Kilonovae:
impact of the *r*-process

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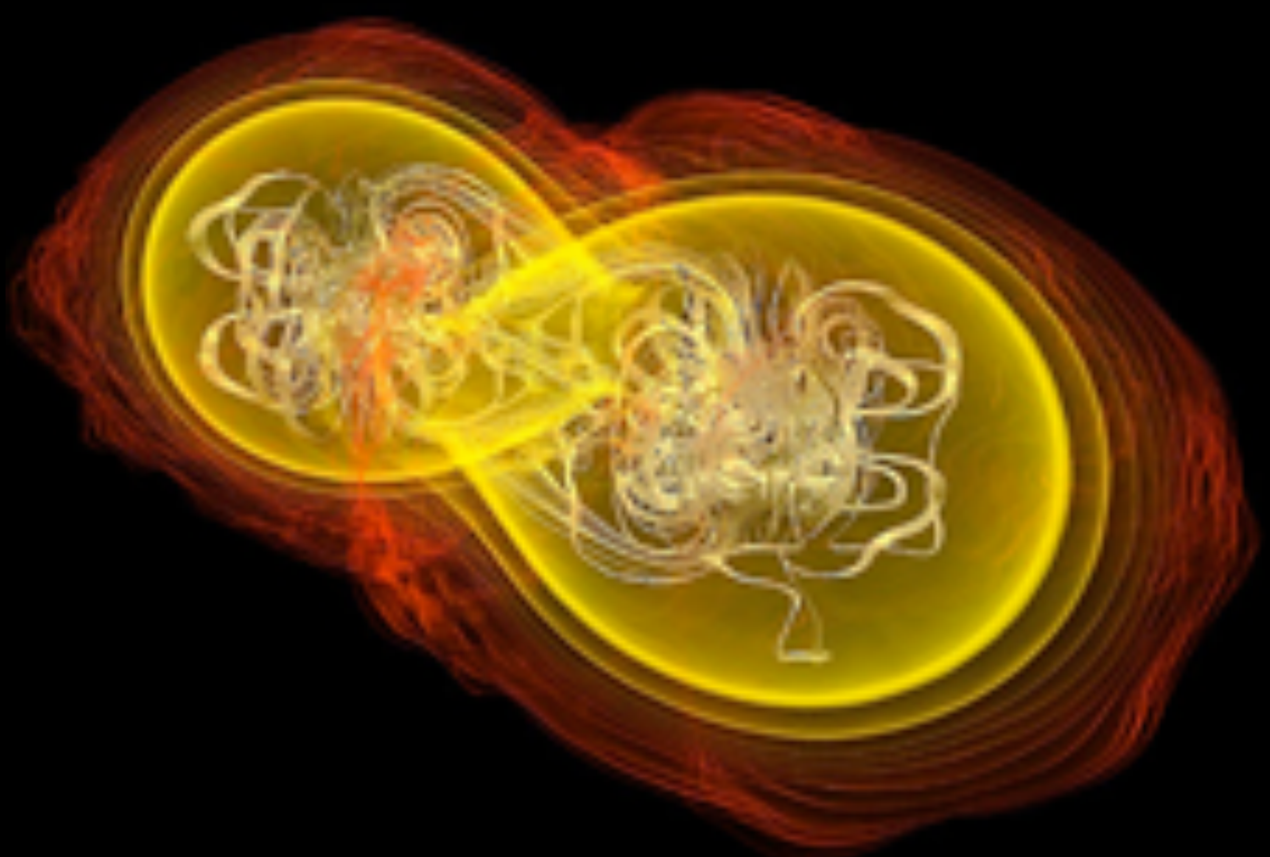
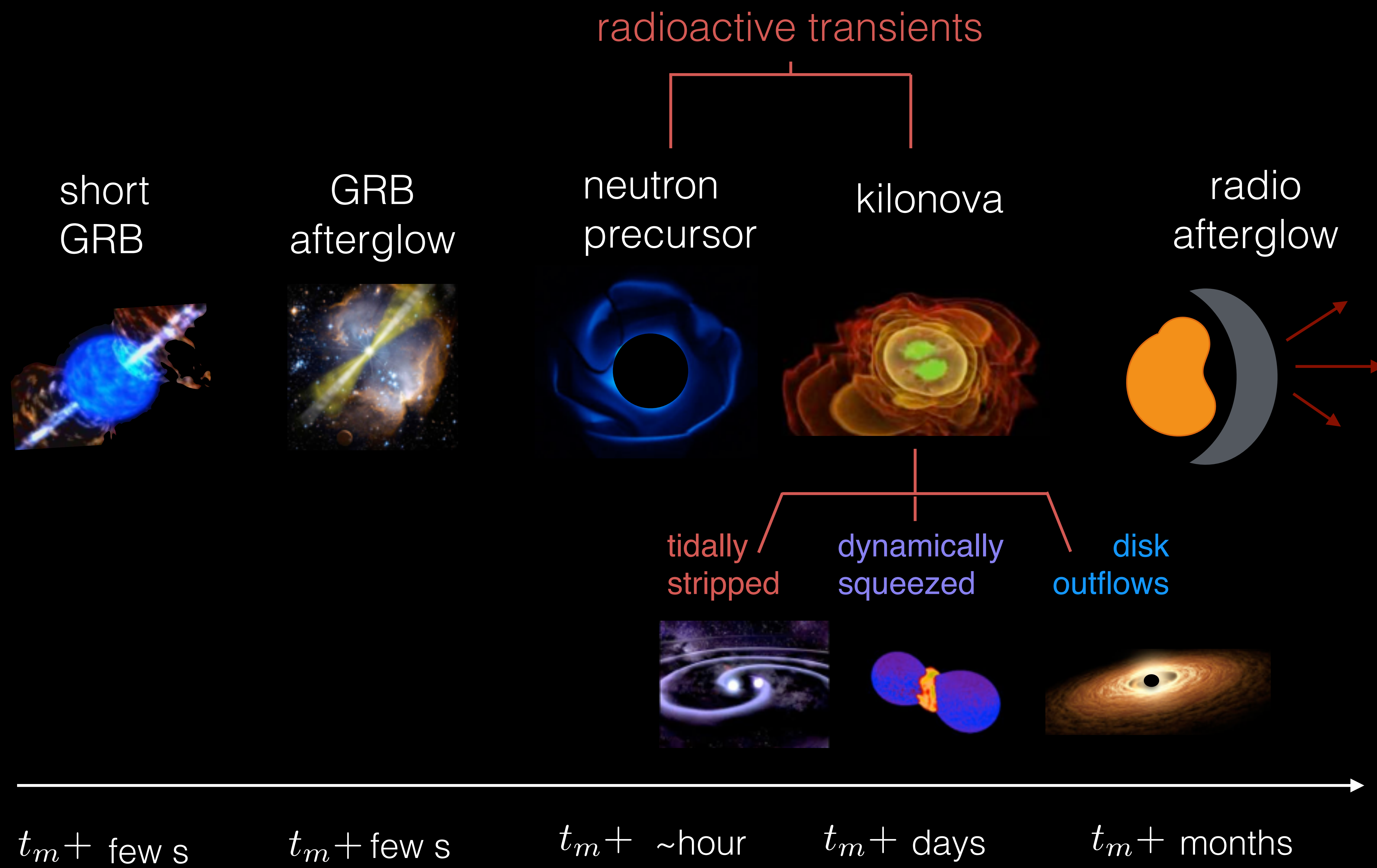
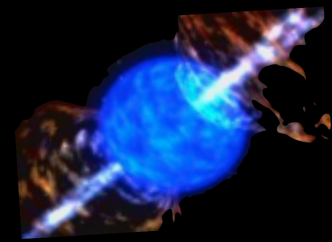
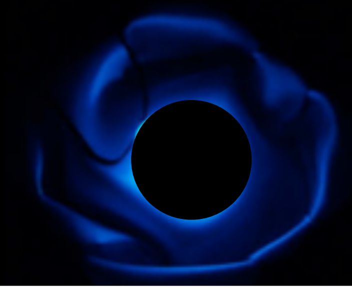
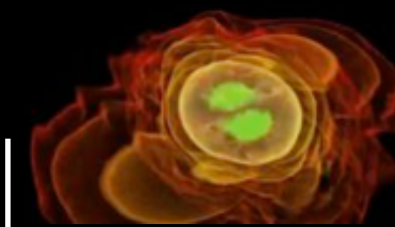
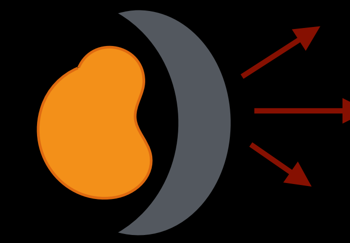


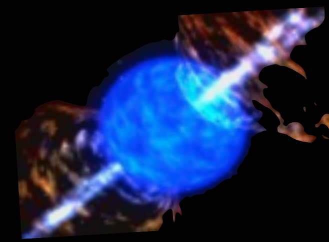
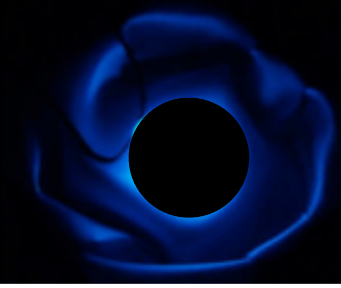
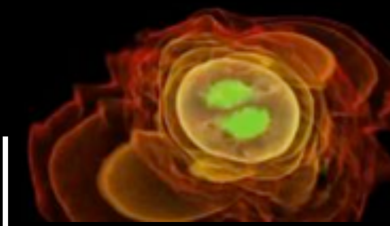
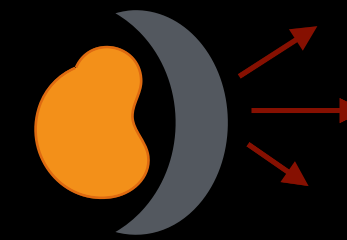
Roadmap

- Counterpart zoo
  - pros and cons
- Neutron precursor
  - relationship to the *r*-process
- traditional kilonovae
  - opacities (red or blue)
  - thermalization

EM Counterparts



					
~consistent	✗	✗?	✗	✓	✓
timely follow-up	✓	✓	✓	✓	✗
“smoking gun”	✓	✓	✓?	✓?	✗
probe *r*-proces	✗	✗	✓?	✓	✗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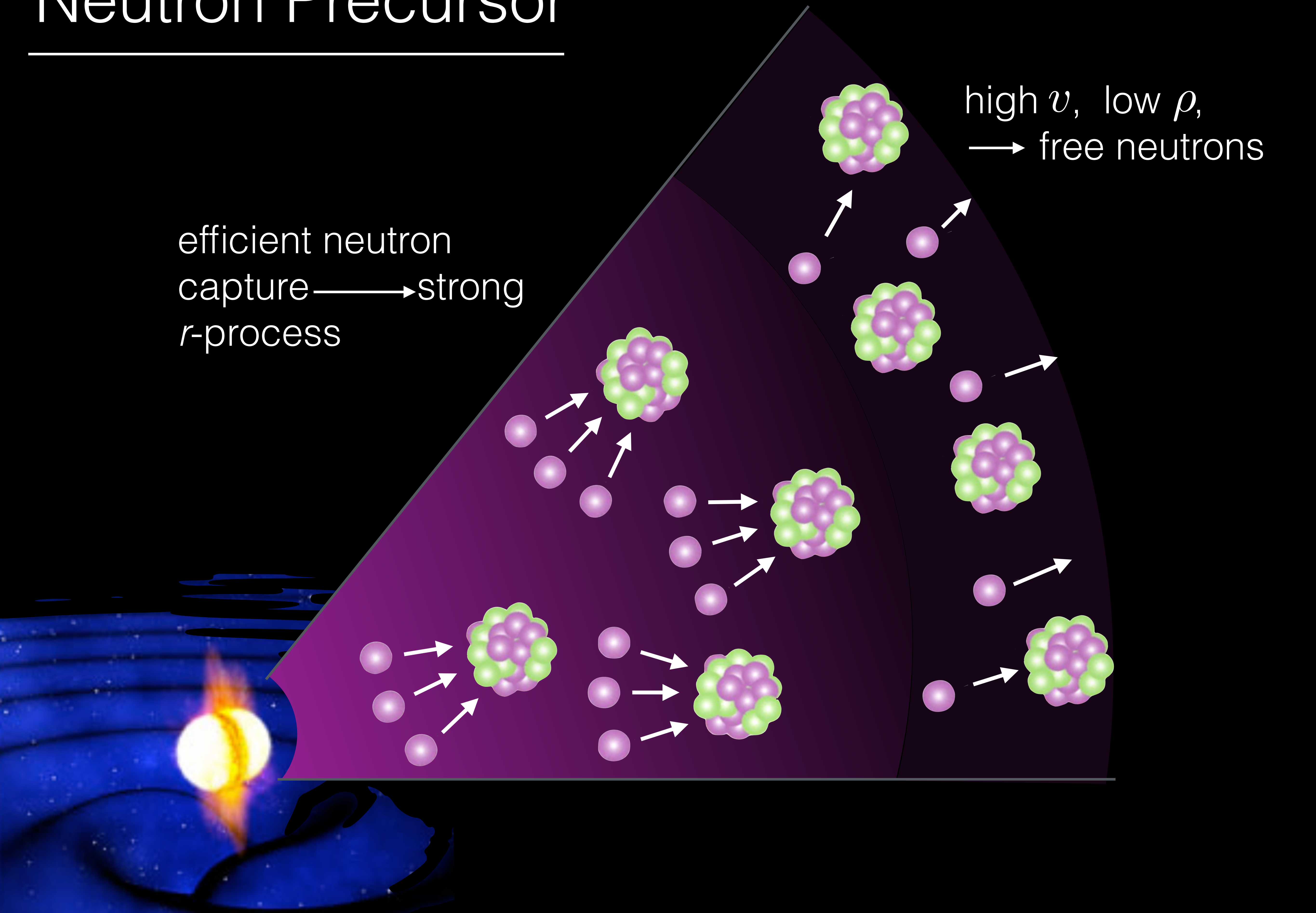
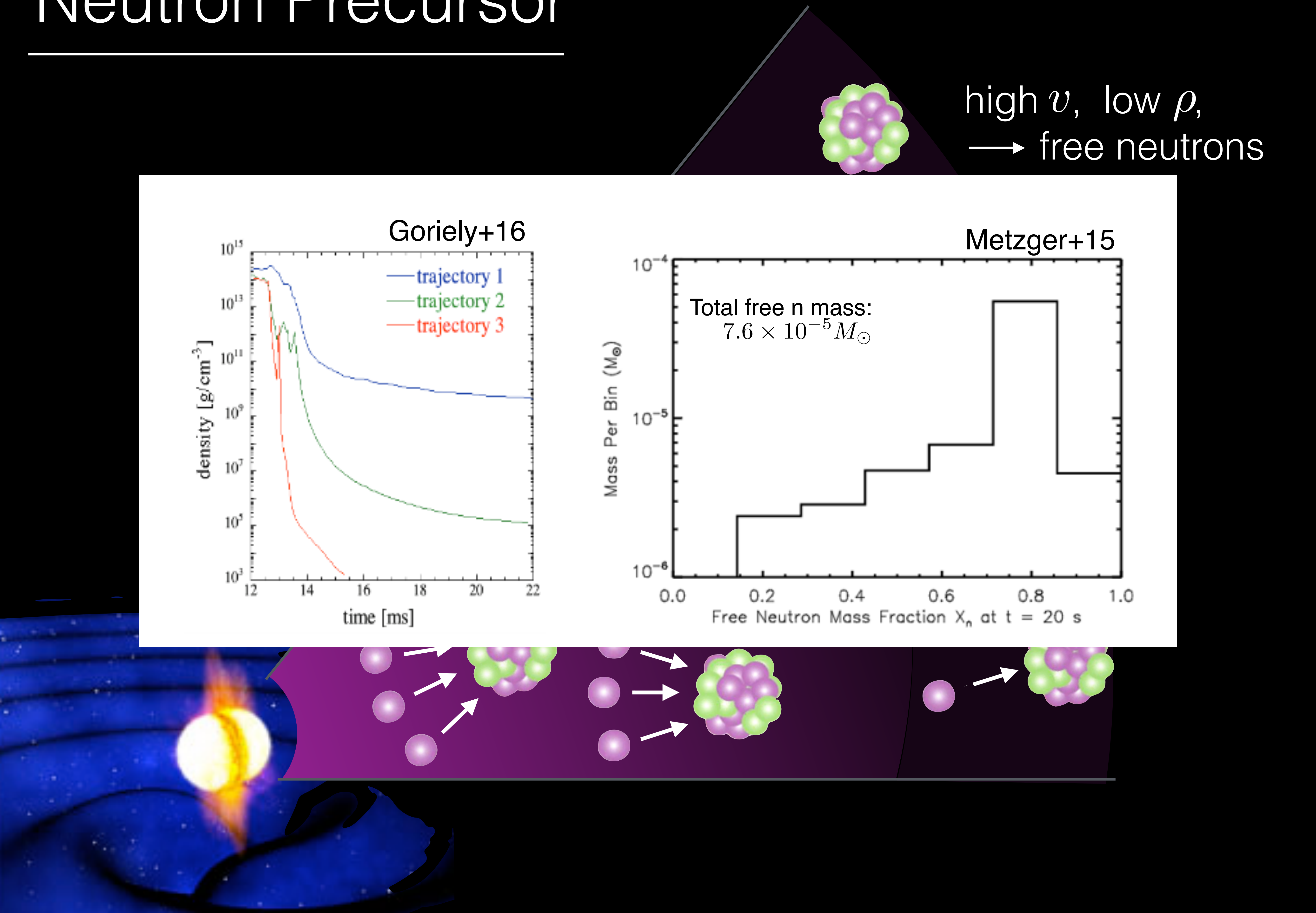
Neutron Precursor

Neutron Precursor



Neutron Precursor

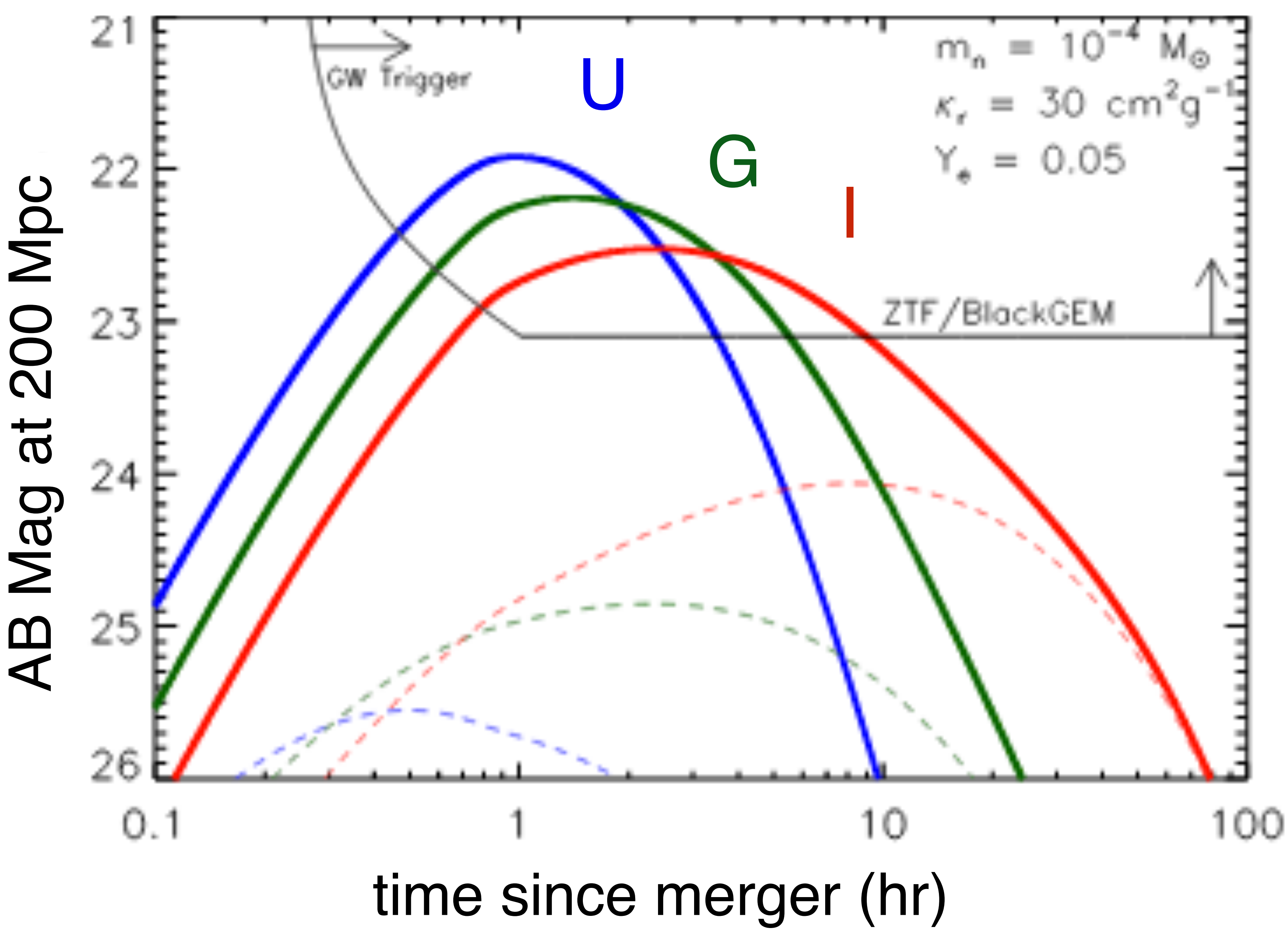
high v, low ρ,
$\longrightarrow$ free neutrons



Neutron Precursor

n → p $\Delta E \ (\beta, \bar{\nu}_{e^-})$

solid: n-heating, dashed: no n-heating



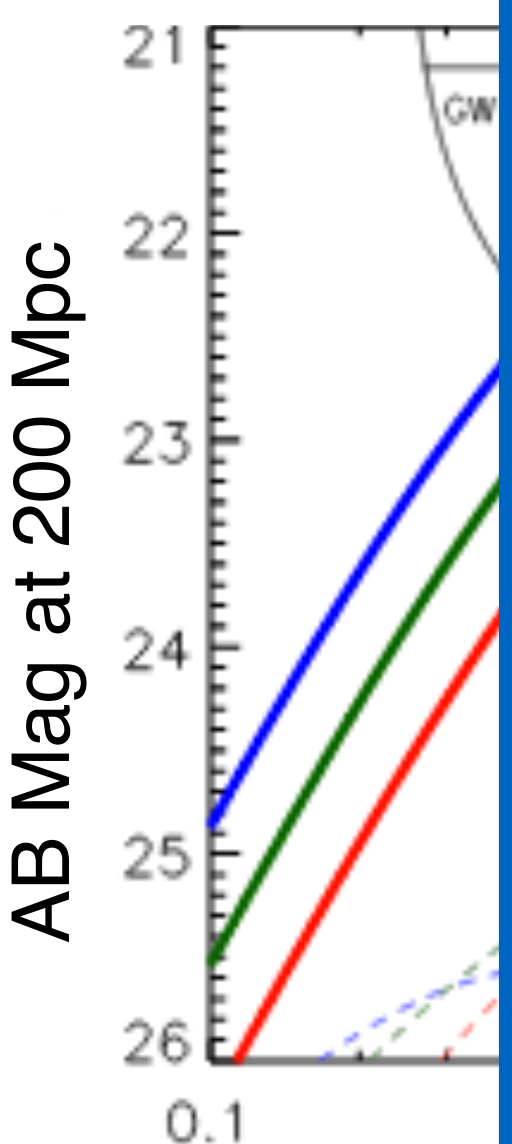
- bright +
- optical +
- brief -
- speculative -

potential useful as optical triggers, but more work is needed

Neutron Precursor

n

solid: r



Questions:

- Which systems produce a sufficient amount of free neutrons?
- How will the energy from free neutron decay heat the ejecta (thermalization)
- How will thermalized energy diffuse (composition and opacity)

+
+
-
ive -

useful
cal
but
rk is
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Kilonovae: opacities

Kilonovae

Characterizing the EM emission

$$L_{\rm peak} \sim L(t_{\rm peak}) \ , \ t_{\rm peak} \sim \left(\frac{M_{\rm ej}\,\kappa}{v_{\rm ej}\,c} \right)^{1/2}$$

How much? How fast?

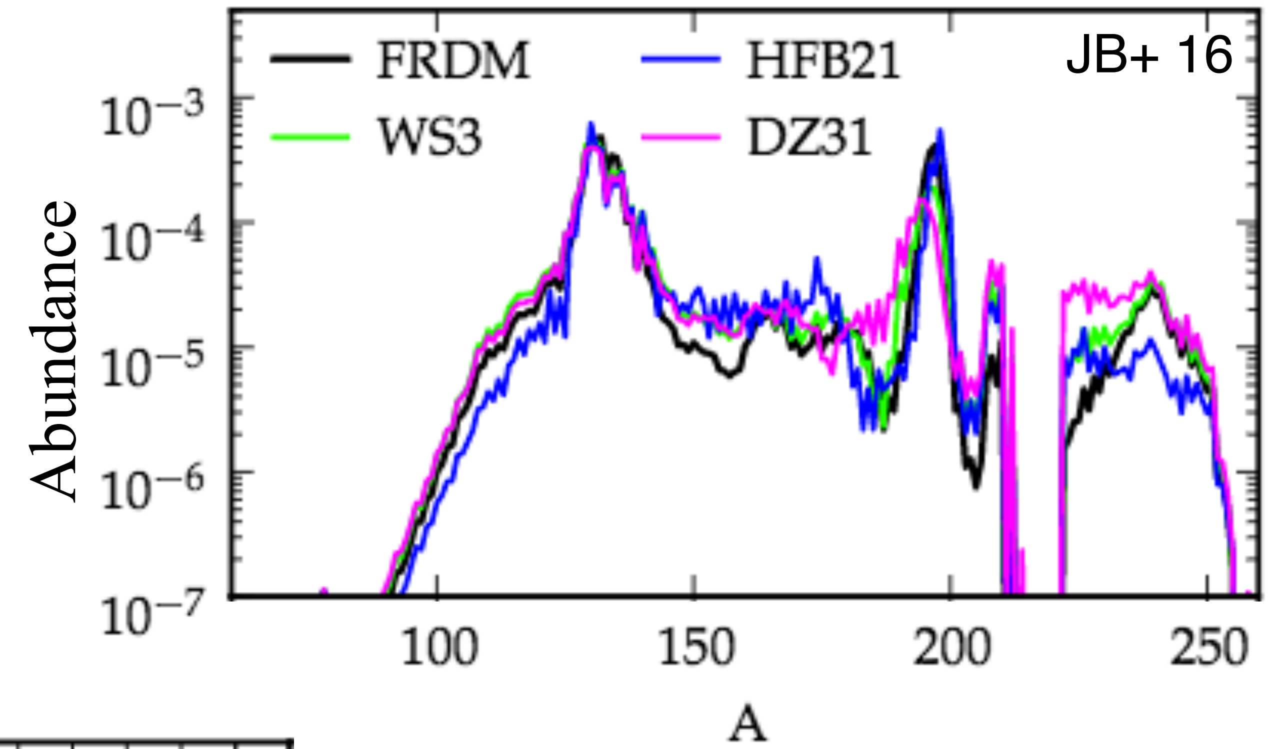
- merger dynamics:
  - binary type
  - mass ratio
  - NS EOS
  - BH spin
  - magnetic fields

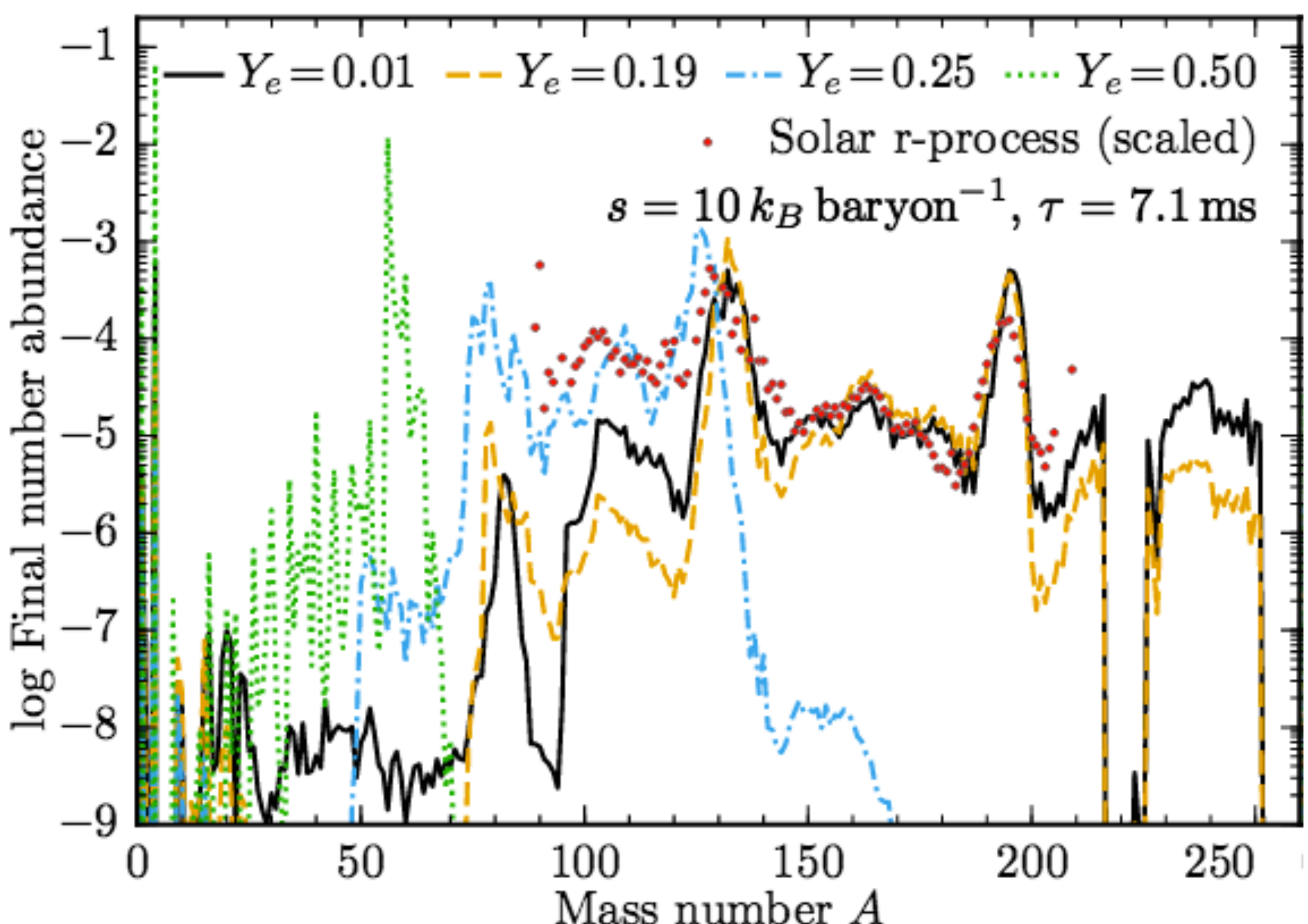
What kind?

- composition/opacity
  - robustness of the *r*-process
    - lanthanides/actinides
    - lighter elements

Kilonovae: opacities

r-process yields are relatively insensitive to nuclear mass model, but do depend on Y_e





Lippuner & Roberts 15

- $Y_\mathrm{e} = 0.25$ emerges as a threshold value
- weak interactions are clearly important

Kilonovae: opacities

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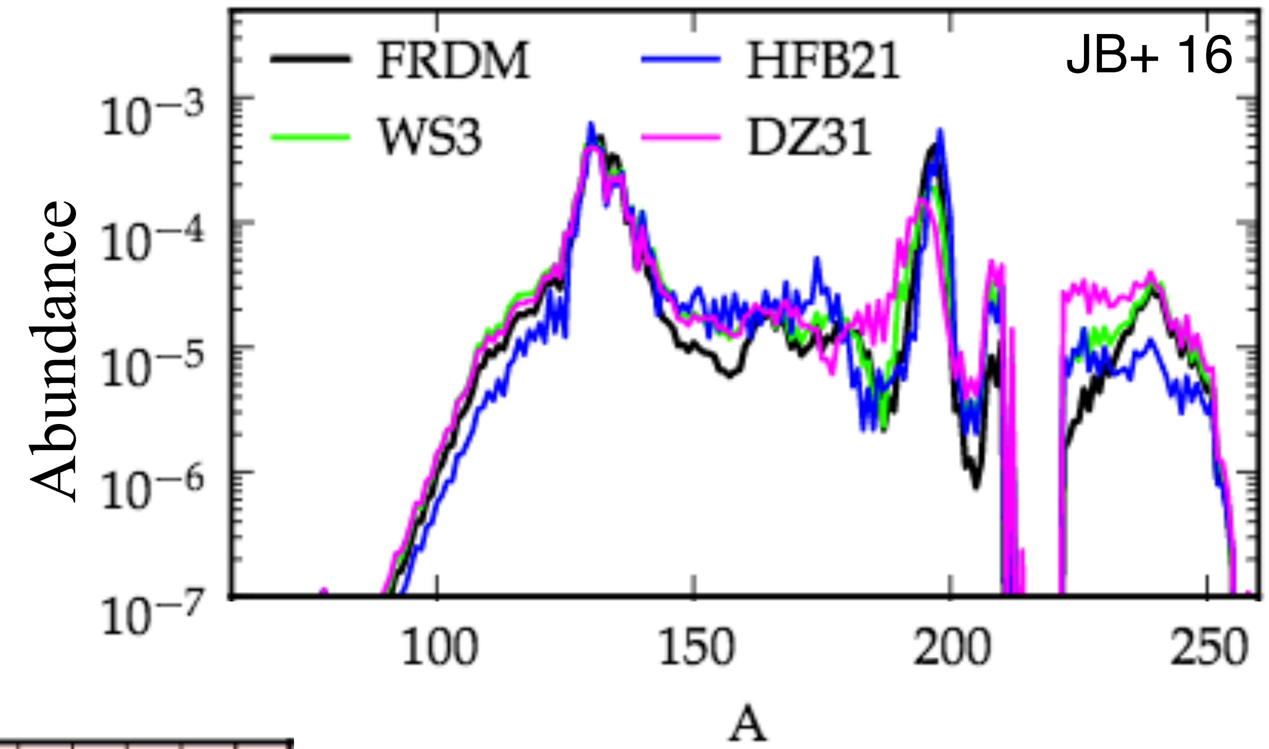

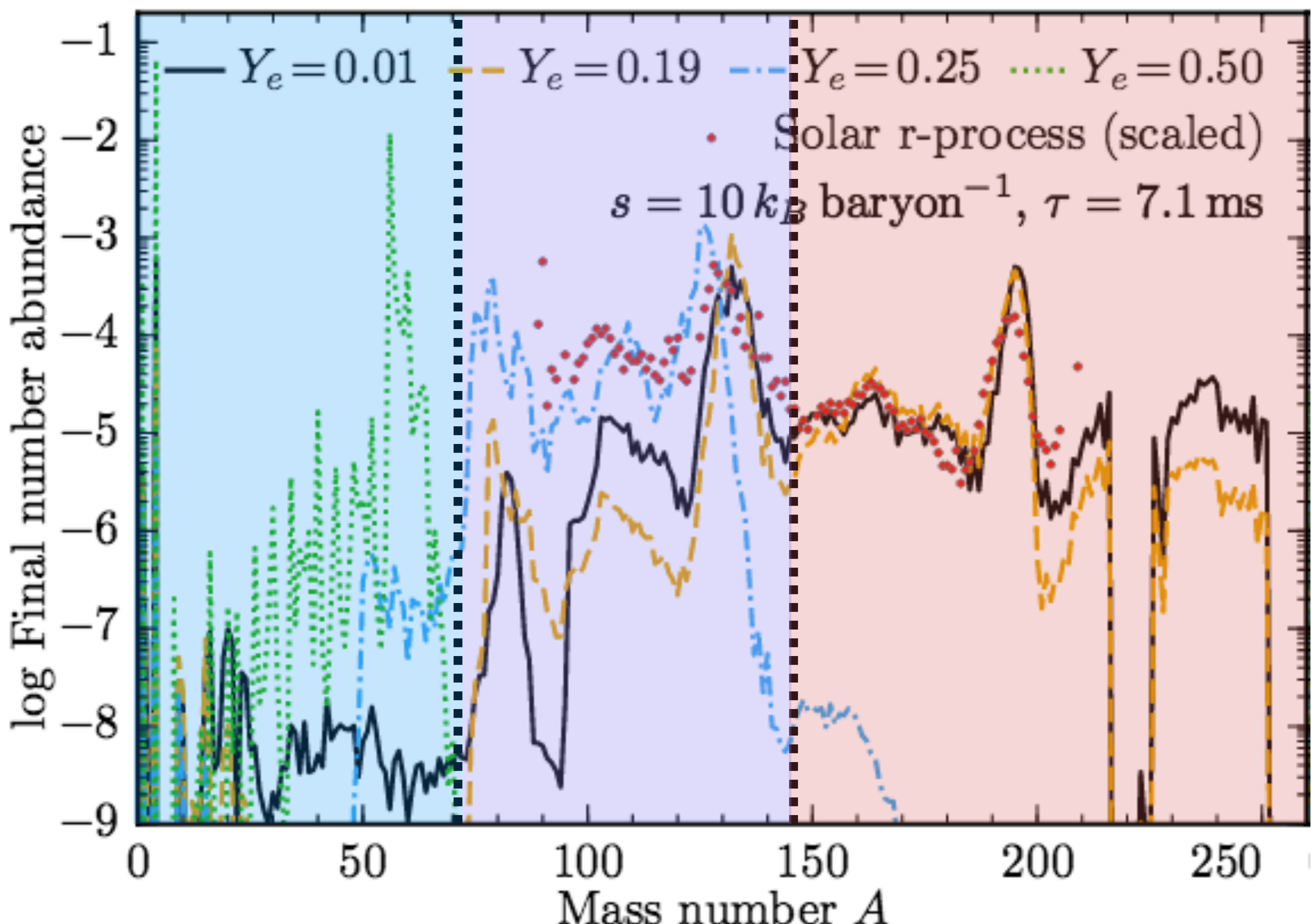

Lippuner & Roberts 15

- $Y_\mathrm{e} = 0.25$ emerges as a threshold value
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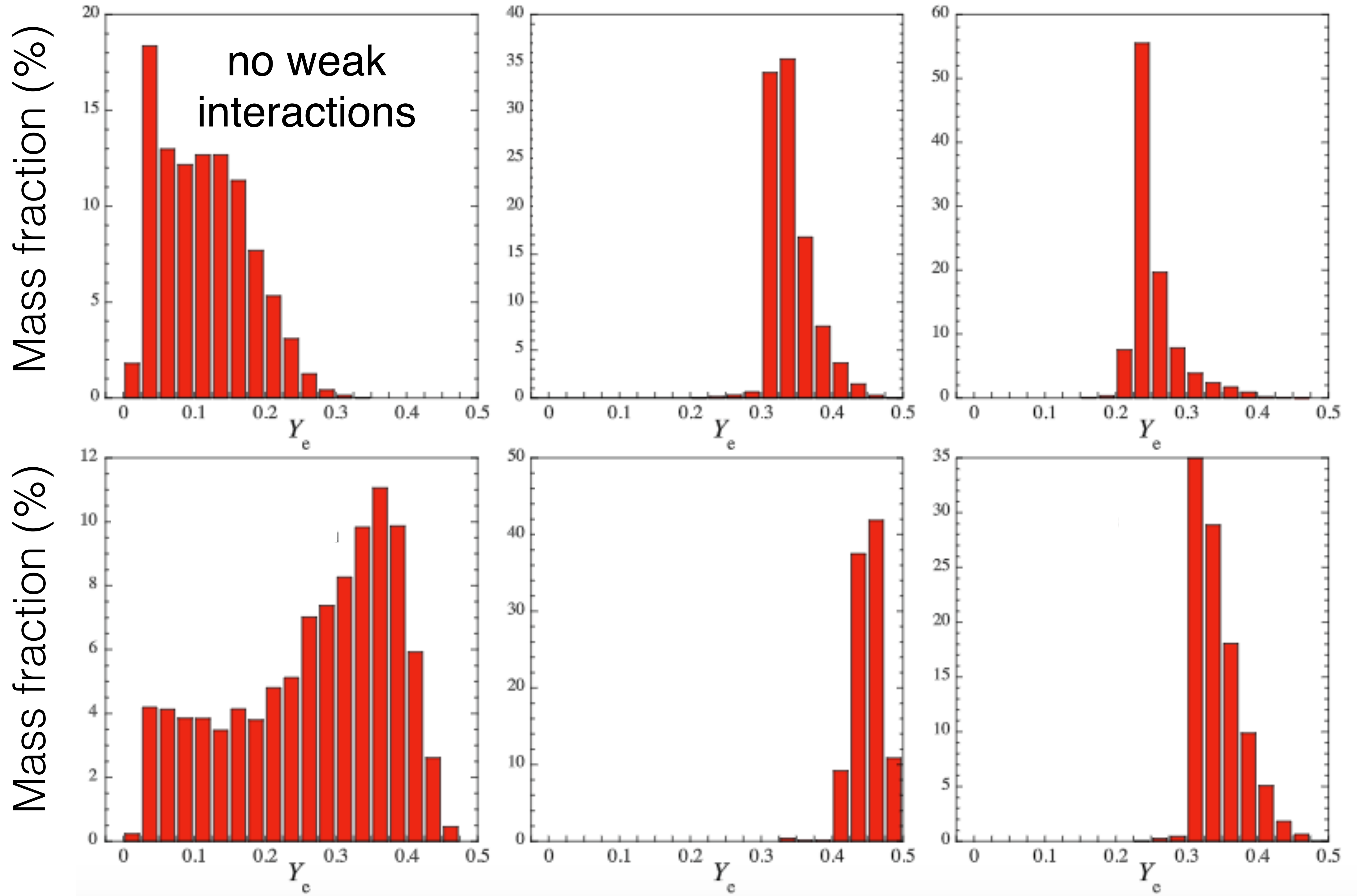
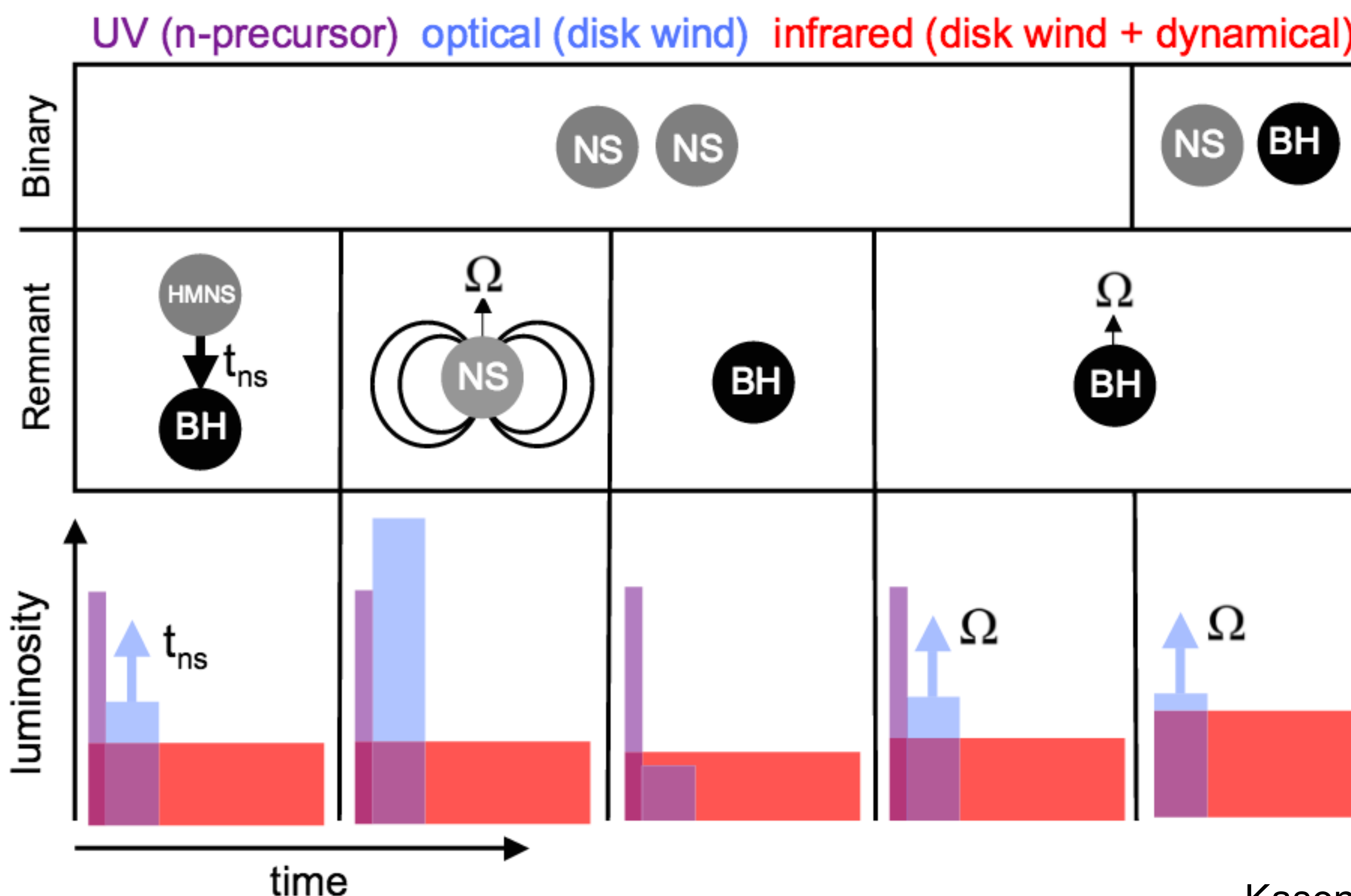
Weak interactions

$$\nu_{\mathrm{e}} + n \Longleftrightarrow p + e^{-}$$
$$\bar{\nu}_{\mathrm{e}} + p \Longleftrightarrow n + e^{+}$$



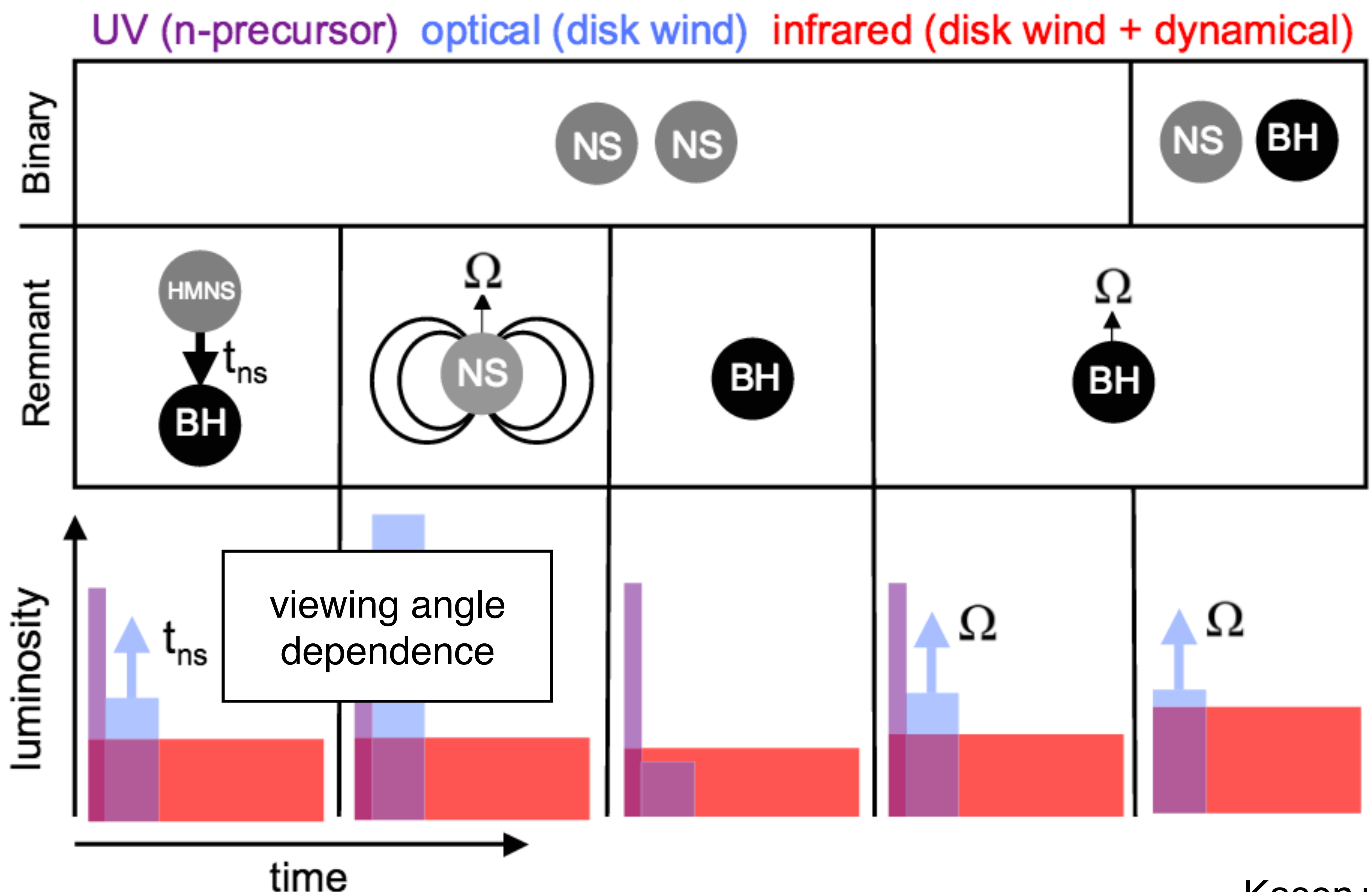
Goriely+15

Weak interactions: effect of system



Kasen+15

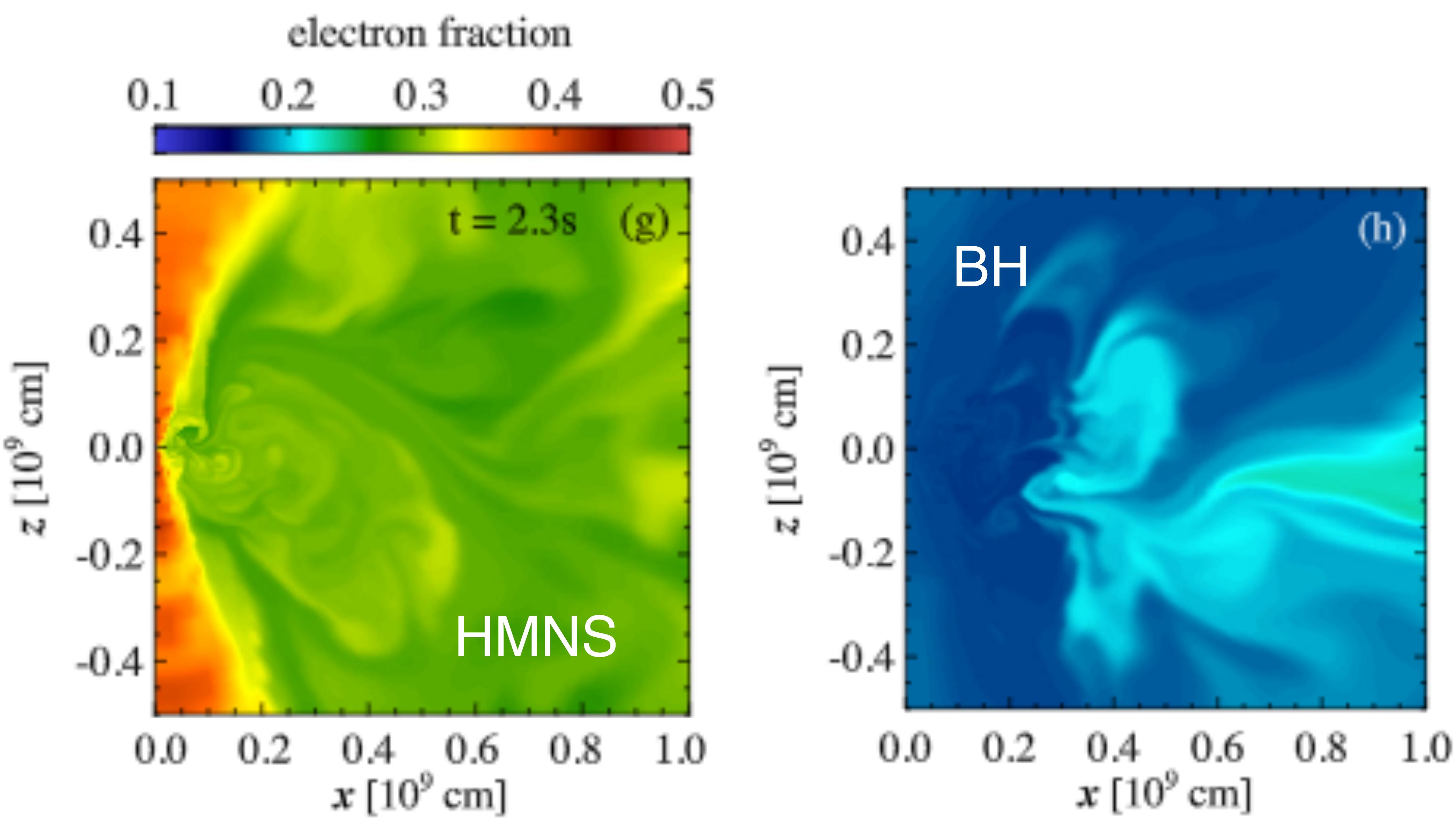
Weak interactions: effect of system



Kasen+15

Weak interactions: viewing angle

A long-lived HMNS raises Y_e preferentially along the poles, leading to a viewing angle dependence (Metzger & Fernández 2014)



Kilonovae: interactions

Nucleosynthesis is not the whole story; we also have to understand how the different components interact

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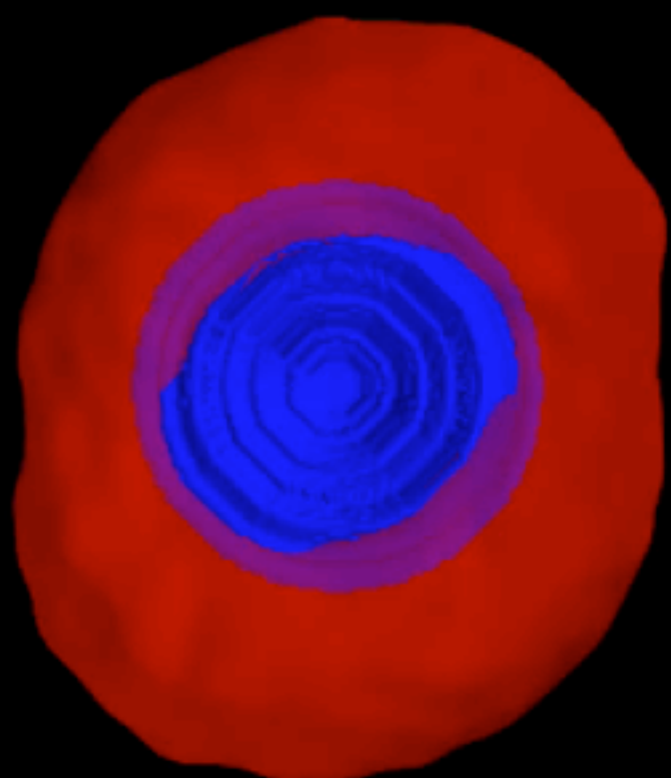

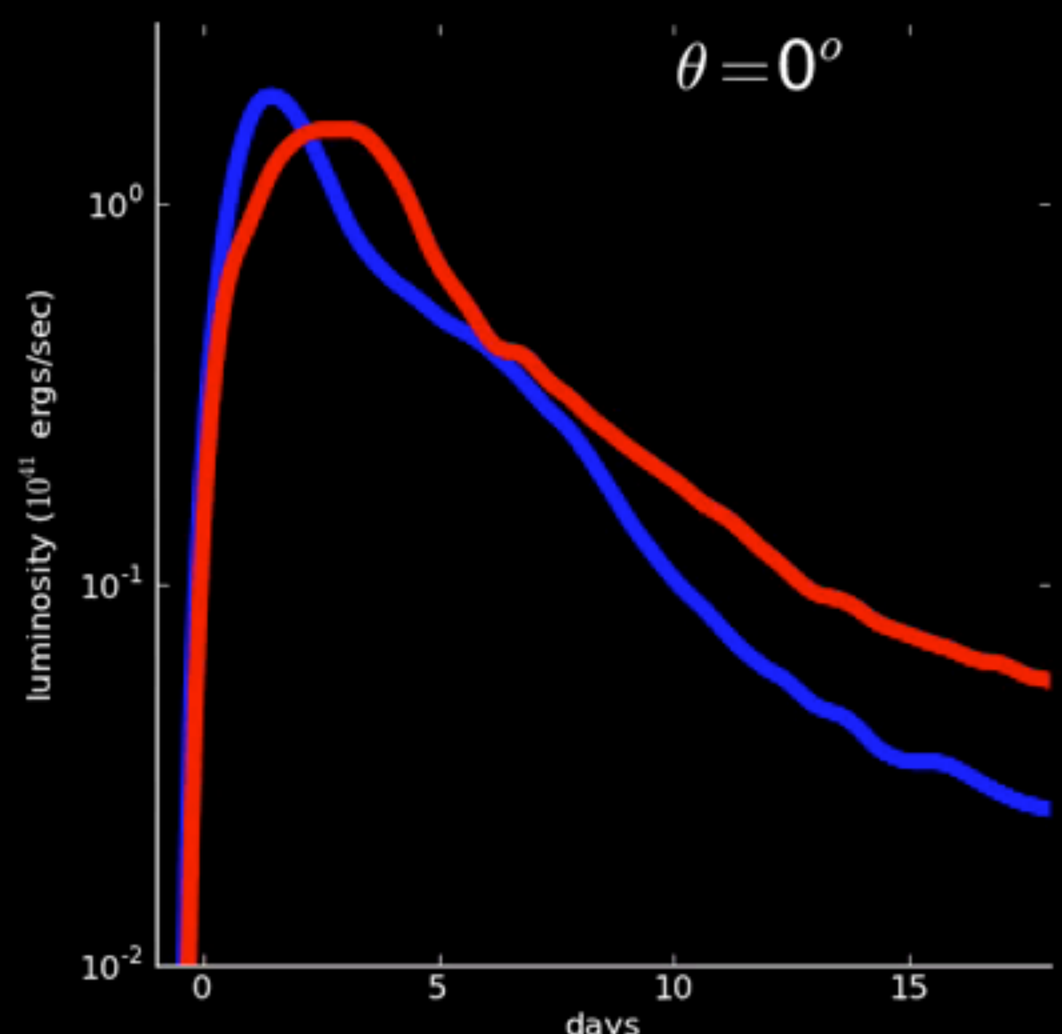

Kilonovae: interactions

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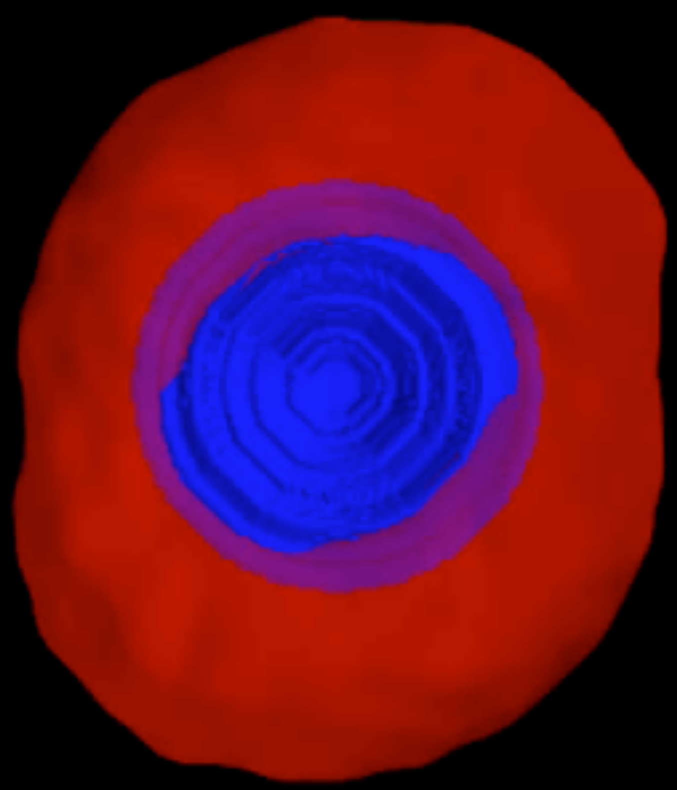
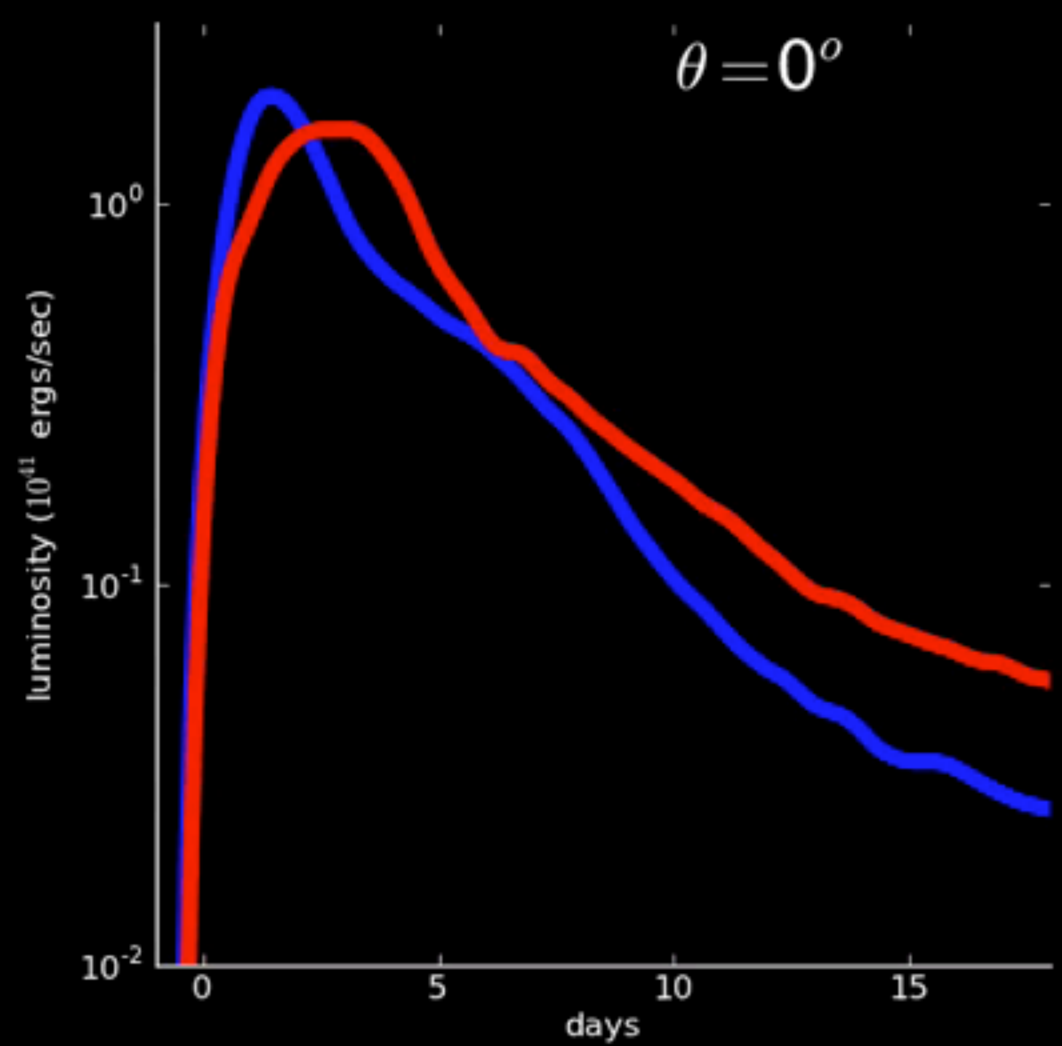
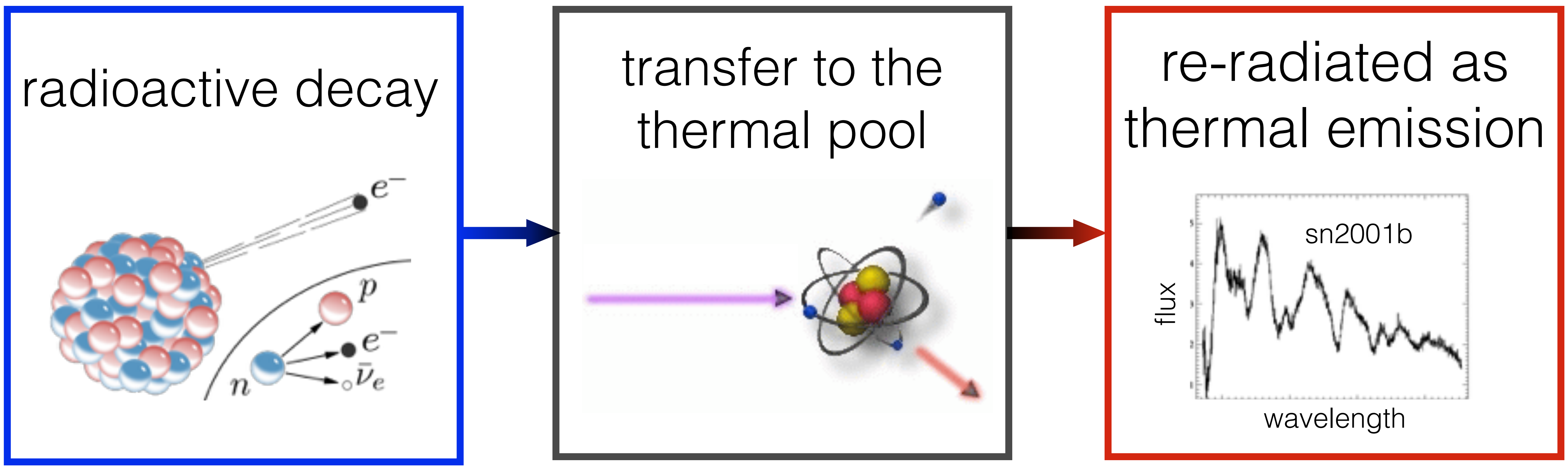




Kilonovae: thermalization

Kilonovae: thermalization

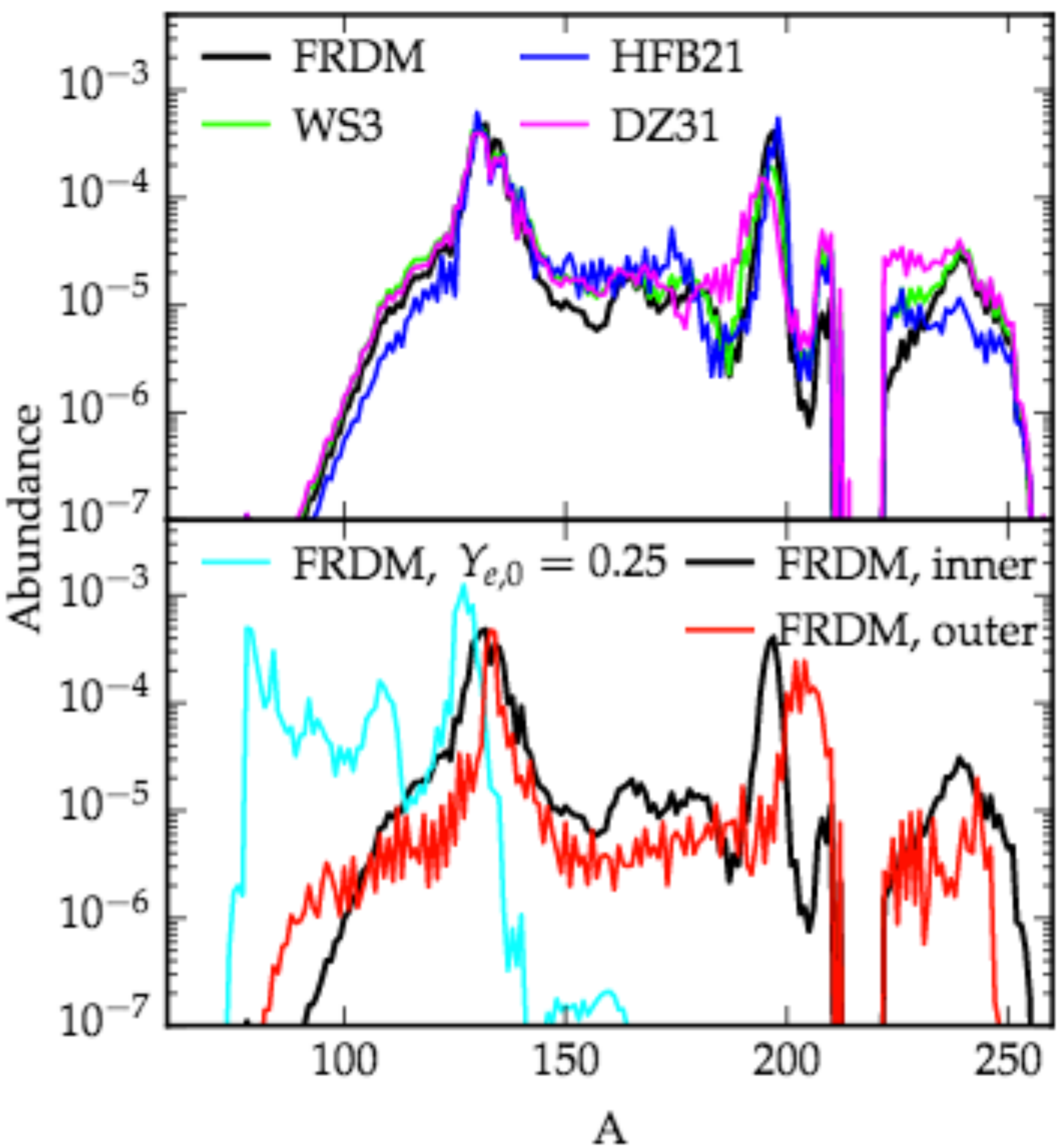
Thermalized energy supplies the kilonova's luminosity budget



Function of ***decay mode***, ***decay spectra*** (including energy partition for β-decay), and the ***density*** and ***composition*** of the ejected material

See also: Hotokezaka+16

Kilonovae: thermalization

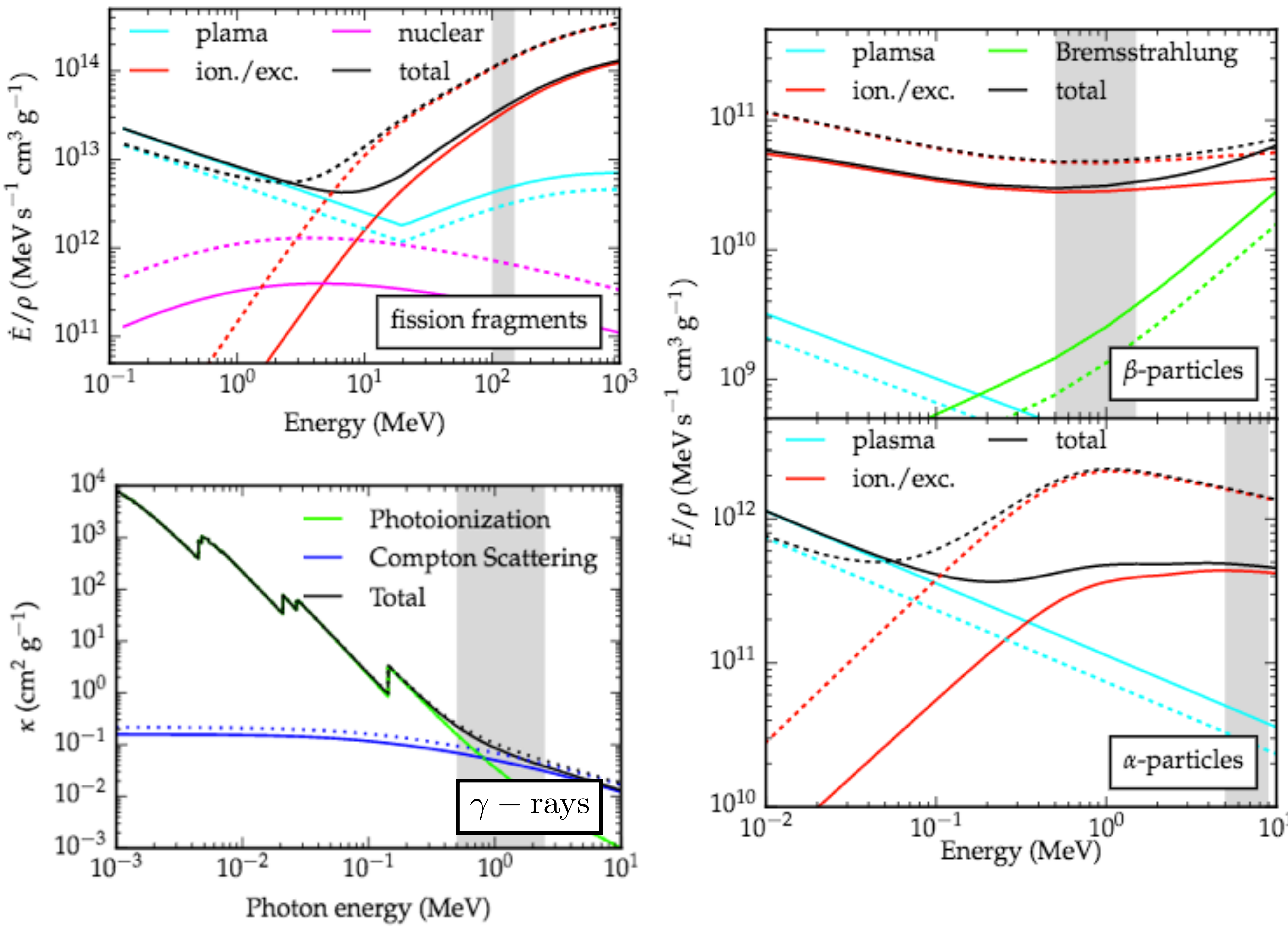


use *r*-process nuclear network calculations to determine the composition

Barnes+16

Thermalization: energy-loss rates

Dominated by Bethe-Bloch interaction (with bound electrons)

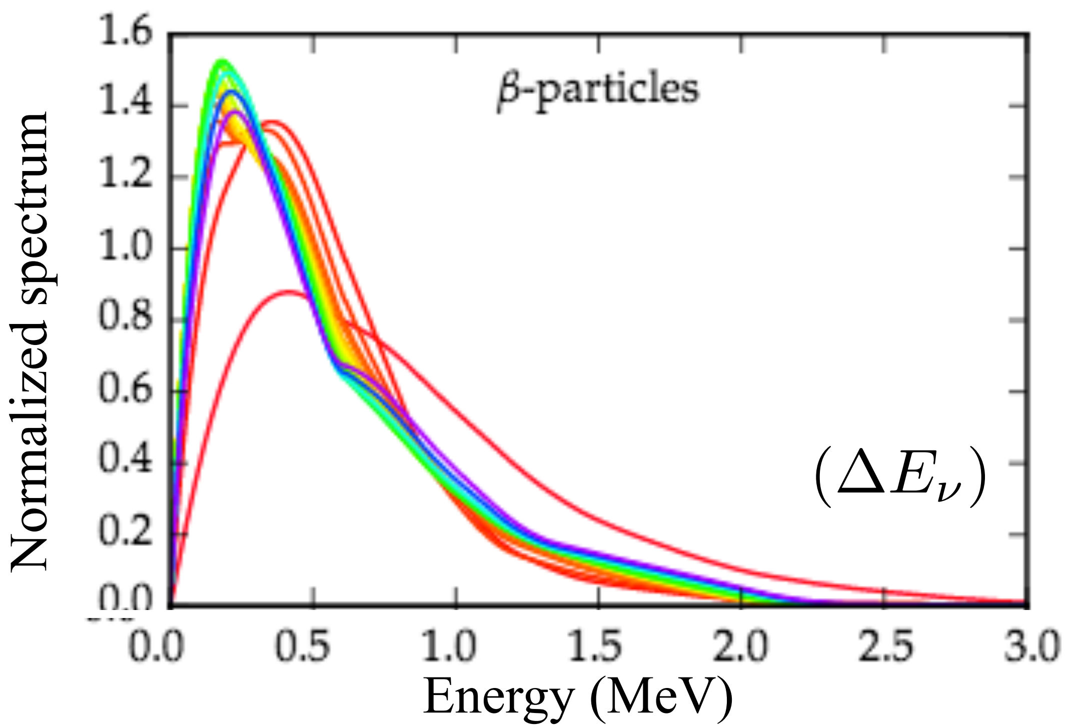


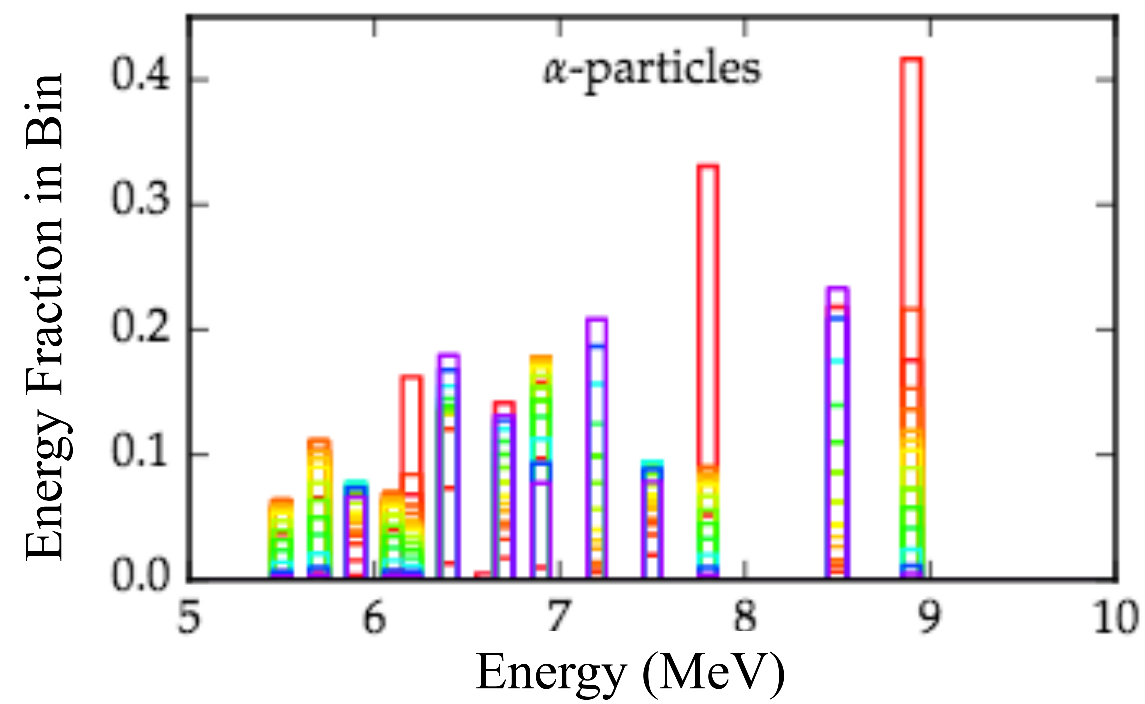
Main points:

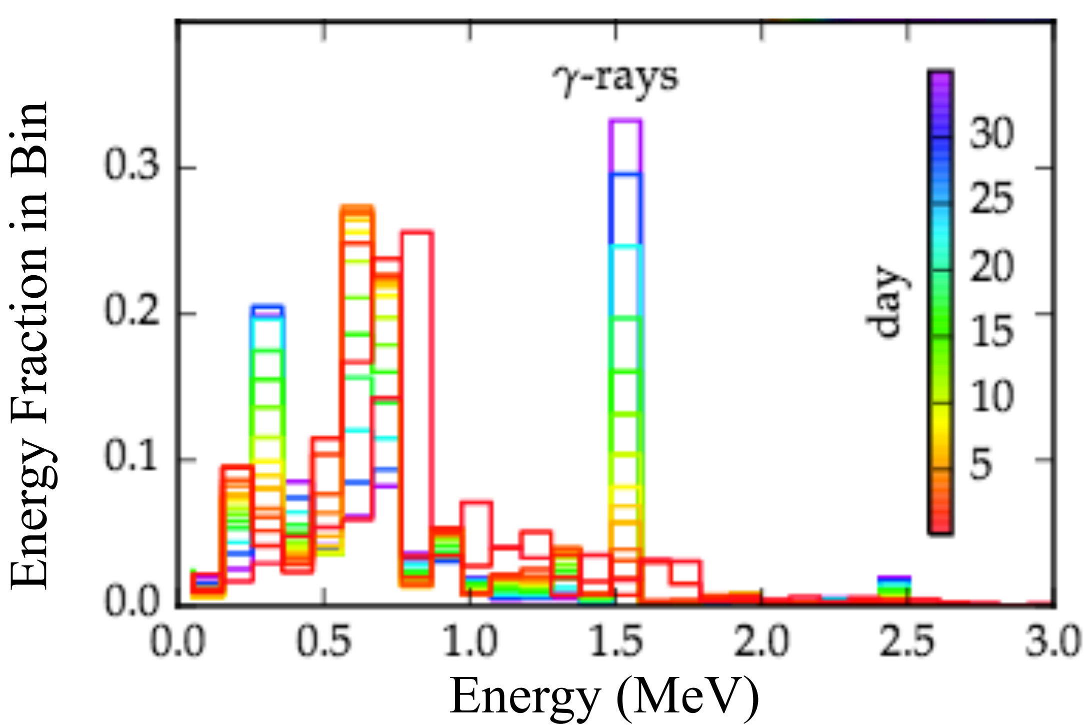
- mild energy dependence: higher energy ⟶ less efficient thermalization
- slight dependence on the background

Barnes+16

Thermalization: decay spectra







specta + $\dot{E}(E) \rightarrow f_{\rm p}(t)$

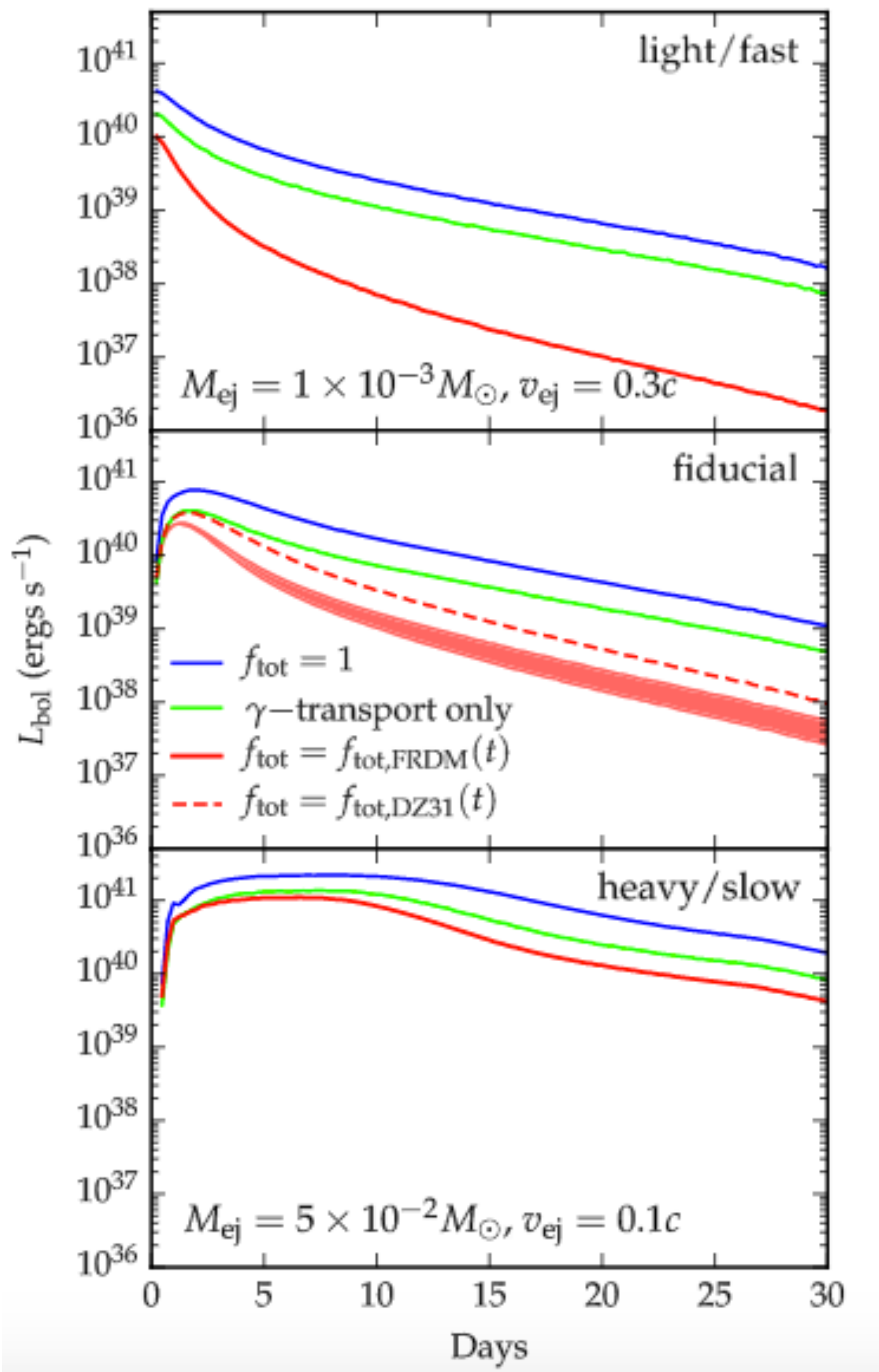
heating rates + $f_{\rm p}(t)$

$\rightarrow f_{\rm tot}(t)$

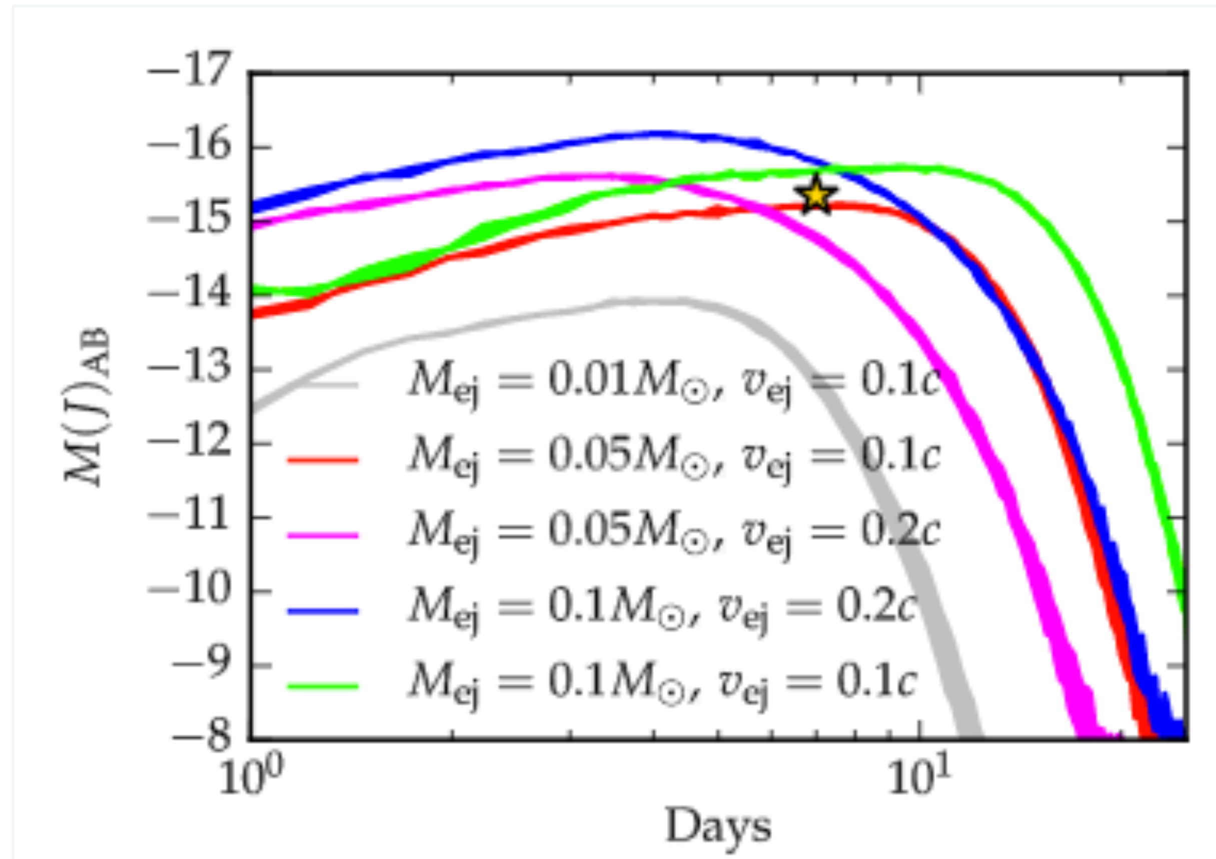
$f_{\rm tot} + {\rm RT} \rightarrow {\rm LC}$

Barnes+16

Effect on Light Curves



New mass estimates for kN associated with GRB 130603B

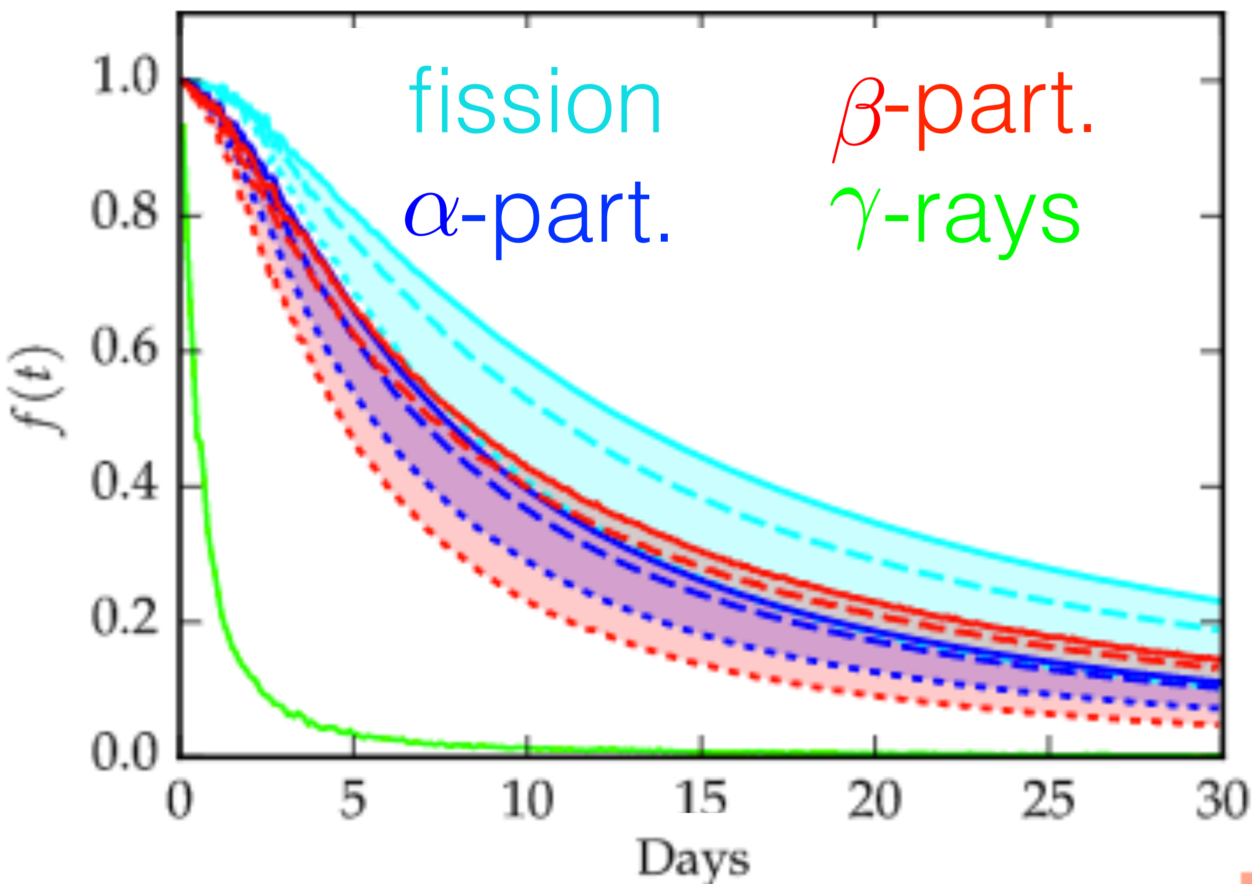


Caveats:

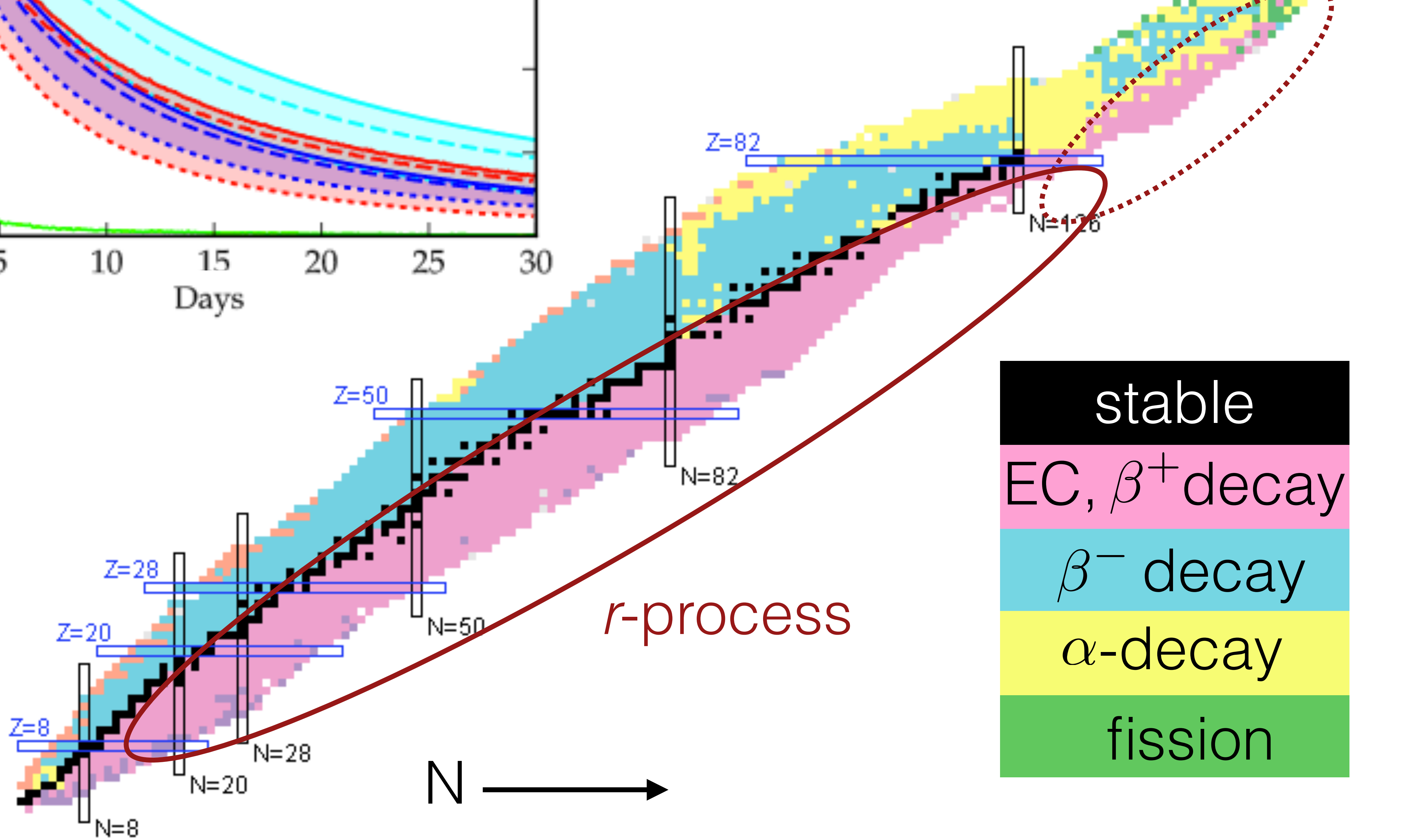
- viewing angle
- oblateness

Barnes+16

Dependence on Decay Mode:

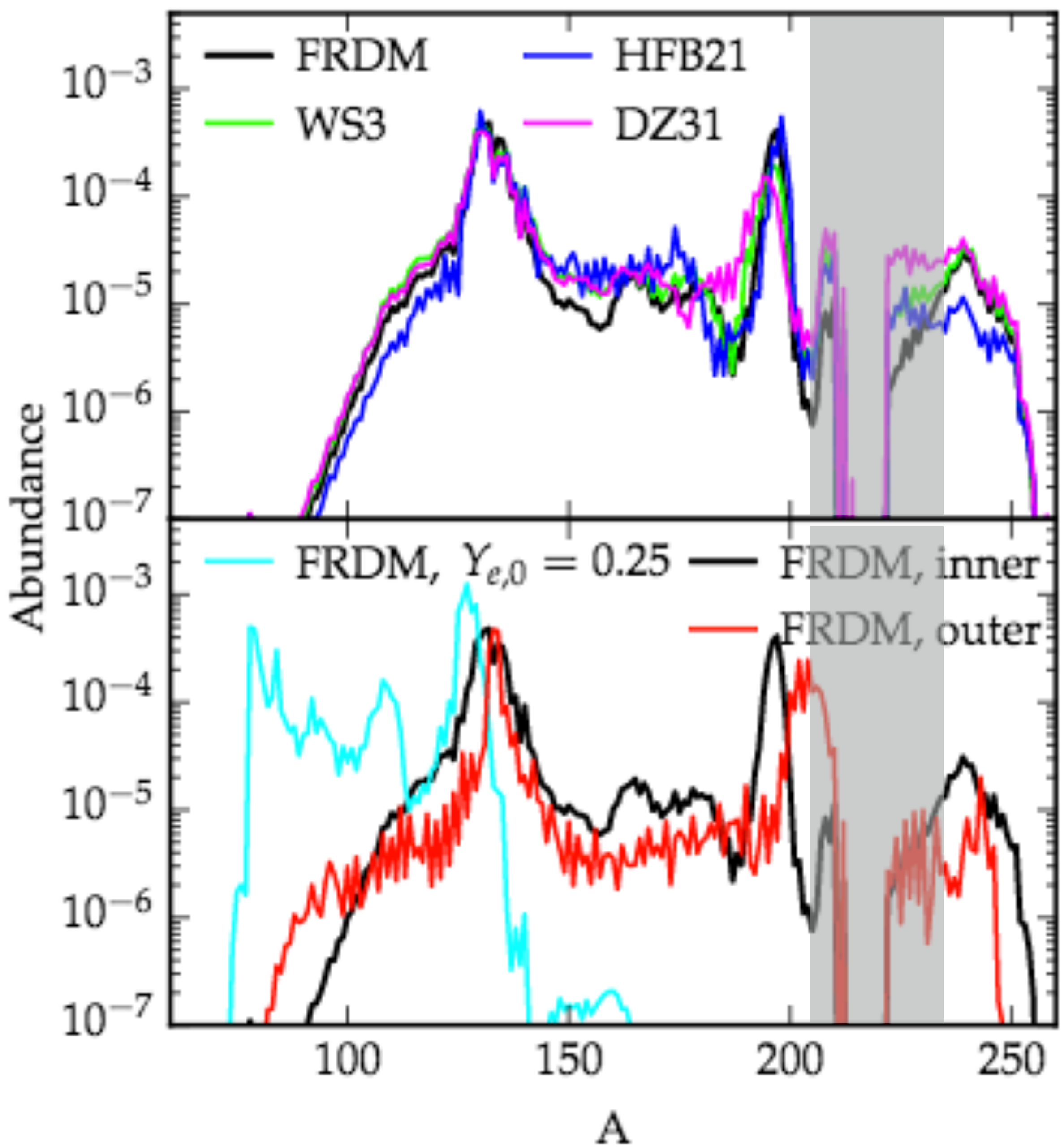


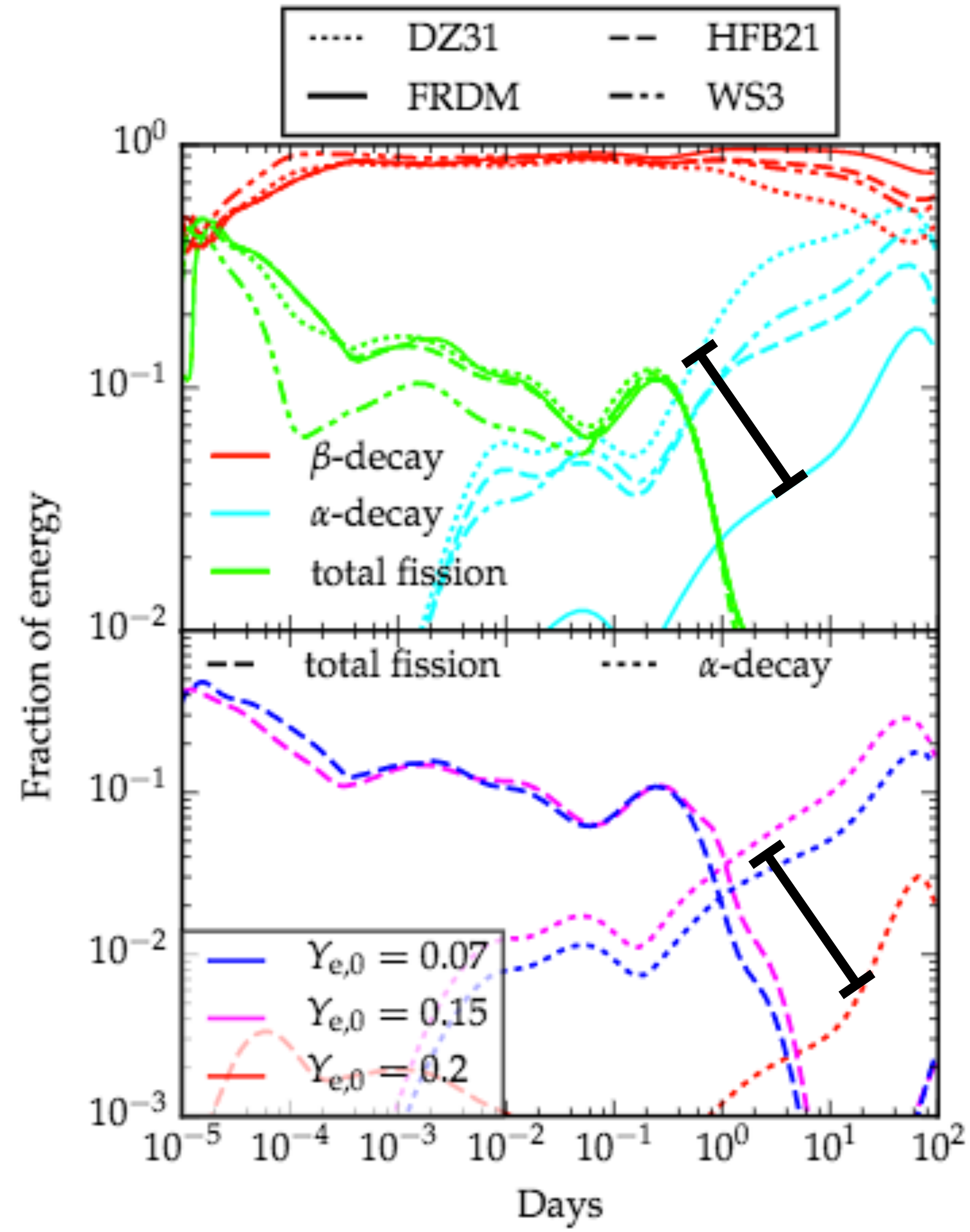
$$f_{\rm fission} > f_\alpha \simeq f_\beta \gg f_\gamma$$



Dependence on Decay Mode:

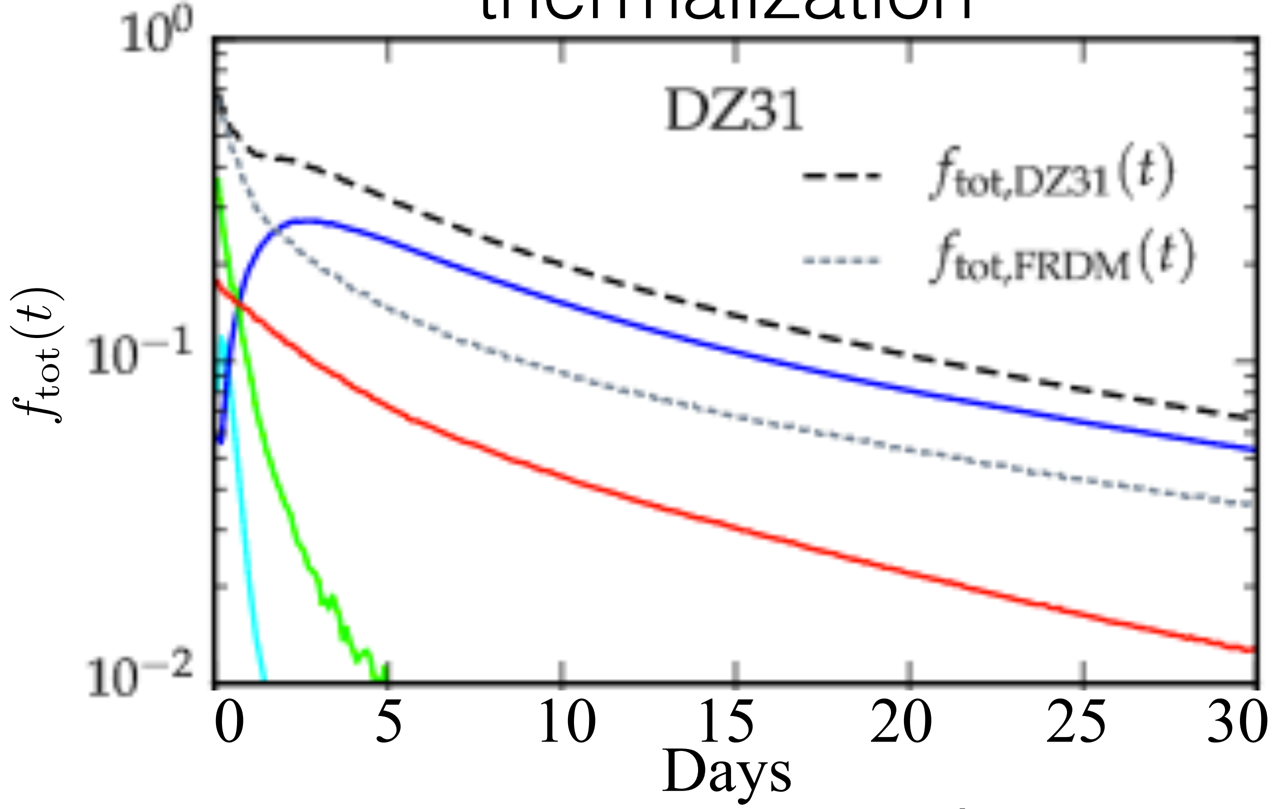
translead production depends on neutron separation energies near $N = 130$
(see Mendoza-Temis+15)



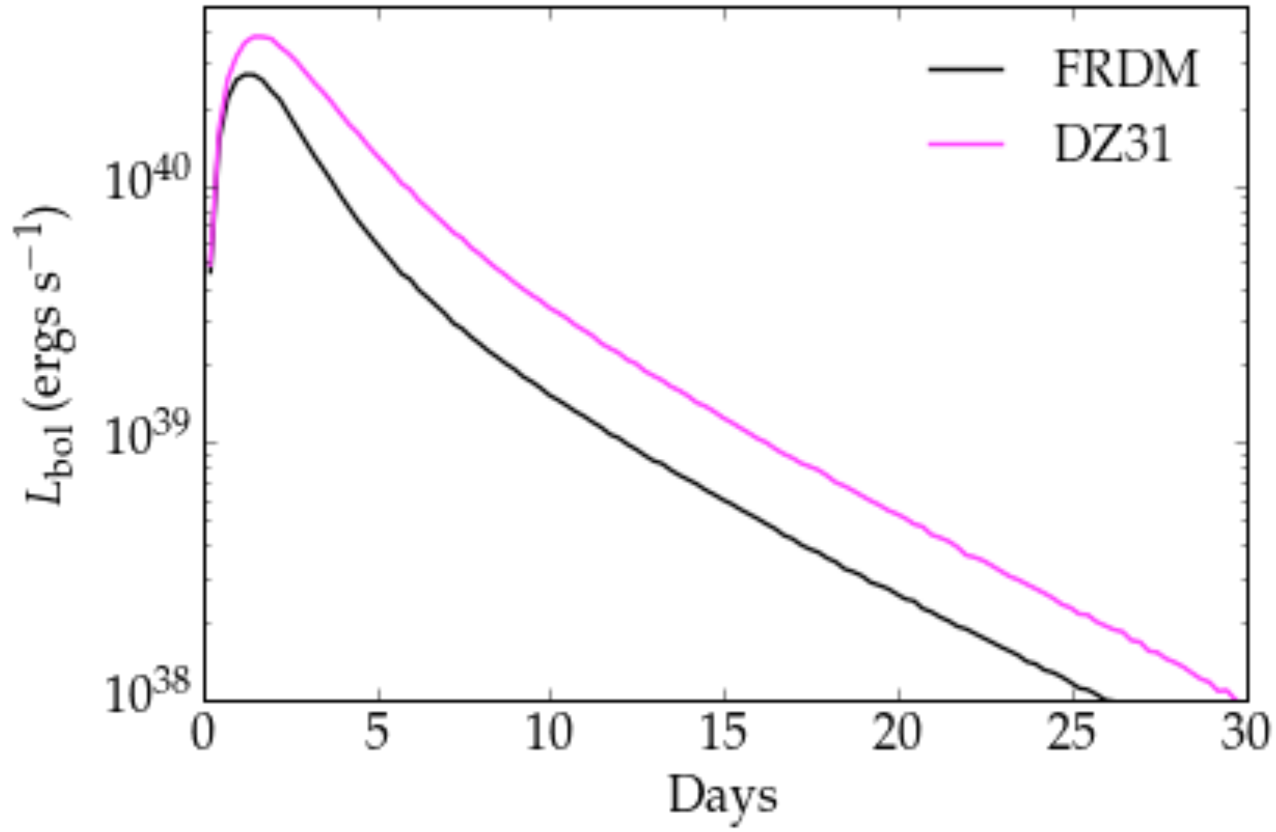


Dependence on Decay Mode:

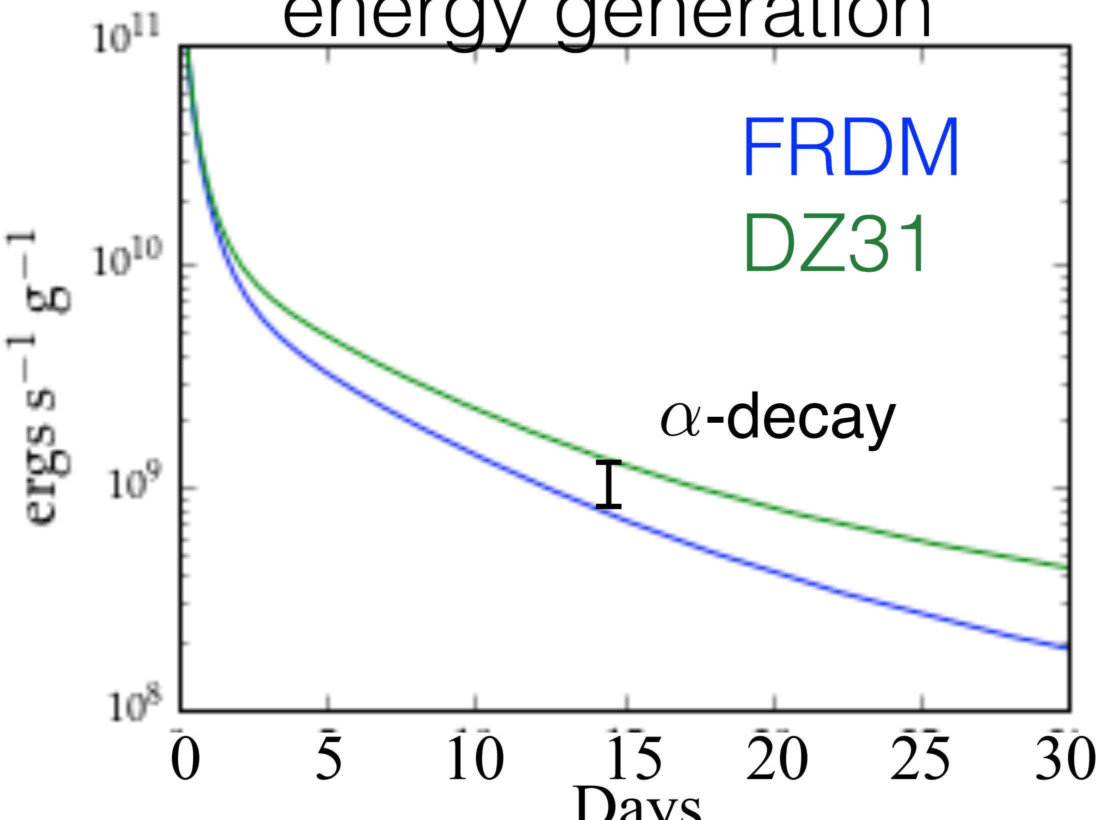
thermalization



luminosity



energy generation

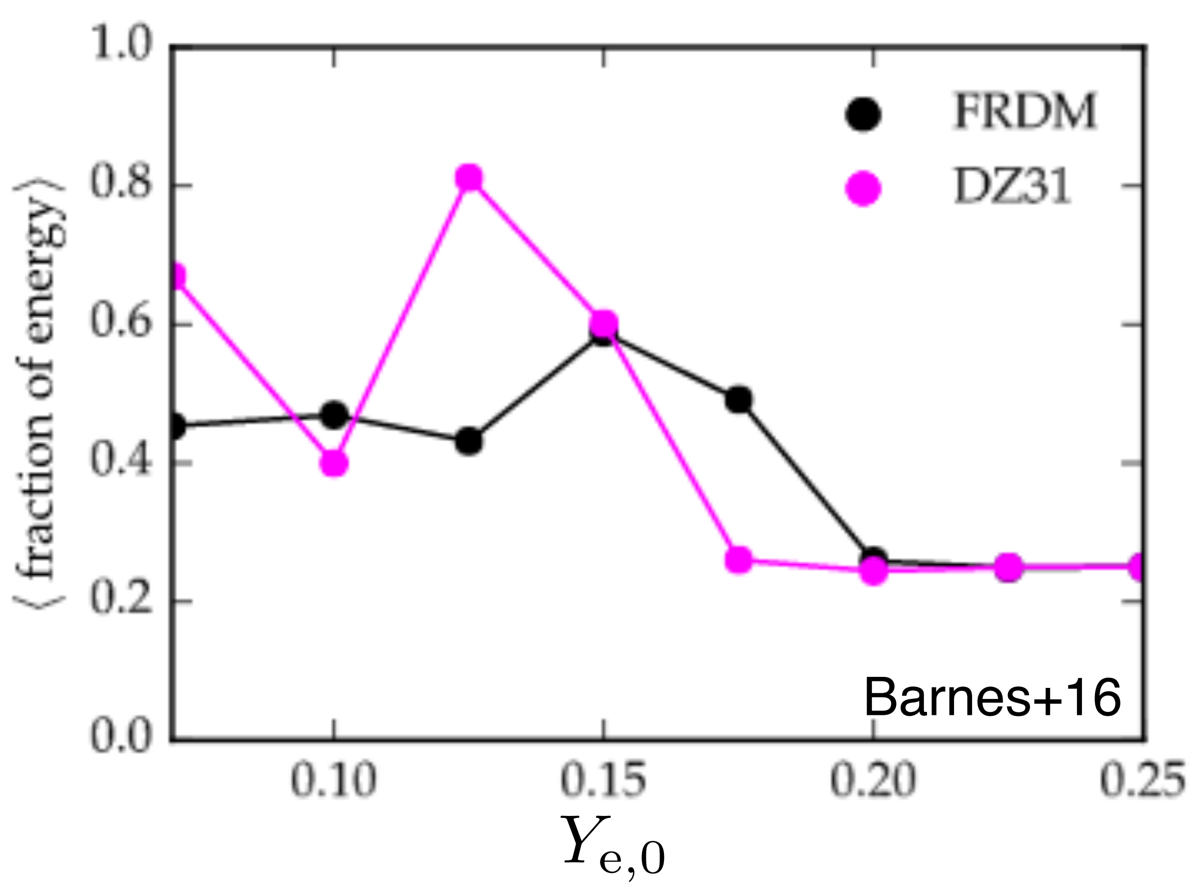


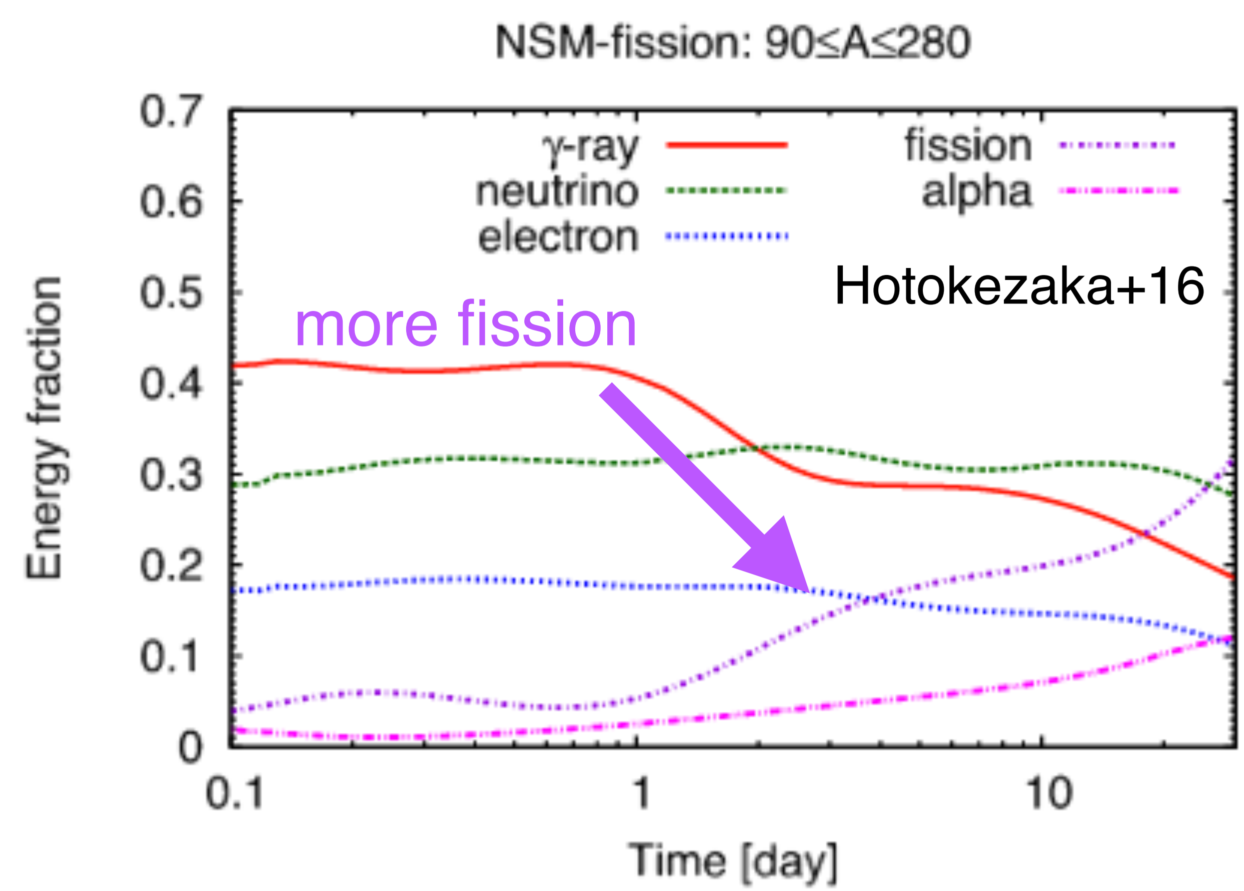
- prevalence of α-decay increases energy generated *and* thermalization
- more tranlead production higher $\longrightarrow L_{\mathrm{bol}}$

Late-time Light Curves

a potential diagnostic for *r*-process robustness

- When the ejecta is optically thin, $L_{\rm bol}$ tracks the instantaneous energy generation rate.
- This could be the best chance to directly measure the prevalence of α-decay (and fission)





The bling-nova knot

a word of caution