Weak r-process in the blue-kilonova of double NS mergers

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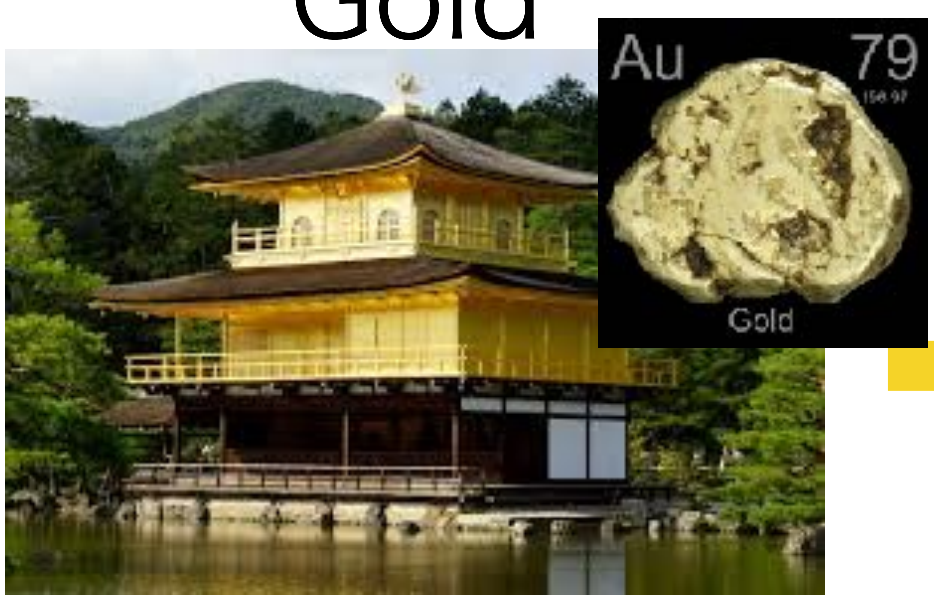
Contents

References

- Fujibayashi+NN+2018 ApJ 860 64
- NN+2018 (in prep.)

Gold

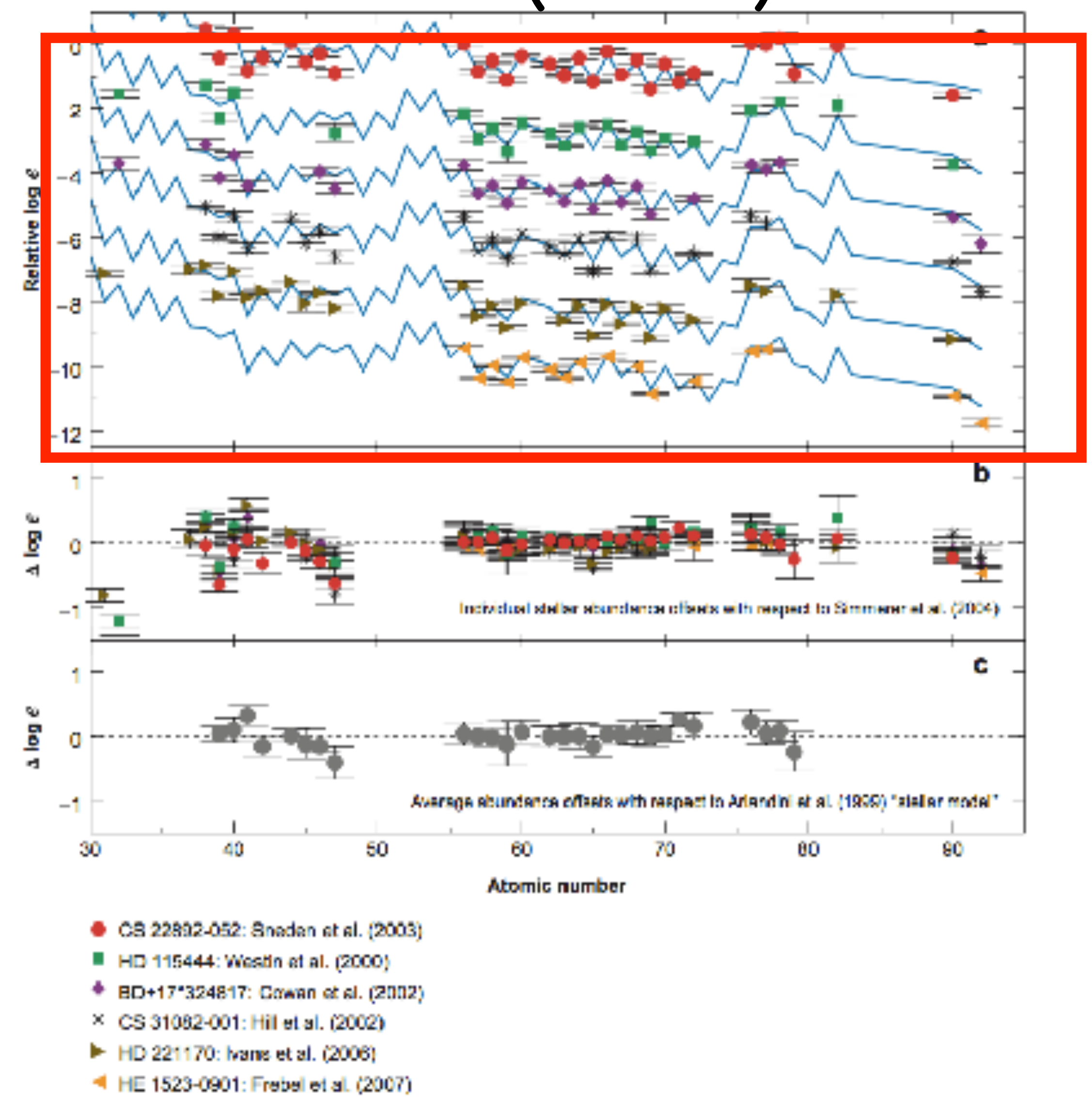


Silver

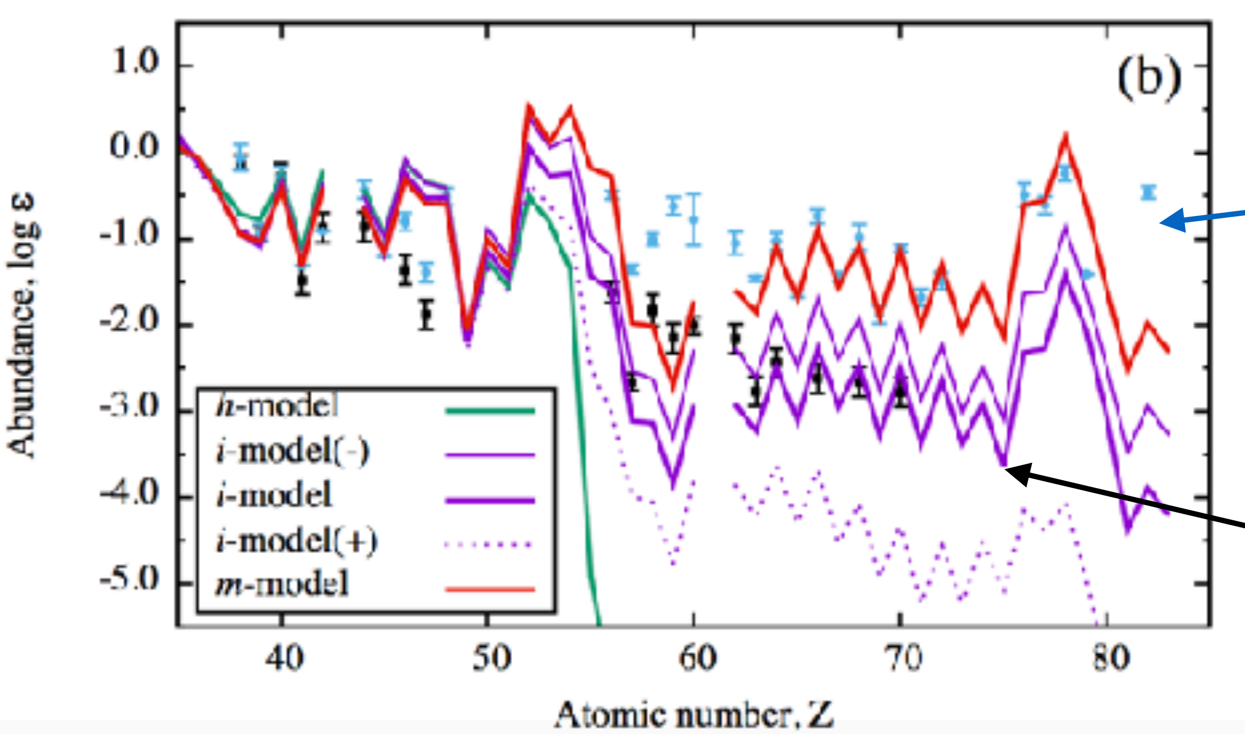
Weak r-process in metal-poor stars?

Sneden+ (2008) ARAA

- many r-rich Galactic halo stars show the solar-like r-pattern
- r-process has happened from the early Galaxy
- astrophysical models reproduce this common pattern (Z>40; A>90)



Nishimura+2017 (poster #73)



"solar" pattern

"intermediate" r-process??

"weak" heavy r pattern
HD122563 (Honda+2006)

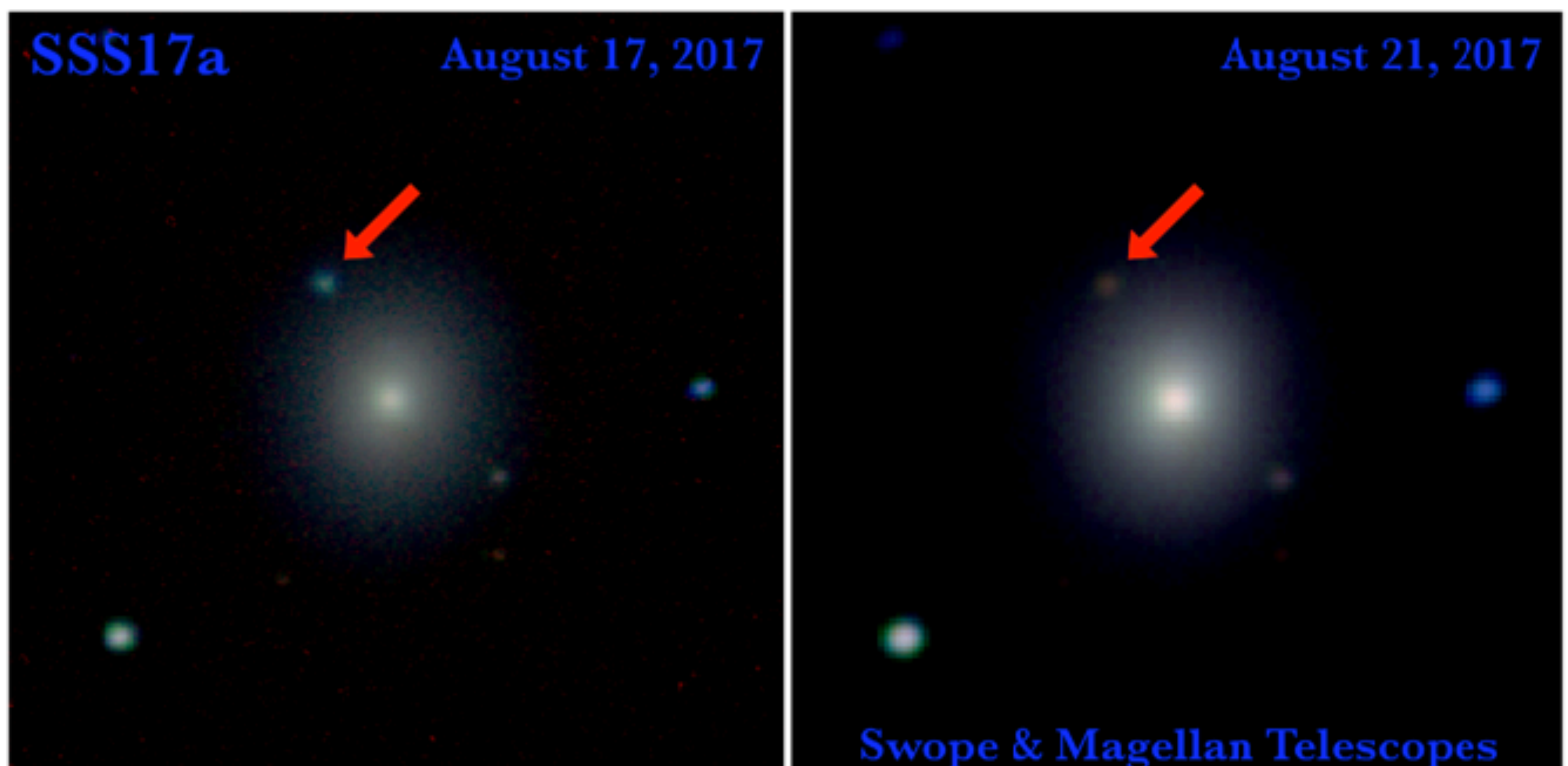
The “kilonova/macronova” with GW

The electromagnetic counter part of GW170817 (17. Aug. 2017)

Energy source?

—> radioactive decay (e.g, β, α & fission etc.) of neutron-rich matter during r-process nucleosynthesis

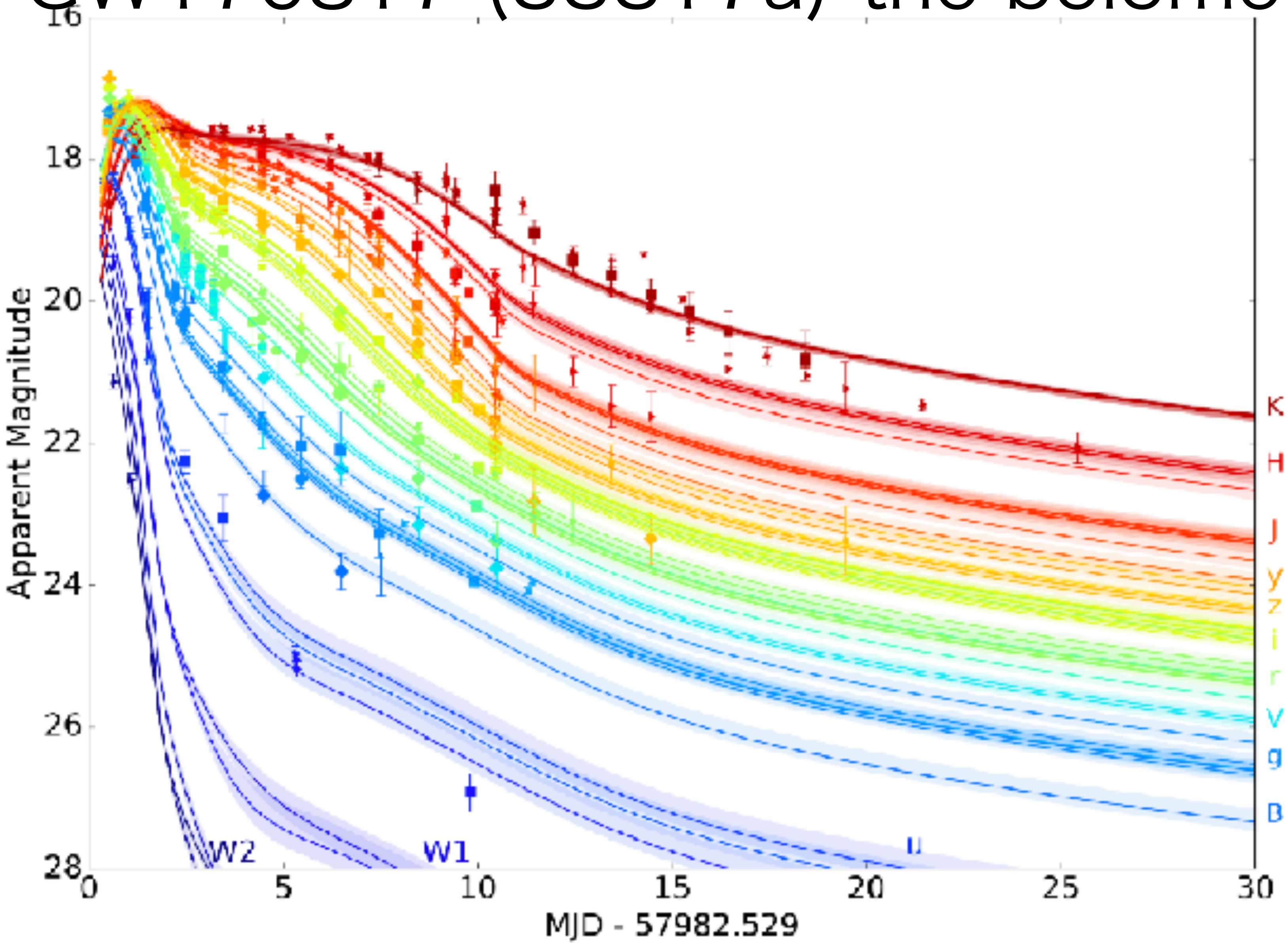
NGC4993 (39.5Mpc)



By Magellan telescope; Drout+2017, Science

Kilonova observation

GW170817 (SSS17a) the bolometric light curve



day

Villar+2017

Light curves, based on 625 flux measurements (38 instruments)

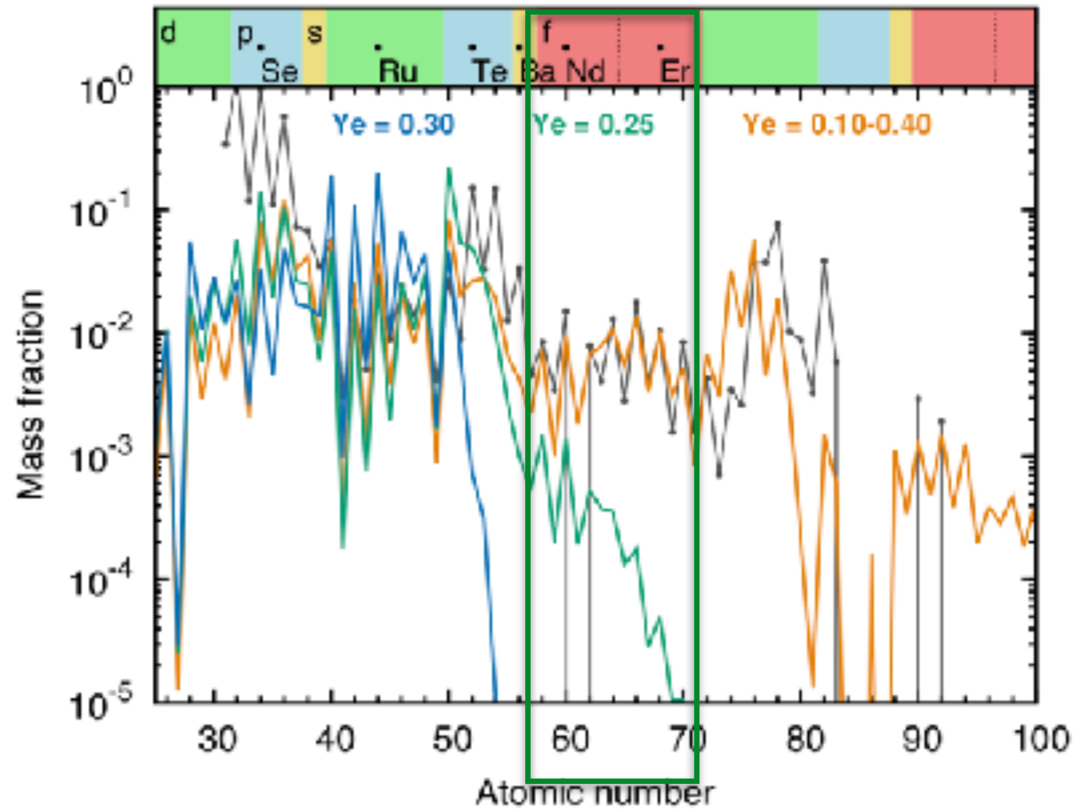
Hydrodynamical calculations are needed to explain this feature.

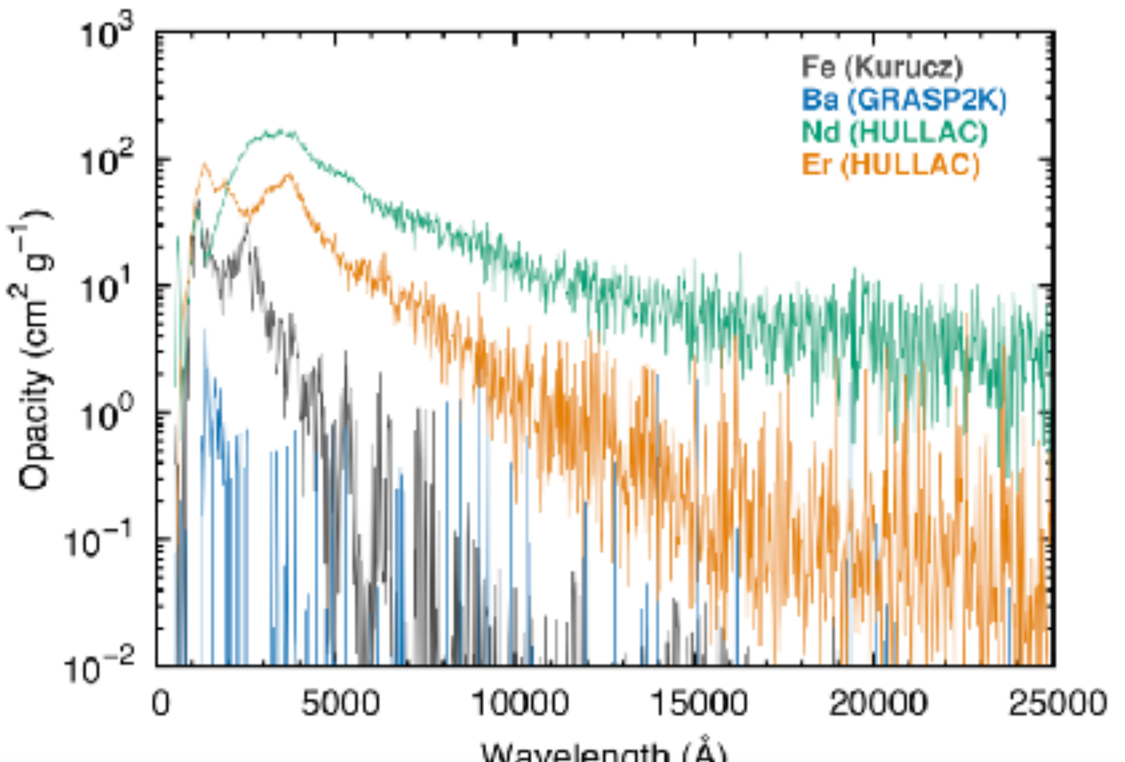
- Realistic set-up
- Log-term evolution (t = 0.1 — 1 s)

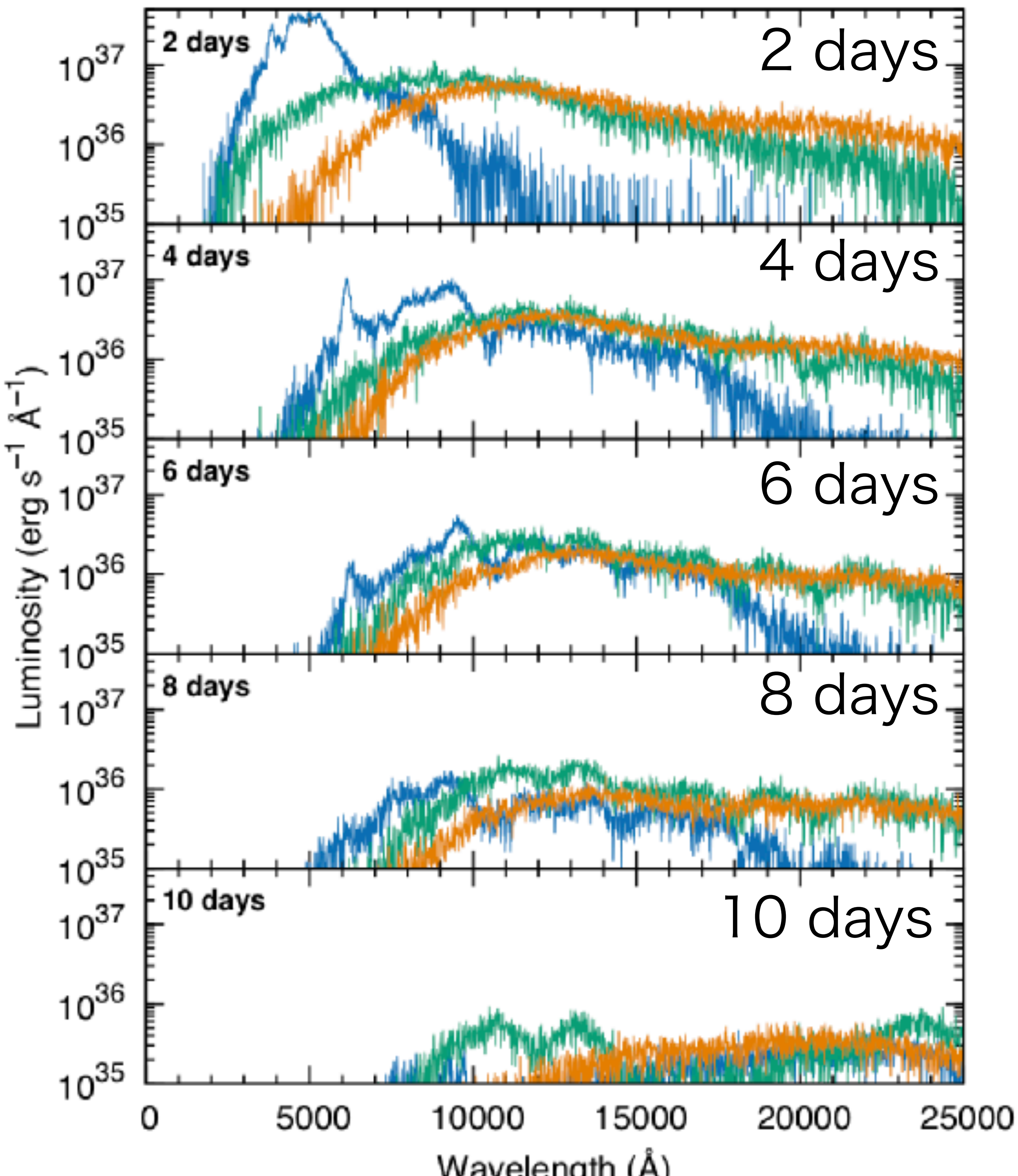
Kilonova prediction

(also, Kasen+2013, Tanaka & Hotokezaka 2013)

Tanaka+2018





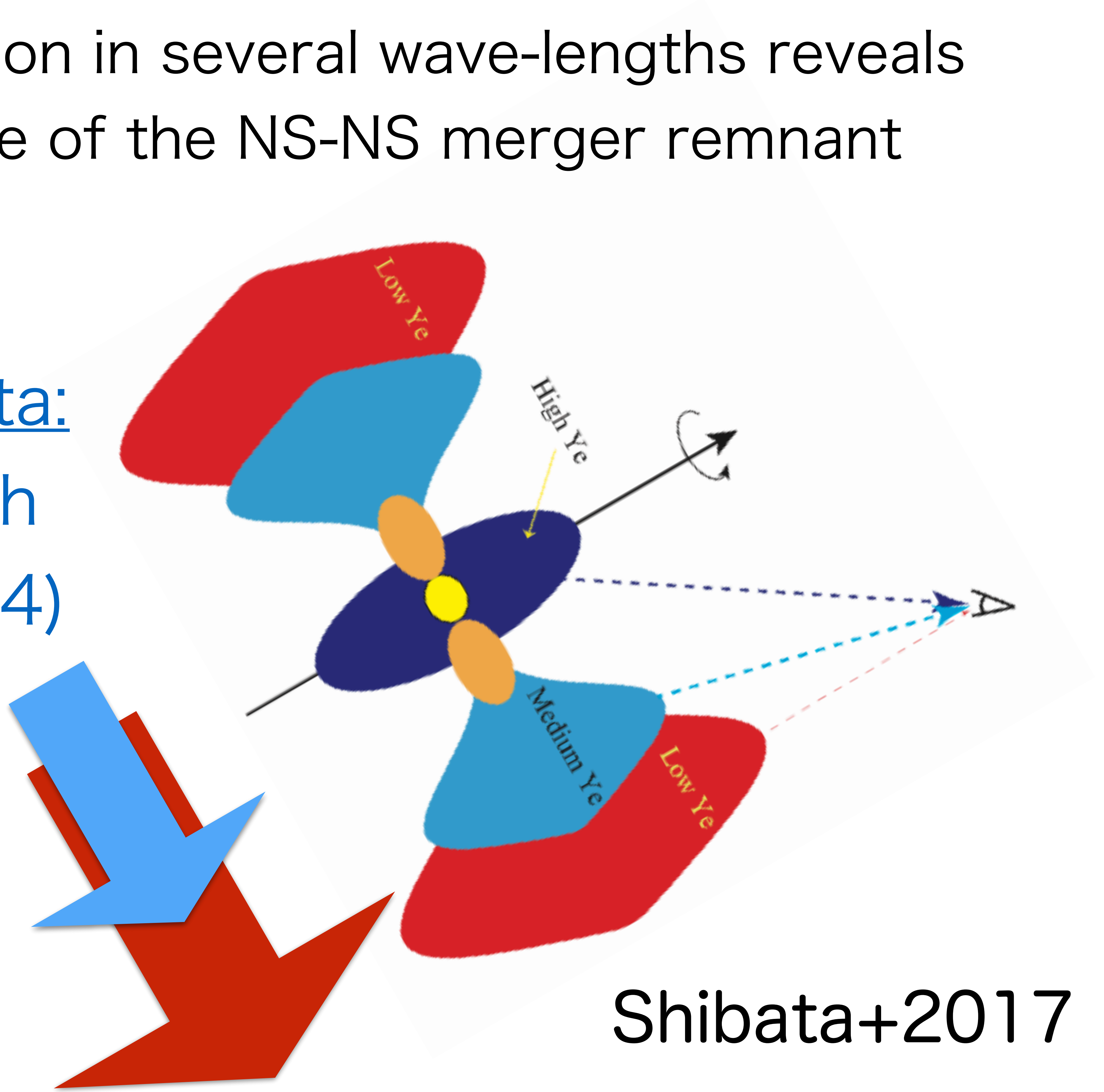


Kilonova model (scenario)

Optical observation in several wave-lengths reveals detailed structure of the NS-NS merger remnant

Later ejecta:
mild n-rich
(0.2<Ye<0.4)

Early ejecta:
very n-rich
(Ye < 0.2)



Shibata+2017

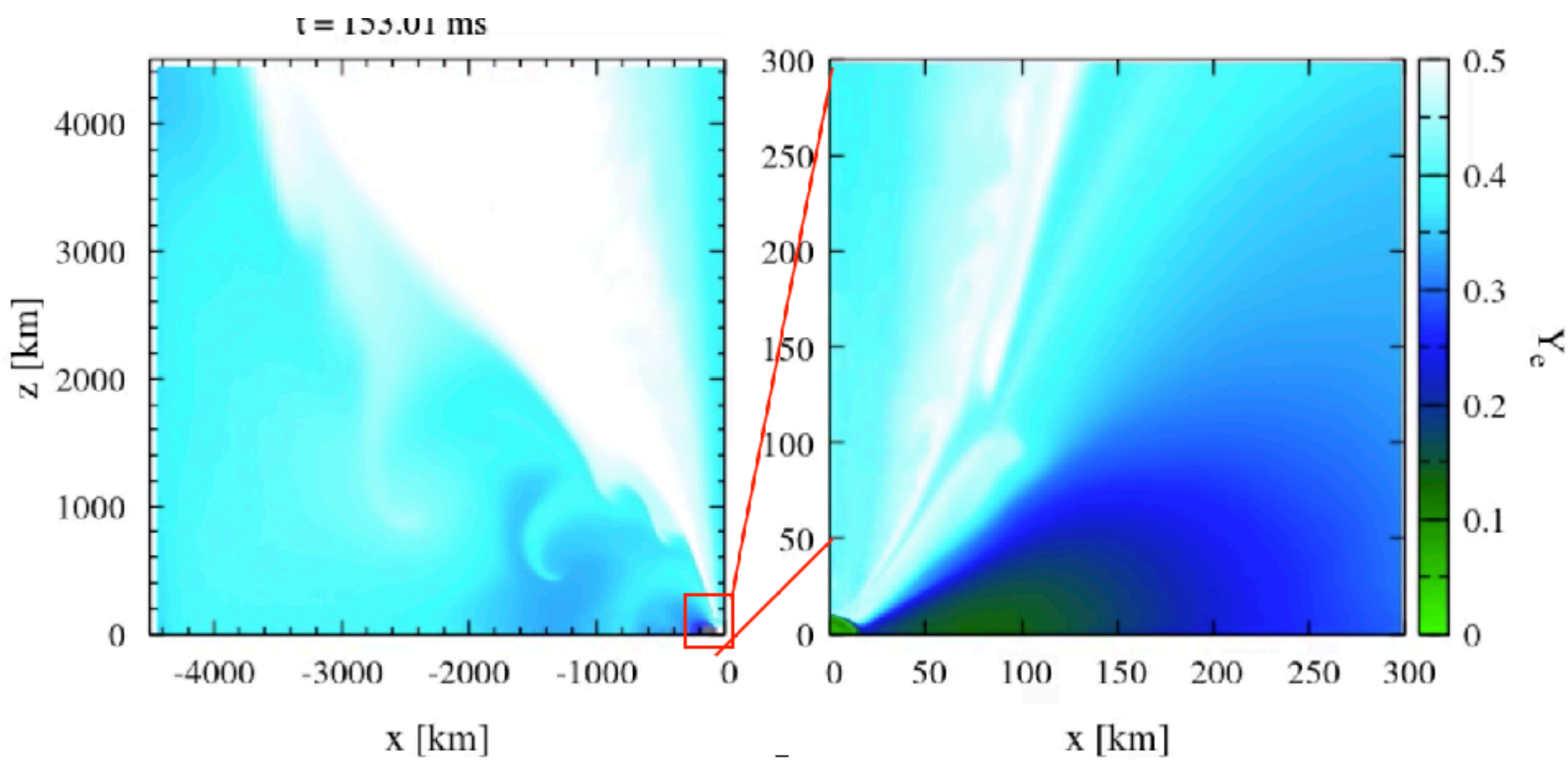
NS-NS merger: post-merger evolution

GR-radiation hydrodynamics (Fujibayashi+NN+2018)

the early phase of NS-NS merger (Sekiguchi+2015)

→ post-merger (in axi-symmetry) from 50 ms after the merger

Ye: electron faction (green: heavy nuclei; blue : lighter nuclei)

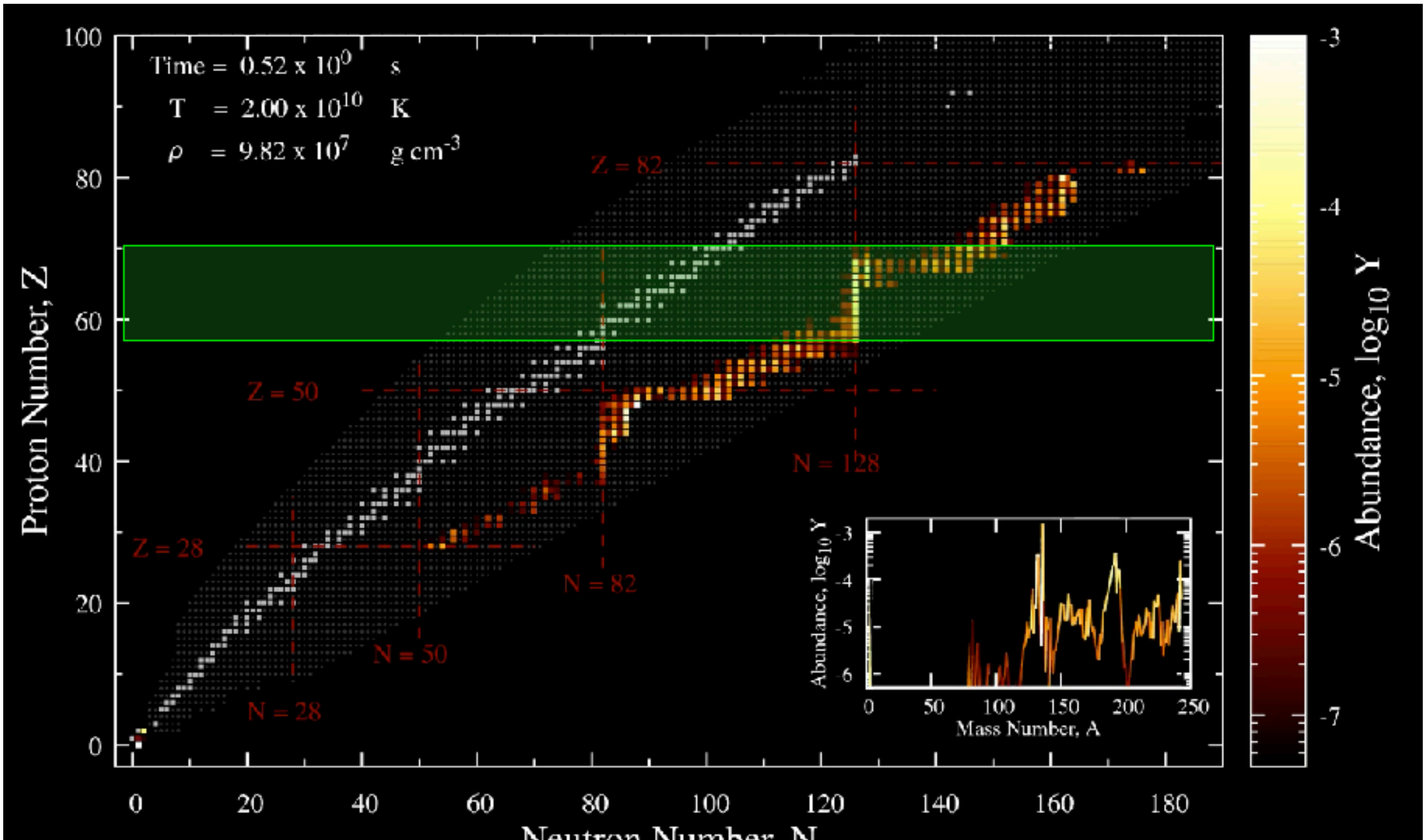


R-process flows

lanthanides

Z = 57—71

Very n-rich (Ye = 0.1)
In dynamical ejecta
—> lanthanide-rich



R-process flows

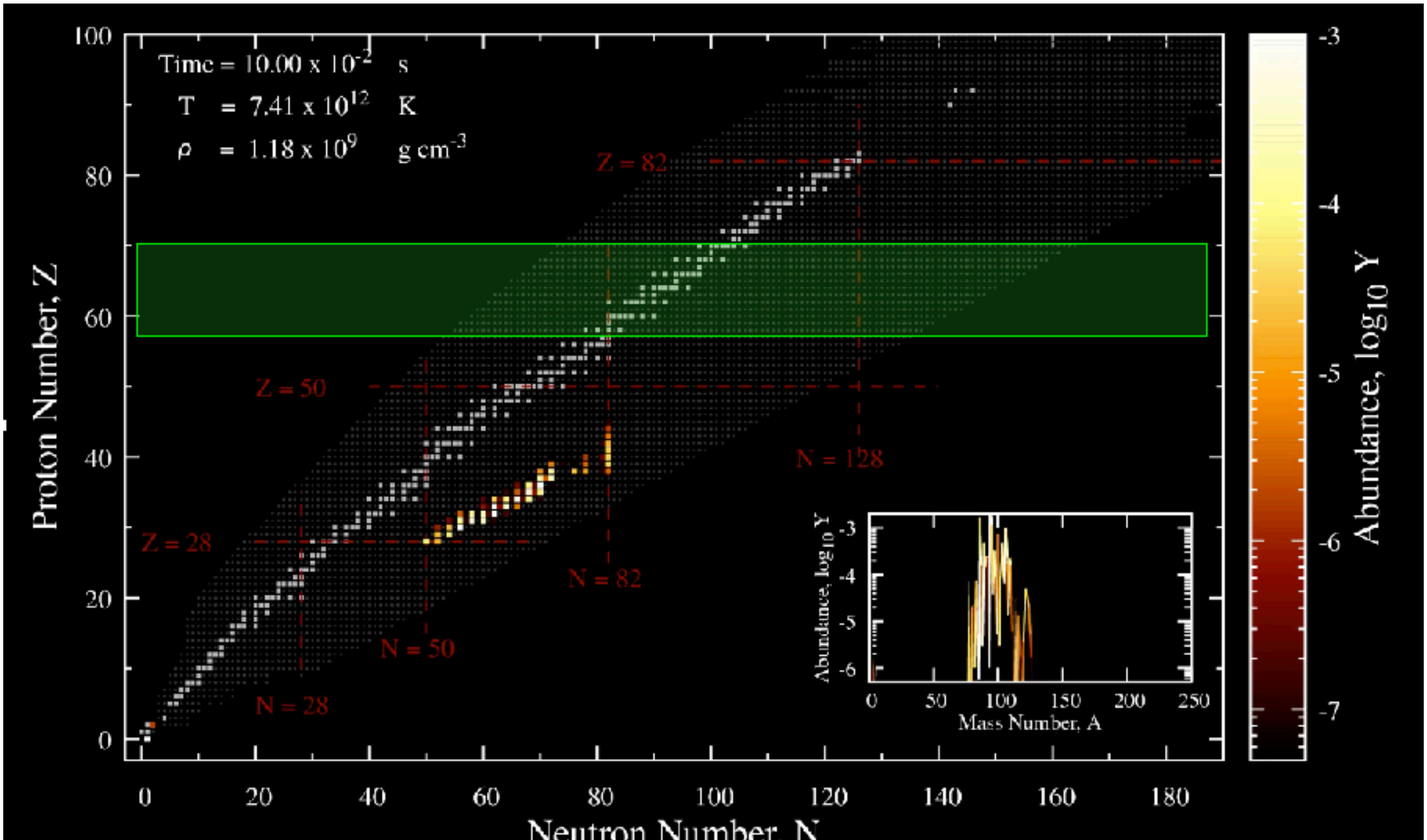
lanthanides

Z = 57—71

Less n-rich (Ye = 0.35)

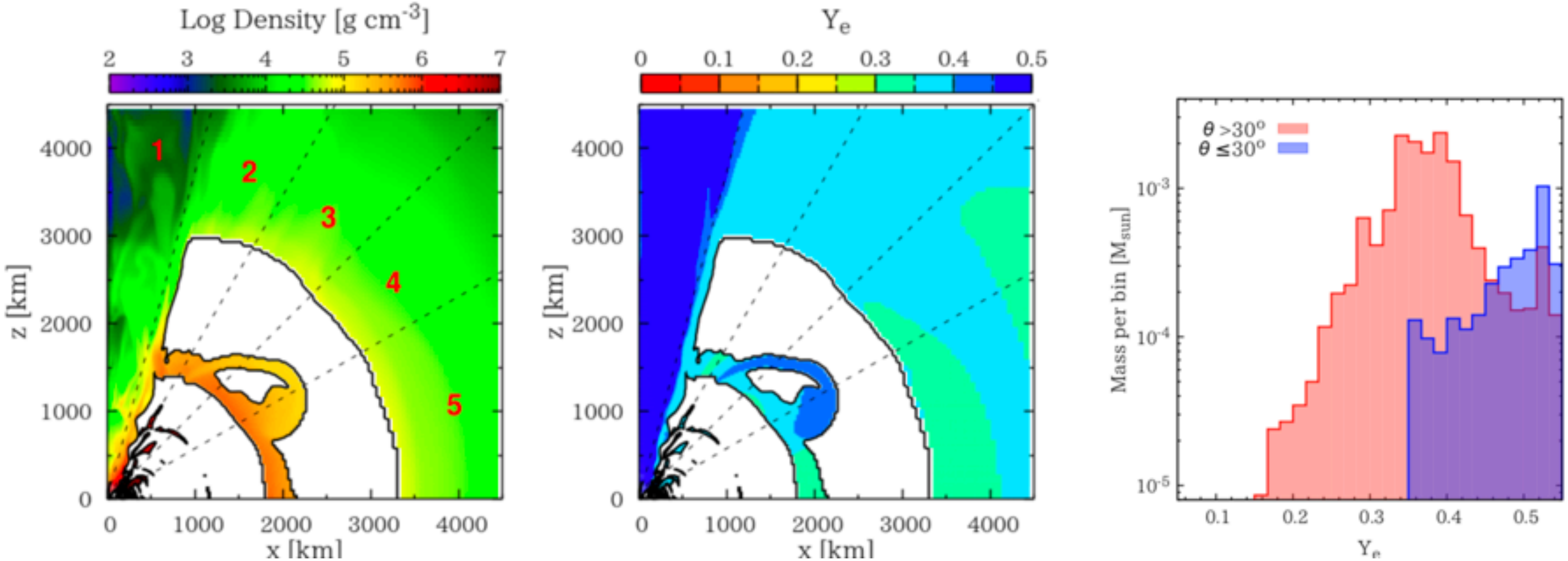
viscous winds Fujibayashi+2017

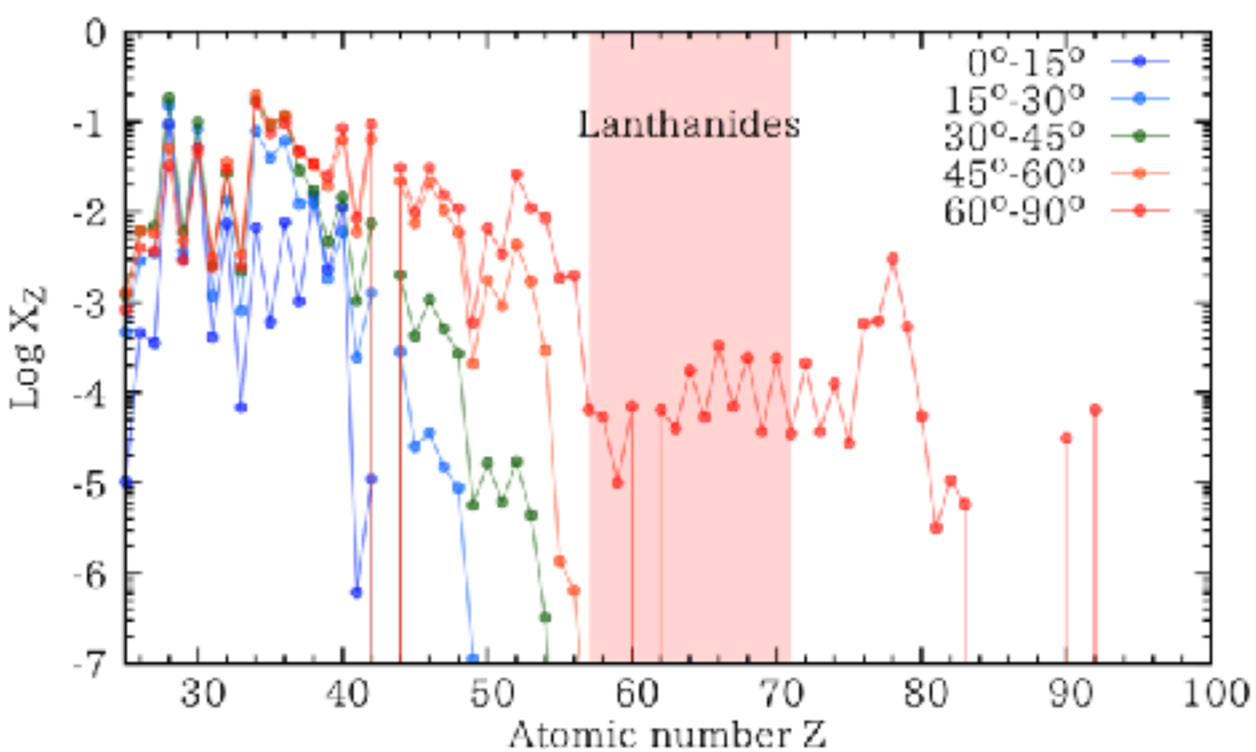
—> lanthanide-free



NS-NS merger (post-merger)

post-merger ejecta (Fujibayashi+2017)

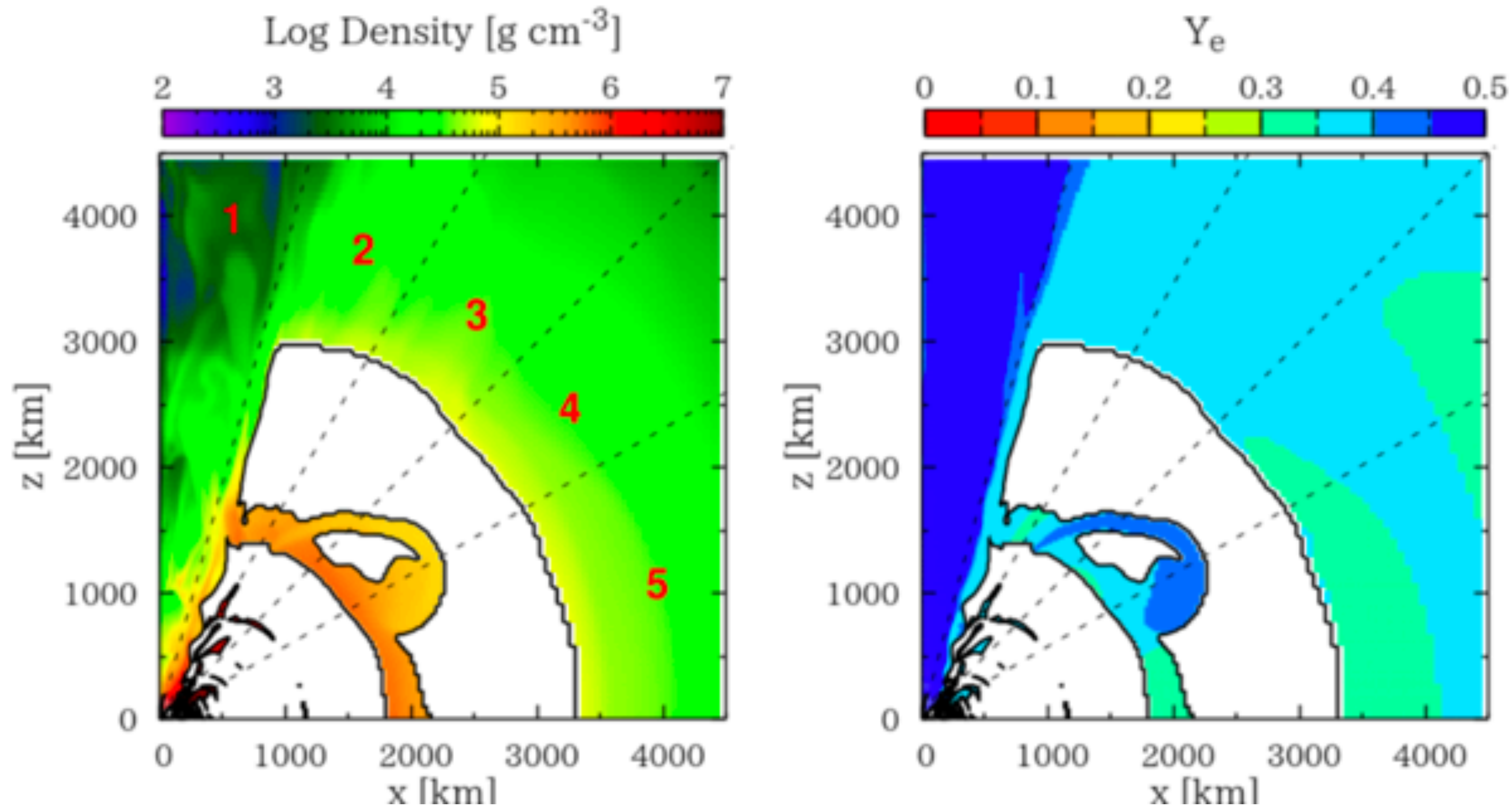


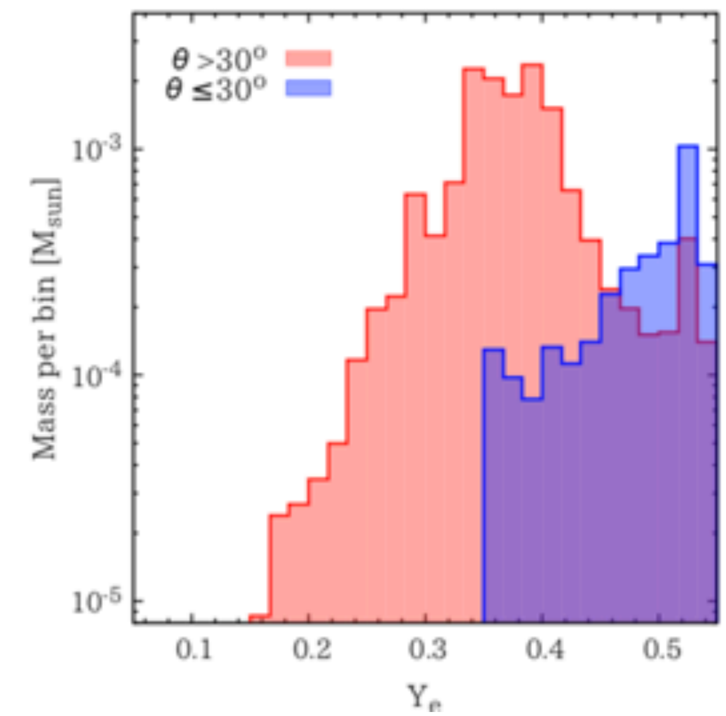


	$\alpha = 0.04 \ (t = 2.8\,\mathrm{s})$	
Region	$X(Z = 57-71)$	$M_{\mathrm{ej}}/M_\odot$
1	2.1×10^{-10}	0.0031
2	2.0×10^{-12}	0.0088
3	1.2×10^{-11}	0.0095
4	7.1×10^{-8}	0.0089
5	1.0×10^{-3}	0.0162
Total	3.6×10^{-4}	0.046

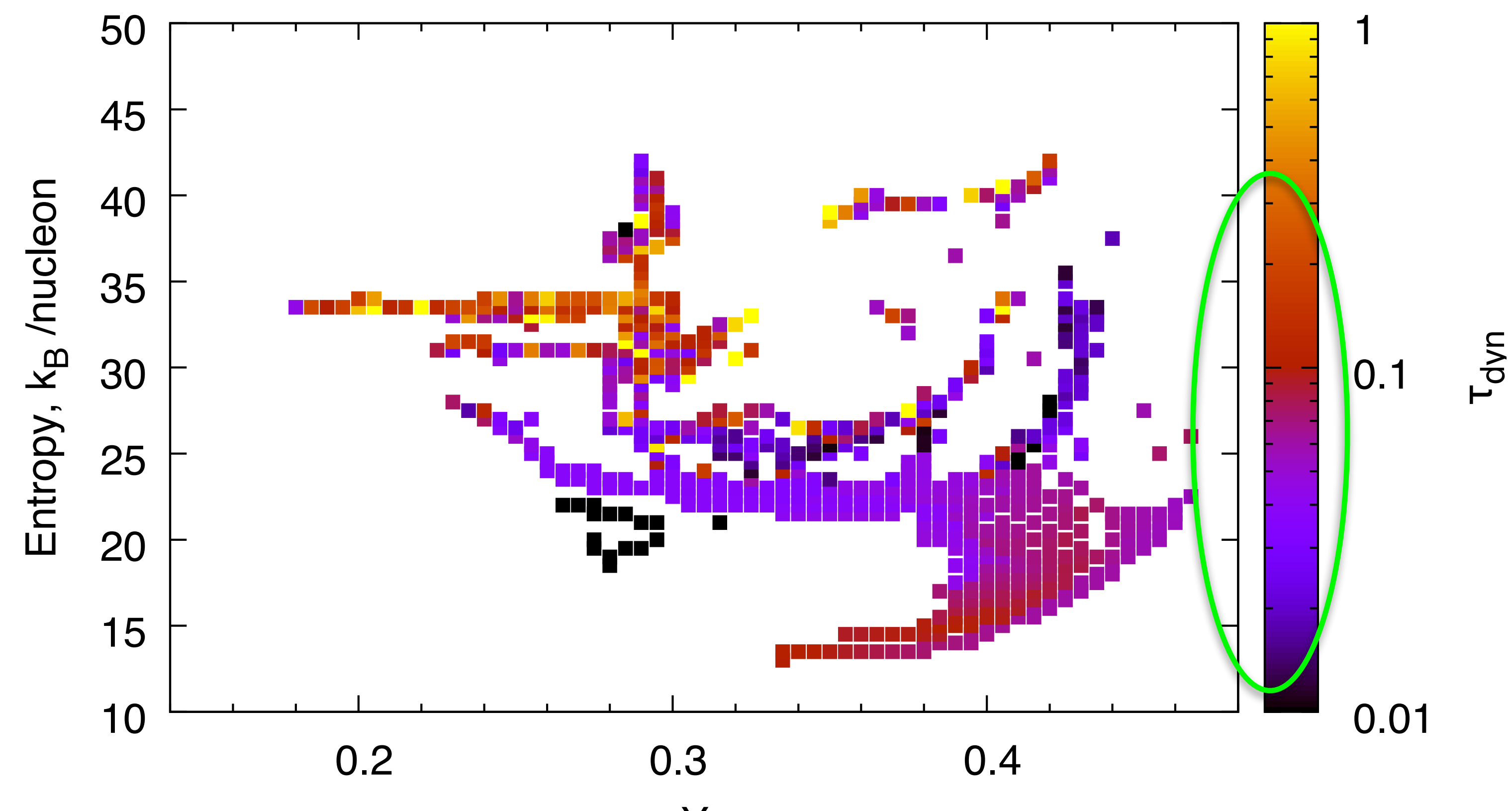
A set of r-process calculations

Fujibayashi+2018





based on Fujibayashi+(2018)

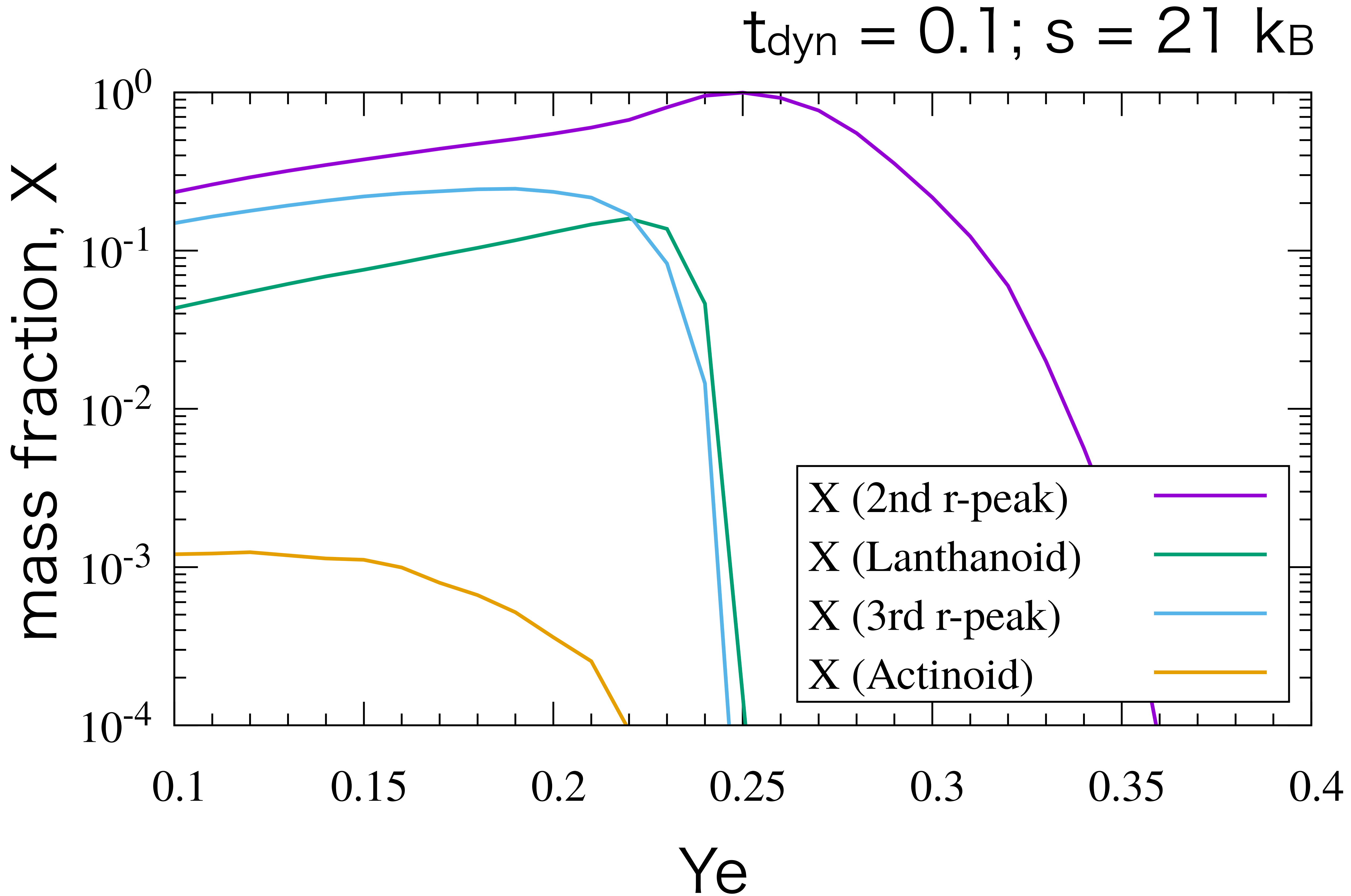


τ_{dyn}: time duration of ejecta

T = 9 —> 2.5 GK

(seed formation)

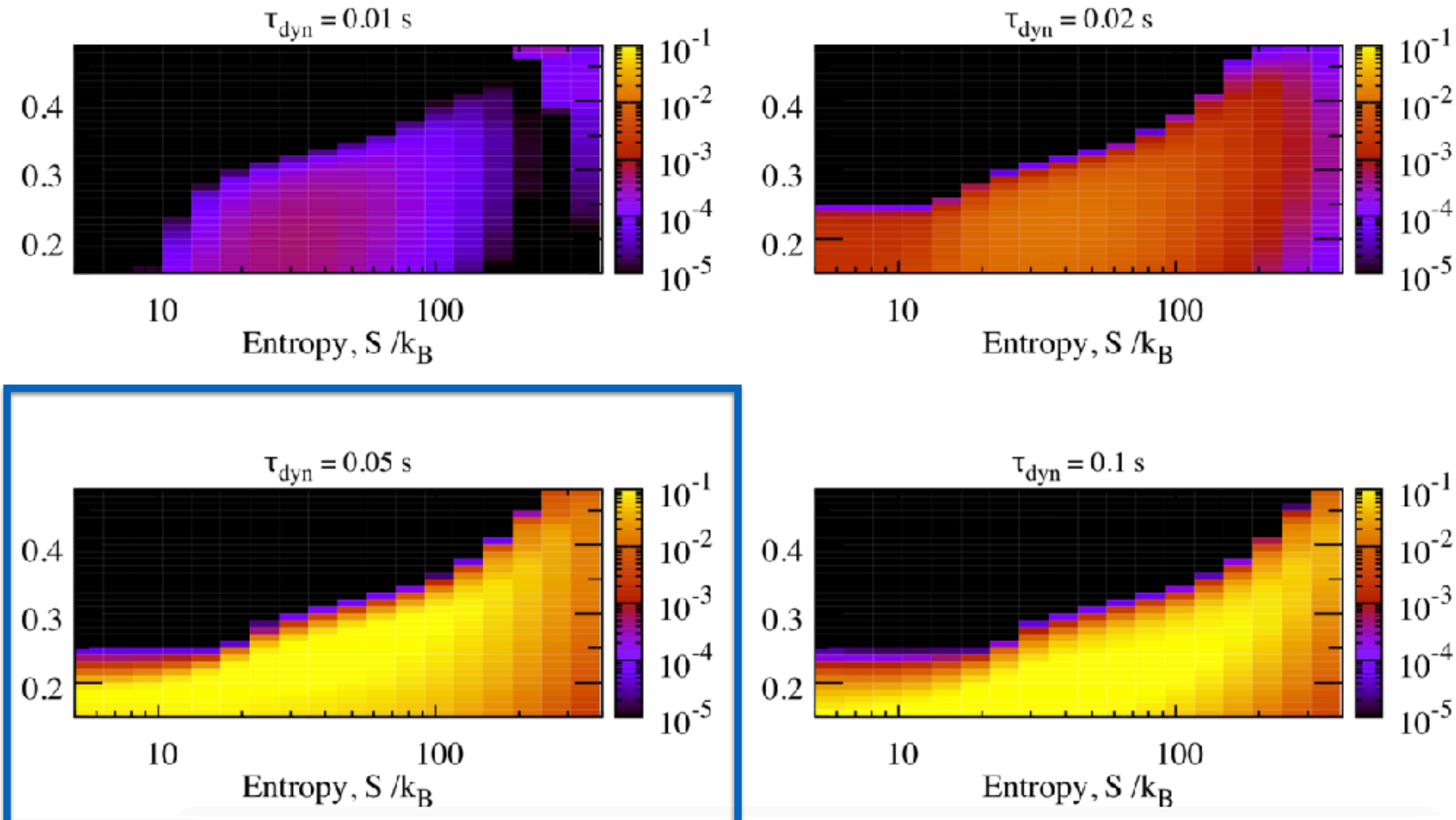
A set of r-process calculations



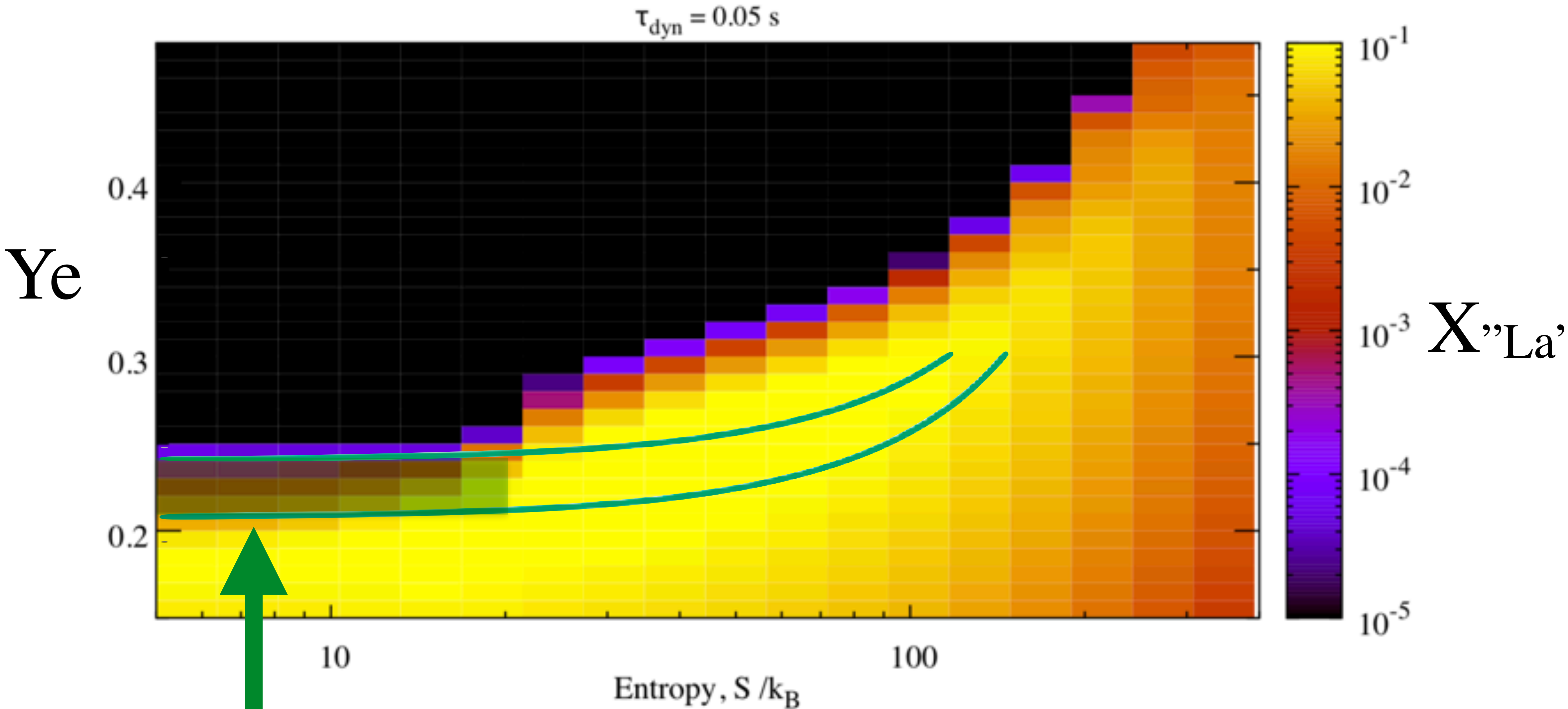
A set of r-process calculations

see, also Lippuner & Roberts (2015)

mass fraction of Lanthanide elements: $X_{\text{"La"}}$



A set of r-process calculations

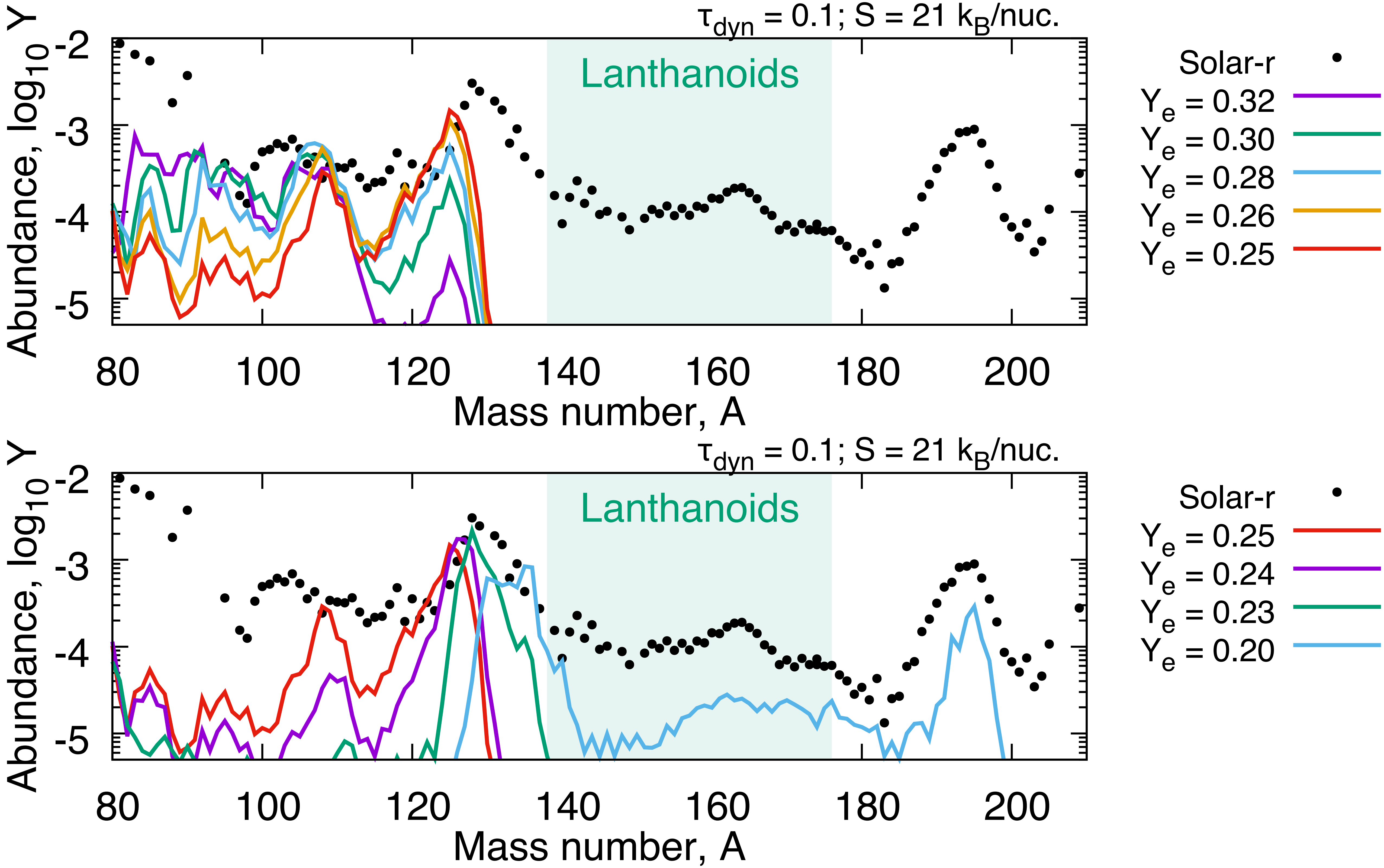


r-process production condition (Hoffman+1997)
for A = 140–160

$$S \approx \left\{ \frac{4 \times 10^7 \bar{Z}(1 - 2Y_{e,i})}{[(1/2 - \bar{Z}/A)/(Y_{e,i} - \bar{Z}/A)]^2 - (1/2Y_{e,i})^2} \left(\frac{\tau_{\mathrm{dyn}}}{\mathrm{s}} \right) \right\}^{1/3}$$

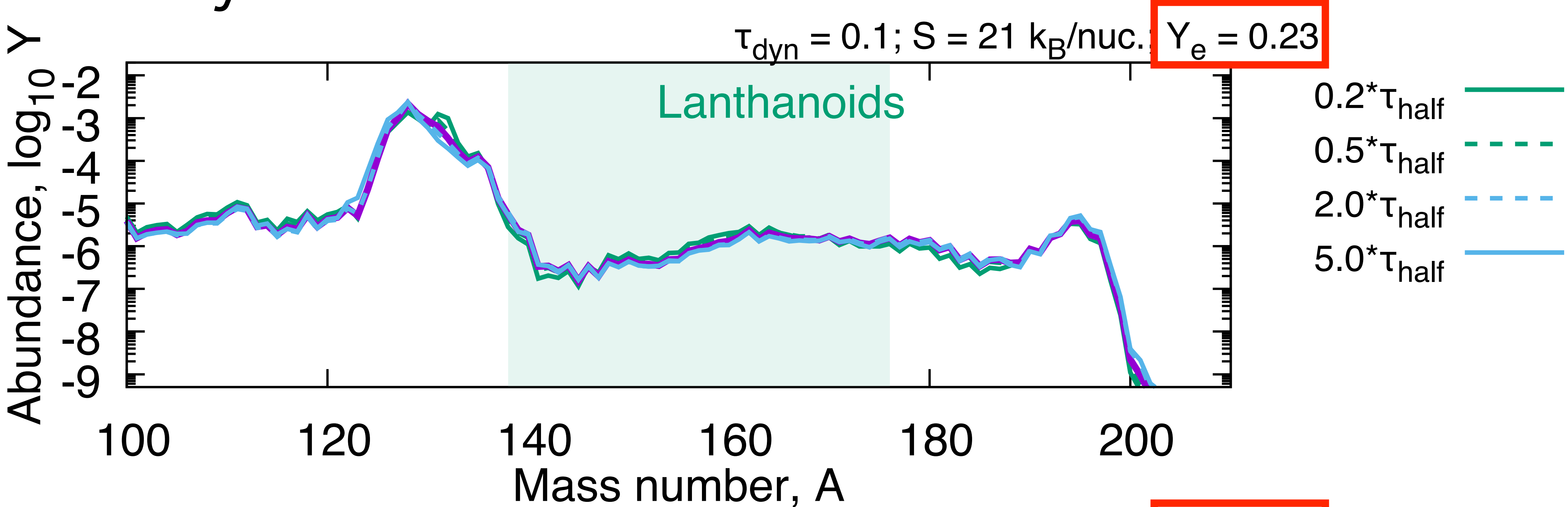
$$\text{for} \quad Y_{e,i} < \frac{\bar{Z}}{\bar{A}},$$

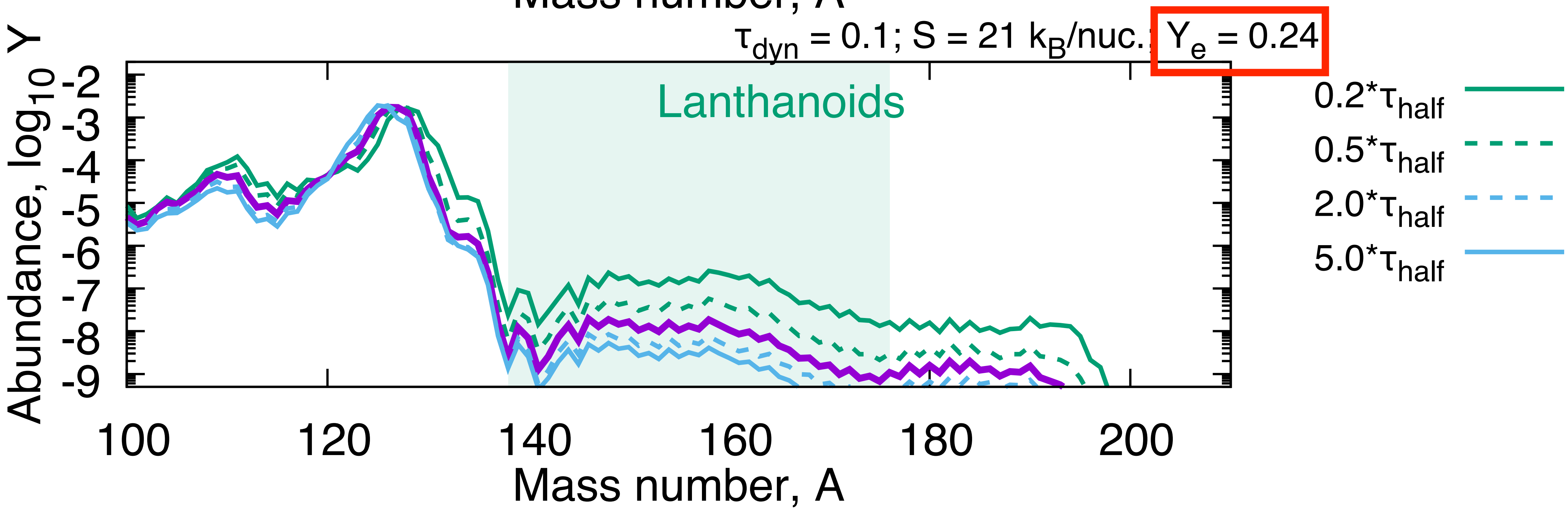
A set of r-process calculations



Impacts of beta-decay uncertainty

uncertainty factor: 2 and 5 on N=82 isotone





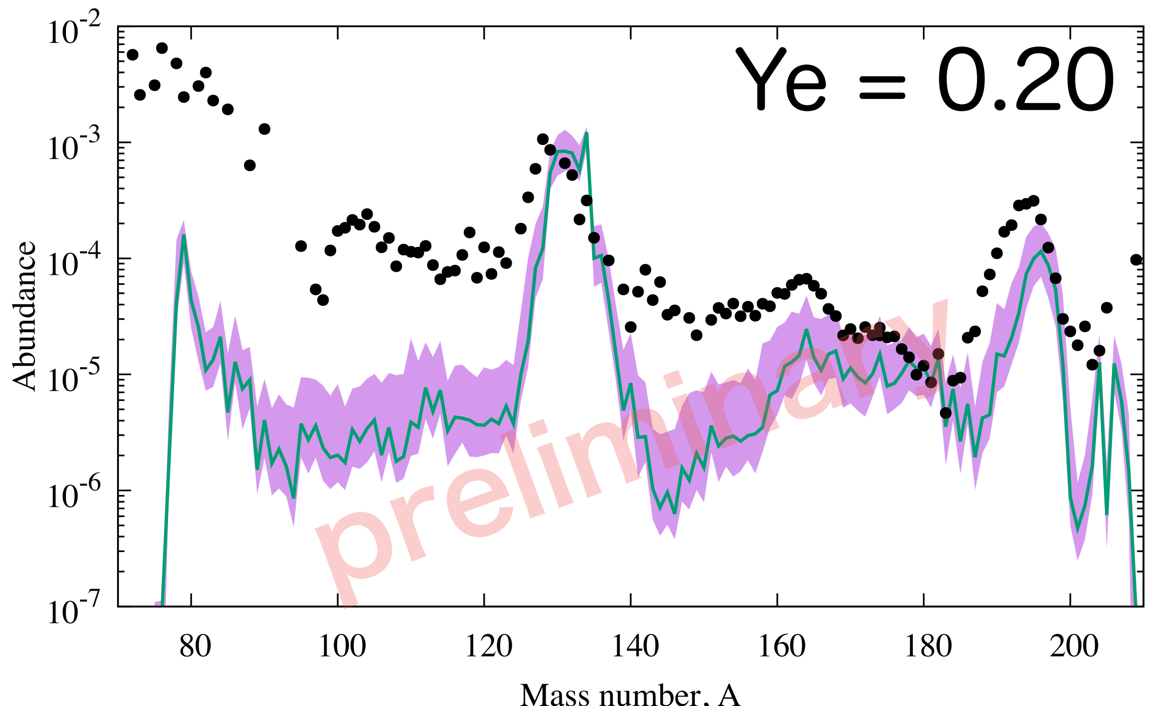
Ye = 0.23: X(Lanthanoids) = 6.35×10^{-3} (∼10% uncertainty)

Ye = 0.24: X(Lanthanoids) = $\underbrace{1.19\times10^{-5}}_{\text{lower}}$ — $\underbrace{4.81\times10^{-5}}_{\text{standard}}$ — $\underbrace{6.41\times10^{-4}}_{\text{upper}}$

Comprehensive uncertainty analysis

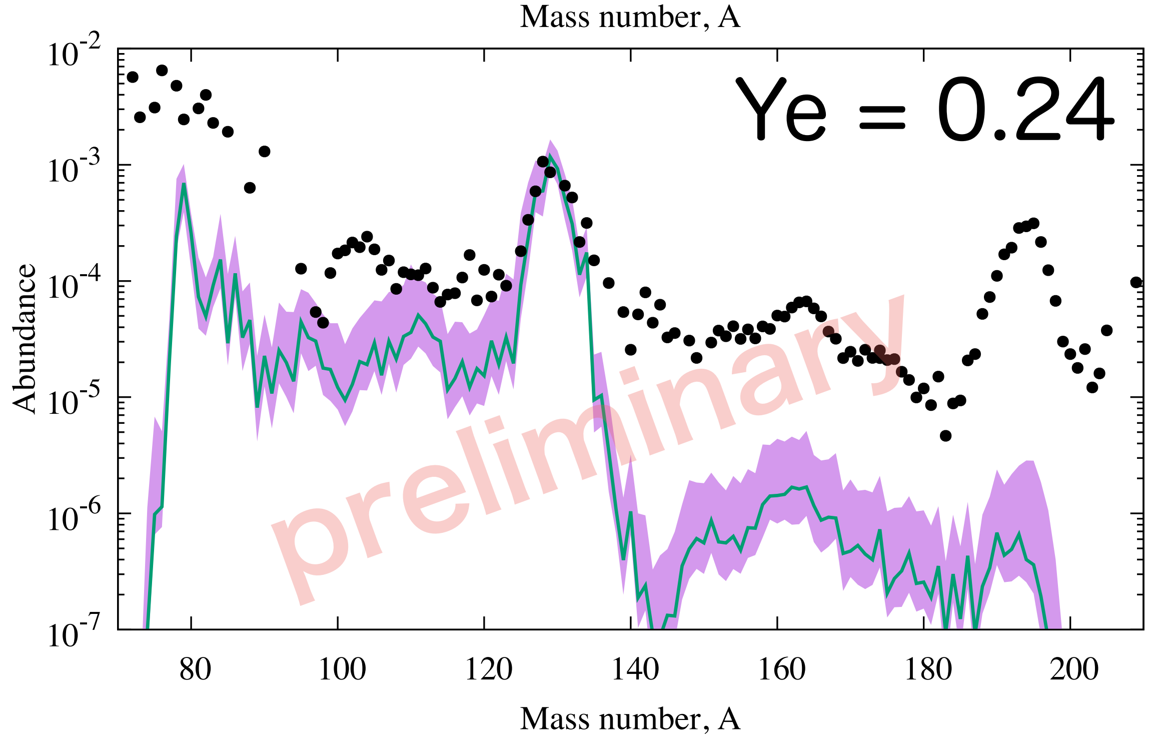
PizBuin MC driver (Rauscher); for details, see posters

#11(s-process; Cescutti); #72(ν p-process; Nishimura)
#82 (gamma-process; Rauscher)

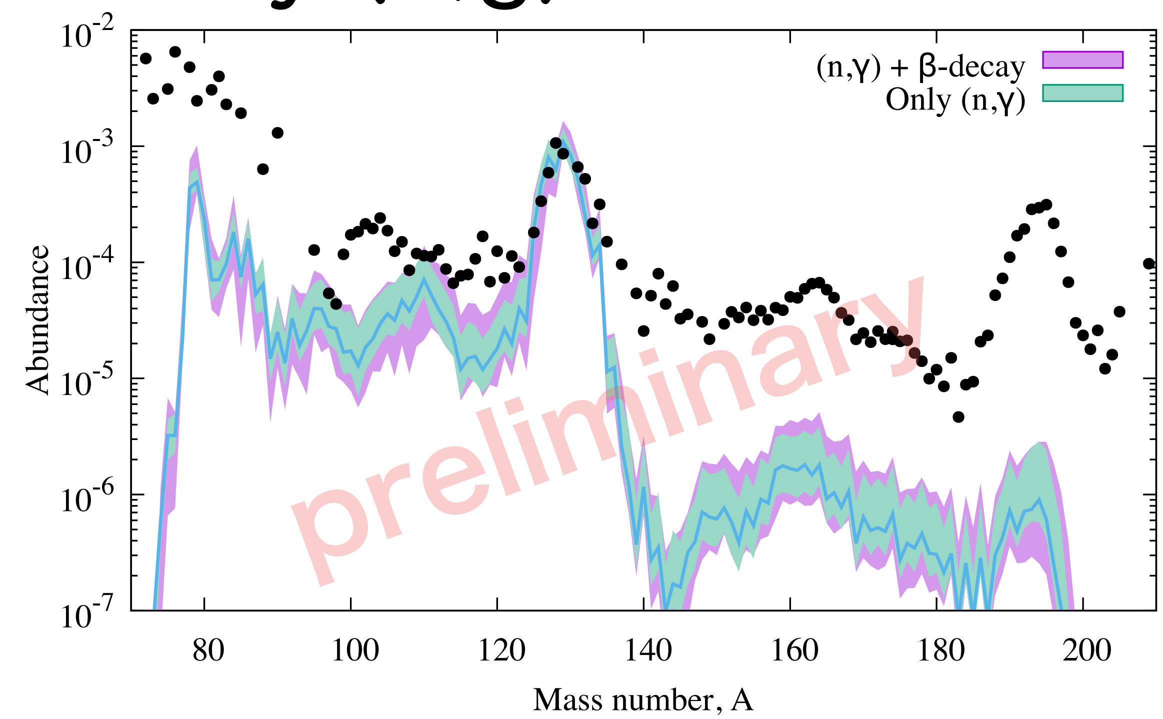


- (n,g) factor 5
- β-decay factor 5
- no variation for mass; e.g., Q_n

—> can be very optimistic



only (n,g)



Summary

- Weak r-process in blue-kilonova
  - GR hydrodynamics simulations indicate “lantanide-poor” component in post-merger ejecta
    —> the “blue”-kilonova component of GW170817
- Production mechanism/uncertainty
  - lanthanide poor if $Y_e > 0.25$
  - strong dependency on Y_e (←post-merger models)
- Nuclear-physics uncertainty (e.g. β-decay)
  - has impacts on the weak r-process
  - possibly much more uncertainty for the n-rich r-process “path” region

—> needs much studies to consider the both of hydro-uncertainties and nuclear-physics uncertainties