Nucleosynthesis in the early neutrino-driven outflows of AGB supernovae

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supernovae from 8-10$M_\odot$ stars

AGB SN from of an ONeMg core (up to ~30% of all SNe)

Nomoto 1984, 1987; Miyaji & Nomoto 1987

- progenitor of Crab SN?

  Nomoto et al. 1982; Davidson et al 1982

  - ➔ carbon-rich?? >9.5$M_\odot$??

    MacAlpine & Satterfield 2008

- low-luminosity SNe?

  SN1997D, Chugai & Utrobin 2000

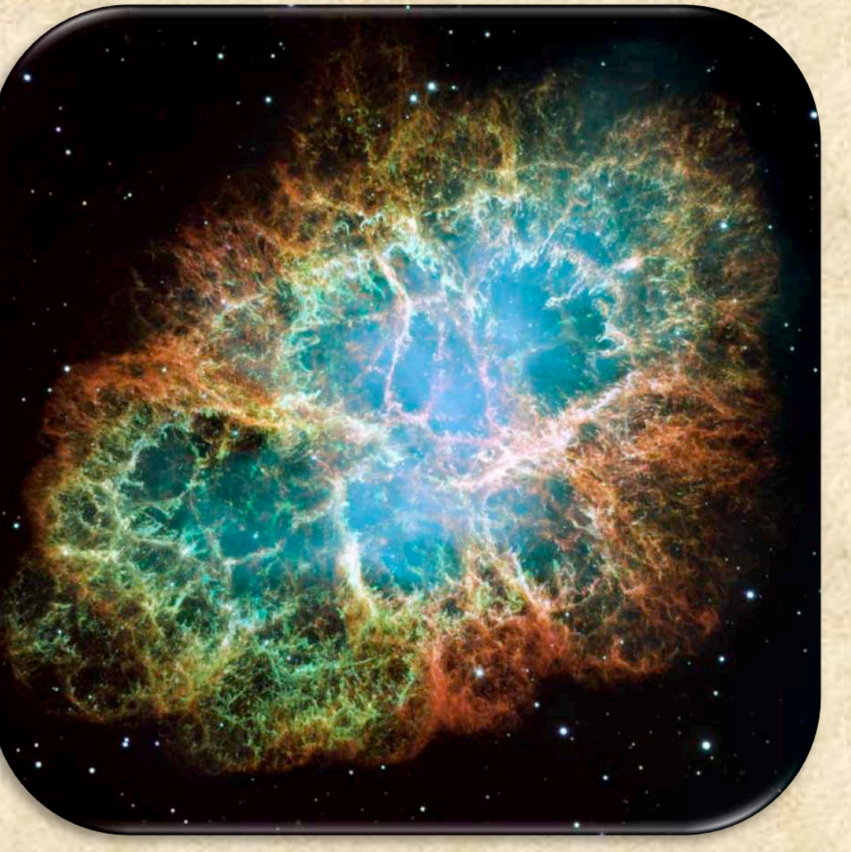
  SN2003gd, Hendry et al. 2005

  - ➔ < 17$M_\odot$ for all SNeIIP??

    Smartt et al. 2008

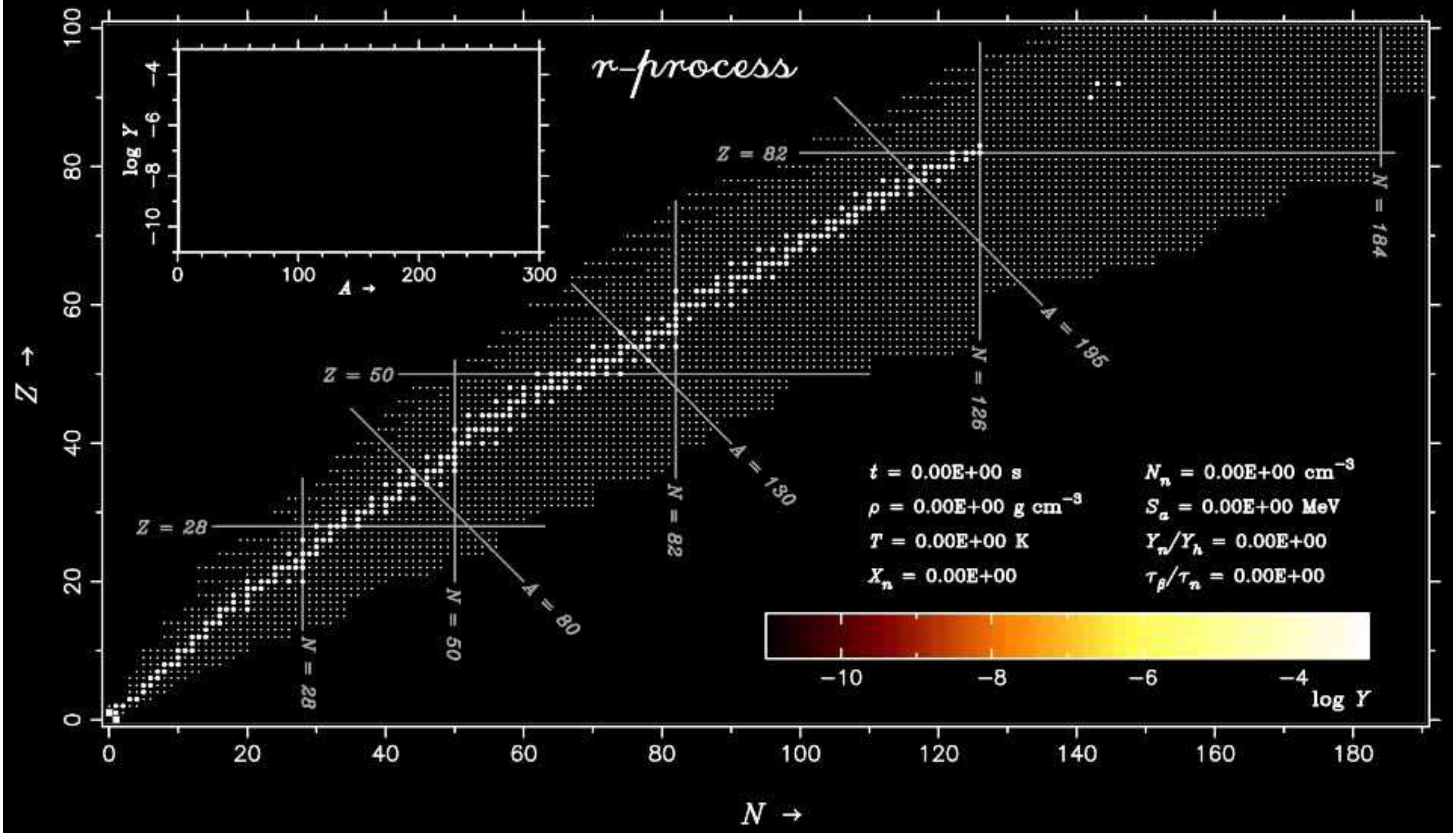
  - ➔ new SNe class of SN2008S-like transients with AGB progenitors??

    Prieto et al. 2008; Thompson et al. 2008

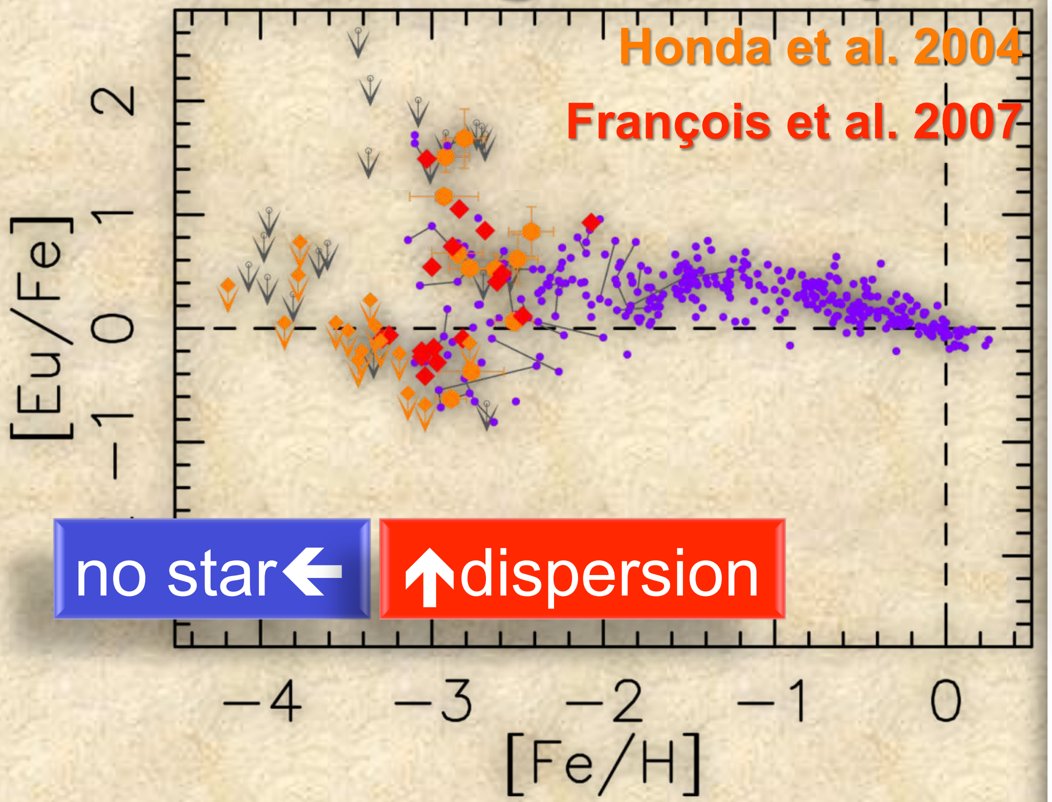


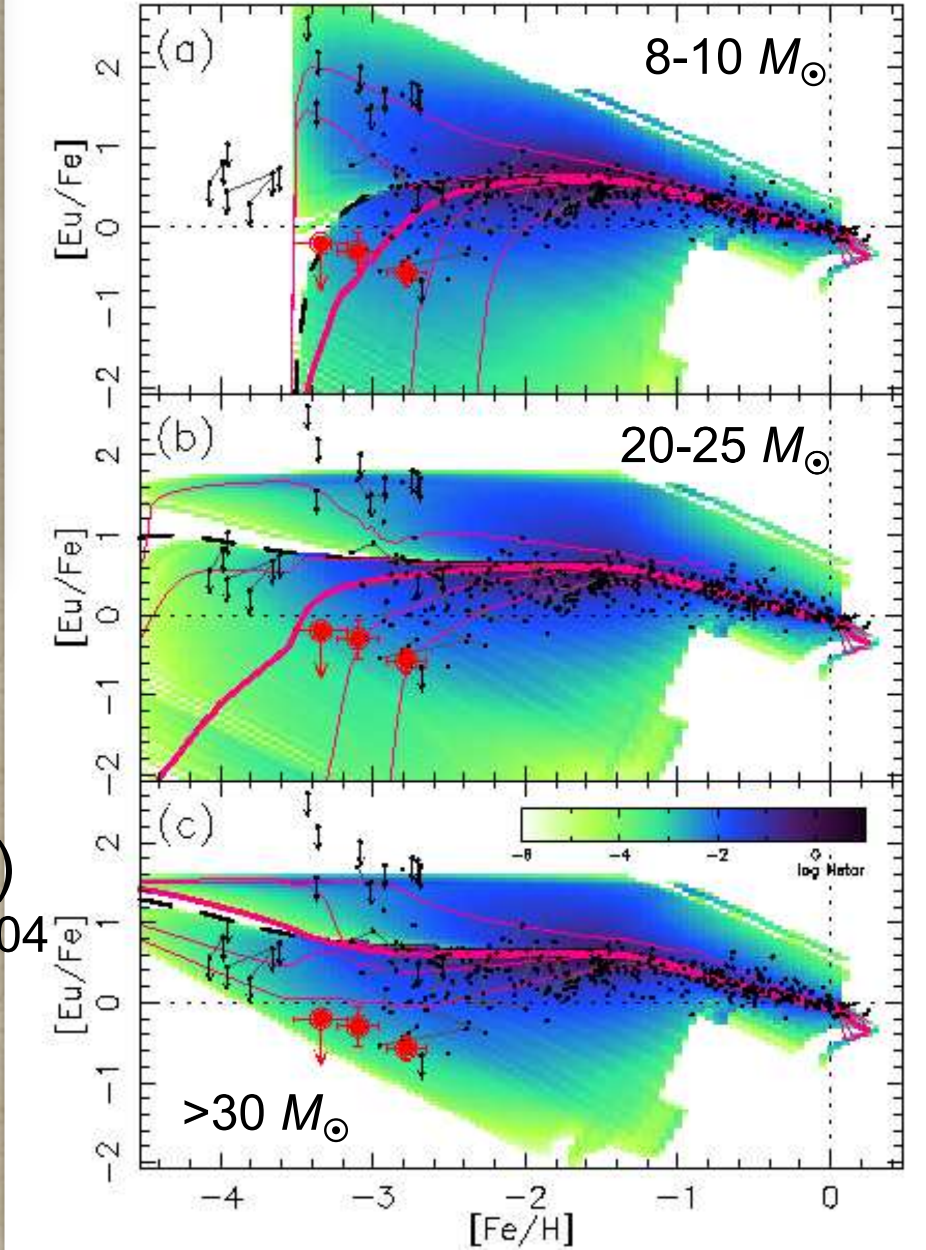
Crab Nebula, hubblesite.org

origin of r-process nuclei?

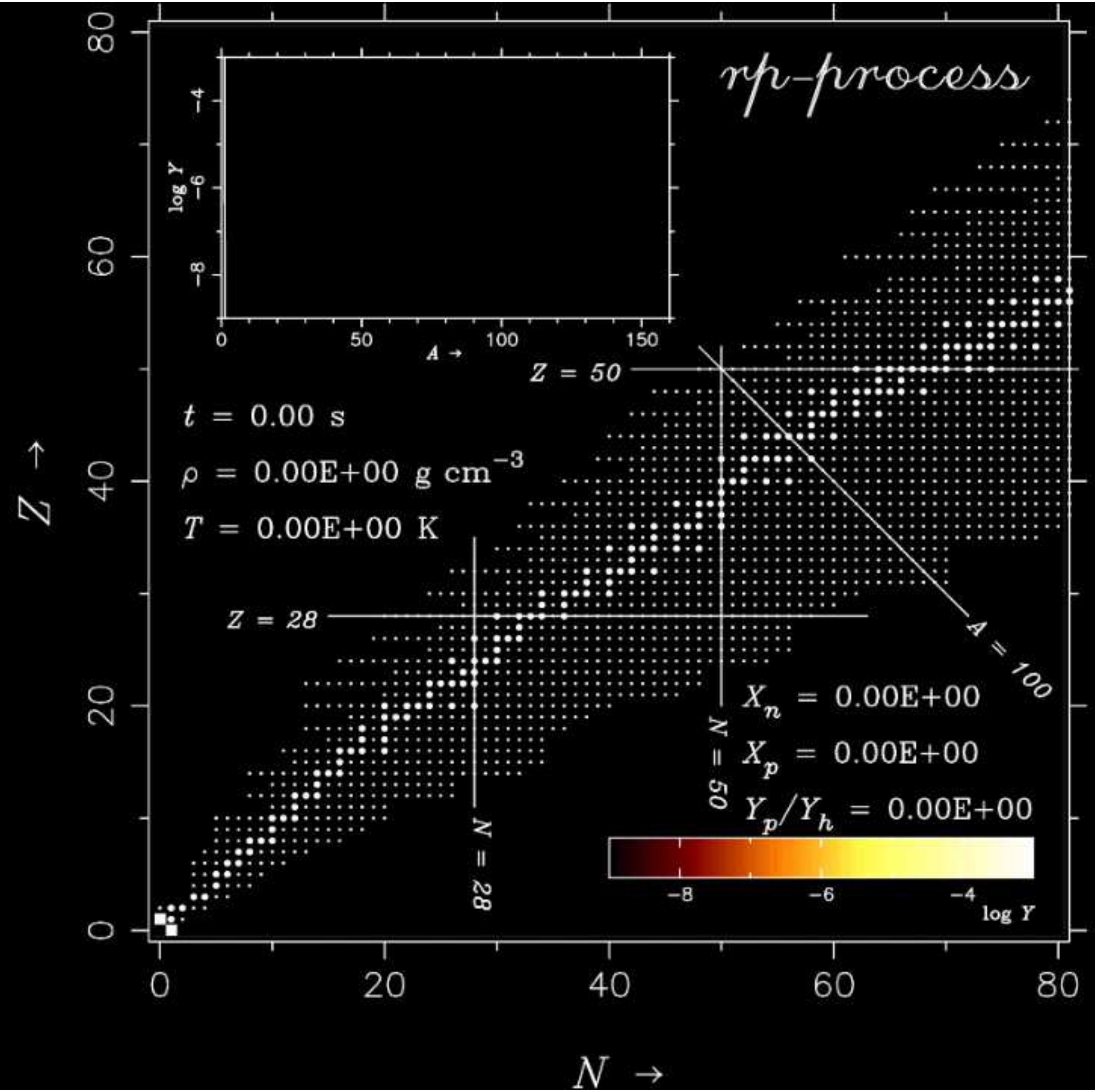


origin of r-process nuclei?





- chemical evolution studies favor the low-mass end (8-10$M_\odot$ stars)
  Ishimaru & Wanajo 1999; Ishimaru et al. 2004
- r-process models related to 8-10$M_\odot$ stars
  Wanajo et al. 2003; Ning et al. 2007
  but Janka et al. 2008; Hoffman et al. 2008



rp-process
t = 0.00 s
ρ = 0.00E+00 g cm−3
T = 0.00E+00 K
Z = 50
Z = 28
N = 28
N = 50
A = 100
X n = 0.00E+00
X p = 0.00E+00
Y p/Y h = 0.00E+00
log Y
A →
Z →
N →

ν p-process?

(Fröhlich et al. 2006; Pruet et al. 2006; Wanajo 2006)

neutrino emission by neutrino capture

$$p + \bar{\nu}_e \rightarrow n + e^+$$

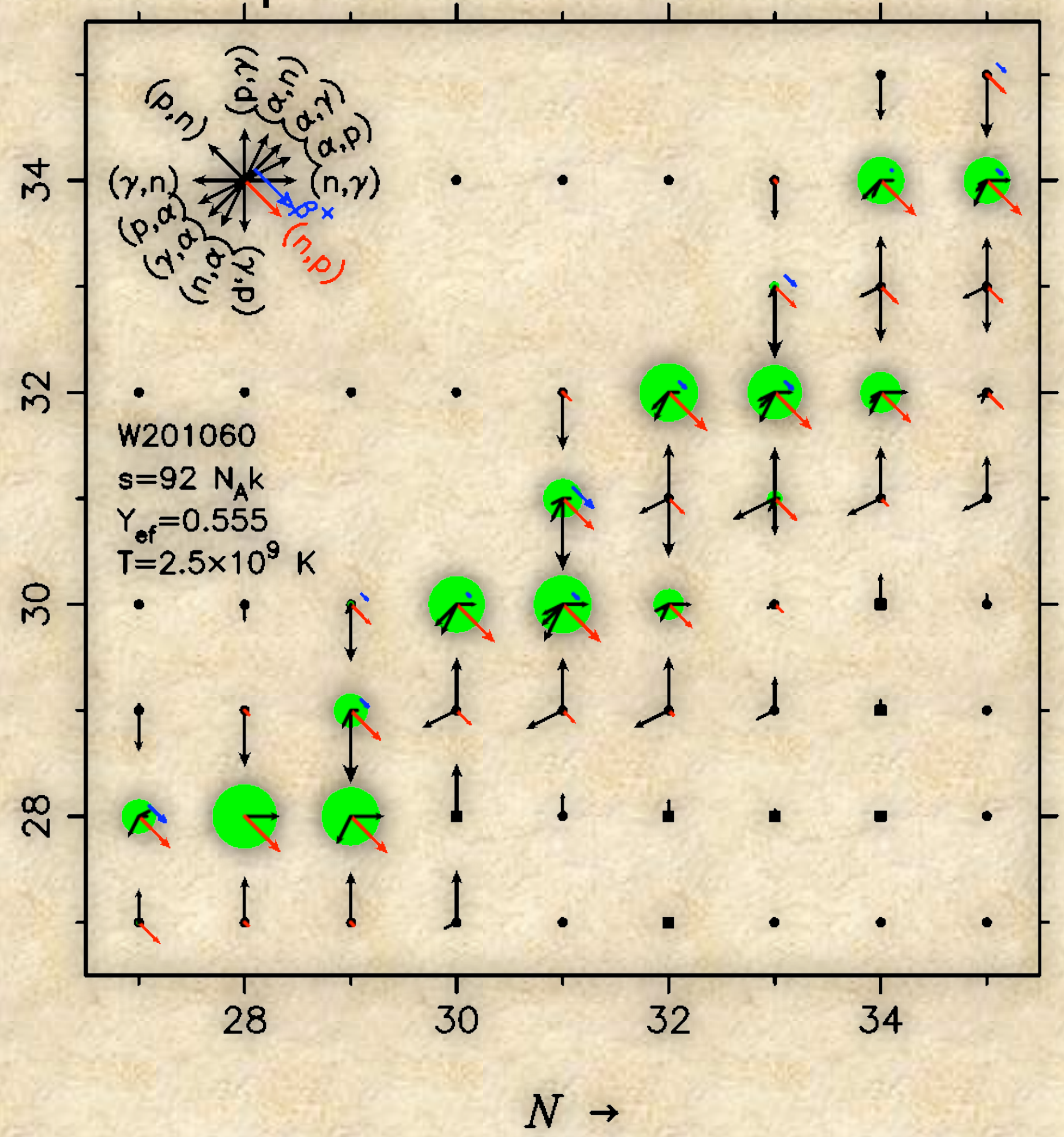
- neutron capture (n, p) bypasses the β^+-decay

- $^{64}Ge \rightarrow {}^{64}Ga + e^+ + \nu_e$
  (1.06 min)

  ⇓

  $^{64}Ge + n \rightarrow {}^{64}Ga + p$
  (~ 10 ms)

- origin of p-nuclei?
  ($^{92,94}Mo$, $^{96,98}Ru$)



self-consistent explosion of a $9M_{\odot}$ star!

weak explosion by neutrino heating

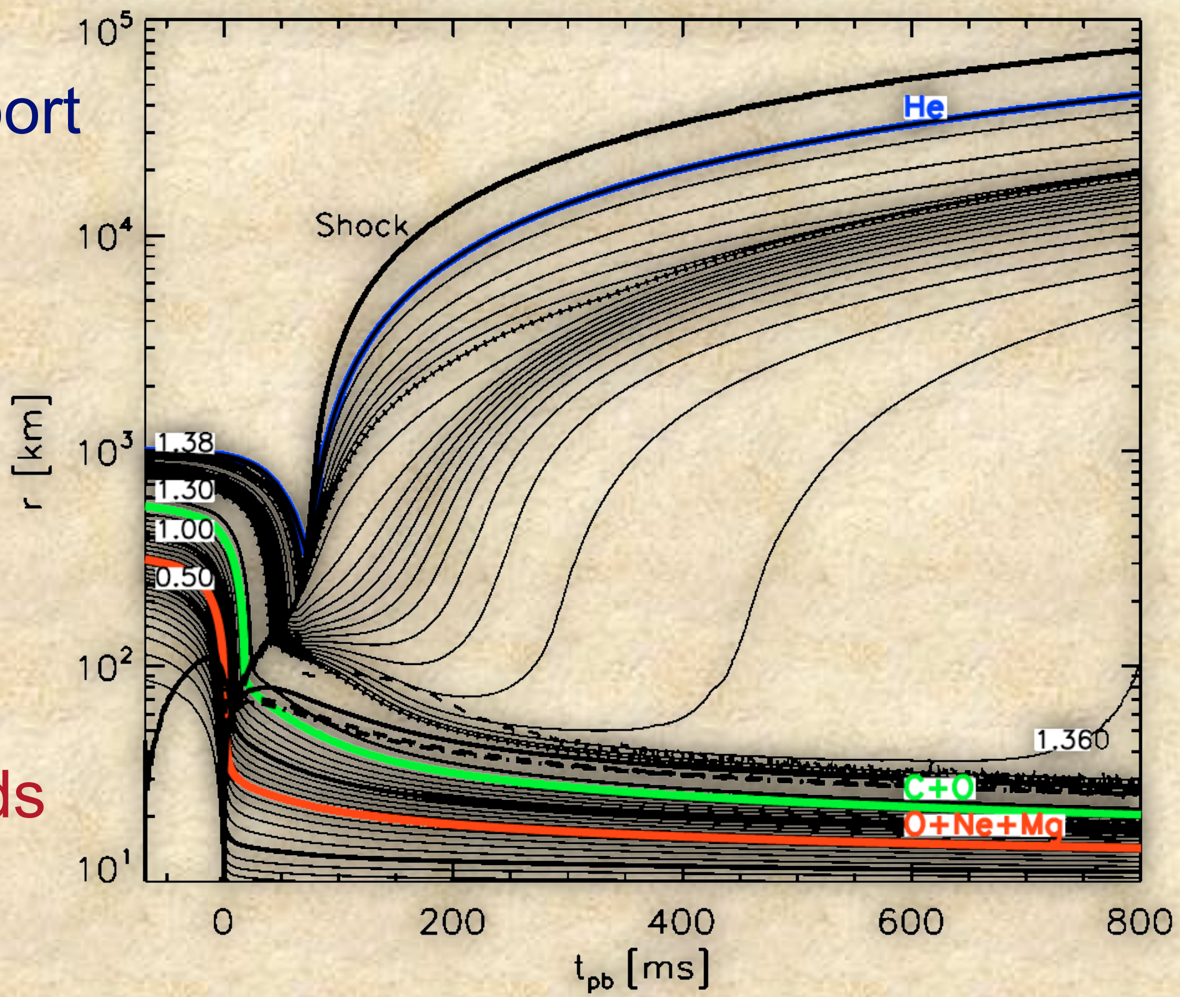
Kitaura, Janka, & Hillebrandt 2006

➔ the only case (1D) with accurate ν transport

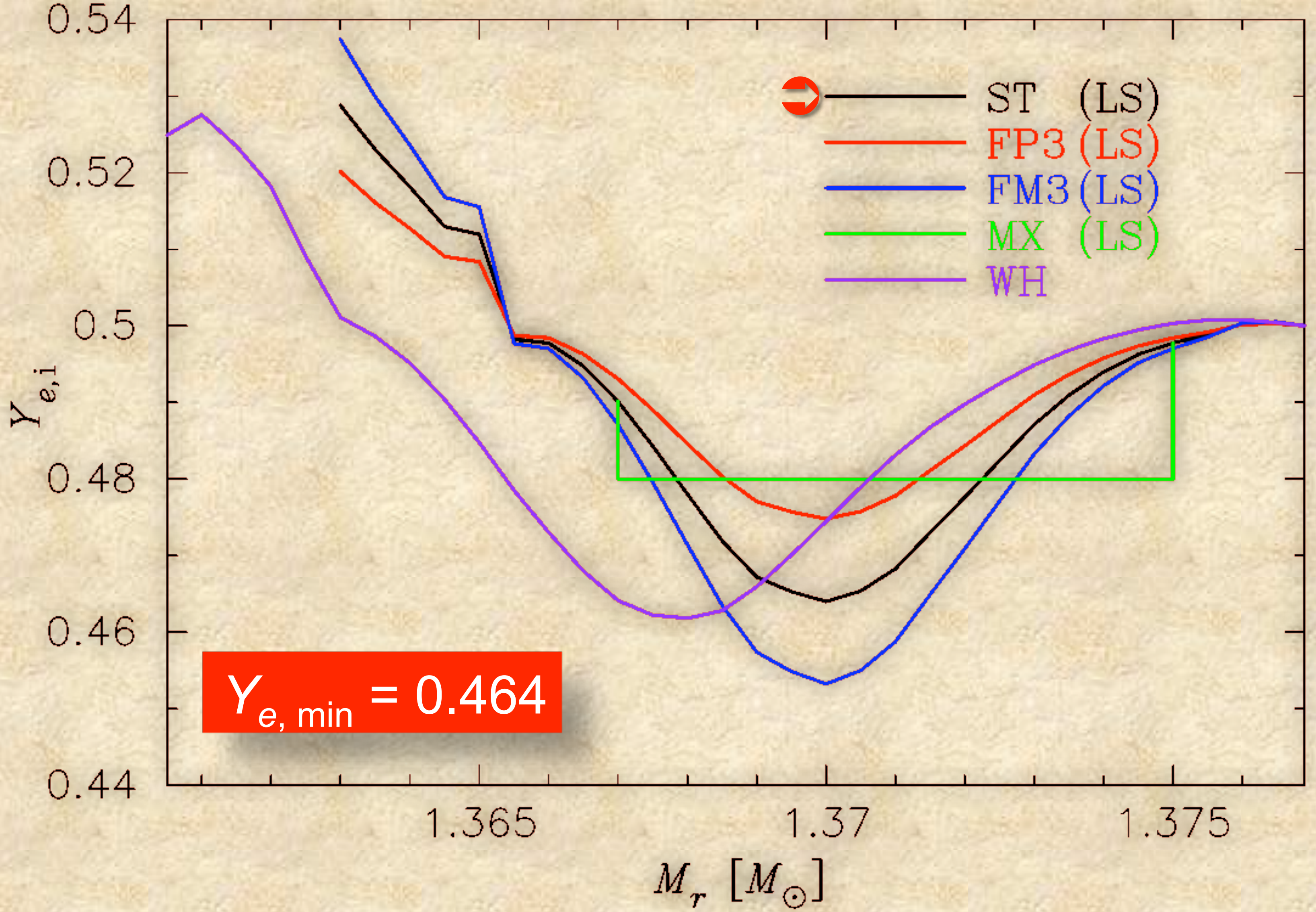
➔ $E_{exp} = 1 \times 10^{50}$ erg
$M_{ej} = 0.014 M_{\odot}$
$s = 10\text{-}30\ k/m_u$
$Y_e = 0.46\text{-}0.53$

Nucleosynthesis in the SN with no parameters

➔ most reliable SN yields to date!?

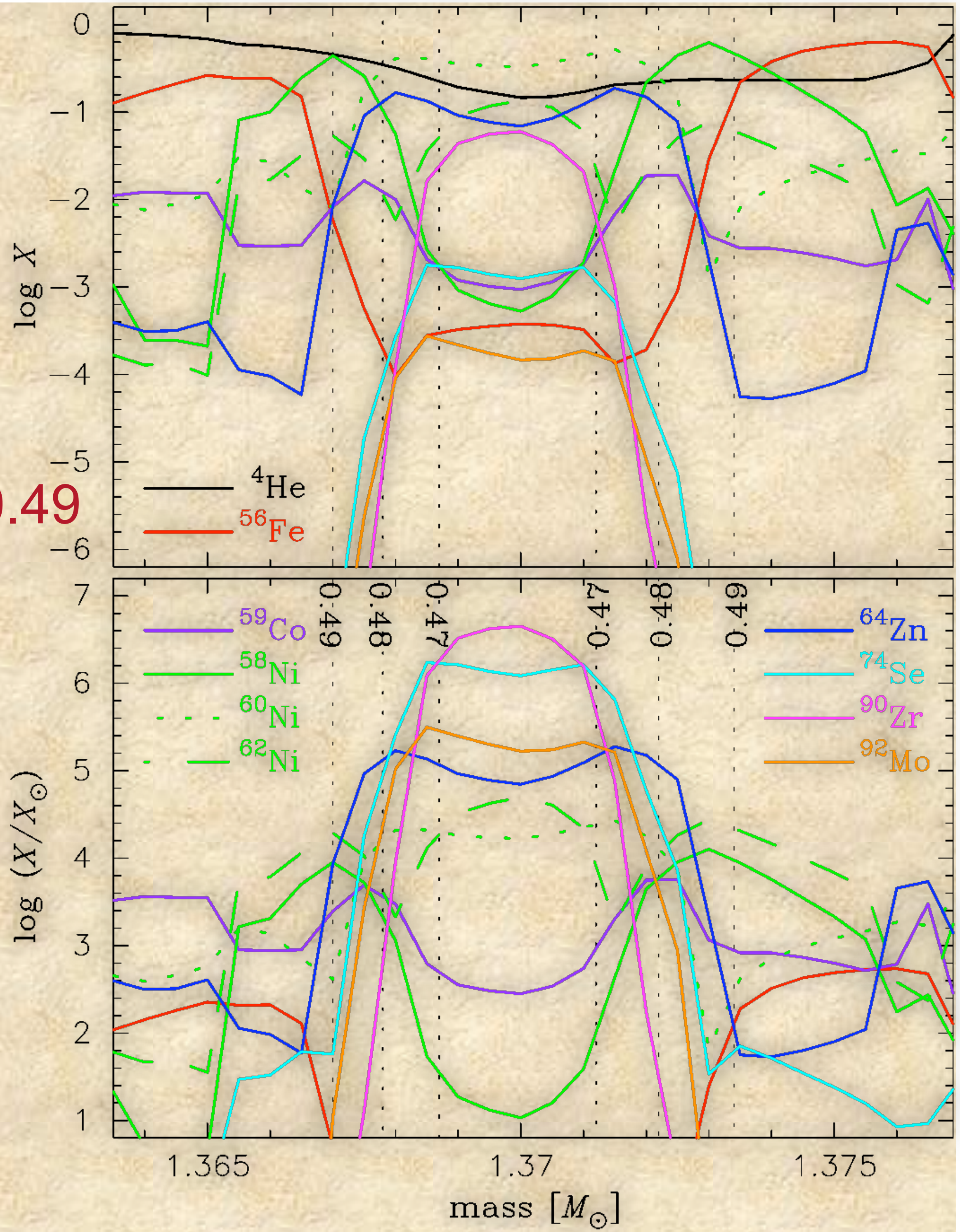


initial compositions (Y_e)



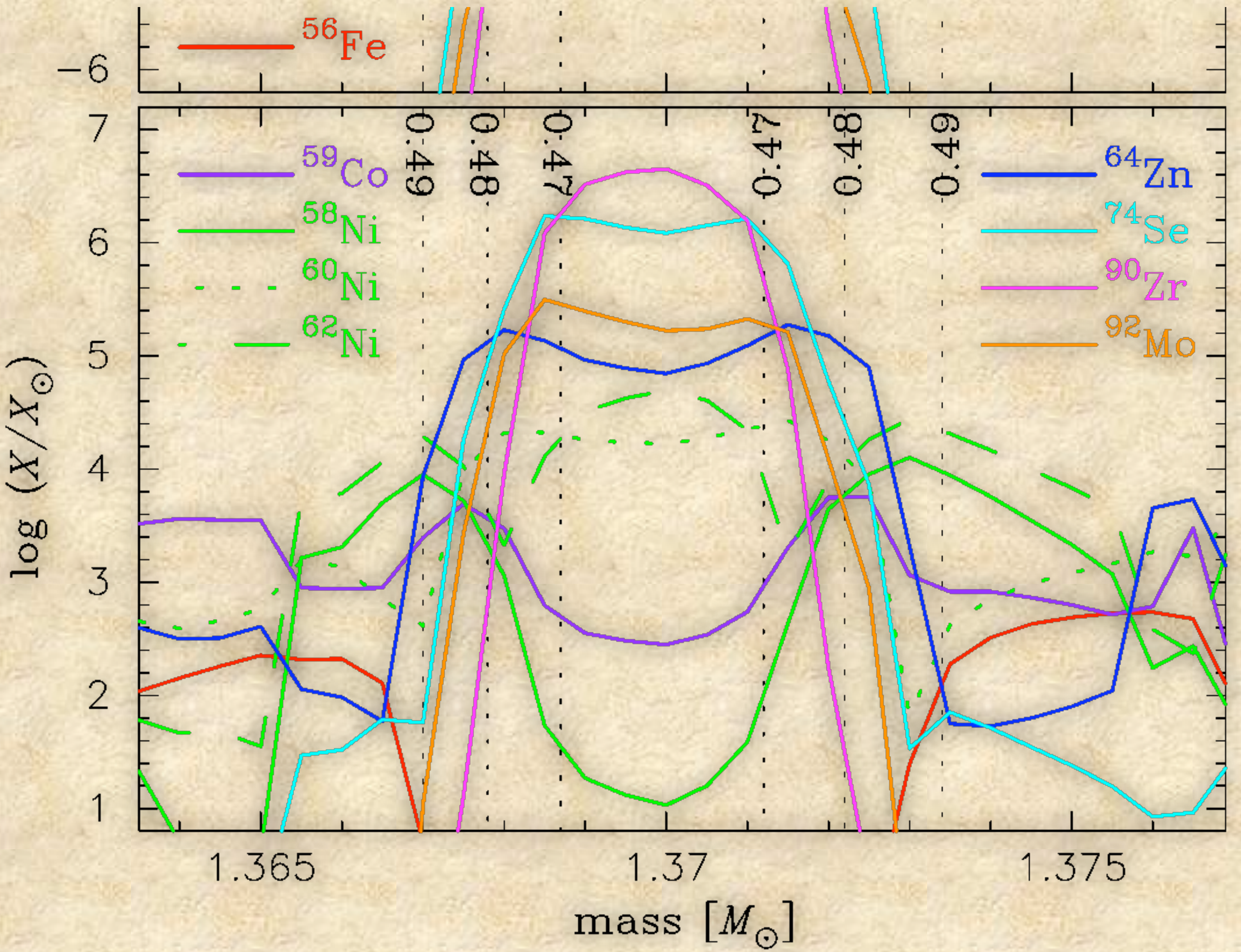
nucleosynthesis

- Fe (as ^{56}Ni) production at $Y_e \geq 0.49$ (0.002-$0.004 M_\odot$)
- ^{64}Zn and light p-nuclei (e.g., ^{92}Mo) at $Y_e = 0.46$-0.49
  Hoffman et al. 1996; Wanajo 2006
- marginal νp-process at $Y_e > 0.50$
  Flohrich et al. 2006;
  Pruet et al. 2006
  Wanajo 2006
- no r-process (up to ^{90}Zr) at least $t_{pb} < 1$s with 1D
  Hoffman et al. 2008



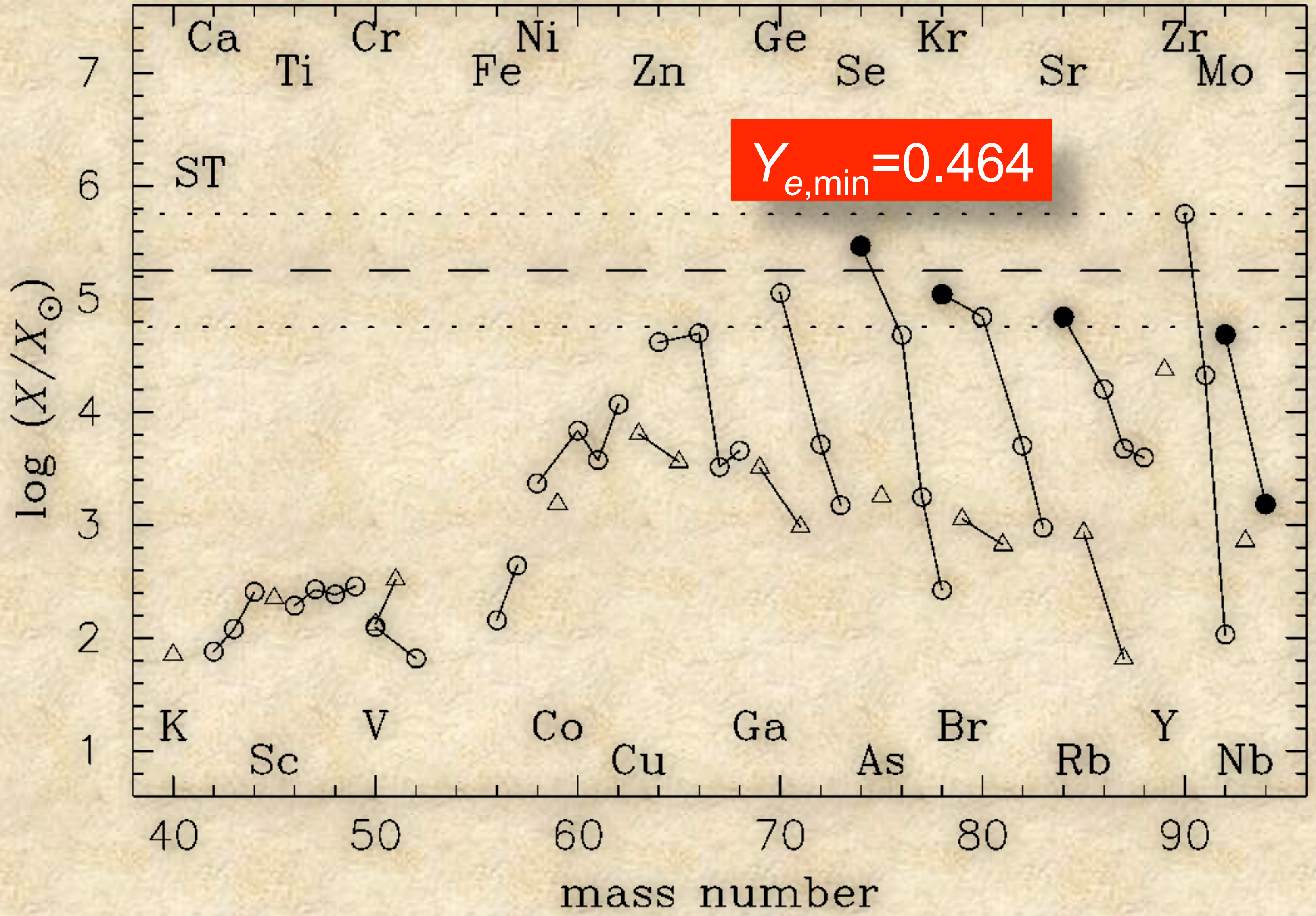
overproduction factors

➲ strong overproduction of ^{90}Zr at $Y_e \sim 0.47$



mass-averaged yields

- ➲ strong overproduction of ^{90}Zr, high Ni/Fe (~ 10 solar)
- ➲ little production of ^{56}Ni (=0.002-0.004$M_{\odot}$ in mass fraction)



contribution to the Galaxy

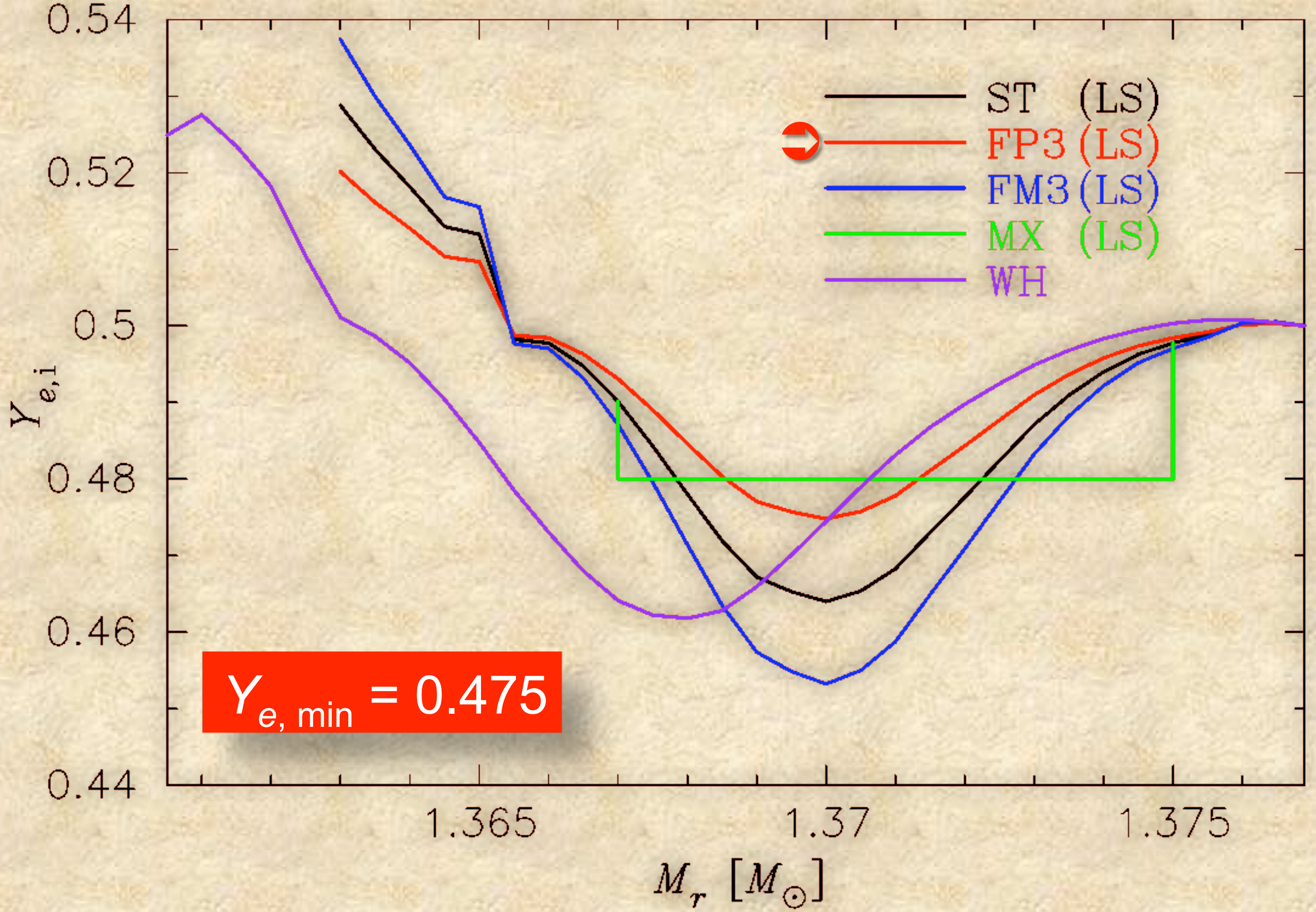
$$\frac{f}{1-f} = \frac{X(^{90}\mathrm{Zr})_{\odot} / X(^{16}\mathrm{O})_{\odot}}{M(^{90}\mathrm{Zr}) / M(^{16}\mathrm{O})_{\mathrm{other}}} = 0.029$$

f : fraction of ONeMg SNe relative to all SNeII/Ibc

$M(^{16}\mathrm{O})_{\mathrm{other}} = 1.5 M_{\odot}$: average ejecta mass of $^{16}\mathrm{O}$ per event from SNe ($> 10 M_{\odot}$)

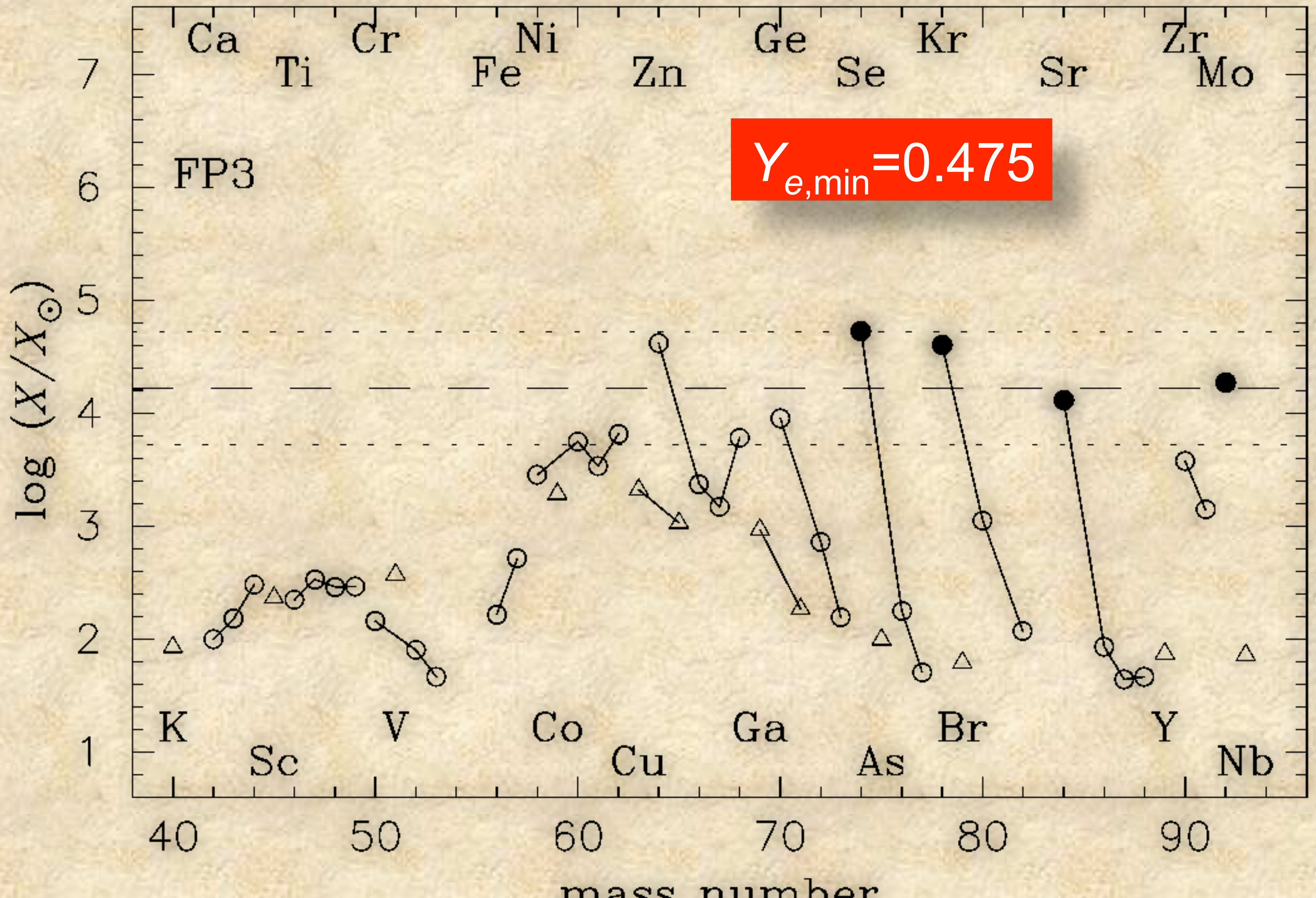
- $f = 0.028$
- 81% of solar ^{90}Zr is from s-process
- no more than 1% of all core-collapse supernovae.... in agreement with Hoffman et al. 2008

initial compositions (Y_e)



mass-averaged yields

- ➲ only 2% increase of $Y_{e,min}$ cures the overproduction of ^{90}Zr !!
- ➲ robust production of ^{64}Zn and p-nuclei ^{74}Se, ^{78}Kr, ^{84}Sr, ^{92}Mo



contribution to the Galaxy

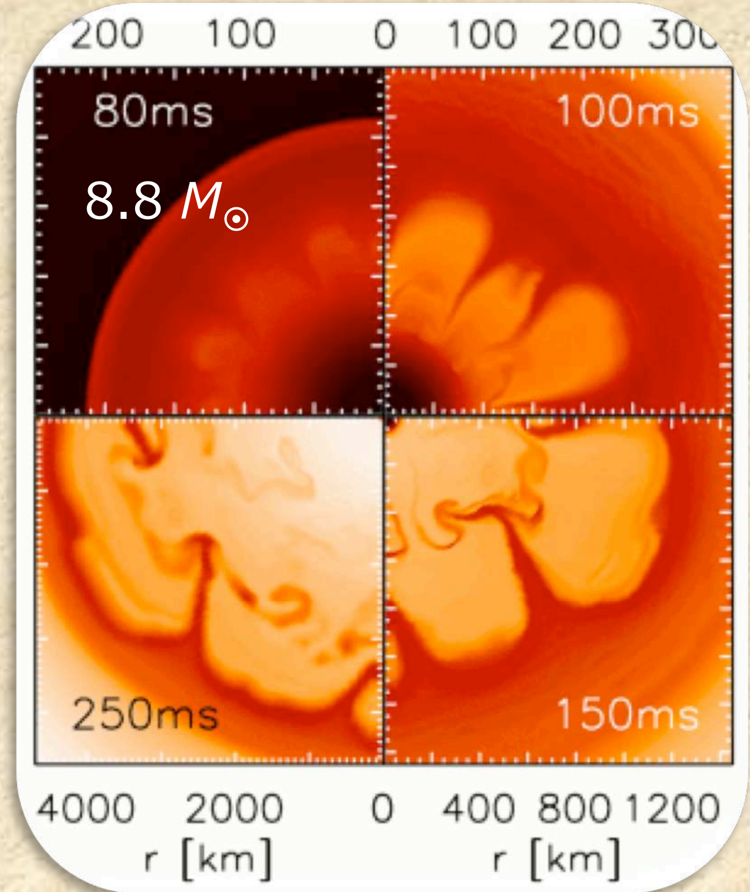
$$\frac{f}{1-f} = \frac{X(^{64}\mathrm{Zn})_\odot / X(^{16}\mathrm{O})_\odot}{M(^{64}\mathrm{Zn}) / M(^{16}\mathrm{O})_{\mathrm{other}}} = 0.39$$

f : fraction of ONeMg SNe relative to all SNeII/Ibc

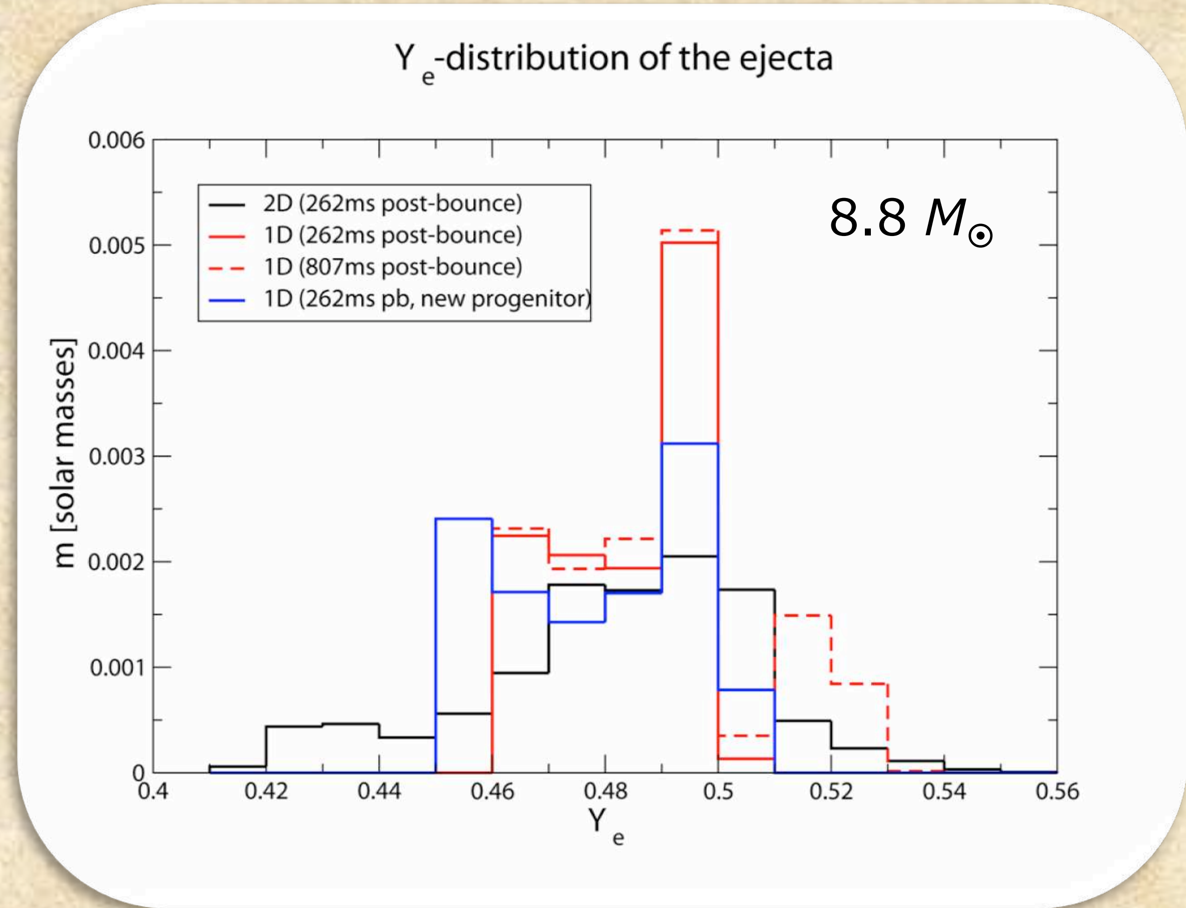
$M(^{16}\mathrm{O})_{\mathrm{other}} = 1.5 M_\odot$: average ejecta mass of $^{16}\mathrm{O}$ per event from SNe ($> 10 M_\odot$)

- ➲ $f = 0.28$
- ➲ origin solar ^{64}Zn (dominant isotope) is uncertain
- ➲ up to ~ 30% of all core-collapse supernovae !!! (consistent with 8-10$M_\odot$)

2D effect ? (preliminary)



(Kitaura et al. 2006)



(Muller & Janka in prep.)

conclusions

➲ up to ~30% (~8-10$M_\odot$) of all core-collapse supernovae possible origin of ^{64}Zn and p-nuclei ^{74}Se, ^{78}Kr, ^{84}Sr, ^{92}Mo

➲ little ^{56}Ni production (=0.002-0.004$M_\odot$ in mass fraction)
consistent with the Crab SN (with high Ni/Fe ~10 solar),
low-luminosity SNeIIP (SN1997D, SN2003gd, ...),
new class of luminous transients (SN2008S, ...)

➲ carbon-rich gas of Crab, AGB progenitor of SN2008S
mass range ~9.5-10 $M_\odot$ (~7-8% of all SNe)