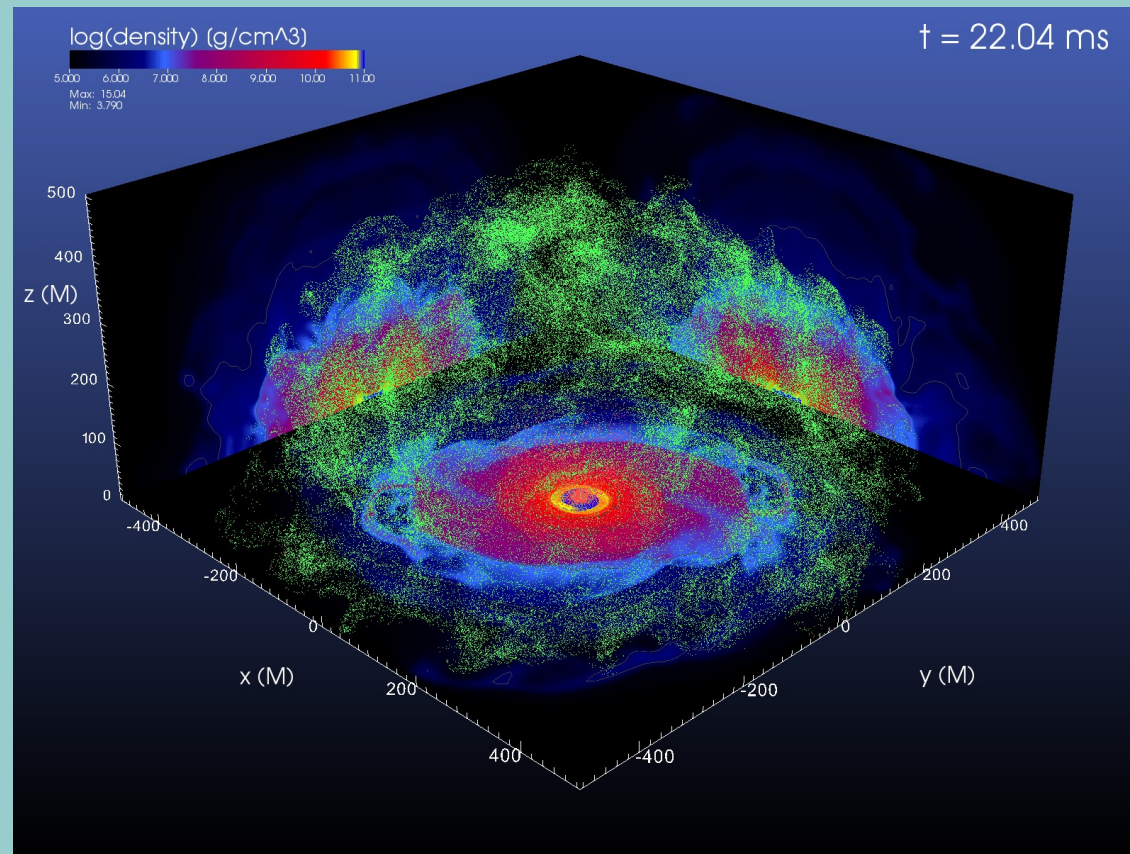


# r-process Nucleosynthesis and Binary Neutron Star Mergers

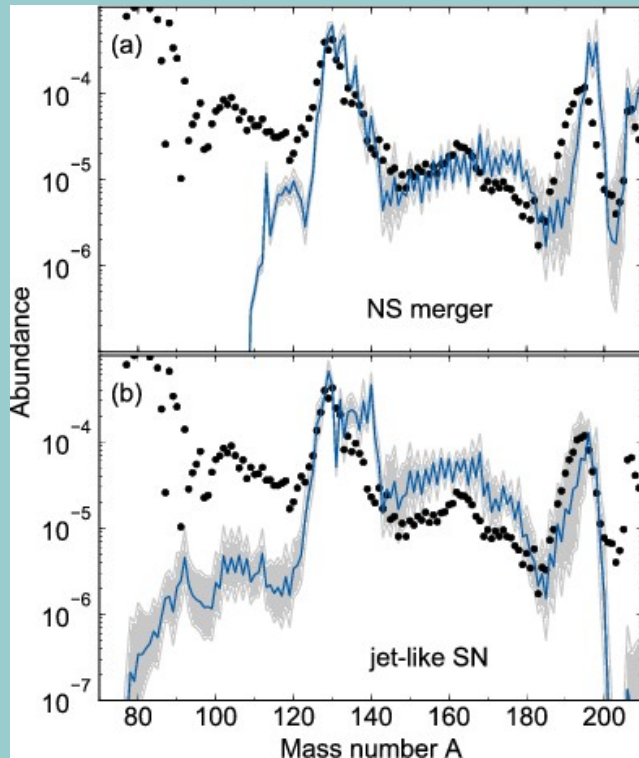


Luke Bovard

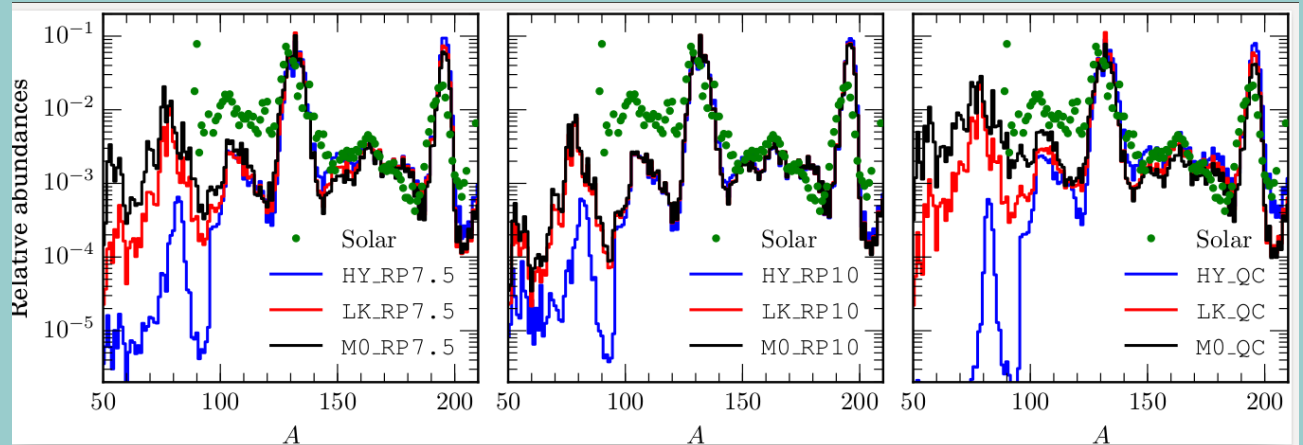
April 28<sup>th</sup>, 2016 – NewCompStar Istanbul

# Nucleosynthesis

- The heavy elements ( $A > 120$ ) in our solar system are derived through the r-process
- Where does this nucleosynthesis takes place?
  - Neutron star mergers vs core collapse supernova (see Andreas' talk yesterday)



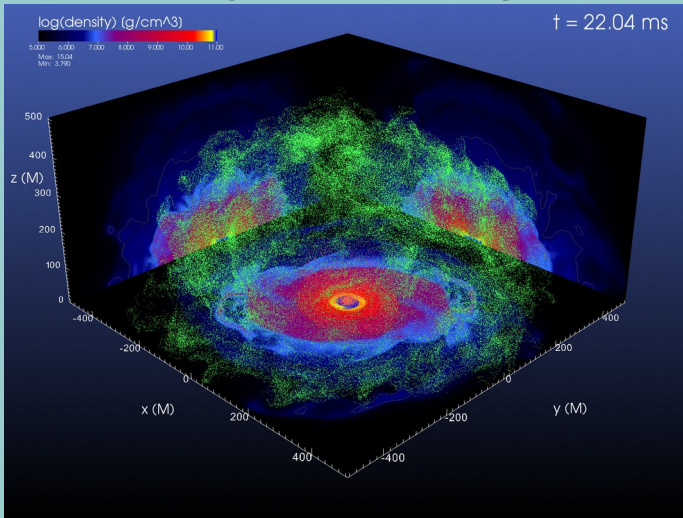
Martin et al. 2015



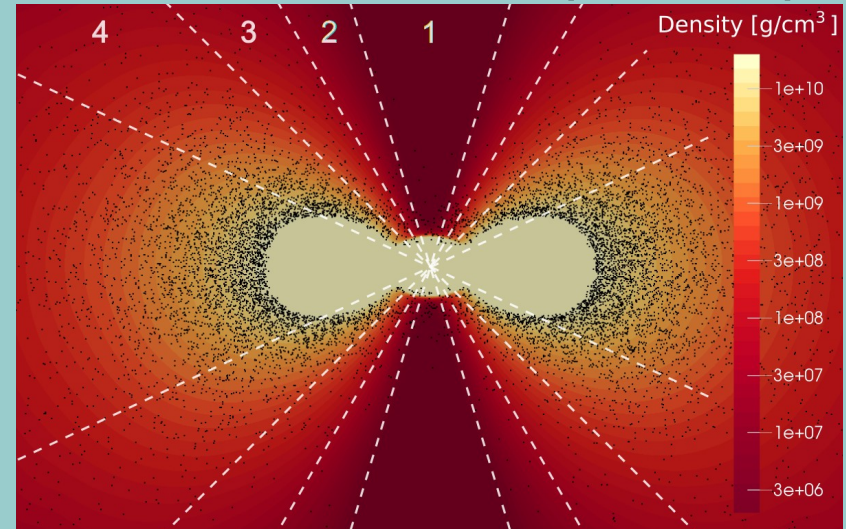
Radice et al. 2016

# Categories of ejecta

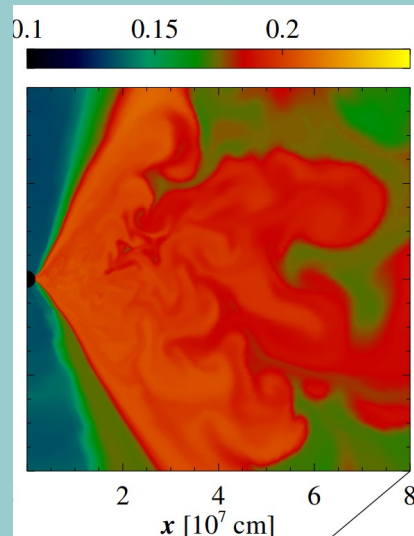
Dynamic ejecta  $\sim O(10 \text{ ms})$



Neutrino wind  $\sim O(100 \text{ ms})$



Viscous Heating  $\sim O(1 \text{ s})$  Martin et al. 2015



Fernández & Metzger  
2013

# Numerics

- Solve the Einstein equations numerically

$$G_{\mu\nu} + \Lambda g_{\mu\nu} = R_{\mu\nu} - \frac{1}{2}R g_{\mu\nu} + \Lambda g_{\mu\nu} = \frac{8\pi G}{c^4}T_{\mu\nu},$$

- Perfect fluid

$$T^{\mu\nu} = (e + p)u^\mu u^\nu + pg^{\mu\nu}$$

- Decompose metric into temporal and spatial terms (Rezzolla & Zanotti 2013):

$$ds^2 = -(\alpha^2 - \beta_i \beta^i)dt^2 + 2\beta_i dx^i dt + \gamma_{ij} dx^i dx^j.$$

- EinsteinToolKit and WhiskyTHC (Radice et al. 2013)
- Implemented a leakage scheme (Galeazzi et al. 2013)

# Tracers

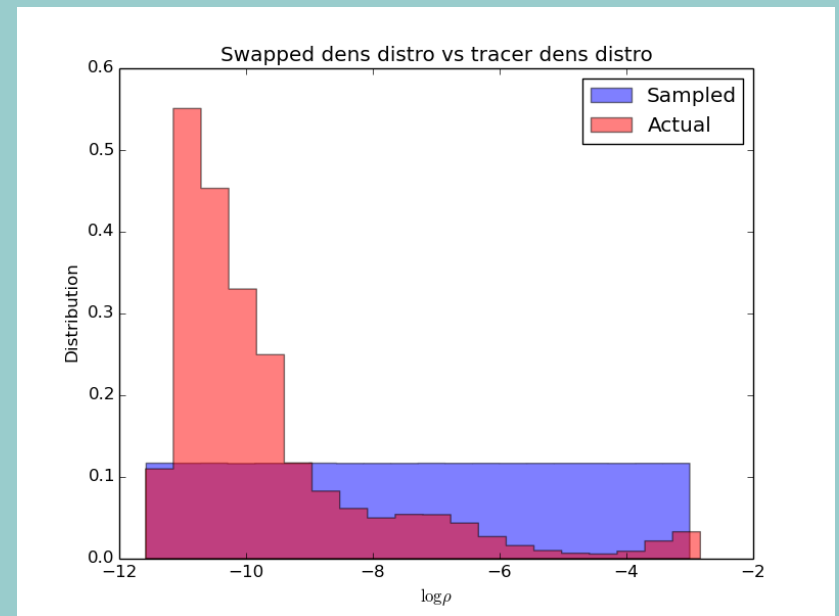
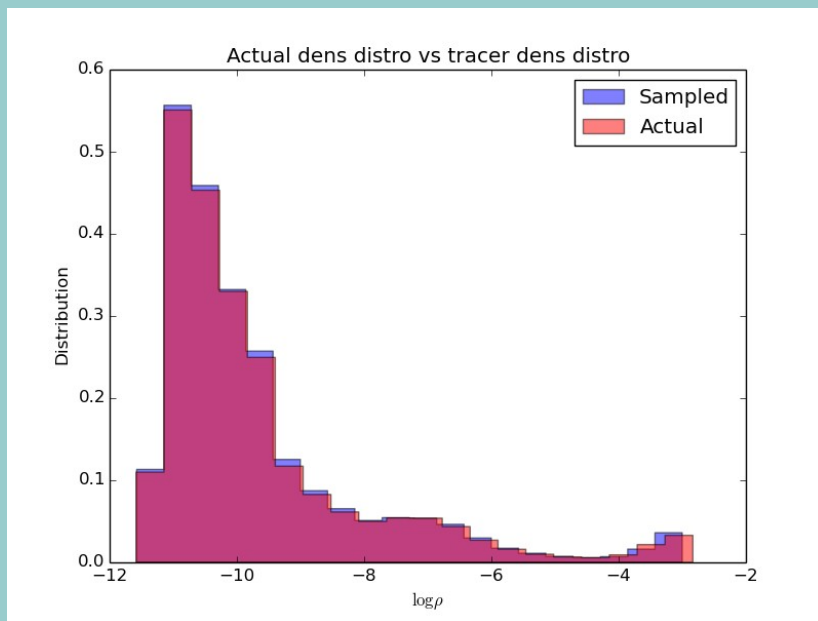
- Tracers record the history of the underlying fluid
- Advected passively

$$\frac{d\vec{x}}{dt} = \vec{v}$$

- Used for input of nucleosynthesis

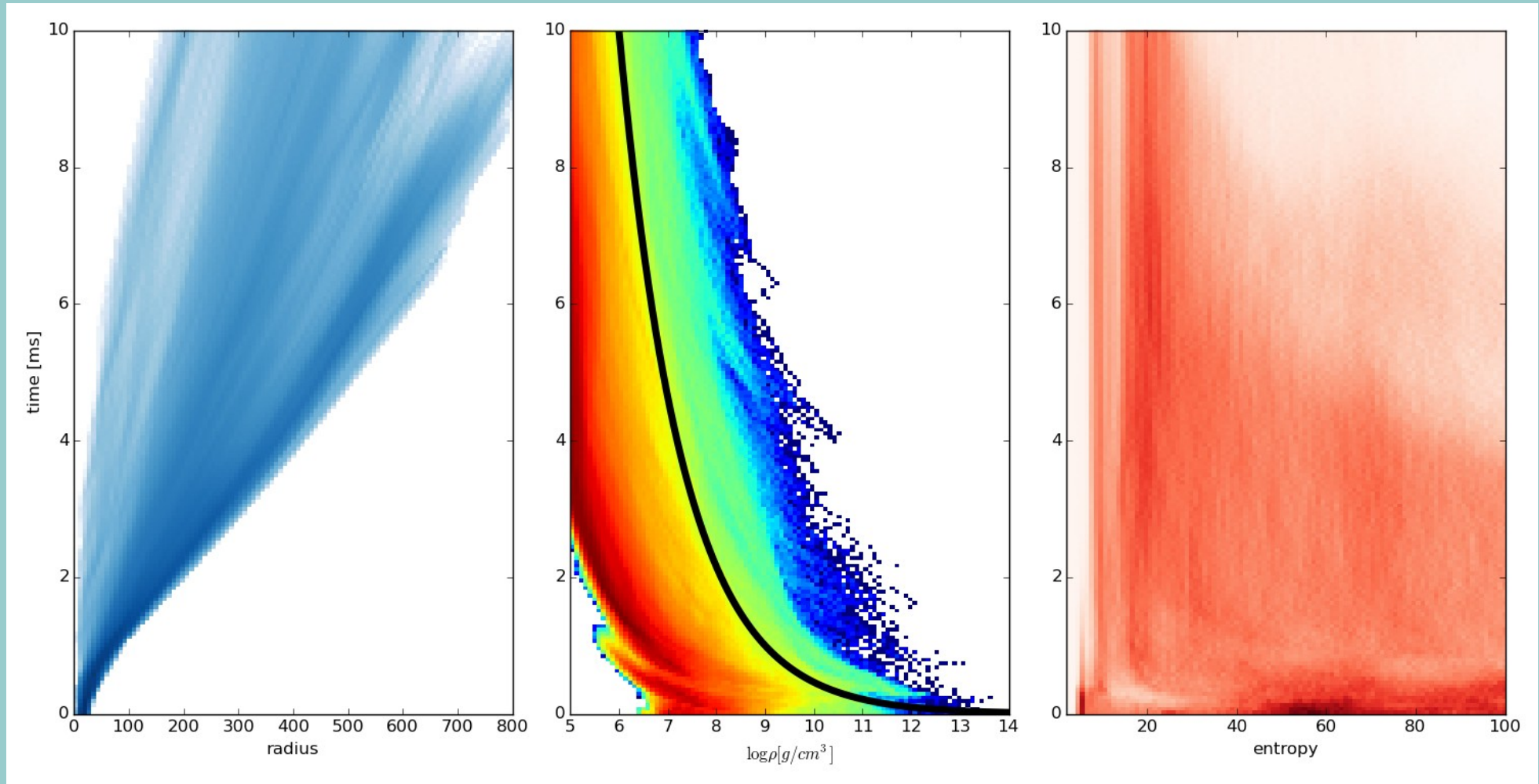
# Placement of tracers

- How we place tracers to best capture the fluid?

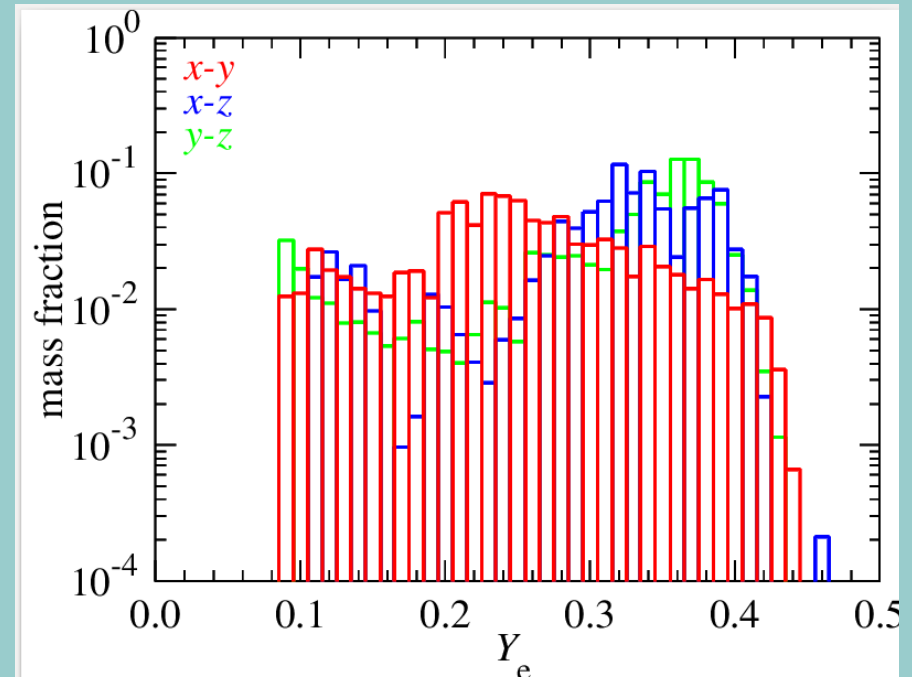
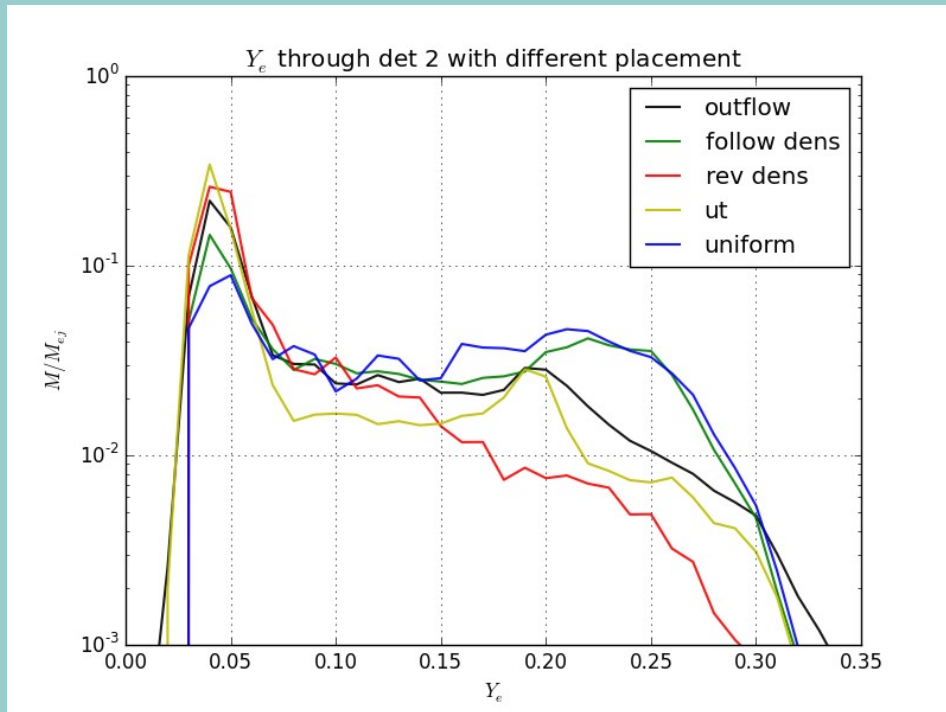


Video

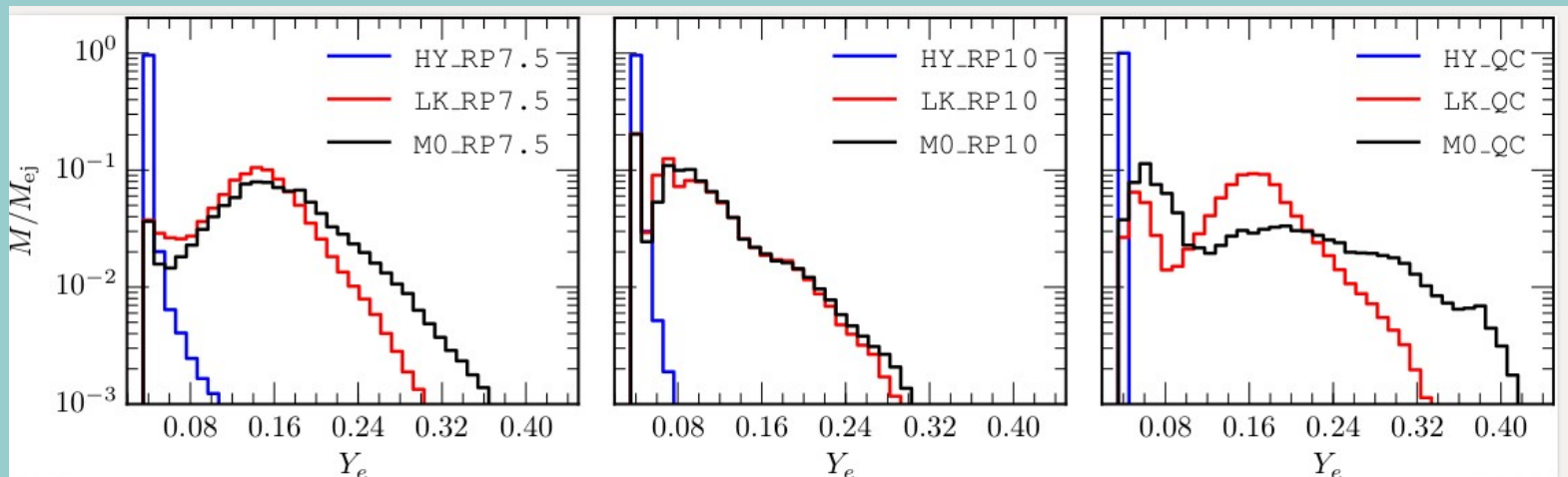
# Spacetime diagrams of tracers



# Comparison with outflow



Wanajo et al. (2014)



Radice et al. (2016)

# Conclusion / Outlook

- Tracers provide a natural way of capturing the long term evolution of the fluid, however care needs to be paid on the placement
- Determine the correct prescription to associate tracers to match the underlying fluid
- Considered different prescriptions and assessed the impact they have on the physical distributions
- Investigate robustness of dynamic ejecta nucleosynthesis for a variety of nuclear EoS, mass ratios, and masses
- We will couple the tracers with nuclear reaction networks to obtain improved estimates of the chemical abundances