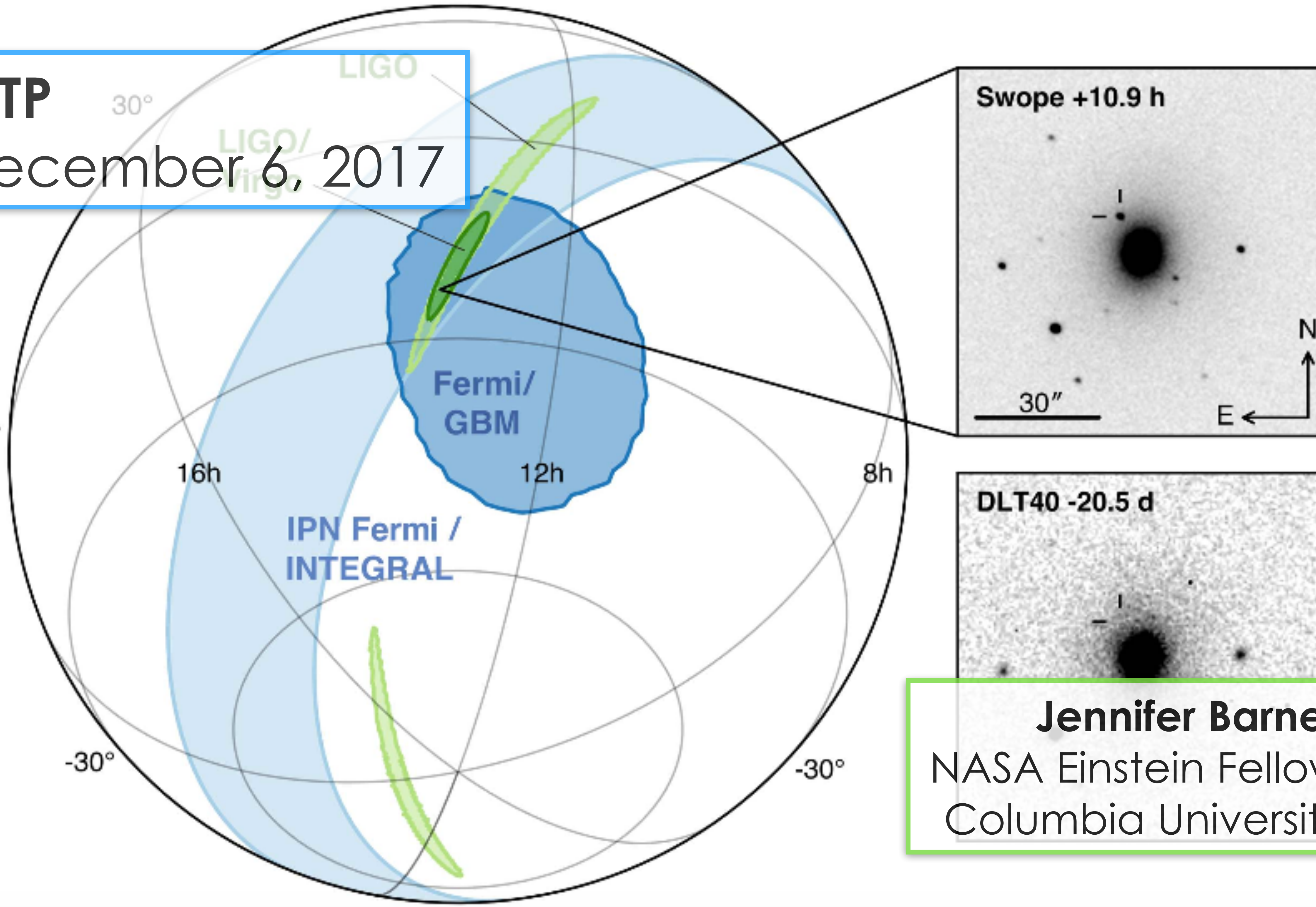
Radiation transport modeling for the kilonova enthusiast

KITP
December 6, 2017



Jennifer Barnes
NASA Einstein Fellow
Columbia University

Abbott+2017, PRL 119

Radiation transport in context

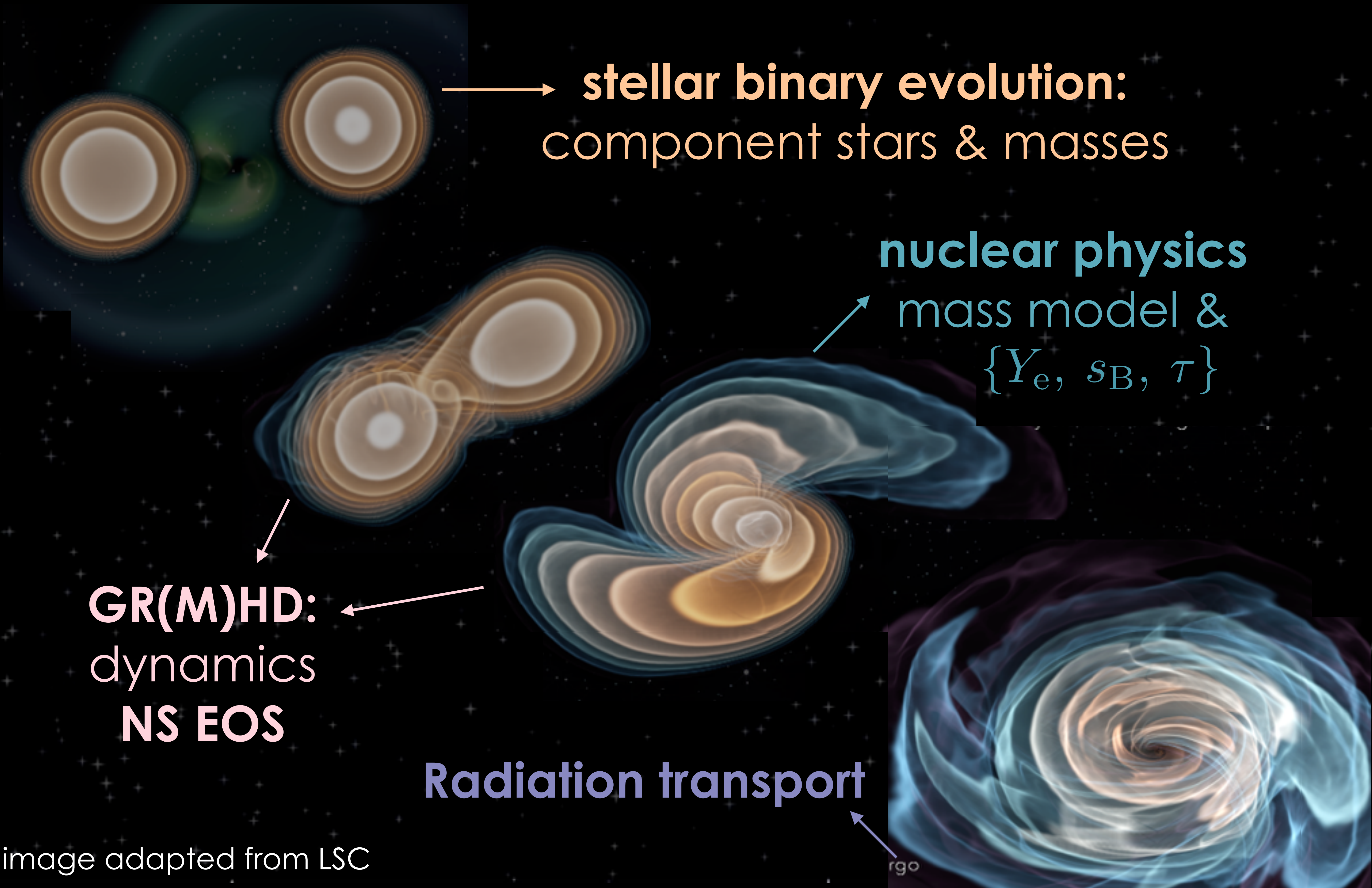
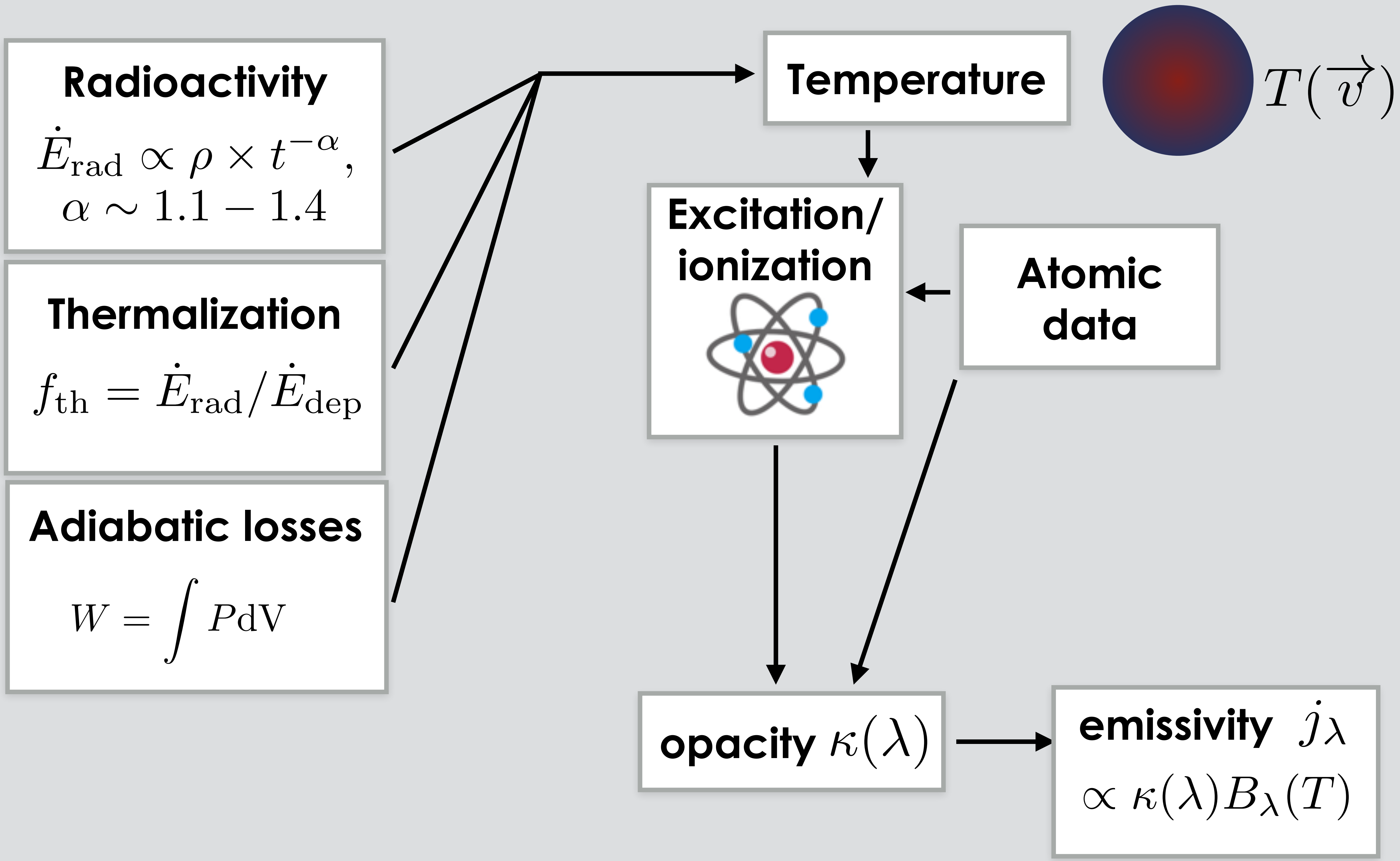


image adapted from LSC

Radiation transport in a nutshell



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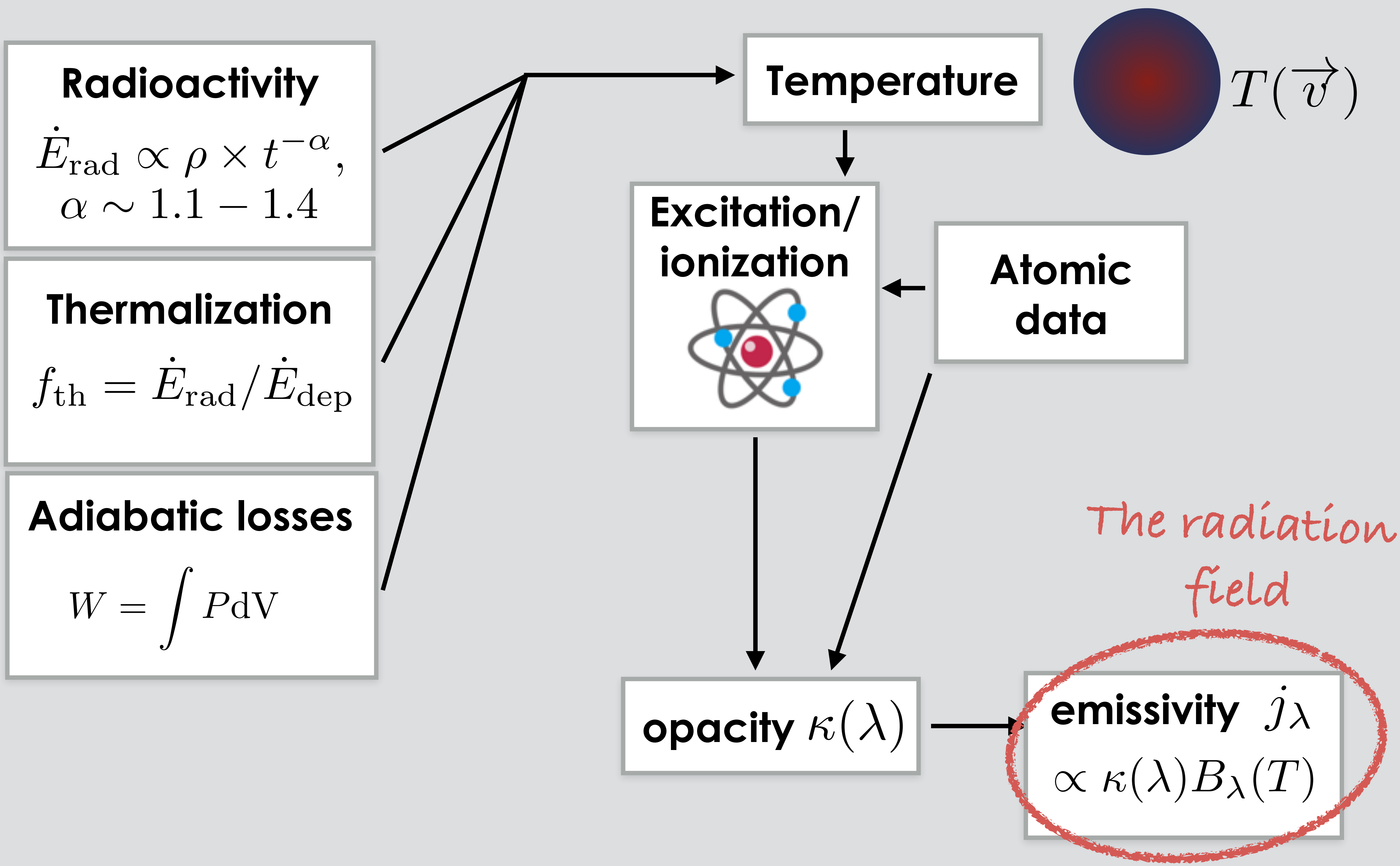

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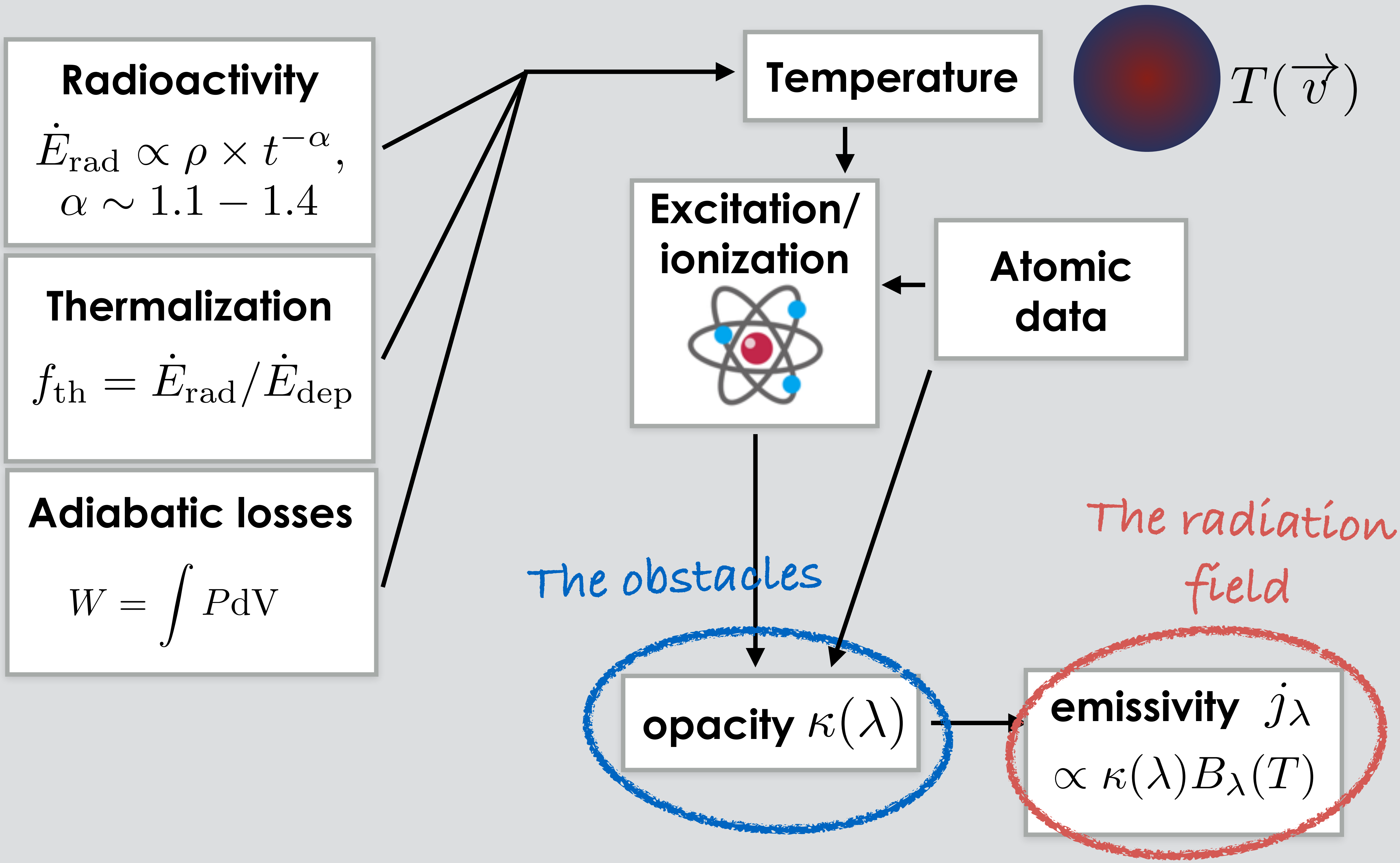
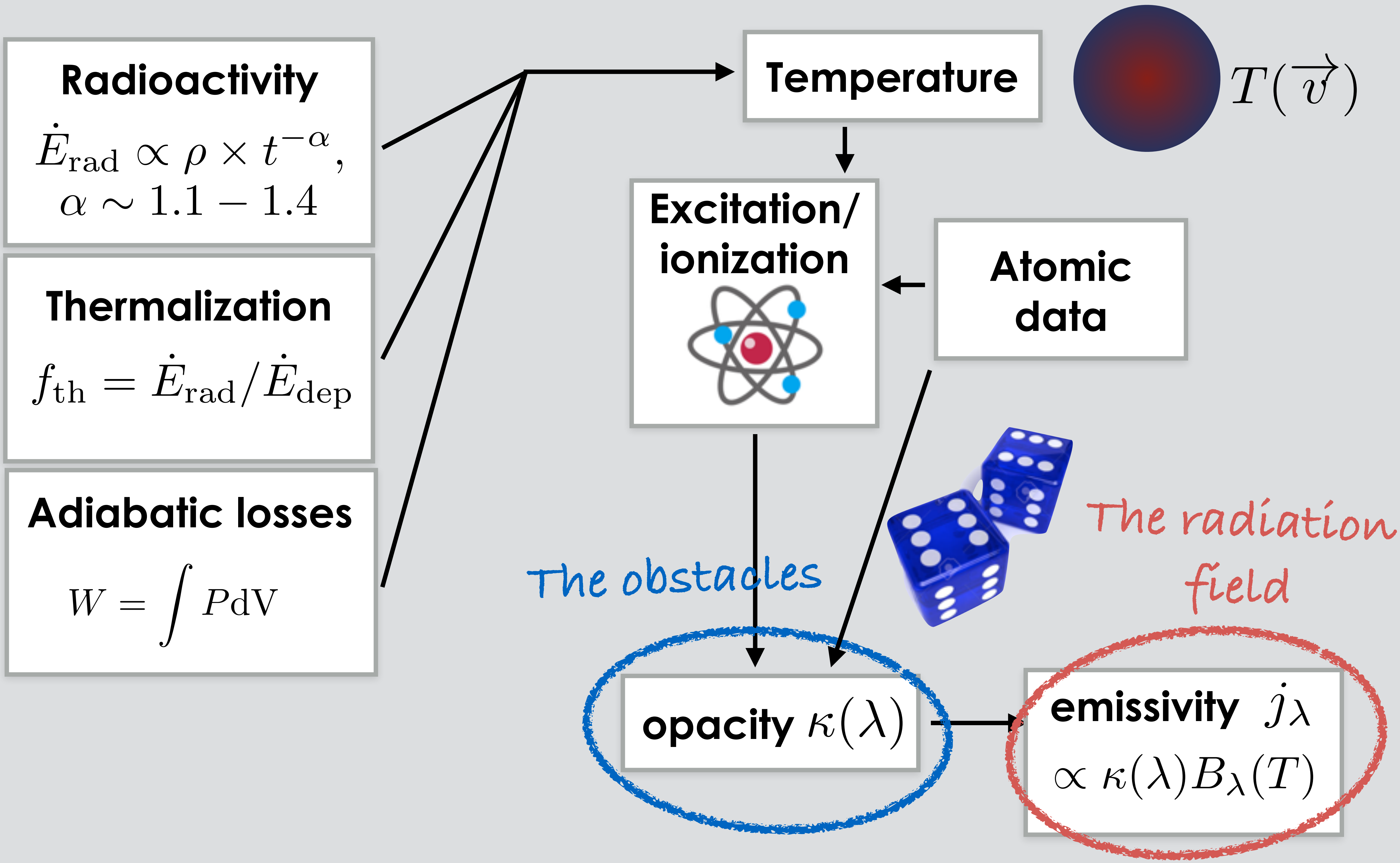


Radiation transport in a nutshell



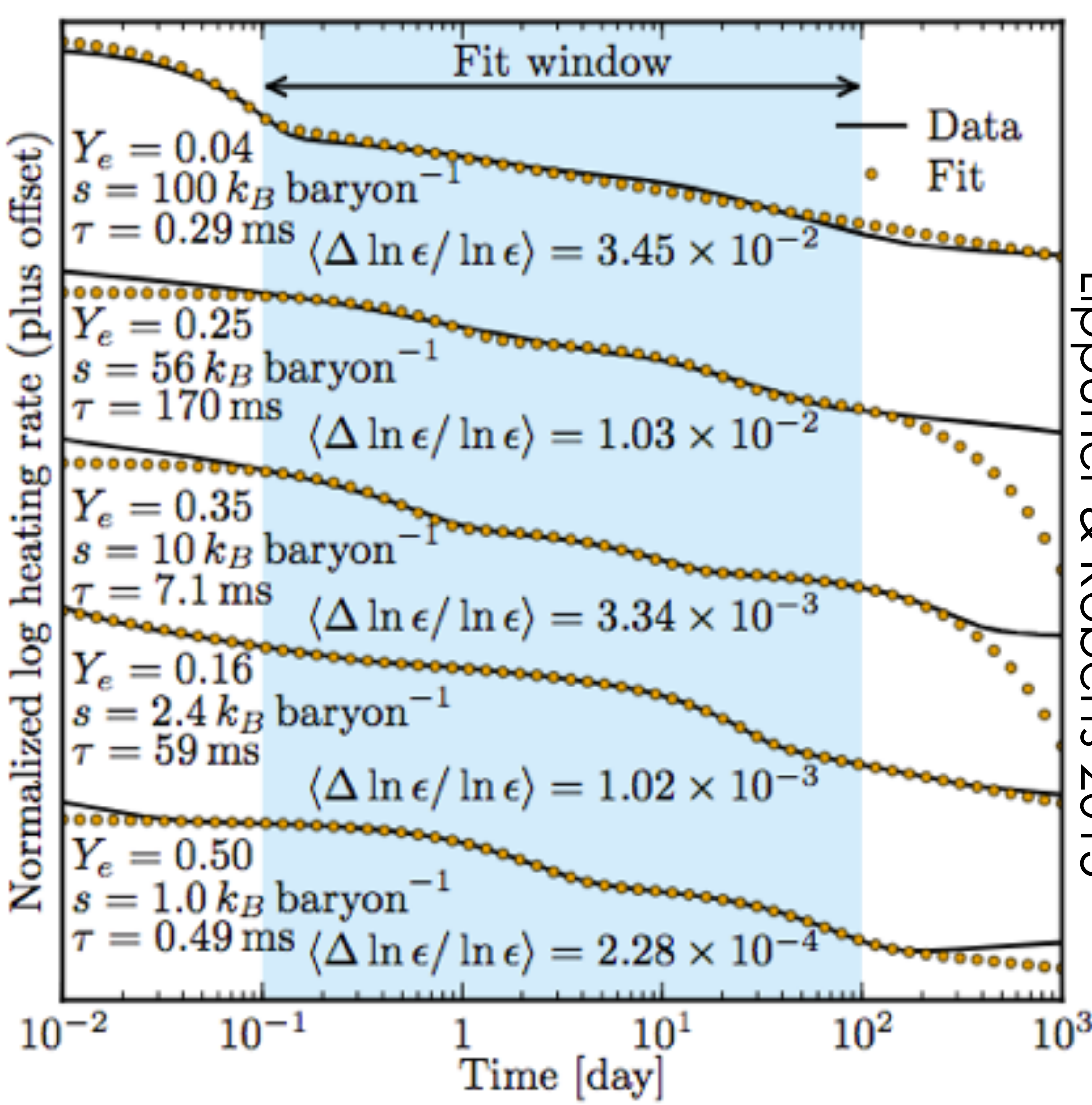
Radiation transport: heating

Heating

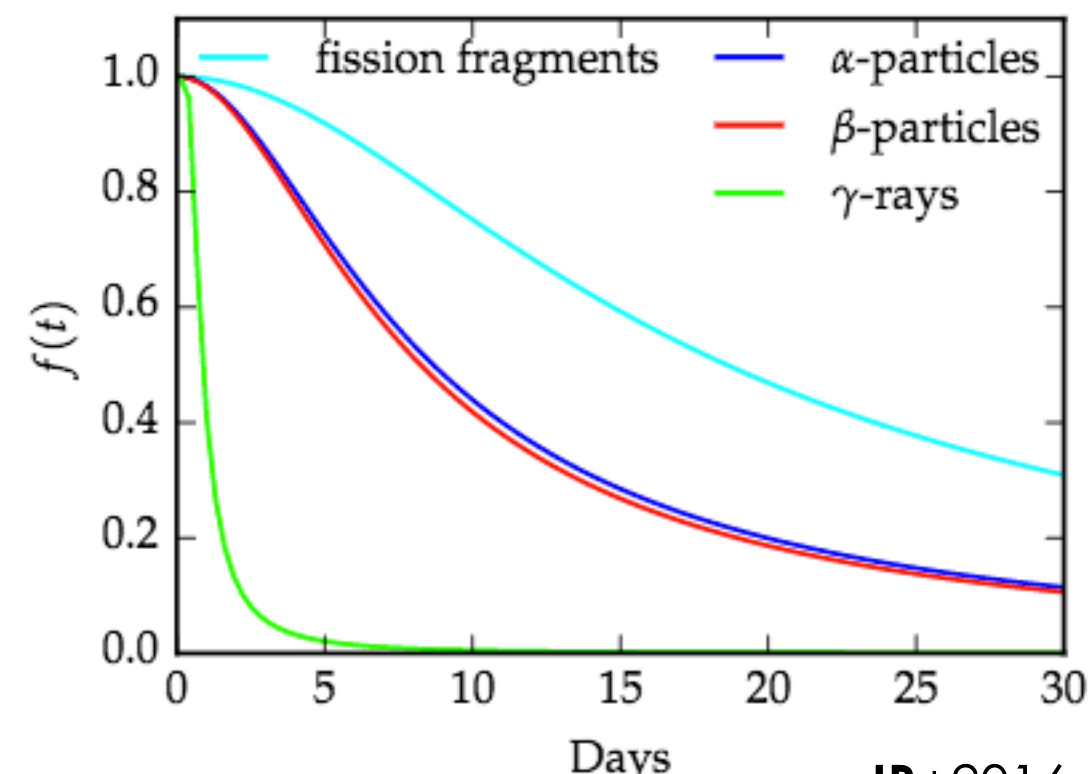
- ~power law, due to many decay chains;
- β-decay, α-decay, fission

Thermalization

- not perfectly efficient
- depends on time, decay mode, decay spectrum



Lippuner & Roberts 2015



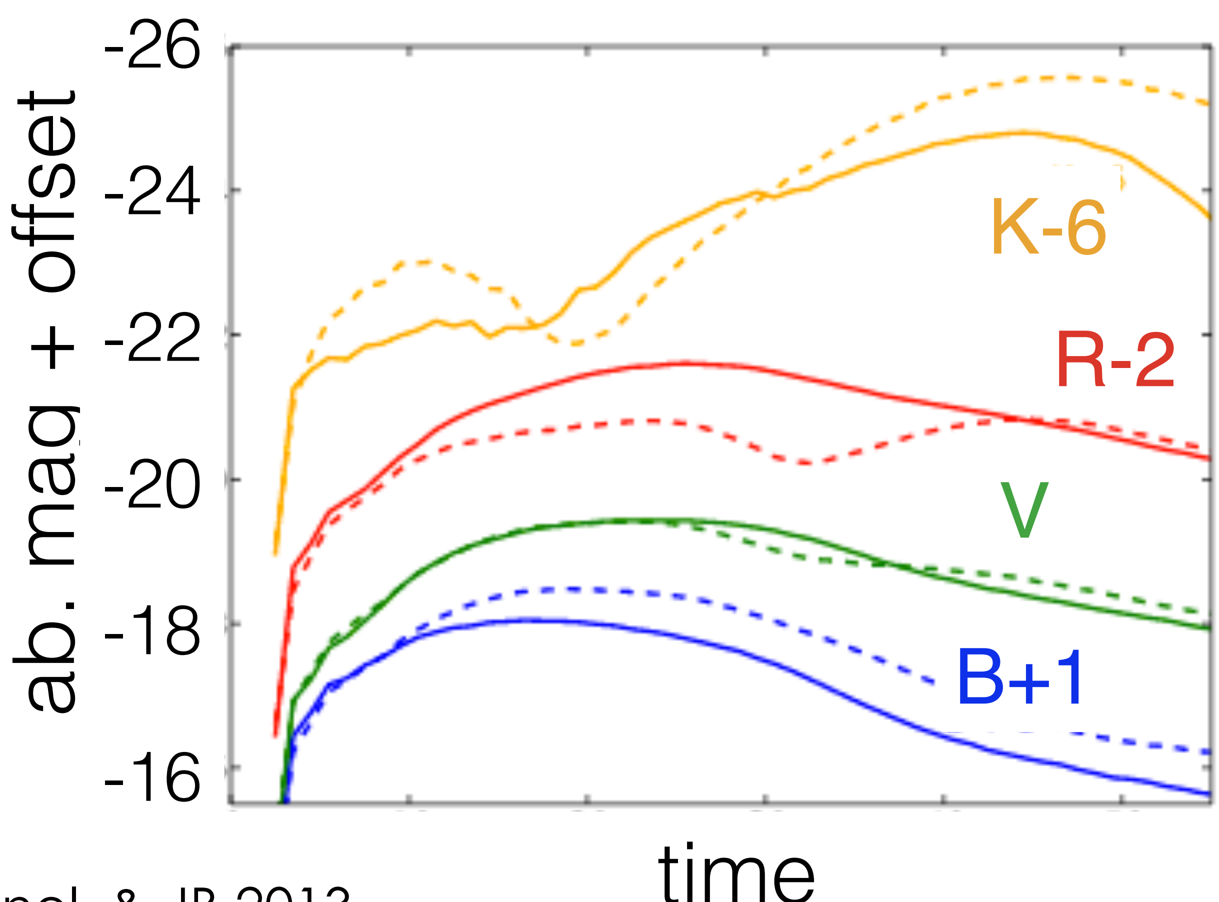
JB+2016

Radiation transport: opacity

Part 1: the ingredients

- Bound-bound opacity dominates
- Energy levels and transition oscillator strengths for *r*-process elements

test case 1: Iron (Z=26)



SN Ia broadbands:
Autostructure (—)
Kurucz CD23 (- -)

Kasen, Badnel, & JB 2013

Radiation transport: opacity

Part 1: the ingredients

- Bound-bound opacity dominates
- Energy levels and transition oscillator strengths for *r*-process elements

test case 1: Neodymium (Z=60)

charge state	N_{levels} (KBB13)	N_{levels} (F+17)	N_{lines} (KBB13)	N_{lines} (F+17)
I	18,104	18,104	~2.46e7	~2.52e7
II	6,888	6,888	~3.87e6	~3.95e6
III	1,650	1,650	~2.33e5	~2.33e5
IV	241	241	5.78e4	~5.78e4

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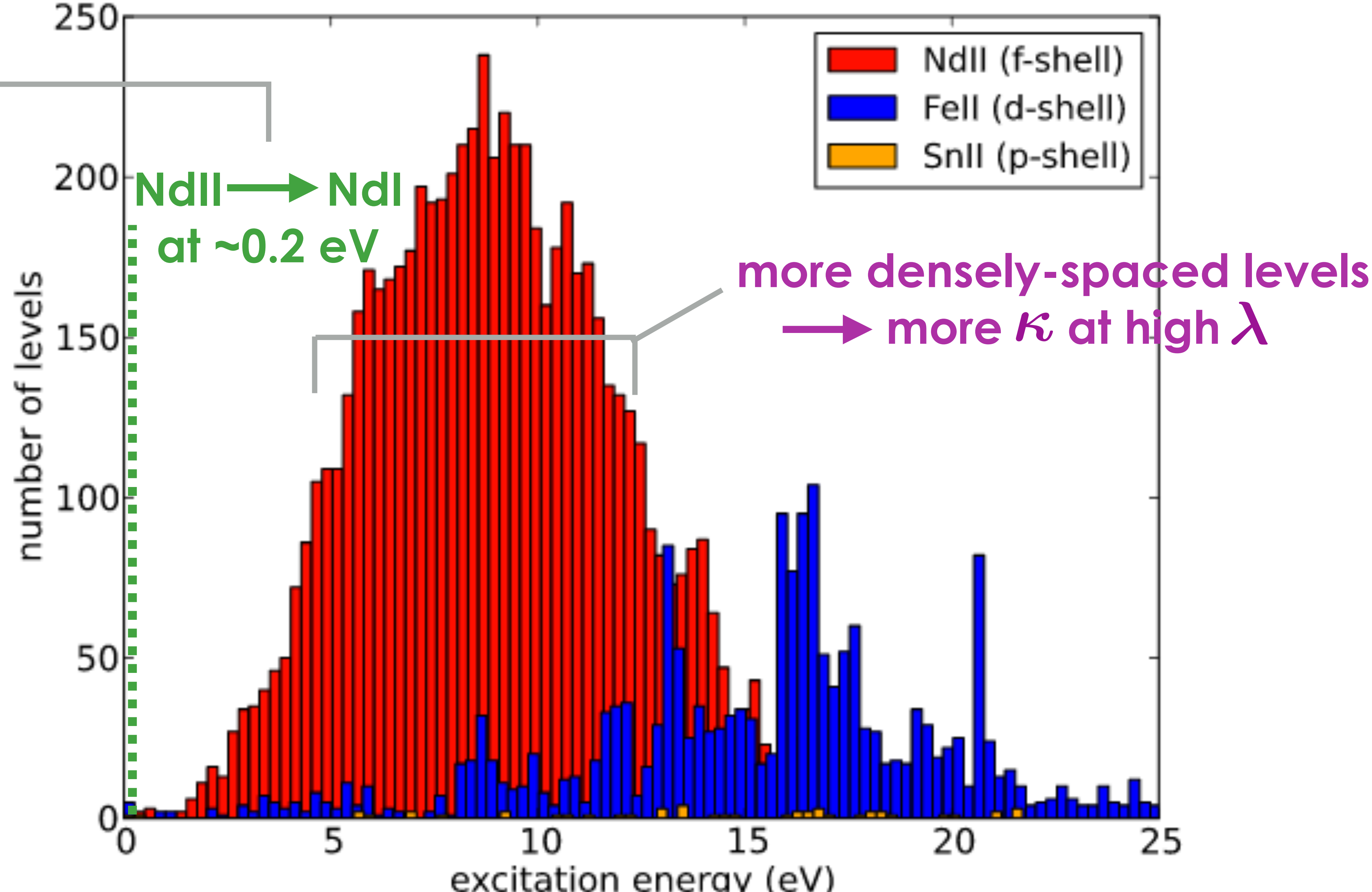
Radiation transport: opacity

Part 1(b): the implications

lanthanides sustain a high opacity at lower *T*

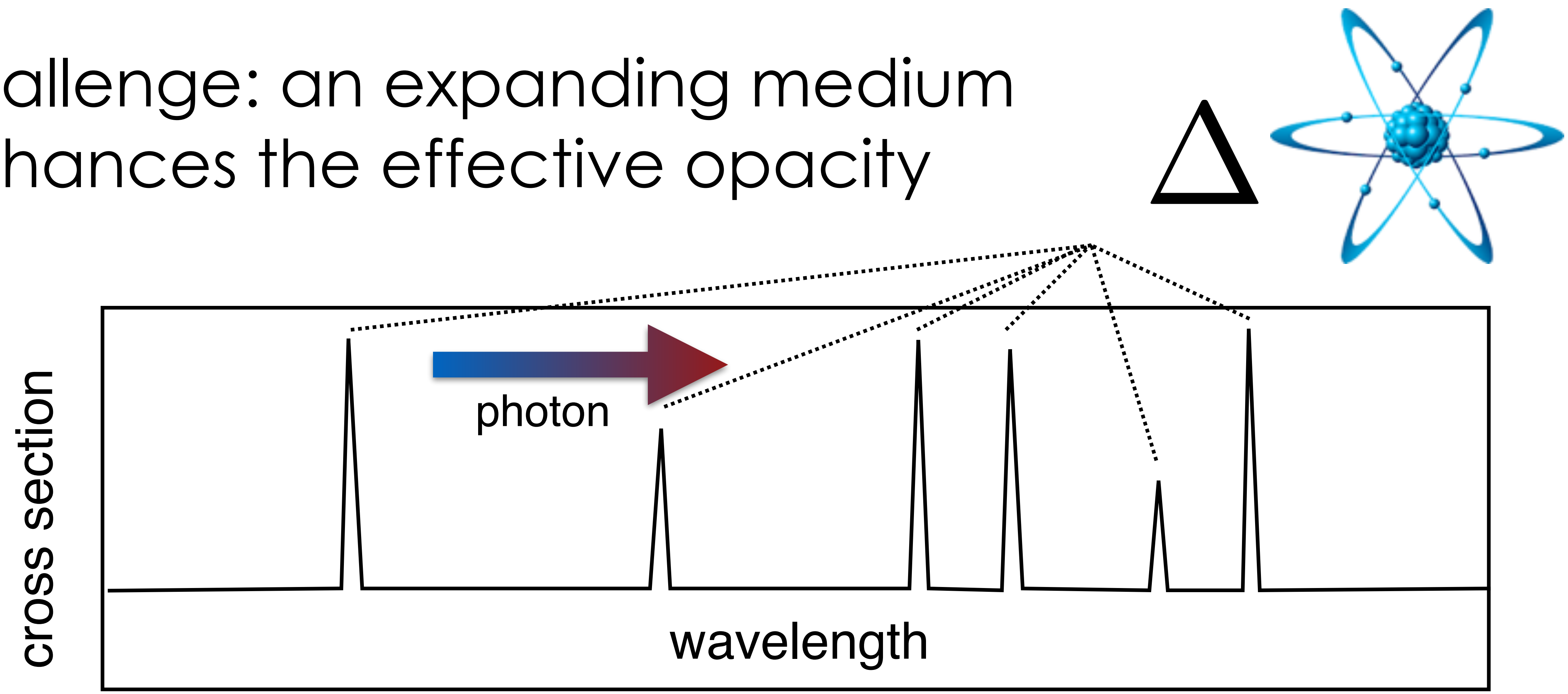


Kasen, Badnel, & JB 2013

Radiation transport: opacity

Part 2: the method

challenge: an expanding medium enhances the effective opacity



$$\tau = \frac{\pi e^2}{m_\mathrm{e} c} f_\mathrm{osc} n_\mathrm{l} t_\mathrm{ej} \lambda_0$$

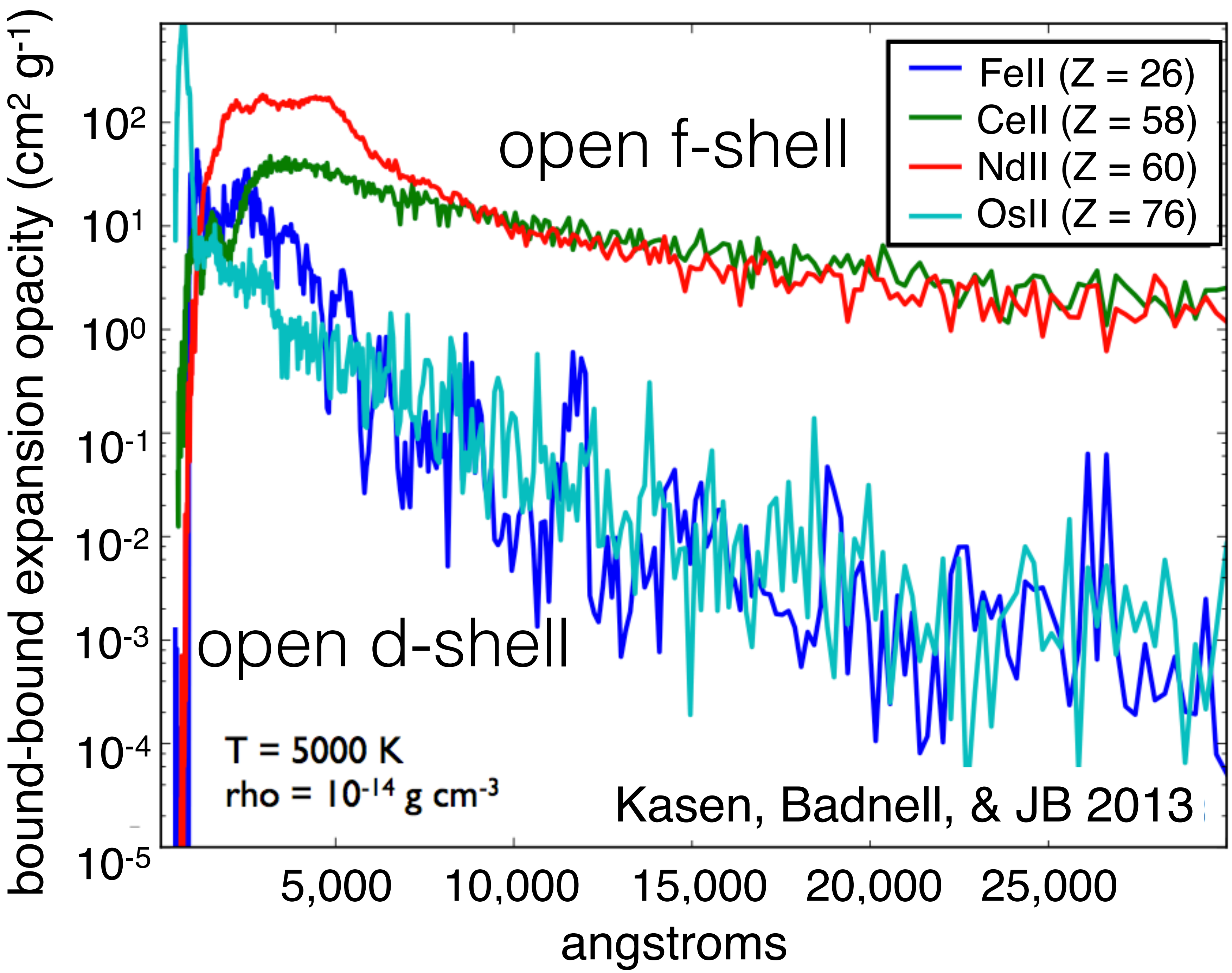
Sobolev τ

$$\kappa_\mathrm{exp} = \frac{1}{\rho c t_\mathrm{exp}} \sum_\mathrm{i} \frac{\lambda_\mathrm{i}}{\Delta\lambda_\mathrm{c}} \left(1 - e^{-\tau_\mathrm{i}}\right)$$

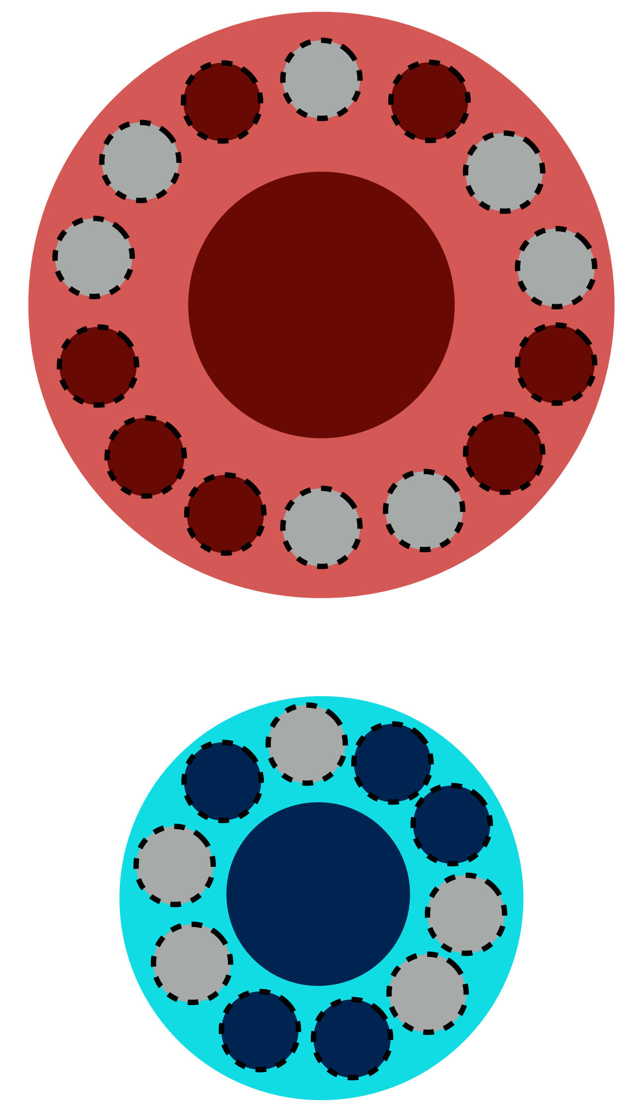
Expansion Opacity

Radiation transport: opacity

Part 3: the results



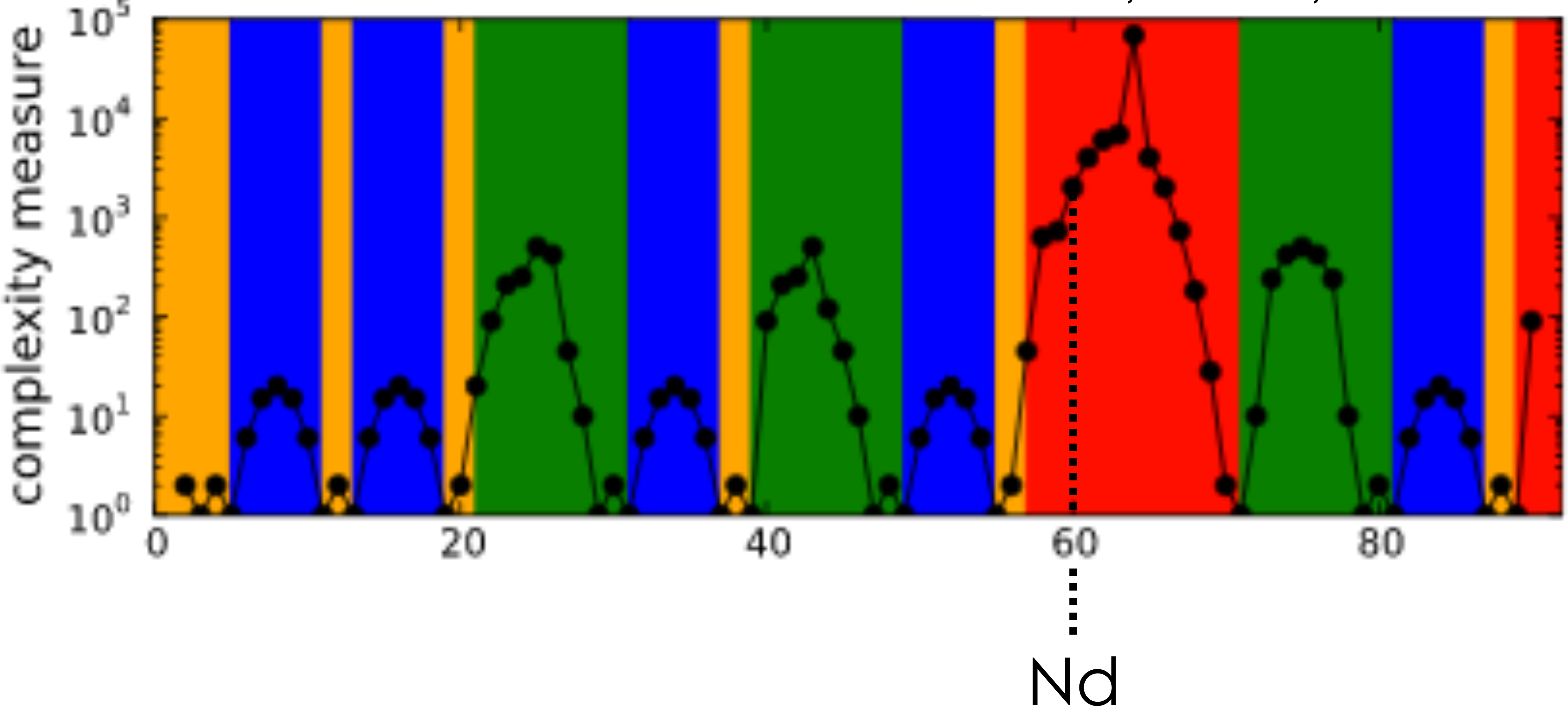
atomic complexity



Pan-lanthanide opacities

Complexity arguments ⟶ Gd catastrophy?!

Kasen, Badnell, & JB 2013



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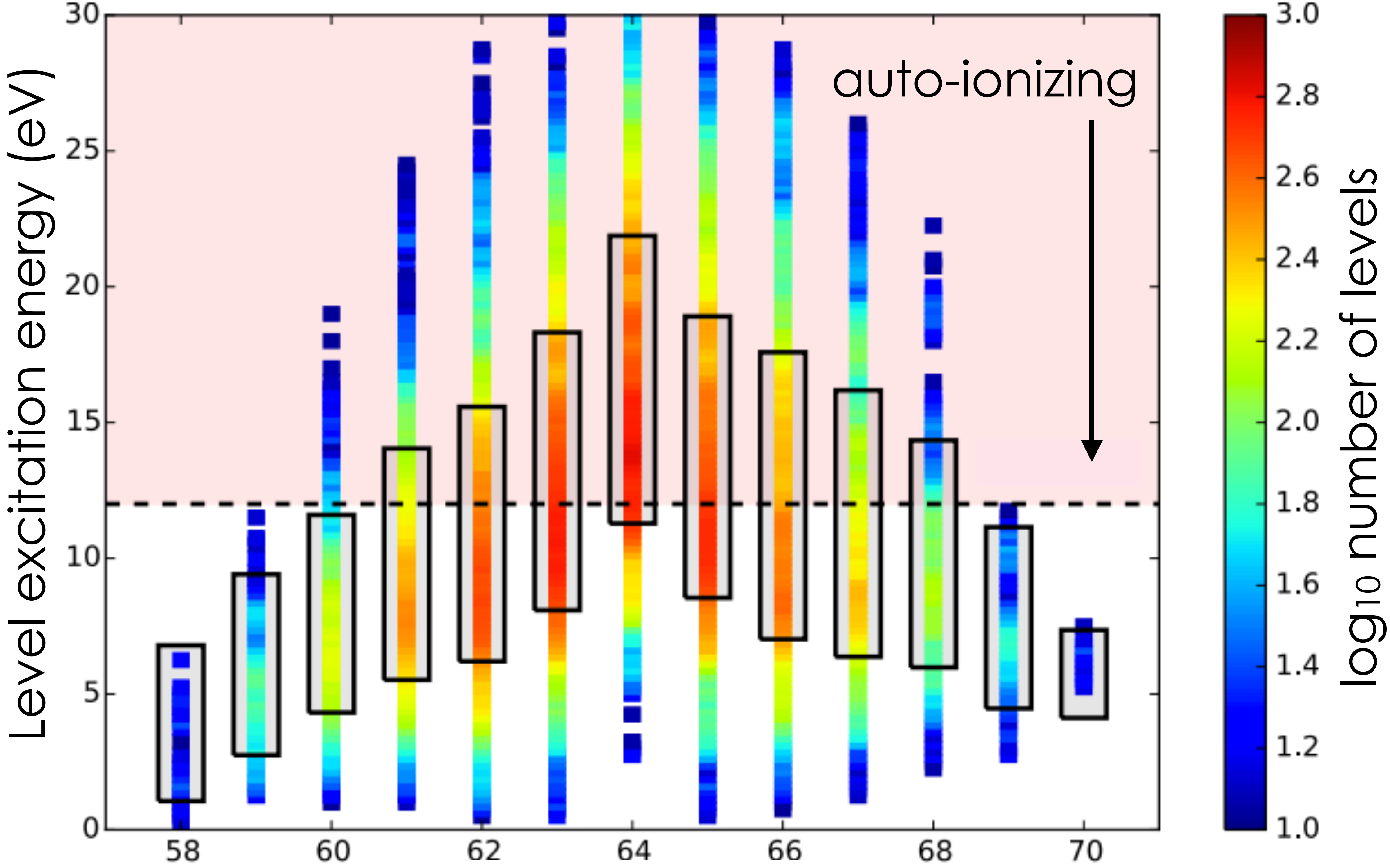
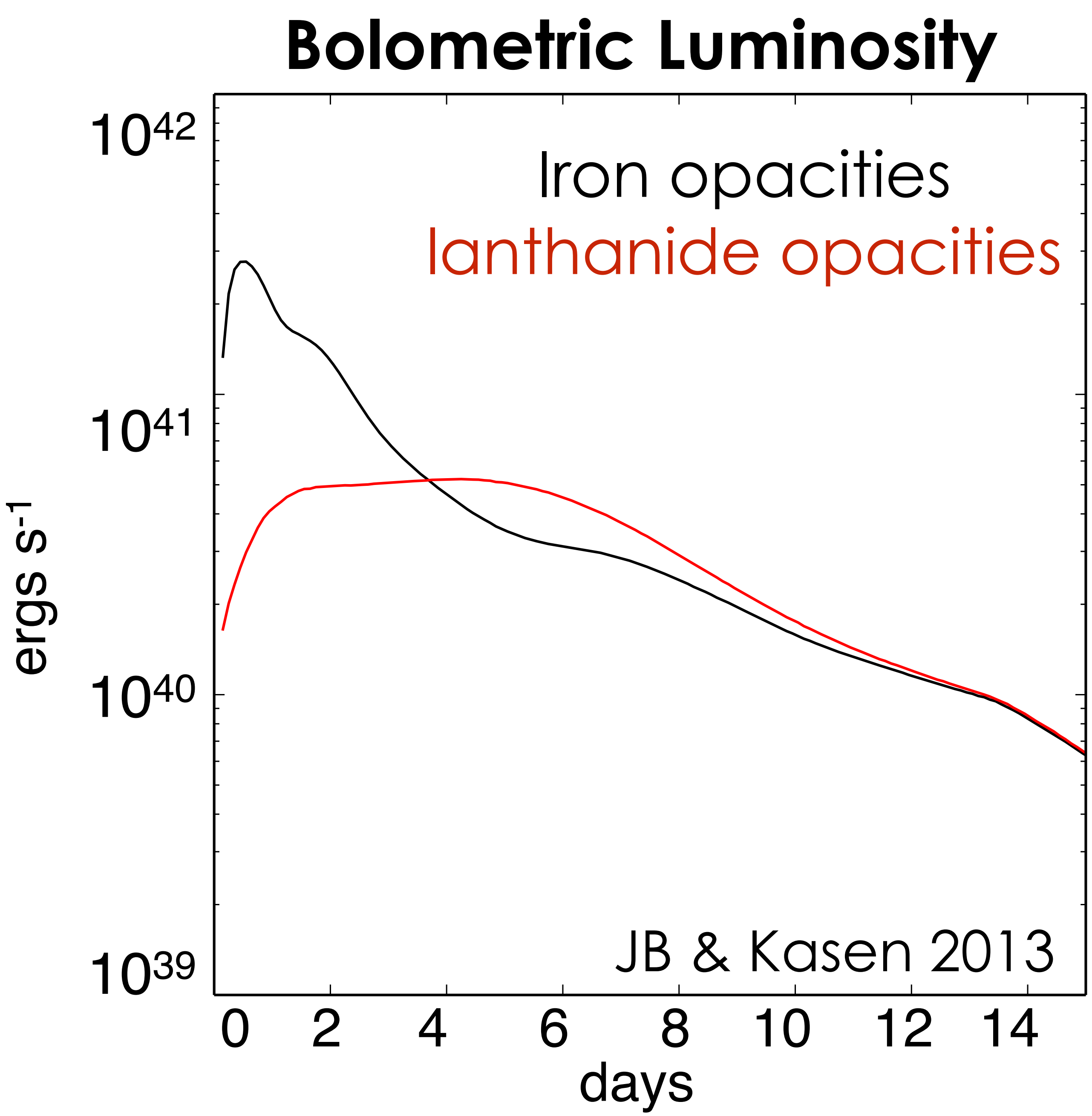
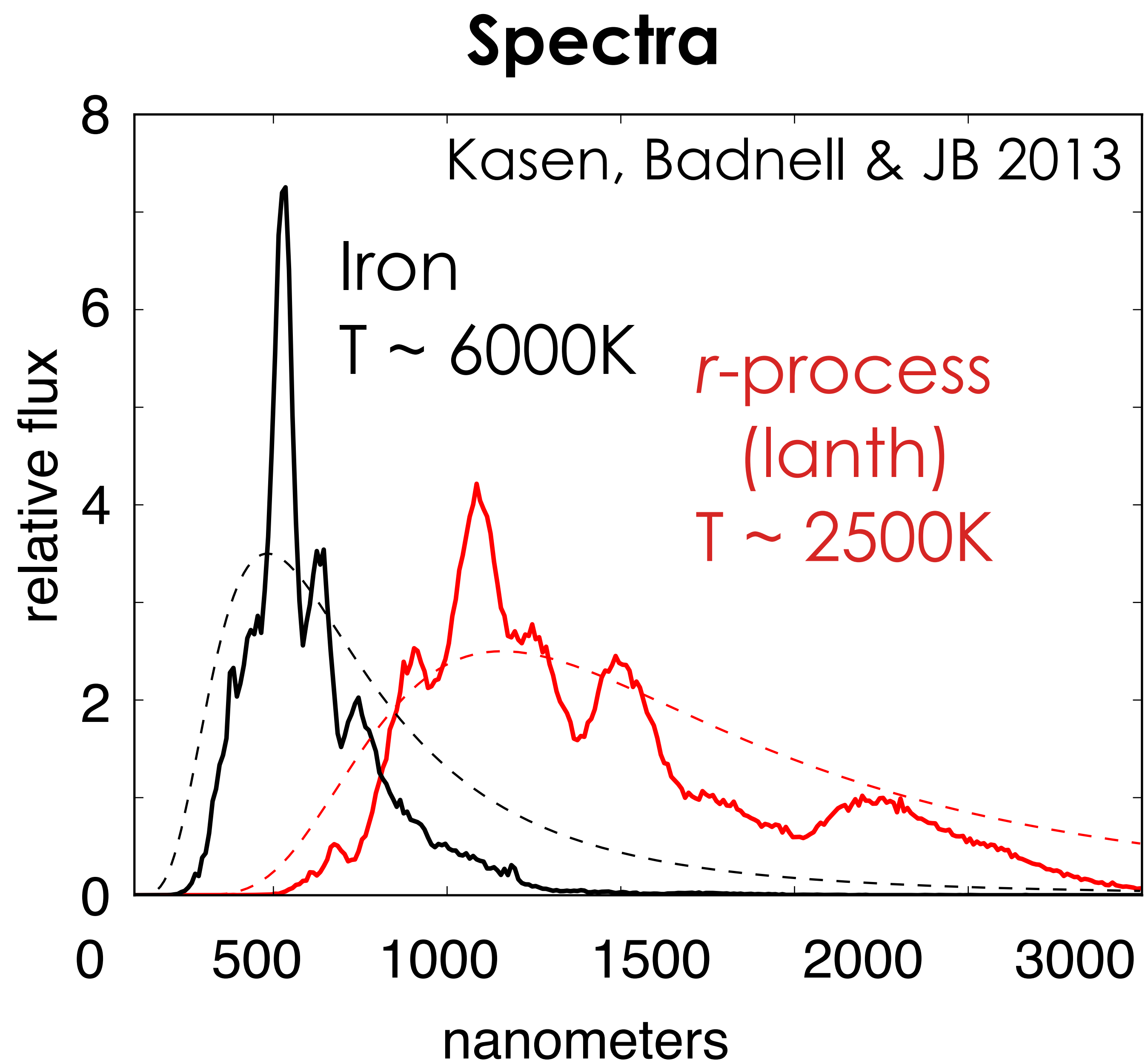


credit: D. Kasen

Effect of opacity



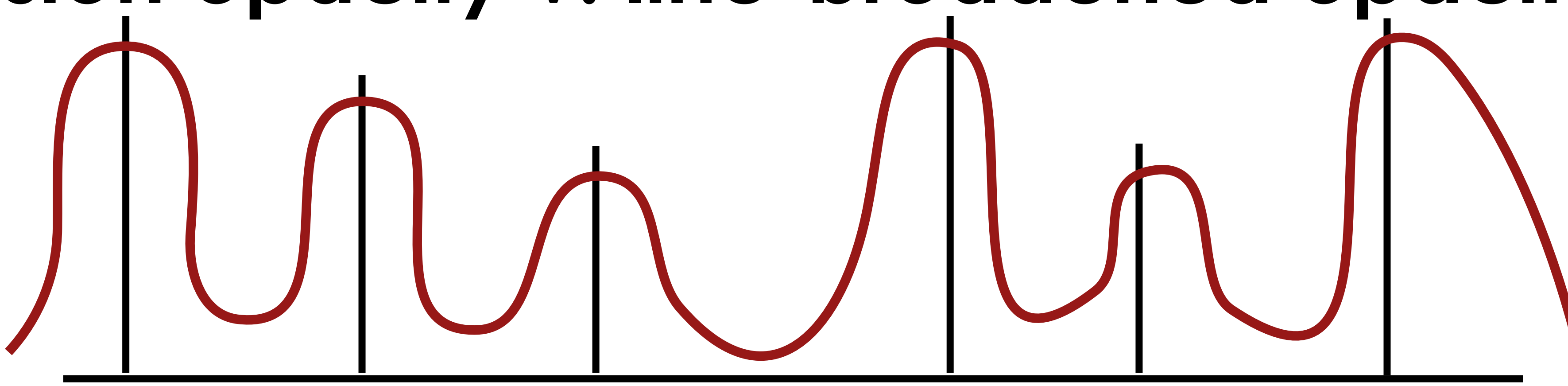


sidebar: how red are they?

(Back to the algorithm)

Use of expansion opacity requires narrow, non-overlapping lines. Otherwise, **SOBOLEV BREAKDOWN**

expansion opacity v. line-broadened opacity

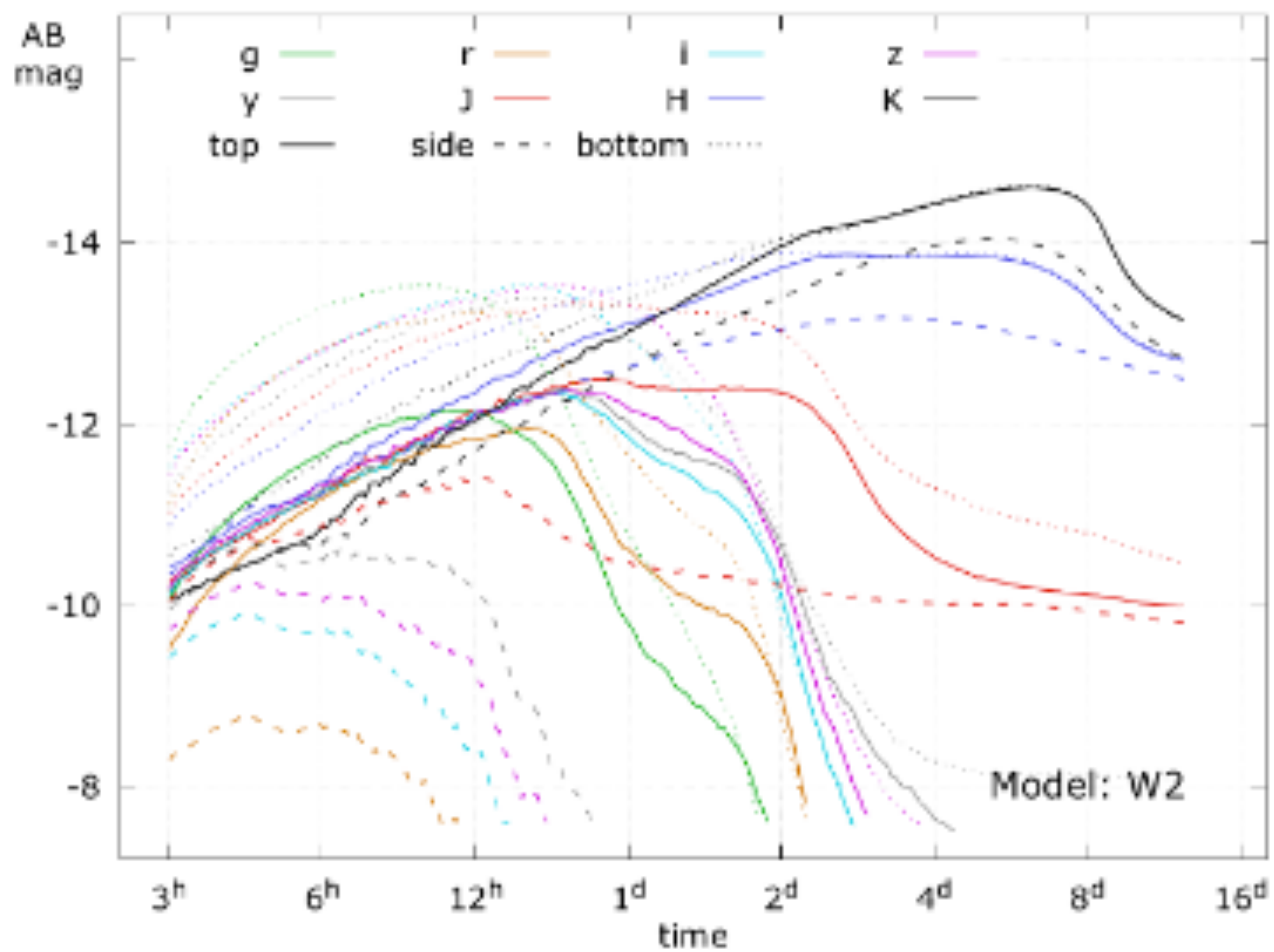


v.

sidebar: how red are they?

BUT: while line-broadening gives much higher *opacities*, the light curves it predicts are not so different.

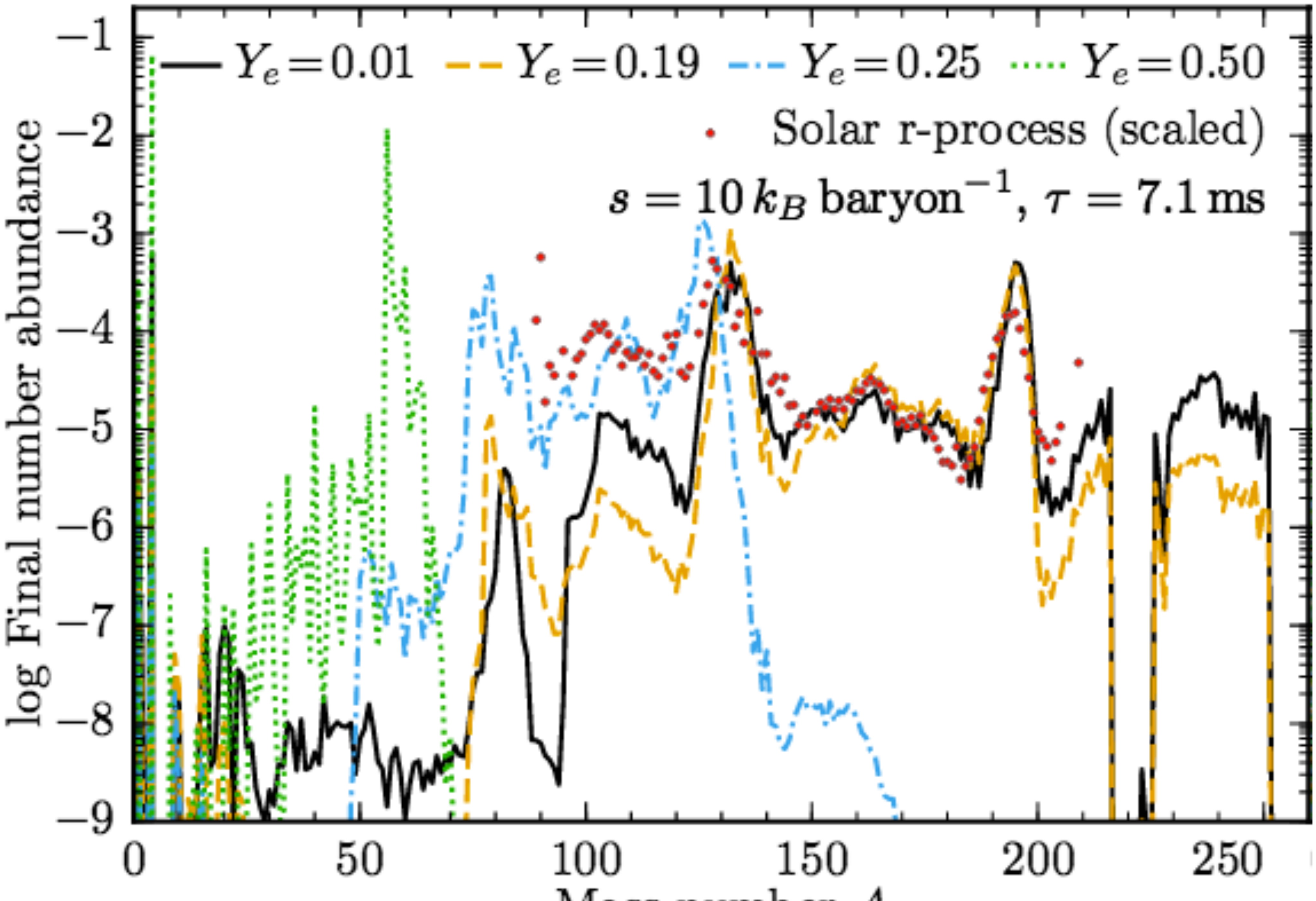
e.g., Wollaeger+2017



(also: we now have observations to work with)

opacities and nucleosynthesis

fewer free n per seed ⟷ more free n per seed



Lippuner & Roberts 2015

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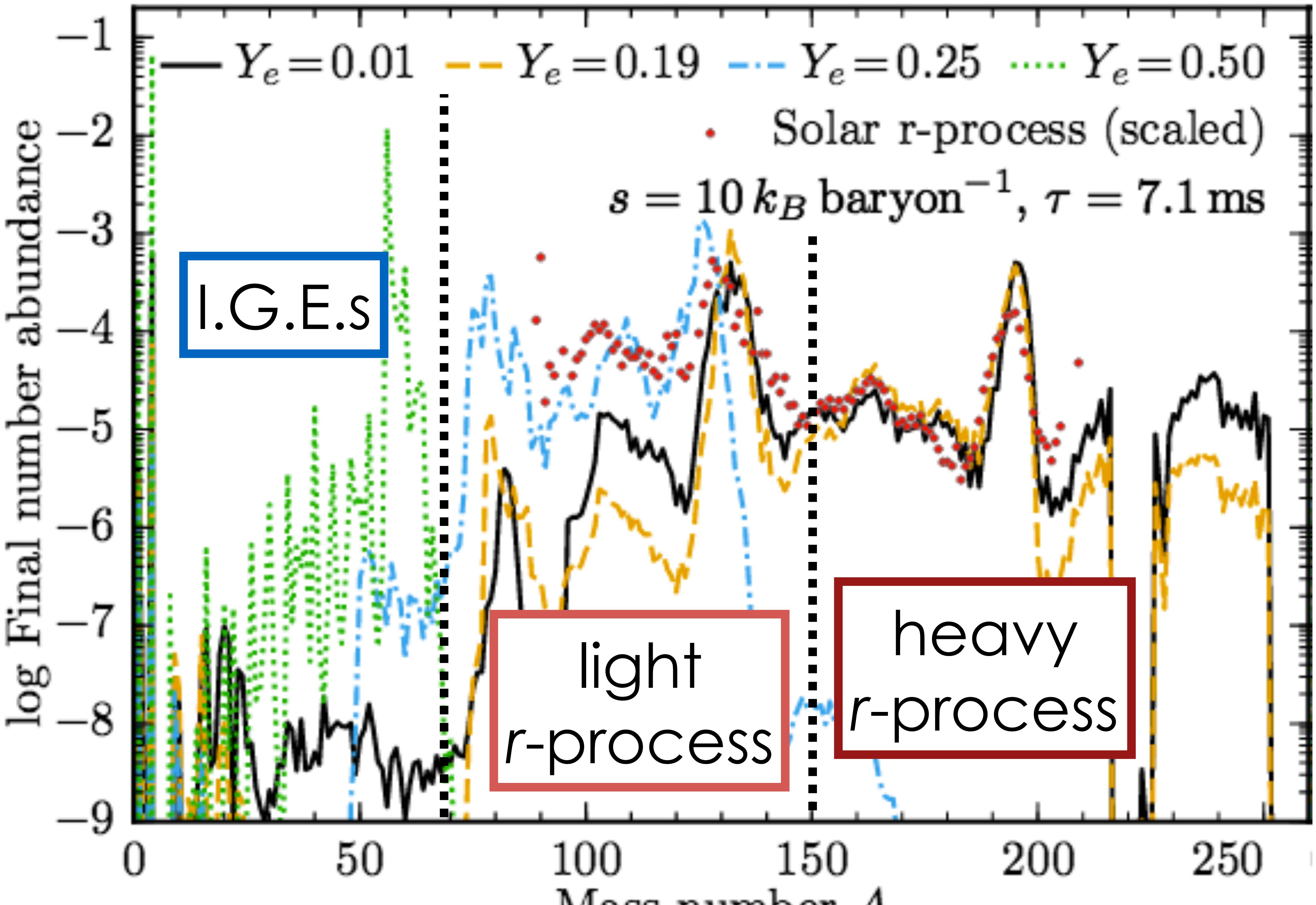
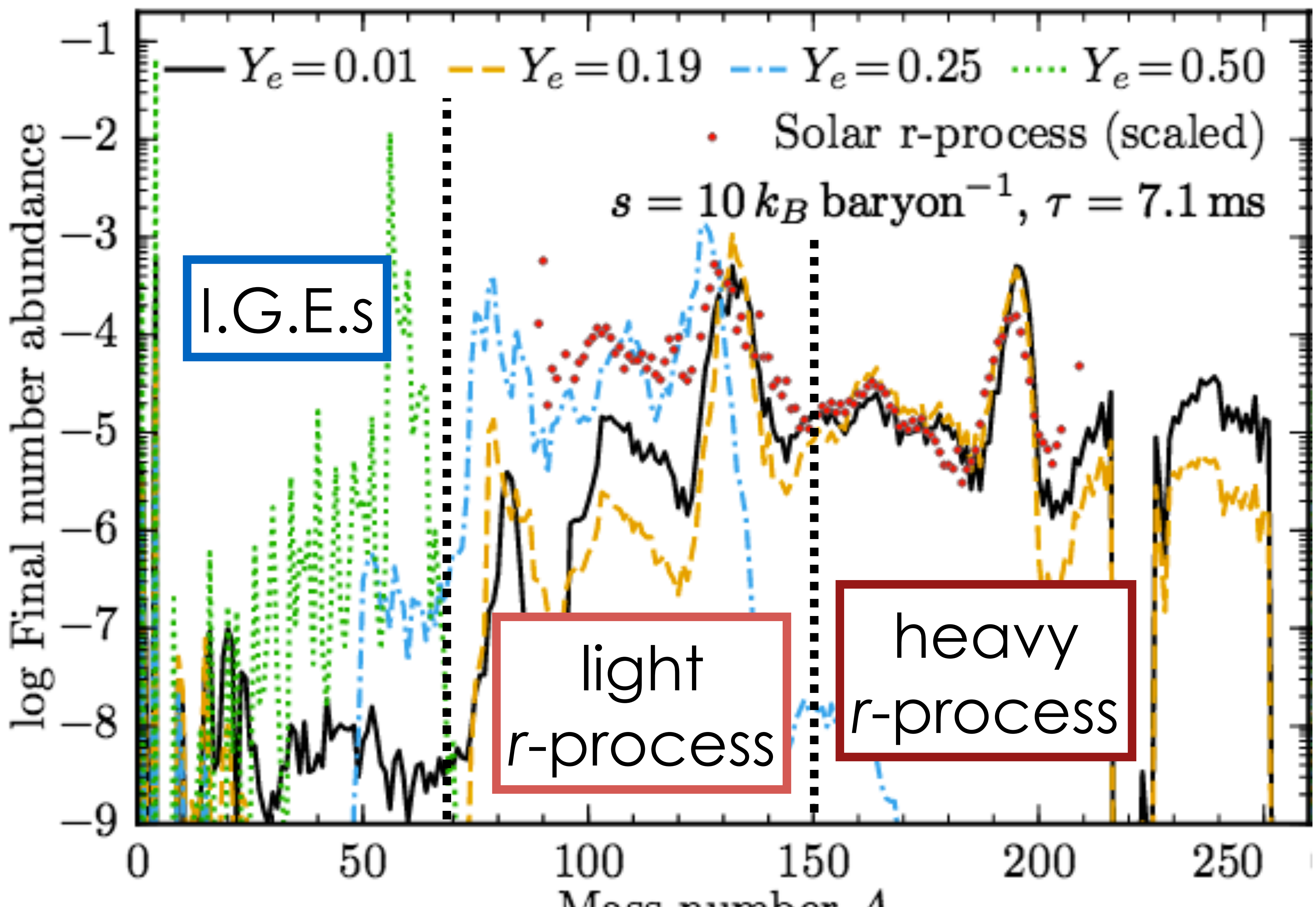


Lippuner & Roberts 2015

opacities and nucleosynthesis

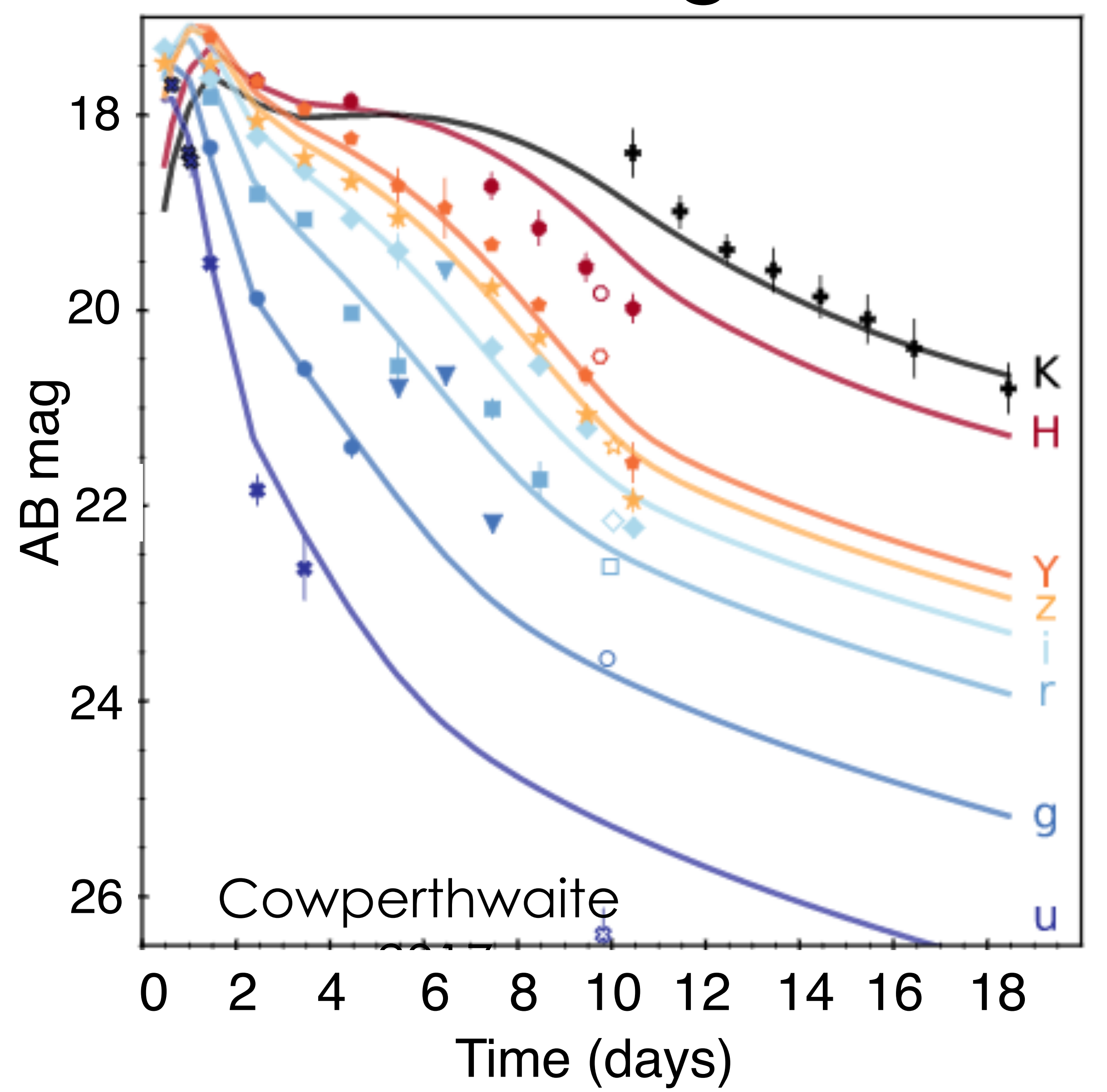
more ν-irradiation ⟷ less ν-irradiation



Lippuner & Roberts 2015

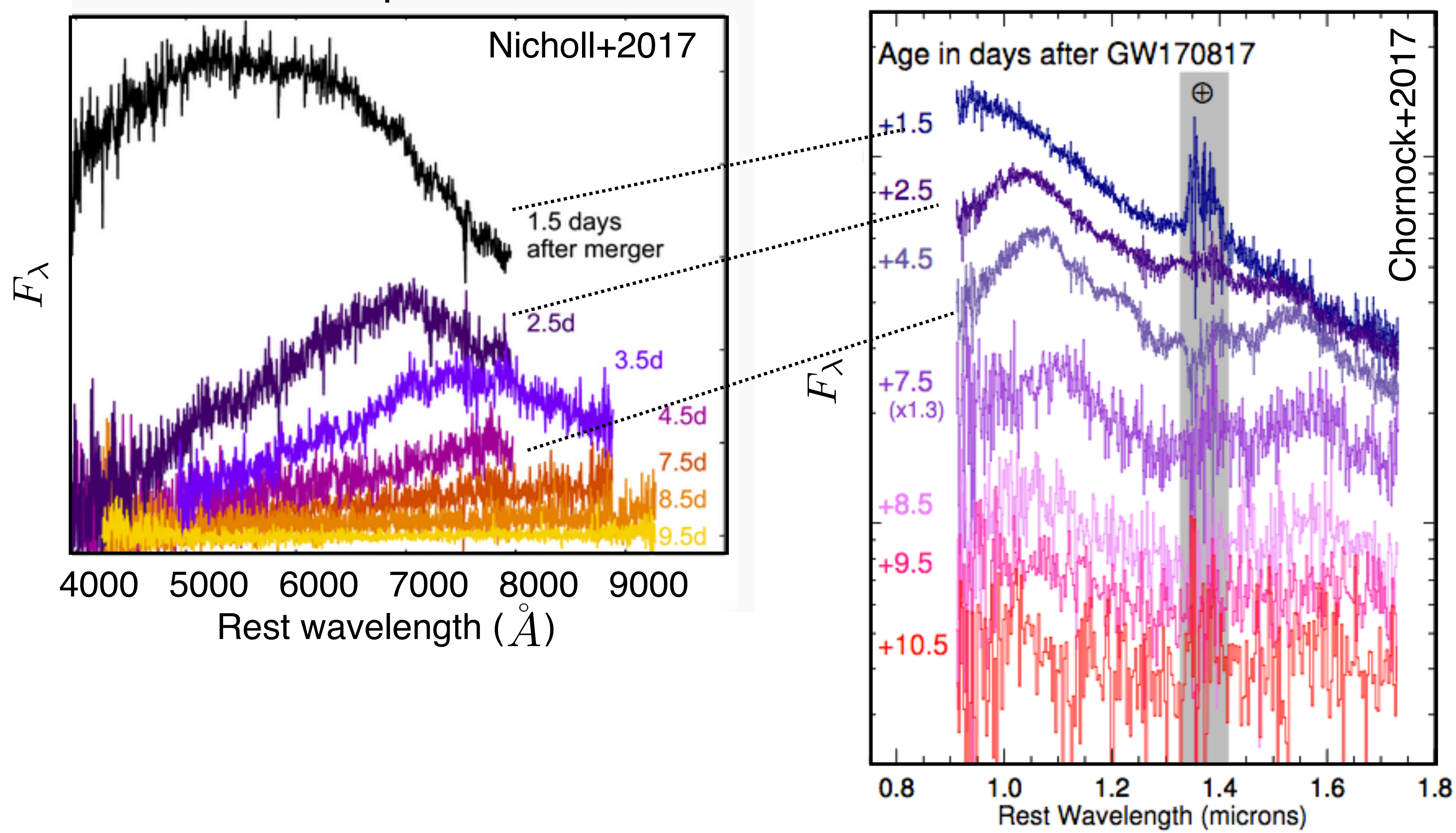
light curves and spectra

broadband light curves

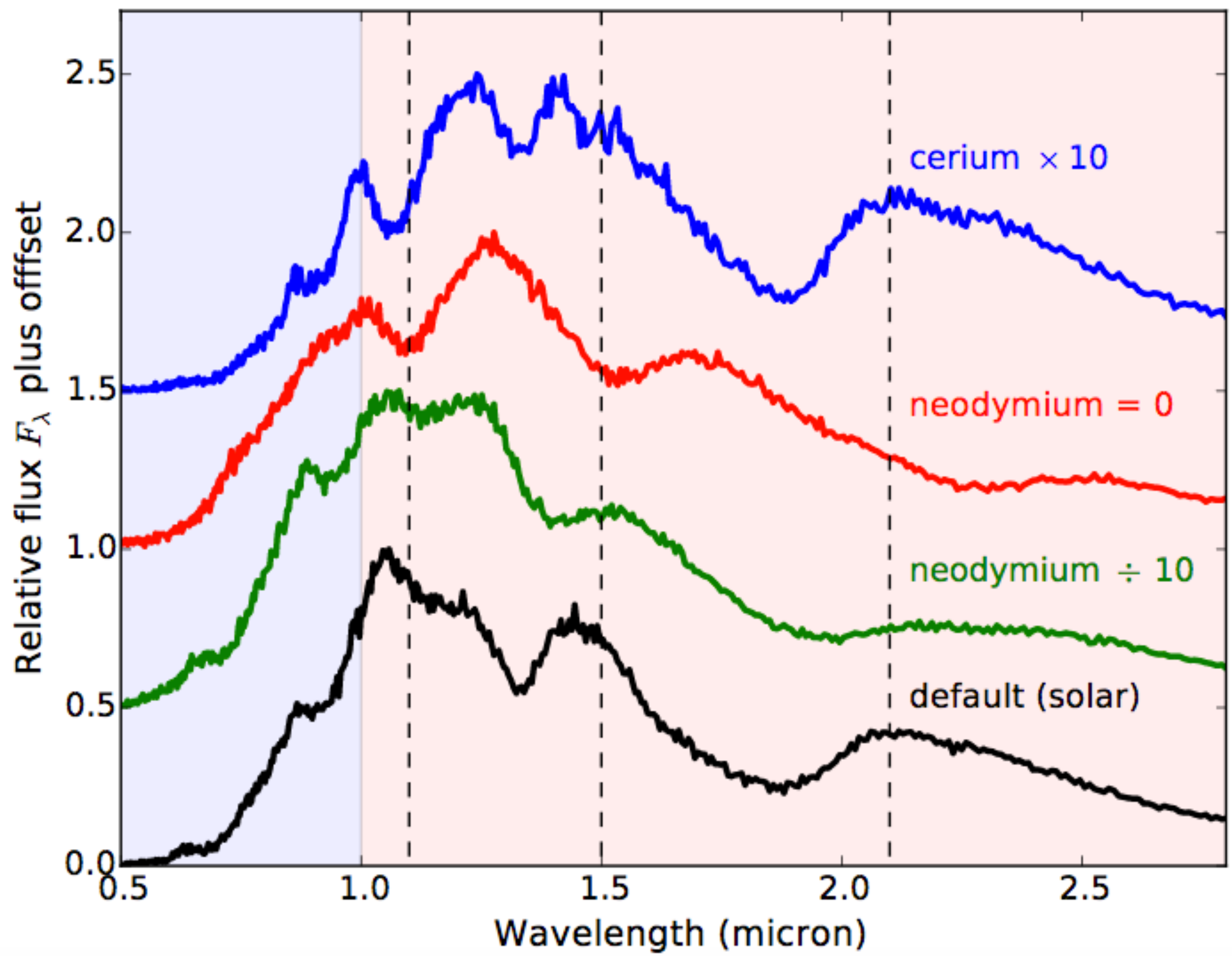


light curves and spectra

UV/optical — NIR

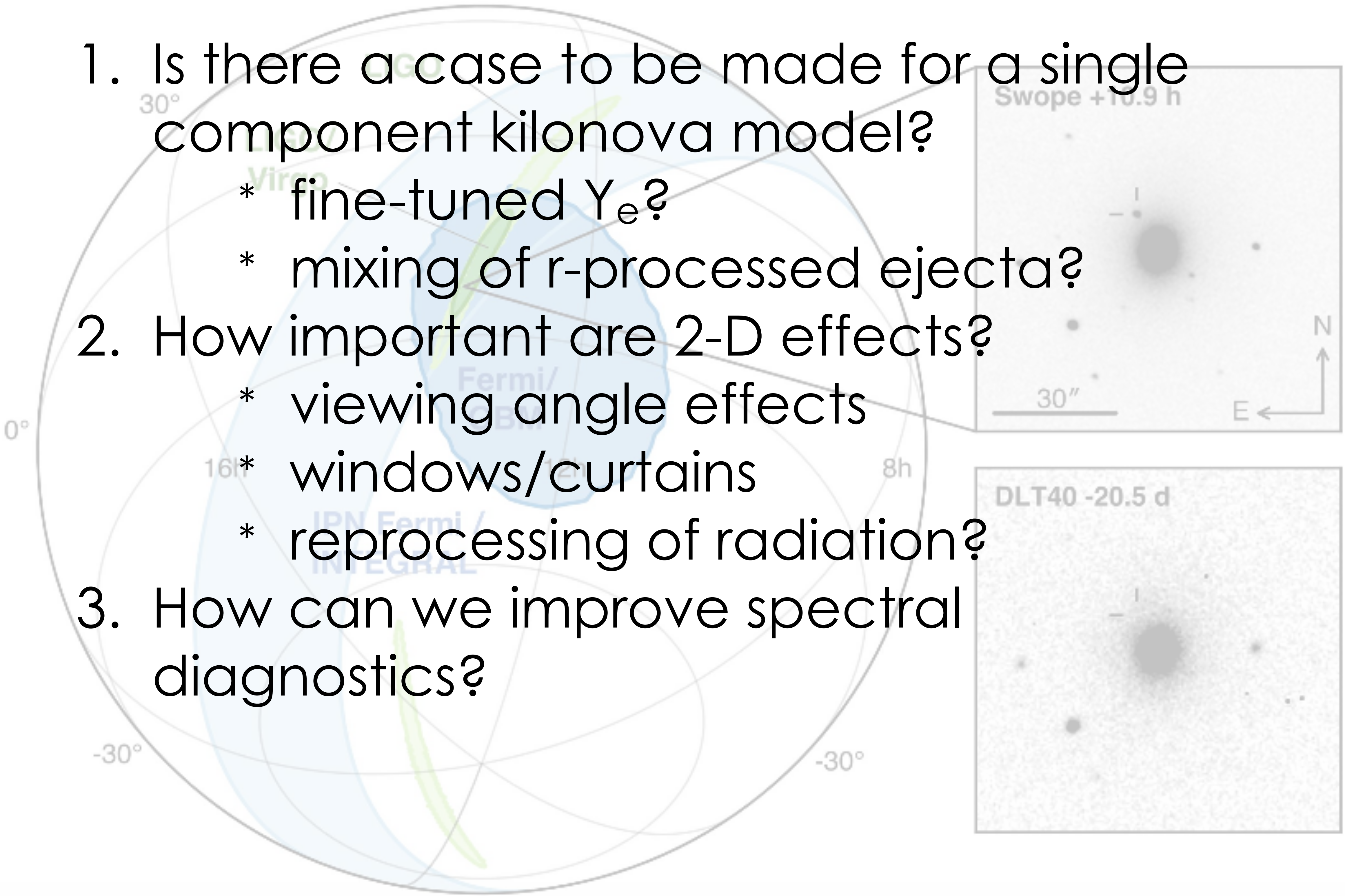


spectral features + diagnostics



Kasen, Metzger, **JB**+17

lingering questions



1. Is there a case to be made for a single component kilonova model?
   * fine-tuned Y_e?
   * mixing of r-processed ejecta?
2. How important are 2-D effects?
   * viewing angle effects
   * windows/curtains
   * reprocessing of radiation?
3. How can we improve spectral diagnostics?