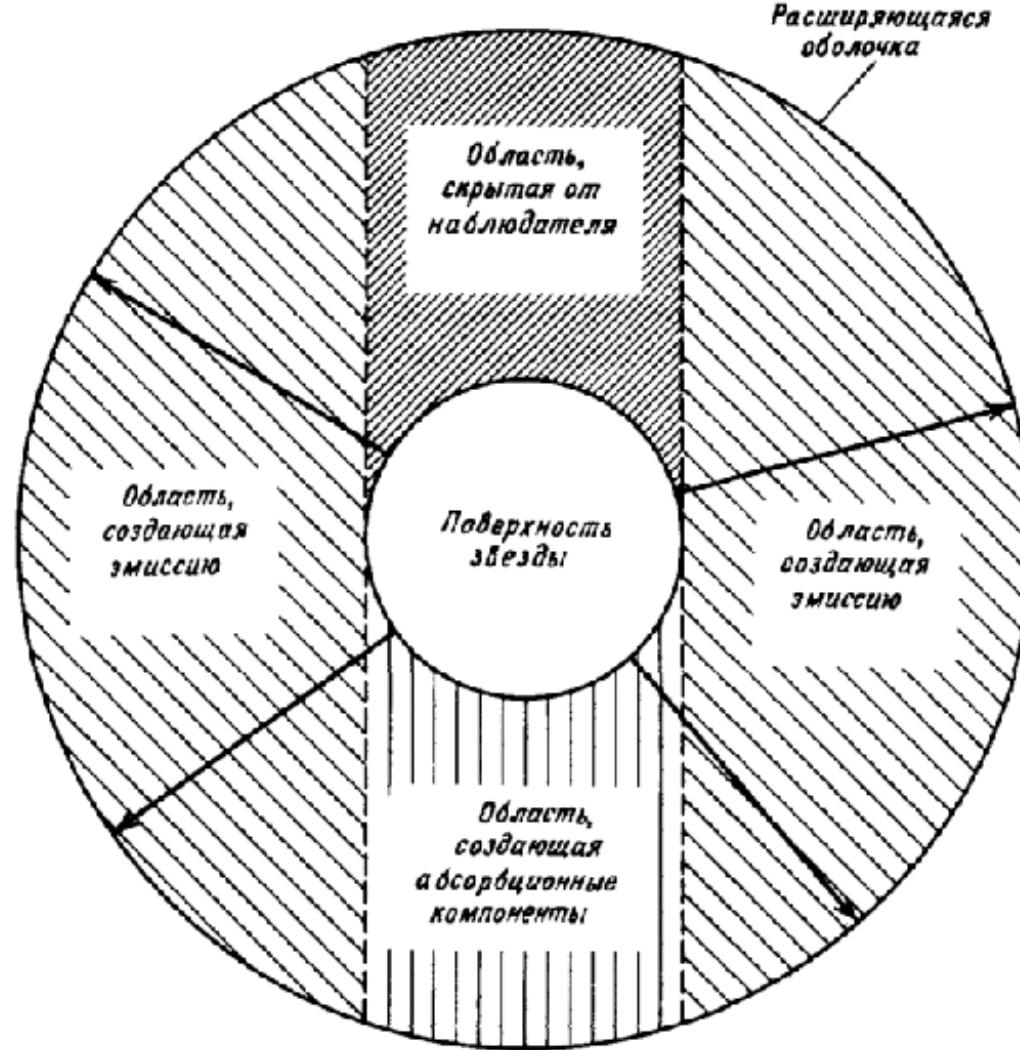


Non-trivial effects of level populations calculation in SNe II atmospheres

Potashov M. Sh.
Blinnikov S. I.
Dolgov A. D.



Наблюдатель

Rate equations

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

Rate equations

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

time-dependent

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

Rate equations

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

time-dependent

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

Rate equations

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

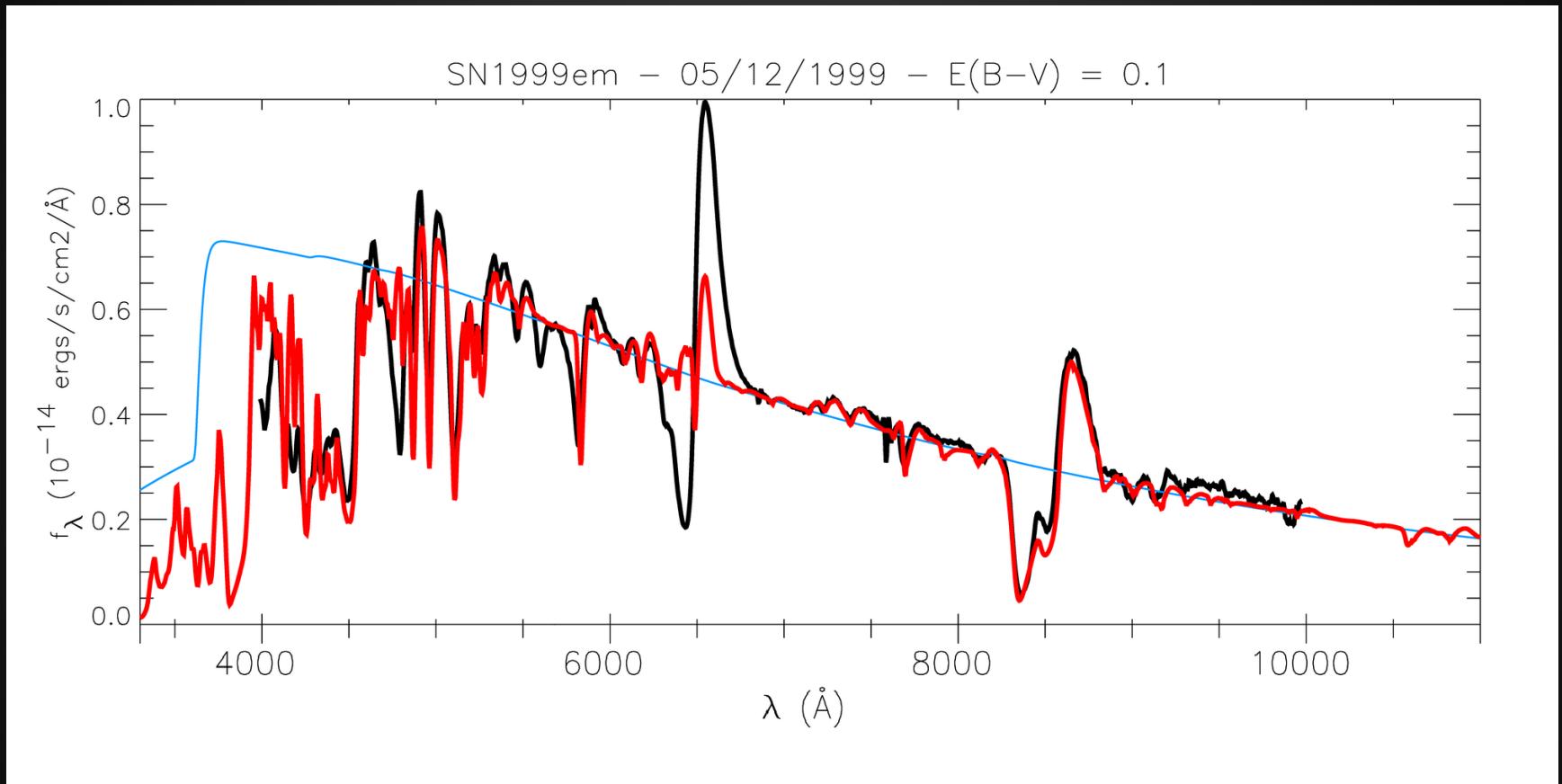
time-dependent

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

steady-state approximation

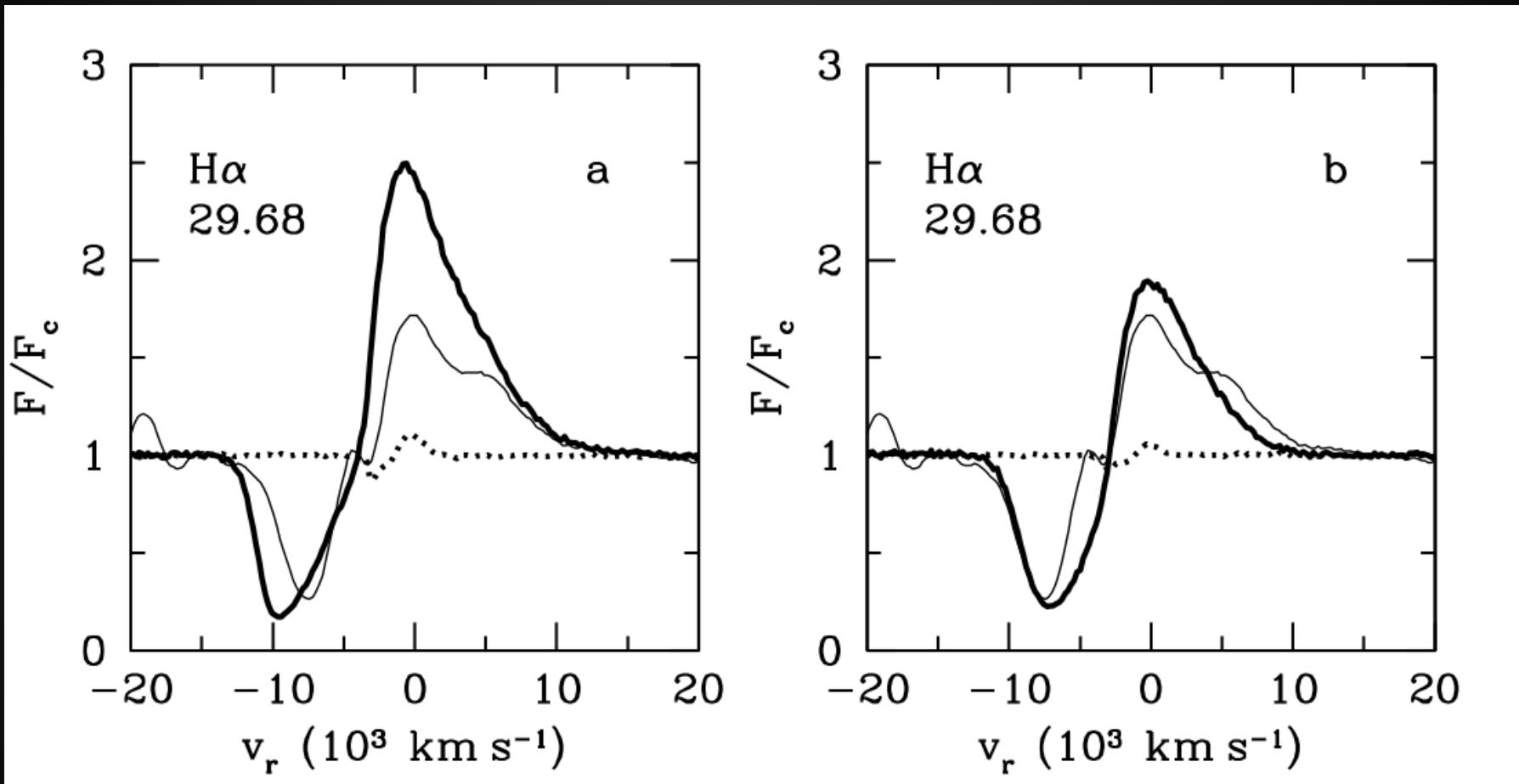
$$\sum_{j \neq i} (n_{z,j} P_{j,i} - n_{z,i} P_{i,j}) = 0$$

Weak line H- α , SN 1999em, 37 day



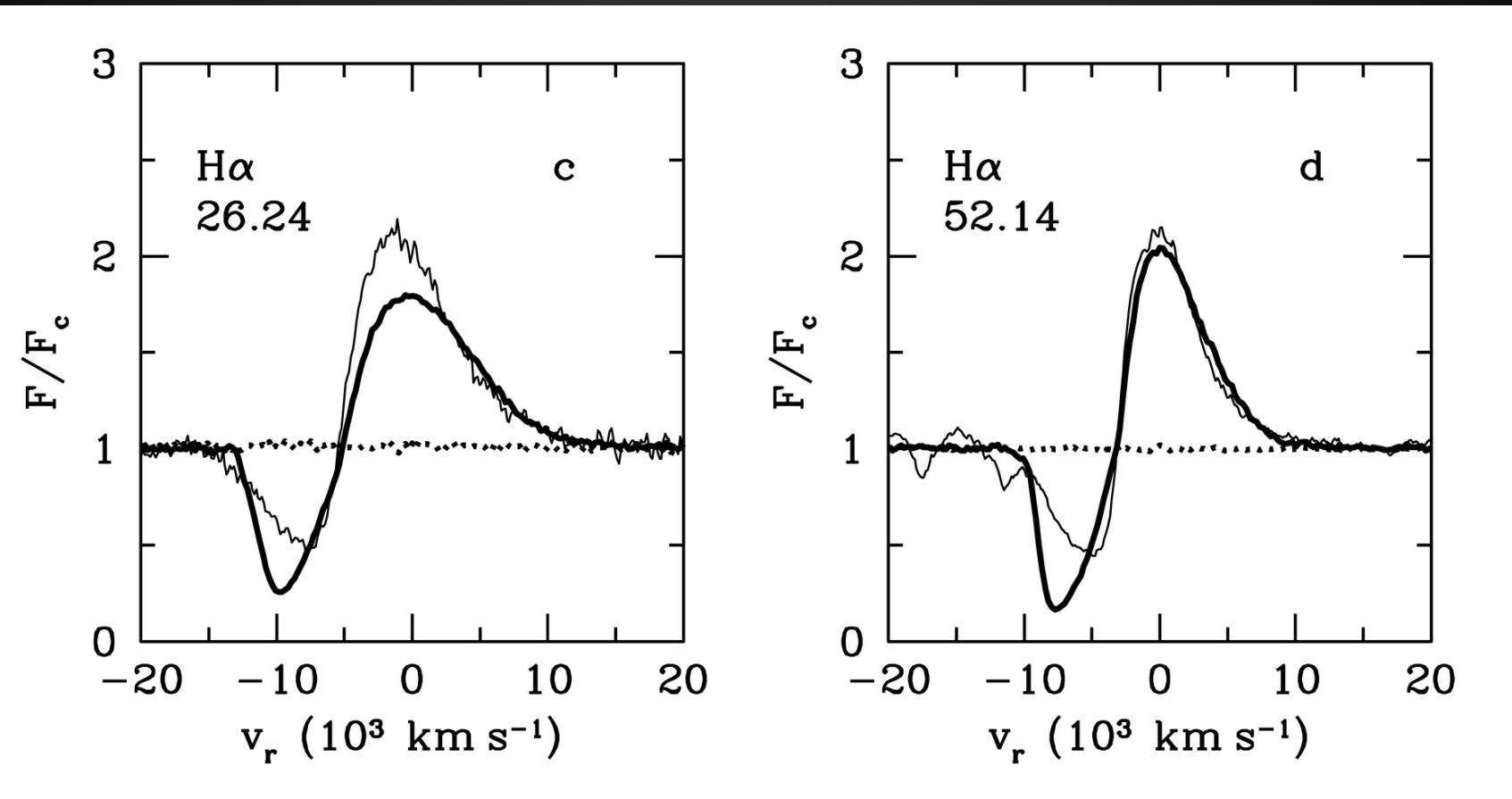
Dessart, L., Hillier, J. 2006, A&A 447, 691–707, CMFGEN

Time-dependent, SN 1987A, ~30 day



Utrobin, V., Chugai N. 2005, A&A 441, 271–281

Time-dependent, SN 1999em, 26 и 52 дни



Utrobin, V. P. 2007, A&A 461, 233–251

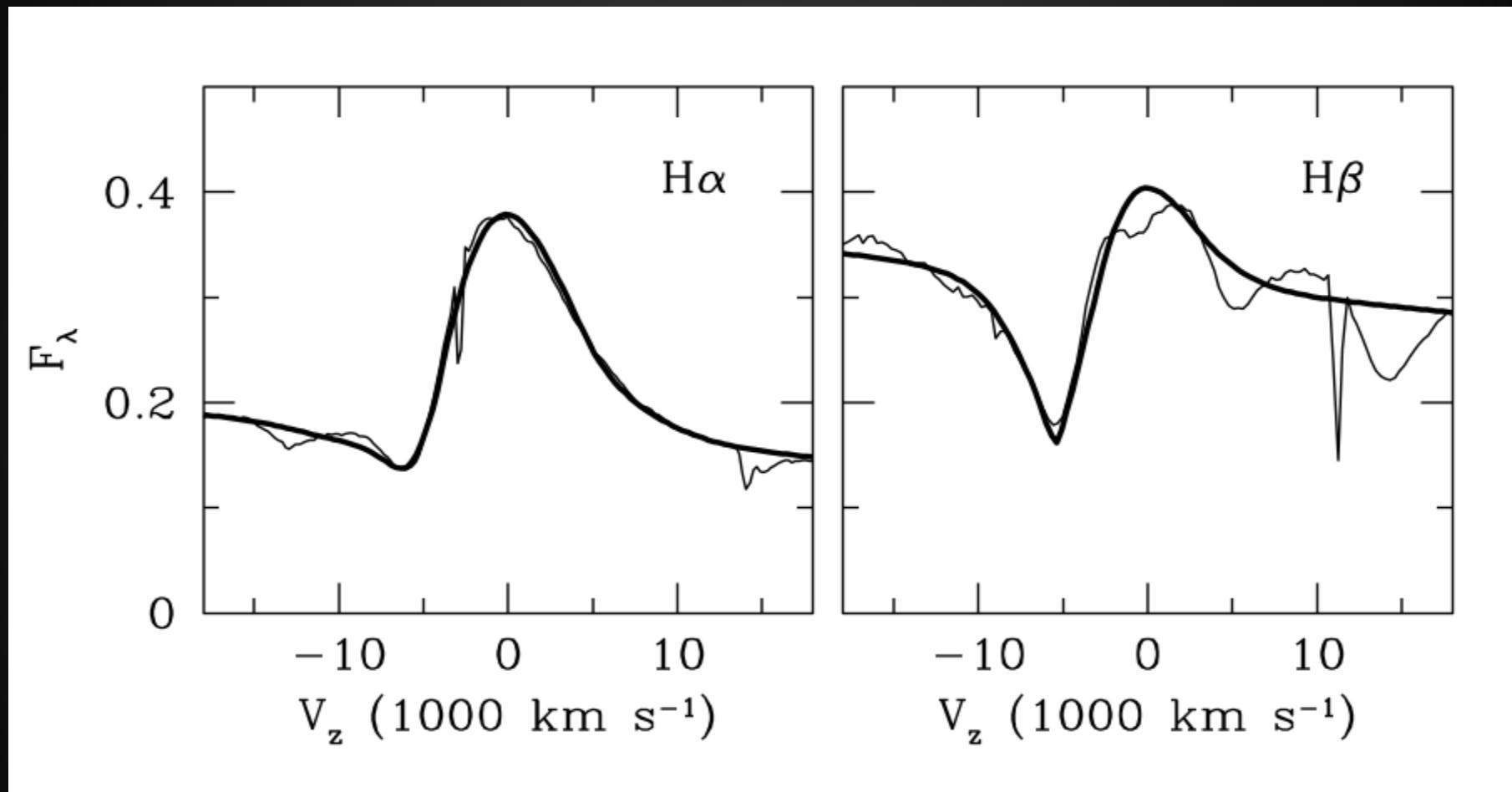
When the time dependence is important?

SN 1999em, 26 and 52 days

phase. Thus, it is possible to conclude that the hydrogen recombination in the atmosphere of SN 1999em during the whole plateau phase is essentially a time-dependent phenomenon.

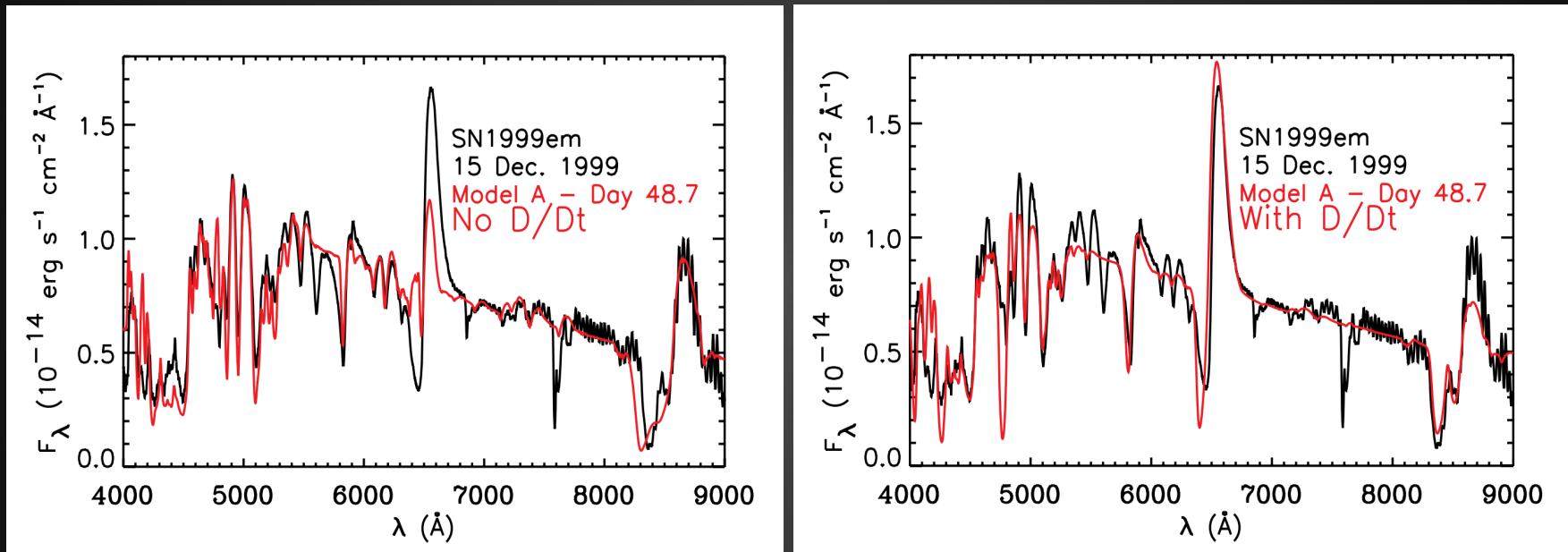
Utrobin, V. P. 2007, A&A 461, 233–251

Time-dependent, SN 2008in, ~18 день



Utrobin, V., Chugai N. 2013, 2013arXiv1309.7814C

Time-dependent, SN 1999em, 48 day



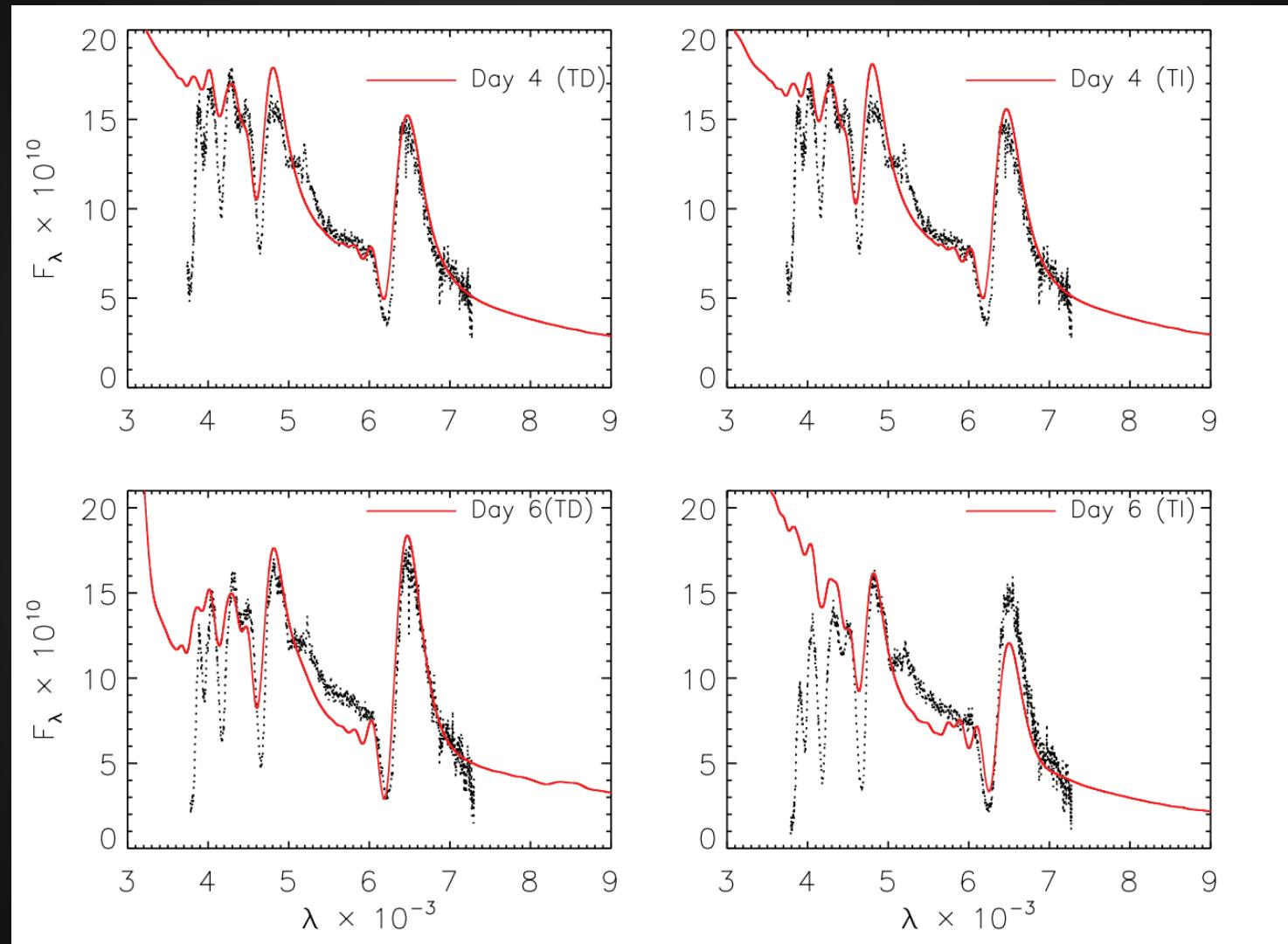
Dessart, L., Hillier, J. 2007, MNRAS 383, 57–74, CMFGEN

When the time dependence is important?

Time-dependent terms in the statistical- and radiative-equilibrium equations become important a few weeks after explosion (Utrobin & Chugai 2005; Dessart & Hillier 2007a,b).

Dessart, L. et al. 2008, ApJ 675, 644–669

Time-dependent, SN 1987A, 4 and 6 days



When the time dependence is important?

SN 1987A also supports the importance of time-dependent rate equations. Therefore, we conclude that time dependence is more important at early times than later times. The effect of multilevel atoms can be seen in Fig. 9 which clearly shows that even at later

De, S., Baron, E. et al. 2010, MNRAS 401, 2081–2092

Contradiction

Utrobin & Chugai Dessart & Hillier

Plateau phase

De & Baron

At early times

STELLA

STELLA



Hydrodynamics

Thermodynamics

Continuum

STELLA

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

Hydrodynamics

Thermodynamics

Continuum

STELLA

LTE

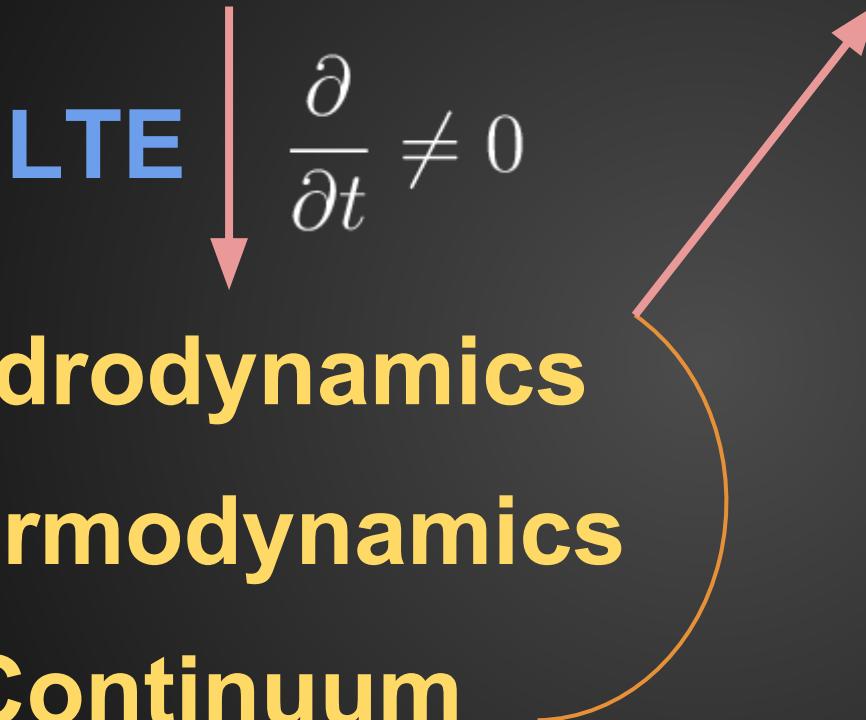
LEVELS

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

Hydrodynamics

Thermodynamics

Continuum



STELLA

LTE

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

LEVELS

Rate equations

Line Transfer

Sobolev appr.

Hydrodynamics

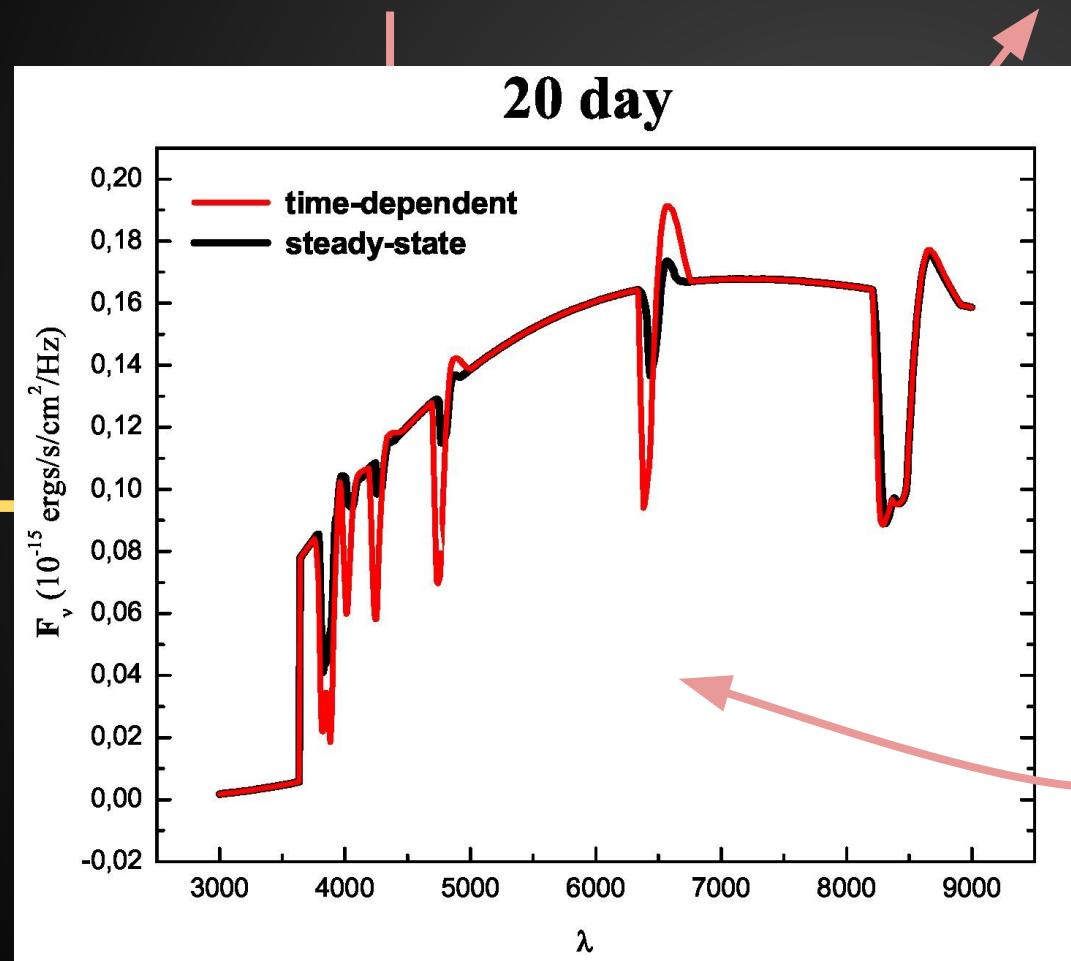
Thermodynamics

Continuum



STELLA

LEVELS



Rate equations
Line Transfer
Sobolev appr.

STELLA

LTE

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

LEVELS

Rate equations

Line Transfer
Sobolev appr.

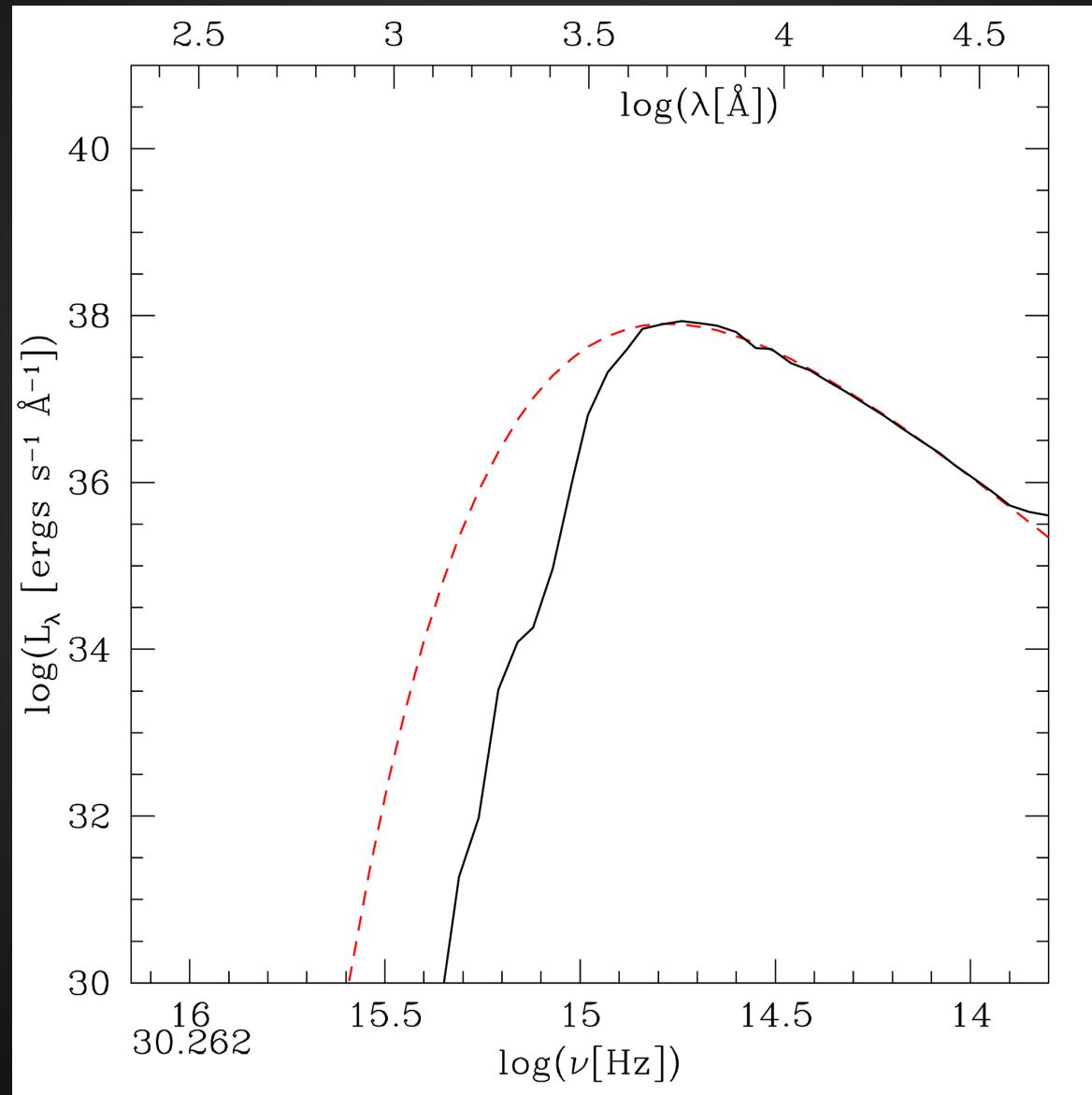
Hydrodynamics

Thermodynamics

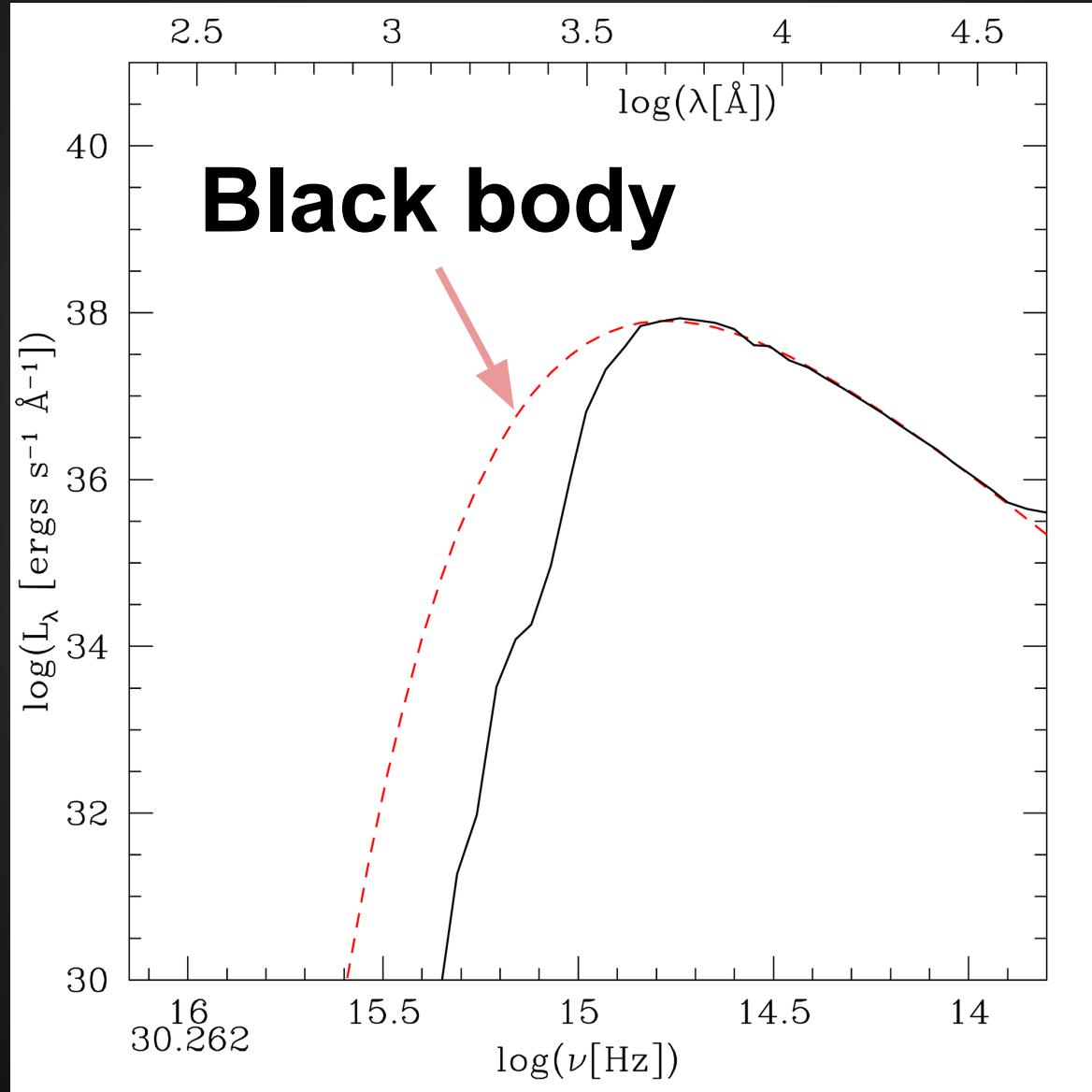
Continuum

no self-consistent continuum!

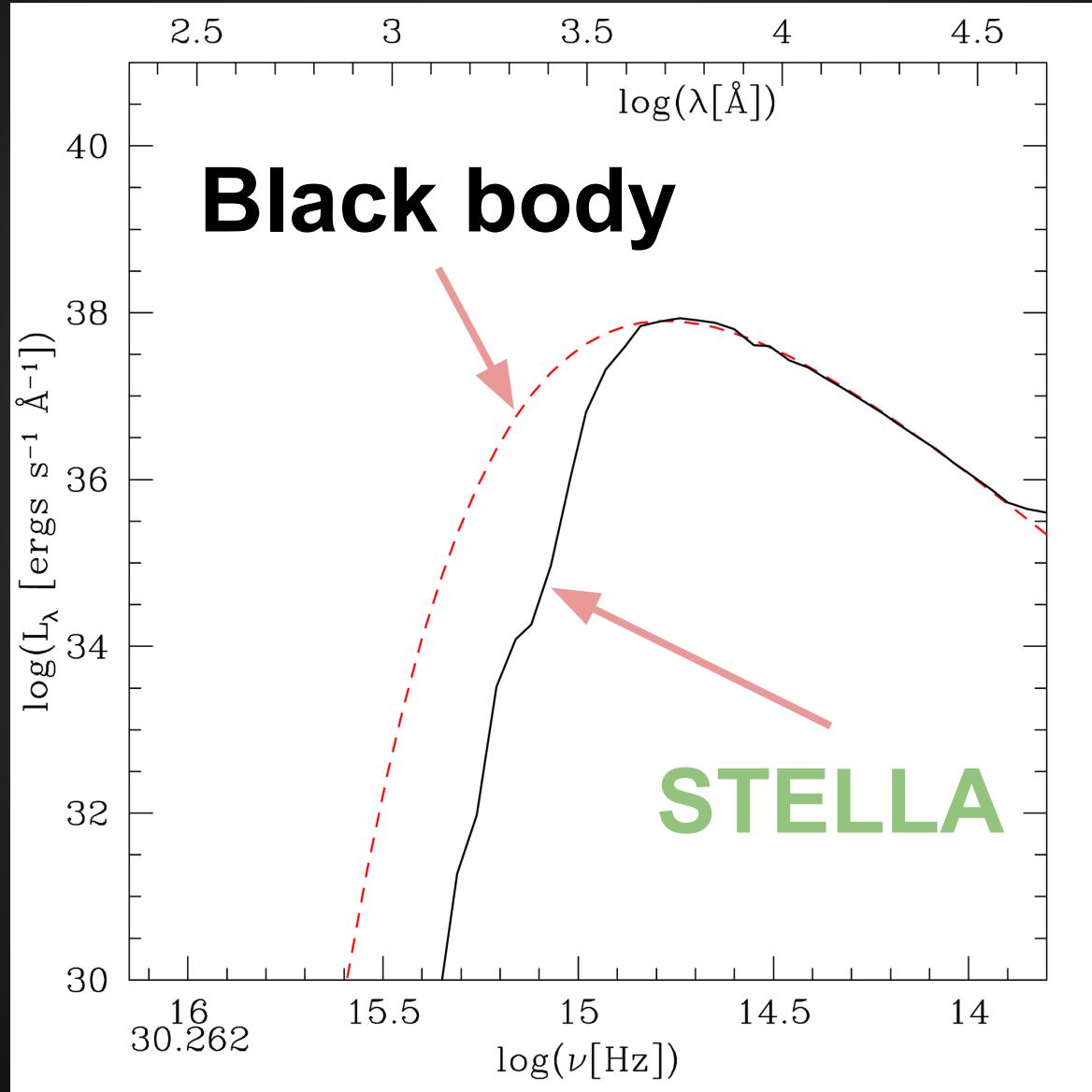
Continuum radiation



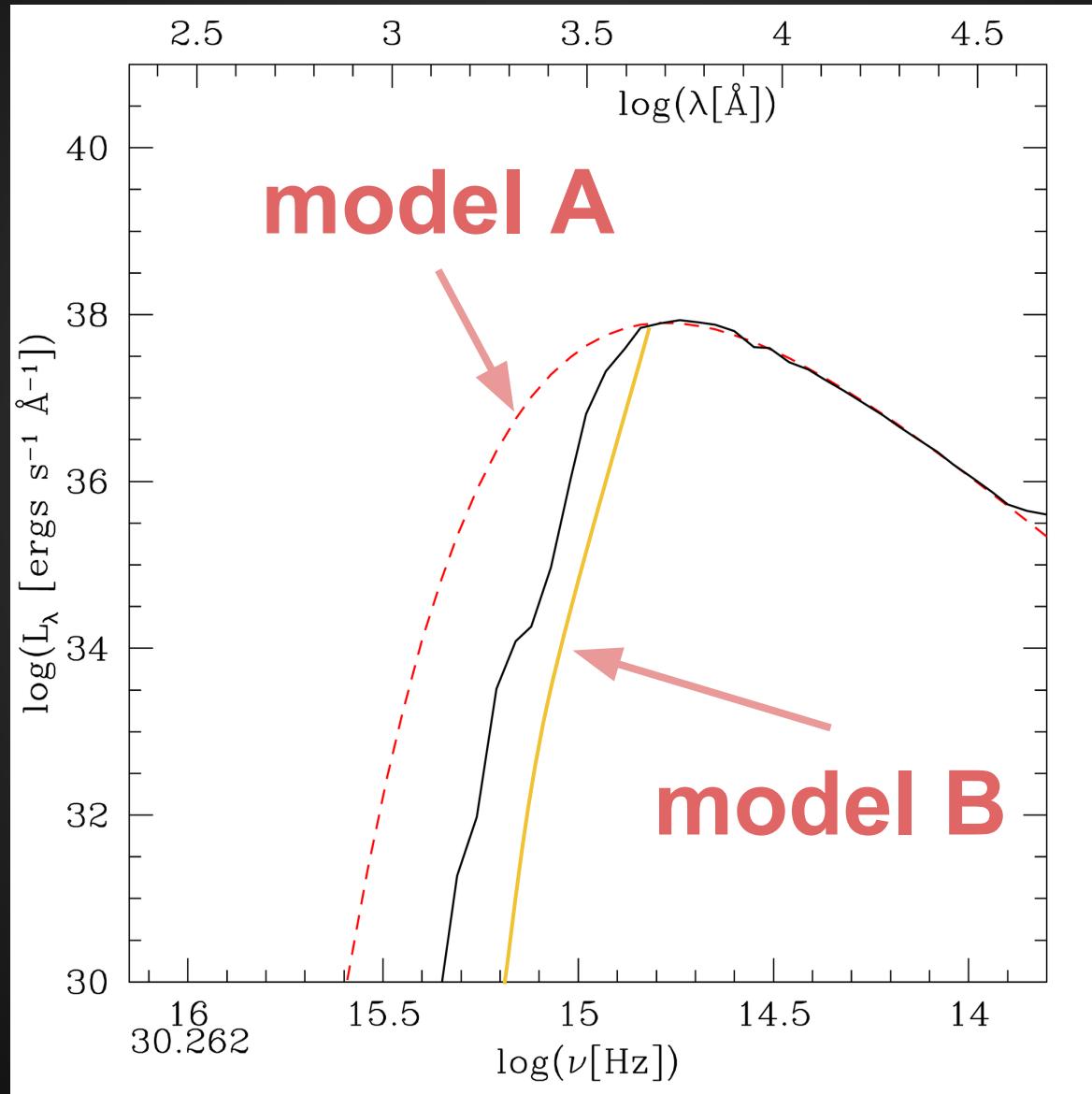
Continuum radiation



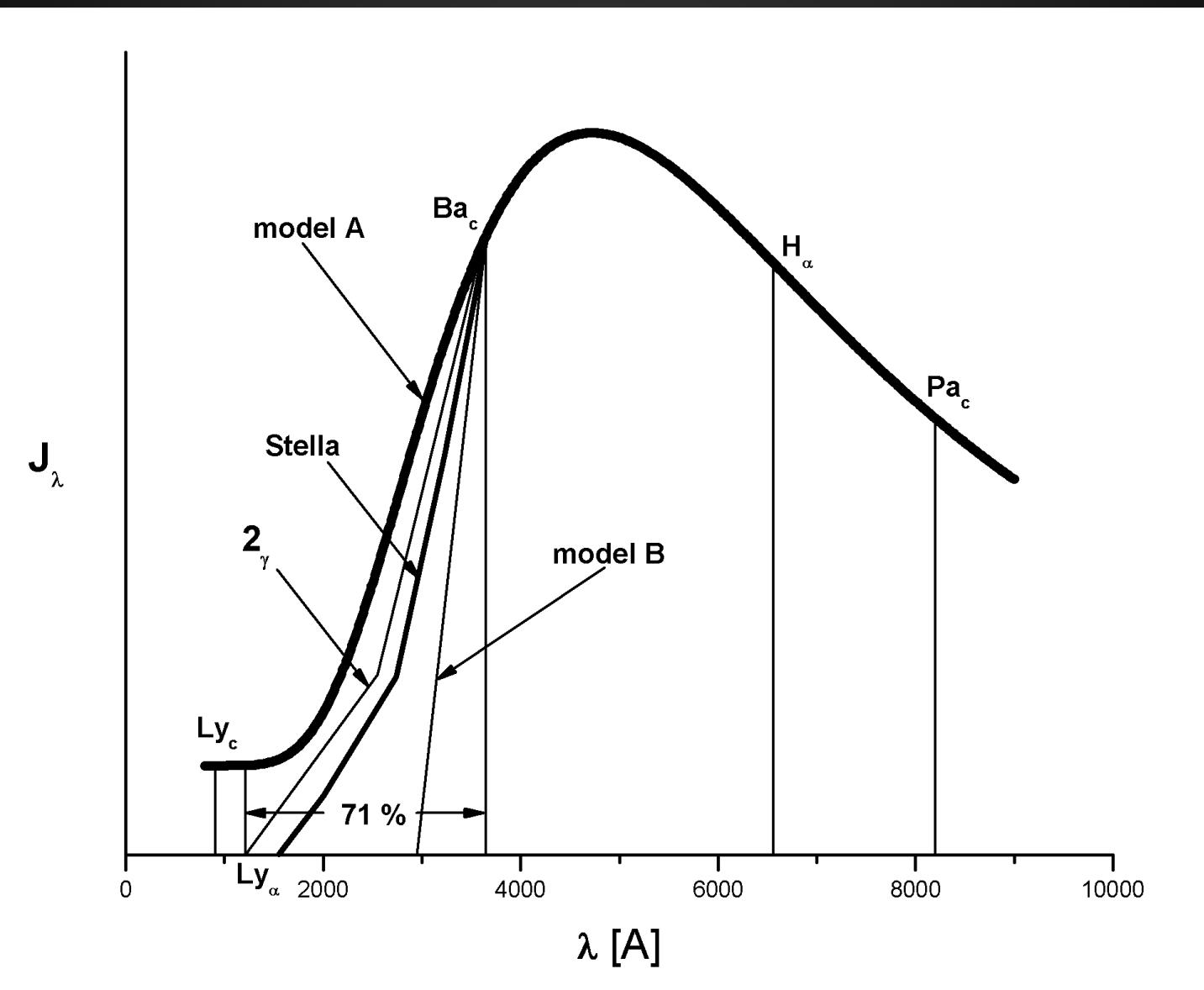
Continuum radiation



Continuum radiation



Continuum radiation



Importance of the I-splitting



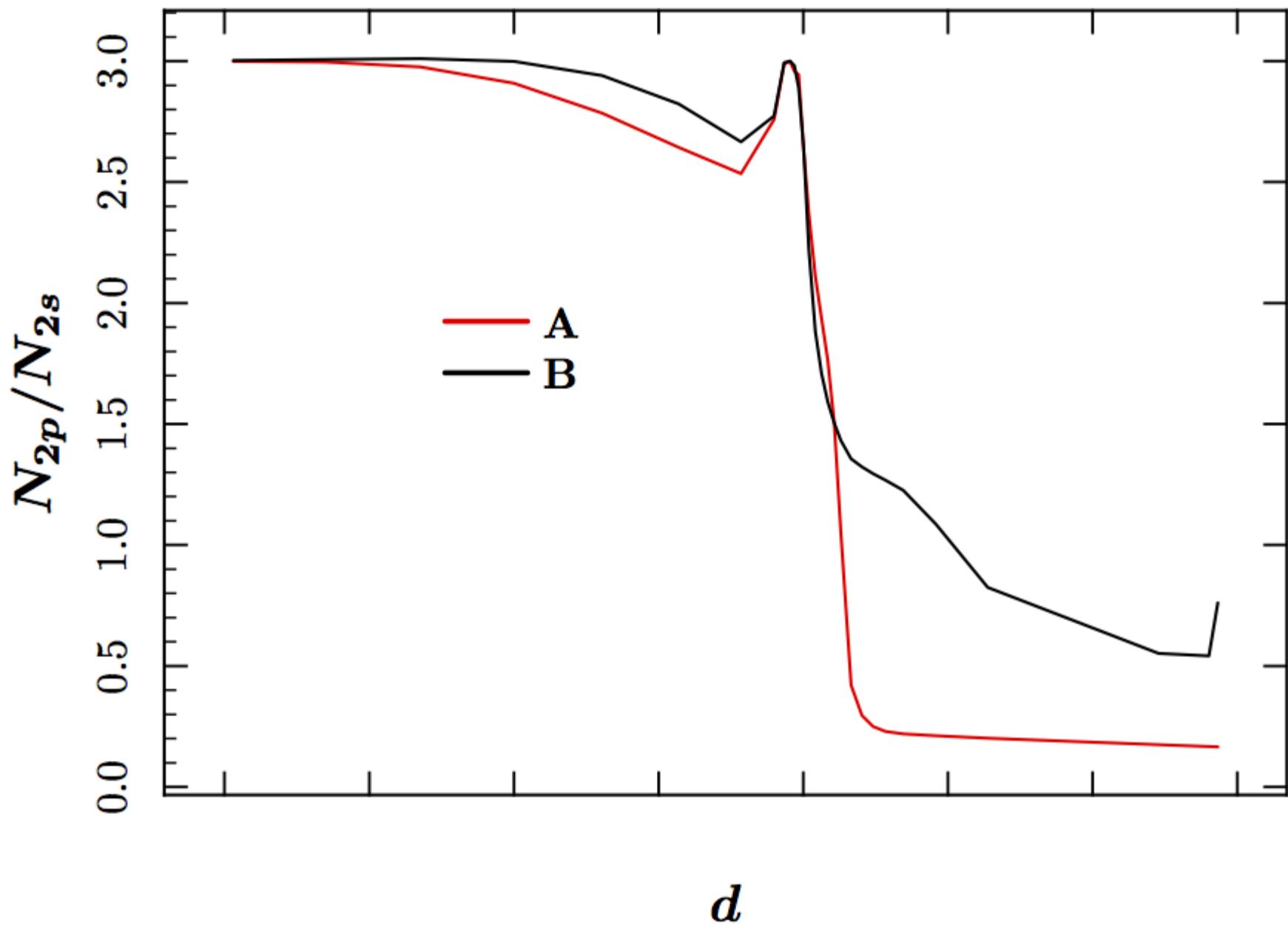
**NO SE among
I sublevels**

The Flexible Atomic Code (FAC)

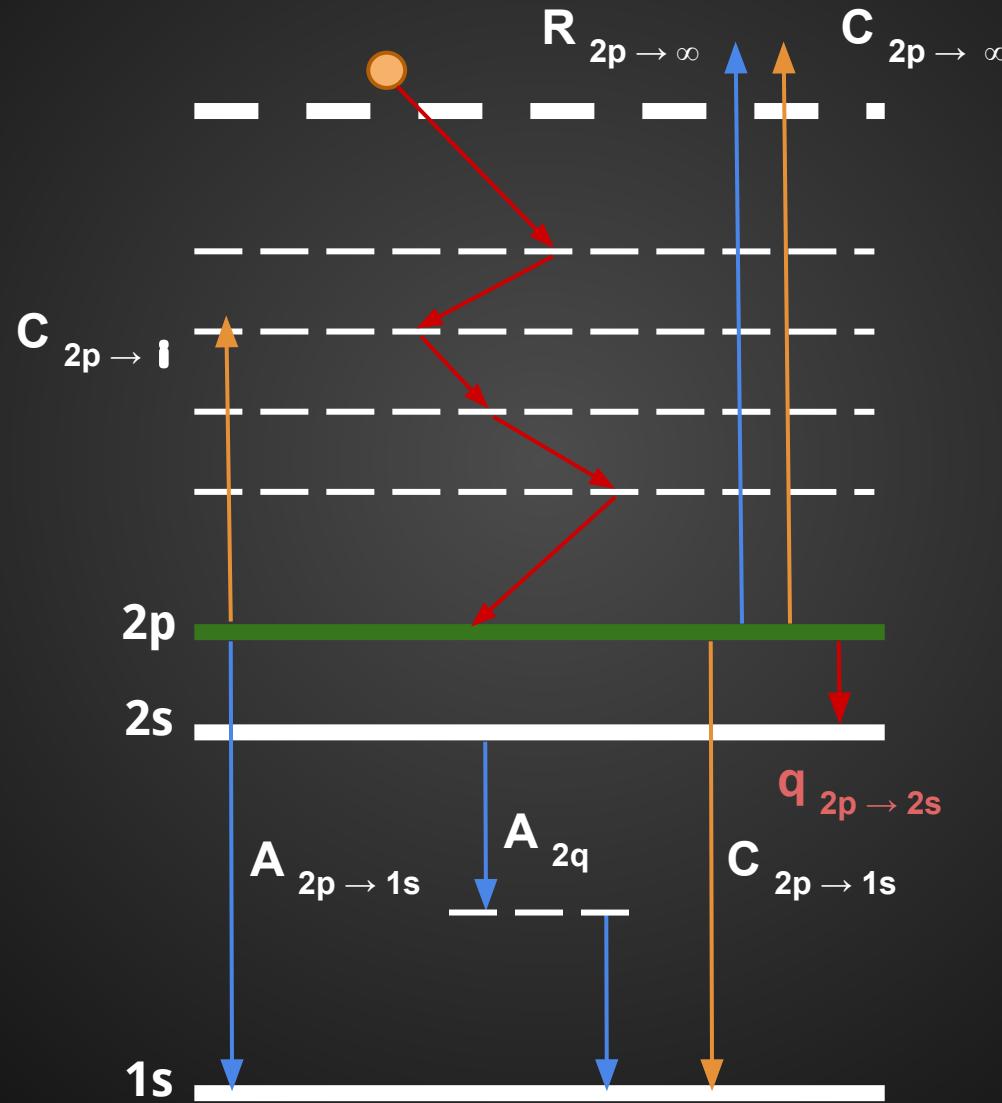
Ming Feng Gu

Hydrogen star
100 level + continuum

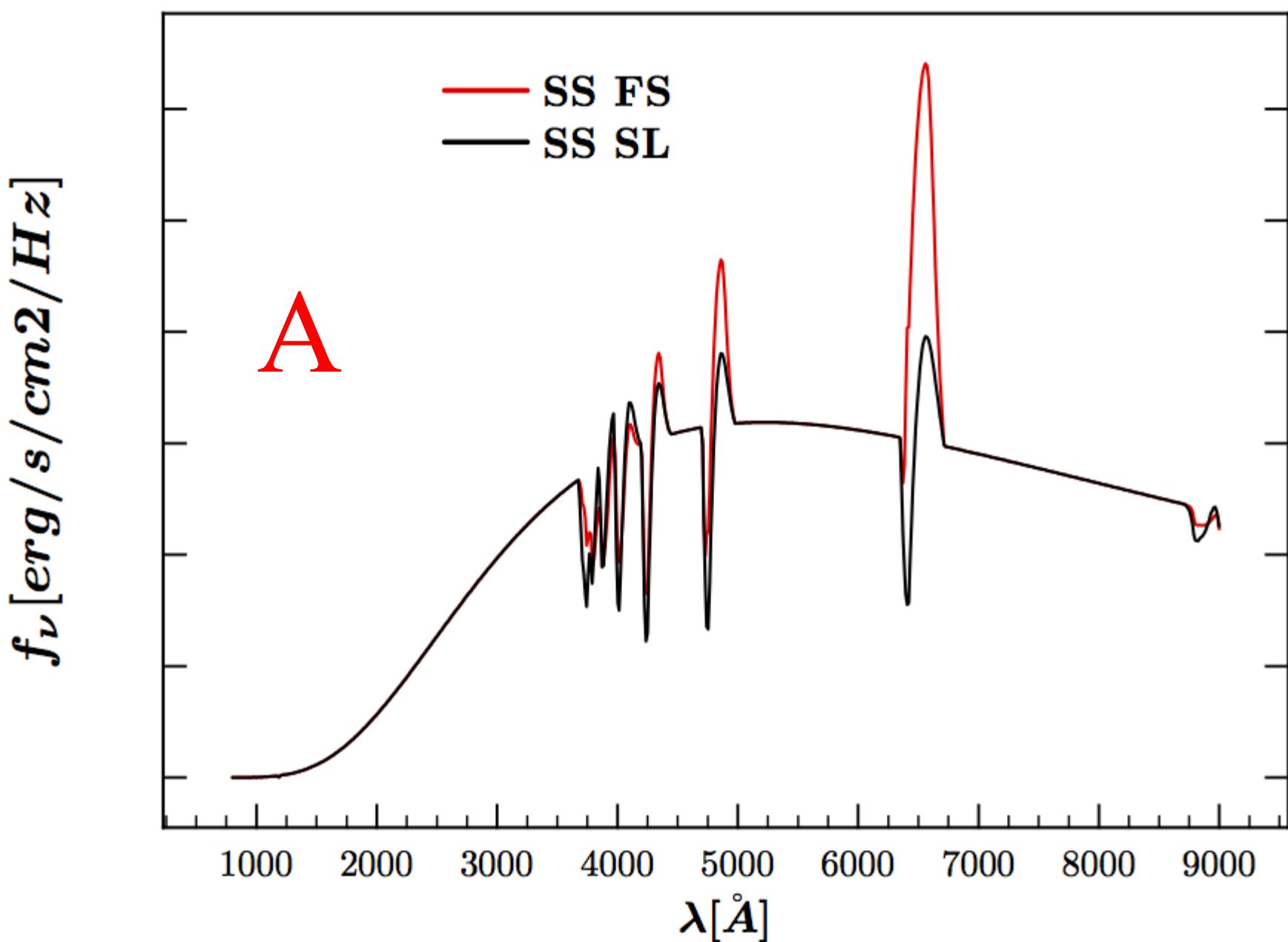
10 day H



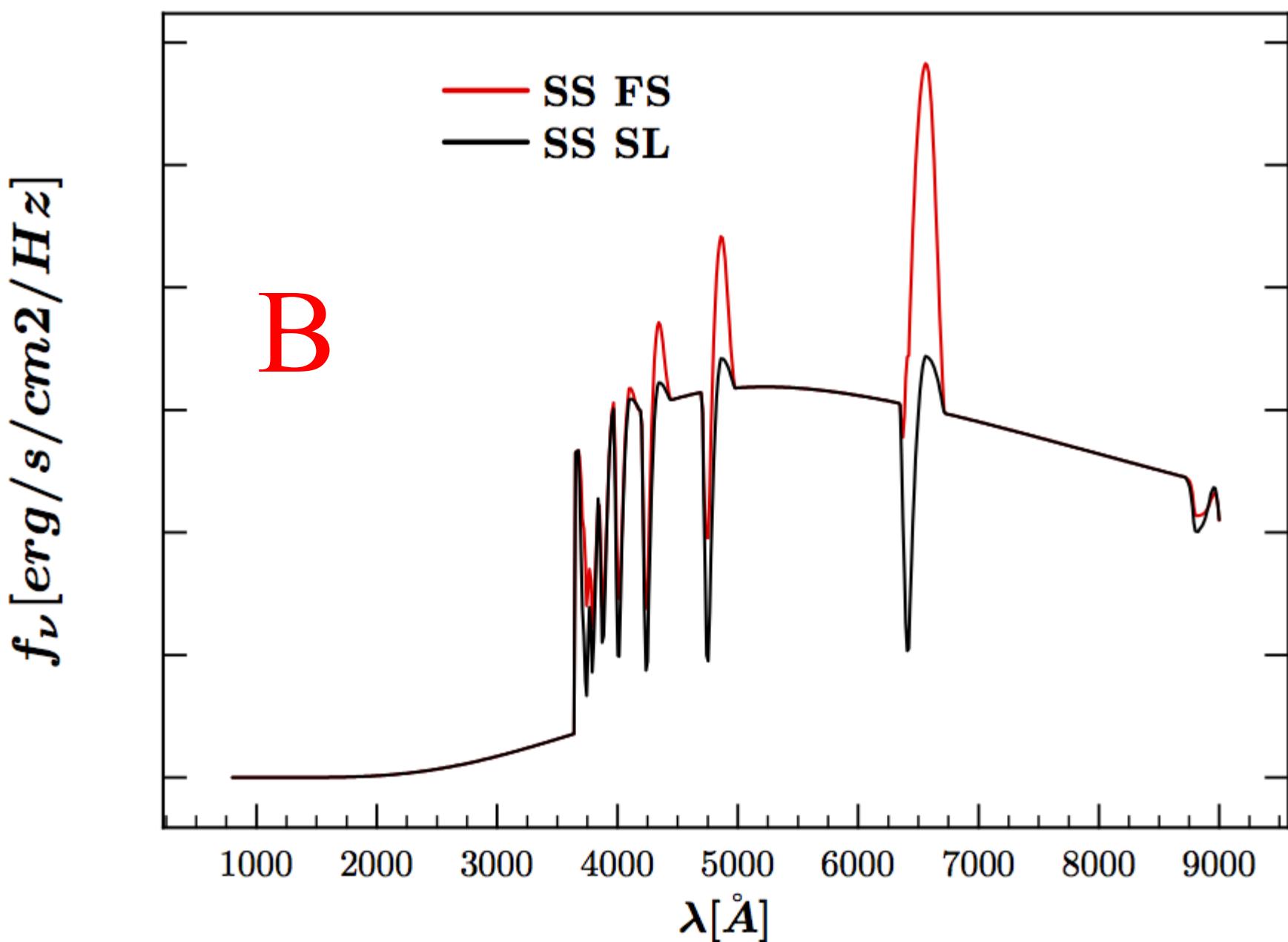
Hydrogen



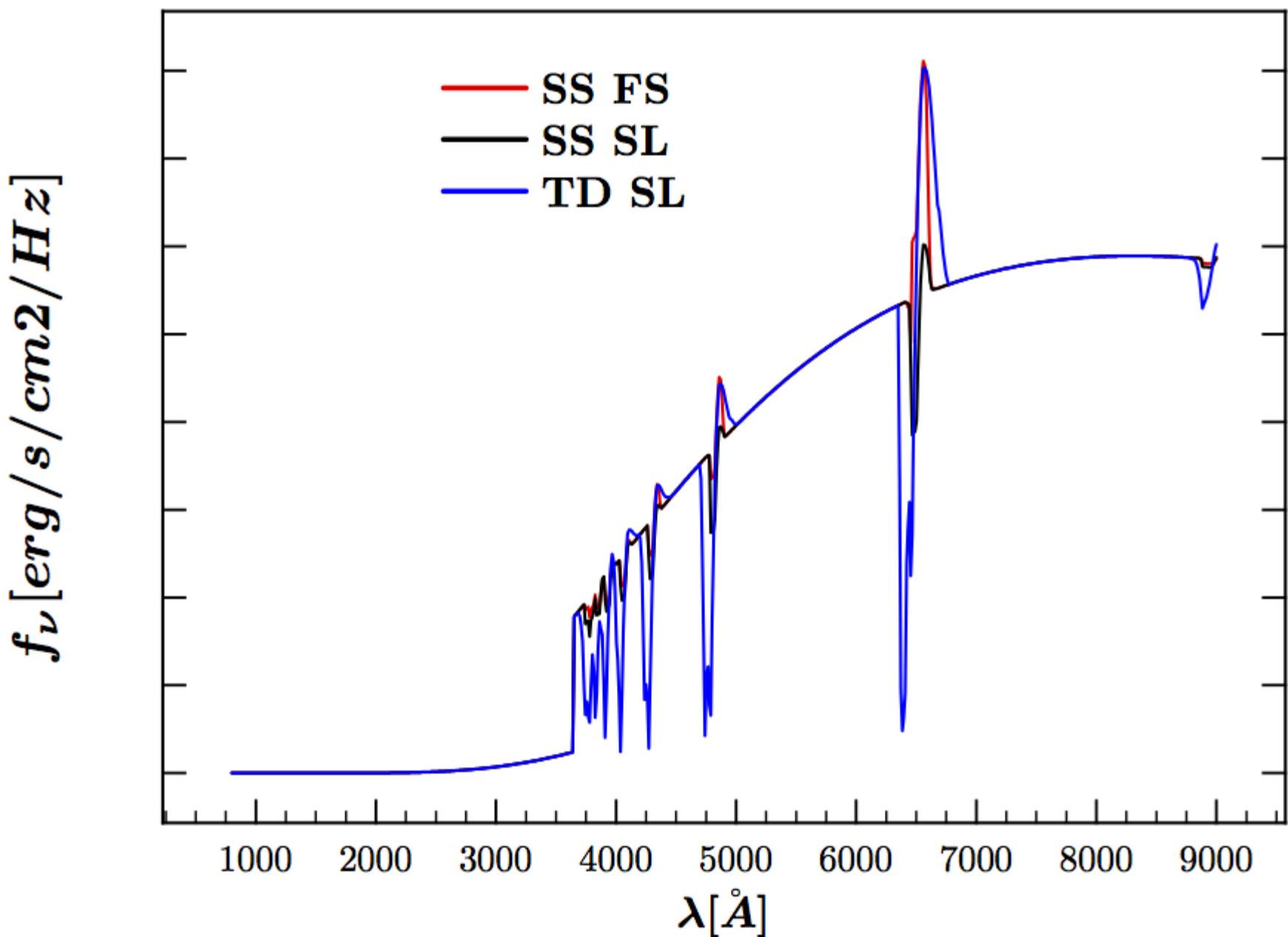
Hydrogen, 10 DAY



Hydrogen, 10 DAY



Hydrogen, 30 DAY



Further steps (instead of conclusions)

- The time dependence effect is not fully understood
- We need to include collisions with protons
- Reject Sobolev approximation in Ly α
- Metal-rich models