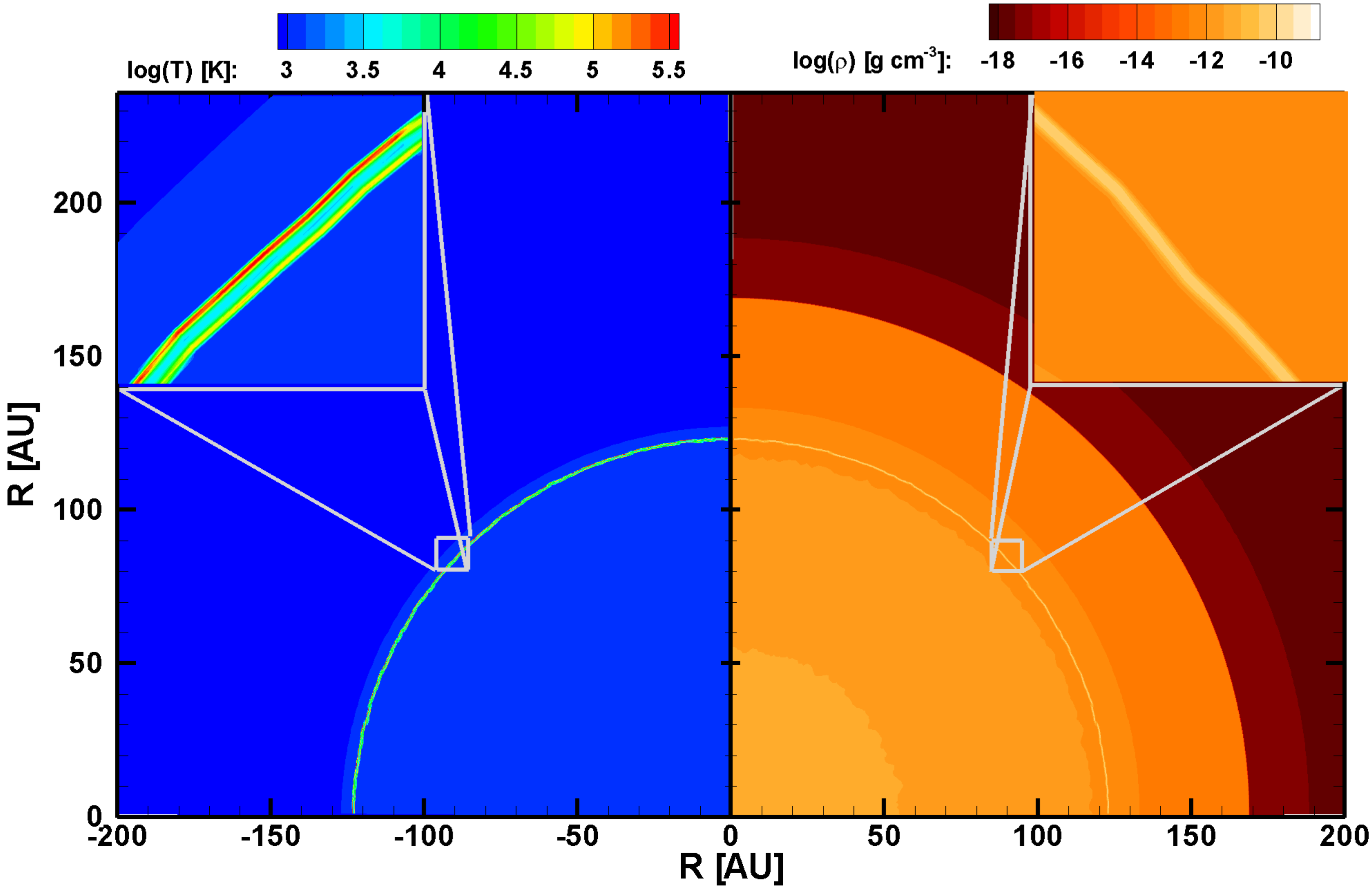


A. J. van Marle et al. MN 2010



23 days

A. J. van Marle et al. MN 2010



87 days

Conclusions

- EPM is based not on Baade-Wesselink, but on Kirshner-Kwan (KK) idea
- Radiating shocks are most probable sources of light in most luminous supernovae of type IIn like SN2006gy
- Most luminous SN IIn events may be observed at high z [for years due to $(1+z)$] and may be useful as direct, primary, distance indicators in cosmology
- The new DSM is based on original Baade idea which really works now
- The shock model requires NLTE and multi-D development
- Accurate observations of spectra must be used together with detailed models to extract velocities