Magnetorotational supernovae

A nucleosynthetic analysis of sophisticated 3D models

M. Reichert, M. Obergaulinger, M. Á. Aloy, M. Gabler, A. Arcones

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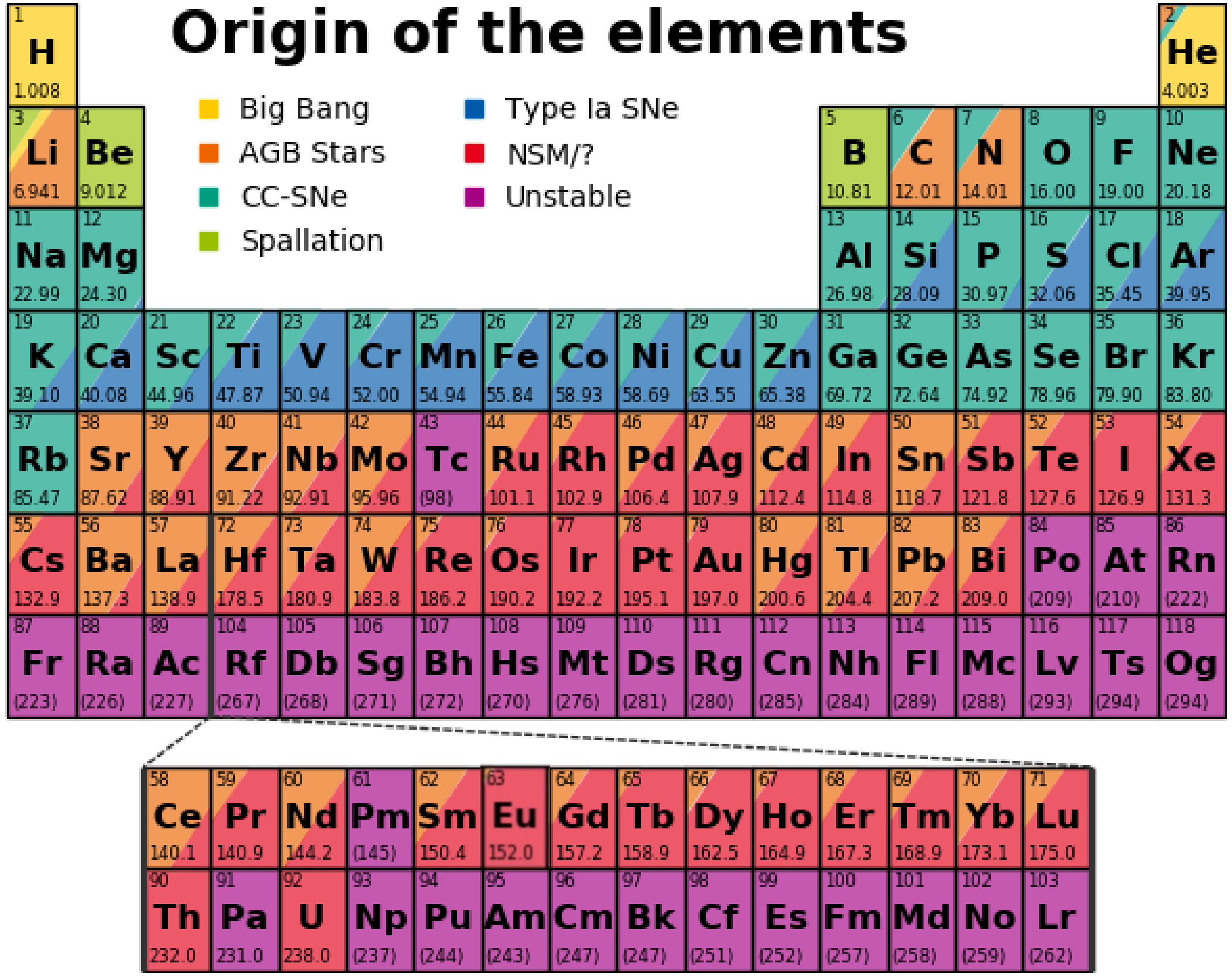


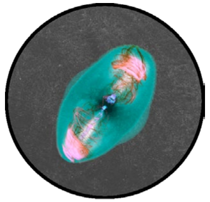
Origin of the elements

- 🟨 Big Bang
- 🟧 AGB Stars
- 🟩 CC-SNe
- 🟩 Spallation
- 🟦 Type Ia SNe
- 🟥 NSM/?
- 🟪 Unstable

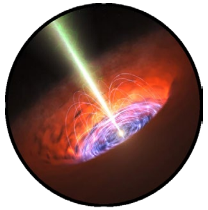
1 H 1.008																	2 He 4.003
3 Li 6.941	4 Be 9.012											5 B 10.81	6 C 12.01	7 N 14.01	8 O 16.00	9 F 19.00	10 Ne 20.18
11 Na 22.99	12 Mg 24.30											13 Al 26.98	14 Si 28.09	15 P 30.97	16 S 32.06	17 Cl 35.45	18 Ar 39.95
19 K 39.10	20 Ca 40.08	21 Sc 44.96	22 Ti 47.87	23 V 50.94	24 Cr 52.00	25 Mn 54.94	26 Fe 55.84	27 Co 58.93	28 Ni 58.69	29 Cu 63.55	30 Zn 65.38	31 Ga 69.72	32 Ge 72.64	33 As 74.92	34 Se 78.96	35 Br 79.90	36 Kr 83.80
37 Rb 85.47	38 Sr 87.62	39 Y 88.91	40 Zr 91.22	41 Nb 92.91	42 Mo 95.96	43 Tc (98)	44 Ru 101.1	45 Rh 102.9	46 Pd 106.4	47 Ag 107.9	48 Cd 112.4	49 In 114.8	50 Sn 118.7	51 Sb 121.8	52 Te 127.6	53 I 126.9	54 Xe 131.3
55 Cs 132.9	56 Ba 137.3	57 La 138.9	72 Hf 178.5	73 Ta 180.9	74 W 183.8	75 Re 186.2	76 Os 190.2	77 Ir 192.2	78 Pt 195.1	79 Au 197.0	80 Hg 200.6	81 Tl 204.4	82 Pb 207.2	83 Bi 209.0	84 Po (209)	85 At (210)	86 Rn (222)
87 Fr (223)	88 Ra (226)	89 Ac (227)	104 Rf (267)	105 Db (268)	106 Sg (271)	107 Bh (272)	108 Hs (270)	109 Mt (276)	110 Ds (281)	111 Rg (280)	112 Cn (285)	113 Nh (284)	114 Fl (289)	115 Mc (288)	116 Lv (293)	117 Ts (294)	118 Og (294)

58 Ce 140.1	59 Pr 140.9	60 Nd 144.2	61 Pm (145)	62 Sm 150.4	63 Eu 152.0	64 Gd 157.2	65 Tb 158.9	66 Dy 162.5	67 Ho 164.9	68 Er 167.3	69 Tm 168.9	70 Yb 173.1	71 Lu 175.0
90 Th 232.0	91 Pa 231.0	92 U 238.0	93 Np (237)	94 Pu (244)	95 Am (243)	96 Cm (247)	97 Bk (247)	98 Cf (251)	99 Es (252)	100 Fm (257)	101 Md (258)	102 No (259)	103 Lr (262)

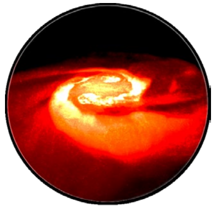
Magnetorotational supernovae



Collapsars

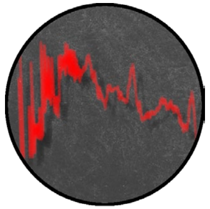


Neutronstar merger

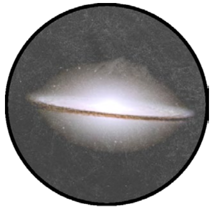


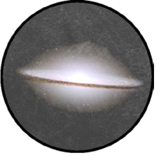
r-process? →

Nucleosynthesis calculations

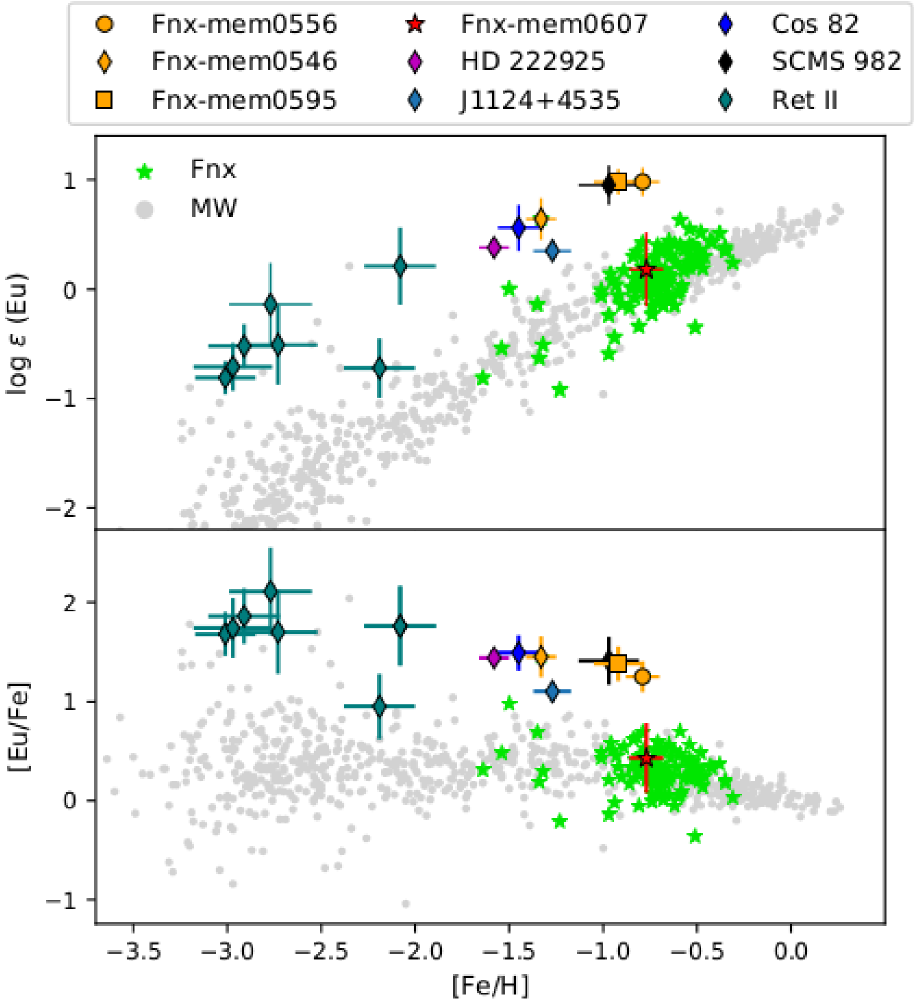


Stellar observations



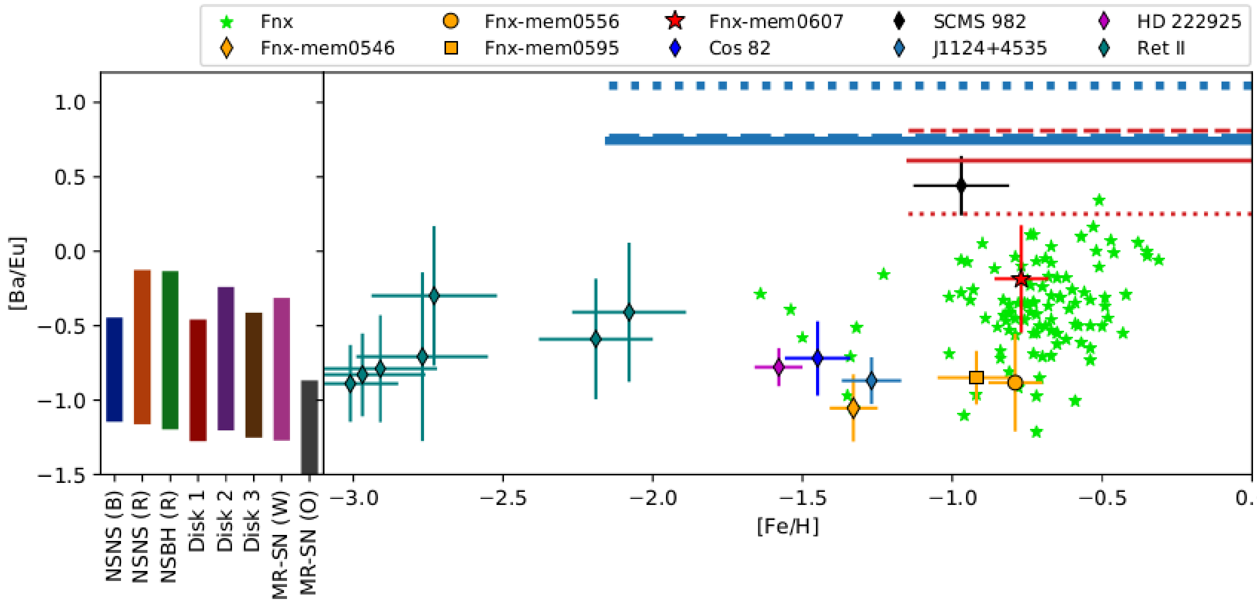


The dwarf spheroidal galaxy Fornax

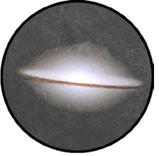


M_{Eu} : $1.5 * 10^{-5} - 3 * 10^{-5} M_{\odot}$

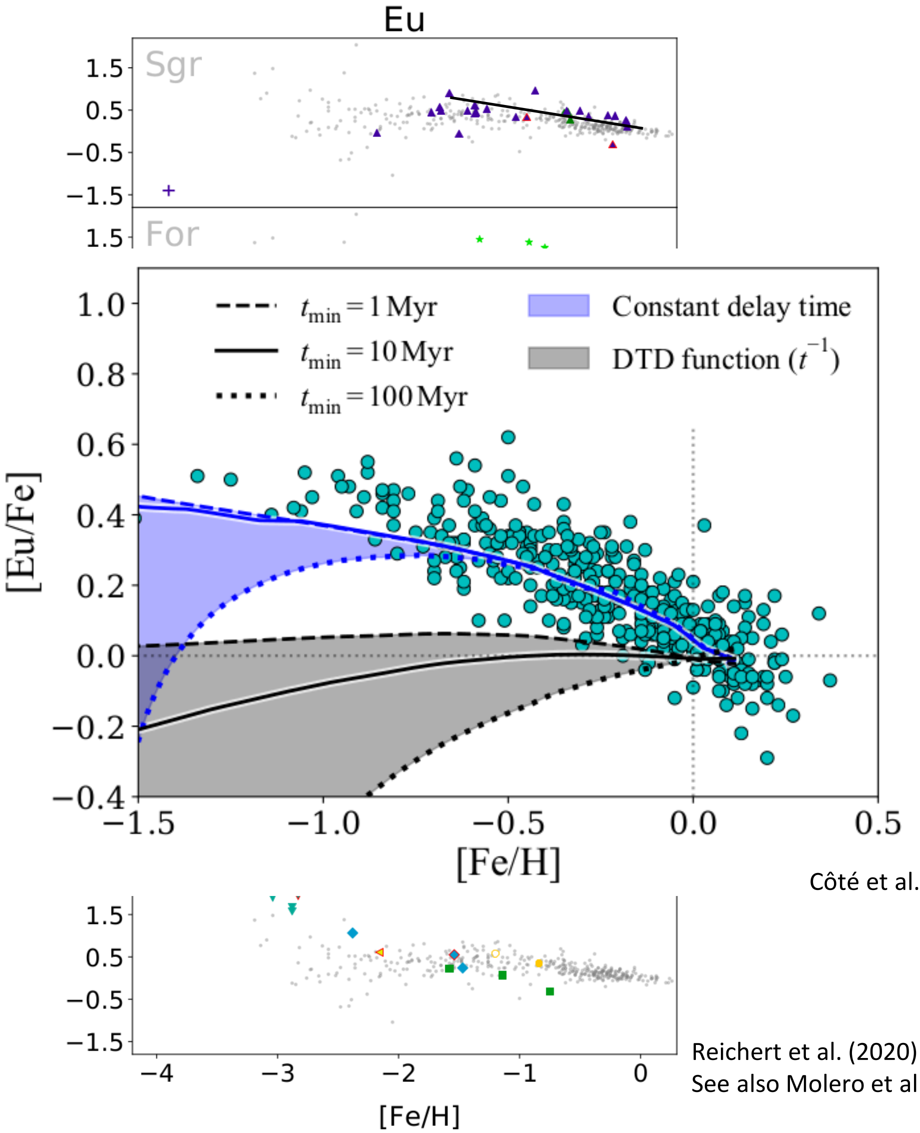
Delay time : $\sim 500\ Myr$



Reichert, Hansen & Arcones (2021), Reichert et al. (2020)



A decreasing Eu trend at high metallicities

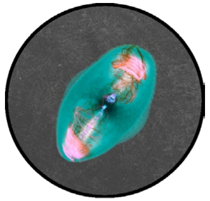


Côté et al. (2019)

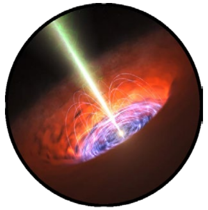
Reichert et al. (2020)
See also Molero et al. (2021)

Event contributing at early time?

Magnetorotational supernovae

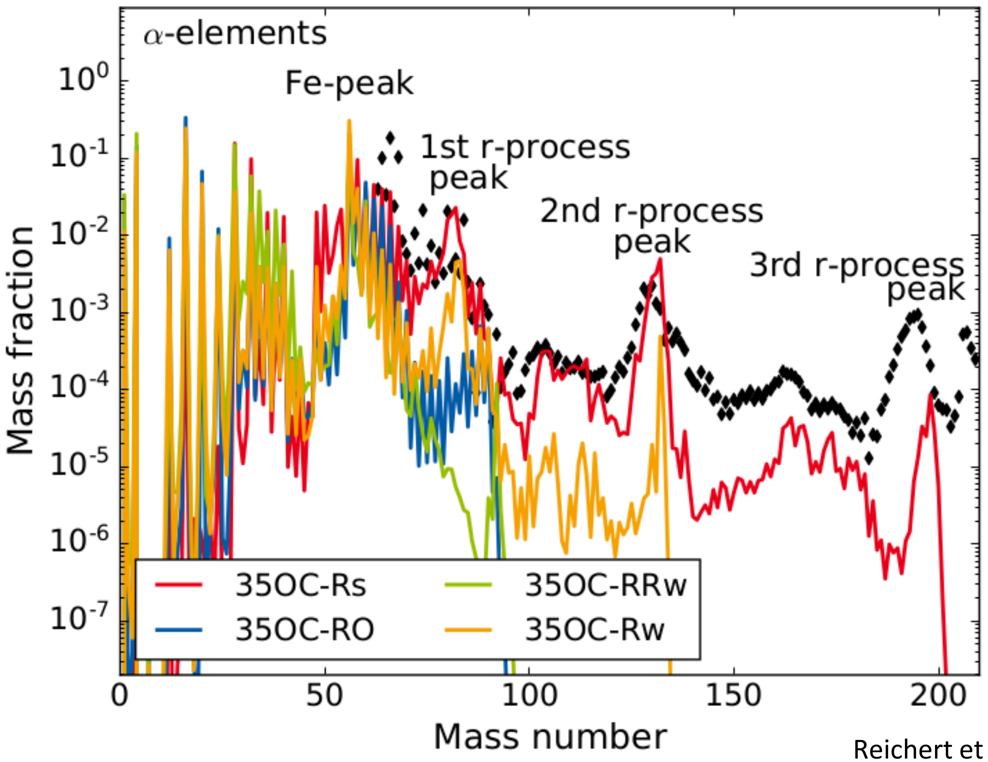


Collapsars



Nucleosynthesis of magnetorotational supernovae

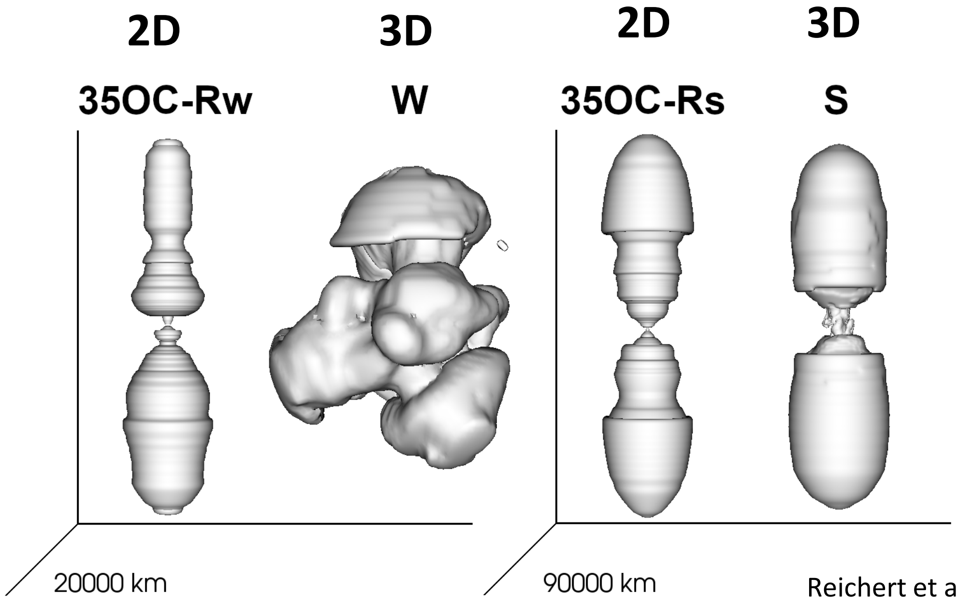
2D models



Reichert et al. (2021b)

Models

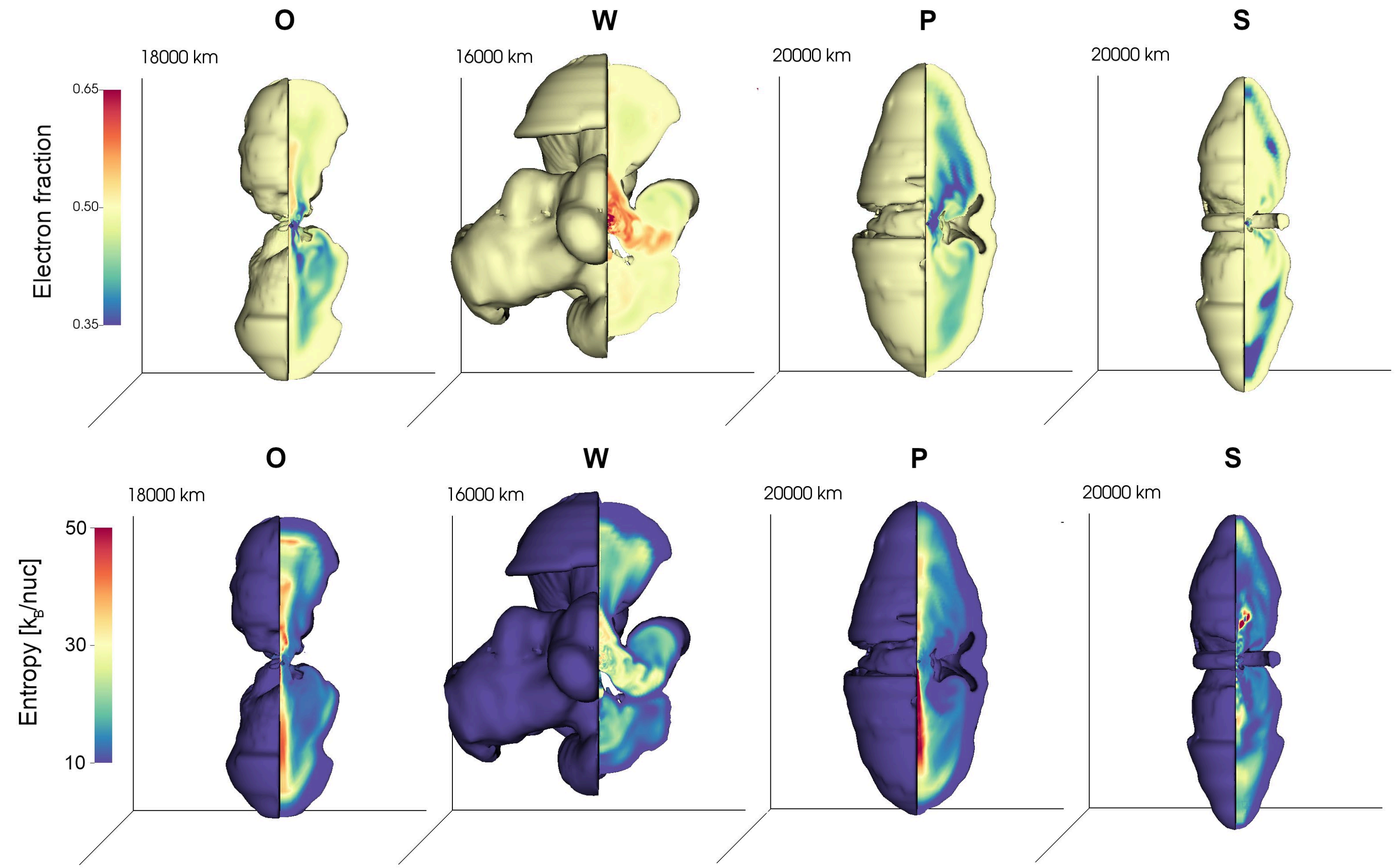
Ordinary magnetic field
Weak magnetic field
Strong magnetic field



Reichert et al. (2022, submitted, arXiv:2206.11914v1)

See also e.g., Obergaulinger & Aloy 2017, 2020, 2021; Aloy & Obergaulinger 2021

Nucleosynthesis of magnetorotational supernovae

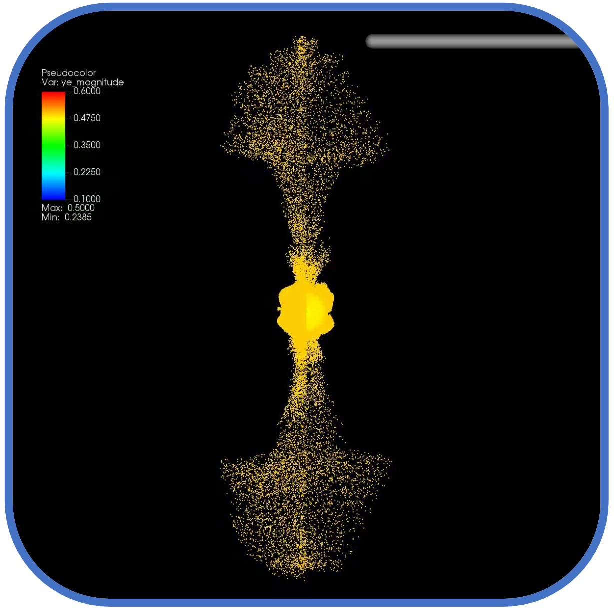


Models

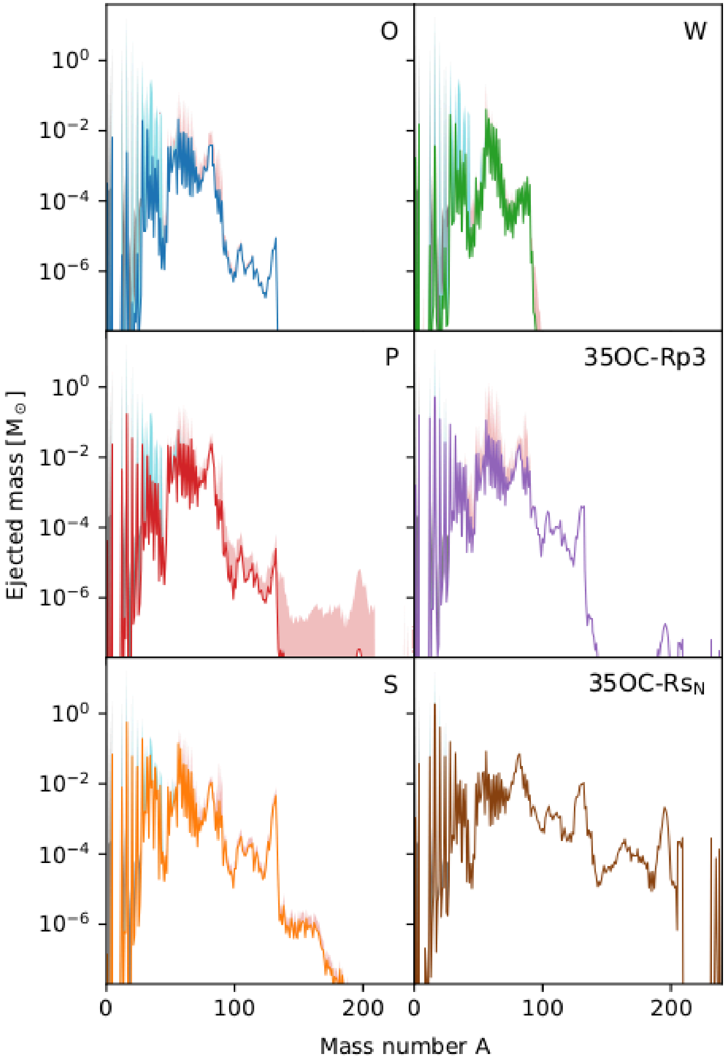
Ordinary magnetic field
Weak magnetic field
Poloidal field x3
Strong magnetic field

Reichert et al. (2022, submitted, arXiv:2206.11914v1), Hydrodynamic simulations of Obergaulinger & Aloy 2021

Nucleosynthesis of magnetorotational supernovae



Abundances



Models

Ordinary magnetic field
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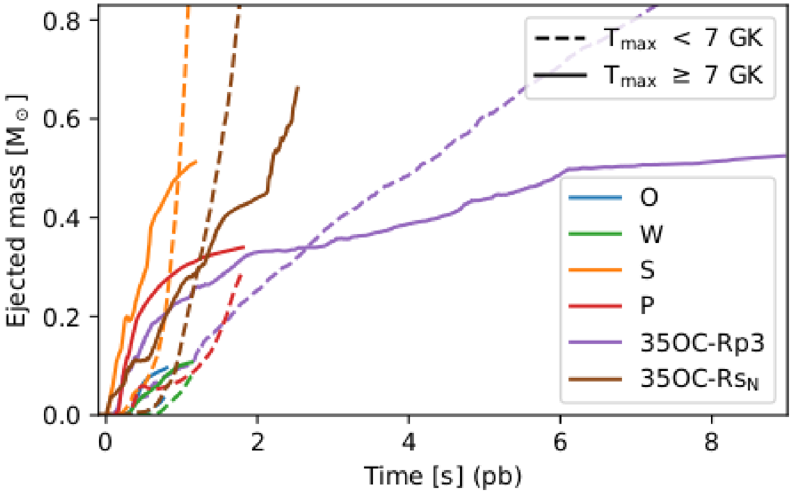
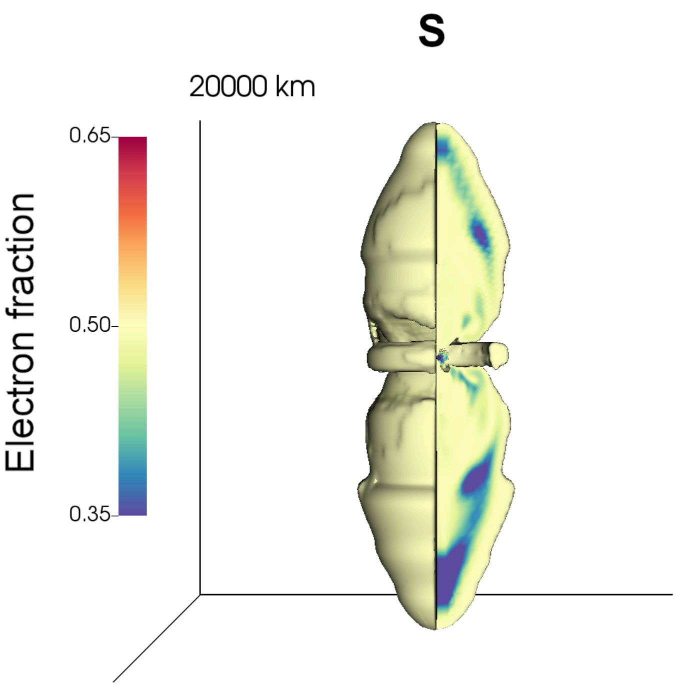


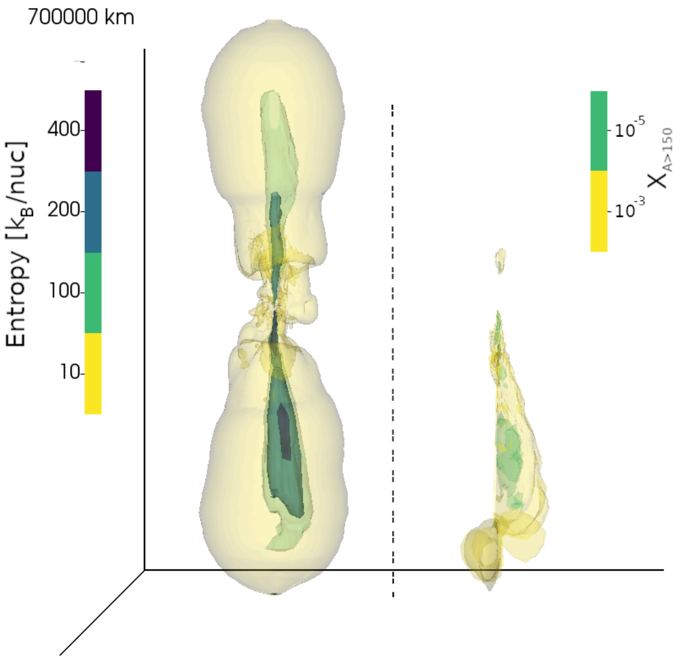
Reichert et al. (2022, submitted, arXiv:2206.11914v1)
Hydrodynamic simulation of Obergaulinger & Aloy 2021

Nucleosynthesis of magnetorotational supernovae, r-process

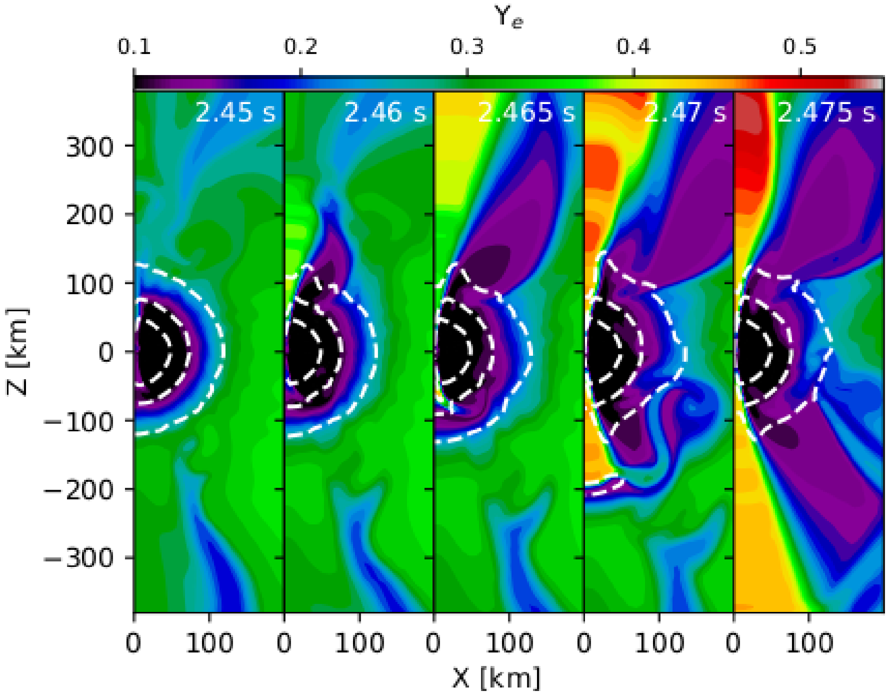
Prompt ejection
(2D)



High entropies
(2D and 3D)



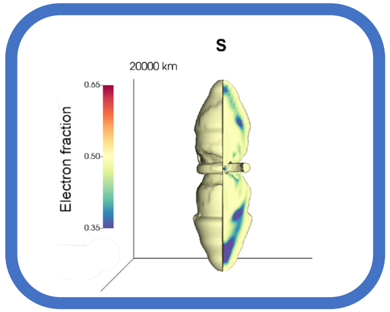
PNS shape reconfiguration
(2D)



Reichert et al. (2022, submitted, arXiv:2206.11914v1)

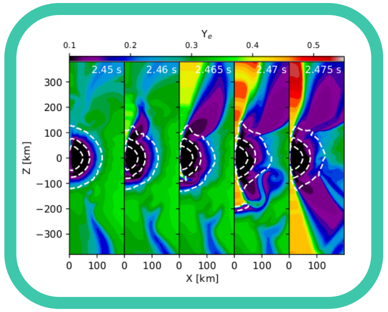
Nucleosynthesis of magnetorotational supernovae, r-process

Prompt



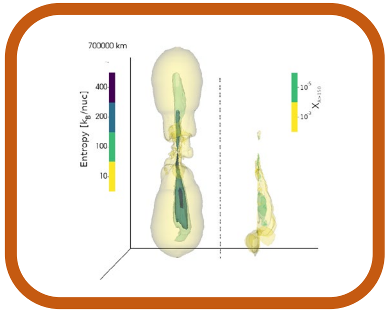
e.g.,
Nishimura et al. 2006; Winteler et al. 2012;
Nishimura et al. 2015,2017; Mösta et al. 2018;
Halevi & Mösta 2018; Reichert et al. 2021, 2022

PNS-Shape

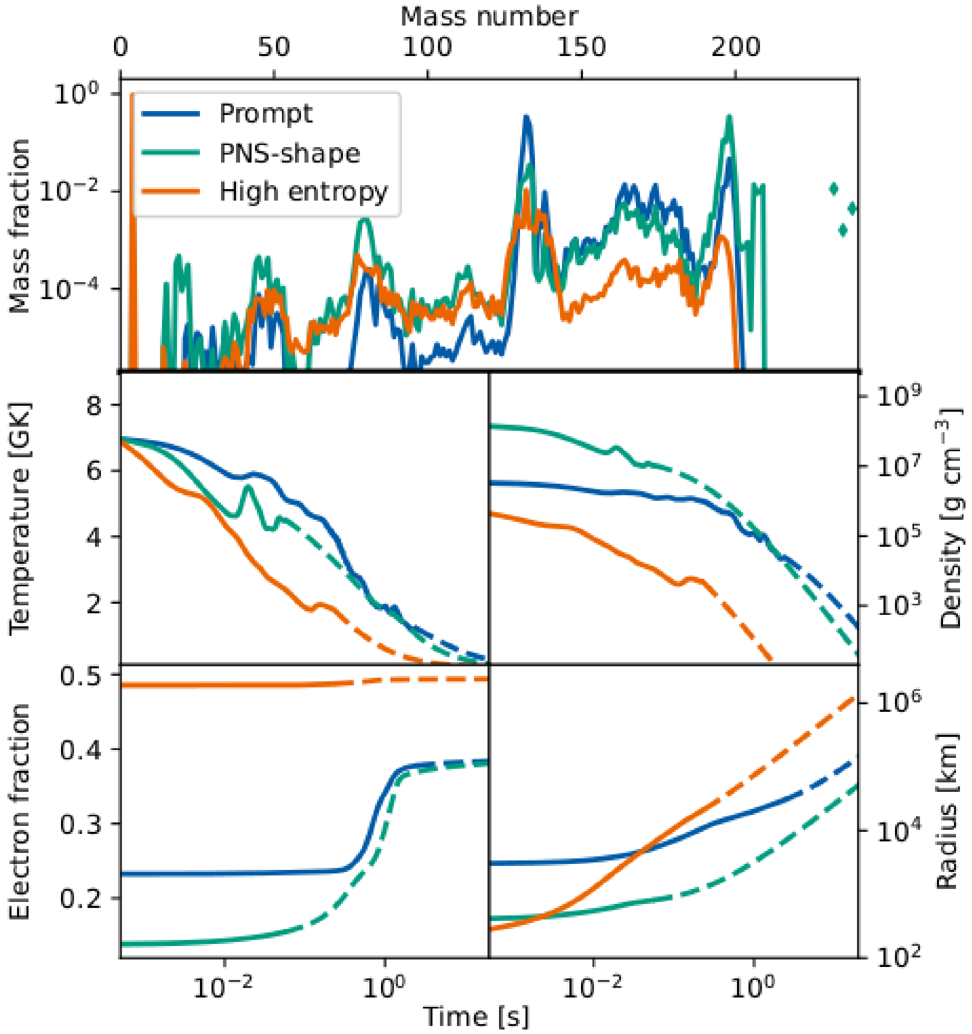


e.g.,
Reichert et al. 2021, 2022

High entropy

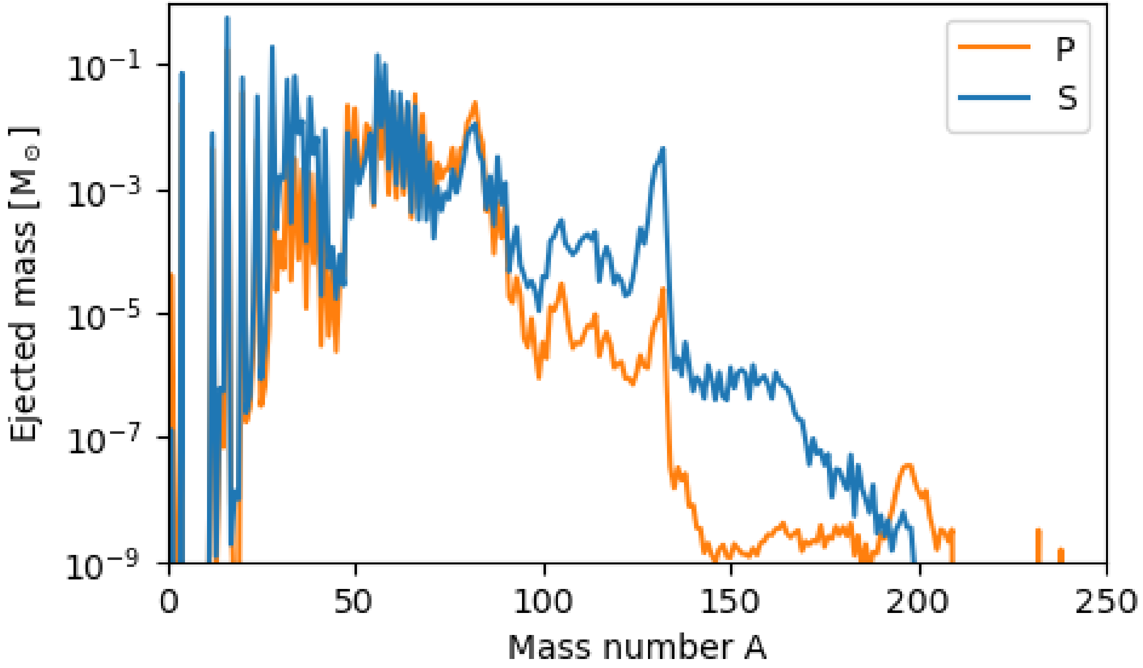


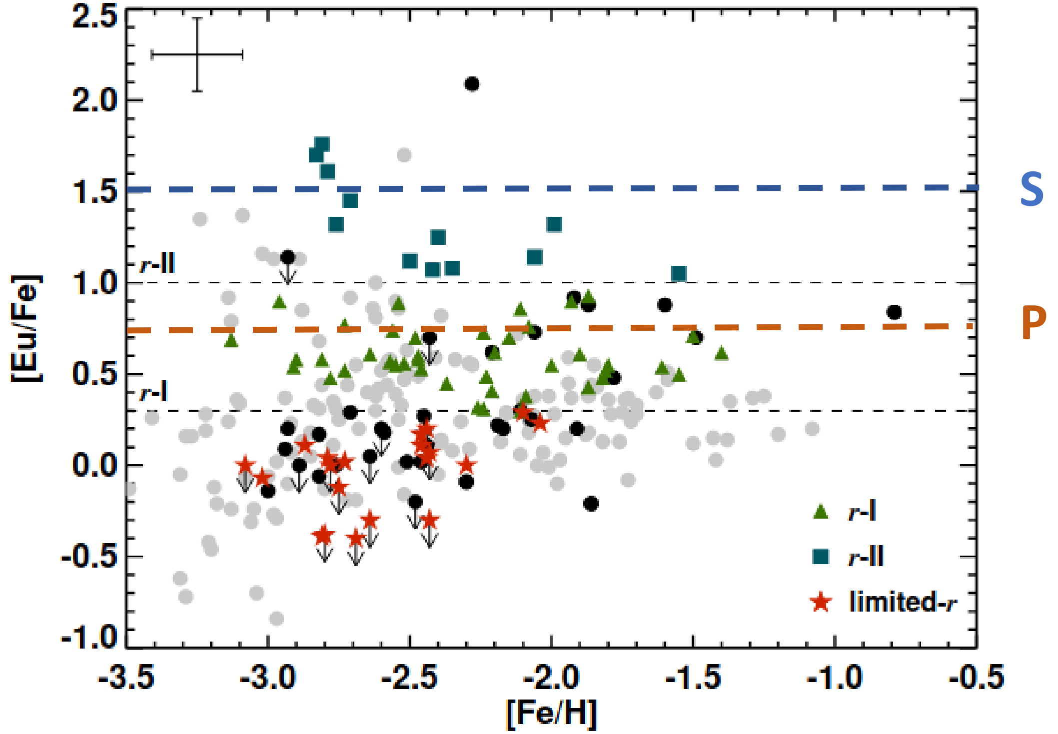
e.g.,
Meyer 1994; Woosley et al 1994;
Wheeler et al. 1998; Freiburghaus et al. 1999;
Meyer 2002, Reichert et al. 2022



Reichert et al. (2022, submitted, arXiv:2206.11914v1)

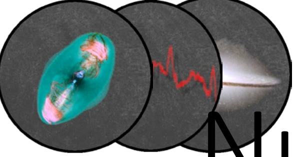
Heavy element production in the light of observations





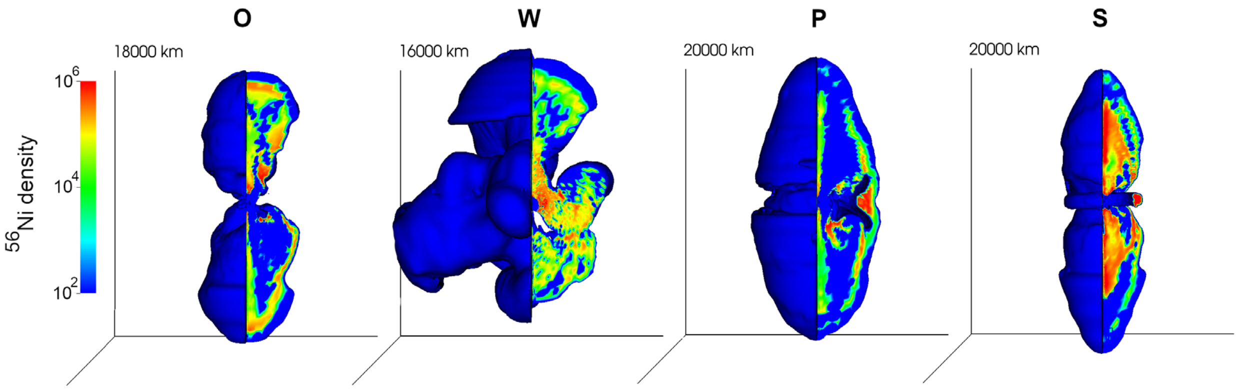
Cowan et al. 2021, Hansen et al. 2018

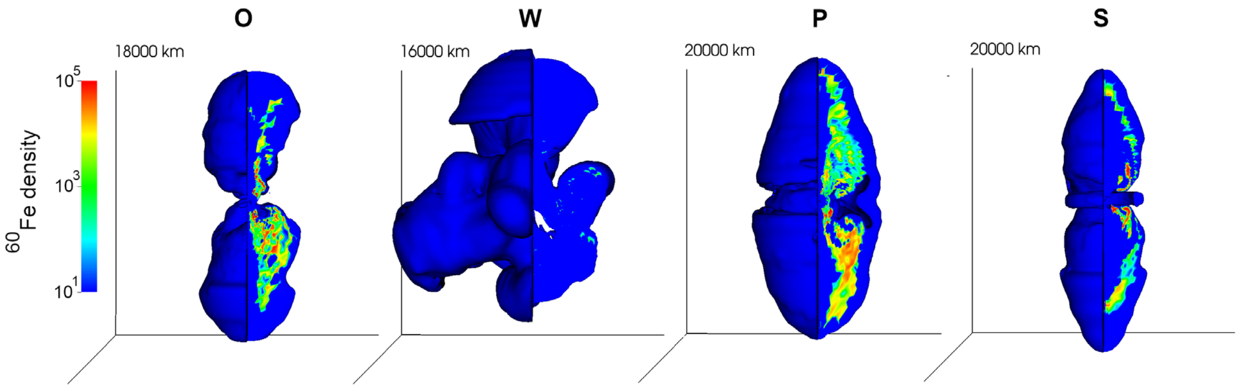
Reichert et al. (2022, submitted, arXiv:2206.11914v1)



Nucleosynthesis of magnetorotational supernovae, radioactive elements

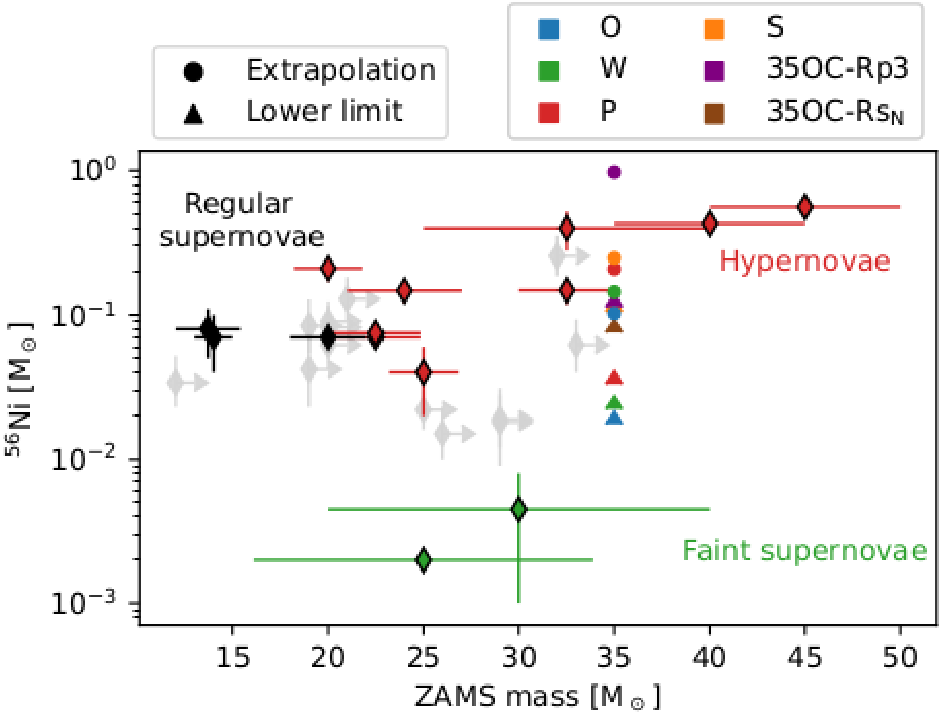
Model	M(^{26}Al)$_l$ [10^{-7} M$_\odot$]	M(^{26}Al)$_e$ [10^{-7} M$_\odot$]	M(^{44}Ti)$_l$ [10^{-5} M$_\odot$]	M(^{44}Ti)$_e$ [10^{-5} M$_\odot$]	M(^{56}Ni)$_l$ [10^{-2} M$_\odot$]	M(^{56}Ni)$_e$ [10^{-2} M$_\odot$]	M(^{60}Fe)$_l$ [10^{-3} M$_\odot$]	M(^{60}Fe)$_e$ [10^{-3} M$_\odot$]	M(^{56}Ni)$_l$/M(^{44}Ti)$_l$ [$\times 10^3$]
35OC-Rp3	21.0	31.4	20.0	521.7	11.3	97.3	3.1	208.5	0.57
35OC-Rs$_N$	8.1	-	4.3	-	7.5	-	1.7	-	1.74
P	6.2	15.4	4.2	36.7	3.3	20.4	5.5	11.7	0.79
O	0.4	5.0	0.9	4.7	1.7	9.7	1.2	5.3	1.89
W	0.1	2.6	1.1	4.7	2.2	14.6	0.1	0.1	2.00
S	16.5	16.6	5.9	16.9	10.5	24.6	2.8	8.4	1.78

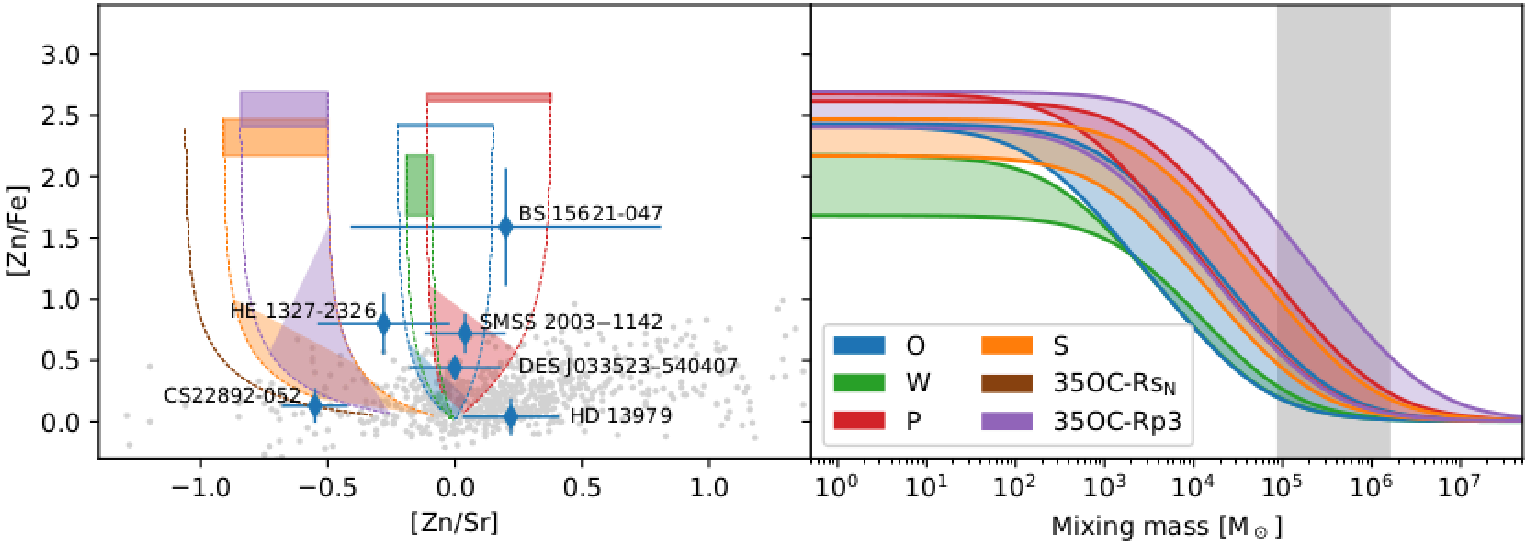




Reichert et al. (2022, submitted, arXiv:2206.11914v1)

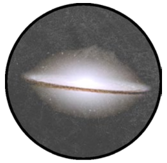
Nucleosynthesis of magnetorotational supernovae, hypernovae connection?





Reichert et al. (2022, submitted, arXiv:2206.11914v1)

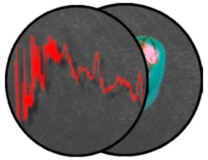
Observational constraints



- Similar in MW and DSph galaxies
- Hints on properties of r-process event
- Eu Masses $\sim 1 * 10^{-5} M_{\odot}$
- Small time delay

e.g., Côte et al. 2019, Reichert et al. 2020,
Molero et al. 2021, Reichert et al. 2021b

Nucleosynthesis calculations



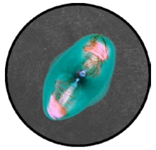
- Reduced r-process yields in early ejecta when moving to 3D
- High entropies could also provide conditions for r-process.
- Actinides rather unstable produced. Variations expected. Actinide boost/deficient stars?
- [Eu/Fe] only compatible with r-I stars due to high Fe ejecta, or pattern not compatible with solar pattern

Reichert et al. 2021a
Reichert et al. (2022, submitted, arXiv:2206.11914v1)

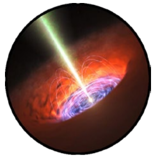
Thank you for your attention!

R-process host event candidates:

Magnetorotational supernovae



Collapsars



Neutronstar merger