Complete r-Process Survey for Different Astrophysical Environments

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Motivation

- r-process occurs under different astrophysical conditions and produces half of the heavy elements and all Th and U in the Universe
- Neutron star mergers (NSM): confirmed r-process site after kilonova associated to gravitational wave signal from NSM (GW170817)
- Galactical chemical evolution: additional, early r-process site probably associated to supernovae $\rightarrow$ magneto-rotational supernovae (MRSN)
- Hydrodynamical simulations of NSM and MRSN are computationally expensive: nucleosynthesis conditions still uncertain and not complete

  $\Rightarrow$ **Parametric studies** are complementary approach to explore broad range of conditions [1]

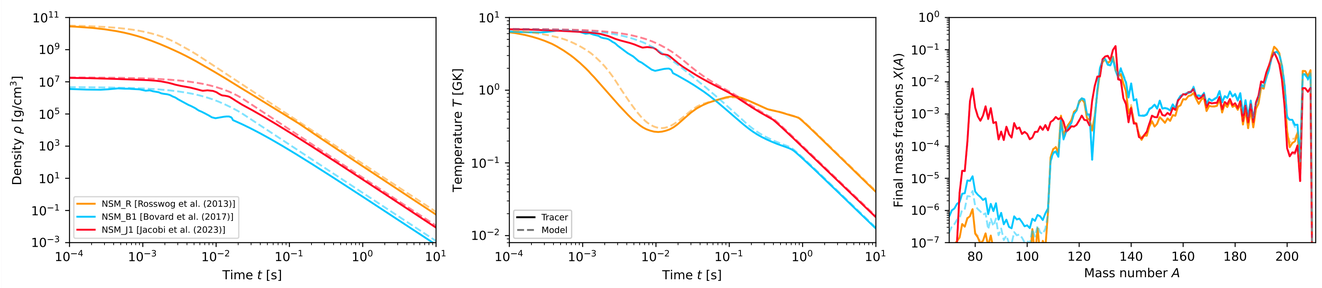
Model

- Parameters: initial (at 7 GK) **entropy** (s_0) and **electron fraction** ($Y_{e,0}$) and **expansion timescale** (τ)
- Density evolution [2]:

$$\rho(t) = \rho_0 \begin{cases} \exp\left(-\frac{t}{\tau}\right) & \text{if } t \leq 3\tau \\ \left(\frac{3\tau}{et}\right)^3 & \text{if } t \geq 3\tau \end{cases}$$

- Temperature evolution from entropy: adiabatic expansion + nuclear energy generation
- Nucleosynthesis: open-source nuclear reaction network WinNet [3]
- Parameter space: $12 \times \tau, 100 \times Y_{e,0}, 100 \times s_0$

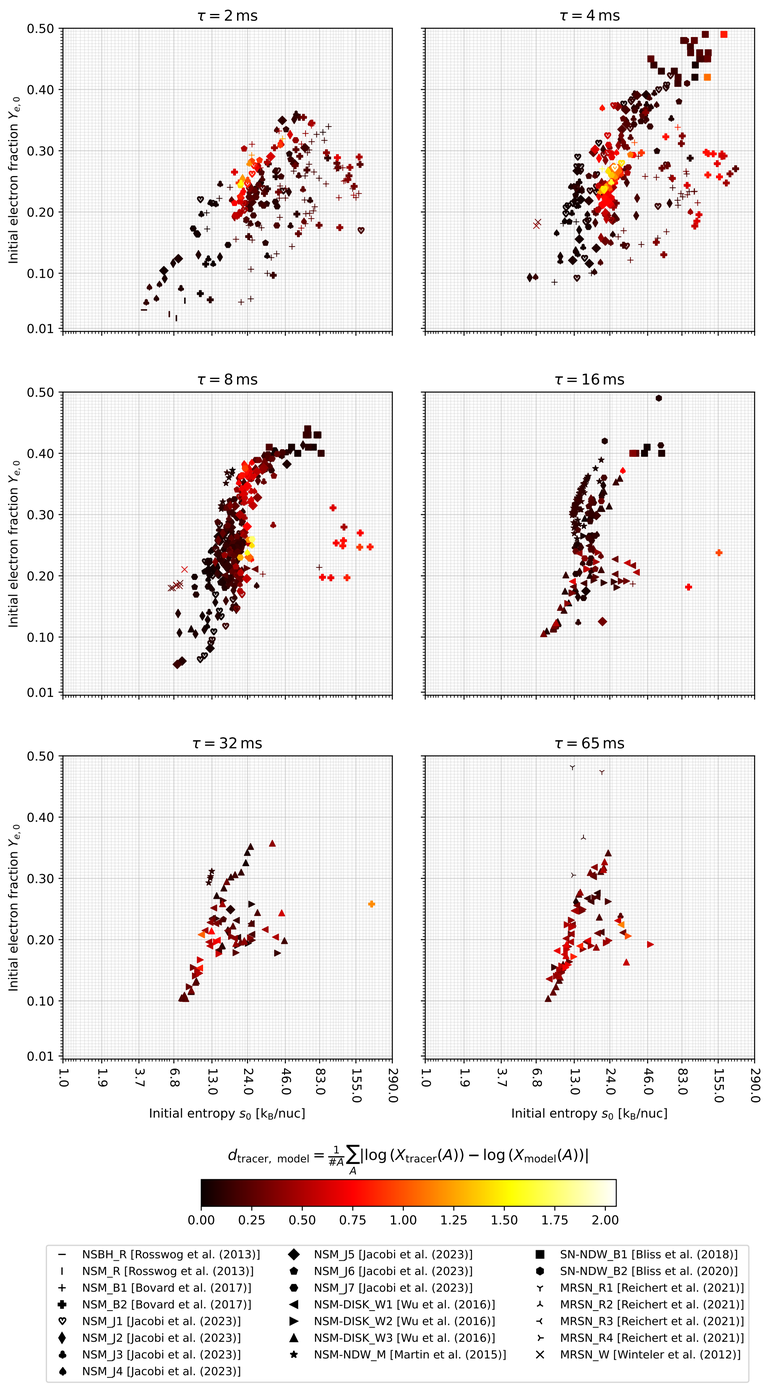
  $\Rightarrow$ 120 000 nucleosynthesis calculations



Left and center: Density and temperature evolution for three representative tracers from hydrodynamical simulations of NSM (solid) and this model (dashed). Right: Final mass fractions, almost identical for the tracers and model.

Comparison to Simulations

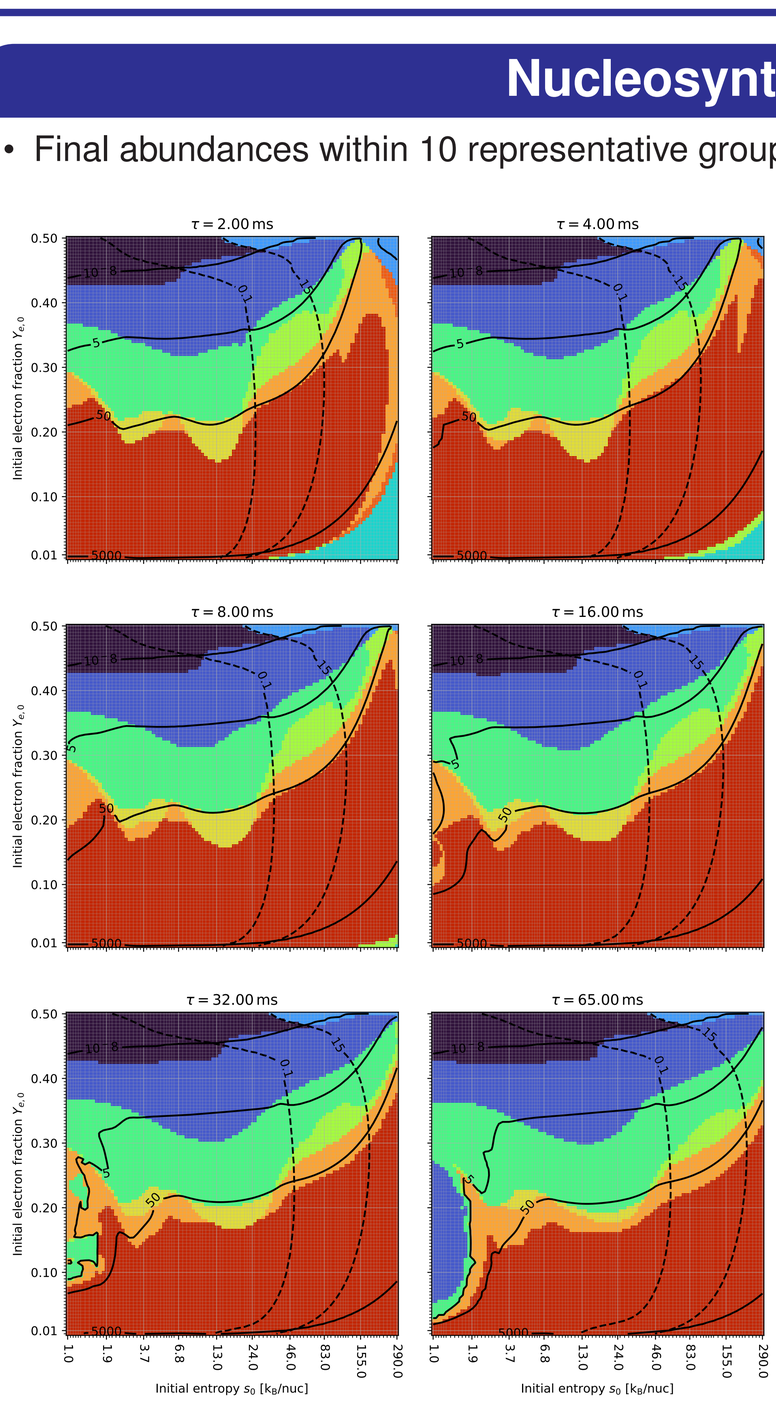
- Model covers all astrophysical conditions found in current simulations of NSM and SN

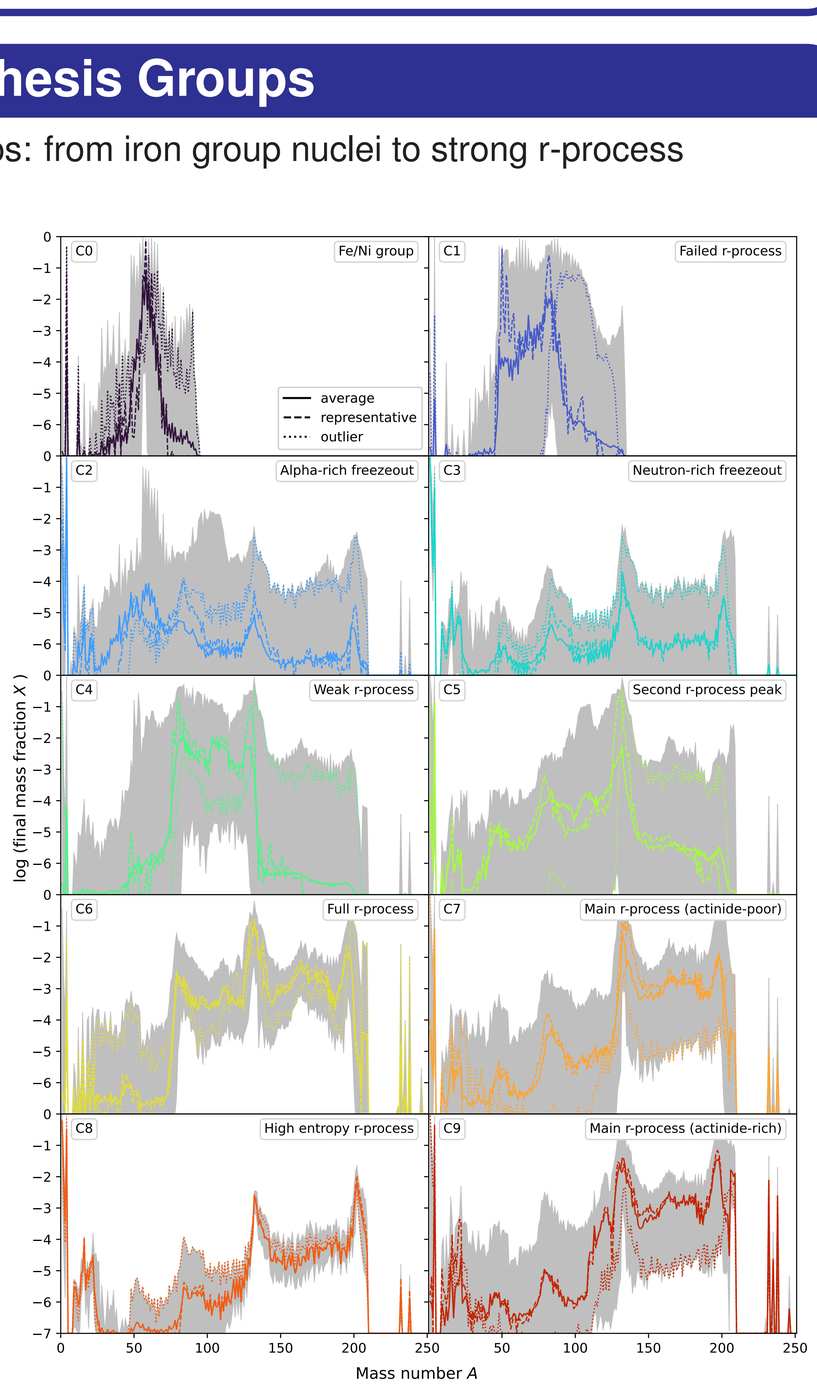


$\Rightarrow$ **Good agreement** of final abundances: Lagrangian tracer particles from hydrodynamical simulations vs. parametric model

Nucleosynthesis Groups

- Final abundances within 10 representative groups: from iron group nuclei to strong r-process





Left: Groups correlate with **neutron-to-seed** (solid black lines) and **alpha-to-seed ratios** (dashed black lines) at charged-particle freezeout (3 GK). Right: Average abundance patterns (solid), most representative (dashed) and outlying (dotted) members of each group.

Summary

- Complete r-process survey: ideal to explore impact from **nuclear physics** input and to constrain **astrophysical conditions** with observations

  $\Rightarrow$ details available in: Kuske et al. 2024 (in prep.)

KEY REFERENCES

[1] Bliss et al., ApJ 855, 135 (2018)
[2] Lippuner J., Roberts L. F., ApJ 815, 82 (2015)
[3] Reichert M. et al., ApJS 268, 66 (2023)

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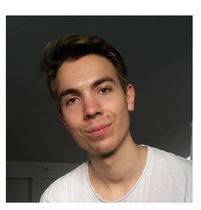

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