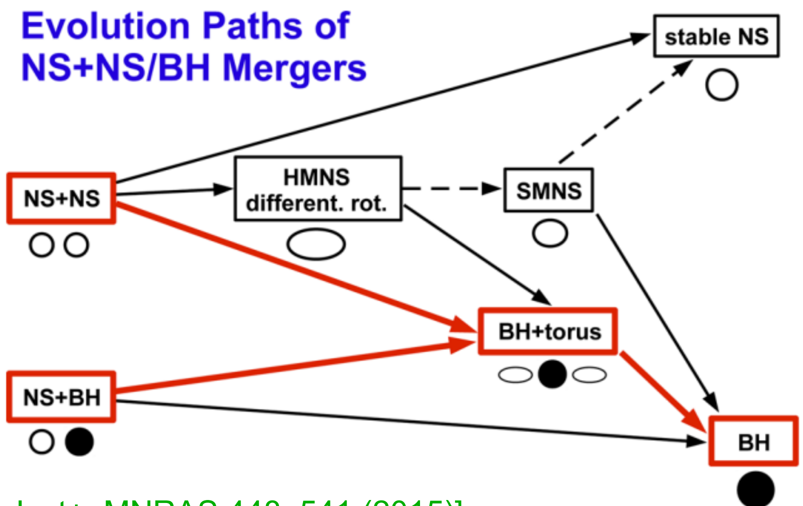
r-process nucleosynthesis in compact binary mergers

Meng-Ru Wu (TU Darmstadt → Niels Bohr Institute)

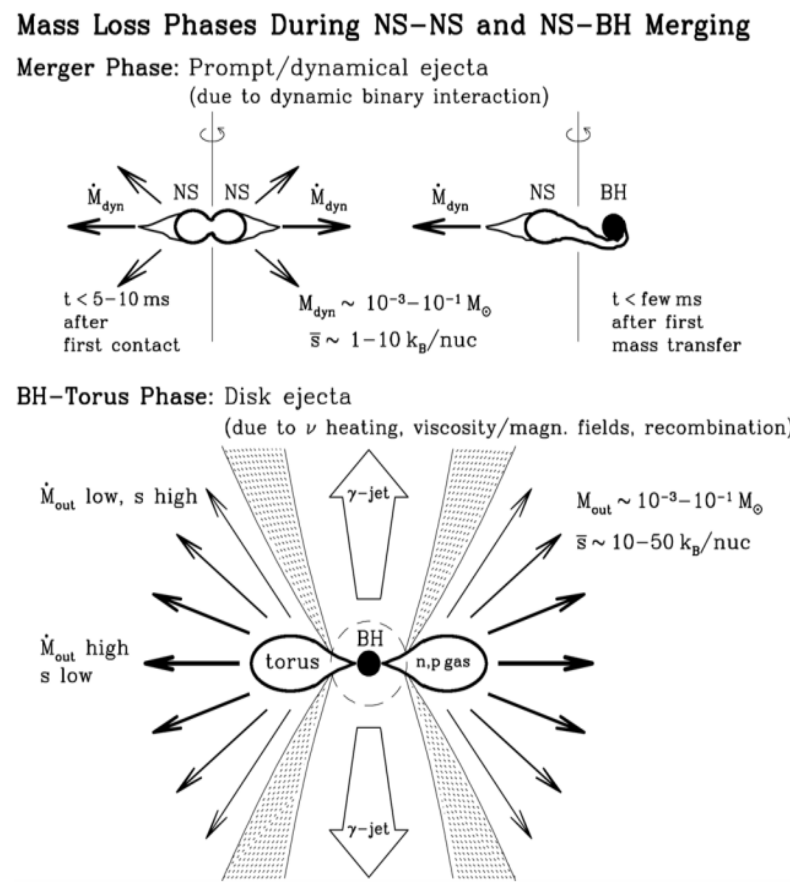
Brainstorming on compact objects, their equation of state,
related explosive events, and their nucleosynthesis
9/29-10/1/2016, Basel, Switzerland

NS–NS and NS–BH mergers

[from Just+, MNRAS 448, 541 (2015)]



[from Just+, MNRAS 448, 541 (2015)]

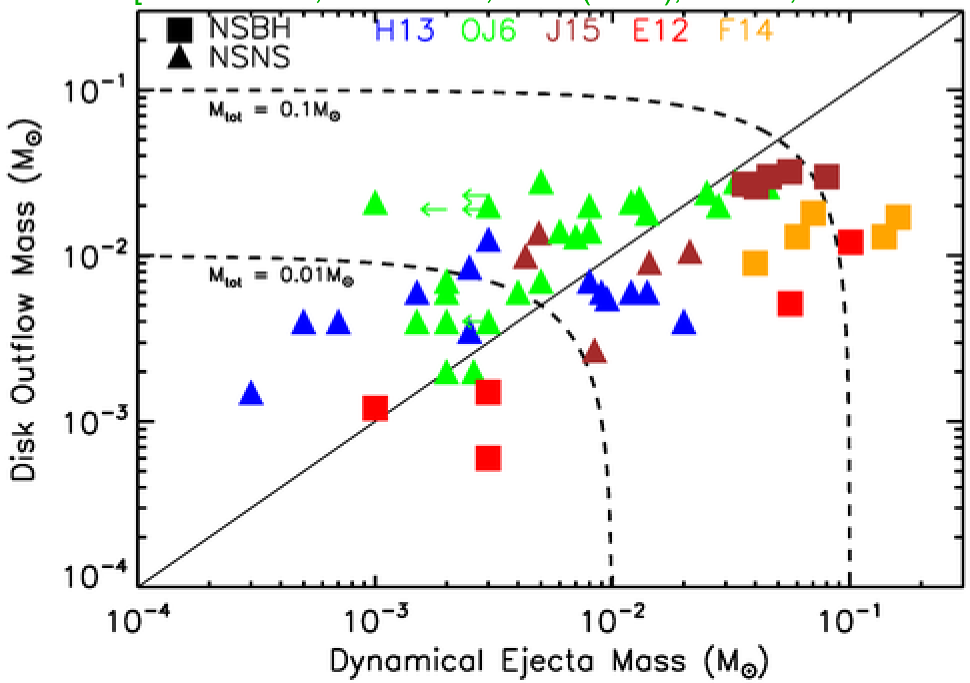


Assuming a certain initial binary configuration, key inputs for r-process nucleosynthesis prediction and the resulting kilonova lightcurves:

Y_e distribution (neutrinos, EoS, viscosity...)
ejecta mass/velocity distribution (EoS, energy inputs...)

Relative contribution?

[Fernandez+, ANPRS 66, 2115 (2016); MRW+, MNRAS 463, 2323 (2016)]

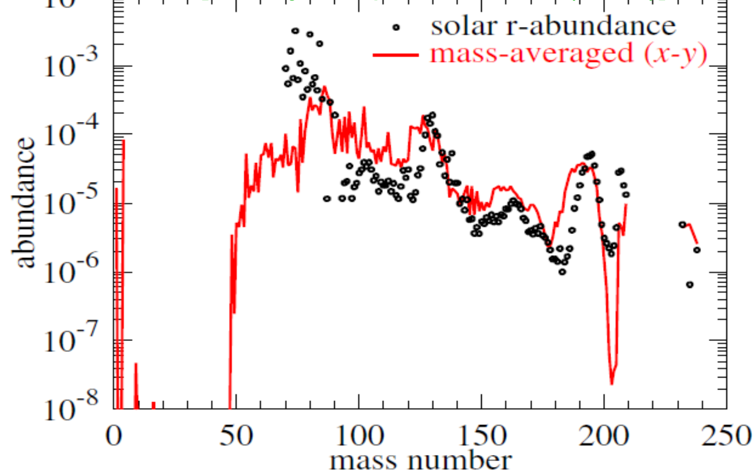


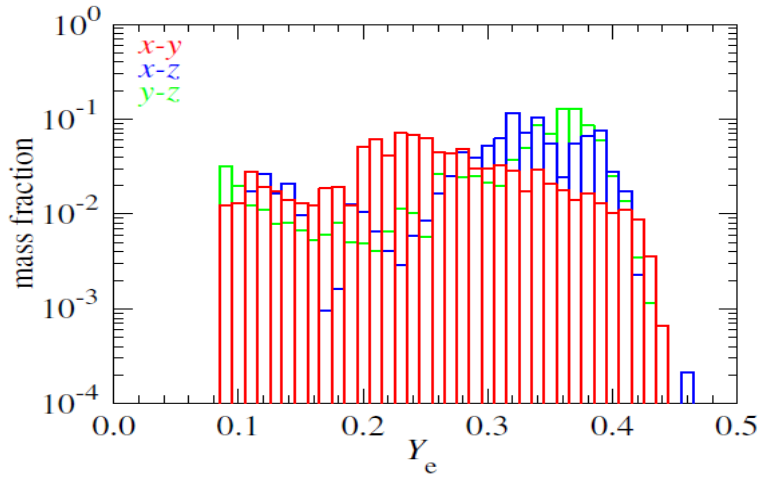
more dynamical ejecta in NS–BH case while similar or disk-dominated ejecta in NS–NS case

**disk outflow mass estimated simply as 10% of the disk mass

Each component gives what? – dynamical ejecta

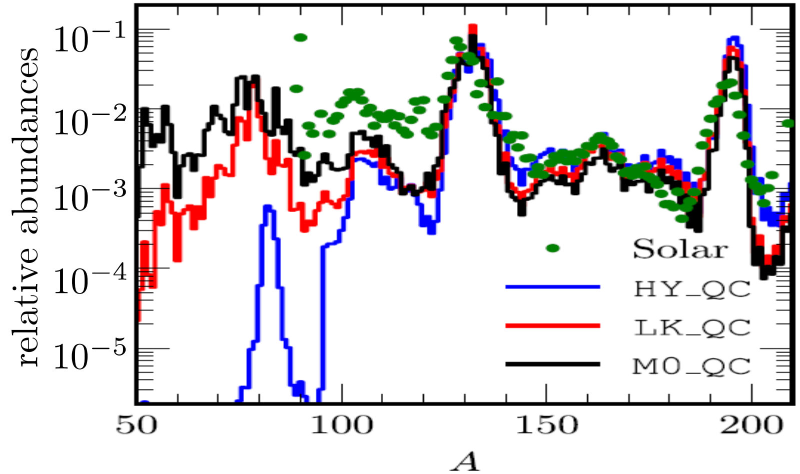
[Wanajo+, ApJL 789, L39 (2014)]

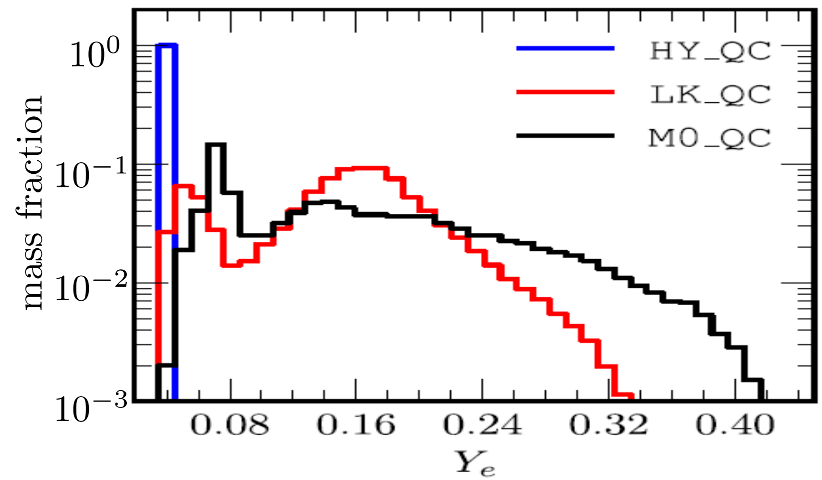




1.3 $M_\odot$–1.3 $M_\odot$, full GR
EoS: Steiner+ 2013 (SFHo)
ν: leakage+M1+heating
**abundances only sample ejecta on the x-y plane

[Radice+, MNRAS 460, 3255 (2016)]

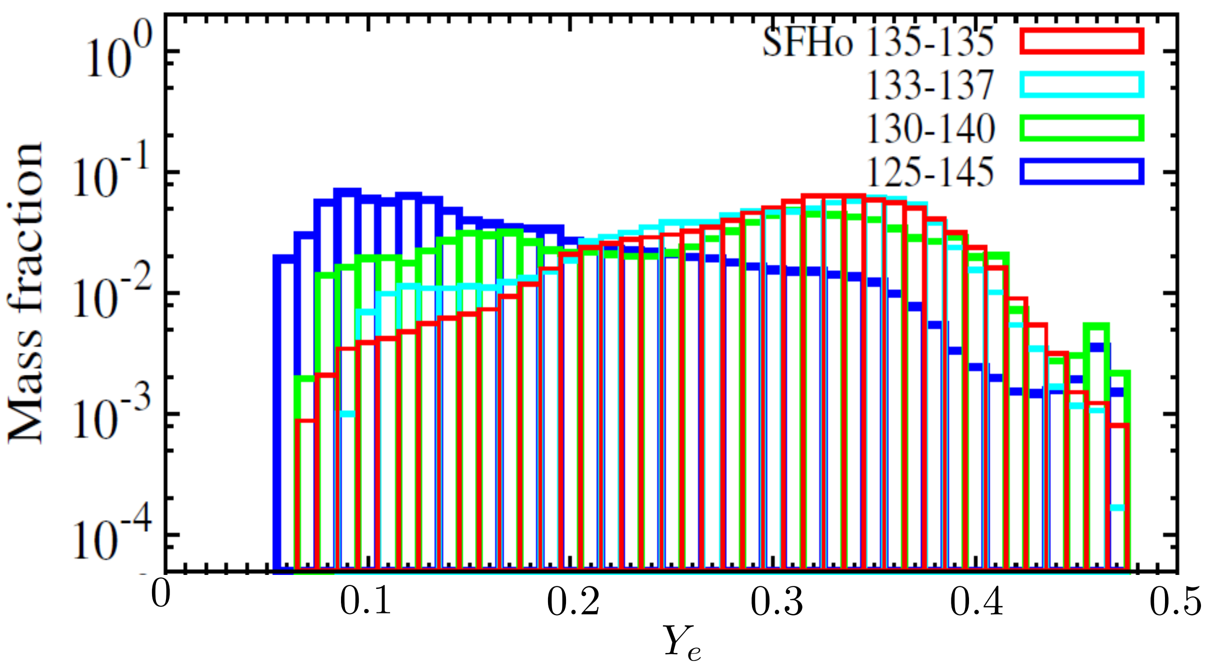




1.4 $M_\odot$–1.4 $M_\odot$, full GR
EoS: Lattimer-Swesty, K=220
ν: grey leakage+M0+heating
**abundances calculated by summing up parametric results in Lippuner+ (2015)

Initial condition of the system – dynamical ejecta

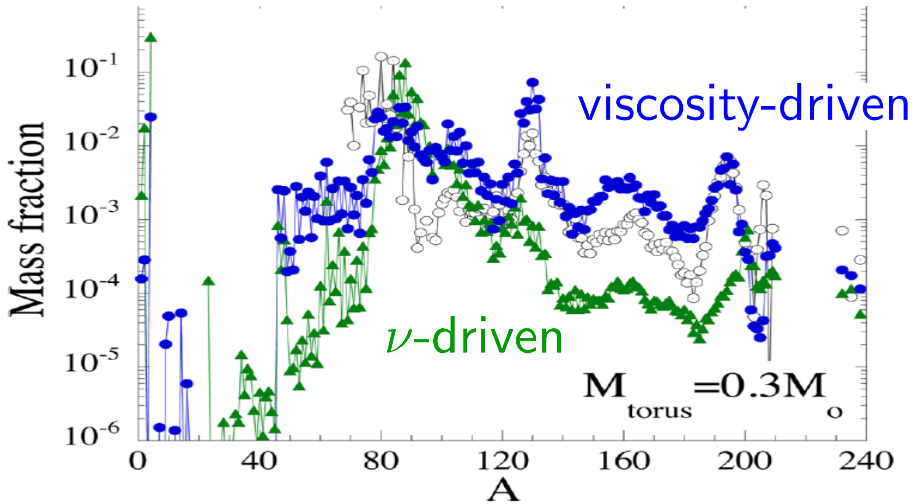
[Sekiguchi+, PRD 93, 124046 (2016)]



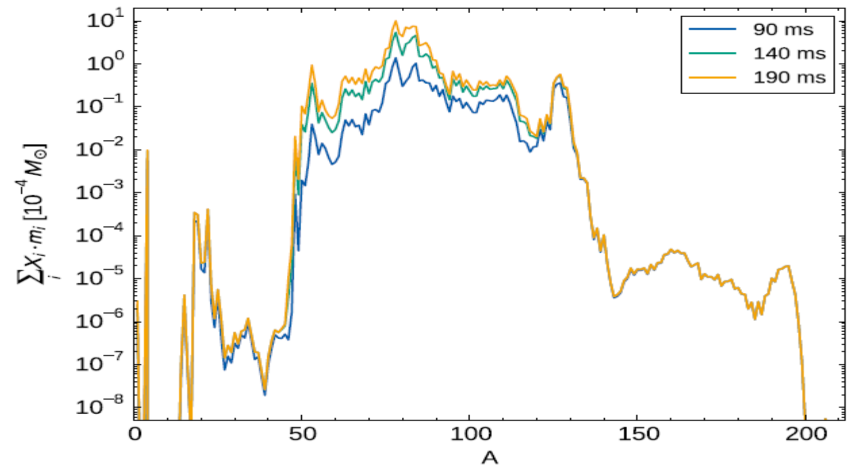
do we still have the robustness of heavy r-abundances against variation of astrophysical condition?

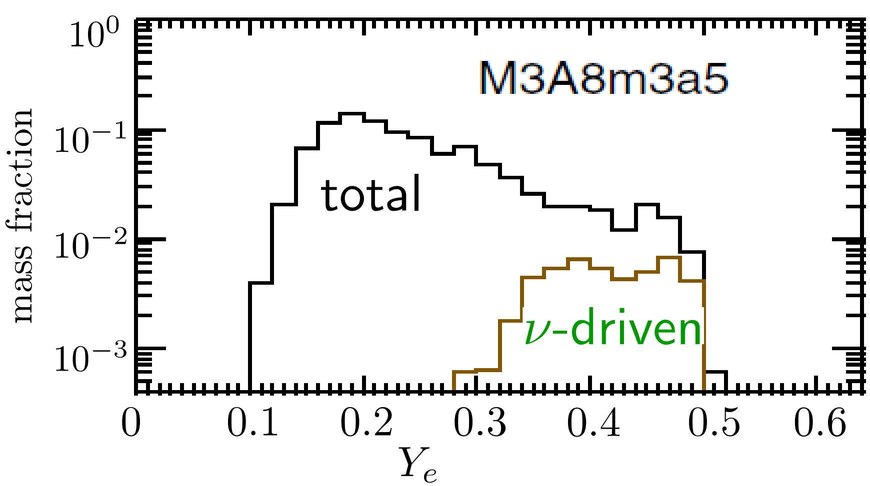
Each component gives what? – disk ejecta

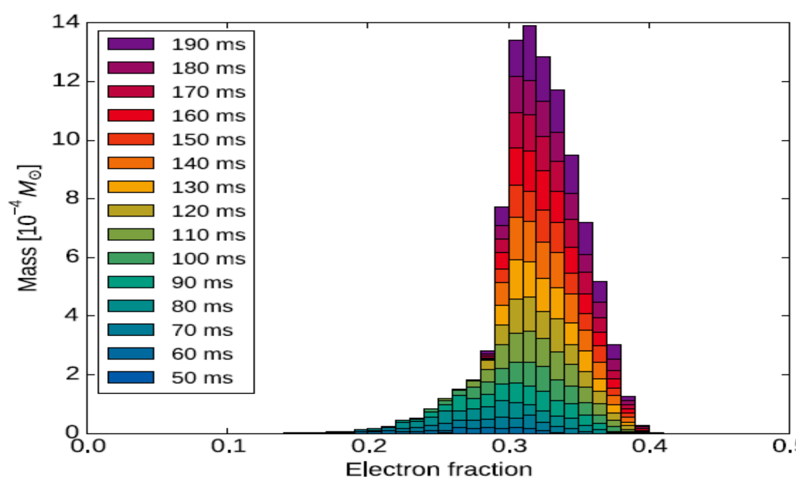
[Just+, MNRAS 448, 541 (2015)]



[Martin+, ApJ 813, 2 (2015)]







BH($3M_{\odot}, \chi = 0.8$)+torus

ν: energy-dependent M1

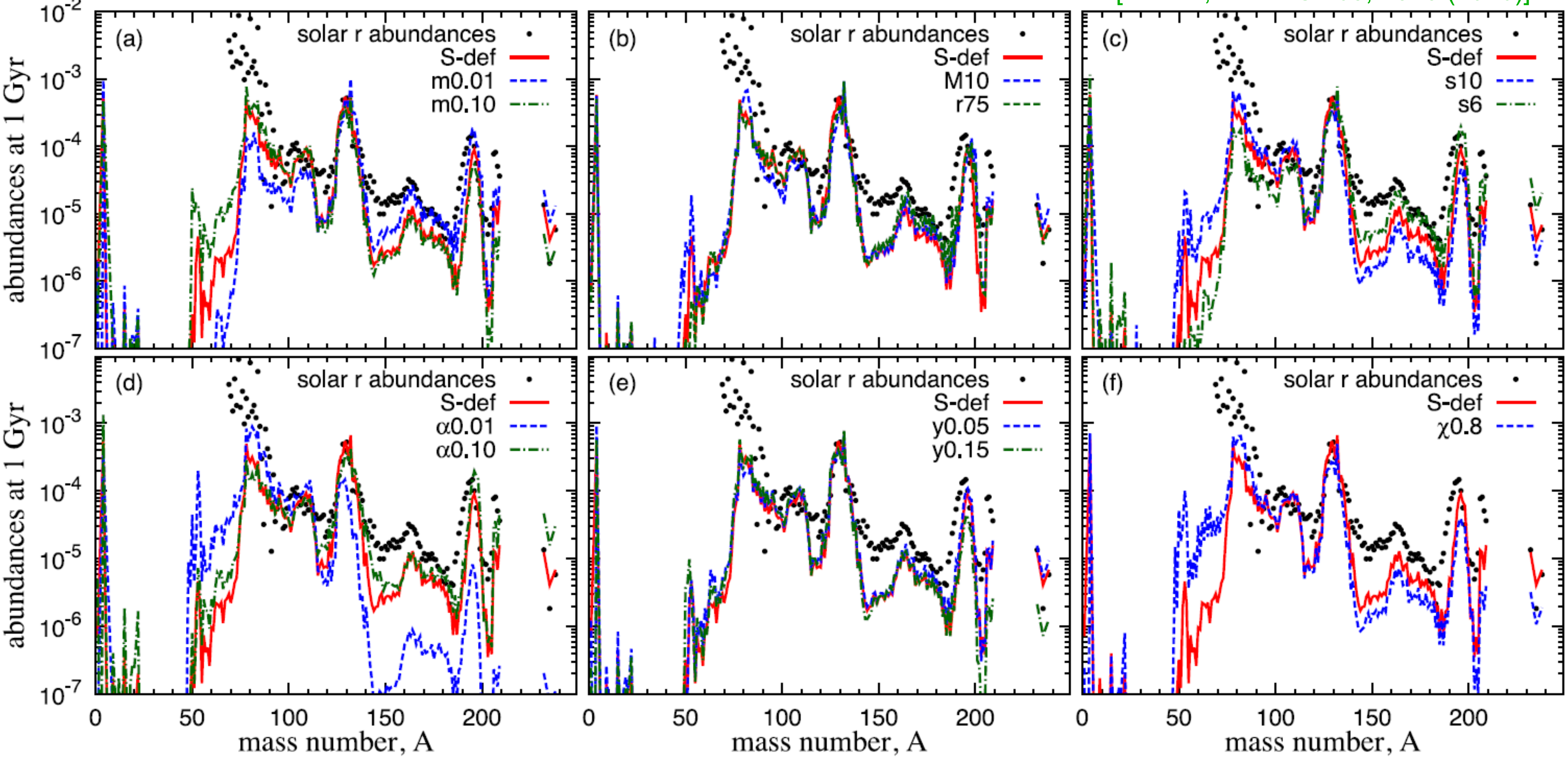
MNS($2.5M_{\odot}$)+disk($0.19M_{\odot}$)

ν: energy-dependent leakage

**no viscosity included in the simulation

Initial condition of the system – disk outflow

[MRW+, MNRAS 463, 2323 (2016)]



viscosity being the most relevant (MHD!),
BH-spin, disk mass, and disk entropy are also important

[S-def: $\mathrm{M}_{\mathrm{BH}} = 3M_{\odot}$, $\mathrm{M}_{\mathrm{disk}} = 0.03M_{\odot}$, $R_0 = 50$ km, $Y_{e,0} = 0.1$, $s_0/k_B/\mathrm{nuc} = 8$, $\alpha = 0.03$, $\chi_{\mathrm{BH,spin}} = 0$]

Anomaly of convective disk

- large convective current may develop in the α-viscosity disk

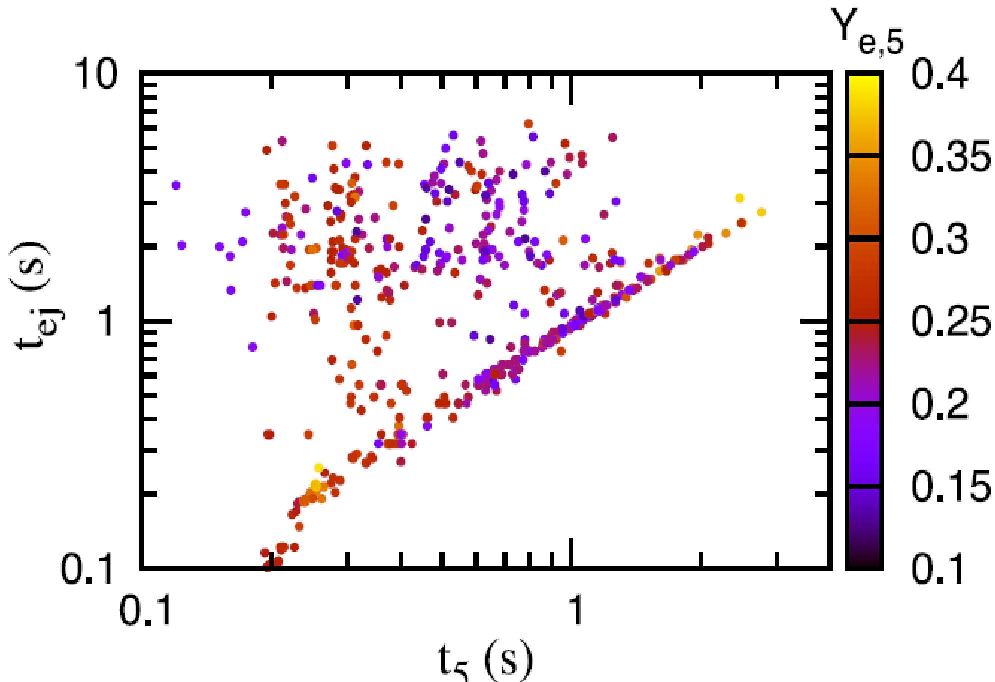
- ejecta can be reheated at late evolution stage to $T \gtrsim 3$ GK such that neutrons are photo-dissociated during the decay of r-process nuclei

$\rightarrow$ pile up of doubly-magic ^{132}Sn

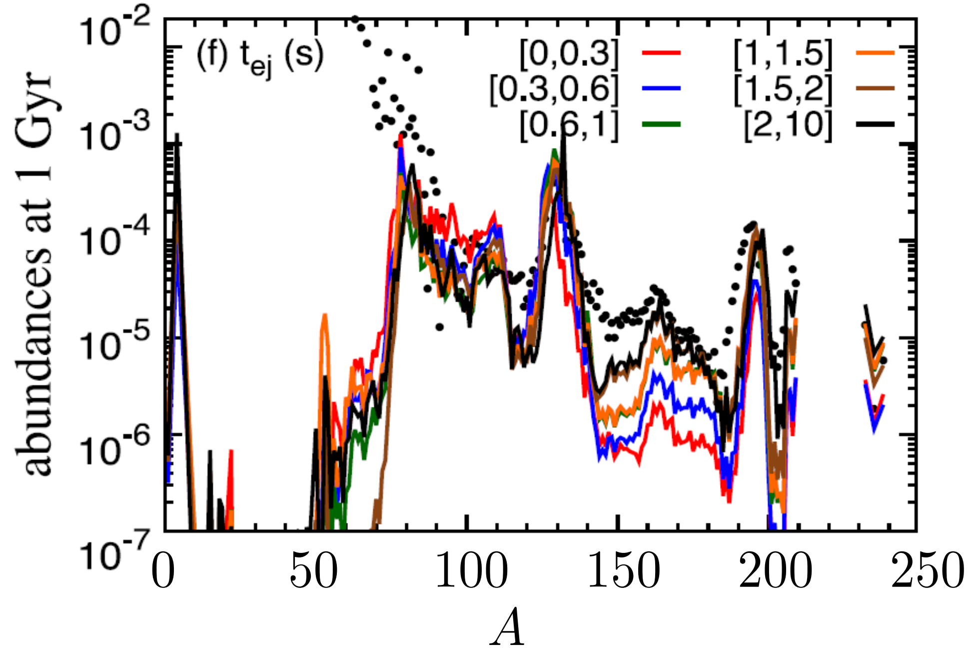
- large or small viscosity may relieve this

- inclusion of nuclear energy release beyond ^{4}He formation(?)

- MHD?

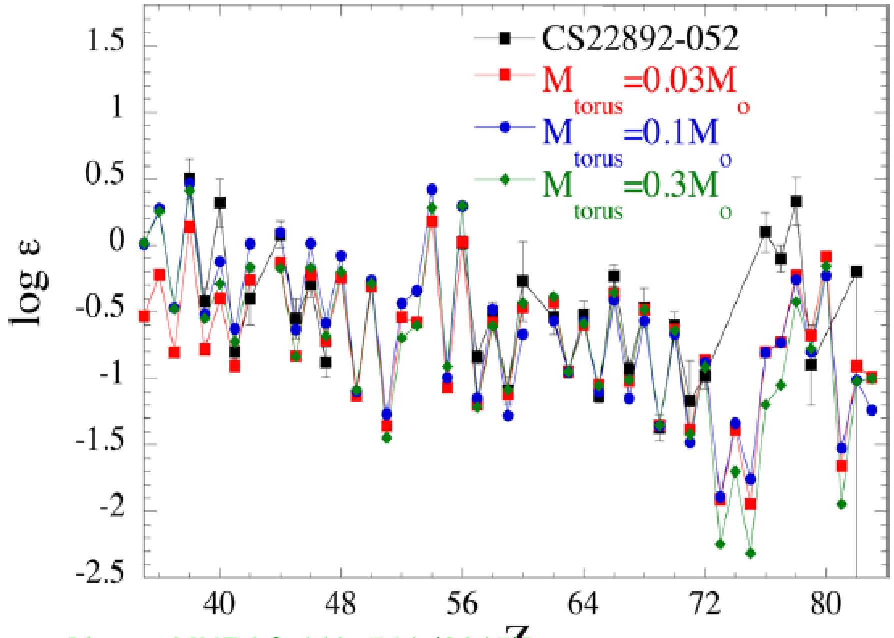


[MRW+, MNRAS 463, 2323 (2016)]



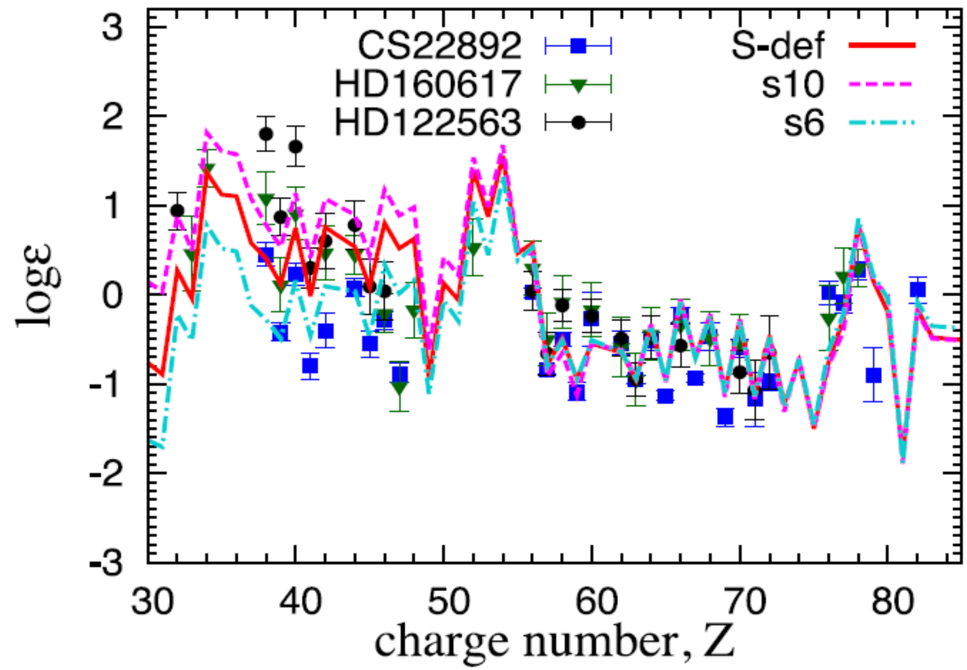
Elemental abundances

(very n-rich) dynamical + disk



[Just+, MNRAS 448, 541 (2015)]

viscously-driven disk only

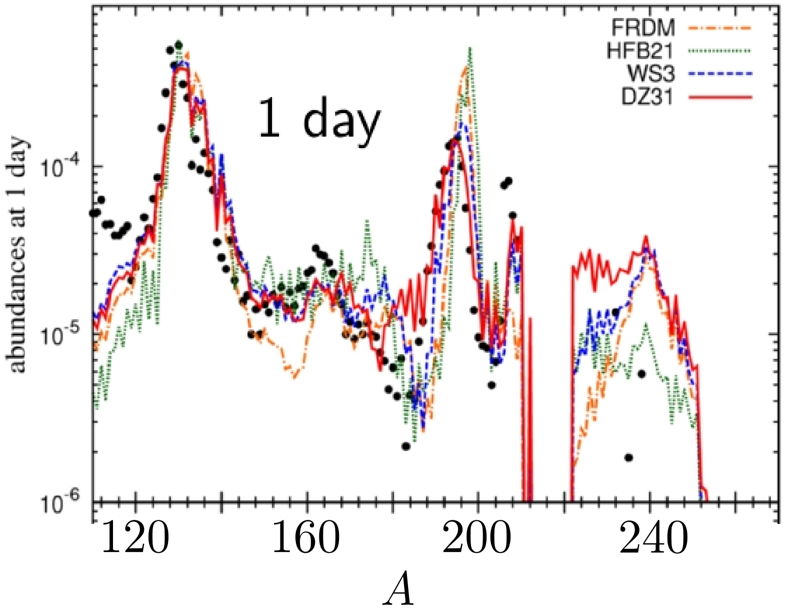


[MRW+, MNRAS 463, 2323 (2016)]

Can mergers & remnants account for the variations seen in metal-poor stars?

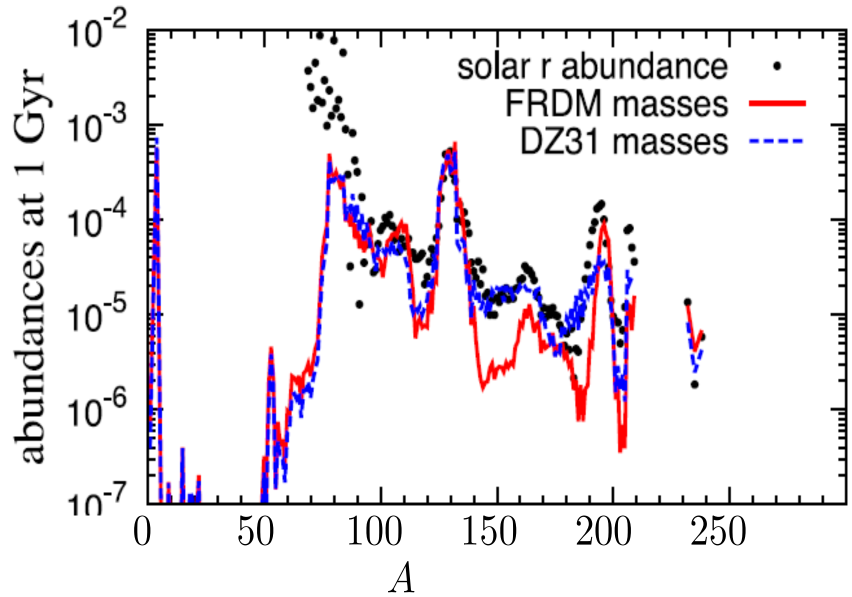
Nullear physics impact

(very n-rich) dynamical ejecta



[Mendoza-Temis+, PRC 92, 055805 (2015)]

viscously-driven disk ejecta

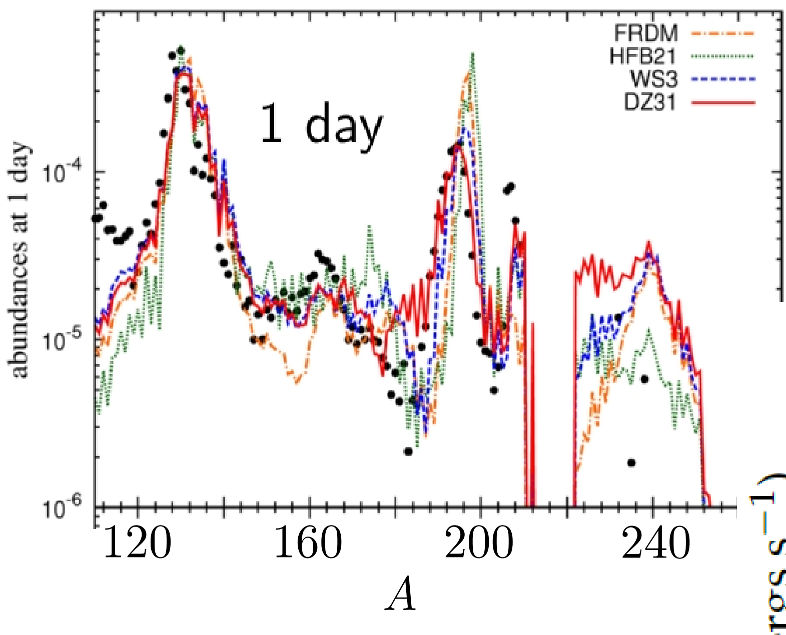


[MRW+, MNRAS 463, 2323 (2016)]

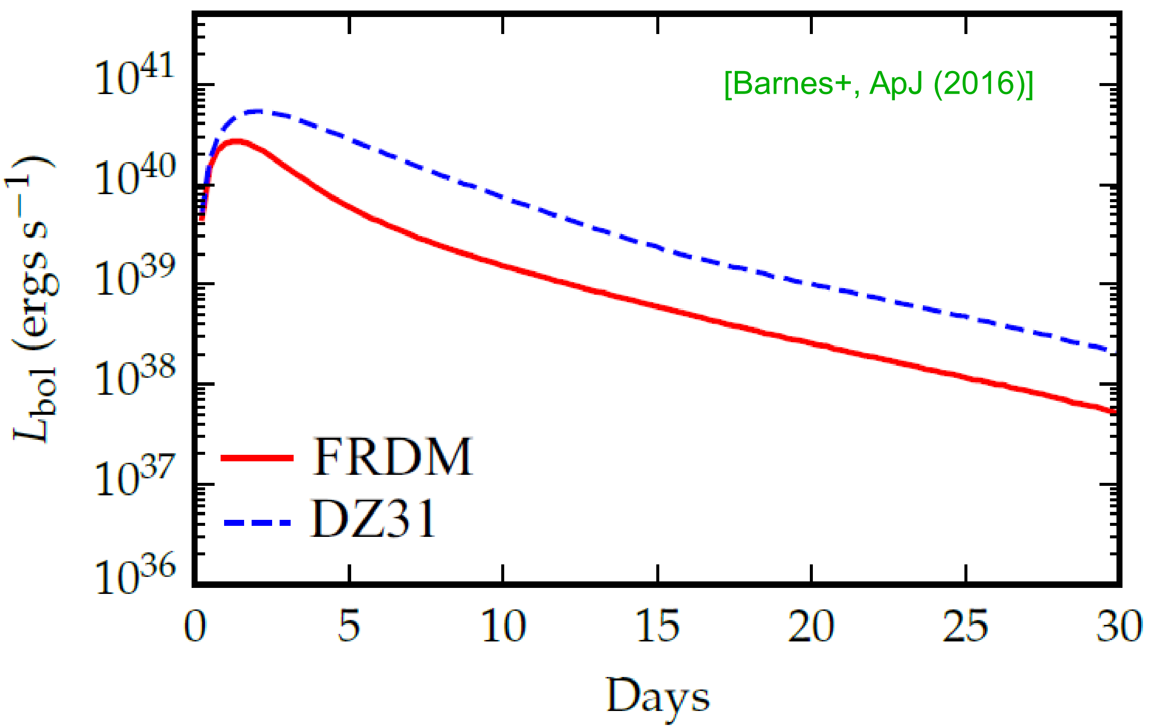
- masses, β-decays, fissions can all be important in shaping the abundances. [see also, e.g., Eichler+ 2015, Martin+ 2016]

Nuclear physics impact

[Mendoza-Temis+, PRC 92, 055805 (2015)]



- amount of transuranic nuclei affects kilonova lighcurve.



Summary & discussions

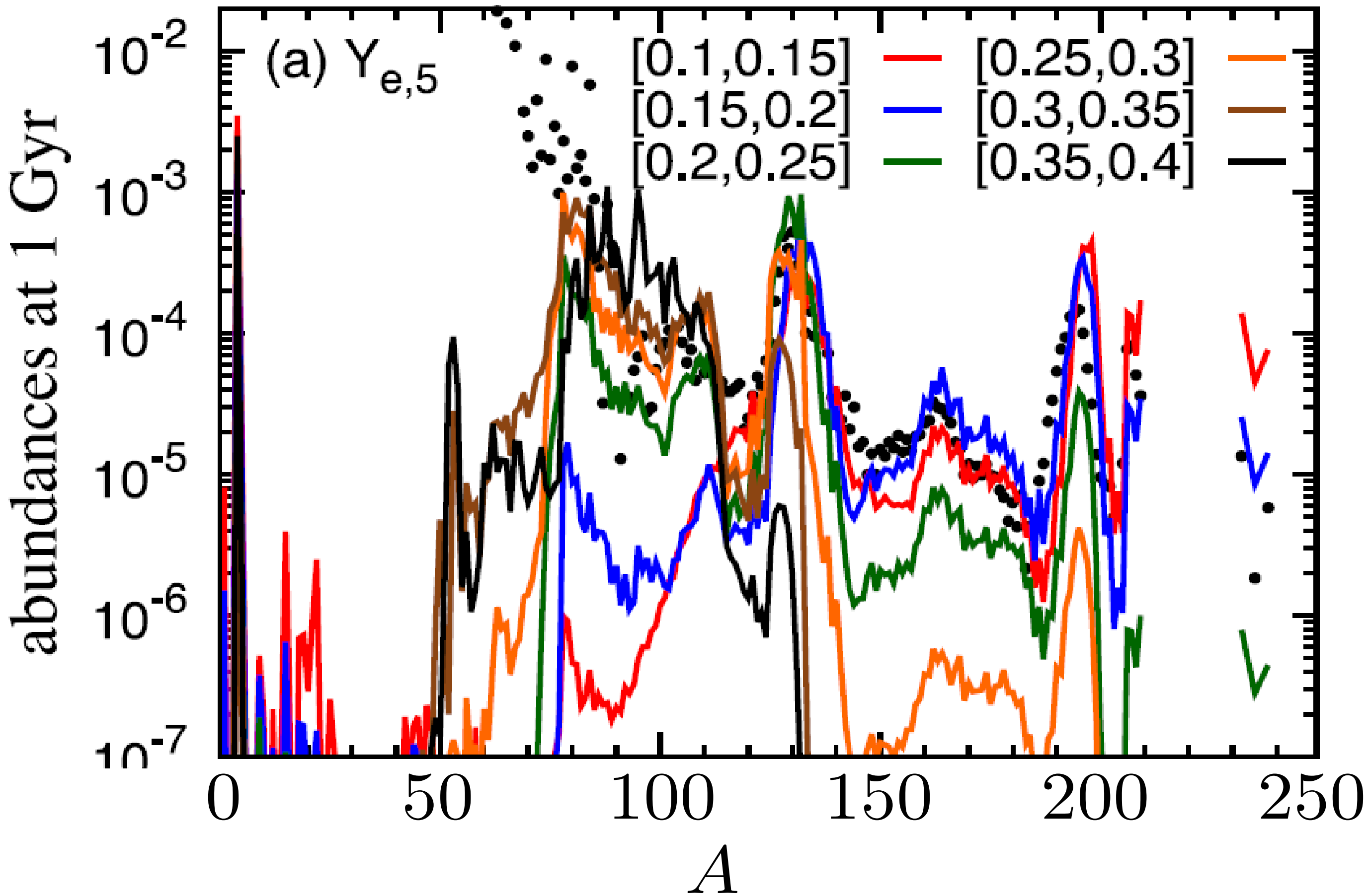
- NH–NS/BH mergers may produce the whole range of r-process nuclides with (the combination of) different components of ejecta.
- Given an initial system, there still exists large discrepance among different predictions (neutrinos, EoS, viscosity). Also, the contribution from different components remain undetermined.
- Can they simultaneous account for the robustness of heavy r abunadnces and the variations of light r abundances?
- Uncertainty in nuclear physics can be influential in both abundances and kilonova lightcurves.

Summary & discussions

- NH–NS/BH mergers may produce the whole range of r-process nuclides with (the combination of) different components of ejecta.
- Given an initial system, there still exists large discrepance among different predictions (neutrinos, EoS, viscosity). Also, the contribution from different components remain undetermined.
- Can they simultaneous account for the robustness of heavy r abunadnces and the variations of light r abundances?
- Uncertainty in nuclear physics can be influential in both abundances and kilonova lightcurves.

\- neutrino flavor oscillations?
\- chemical evoultion & observational constraints?
\- sGRB?

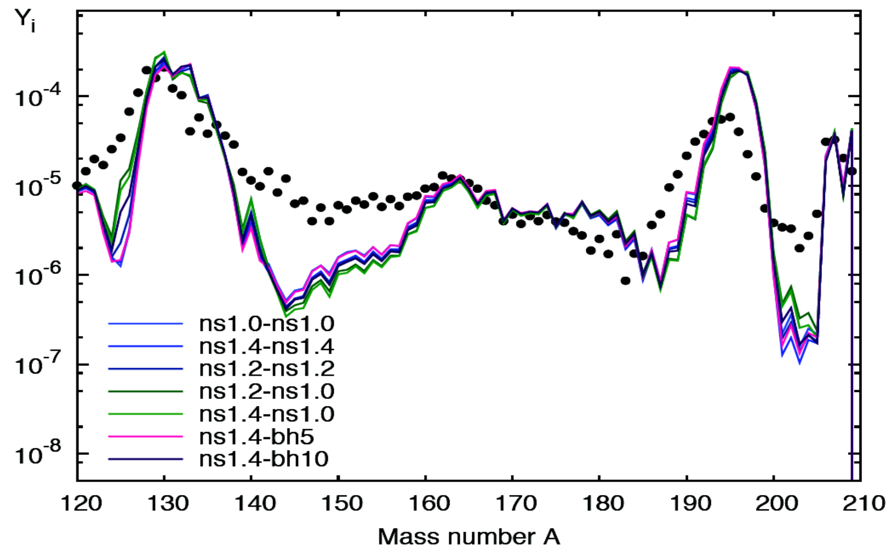
Y_e dependence



dynamical ejecta : robust r-process

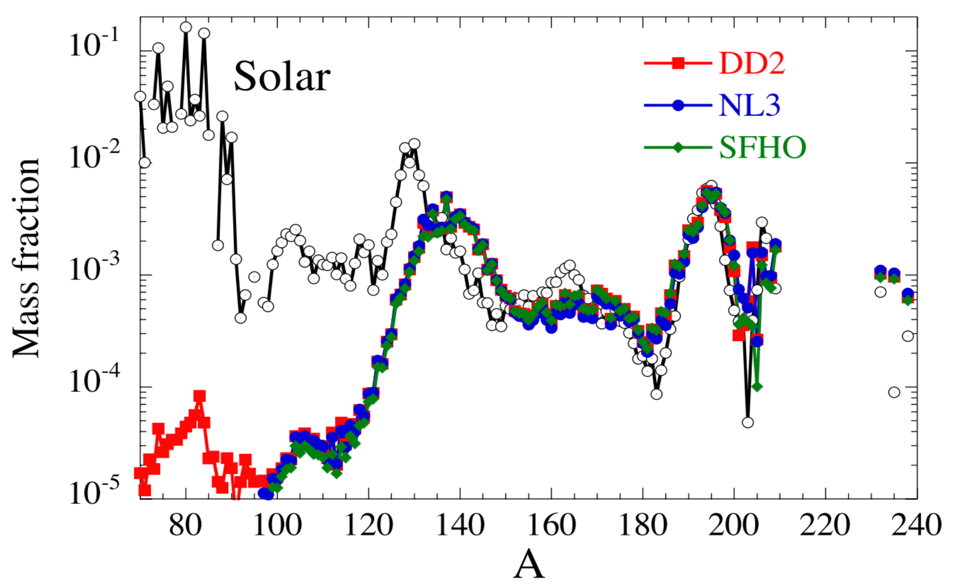
- different merging objects:

[Korobkin, Rosswog, Arcones, Winteler, MNRAS 426, 1940 (2012)]



- different equations of state:

[Bauswein, Goriely, Janka, ApJ 773, 78 (2013)]

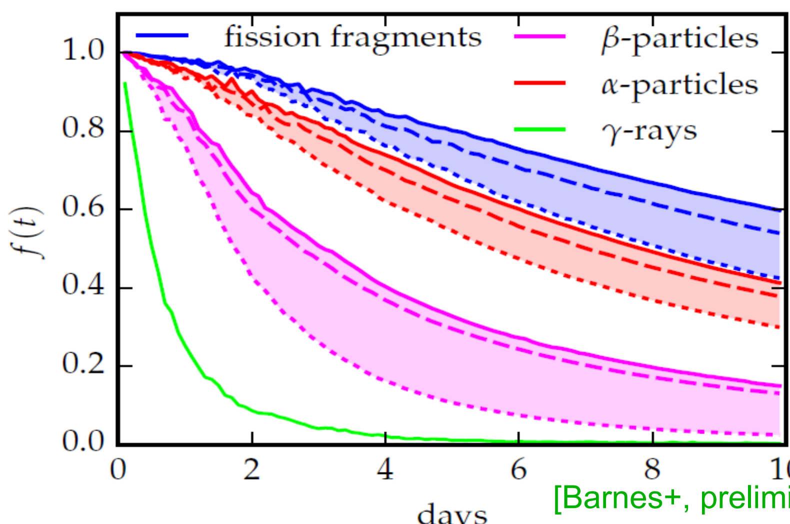


kilonova heating rates

- slow ejecta dominate the energy production during the kilonova time scale of days.

- fast ejecta may give rise to a precursor powered by neutron decays at $\sim$ hours due to its lower density. [Metzger et.al., MNRAS 446, 1115 (2015)]

- lightcurve predicted with different nuclear inputs may differ significantly, due to different thermalization efficiency of decay/fission products.



[Barnes+, preliminary]