Mass ejection, nucleosynthesis and light curves in binary mergers

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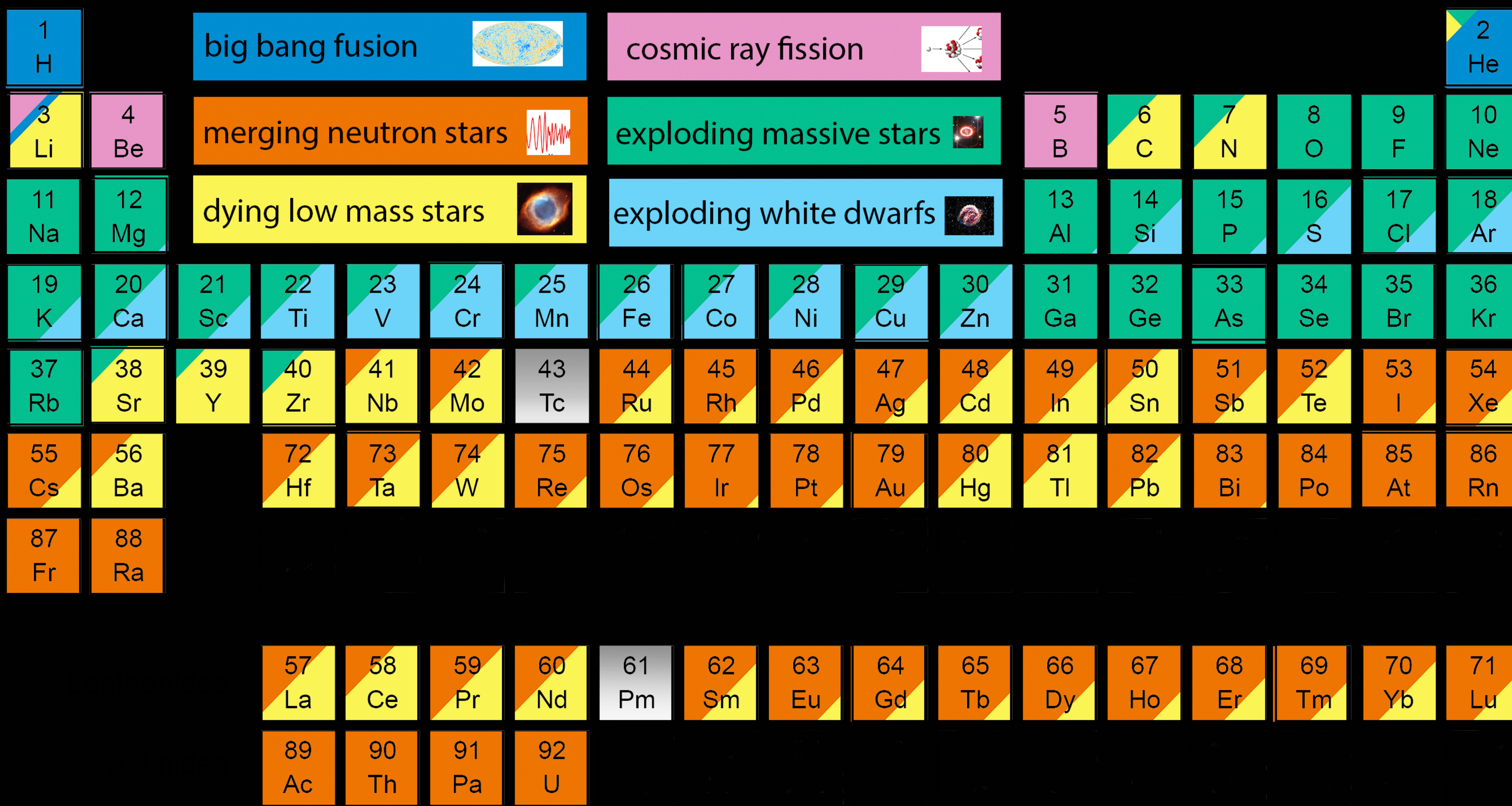
The Origin of the Solar System Elements



Graphic created by Jennifer Johnson

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Nucleosynthesis

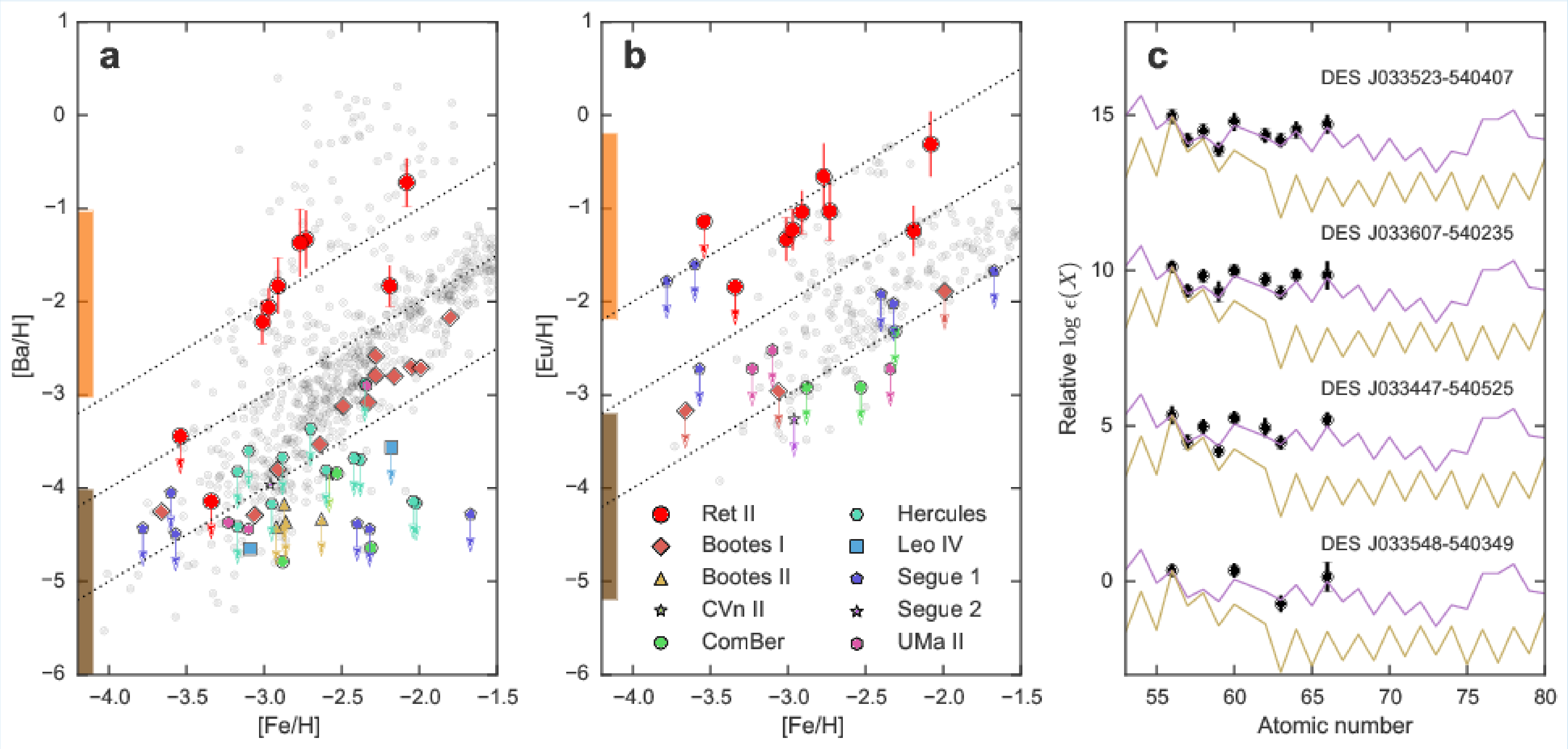
- *What is the origin of the heavy elements in the universe?*
- *r-process requires a neutron rich environment*
- *Still a lot of uncertainty in nuclear physics of the r-process*

see e.g. Eichler, Matthews, Steiner talk

Astrophysical origin of nucleosynthesis

- *Supernovae*
  - *less favoured*
  - *scenarios still possible (SN with jets)*
- *Neutron star mergers?*
  - *neutron rich environment*
- *Experimental evidence?*
  - *Metal poor dwarf galaxies favour NS (Ji et al. 2016)*
  - *all talks on Tuesday*

r-process in Ret II



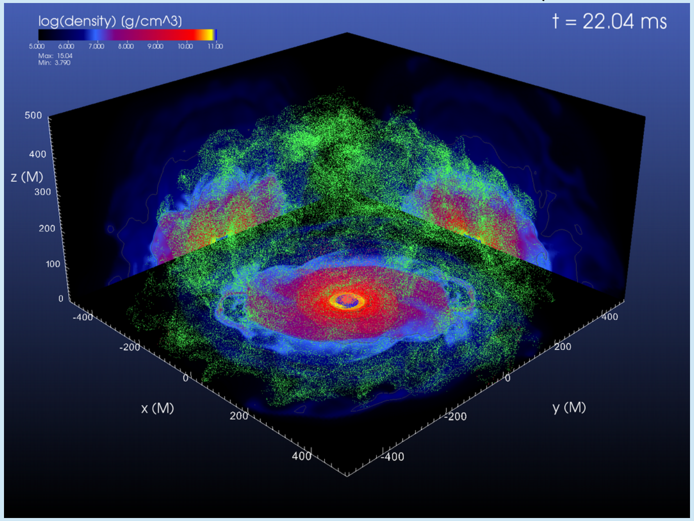
Ji et al. 2016

see talk by Frebel

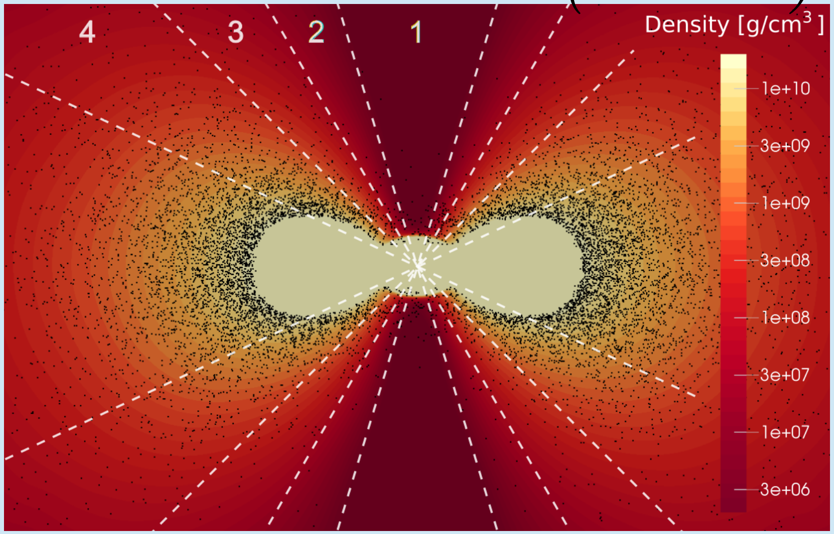
Categories of ejecta

Martin et al. 2015, Fujibayashi 2017

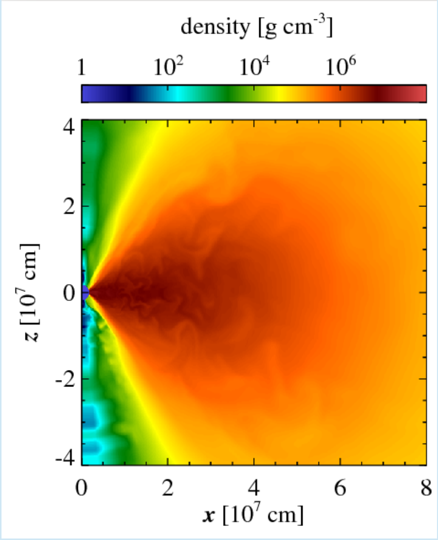
Dynamic ejecta ~ O(10 ms)



Neutrino wind ~ O(100 ms)



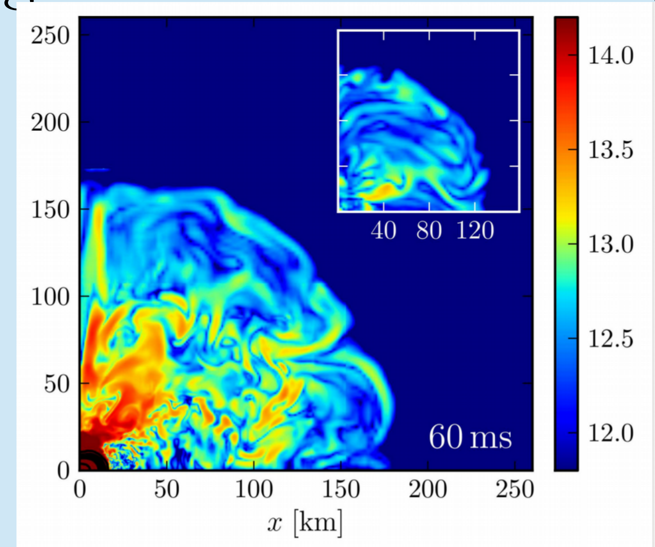
Viscous Heating ~ O(1 s)



see Shibata, Siegel talks

Fernández & Metzger 2013

Magnetic driven wind~ O(50 ms)



see Giacomazzo talk

Siegel et al. 2014

Numerical set-up

- *EinsteinToolKit and WhiskyTHC (Radice et al. 2013)*
- *Neutrino leakage scheme (Galeazzi et al. 2013)*

see talks by Foucart, Just

- *No magnetic fields*

see talks by Giacomazzo, Shibata

Initial data and Procedure

- *3 EOS: LS220, DD2, SFHo*
  see Lattimer talk
- *3 equal masses: 1.25, 1.35, 1.45* $M_\odot$
- *1 unequal mass:* $q=0.9$ *(1.22* $M_\odot$ *- 1.35* $M_\odot$*)*
- *Compactness* $\sim 0.140 - 0.181$
- *Radii* ~ 11.8 *km* $-$ *13.3 km*

Initial data and Procedure

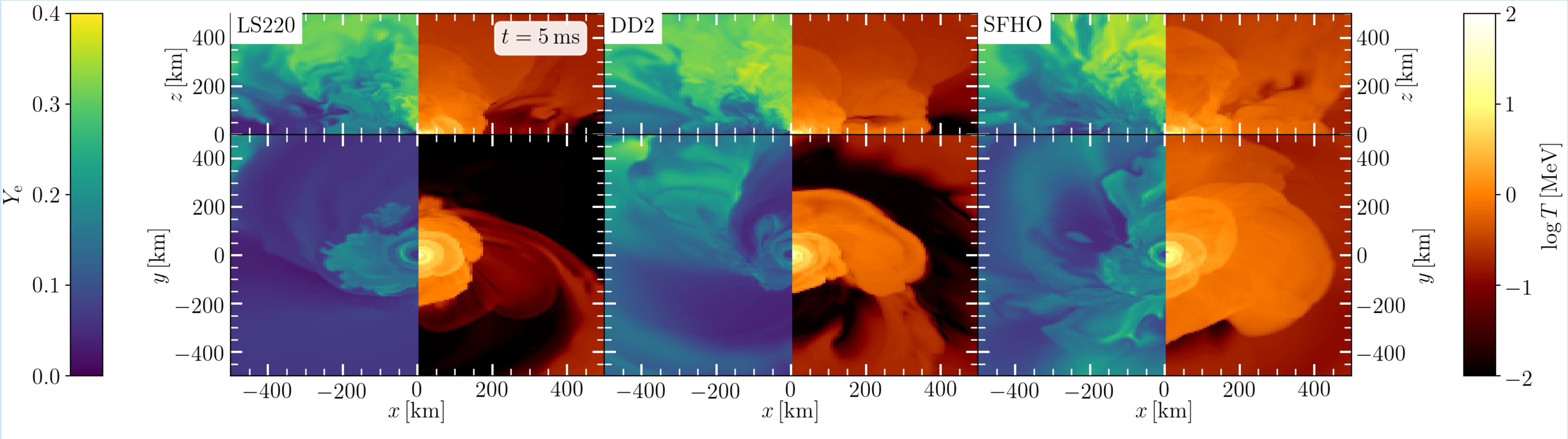
- *Tracers are placed in simulation and used as input for the nuclear network* (Bovard & Rezzolla 2017)*

- *Fluid properties are measured through detectors placed at different radii (compare with volume integral)*

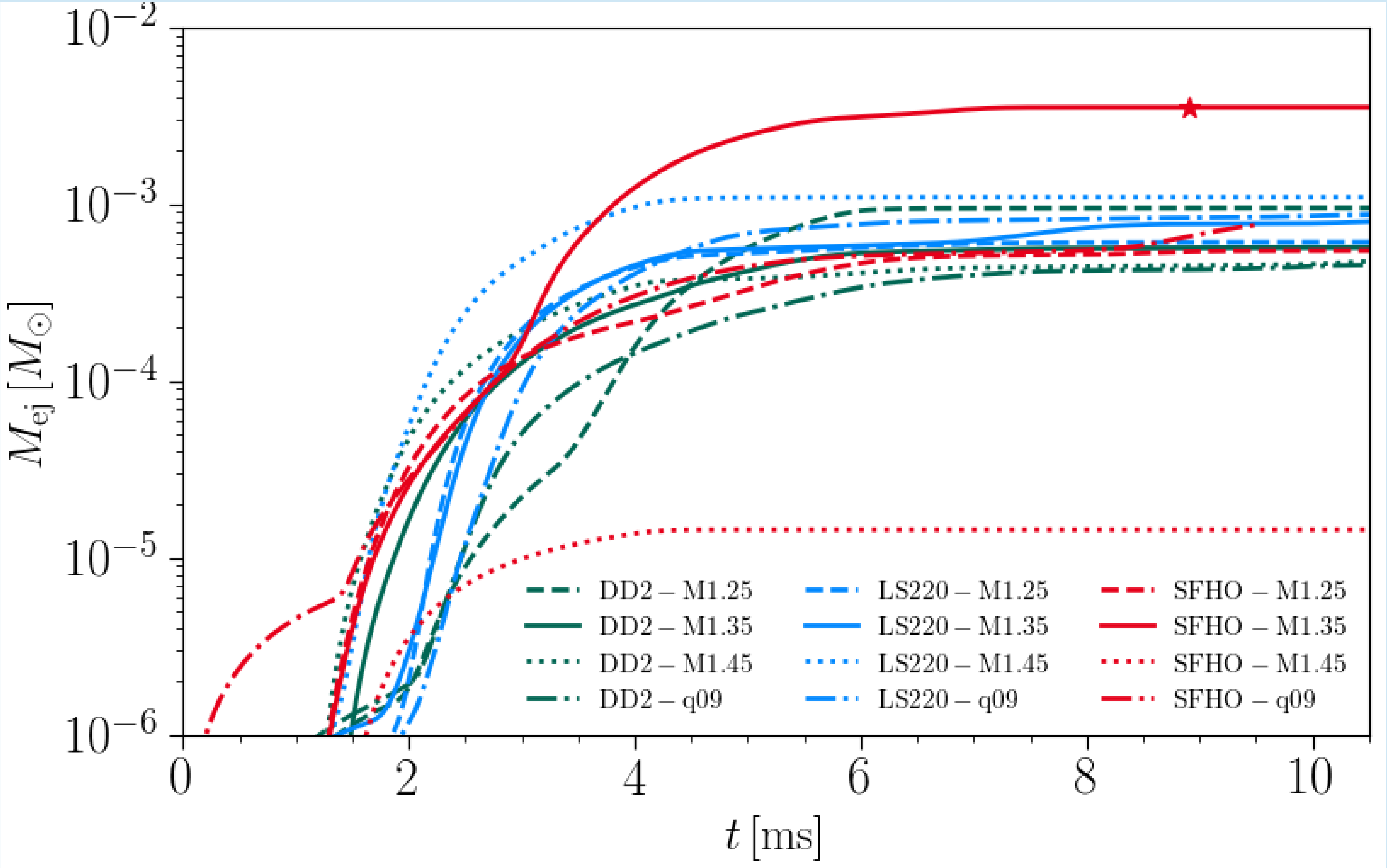
- *Requirement for unbound material* $u_t < -1$ *(geodesic) or* $hu_t < -1$ *(Bernoulli)*

**and willing to share*

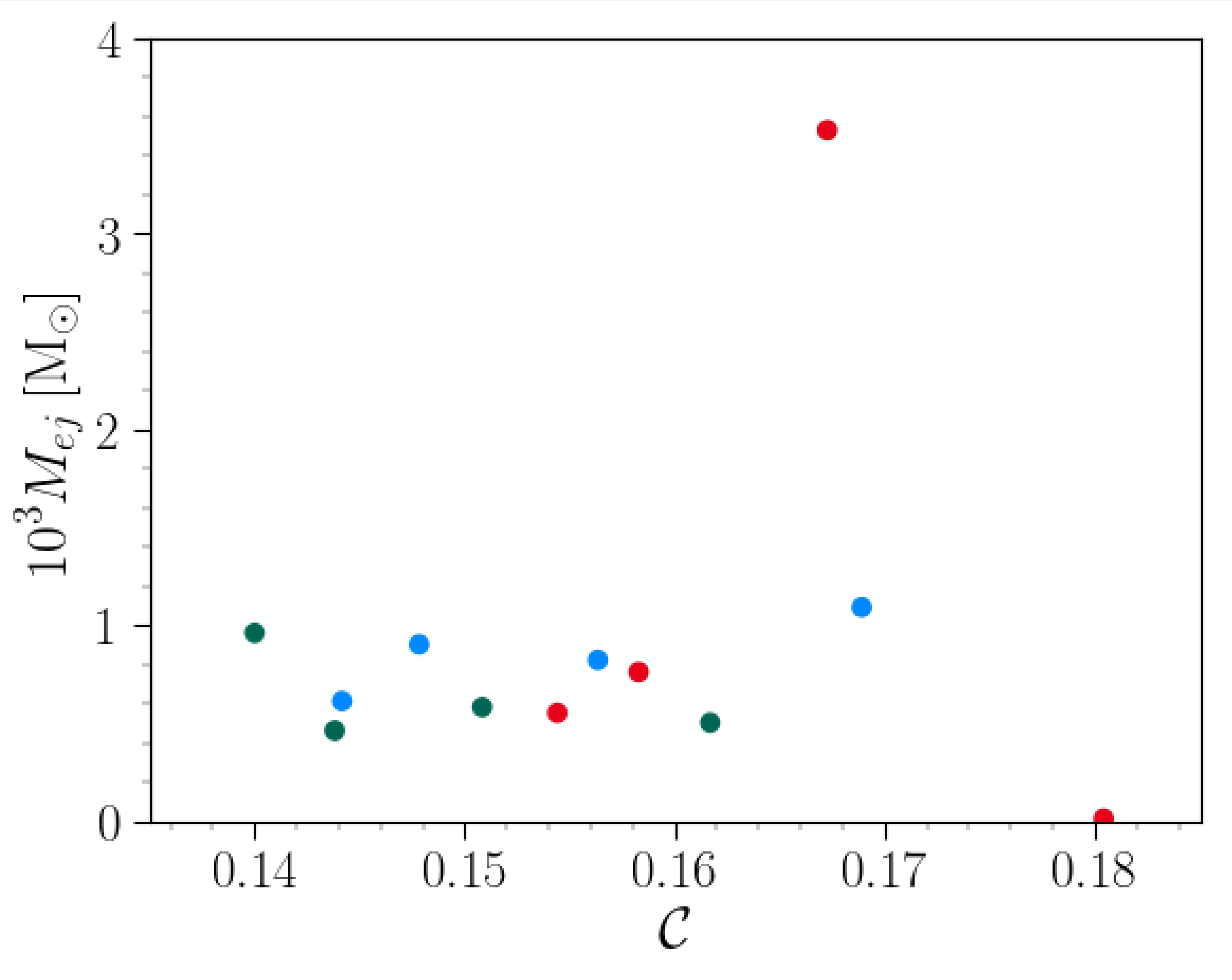
Distributions



Mass ejection



Mass ejection



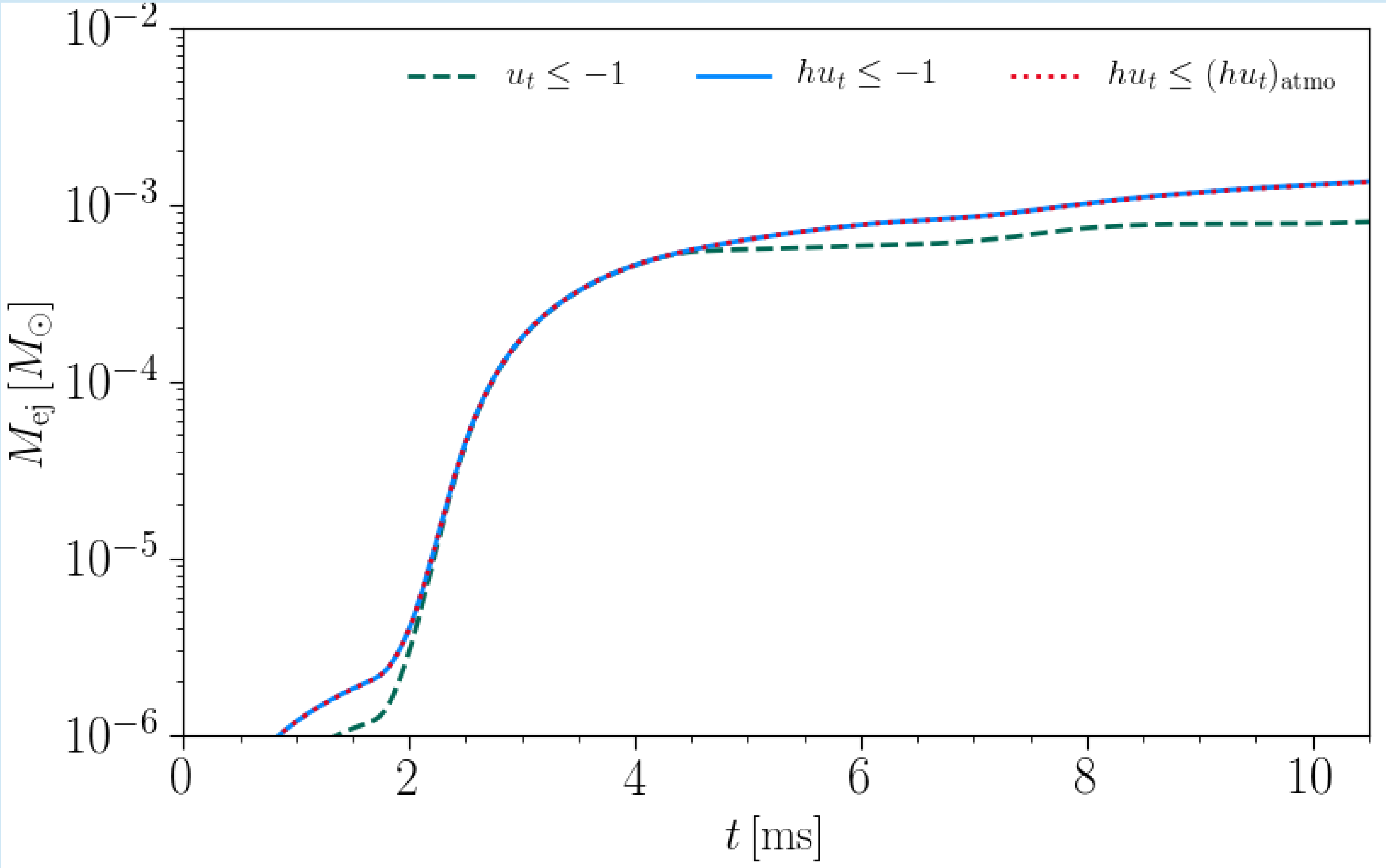
See Dietrich et al. 2016

Mass ejection

How sensitive is mass ejection to simulation set-up?

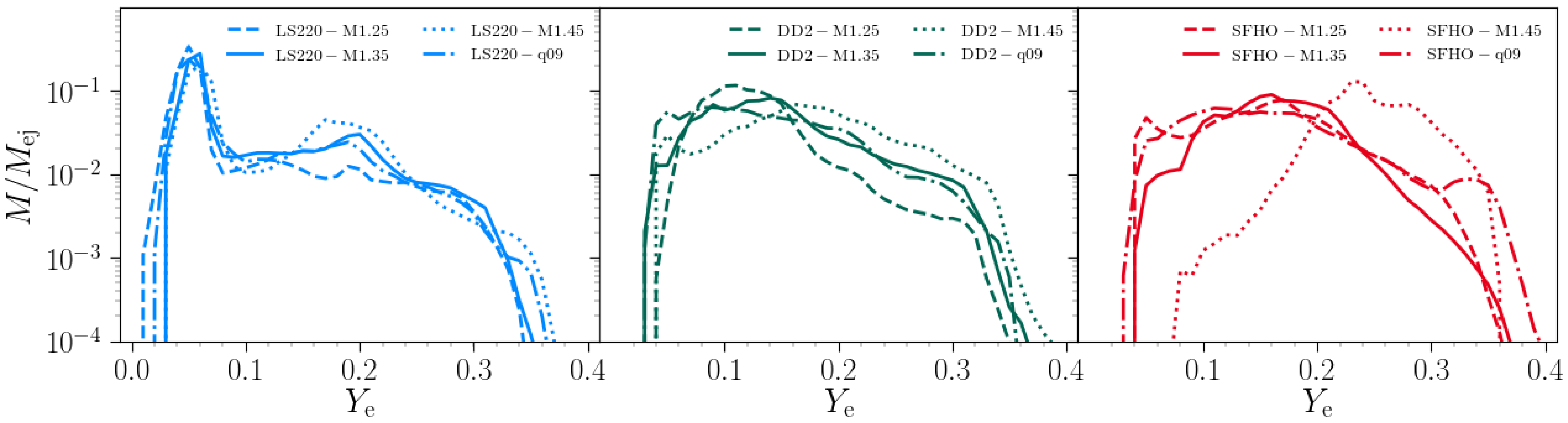
DD2 M1.35-M1.35	Mass ejection ($10^{-3}\,M_\odot$)	Set-up
Sekiguchi 2015	2.1	M1 w/ heating high resolution
-	1.9	M1 w/ heating low resolution
-	0.9	Leakage low resolution
Bauswein 2013	3.07	SPH
Lehner 2016	0.43	Leakage
Bovard 2017	0.58	Leakage

Mass ejection



Changing selection criteria can change mass ejection by factor of 3

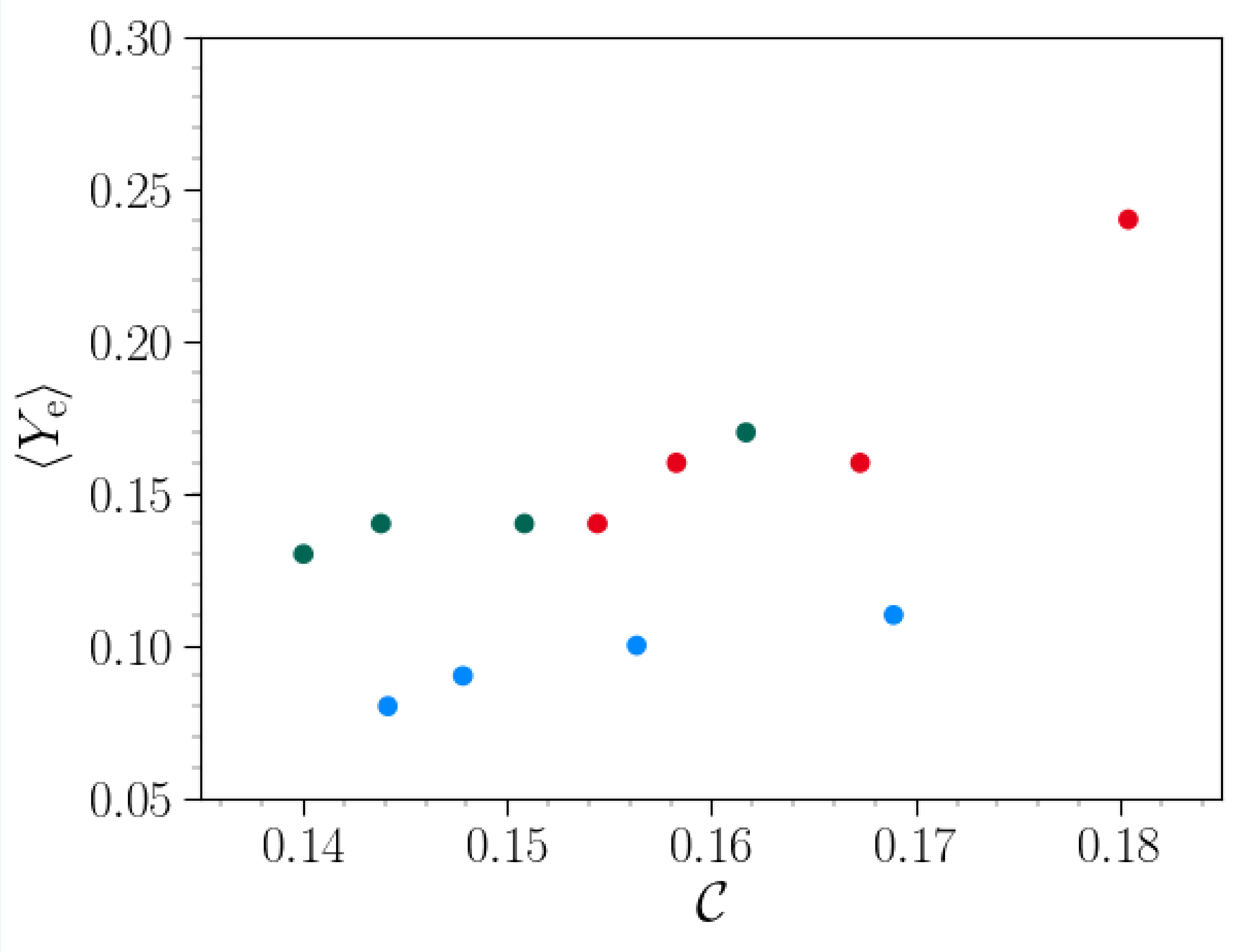
Composition



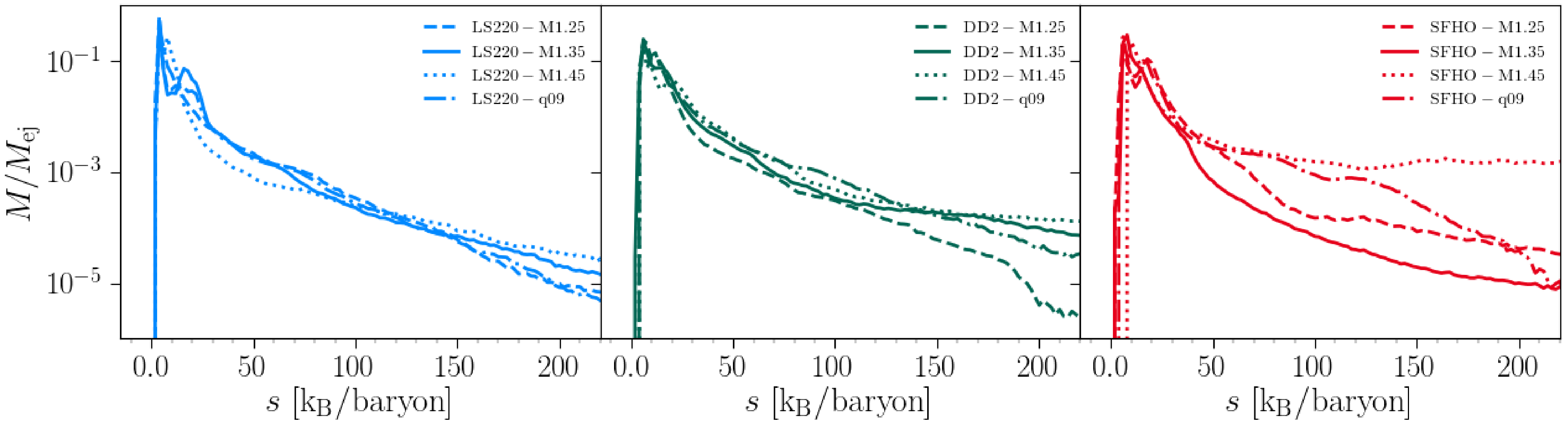
$<Y_e> \sim 0.16$ compare with $<Y_e> \sim 0.30$ from (Sekiguchi 2015) for SFHo 1.35-1.35

$<Y_e> \sim 0.14$ compare with $<Y_e> \sim 0.25$ from (Sekiguchi 2015) for DD2 1.35-1.35

Composition

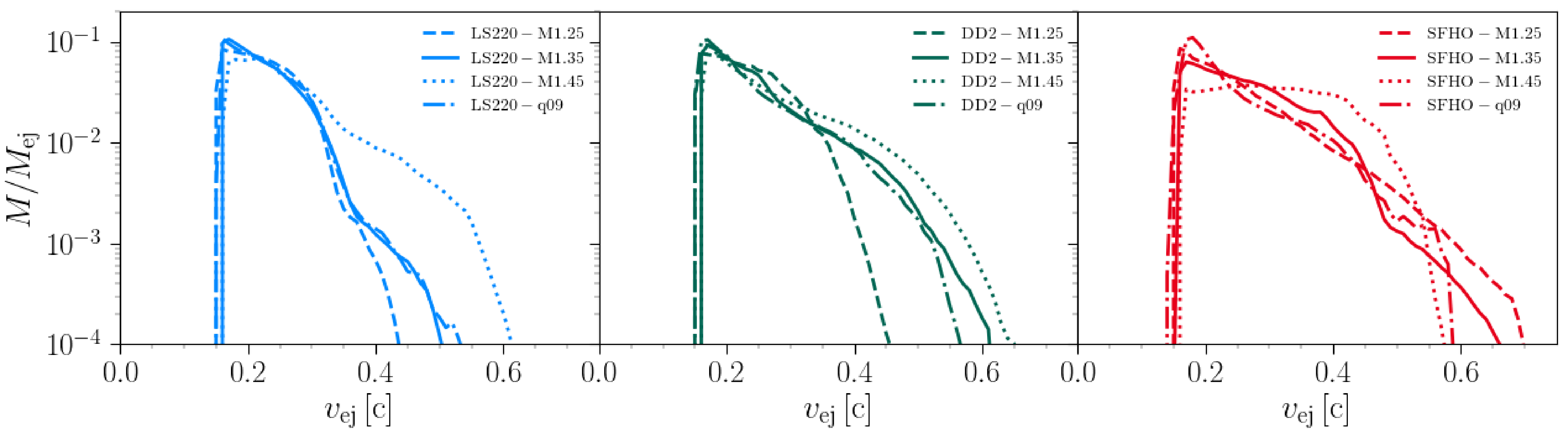


Entropy



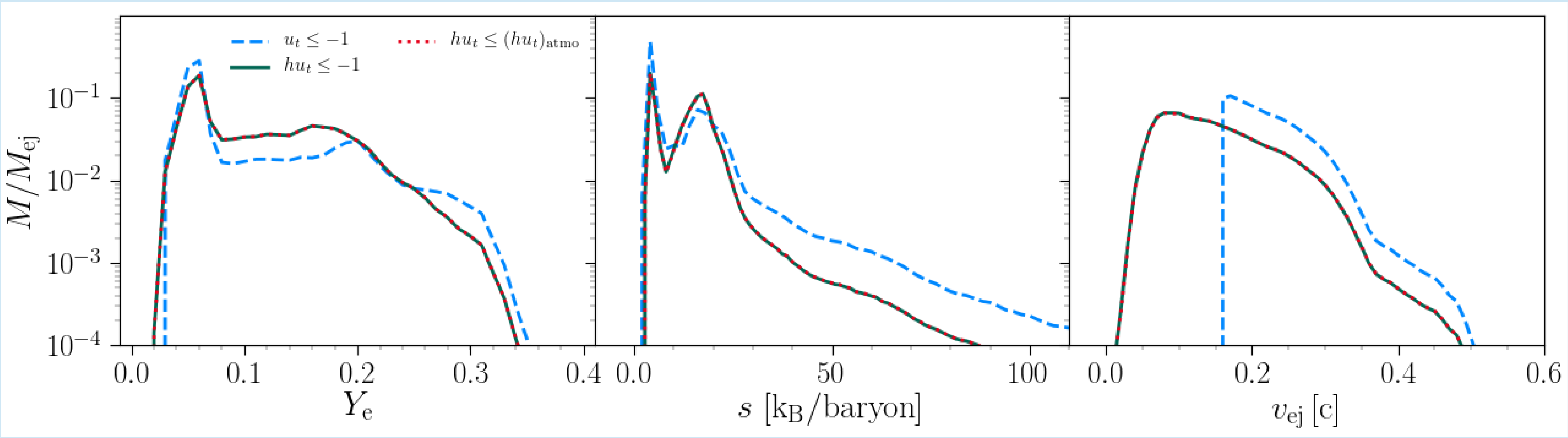
$<s> \sim 15\ k_B/baryon$

Velocity



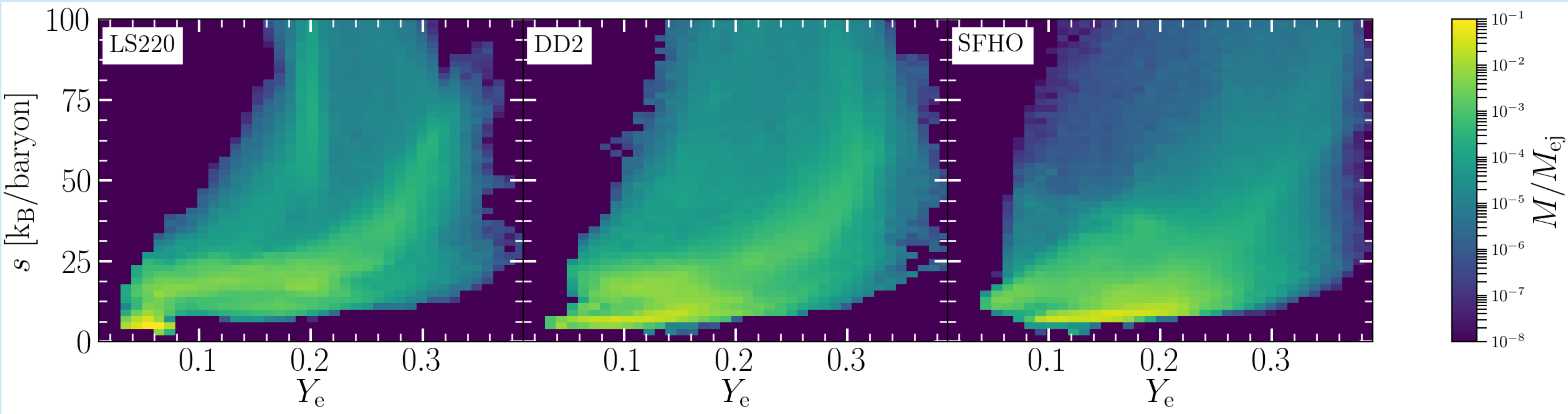
$<v_{ej}> \sim 0.23$ c compare with $<v_{ej}> \sim 0.2$ c from (Sekiguchi 2015)

Selection criteria

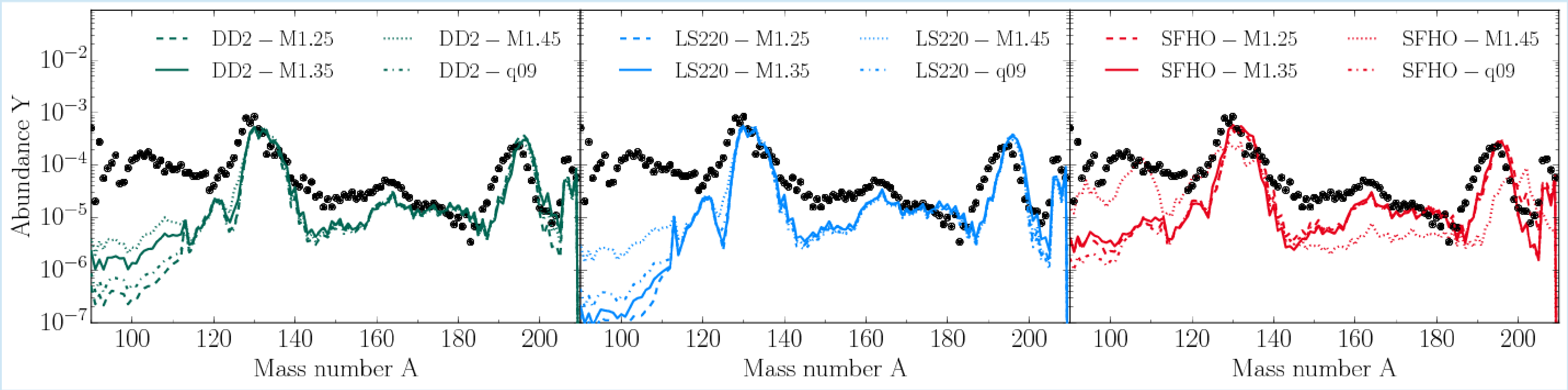


$\langle Y_e \rangle$, $\langle s \rangle$ remain unchanged, $\langle v_{ej} \rangle$ ~ 0.15c

entropy, Ye correlations

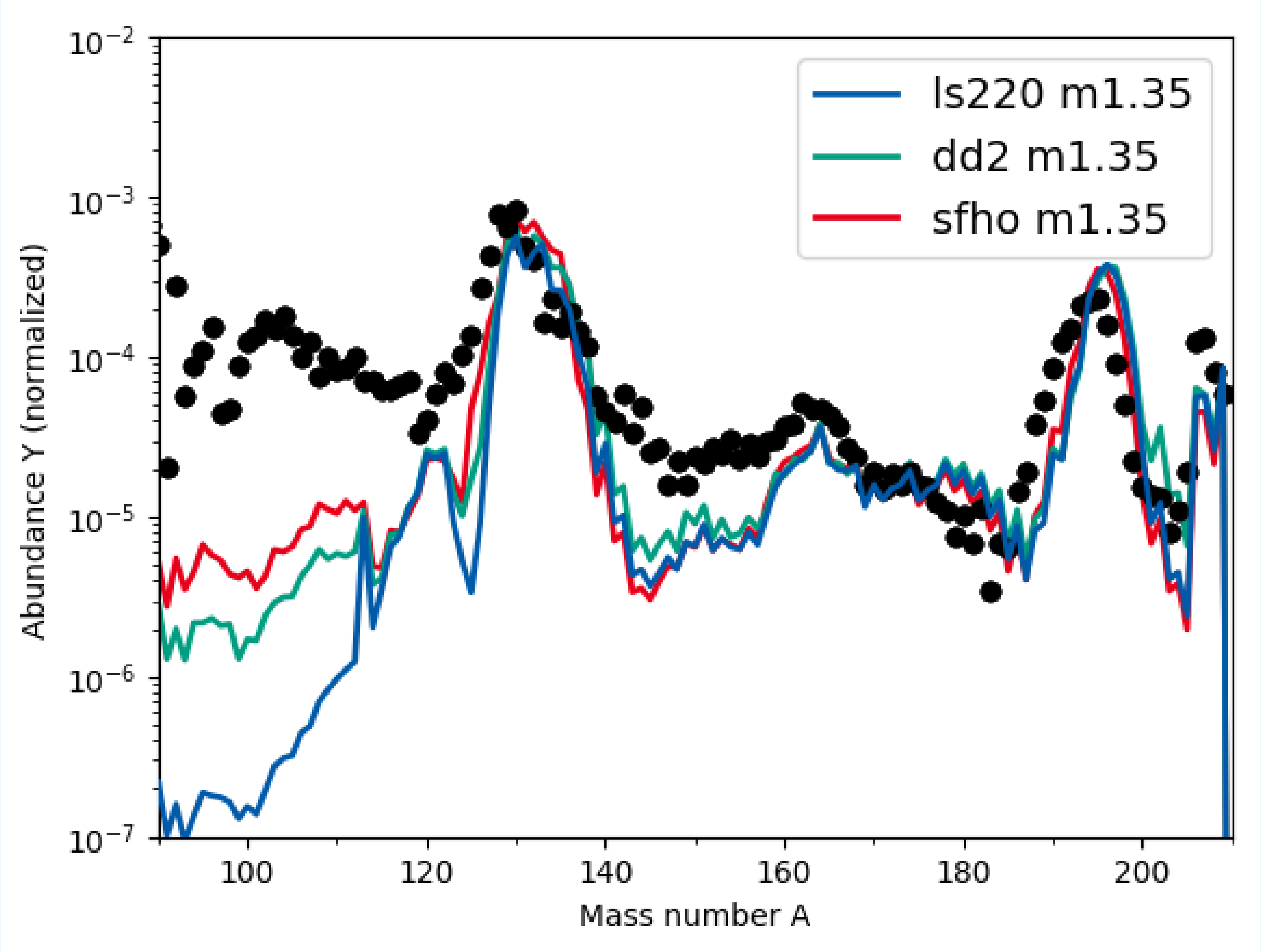


Nucleosynthesis



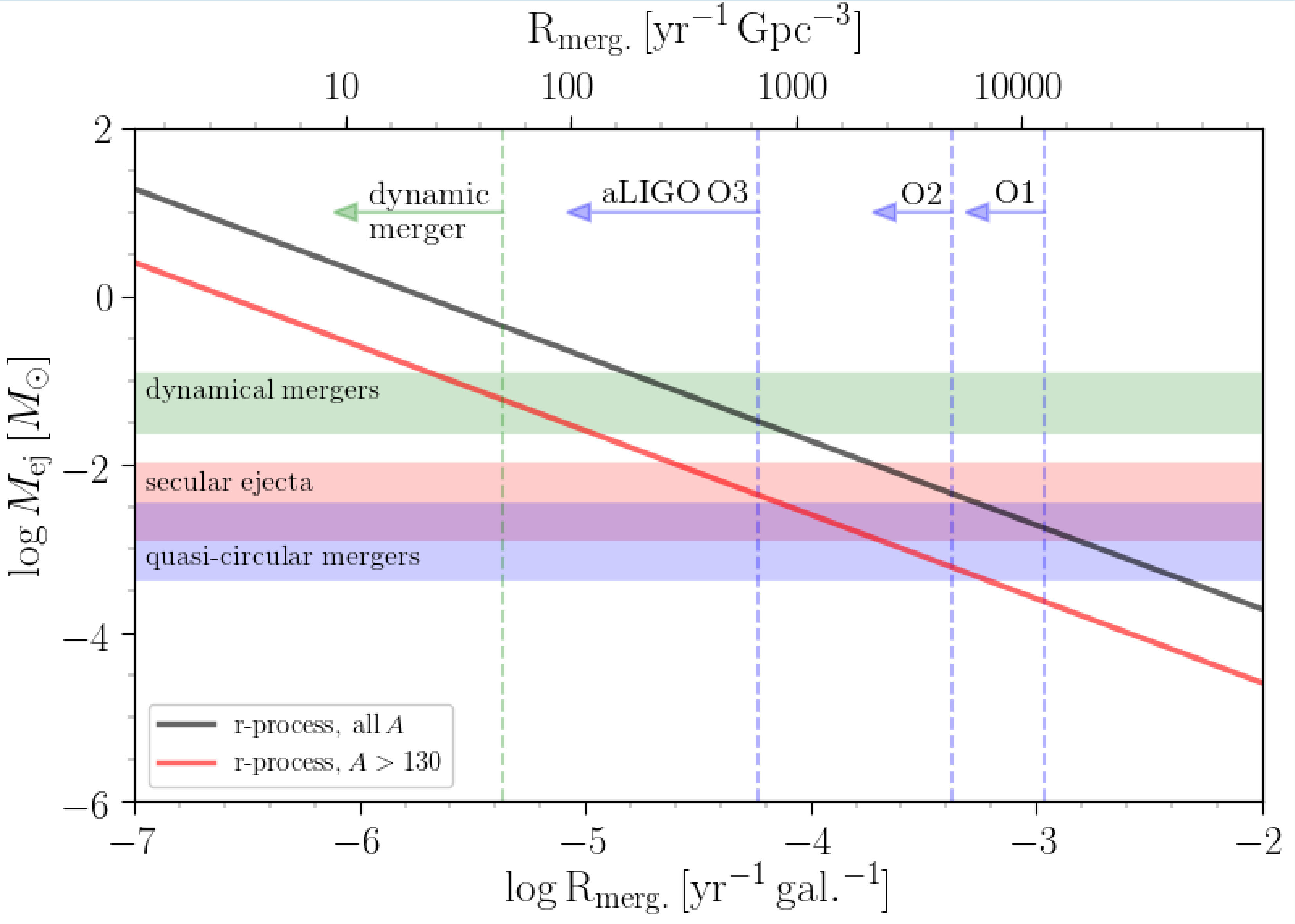
Nucleosynthesis by D. Martin with Winnet

Nucleosynthesis



Nucleosynthesis by D. Martin with Winnet

Detectability

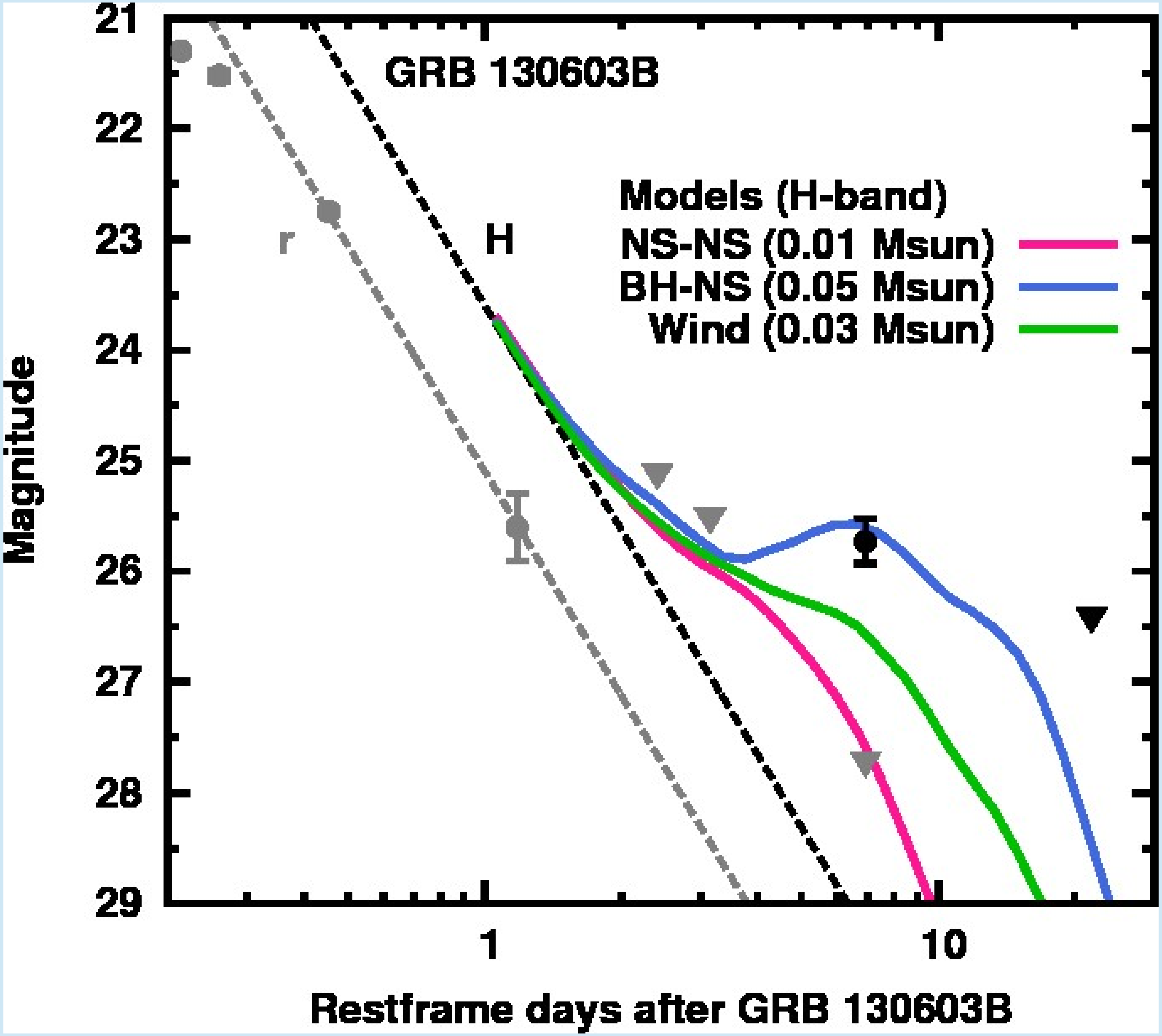


adapted from Hotokezaka 2015, Rosswog 2017

Kilonova/Macronovas

- *Gravitational waves are exciting, EM counterparts even more so (multi-messenger astronomy)*
- *r-process material undergoes radioactive decay (Li & Paczyński 1998)*
- *Observed with GRB 130603B*
- *Recent reviews: Metzger 2016, Tanaka 2016*

GRB 130603B



Tanaka 2016

Kilonova/Macronovas

Grossman et al. 2014

$$t_{\rm peak} = 4.9 \text{ days} \times \left(\frac{M_{ej}}{10^{-2}M_\odot}\right)^{\frac{1}{2}} \left(\frac{\kappa}{10{\rm cm}^2{\rm g}^{-1}}\right)^{\frac{1}{2}} \left(\frac{v_{\rm ej}}{0.1}\right)^{-\frac{1}{2}},$$

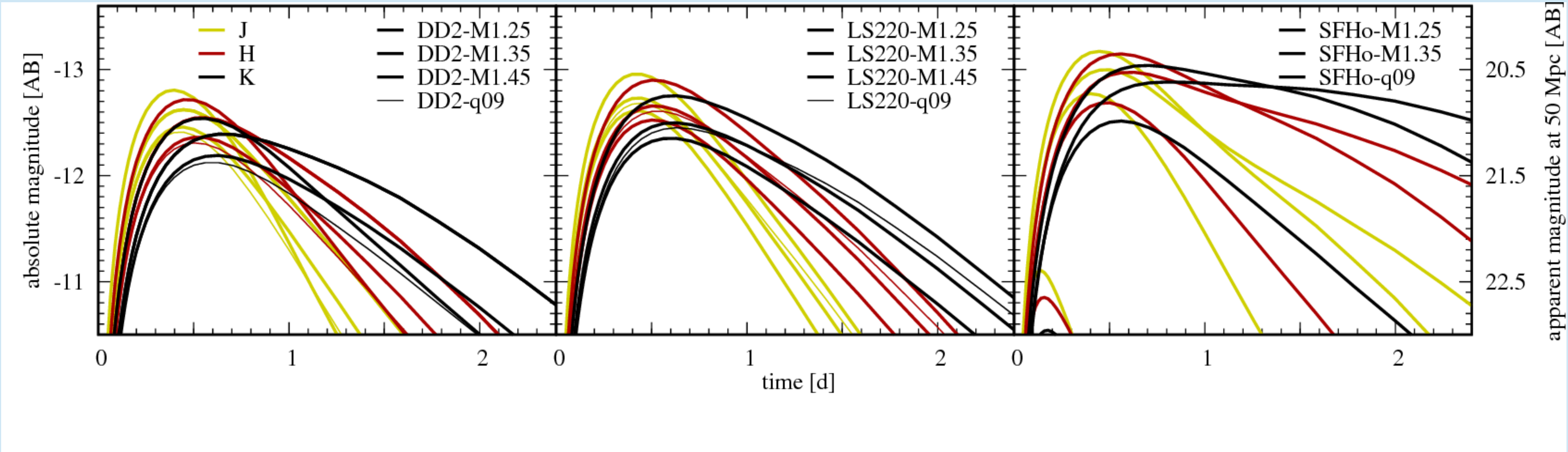
$$L_{\rm peak} = 2.5 \cdot 10^{40} {\rm erg\,s}^{-1} \times \left(\frac{M_{ej}}{10^{-2}M_\odot}\right)^{1-\frac{\alpha}{2}} \left(\frac{\kappa}{10{\rm cm}^2{\rm g}^{-1}}\right)^{-\frac{\alpha}{2}} \left(\frac{v_{\rm ej}}{0.1}\right)^{\frac{\alpha}{2}},$$

$$T_{\rm peak} = 2200{\rm K} \times \left(\frac{M_{ej}}{10^{-2}M_\odot}\right)^{-\frac{\alpha}{8}} \left(\frac{\kappa}{10{\rm cm}^2{\rm g}^{-1}}\right)^{-\frac{\alpha+2}{8}} \left(\frac{v_{\rm ej}}{0.1}\right)^{\frac{\alpha-2}{8}}.$$

$\alpha = 1.3$

see talks next week on opacities + Tanaka

Kilonova/Macronovas



see talk by Korobkin

figure by O. Korobkin

Kilonova/Macronovas

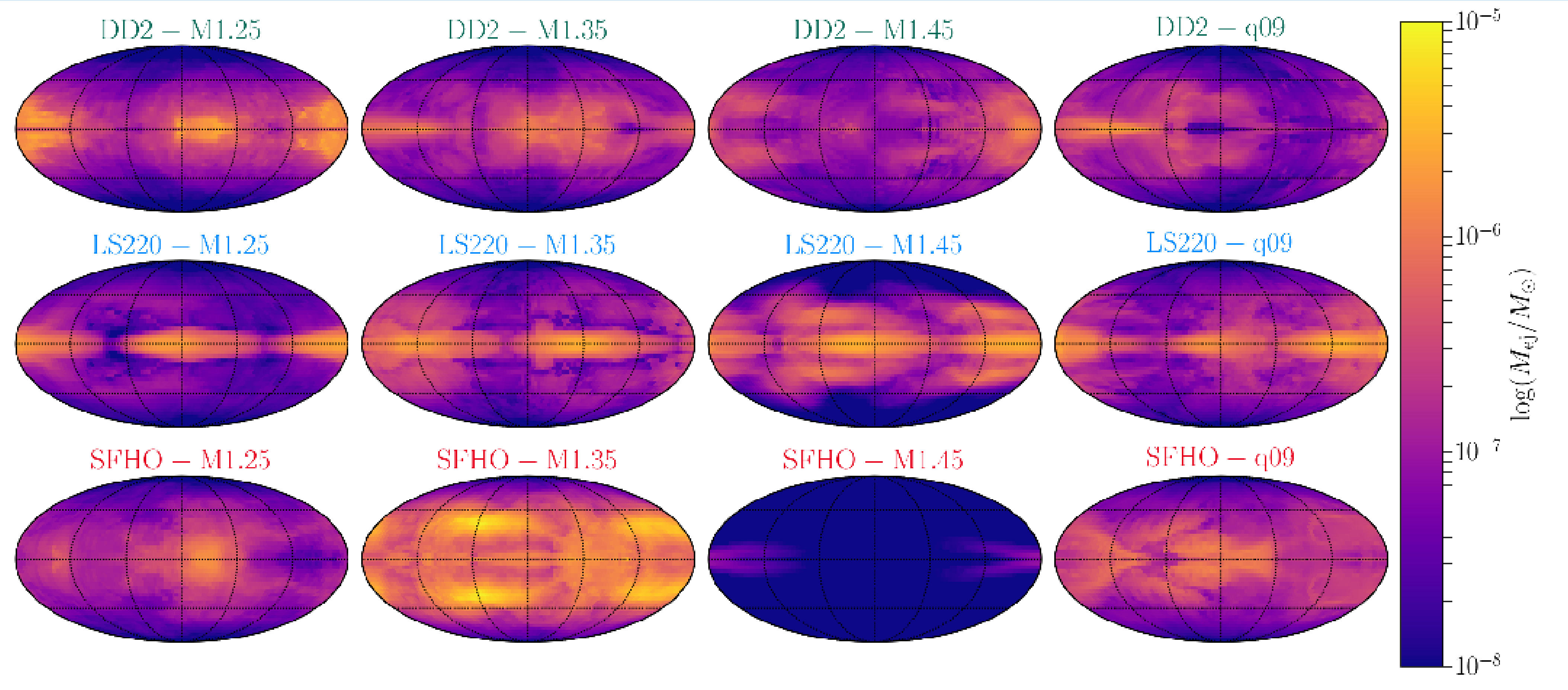


figure by F. Guercilena

Kilonova/Macronovas

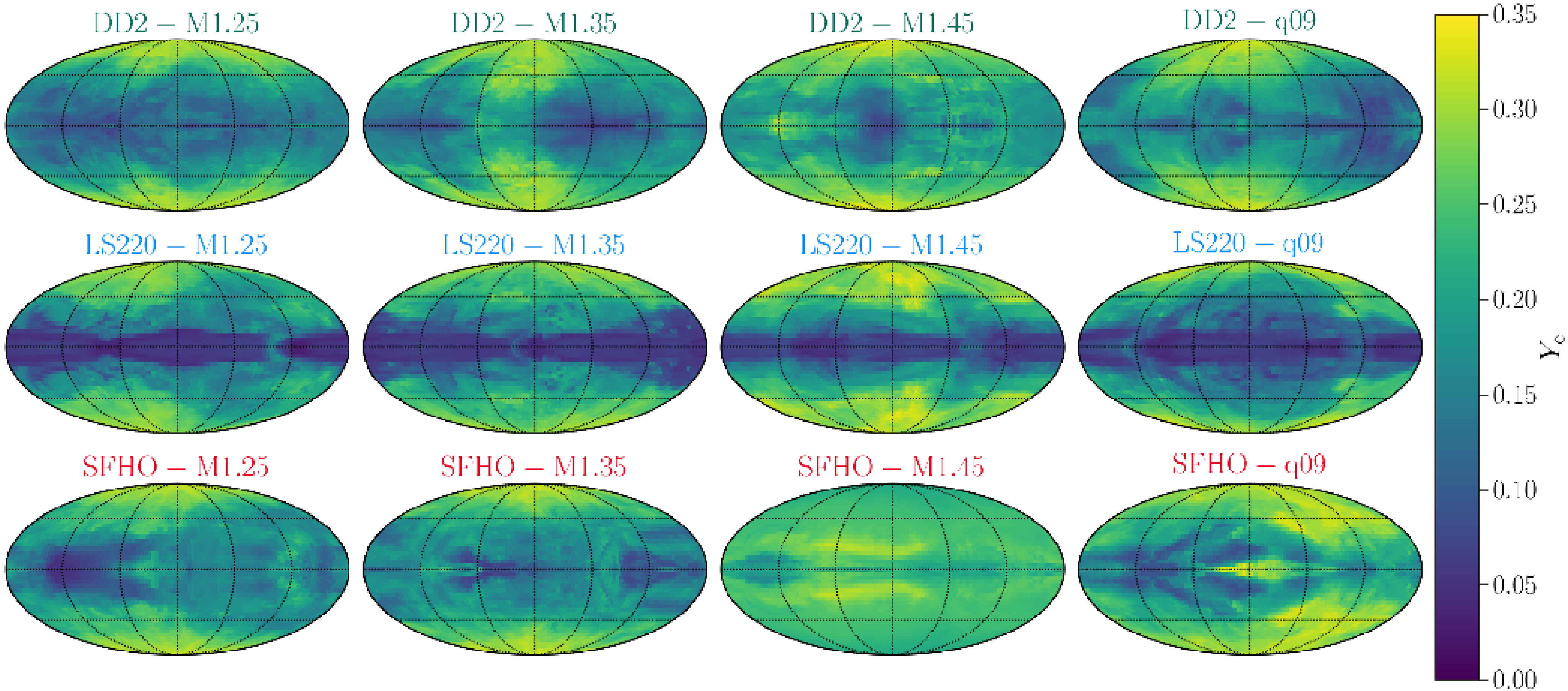


figure by F. Guercilena

Conclusions

- *Dynamical mass ejection values are converging*
- *Robust r-process produced from different EOS and masses*
- *Improved neutrino treatment critical for kilonova/macronova modeling*