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Nucleosynthetic signatures in magneto-rotational driven core-collapse supernovae

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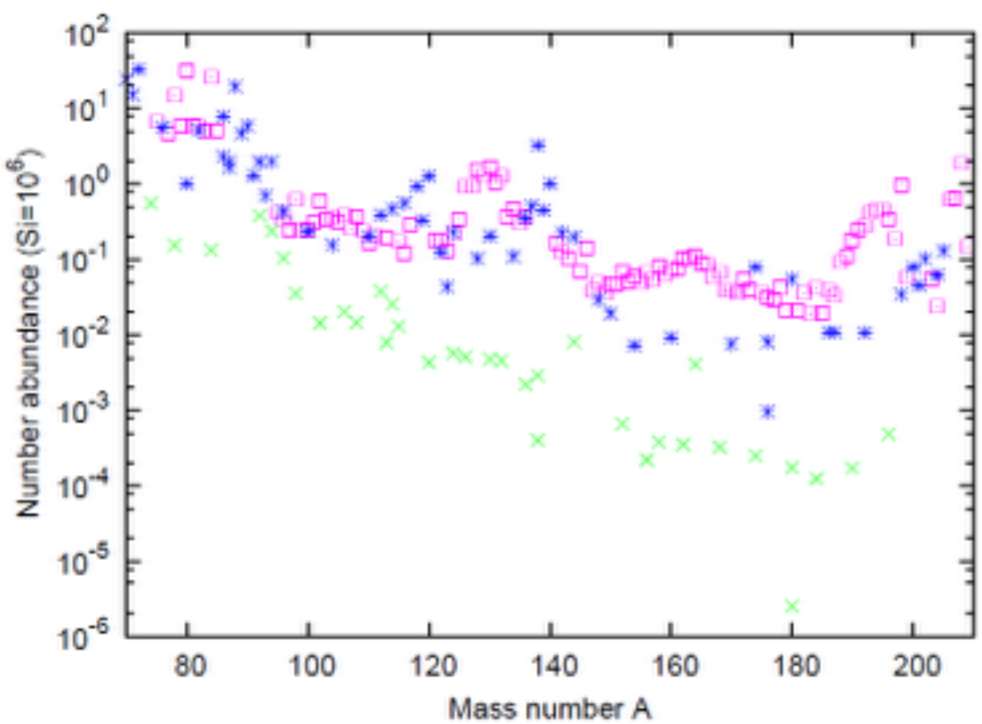
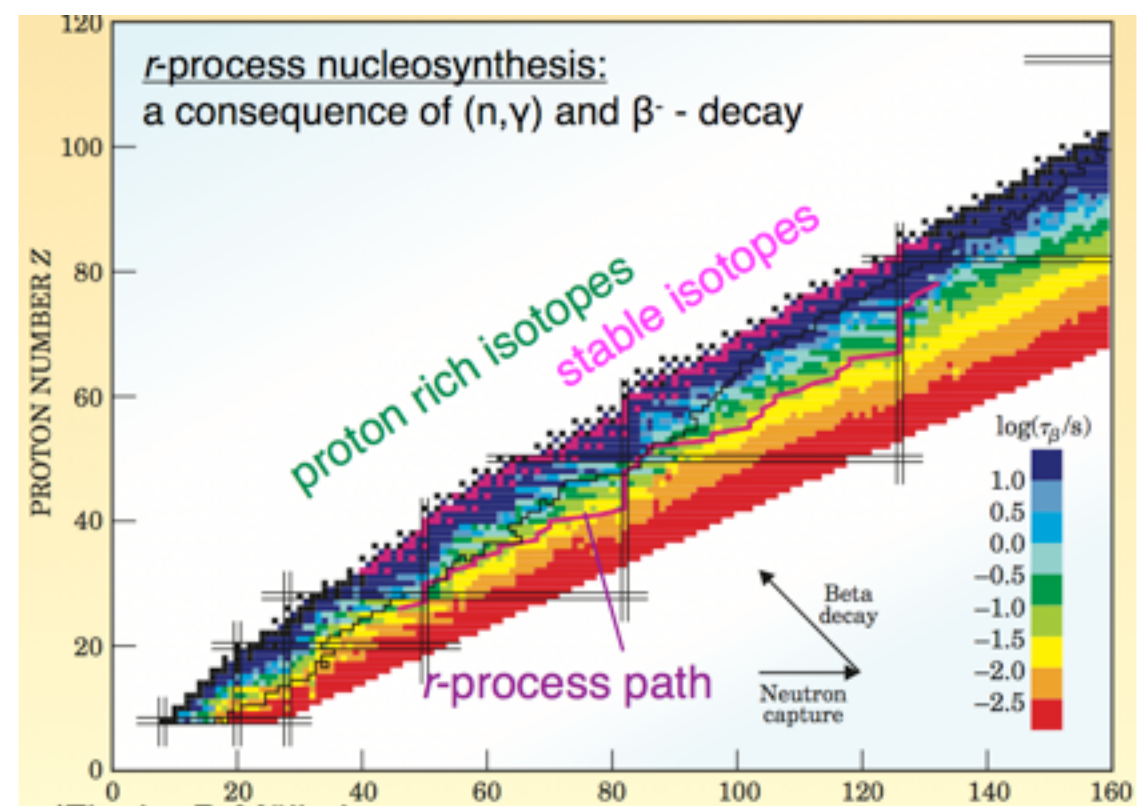
based on
N. Nishimura, T. Takiwaki, and F.-K. Thieleman
(2013 in prep.)

r-process: "cosmic alchemy"

- origin of heavy elements (with s-process)
    - e.g., gold, actinide
- nuclear physics
    - rapid-neutron captures (related to unstable isotopes)
- Astronomical sites (?)
    - non-standard Supernova (SN)
    - neutron star mergers

Solar system abundance
Anders & Grevesse (1989)

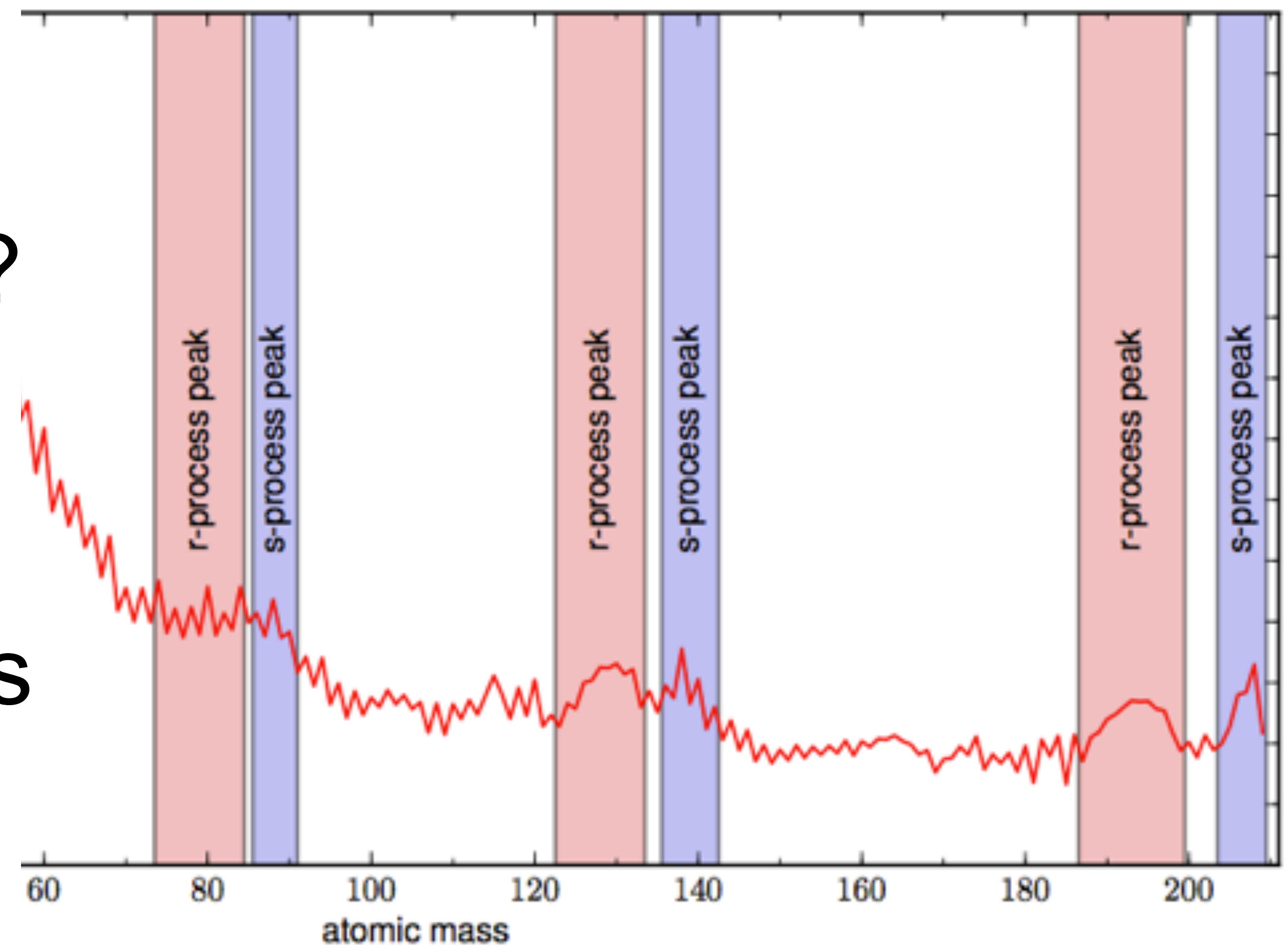




(Fig. by P. Möller)

r-process: physics & astronomical sites

- **high neutron density**
  - neutron rich matter from NS?
  - explosive events
    (<< 1 min, neutron's half life)
  - separated from the s-process



- **Astronomical sites**
  - core-collapse supernova (formation of NS)
  - merger of NS-NS / BH-NS binary
    → short GRB? (*talk by Wanajo*)
  - "collapsar" jet or disk
    → long GRB? (*talk by Surman*)

Core-Collapse Supernovae: > 10 M_{sun}

the end of the evolution

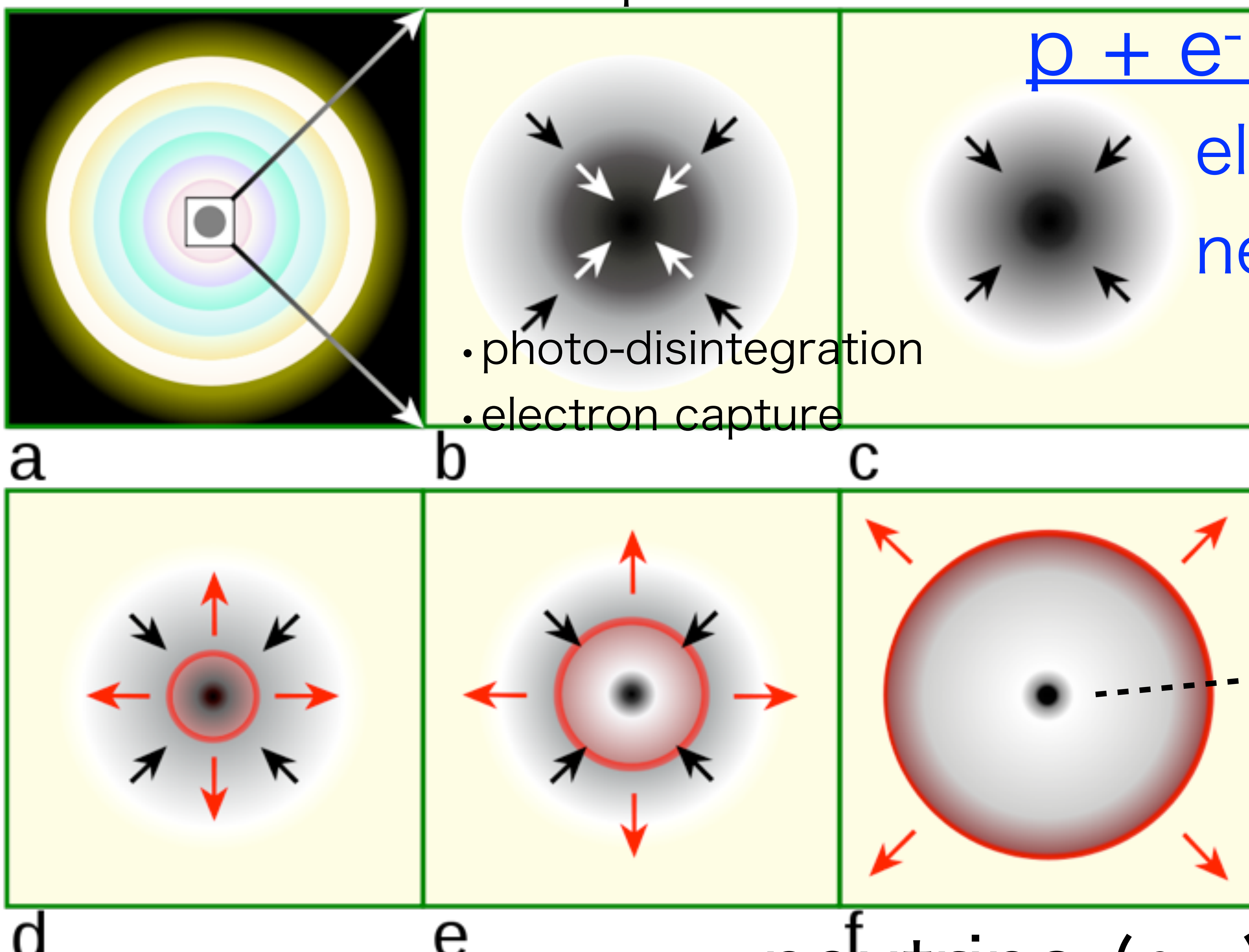
the core collapses

a proto-neutron star is formed

$p + e^- \rightarrow n + \nu_e$

electron-capture

neutronization



• photo-disintegration

• electron capture

shock

proto-neutron star

neutrino (ν_e)-burst

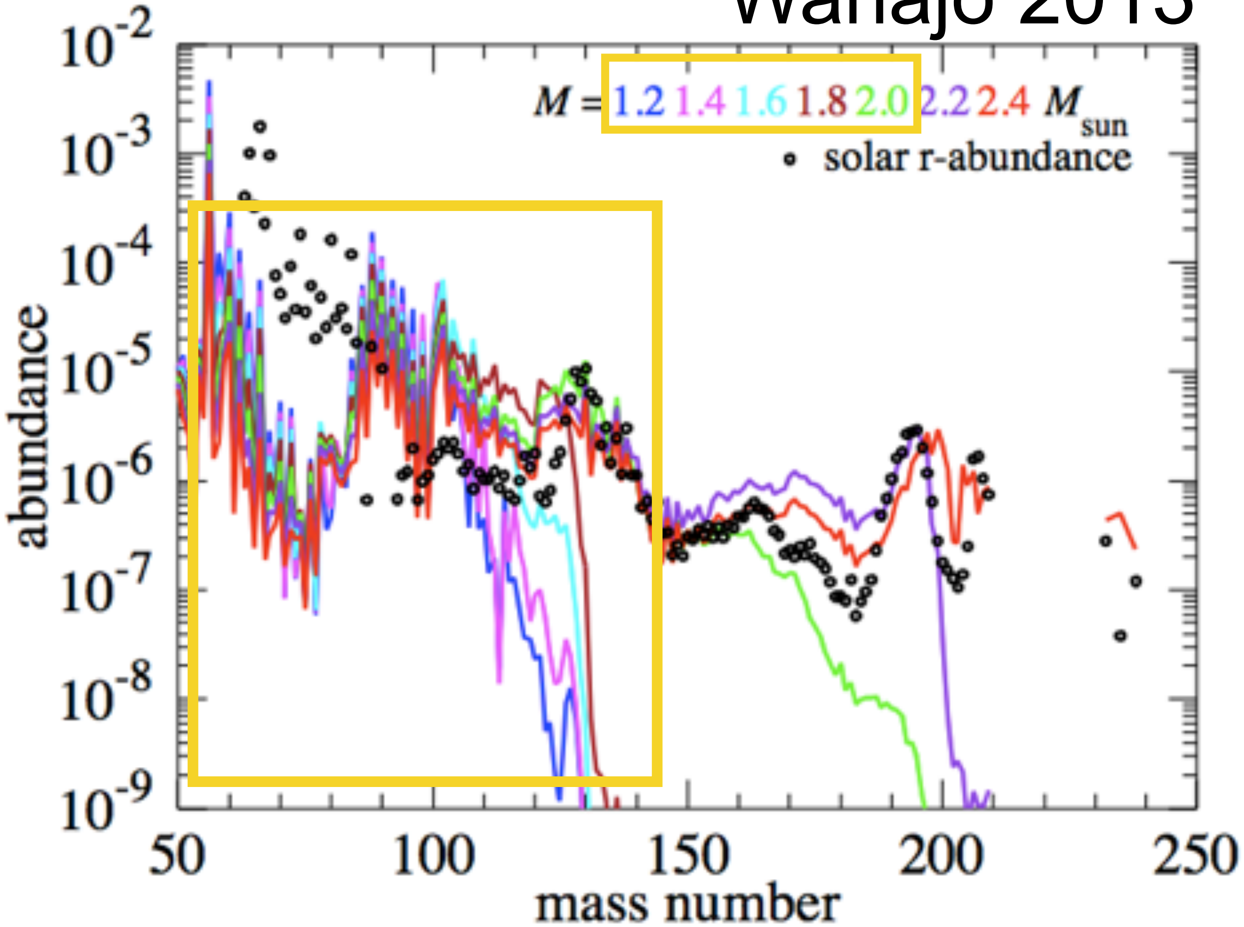
$n + \nu_e \rightarrow p + e^-$

figure: wikipedia

core-collapse supernovae

- supernova ejecta → iron group elements including ^{56}Ni
- neutrino-driven proto-neutron star wind

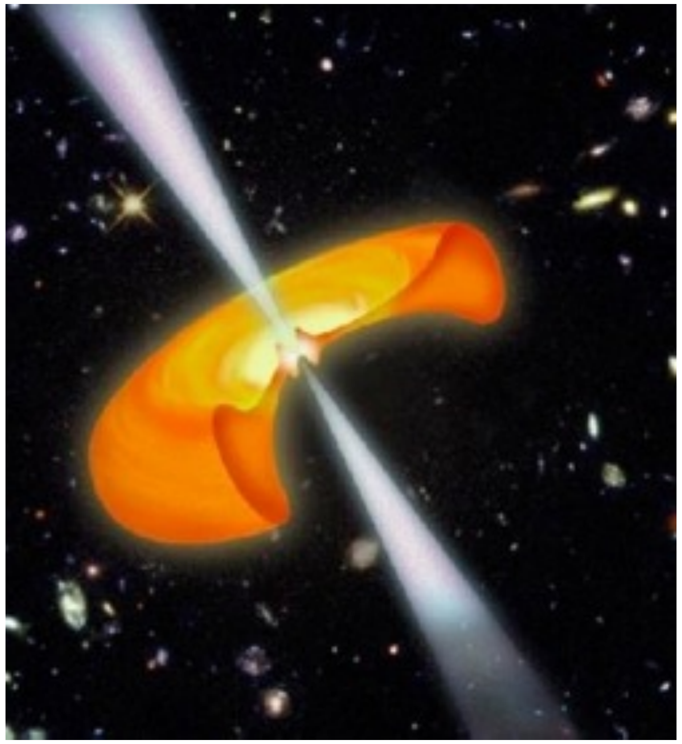
Wanajo 2013



- difficult to have suitable condition for the r-process
- not very neutron-rich (> 0.4)
- not high entropy (< 200)
- supported by several studies
  Fischer et al. 2010,
  Hüdepohl et al. 2010 etc.

→ alternative energetic supernova scenario?

Magnetohydrodynamic (MHD) SNe and magnetars



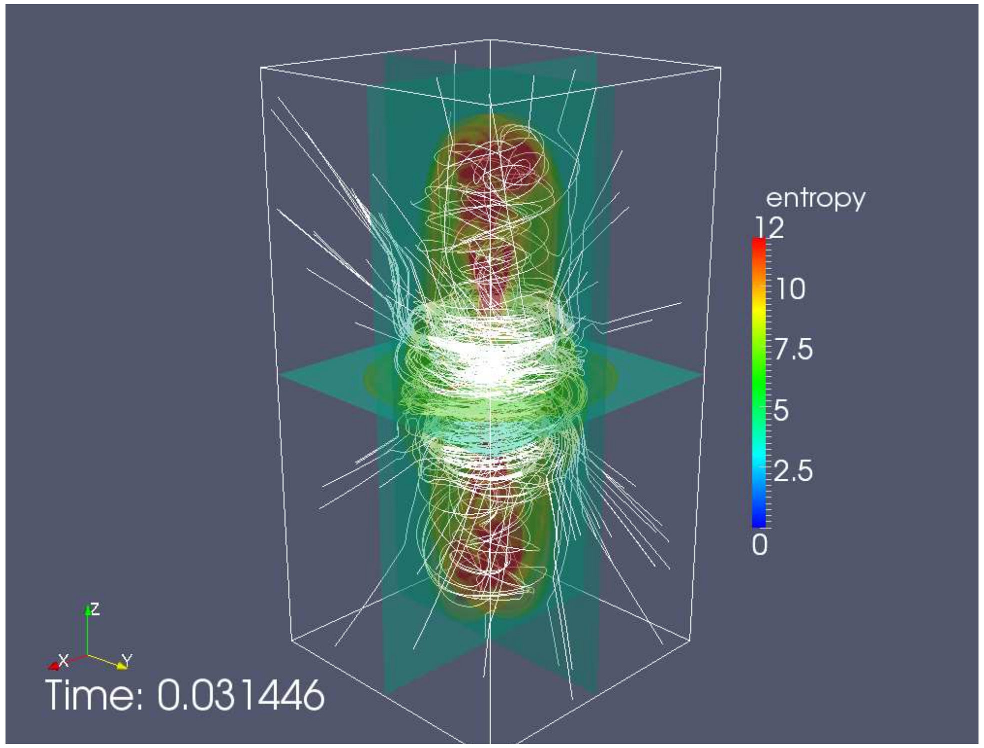
hypernova/jet-like SN

r-process studies

- 2D MHD-SNe
  - Nishimura et al. 2006
  - Fujimoto, Nishimura,and Hashimoto 2008 (central Black-Hole and disk)
- 3D MHD-SNe with neutrino
  - Winteler et al. 2012

- Magnetar
  - strong magnetic field $\sim 10^{15}$ G

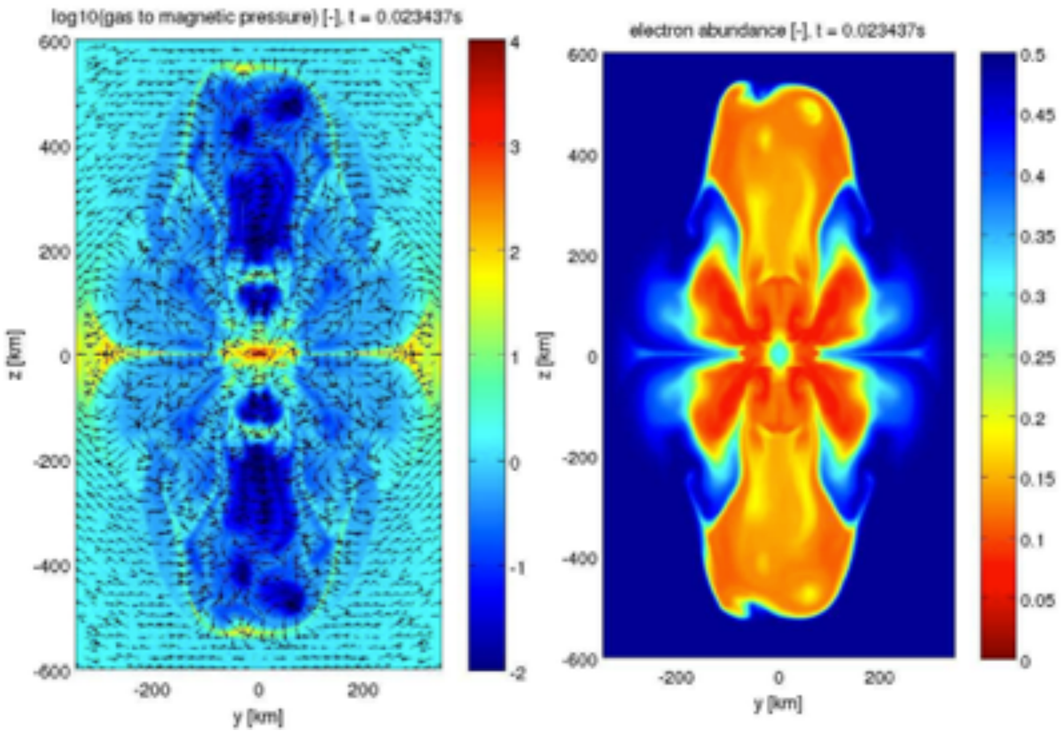
  (∼1 % of all neutron stars)
- Magneto-driven Supernovae?
  - GRB central engine
  - Hypernovae



3D MHD simulation
Winteler et al. (2012)

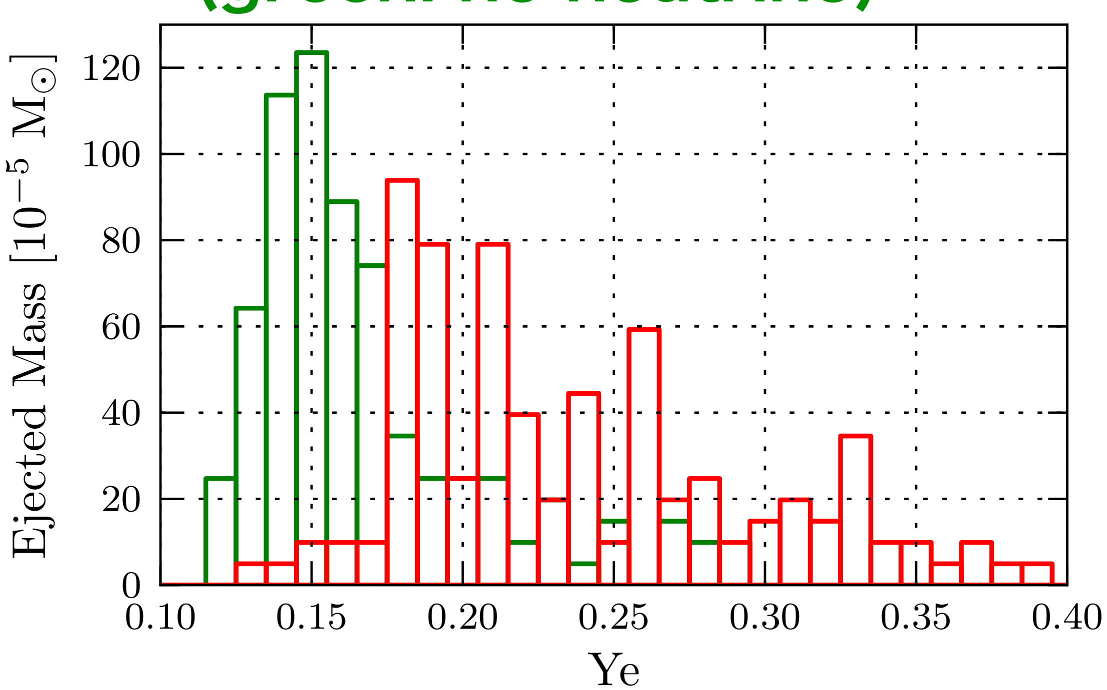
3D-MHD model with leakage scheme

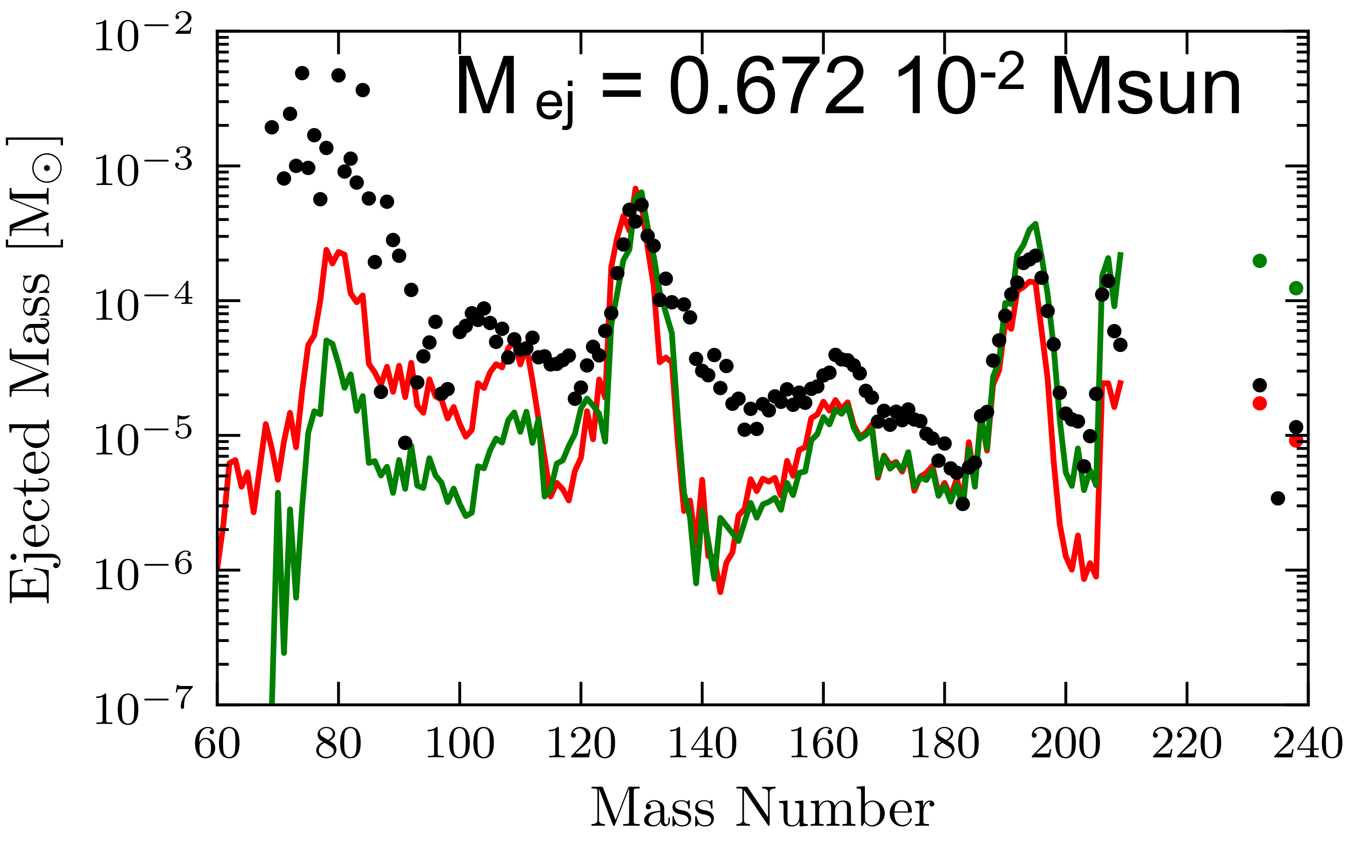
Winteler, Käppeli, Perego, Arcones, Vasset, Nishimura, Liebendörfer, Thielemann Basel collaboration) 2012, ApJL



MHD code :
FISH (Käppeli et al. 2011)
progenitor :
15Msun (Heger&Woosely 2002)
magnetic fields :
poloidal 5×10^{12} [G] (initial)

red: neutrino absorption
(green: no neutrino)



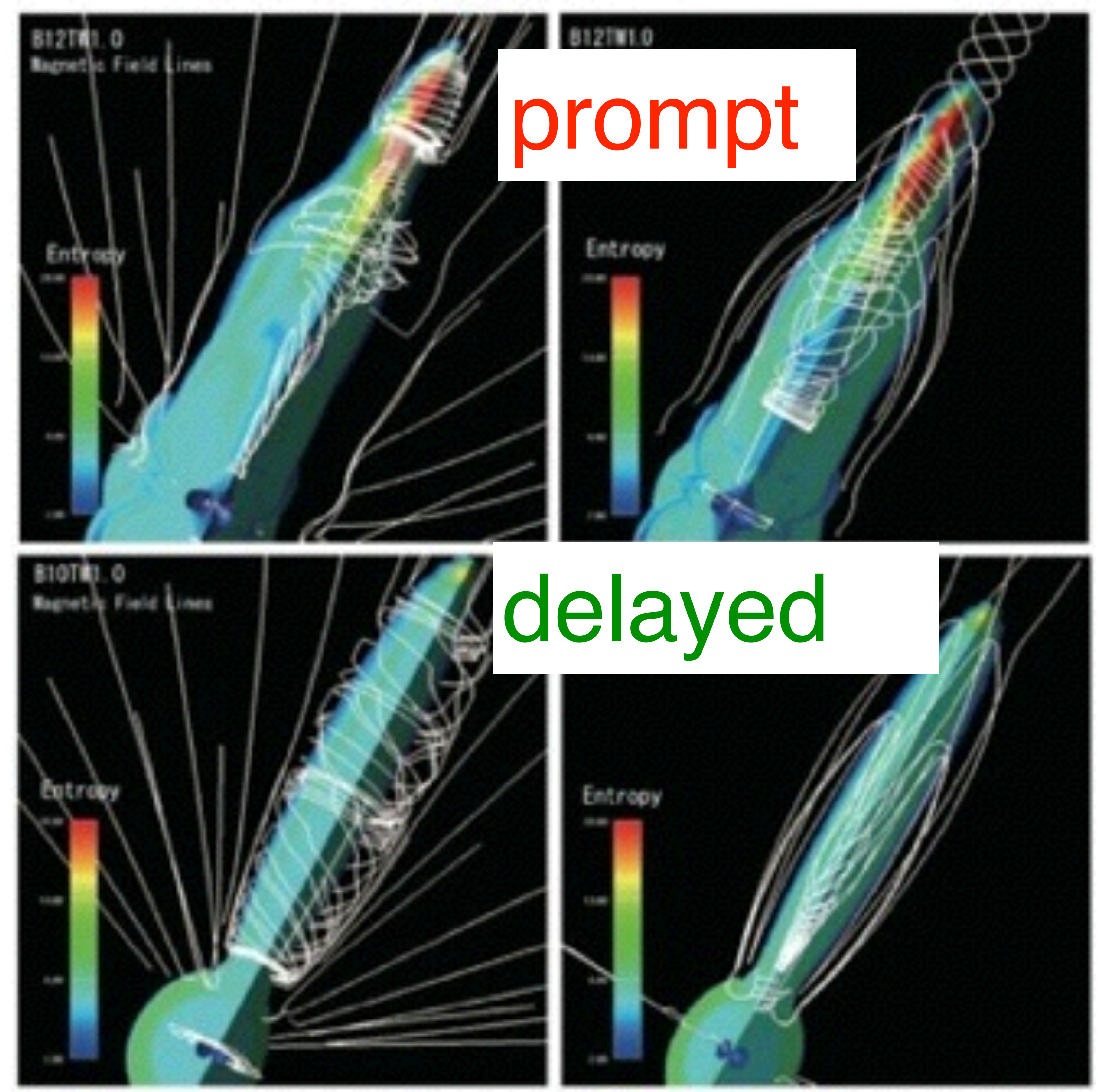


r-process in MHD-SNe: “prompt” vs “delayed”

- more long-term simulation model
- robustness of resulting r-process
- dependency on the explosion mechanism

- axisymmetric
- special relativistic MHD
- leakage scheme for neutrino cooling
- $25M_{sun}$ WR star (Heger & Woosley)

Takiwaki et al. 2009

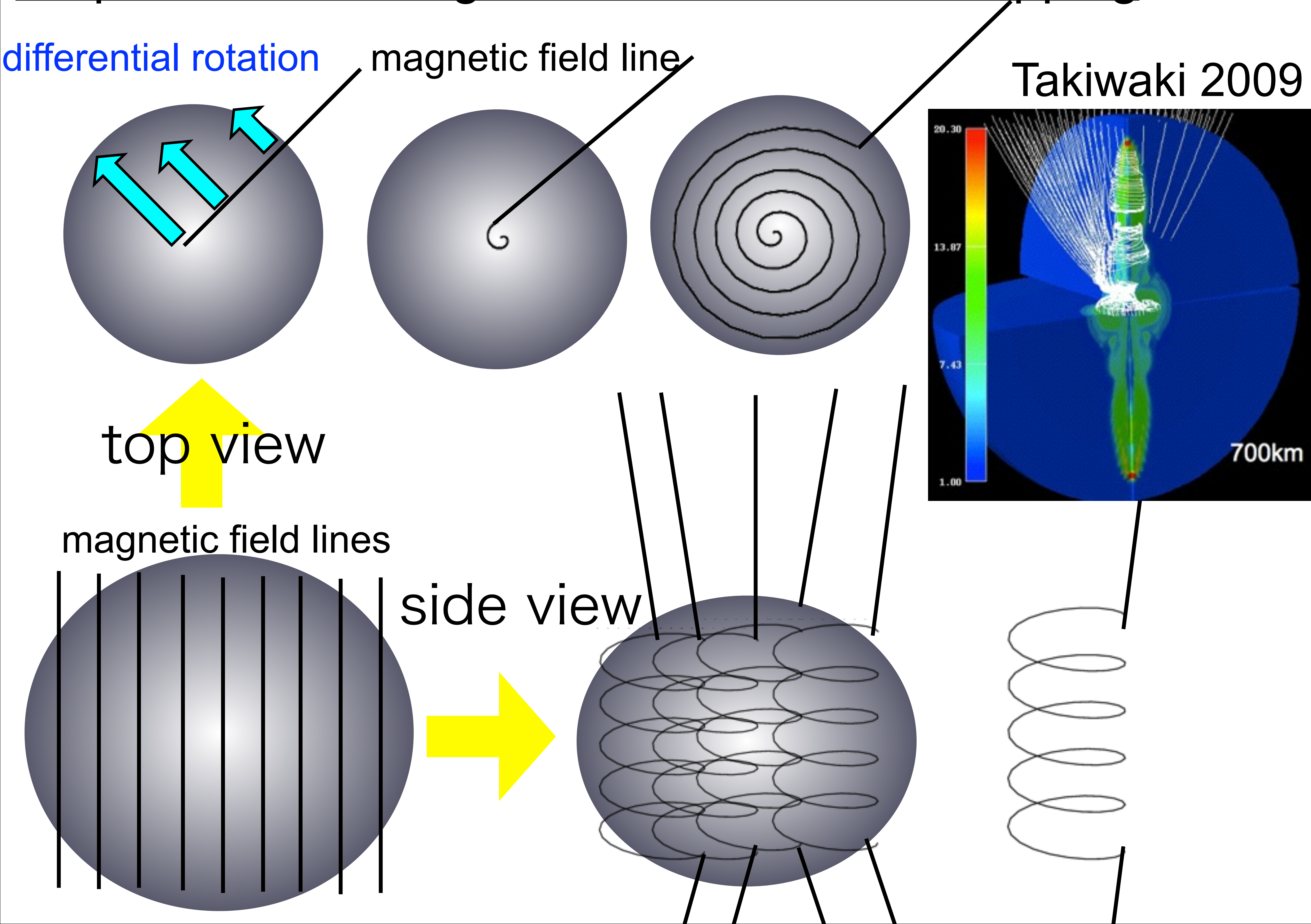


time duration of explosion delayed

		$T/\|W\|(\%)$		
		0.25%	1.0%	4.0%
B_0(Gauss)	10^{10}G	122 ms	96 ms	104 ms
	10^{11}G	72 ms	27 ms	32 ms
	10^{12}G	32 ms	20 ms	25 ms

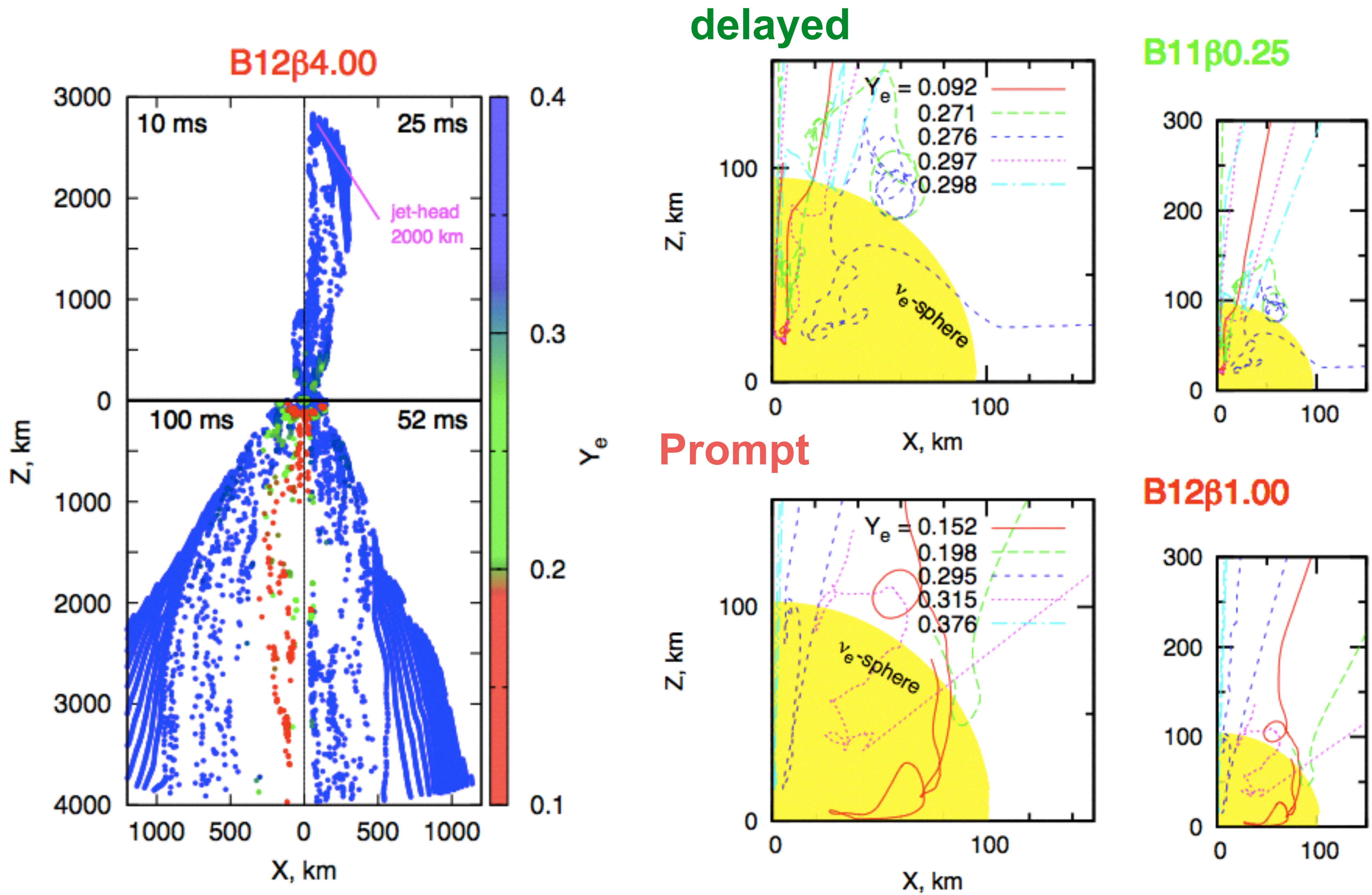
prompt

Amplification of magnetic fields via field wrapping

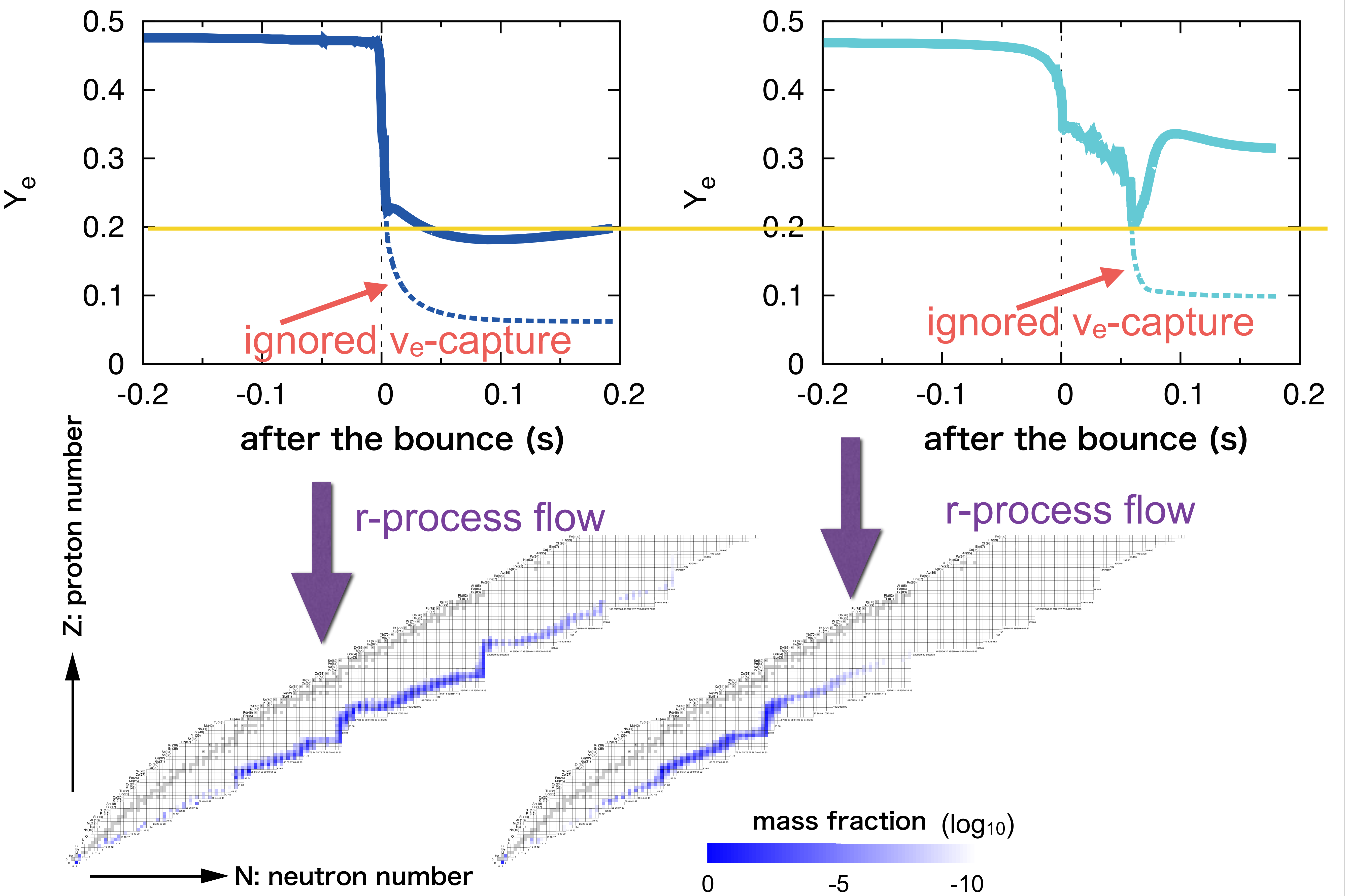


Ejected matter: ejection motion and Y_e

path of ejected tracer particles (post-process)



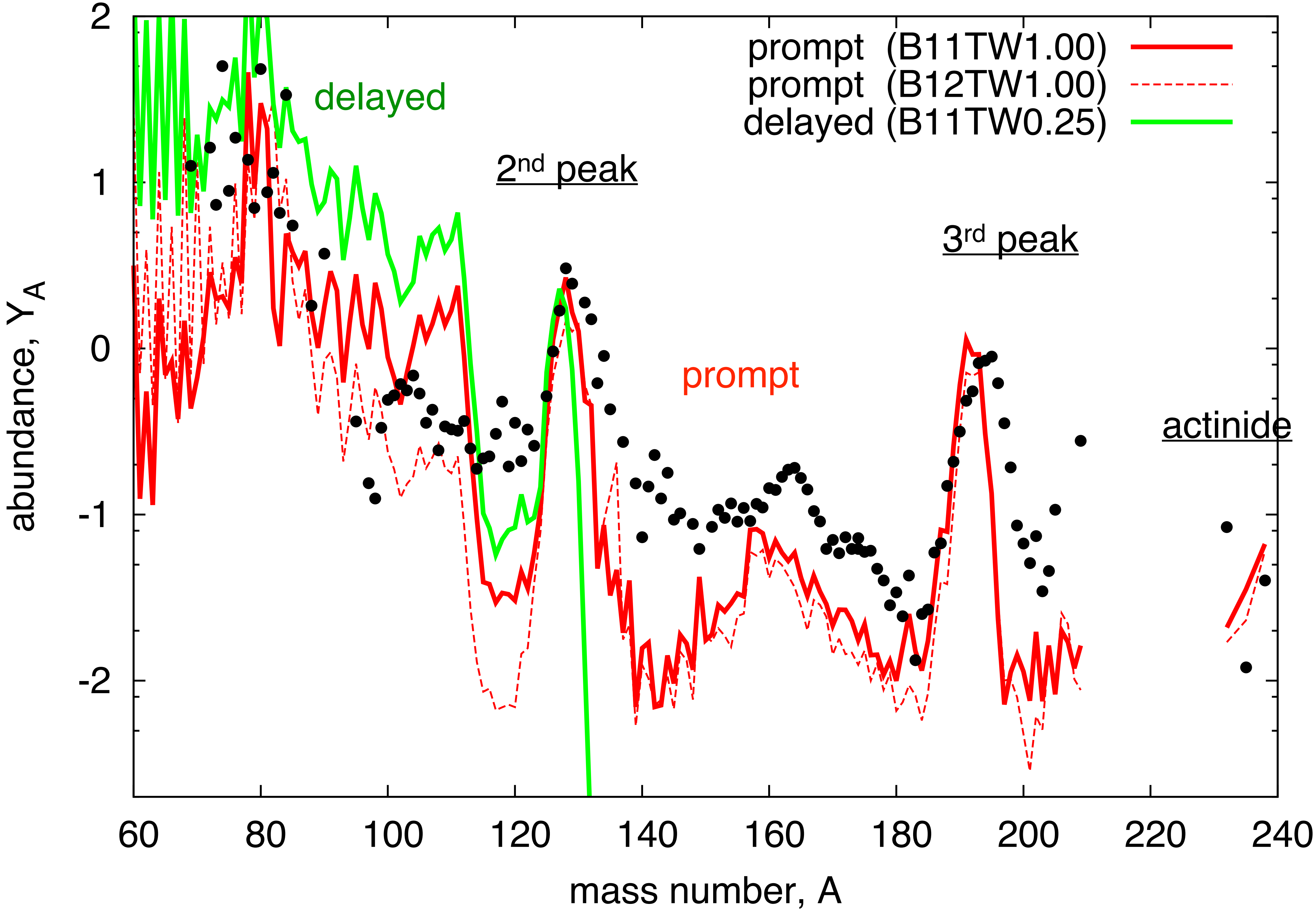
Y_e evolution for different ejecta



r-process in MHD-SNe: "prompt" vs "delayed"

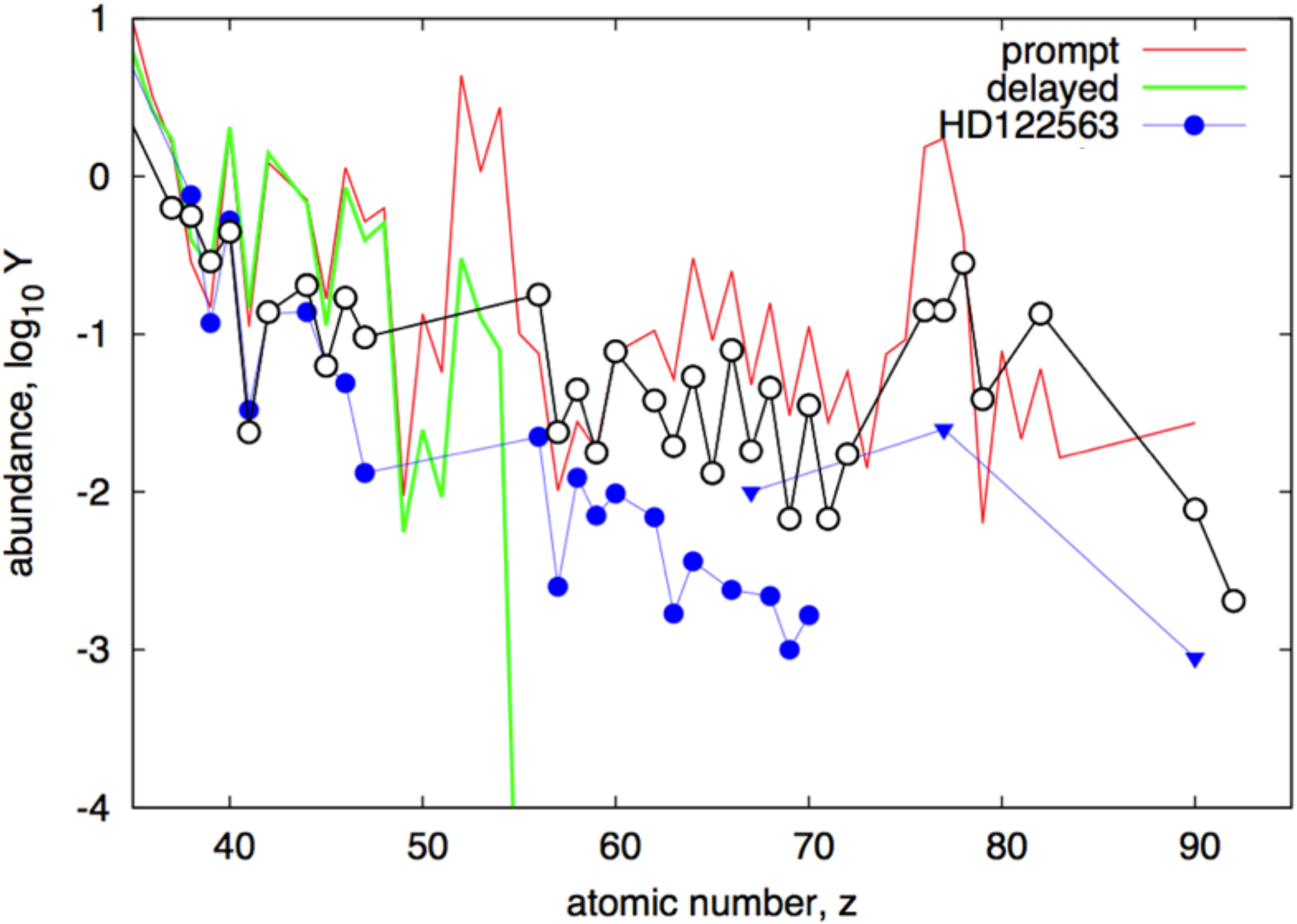
successful r-process (prompt)

r-process is suppressed up to second peak (delayed)



r-process result (2/3): “weak” *r*-elements

“weak” r-process pattern (HD122563; Honda 2006)



nucleosynthesis result: key amounts

	B11TW0.25	B11TW1.00	B12TW0.25	B12TW1.00	B12TW4.00
type	delayed	prompt	prompt	prompt	prompt
ejected mass (10^{-2} M_{sun})	1.27	6.88	3.42	9.48	9.38
r-proc. mass (10^{-3} M_{sun})	0.963	1.54	1.15	2.05	2.67
^{56}Ni (10^{-2} M_{sun})	1.07*	-	0.63*	1.19*	1.21*

* minimum values (component in the first shock wave)

- significant amount of r-process matter compared with normal supernova (10^{-5} M_{sun} from PNS wind)
- low event rate (～ 0.1 - 1 % of all supernova)

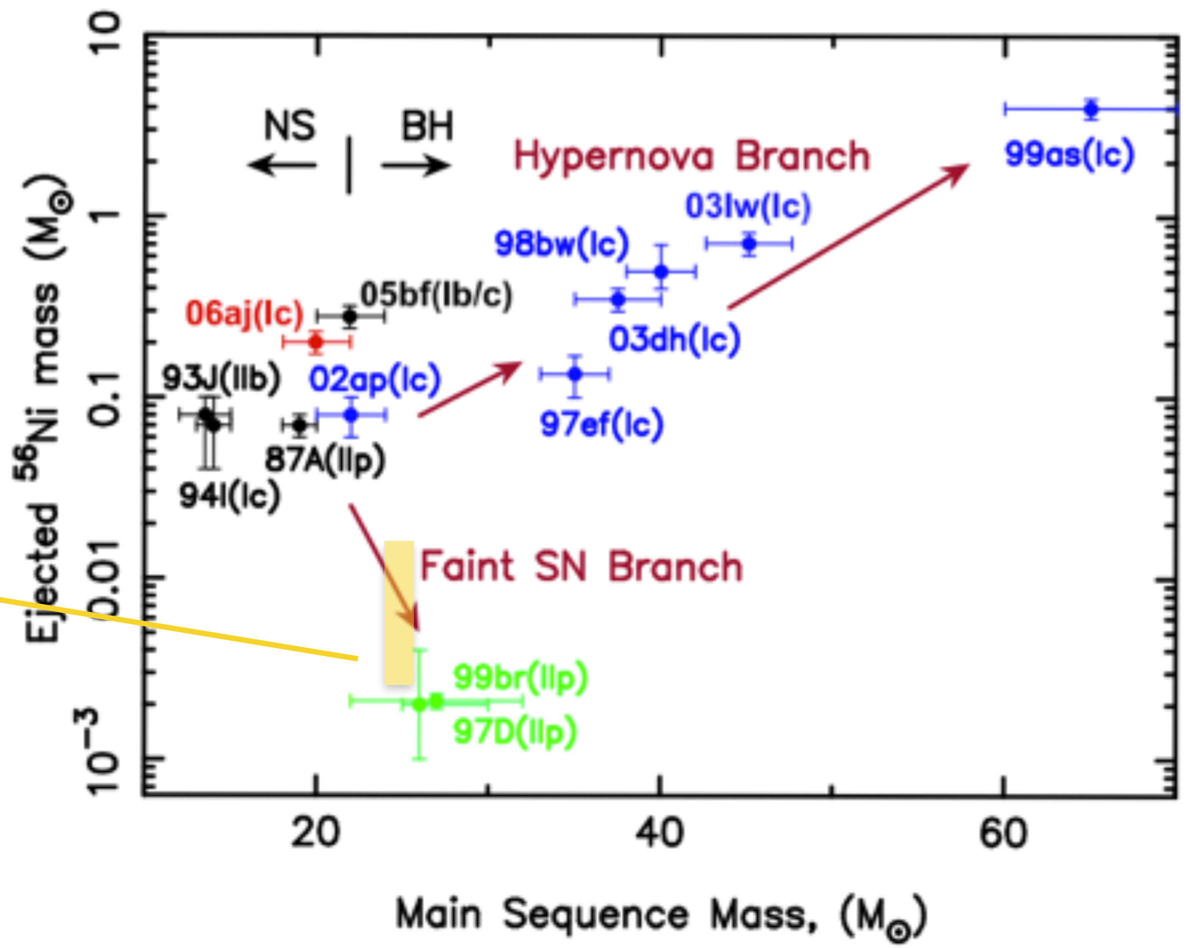
have impact on chemical evolution/obervation

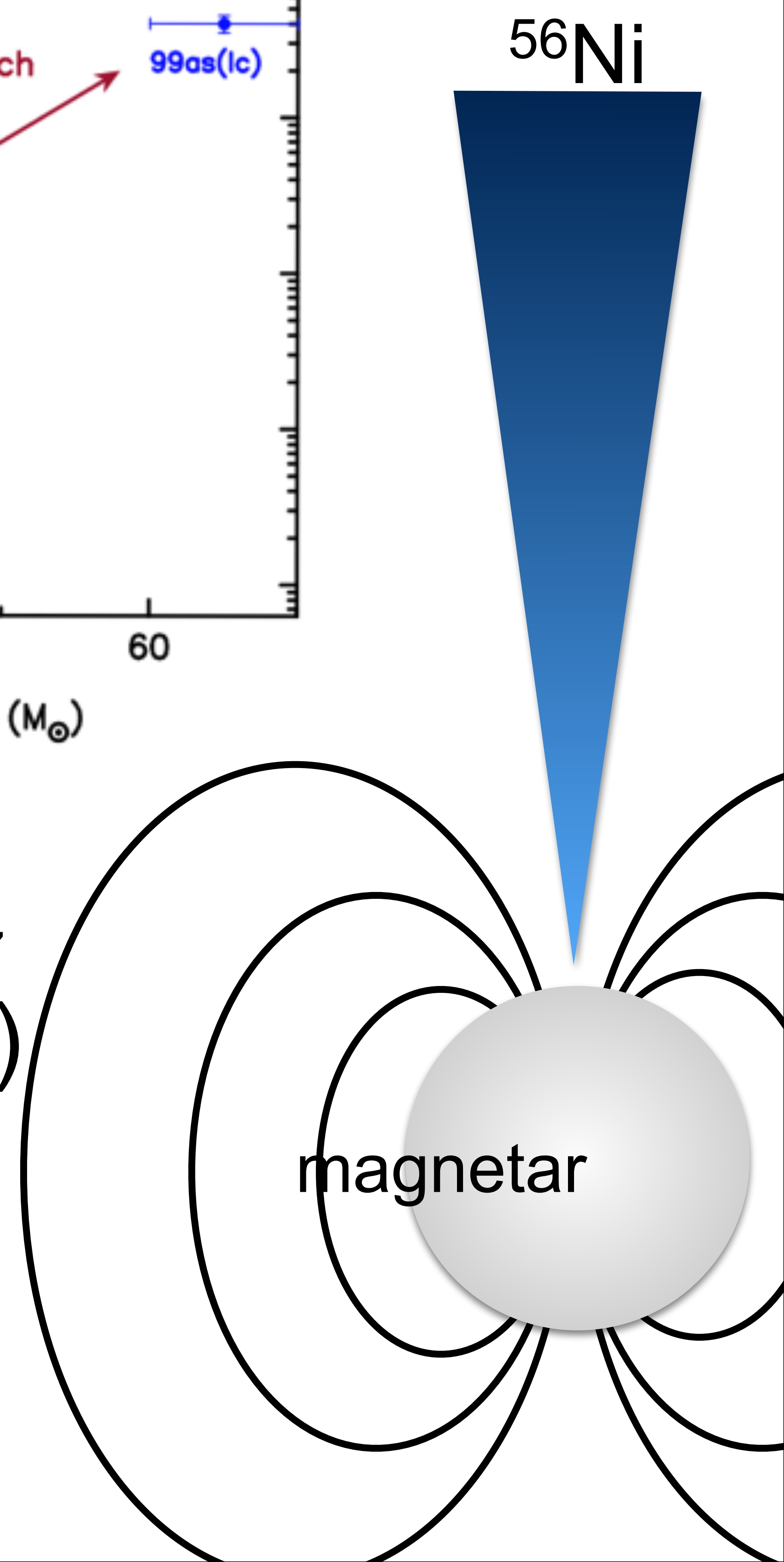
optical observation:

Nomoto et al. 2006

smaller amount of ^{56}Ni
faint SN ?

our results





^{56}Ni with magnetar formation

Maeda et al. 2007

SN2005bf (type Ib with double peak)

- ^{56}Ni ～ 0.02 - 0.06 M_{sun}
- strong magnetic field ～10^{15} G

XRF060218 (SN2006aj)

Mazzali et al. 2006, Maeda et al. 2007

Summary

- MHD-SNe are still possible candidate for r-process
  - prompt-magnetic-jets : "main" r-process
  - delayed-magnetic-jets : "weak" r-process?
- Large amount of r-process elements ($\sim 10^{-3}$ M_{sun})
- MHD-SNe are faint ? and have relation to peculiar SN/XRF.

remaining problem

- Long-term simulations
- dependence of initial rotations and magnetic fields
- MHD-SN always produce "solar" r-process pattern?
- uncertainties of micro physics (neutrino, ...)
- cases of large off-axisymmetry
- physics of MHD amplification process (MRI, reconection ..)

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