Some problems in spectral modelling of pulsational pair instability SN 2006gy

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based on paper with S. Blinnikov, V. Utrobin

“High-Energy Phenomena in Relativistic Outflows VI”

September 15, 2017, IKI

Outline

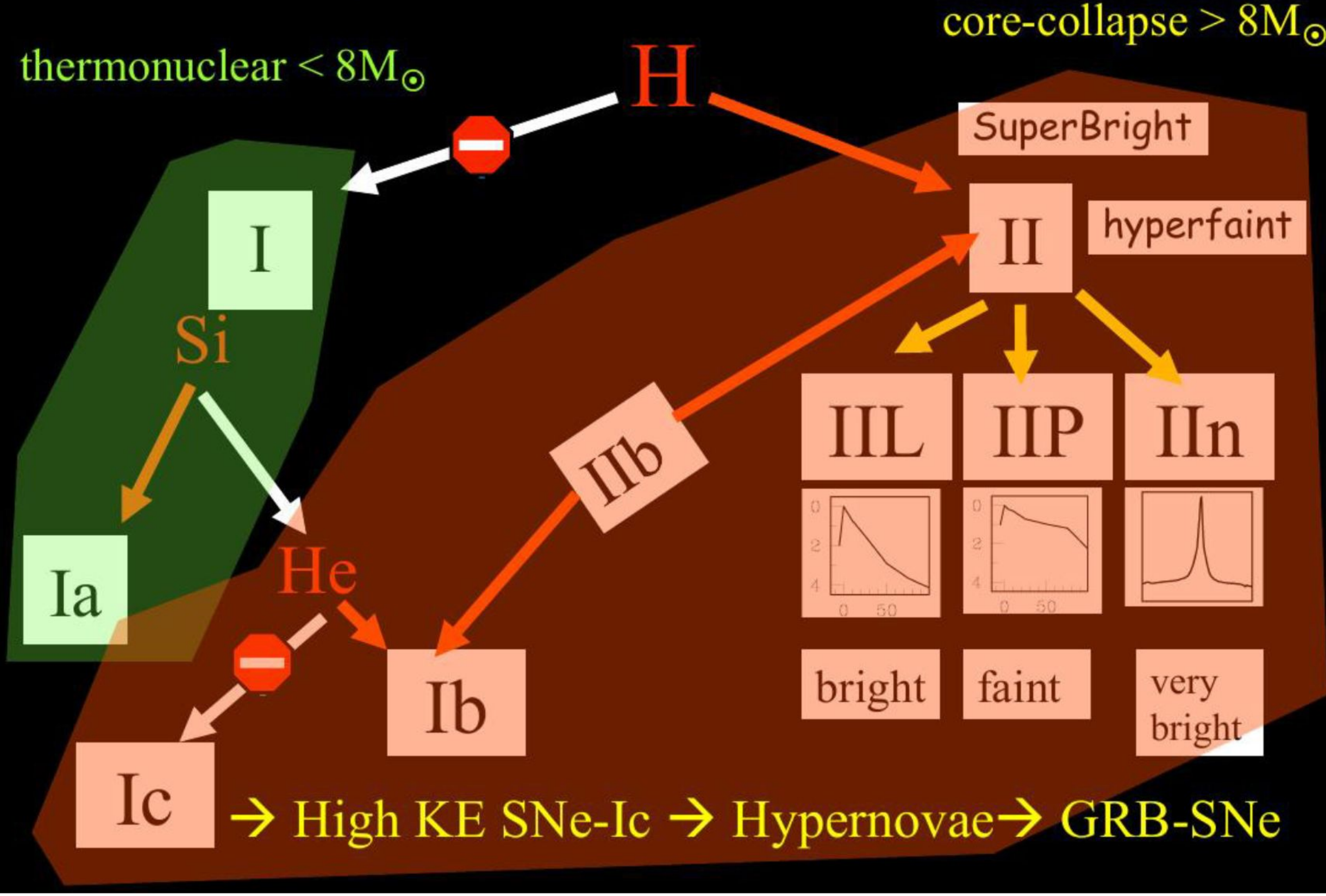
- Supernova taxonomy

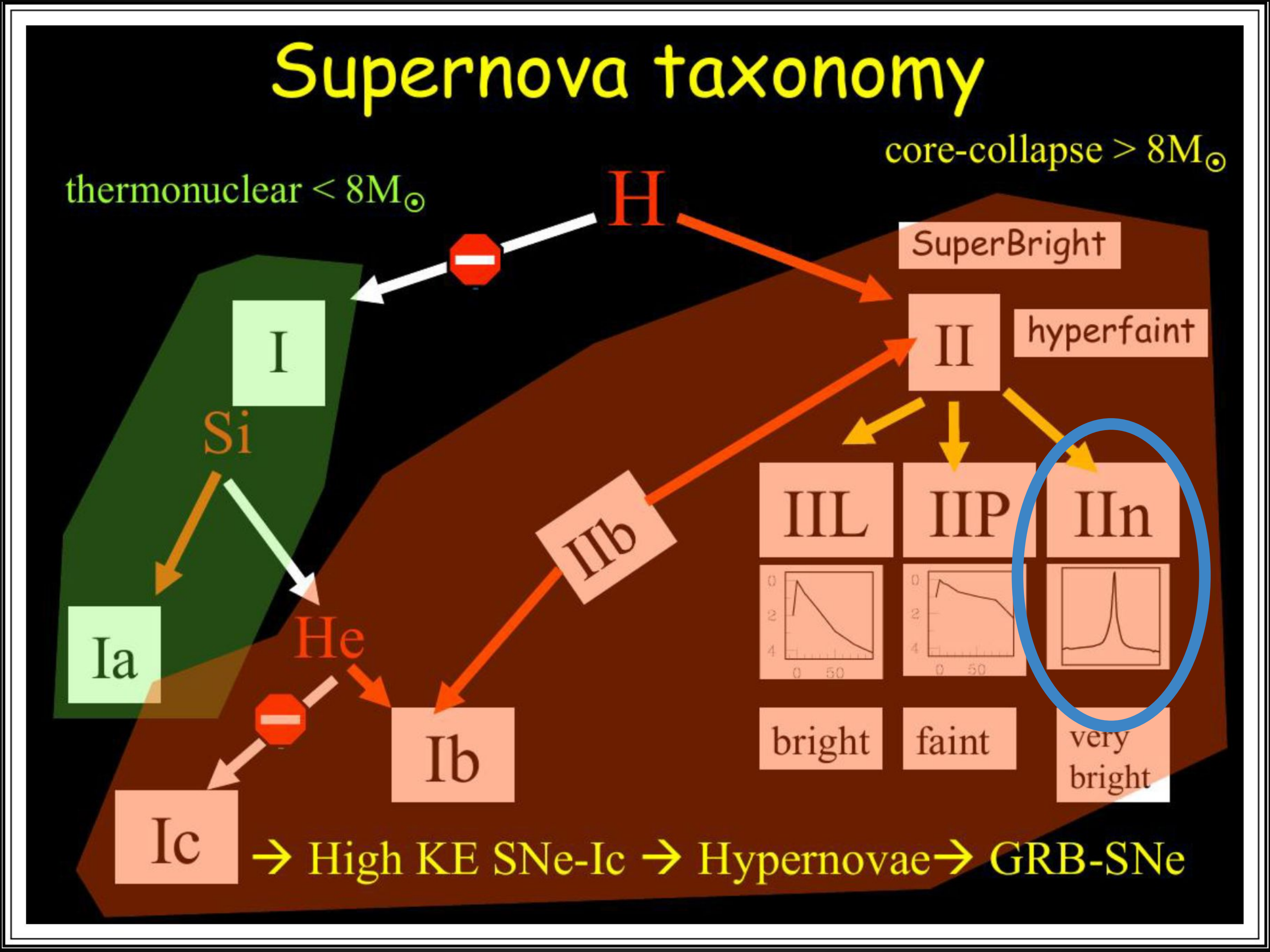
- SN 2006gy
  - Narrow and Wide components of lines
  - Dense Shell
  - Why don’t we see big velocities?

- Modelling
  - LEVELS
  - Spectra
    - Steady-state approximation
    - Importance of time-dependence

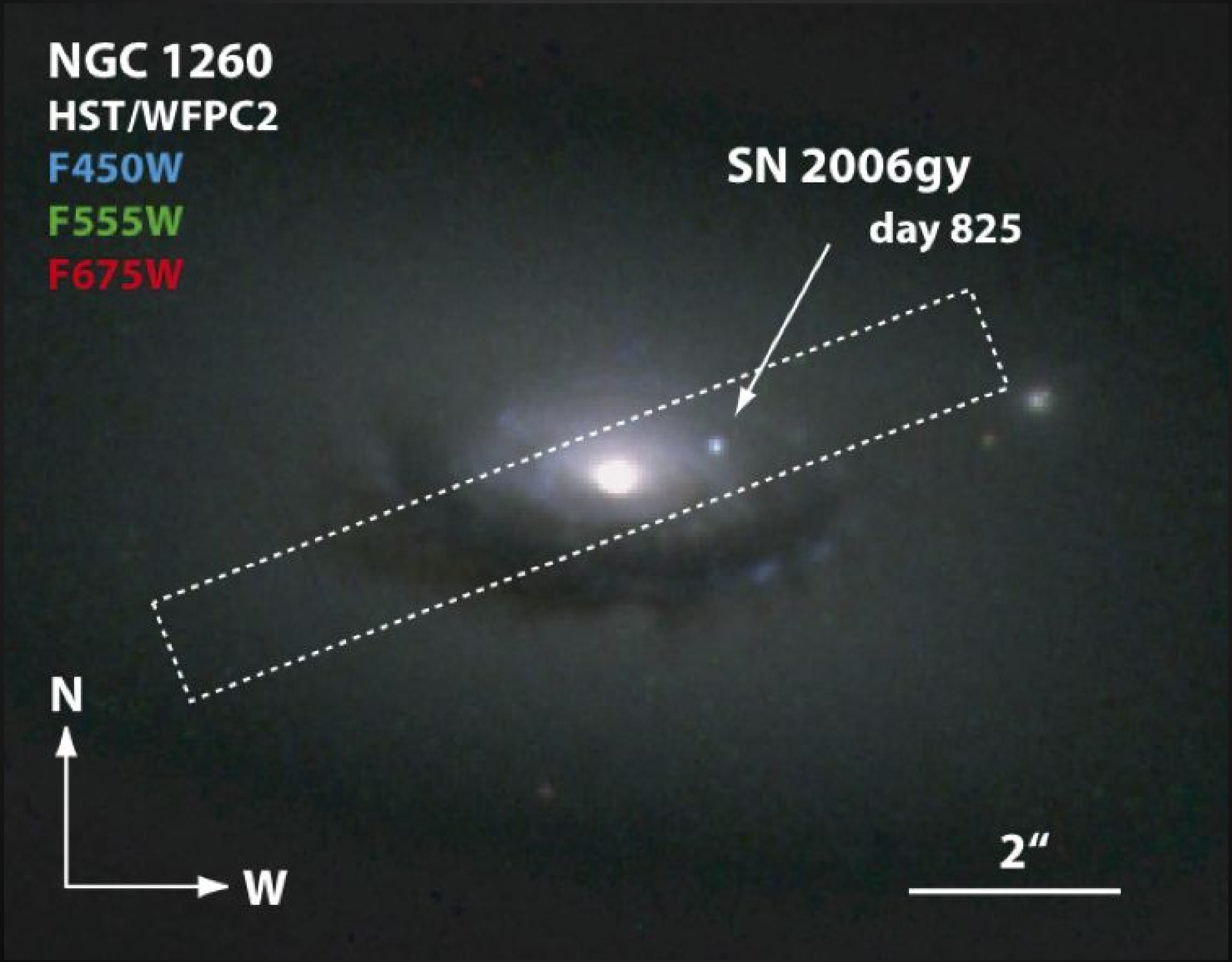
- Conclusions

Supernova taxonomy

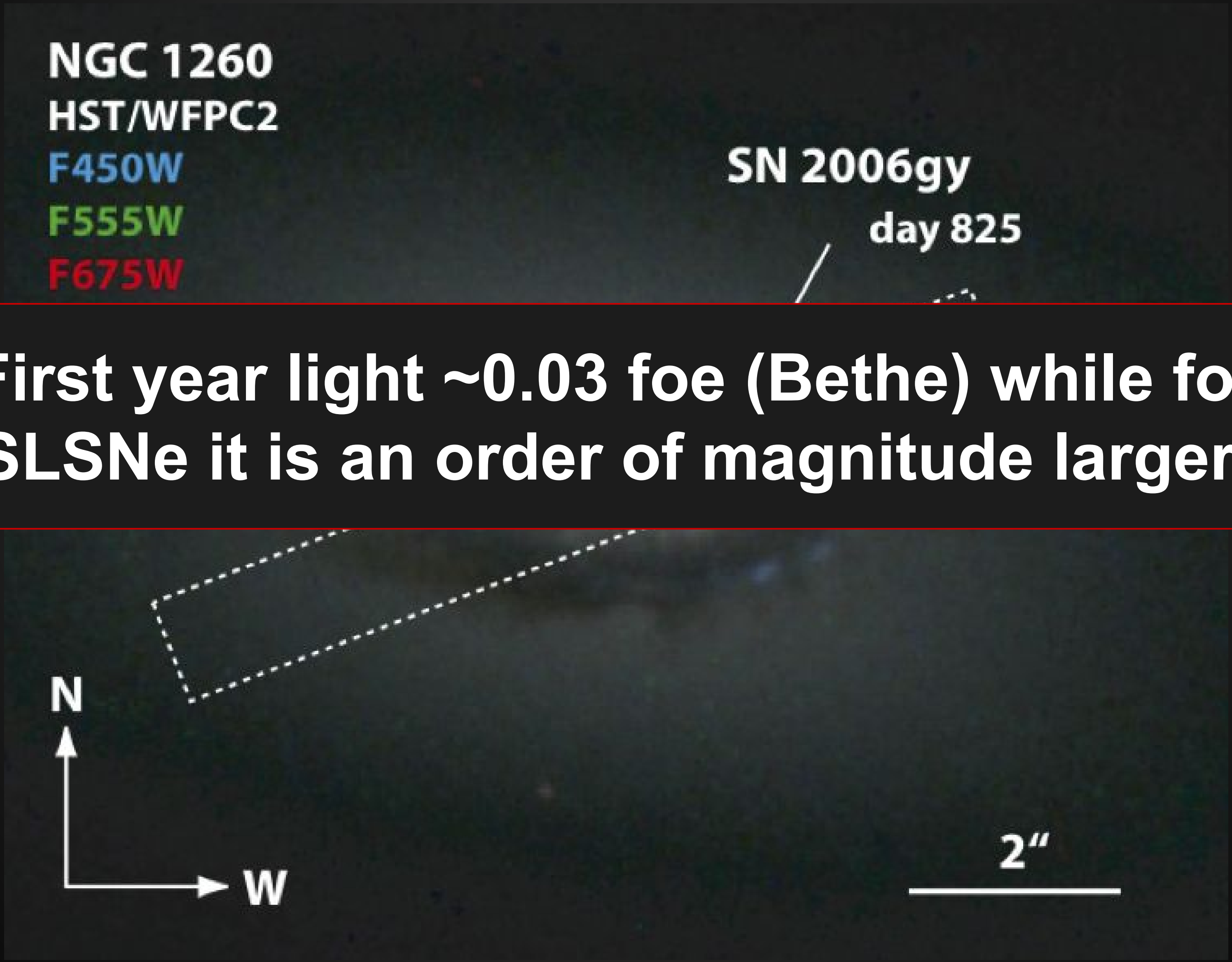



Supernova taxonomy
core-collapse > 8M☉
thermonuclear < 8M☉
H
SuperBright
I
II
hyperfaint
Si
IIL
IIP
IIn
IIb
0
2
4
0 50
0
2
4
0 50
Ia
He
Ib
bright
faint
very bright
Ic
→ High KE SNe-Ic → Hypernovae→ GRB-SNe

SN 2006gy

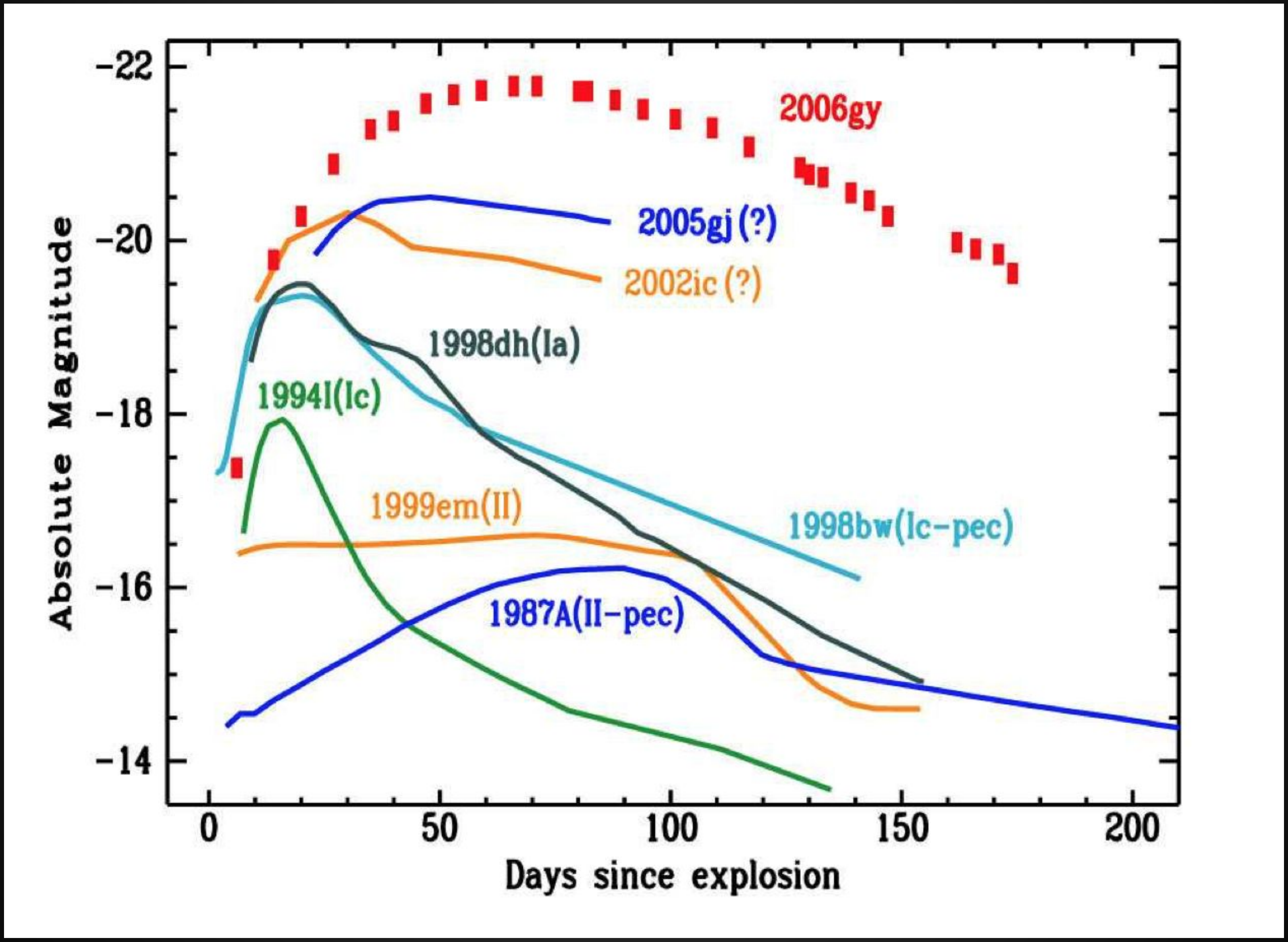


SN 2006gy

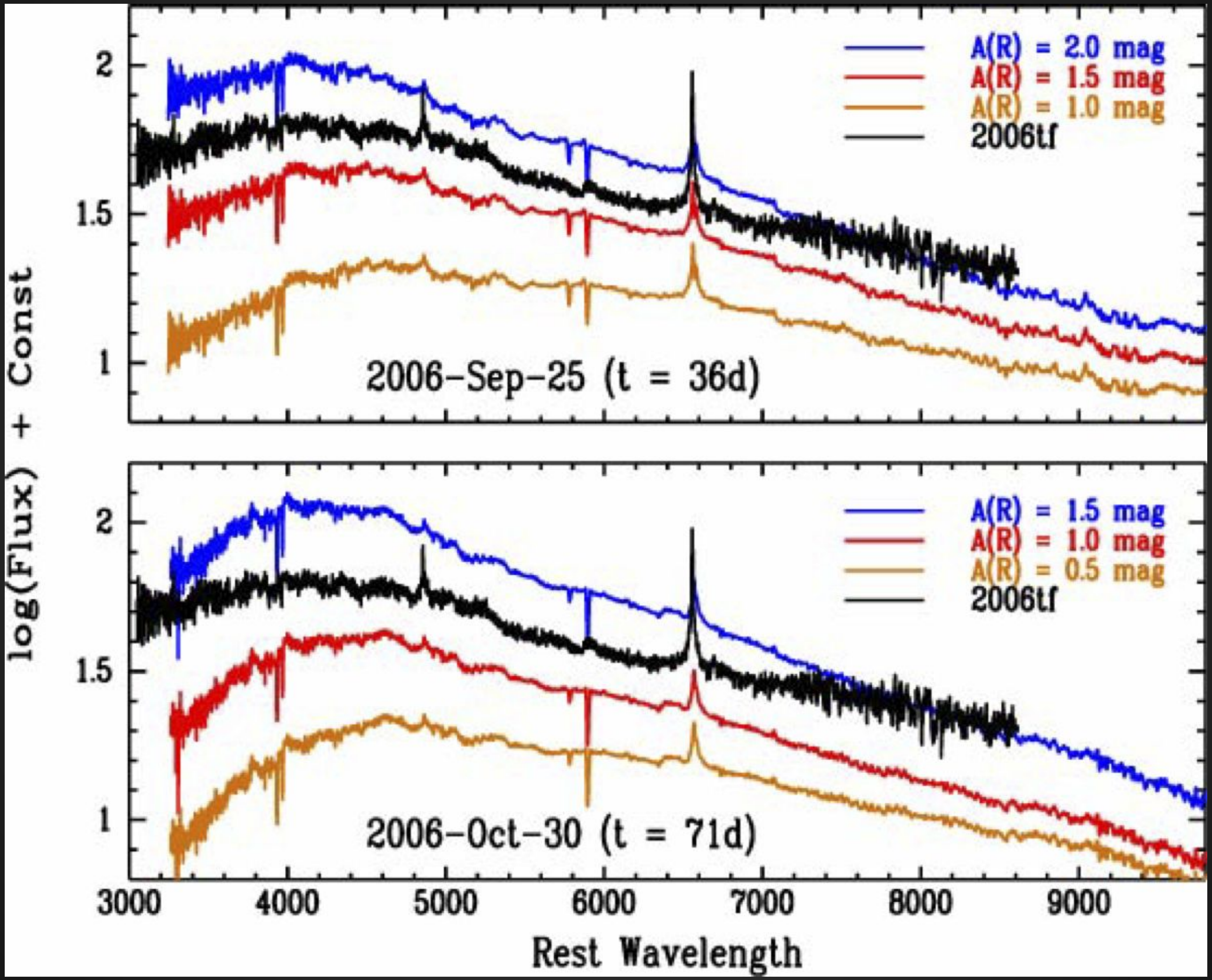


First year light ~0.03 foe (Bethe) while for SLSNe it is an order of magnitude larger.

Light curves

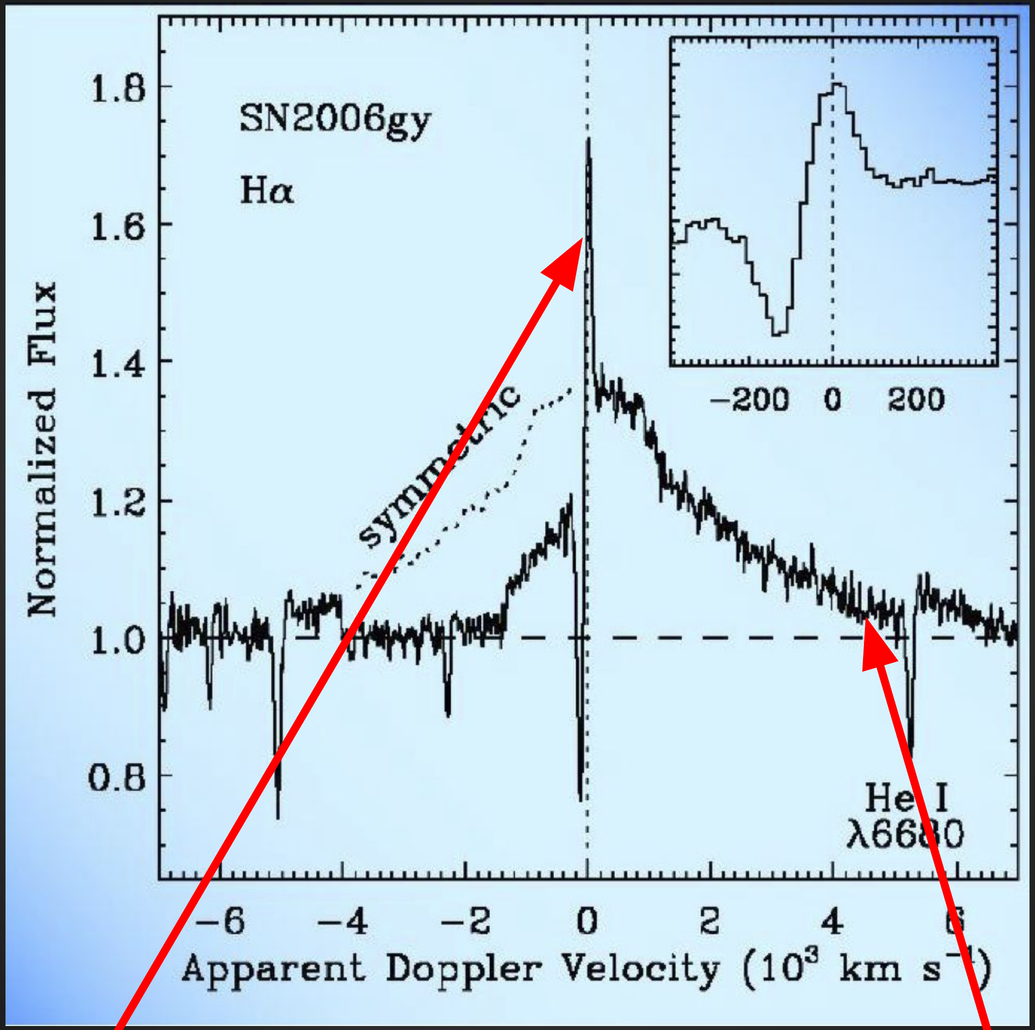


Spectrum of SN 2006gy



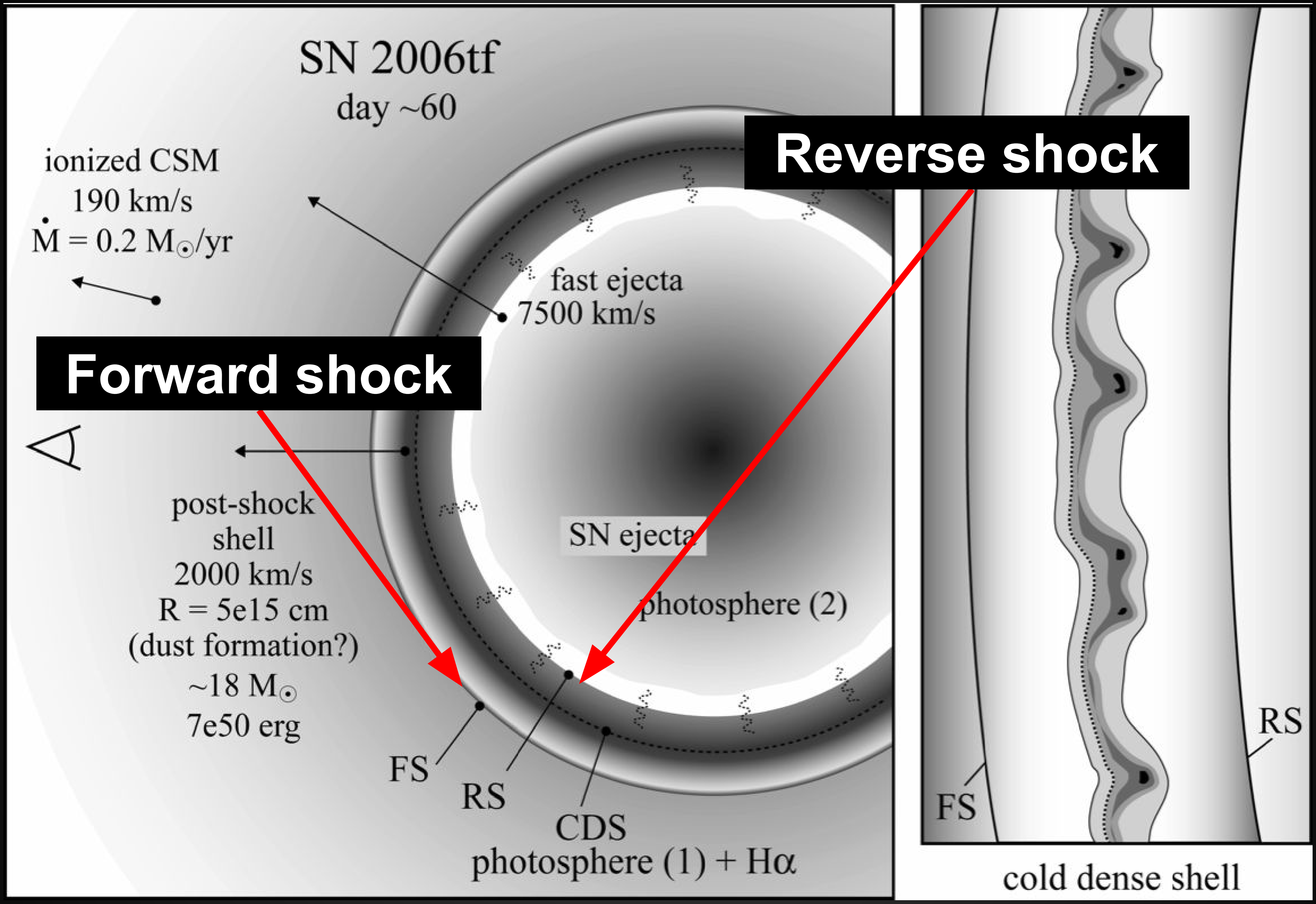
N. Smith (2007), et al. Astrophys. J. 666, 1116

SN 2006gy Hα profile

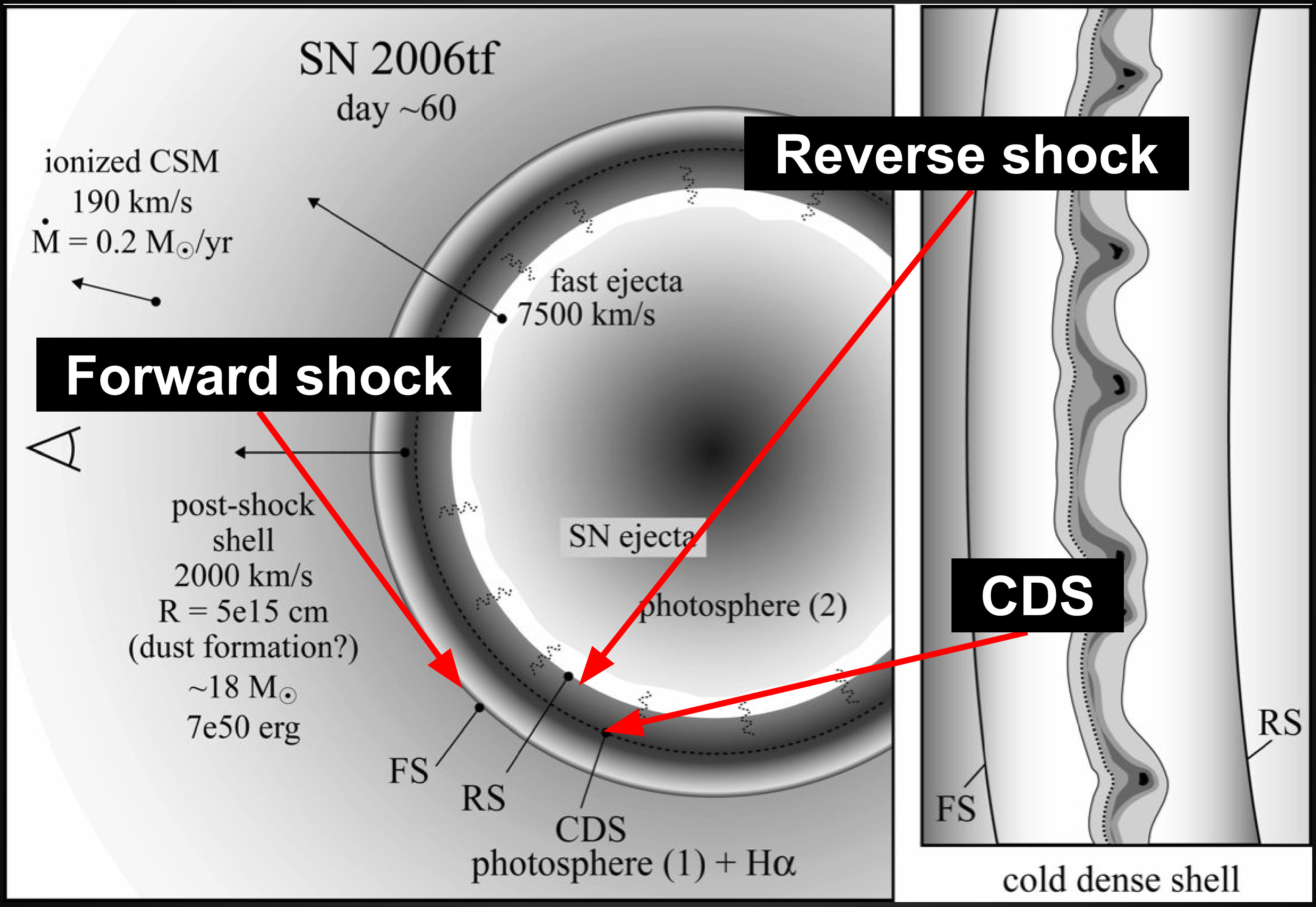


N. Smith, et al. Astrophys. J. 666, 1116 (2007)

narrow $v \sim 200\mathrm{km/s}$ **wide** $v \sim 5000\mathrm{km/s}$

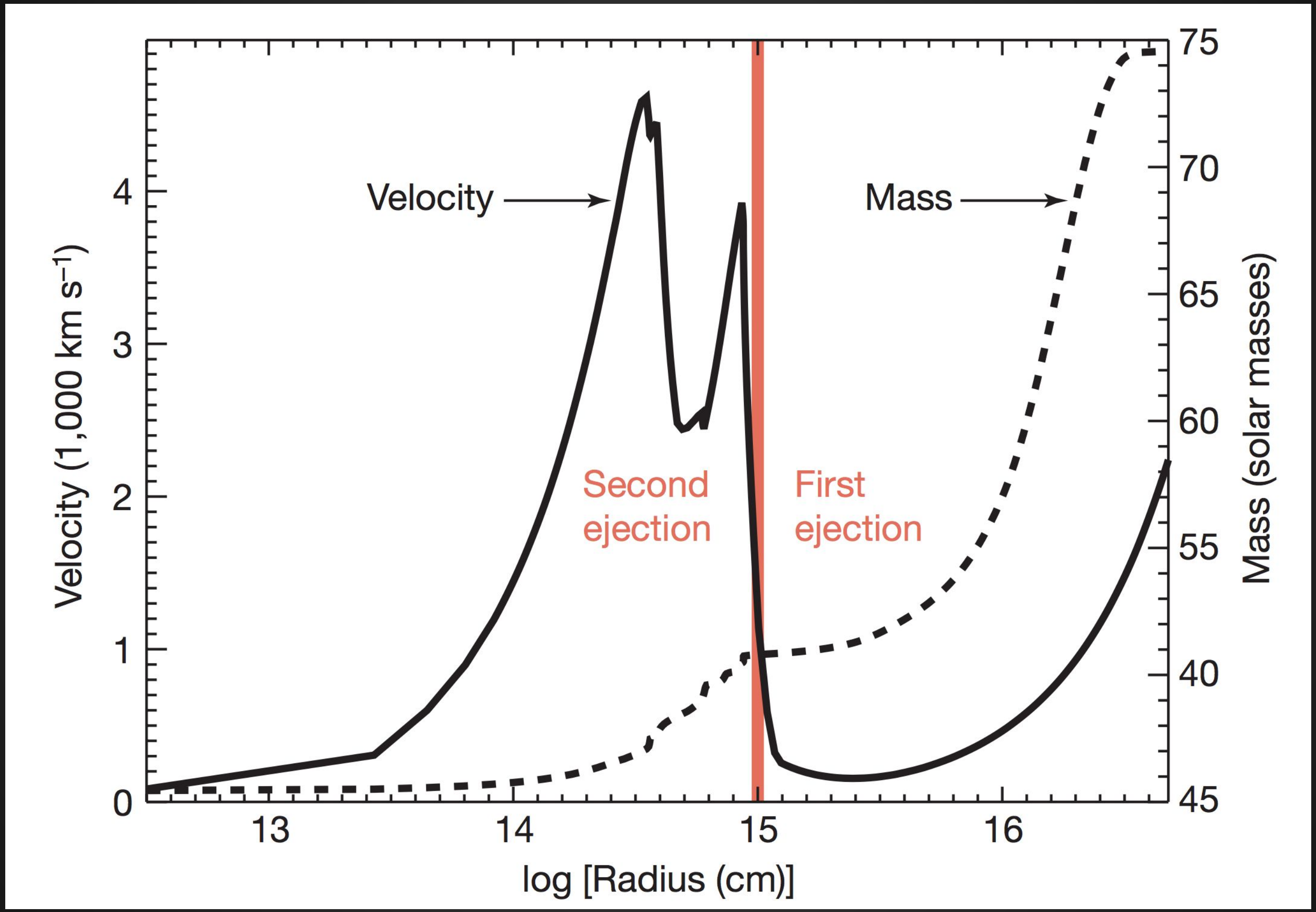


N. Smith (2008), et al. Astrophys. J. 686, 467



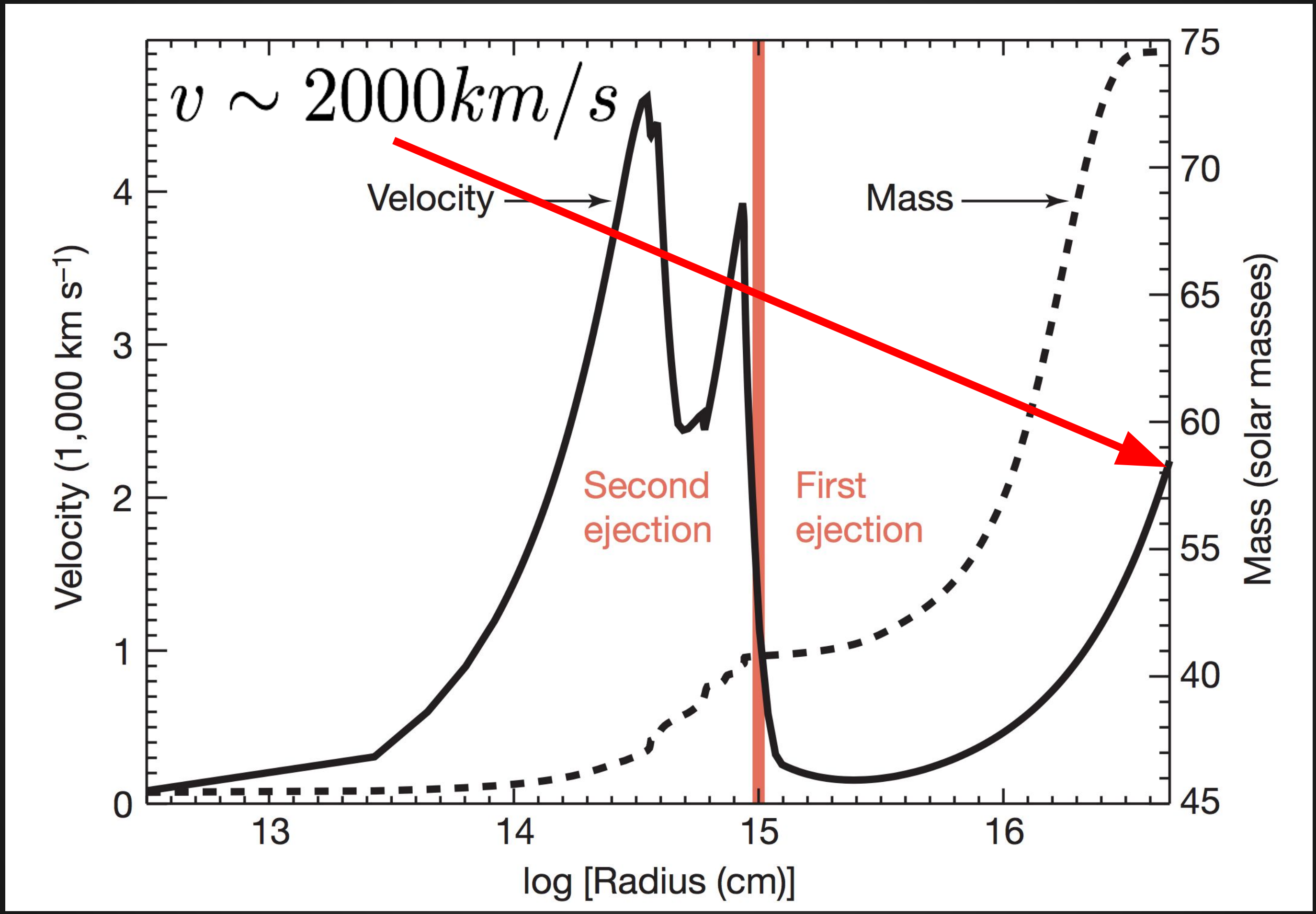
N. Smith (2008), et al. Astrophys. J. 686, 467

SN 2006gy



Woosley, S. E., Blinnikov, S. I., & Heger, A. (2007), Nature, 450(7168), 390–392

Why don't we see it?



Woosley, S. E., Blinnikov, S. I., & Heger, A. (2007), Nature, 450(7168), 390–392

Modelling

LEVELS

STELLA

LEVELS

STELLA

↓

Hydrodynamics

Thermodynamics

Continuum

LEVELS

STELLA

LTE $\frac{\partial}{\partial t} \neq 0$

Hydrodynamics

Thermodynamics

Continuum

LEVELS

STELLA

LTE

$$\frac{\partial}{\partial t} \neq 0$$

Hydrodynamics

Thermodynamics

Continuum

LEVELS

LEVELS

STELLA

LTE $\frac{\partial}{\partial t} \neq 0$

Hydrodynamics

Thermodynamics

Continuum

LEVELS

Rate equations

Line Transfer

Sobolev appr.

We apply for all resonance Lyman lines the approximation of Chugai.

Chugai, N. N. (1987), *Astrofizika, 26*, 89–96.

For all other strong lines we apply Sobolev + continuum (the so-called “U-function” approximation).

Hummer, D. G., & Rybicki, G. B. (1985), *The Astrophysical Journal*, *293*, 258.

LEVELS

Rate equations

Line Transfer

Sobolev appr.

The calculations take into account the direct radiative coupling of the components of the Fe II multiplets...

Andronova A.A. (1990), *Astrofizika*, 32, 415–428

...and the absorption in metal lines (a large number of Fe II lines are in the vicinity of Lα)

Chugai, N. N. (1998), *Astronomy Letters*, *24*(5)

LEVELS

Rate equations

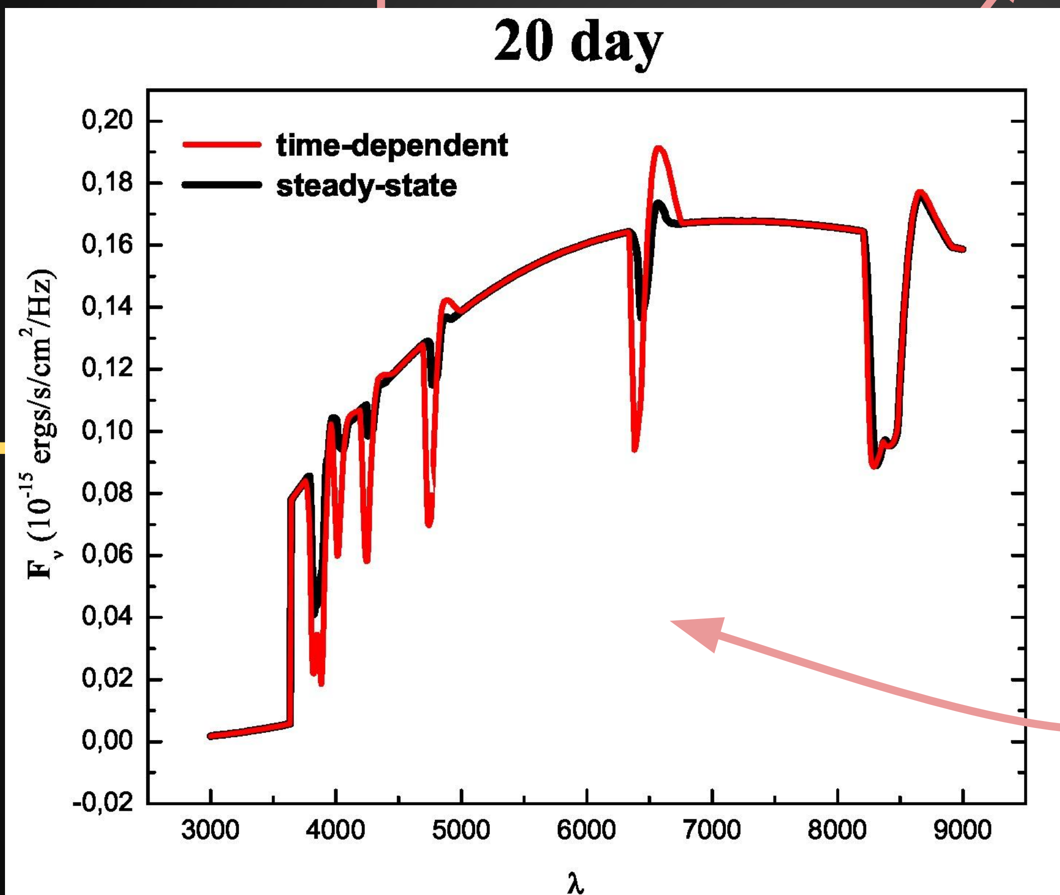
Line Transfer

Sobolev appr.

LEVELS

STELLA

LEVELS

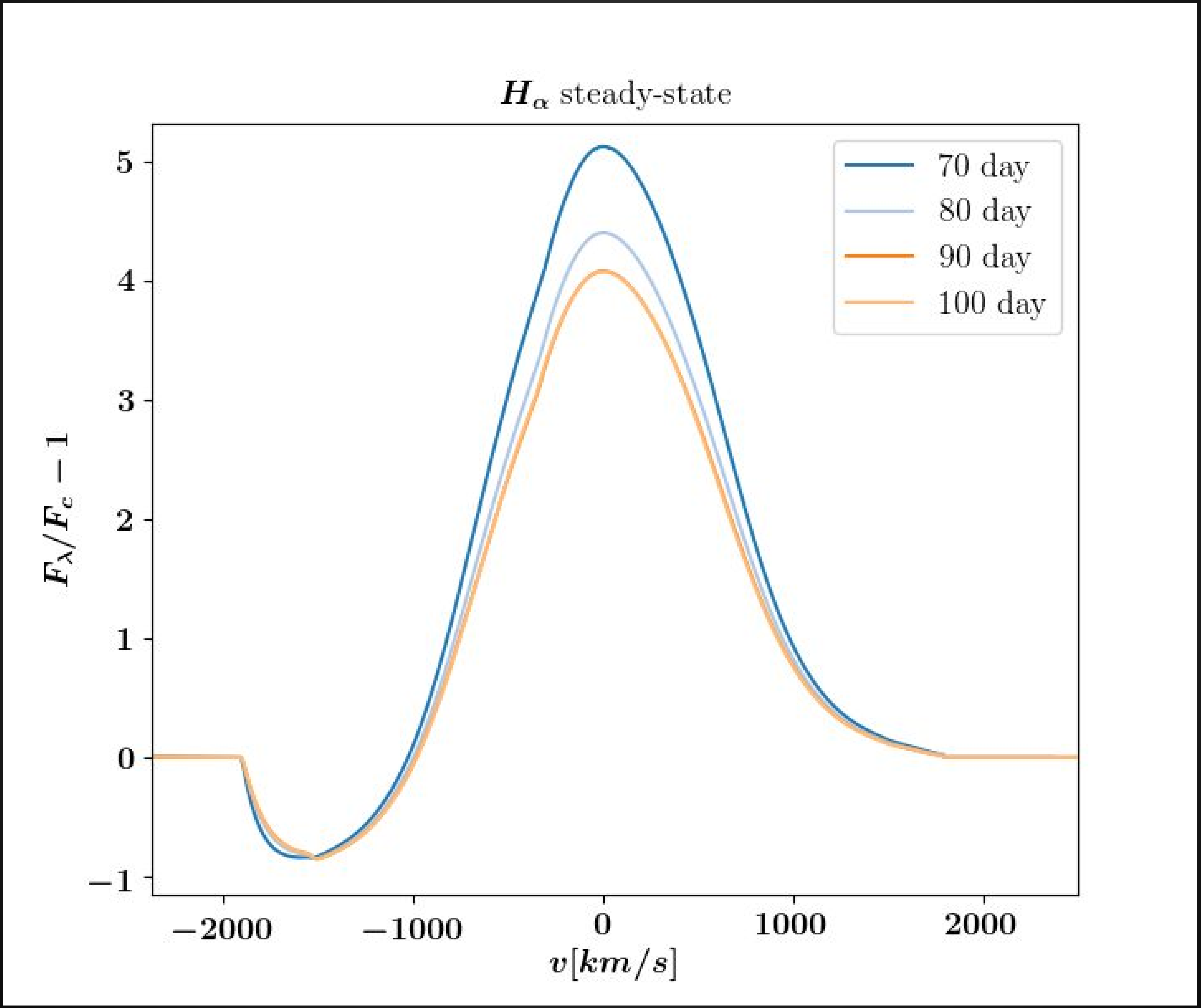


Rate equations

Line Transfer

Sobolev appr.

Steady-state approximation



Rate equations

$$\frac{\partial n_{\mathrm{z},\,i}}{\partial t} + div(n_{\mathrm{z},\,i}\overrightarrow{v}) = \sum_{j\neq i}(n_{\mathrm{z},\,j}P_{j,\,i} - n_{\mathrm{z},\,i}P_{i,\,j})$$

Rate equations

$$\frac{\partial n_{\mathrm{z},\,i}}{\partial t} + div(n_{\mathrm{z},\,i}\,\overrightarrow{v}) = \sum_{j\neq i}(n_{\mathrm{z},\,j}P_{j,\,i} - n_{\mathrm{z},\,i}P_{i,\,j})$$

time-dependent

$$\frac{\mathrm{D}n_{\mathrm{z},i}}{\mathrm{D}t} + \frac{3n_{\mathrm{z},\,i}}{t} = \sum_{j\neq i}(n_{\mathrm{z},\,j}P_{j,\,i} - n_{\mathrm{z},\,i}P_{i,\,j})$$

Rate equations

$$\frac{\partial n_{z,i}}{\partial t} + div(n_{z,i}\overrightarrow{v}) = \sum_{j \neq i}(n_{z,j}P_{j,i} - n_{z,i}P_{i,j})$$

time-dependent

$$\frac{\mathrm{D}n_{z,i}}{\mathrm{D}t} + \frac{3n_{z,i}}{t} = \sum_{j \neq i}(n_{z,j}P_{j,i} - n_{z,i}P_{i,j})$$

Rate equations

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time-dependent

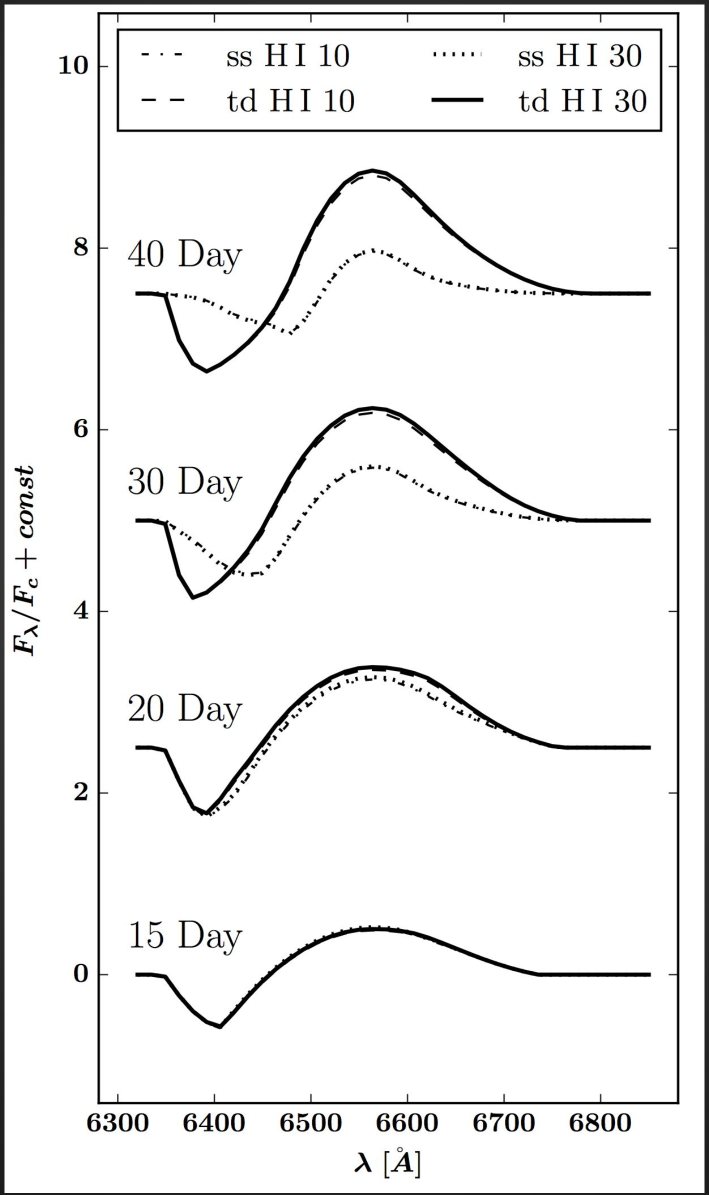
$$\frac{\mathrm{D}n_{\mathrm{z},\,i}}{\mathrm{D}t} + \frac{3n_{\mathrm{z},\,i}}{t} = \sum_{j\neq i}(n_{\mathrm{z},\,j}P_{j,\,i} - n_{\mathrm{z},\,i}P_{i,\,j})$$

steady-state approximation

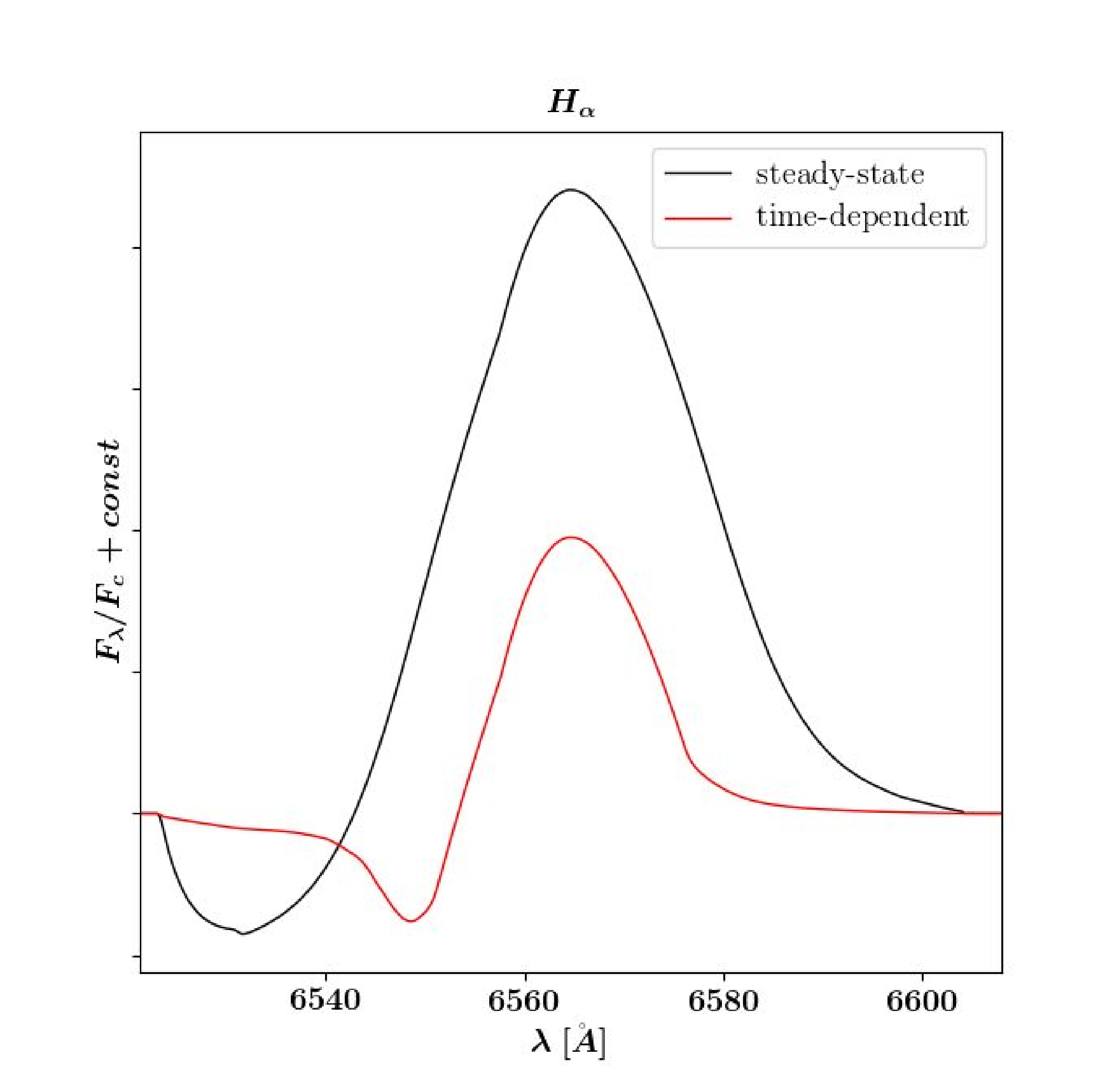
$$\sum_{j\neq i}(n_{\mathrm{z},\,j}P_{j,\,i} - n_{\mathrm{z},\,i}P_{i,\,j}) = 0$$

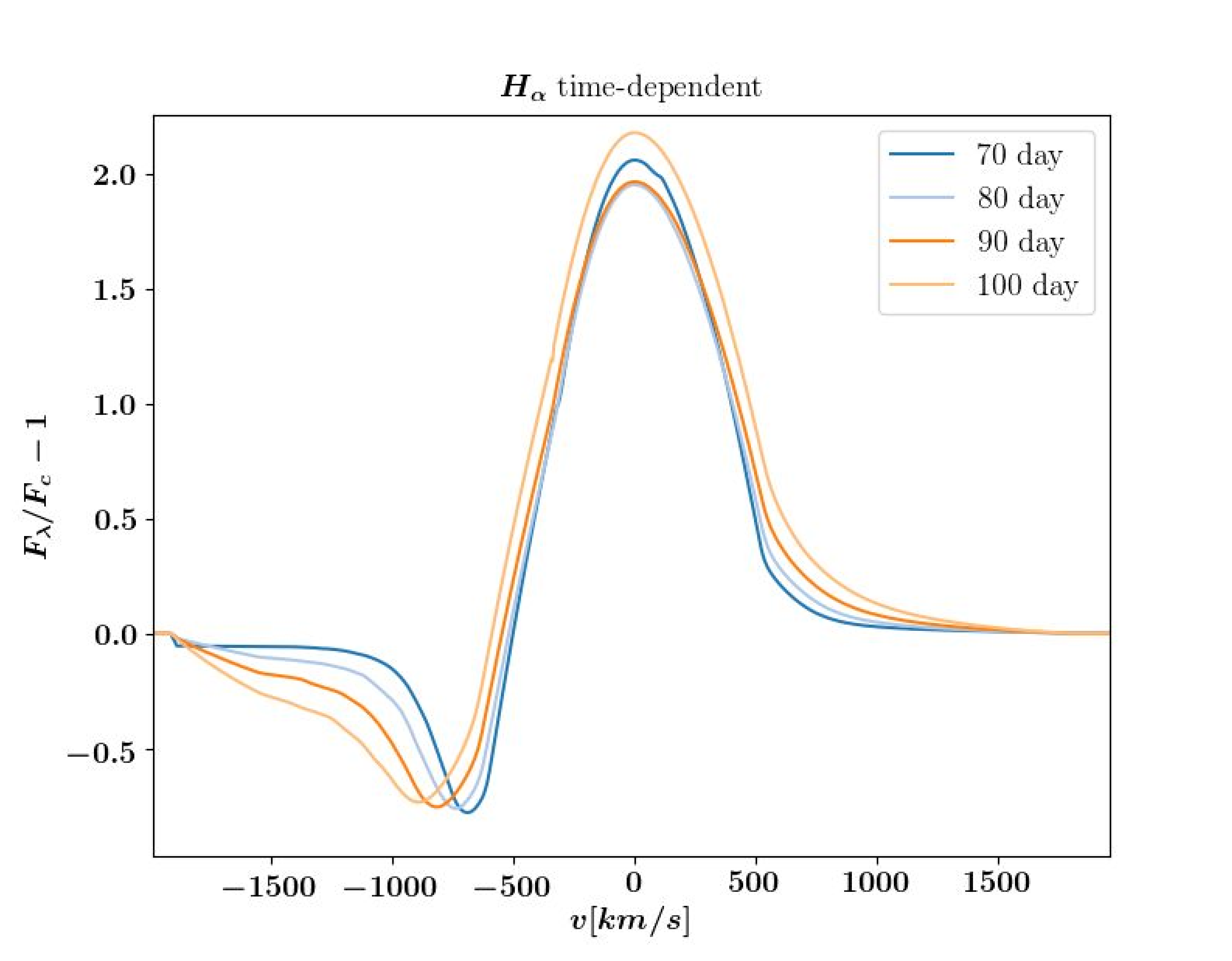
Time-dependence is important! SN 1999em, Prev. result

Potashov, M. S., Blinnikov, S. I., & Utrobin, V. P. (2017), Astronomy Letters, 43(1), 36–49.



Time-dependent effect has inverse sign!

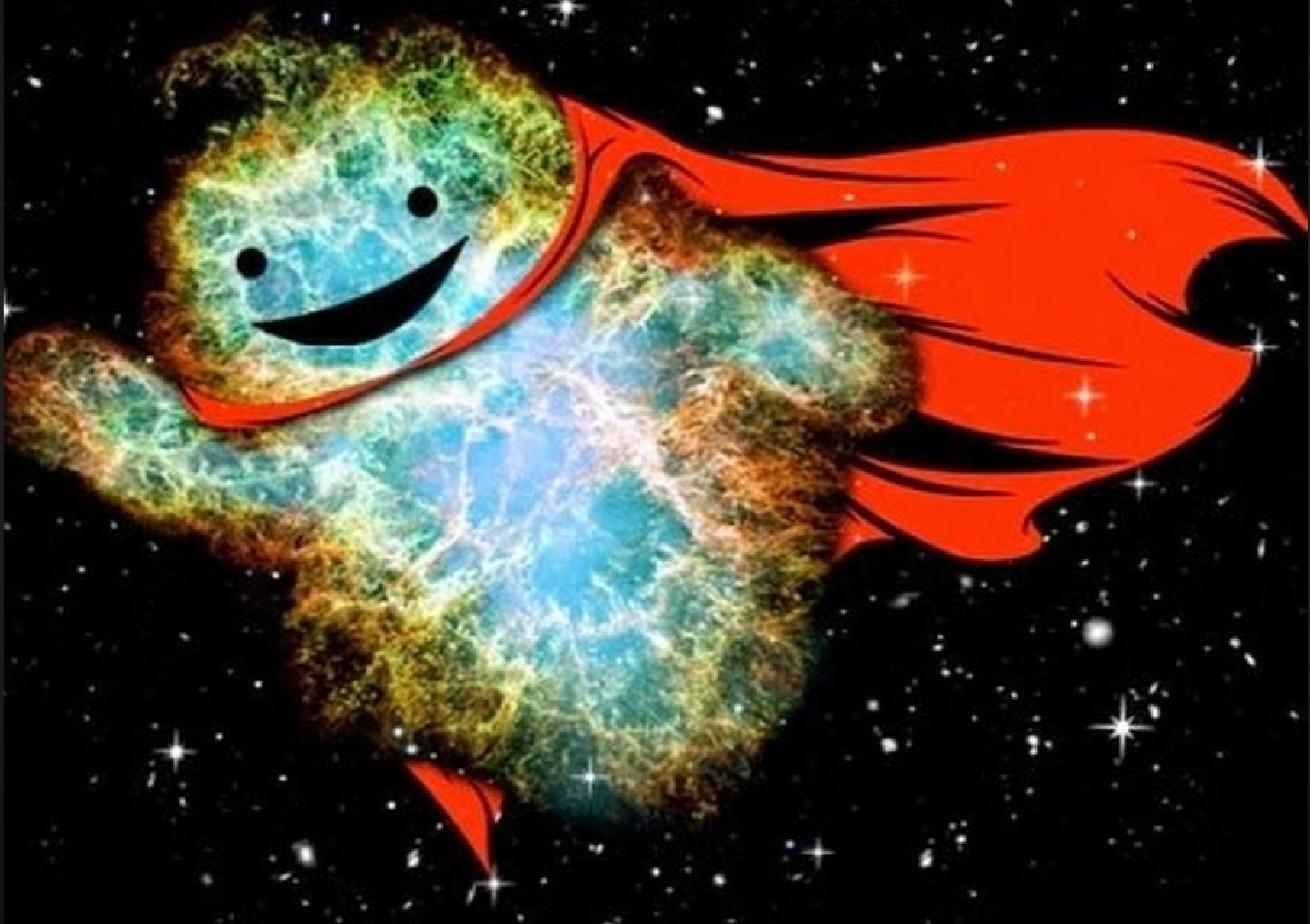



H_α time-dependent
70 day
80 day
90 day
100 day
2.0
1.5
1.0
0.5
0.0
−0.5
$F_\lambda/F_c - 1$
−1500
−1000
−500
0
500
1000
1500
$v[km/s]$

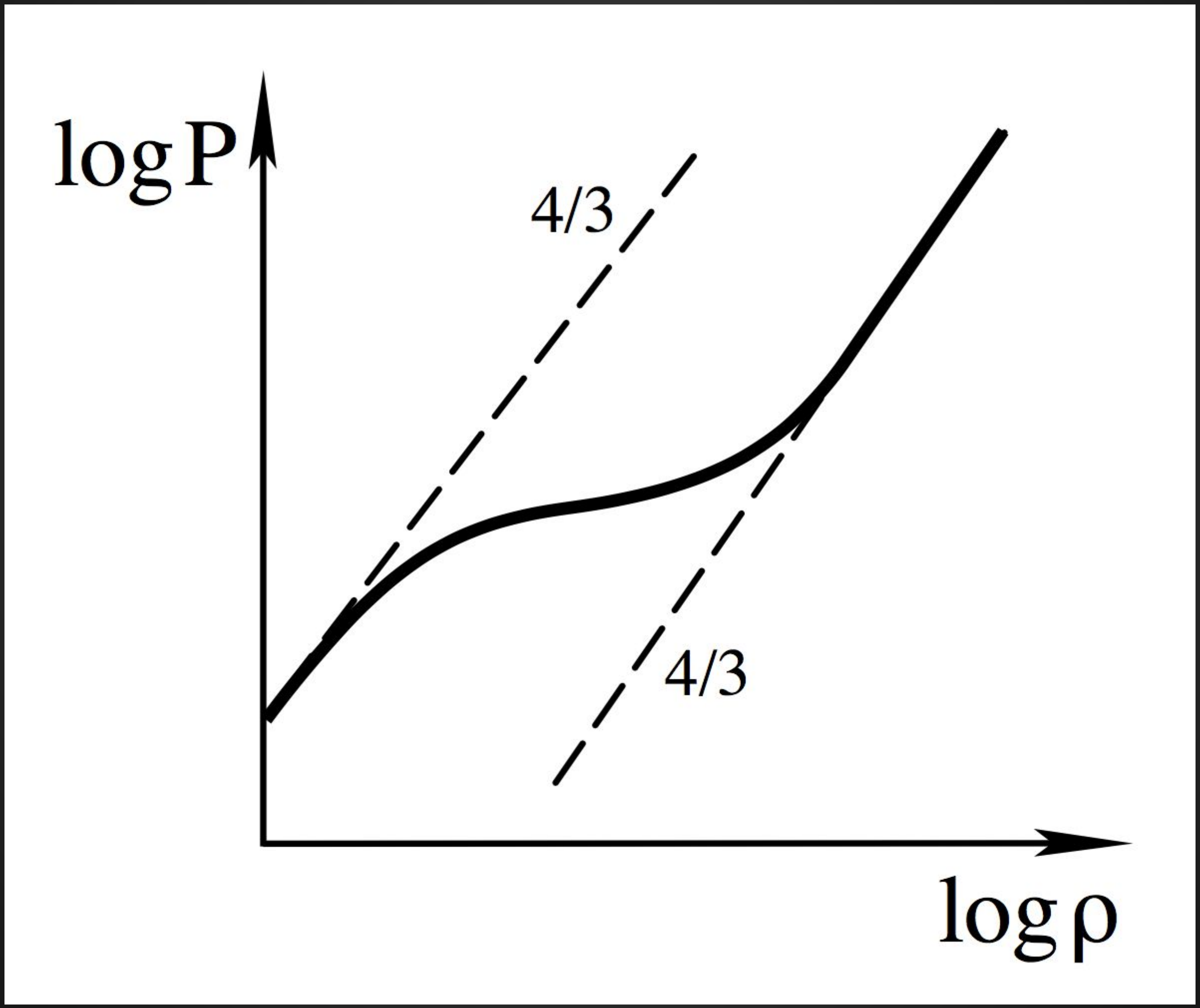
Conclusions

- Taking into account of time-dependent effect in PPISN model allows to explain small velocities in the narrow components of spectral lines.
- Time-dependent effect decreases the strength of lines unlike of ordinary SNIIP.

Thank you!



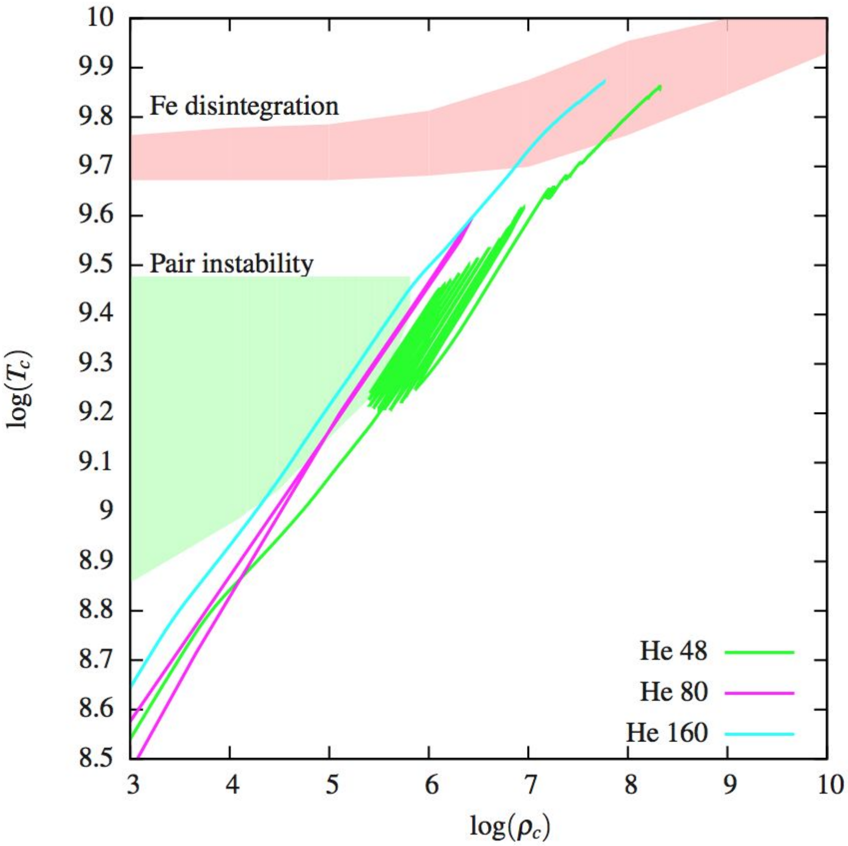
Pulsational pair-instability (PPI) SN



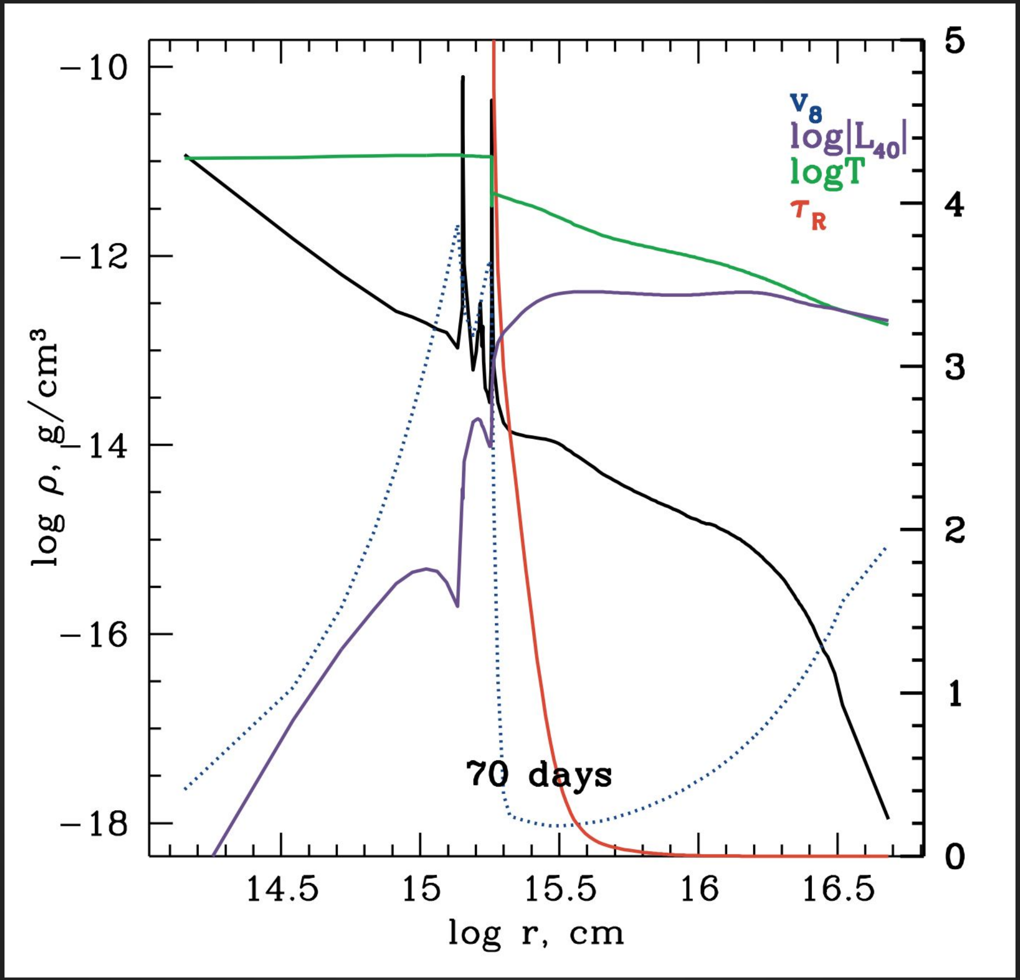
$$\gamma \leqslant \frac{4}{3}$$

Pulsational pair-instability (PPI) SN

Here are only He-core models, labeled by “He” and the mass of the core. They all reach pair instability, subsequently experiencing 1) pulsations (He48),
2) complete disruption (He80), or
3) direct collapse (He160).

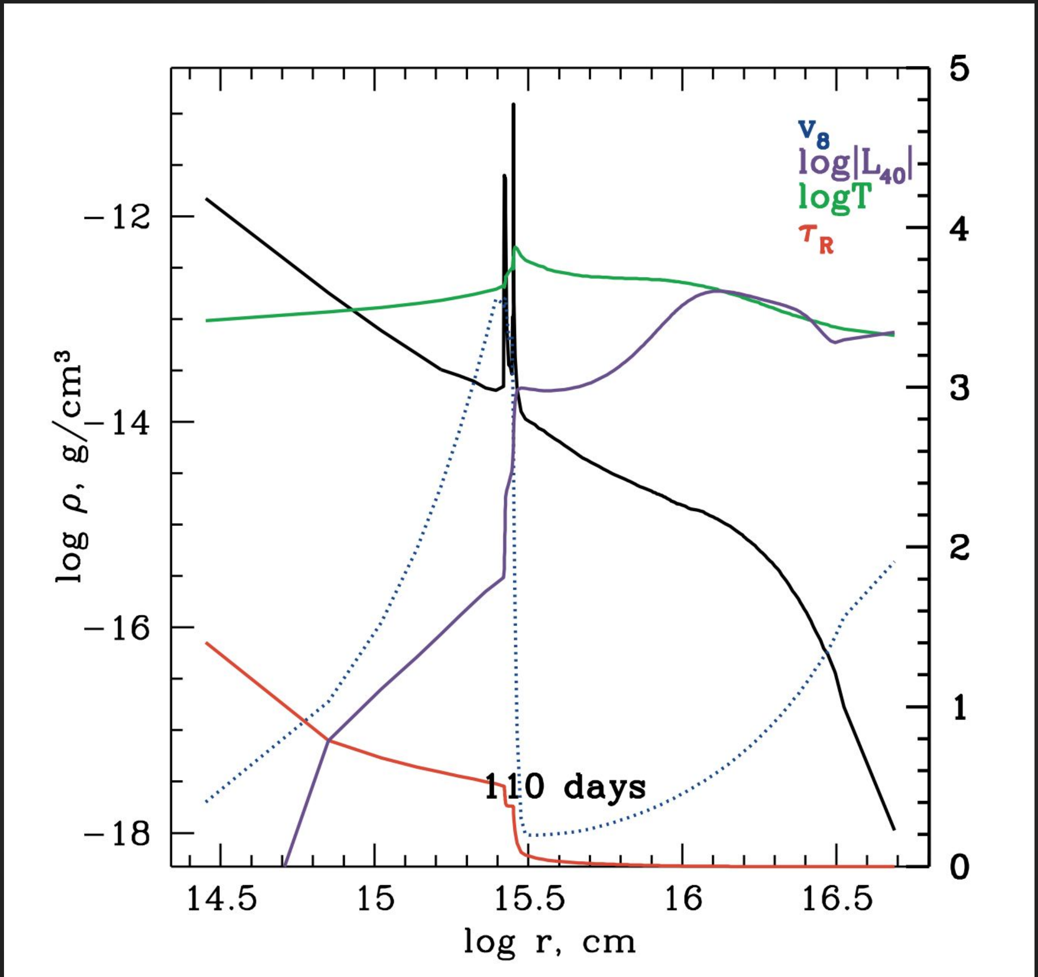


SN 2006gy - Photospheric structure at 70 days.



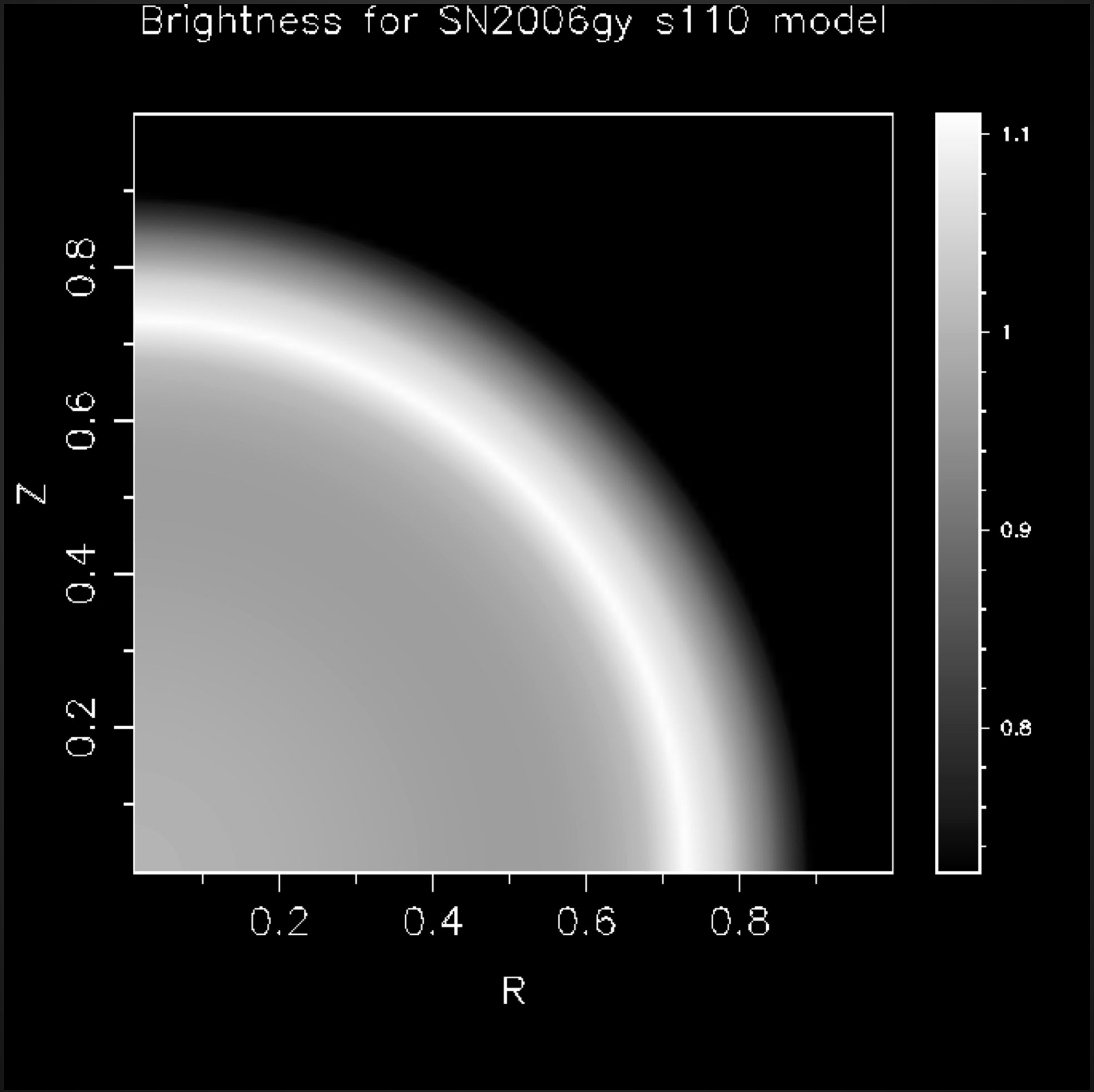
Woosley, S. E., Blinnikov, S. I., & Heger, A. (2007), Nature, 450(7168), 390–392

SN 2006gy - Photospheric structure at 110 days.

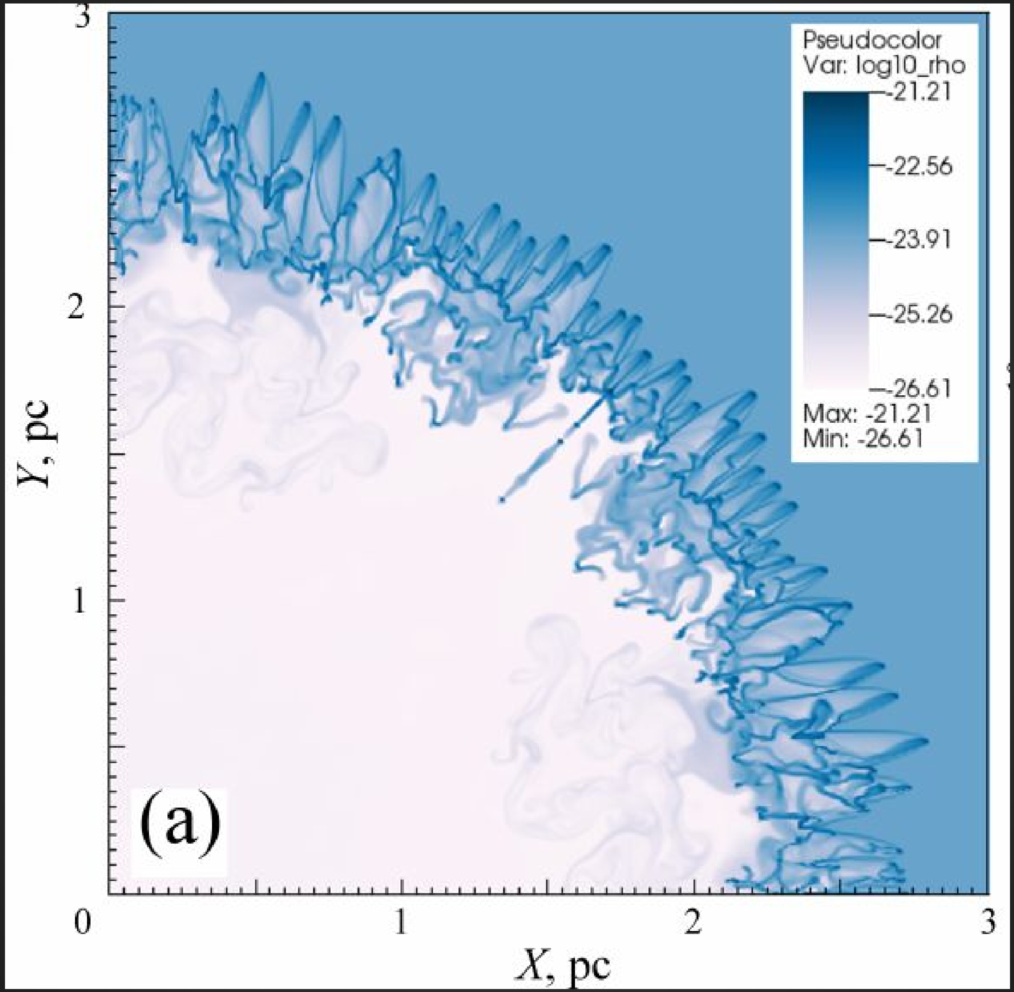


Woosley, S. E., Blinnikov, S. I., & Heger, A. (2007), Nature, 450(7168), 390–392

‘Visible’ disk of SN 2006gy



Development of new patterns of 3D-instability



Badjin, D. A., Glazyrin, S. I., Manukovskiy, K. V., & Blinnikov, S. I. (2016), MNRAS 459(2), 2188–2211

Background continuum:

For the ultraviolet and optical bands ($\nu < \nu_{LyC}$) we use the approximation of an optically thin medium (black body). For the hard frequency range ($\nu \geqslant \nu_{LyC}$), we assume a thermodynamic equilibrium between radiation and matter.

Potashov, M.Sh., Blinnikov, S.I., & Utrobin, V.P. (2017), *Astronomy Letters*, 43 (1), 36-49

LEVELS

Rate equations

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Sobolev appr.