# Stellar Nucleosynthesis:
## *the key to galactic evolution*

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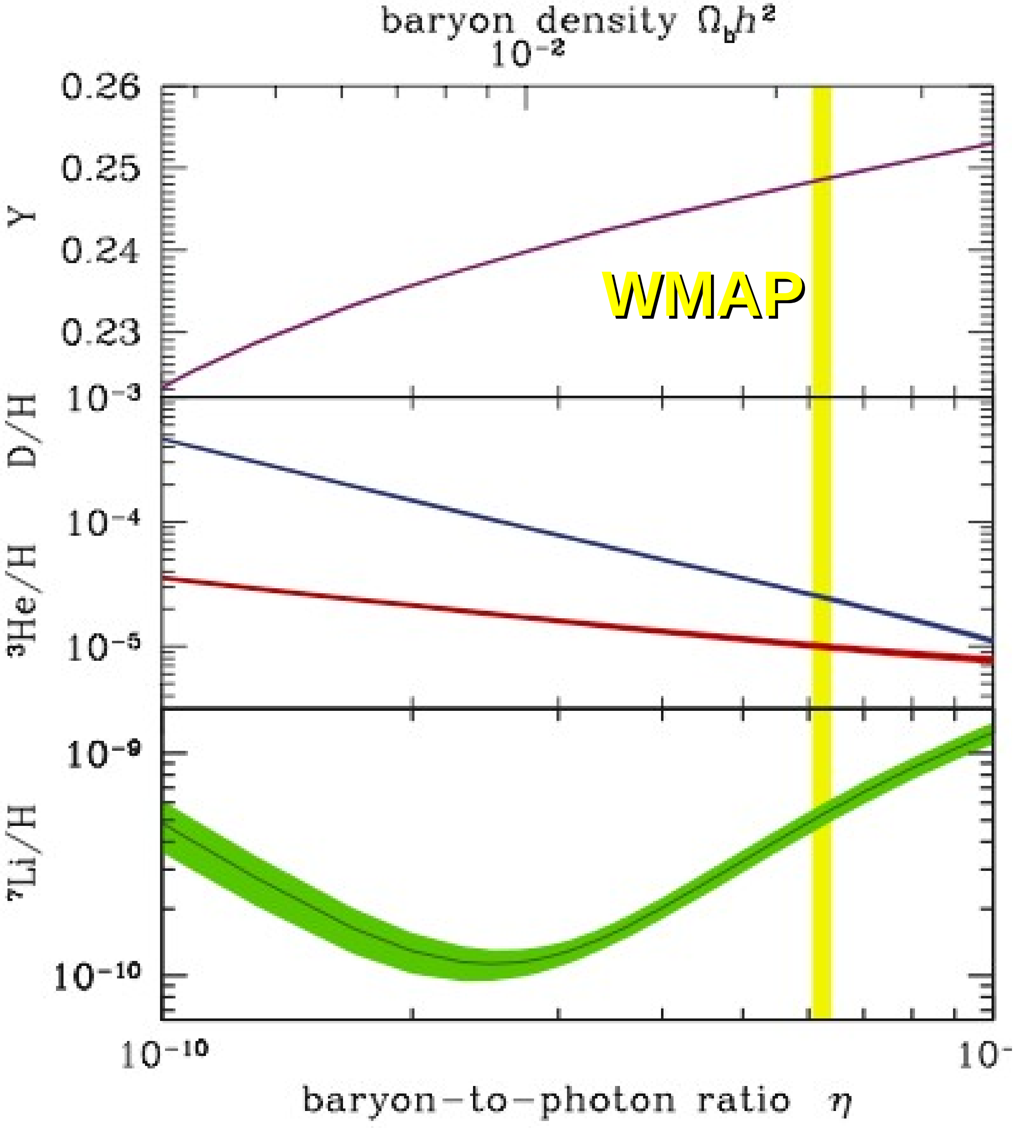
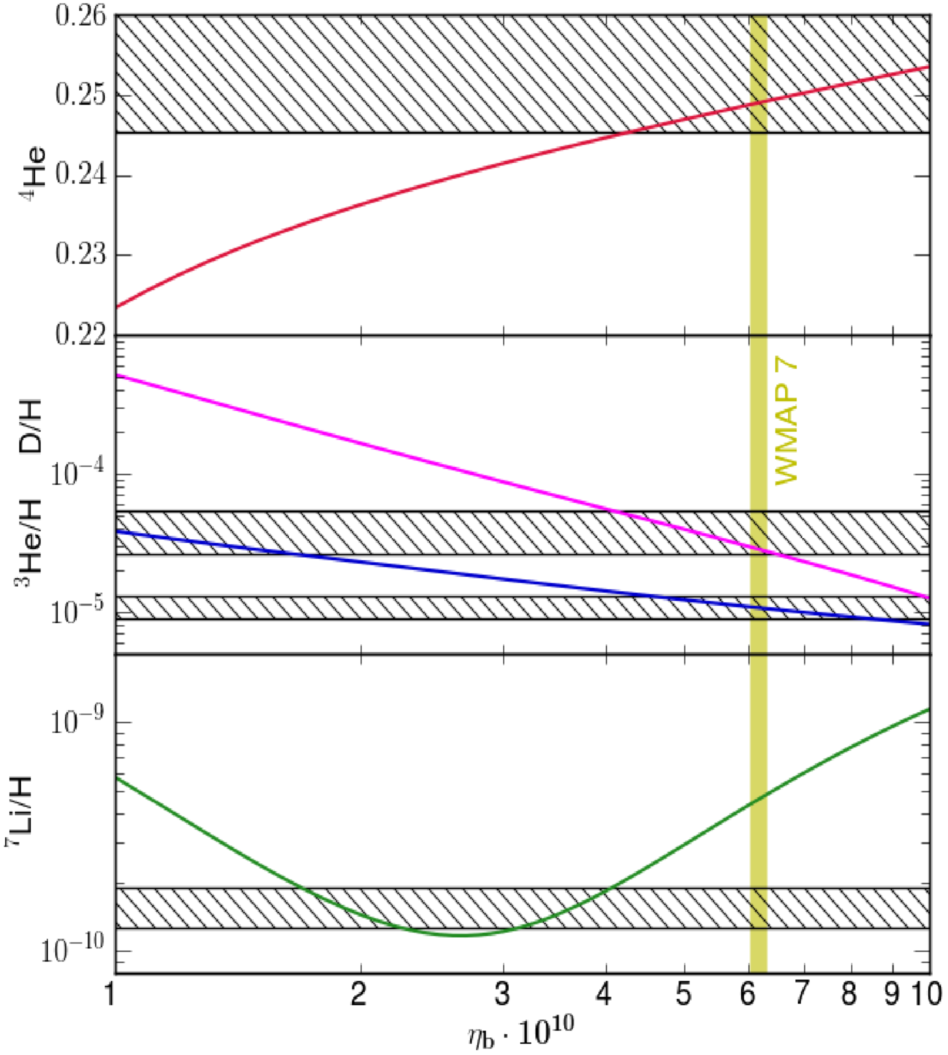
# Before the first stars: Observations vs BBNS



**Cyburt et al. 2008**

**Winteler et al. 2011**



***$^4$He: ok?***

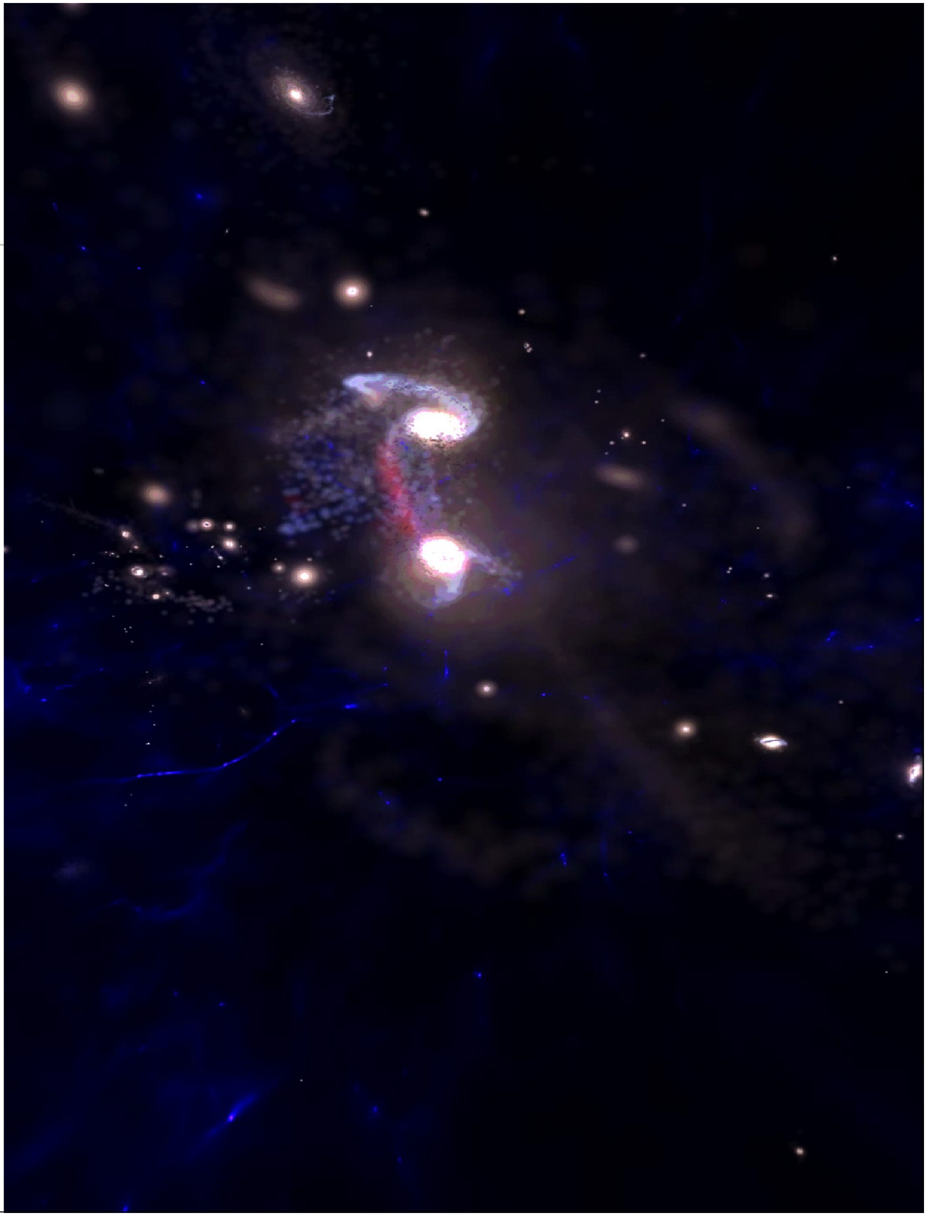
***D and $^3$He: ok***

***$^7$Li discrepant by a factor of ~3-4***

***- Nuclear physics in BBNS No***

- ***Stellar $T_{eff}$-scale No***
- ***Stellar atmospheres + line formation No***
- ***Stellar $^7$Li depletion Perhaps***
- ***Non-standard physics Speculative***

# The First Stars

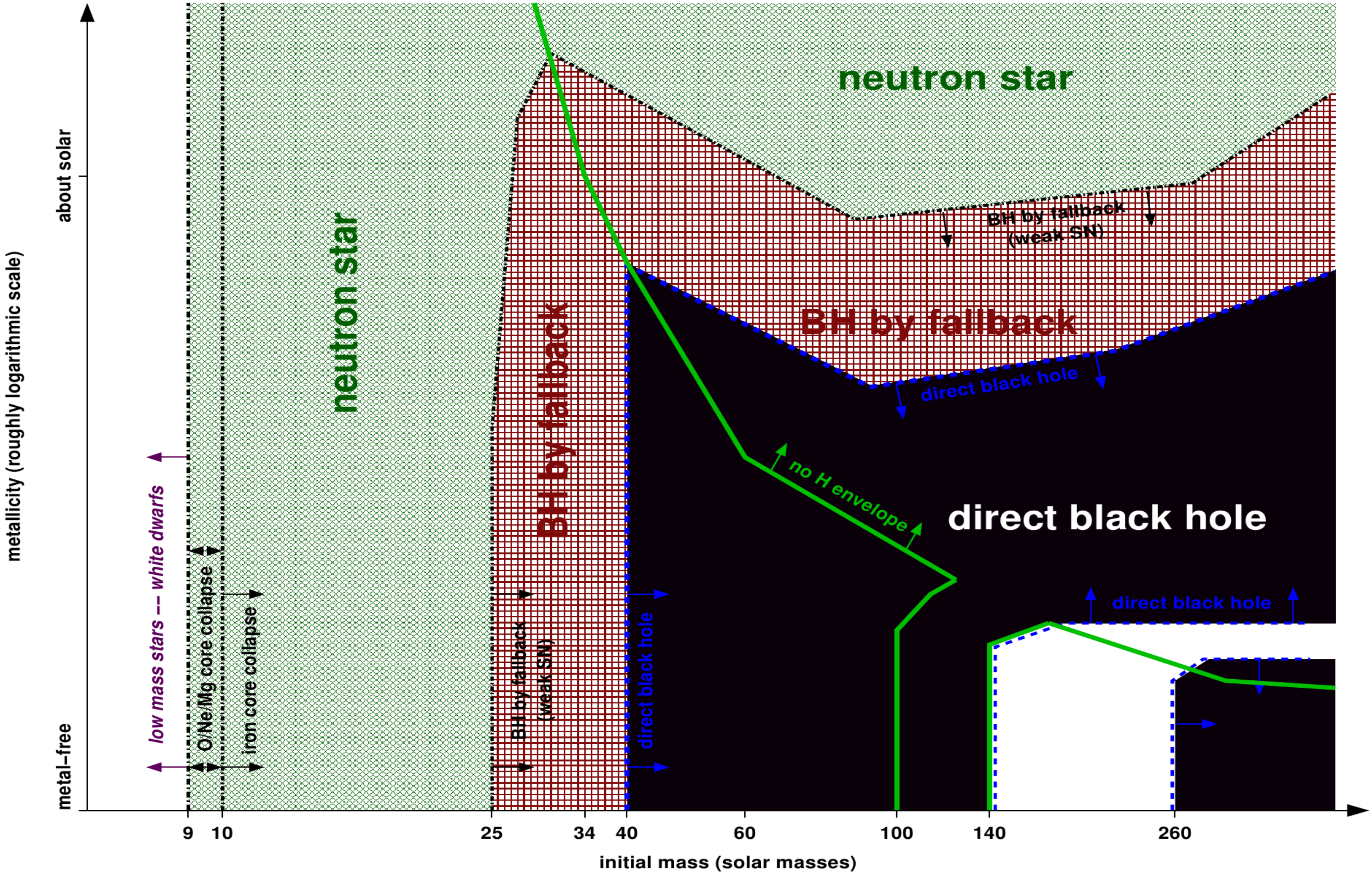


from Tom Abel

*First stars (Pop III.1) are massive, (believed to be in the mass range 60-300 $M_\odot$), if formed in dark matter minihalos with $H_2$ cooling.*

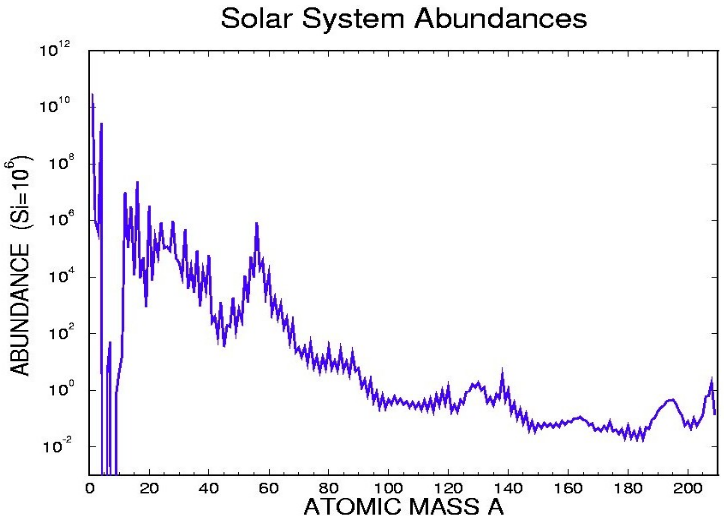
*But also $10_\odot$ stars can be formed, when the HD molecule is responsible for cooling*

(Karlsson, Bromm, Bland-Hawthorne 2011)

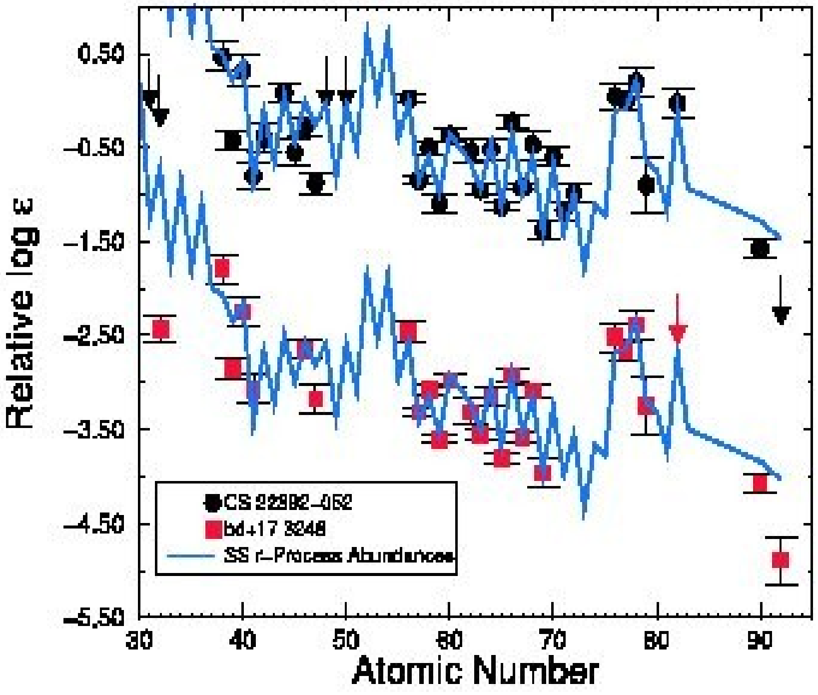


Thus, we have to expect the following objects, presented hereas a function of initial stellar mass, with mass loss dependent on metallicity (Heger et al. 2003).

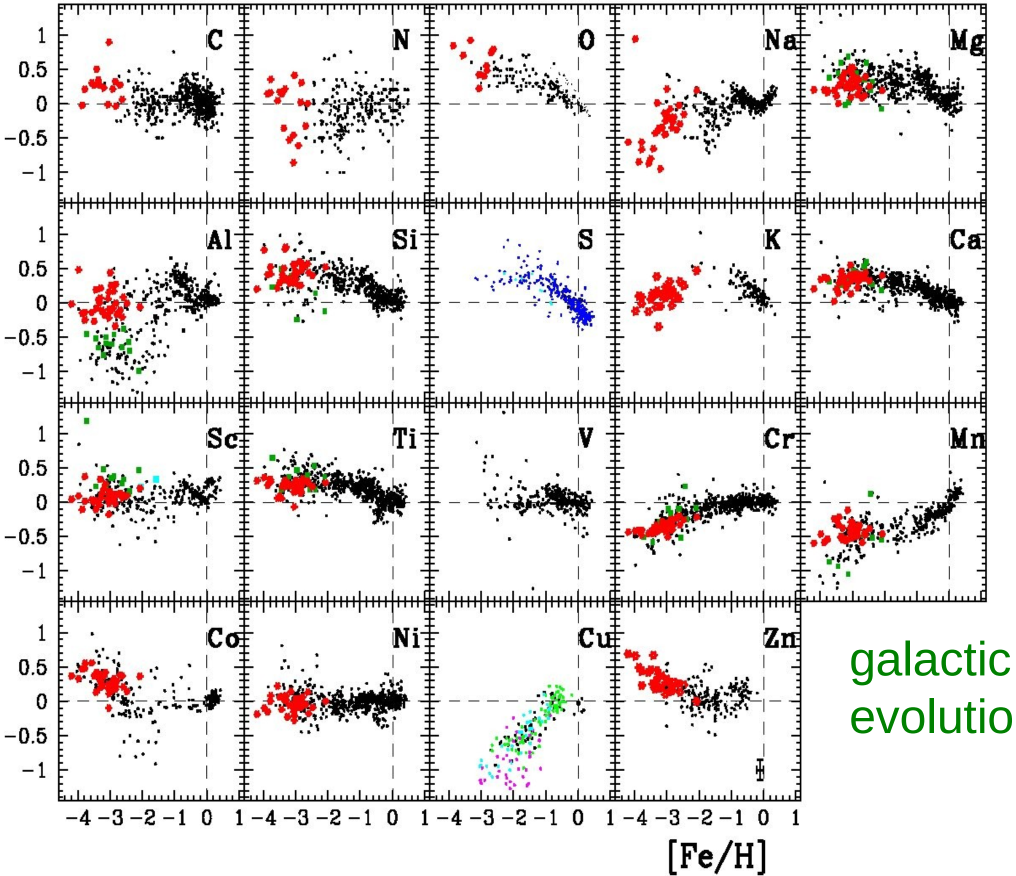
*But what happens for rotating objects?*



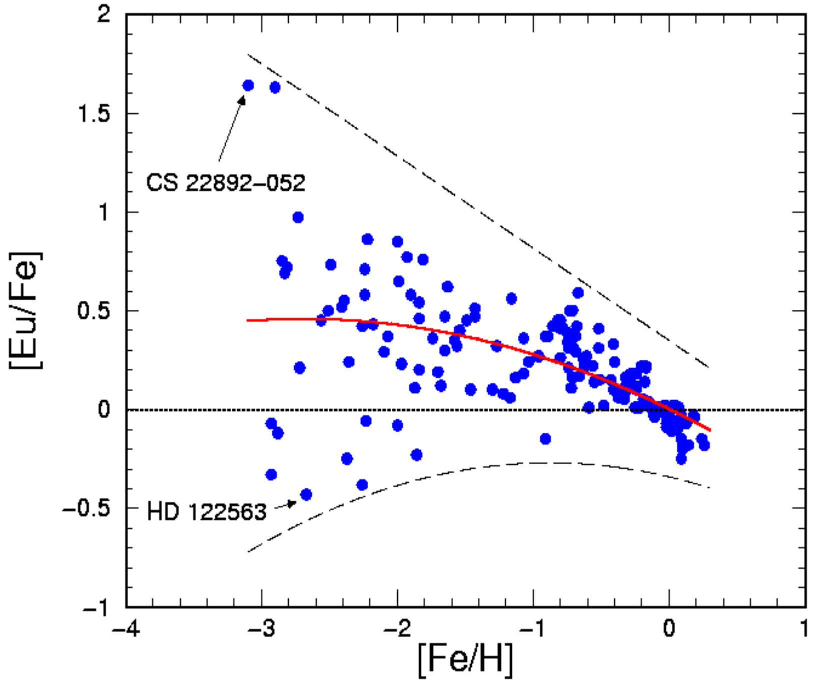
How do we understand: solar system abundances..



low metallicity stars ...



galactic evolution?



# Brief Summary of Burning Stages (Major Reactions)

1. Hydrogen Burning T = $(1\text{-}4)\times10^{7}$K

pp-cycles -> $^{1}\mathrm{H}(p,e^{+}\nu)^{2}\mathrm{H}$

CNO-cycle -> slowest reaction $^{14}\mathrm{N}(p,\gamma)^{15}\mathrm{O}$

2. Helium Burning T=$(1\text{-}2)\times10^{8}$K

$^{4}\mathrm{He}+^{4}\mathrm{He} \Leftrightarrow {}^{8}\mathrm{Be}$ $^{8}\mathrm{Be}(\alpha,\gamma)^{12}\mathrm{C}[(\alpha,\gamma)^{16}\mathrm{O}]$

$^{14}\mathrm{N}(\alpha,\gamma)^{18}\mathrm{F}(\beta^{+})^{18}\mathrm{O}(\alpha,\gamma)^{22}\mathrm{Ne}(\alpha,n)^{25}\mathrm{Mg}$ (n-source, alternatively $^{12}\mathrm{C}((\alpha,n)^{16}\mathrm{O})$

3. Carbon Burning T=$(6\text{-}8)\times10^{8}$K

$^{12}\mathrm{C}(^{12}\mathrm{C},\alpha)^{20}\mathrm{Ne}$ $^{23}\mathrm{Na}(p,\alpha)^{20}\mathrm{Ne}$

$^{12}\mathrm{C}(^{12}\mathrm{C},p)^{23}\mathrm{Na}$ $^{23}\mathrm{Na}(p,\gamma)^{24}\mathrm{Mg}$

ongoing measurements of key fusion reactions at low energies

4. Neon Burning T=$(1.2\text{-}1.4)\times10^{9}$K

$^{20}\mathrm{Ne}(\gamma,\alpha)^{16}\mathrm{O}$

$^{20}\mathrm{Ne}(\alpha,\gamma)^{24}\mathrm{Mg}[(\alpha,\gamma)^{28}\mathrm{Si}]$ 30kT = 4MeV

5. Oxygen Burning T=$(1.5\text{-}2.2)\times10^{9}$K

$^{16}\mathrm{O}(^{16}\mathrm{O},\alpha)^{28}\mathrm{Si}$ $^{31}\mathrm{P}(p,\alpha)^{28}\mathrm{Si}$

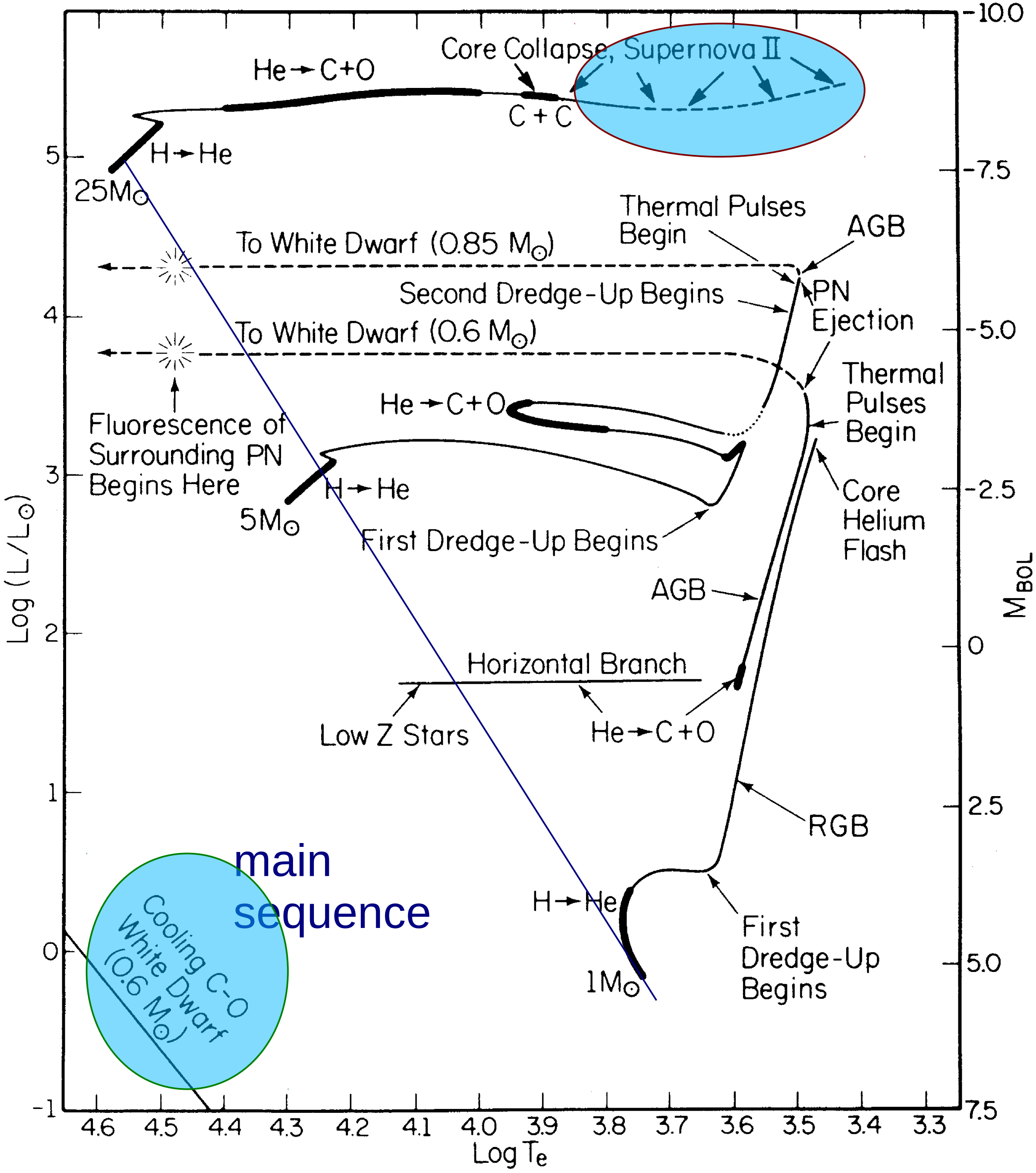
$\ldots\ldots,p)^{31}\mathrm{P}$ $\ldots,n)^{31}\mathrm{S}(\beta^{+})^{31}\mathrm{P}$ $^{31}\mathrm{P}(p,\gamma)^{23}\mathrm{S}$

6. “Silicon” Burning T=$(3\text{-}4)\times10^{9}$K

(all) photodisintegrations and capture reactions possible

⇒ thermal (chemical) equilibrium

# Astrophysical Sites



Hertzsprung-Russell Diagram of Stellar Evolution from Iben, showing as end stages

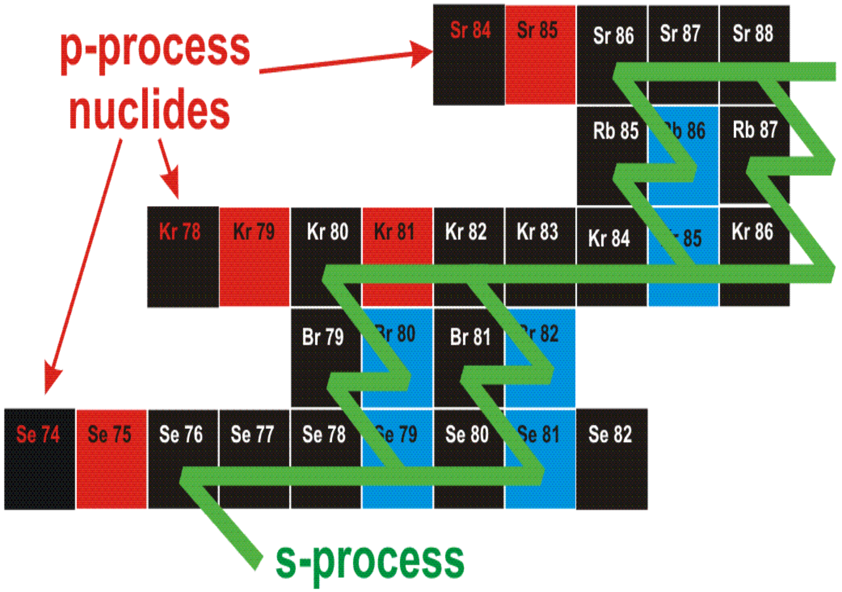
- white dwarfs

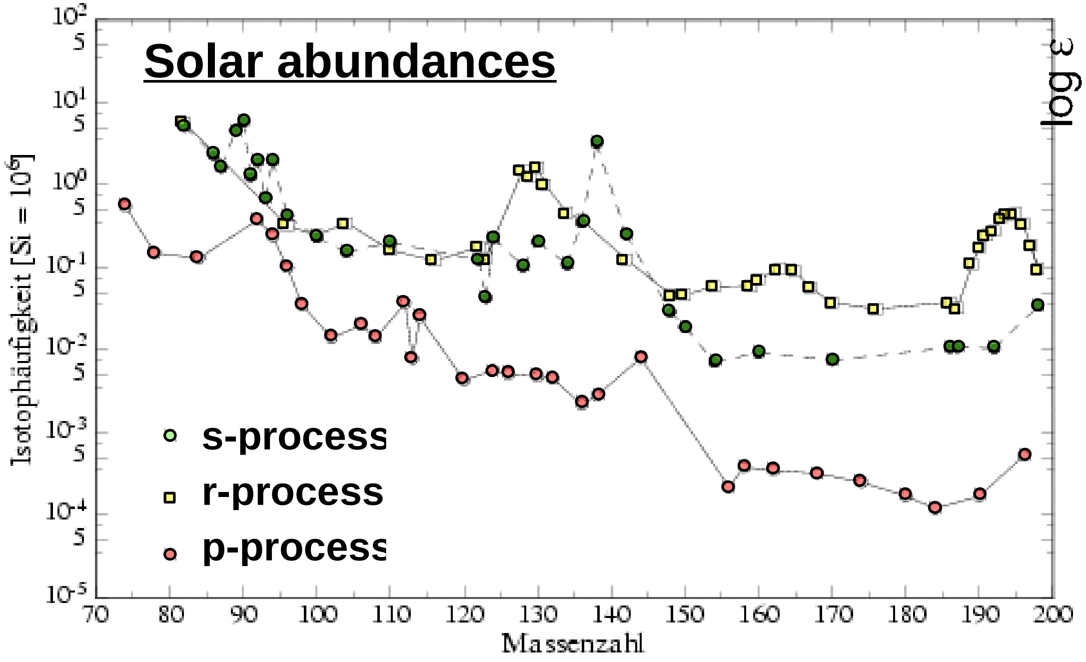
and

- core collapse (supernovae/neutron stars, black holes, hypernovae, GRBs), pair instability SNe?

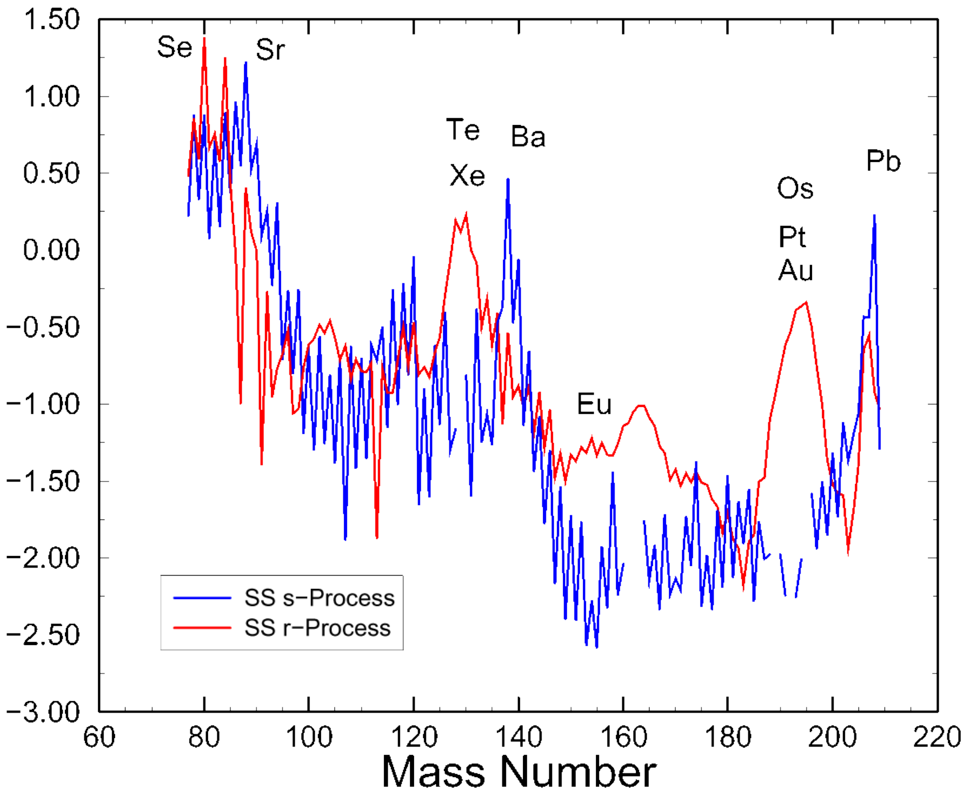
*influence of reaction cross sections, e-capture in late burning stages, metallicity, rotation, magnetic fields,* stellar winds *on final outcome*

# Decomposition of the heavy elements





?



How do stars contribute to s-, r-, and p-process abundances?

# s-Process (neutron) Sources

## Core burning of massive stars (weak s-process)

1. Helium Burning T=(1-2)x10$^8$K

$^4\mathrm{He}+^4\mathrm{He} \Leftrightarrow {}^8\mathrm{Be}$ $^8\mathrm{Be}(\alpha,\gamma)^{12}\mathrm{C}[(\alpha,\gamma)^{16}\mathrm{O}]$

$^{14}\mathrm{N}(\alpha,\gamma)^{18}\mathrm{F}(\beta^+)^{18}\mathrm{O}(\alpha,\gamma)^{22}\mathrm{Ne}(\alpha,n)^{25}\mathrm{Mg}$

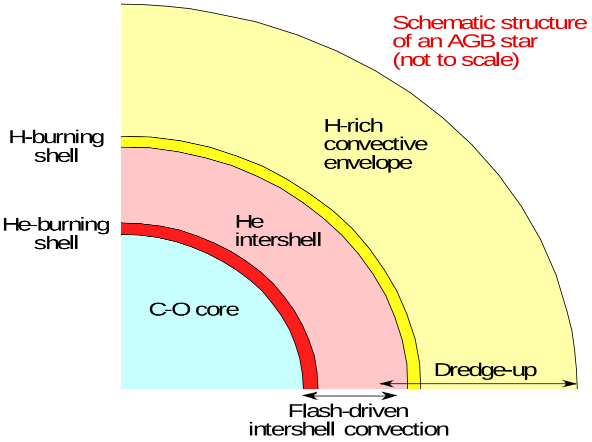
2. Carbon Burning T=(6-8)x10$^8$K

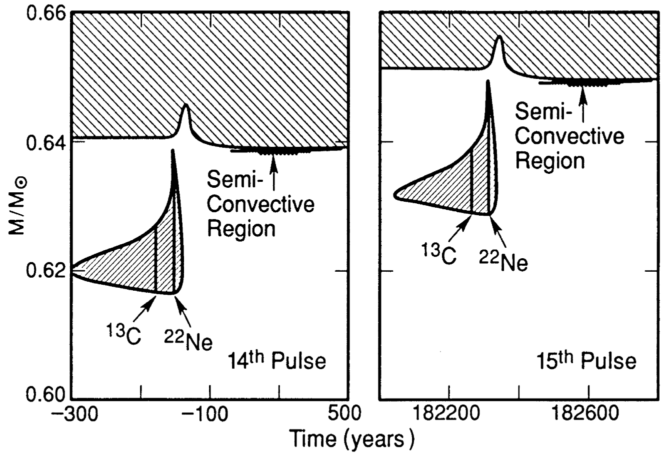
$^{12}\mathrm{C}(^{12}\mathrm{C},\alpha)^{20}\mathrm{Ne}$ $^{12}\mathrm{C}(p,\gamma)^{13}\mathrm{N}(\beta^+)^{13}\mathrm{C}$

$^{12}\mathrm{C}(^{12}\mathrm{C},p)^{23}\mathrm{Na}$ $^{13}\mathrm{C}(\alpha,n)^{16}\mathrm{O}$

protons as well as alphas are not existing intrinsically in C-burning, as destroyed in prior H-burning and He-burning. They come from the C-fusion reaction

## He-shell flashes in AGB stars (strong s-process)





protons are mixed in from the H-shell and produce $^{13}$C (as in 2. above), but the latter can react with the full He-abundance in He-burning and produce a strong neutron source.

# Observations of post-AGB stars, indicating the intrinsic pollution due to strong s-processing

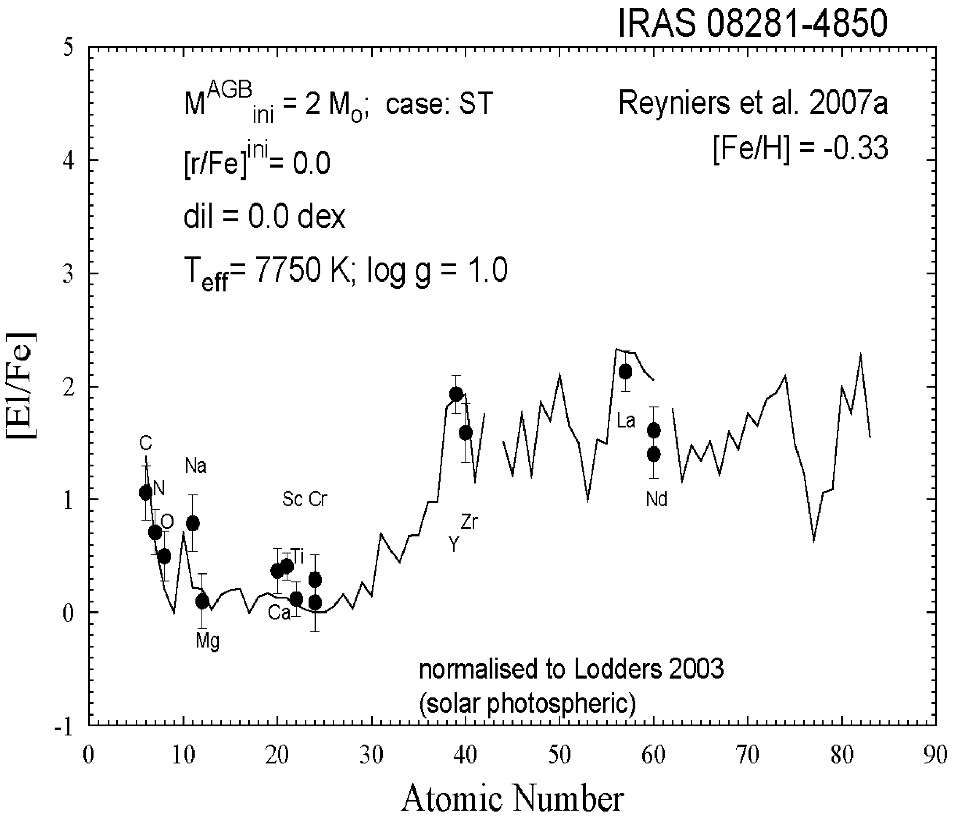
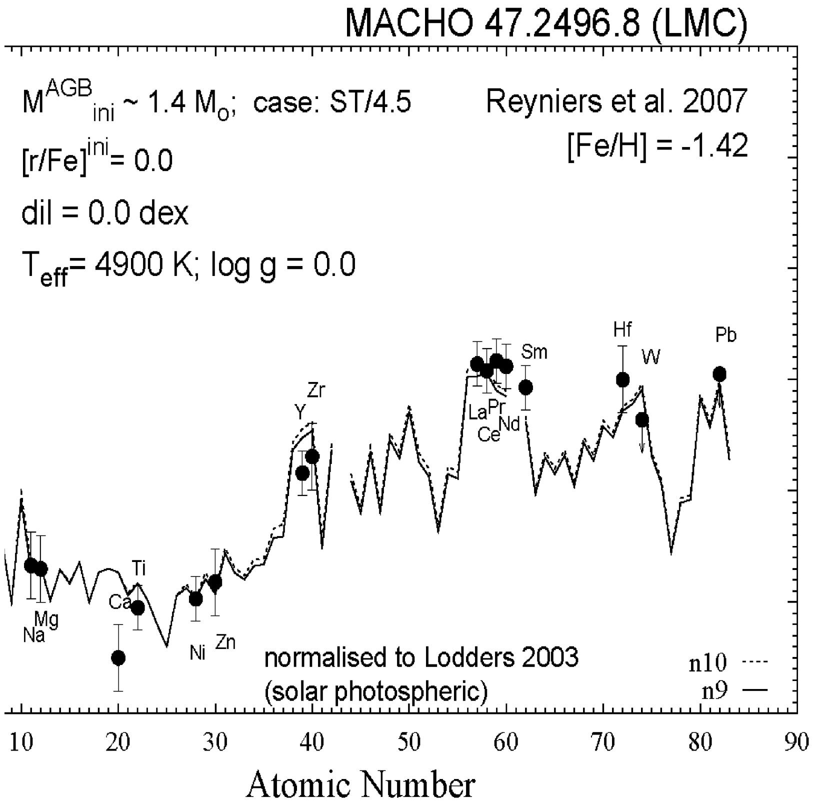
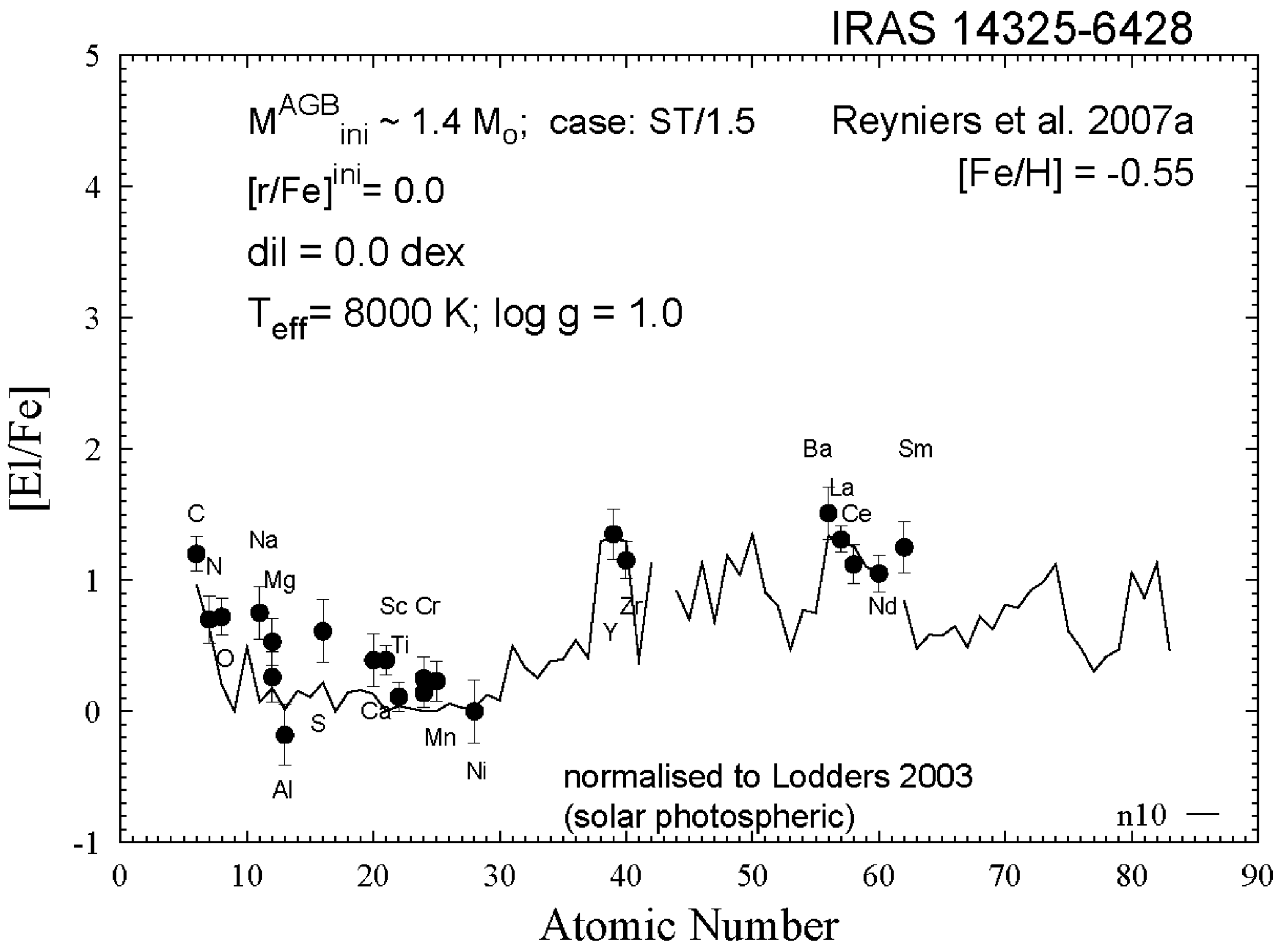


**FIGURE 1.** Theoretical interpretation of the post-AGB star IRAS 08281-4850 by Reyniers et al. (2007a) [2], with $M_{\mathrm{ini}}^{\mathrm{AGB}} = 2\ \mathrm{M}_{\odot}$, case ST.



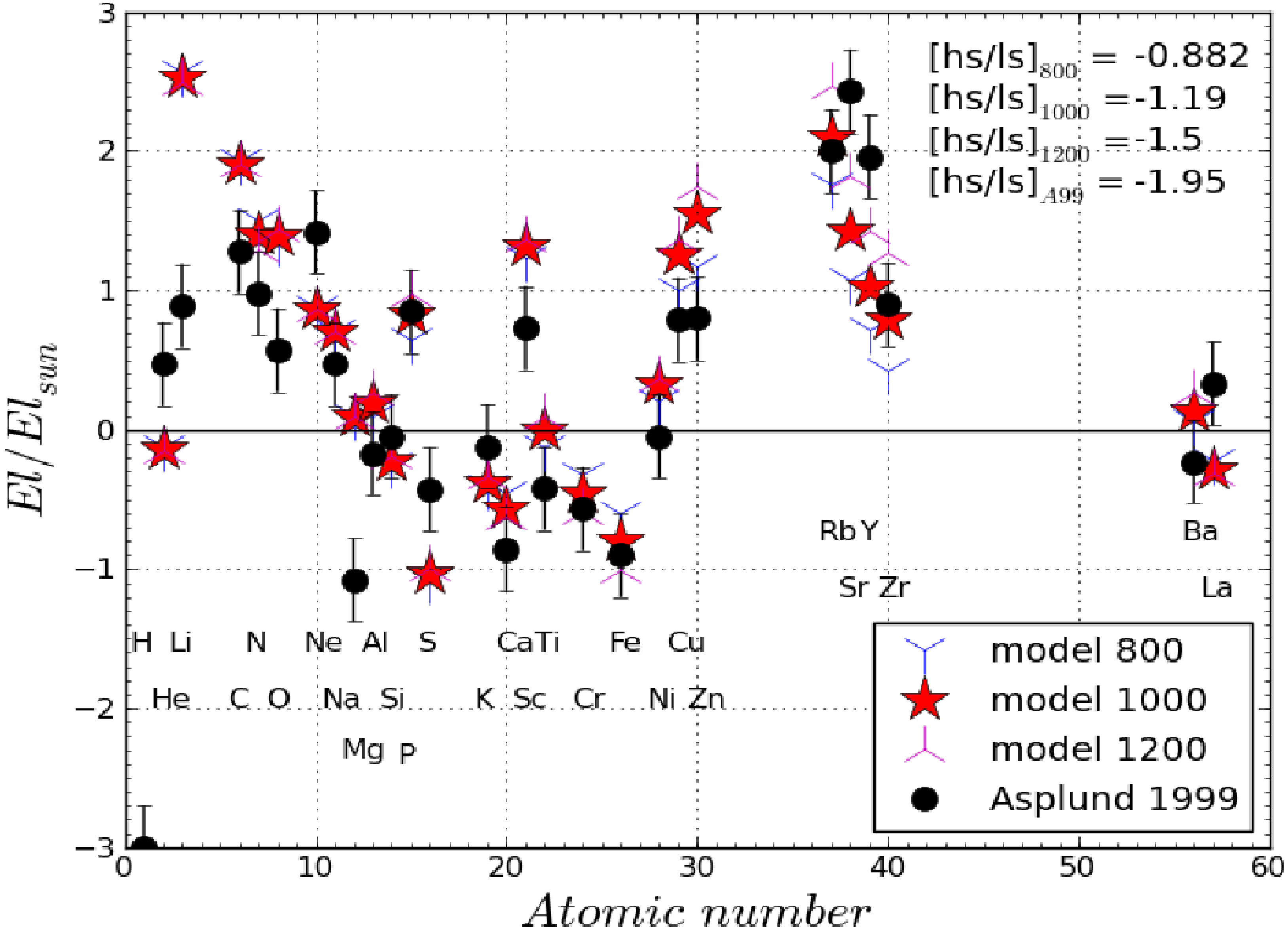
Gallino et al. (2008)

the process of multi-D mixing is not fully understood yet (resolution and 3D), thus the mixing efficieny is introduced by a paramter (here ST*fac)

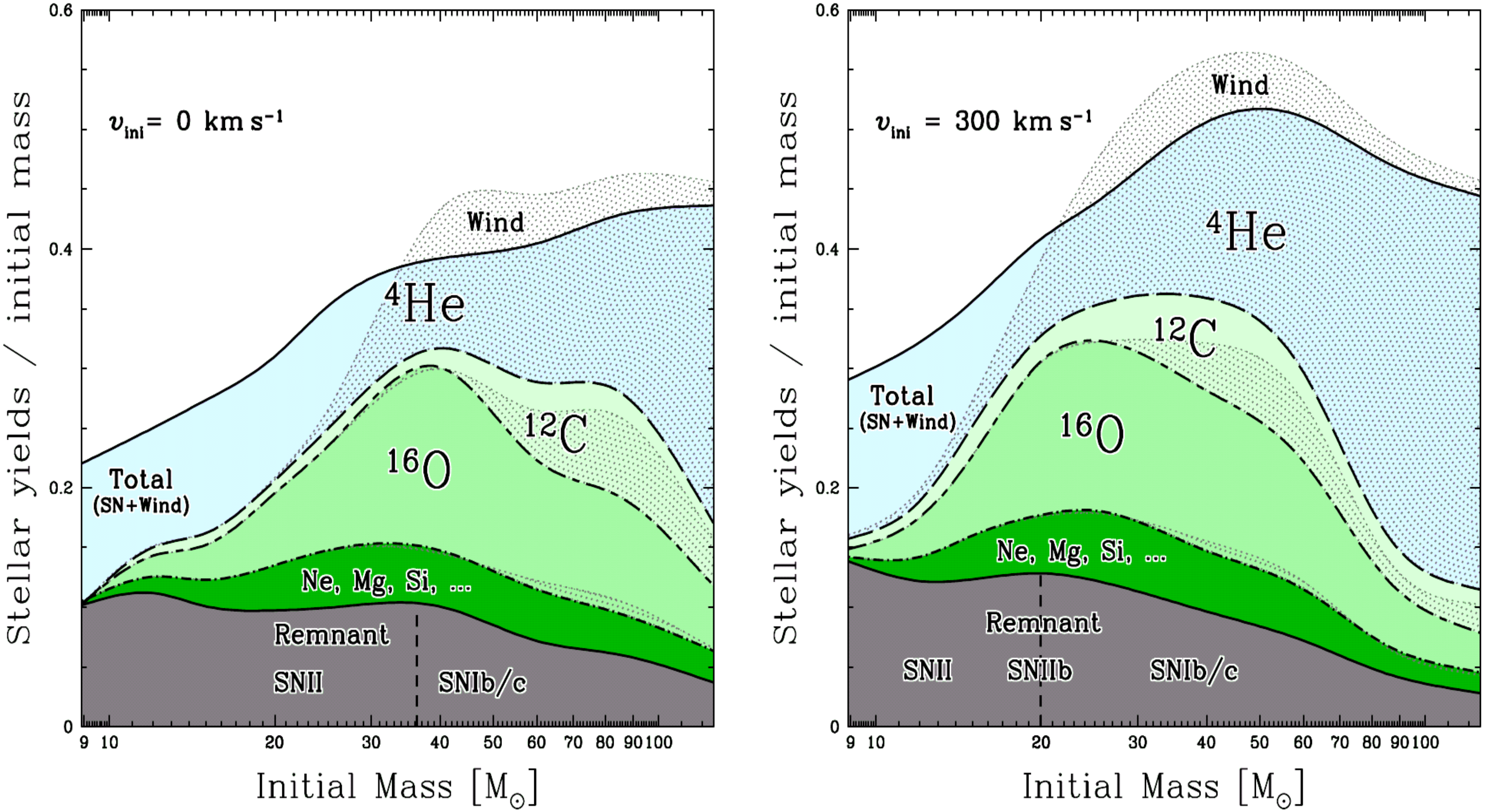


each star shows a specific stage of s-processing, i.e. we have no overall agreement with „solar“ s-process abundances in a single star. Solar s-abundances are only obtained via integrating over an IMF and over galactic evolution with increasing metallicity

# Sakurai's object and the importance of 3D convective nucleosynthesis (Herwig et al. 2011)

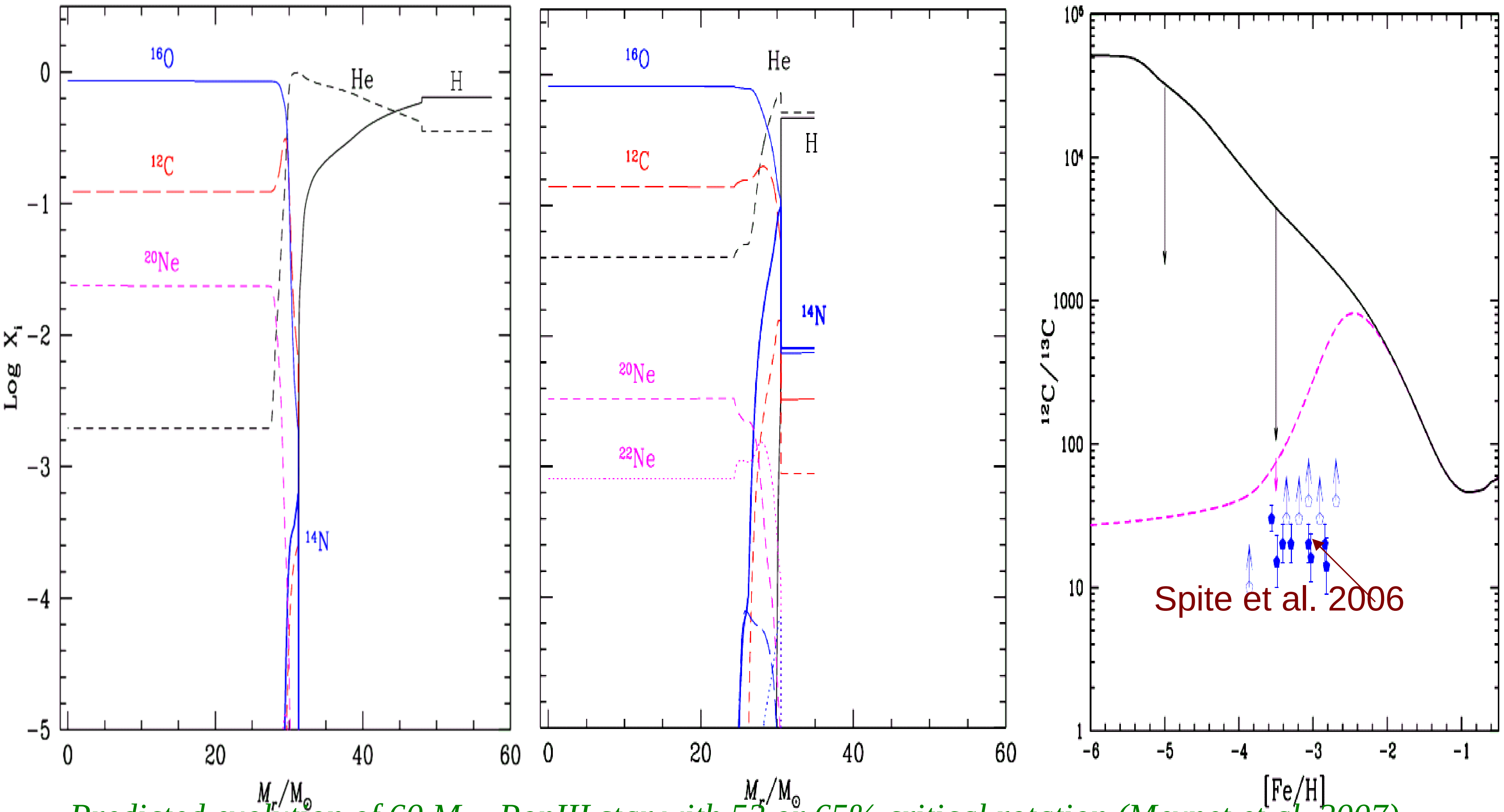


# Wind Losses During Stellar Evolution (Effects of Rotation)



*Stellar yields divided by the initial mass as a function of the initial mass for non–rotating (left) and rotating (right) models at solar metallicity (Hirschi et al. 2005, Yusof et al. 2010)*

# Effect of fast Rotation on Stellar Evolution and Wind Losses

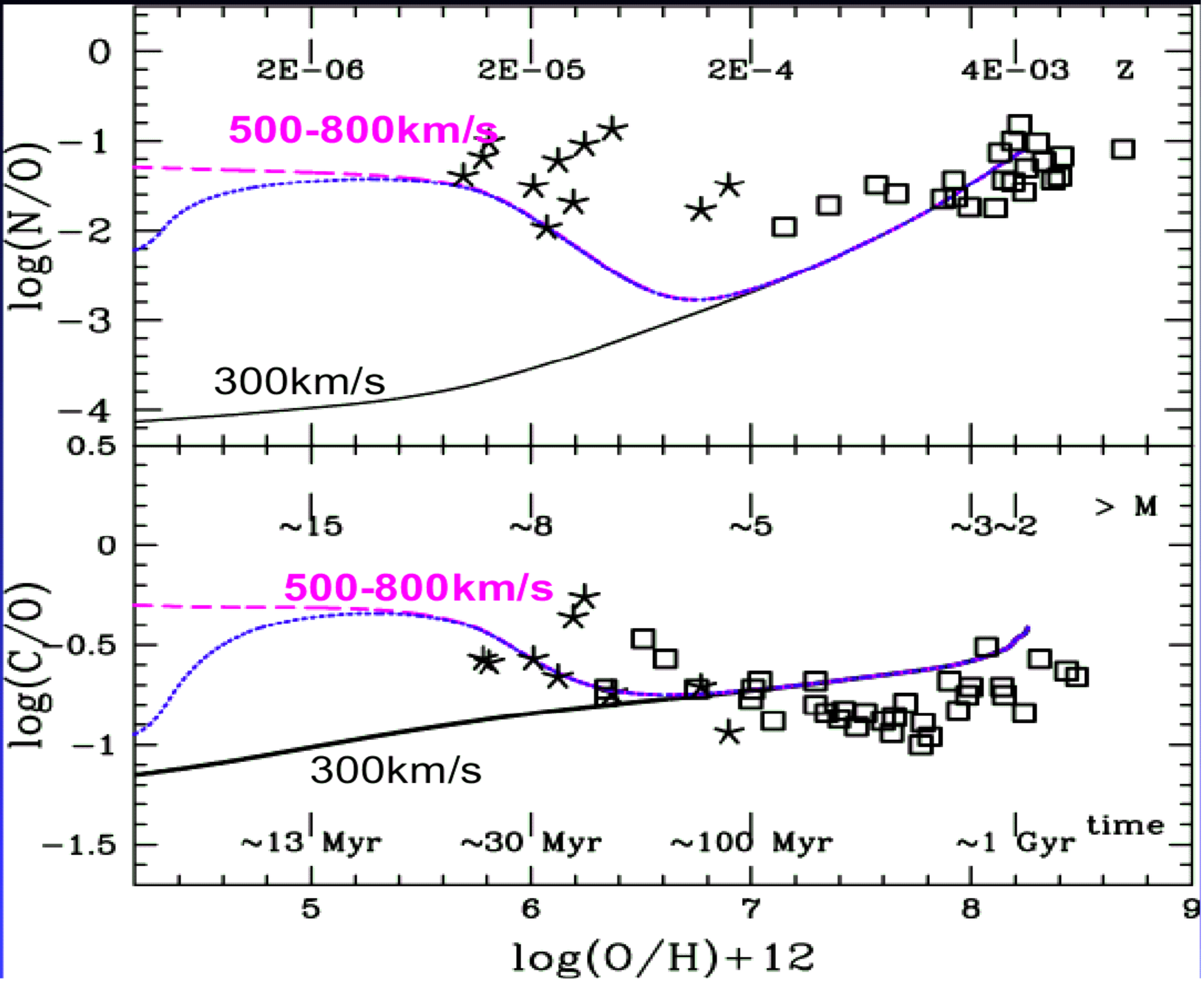


*Predicted evolution of 60 $M_{sol}$ PopIII star with 52 or 65% critical rotation (Meynet et al. 2007). Similar results for more massive stars, which would – without rotation-enhanced mass loss – end as pair instability SNe. Evolution of $^{12}C/^{13}C$ ratio for stellar yields without or with the inclusion of fast rotators for metallicities below $Z = 10^{-5}$ solid line/dashed line (Chiappini et al. 2009), also producing primary N and increasing N/O and C/O (Hirschi et al. 2008, Yusof et al. 2010).*

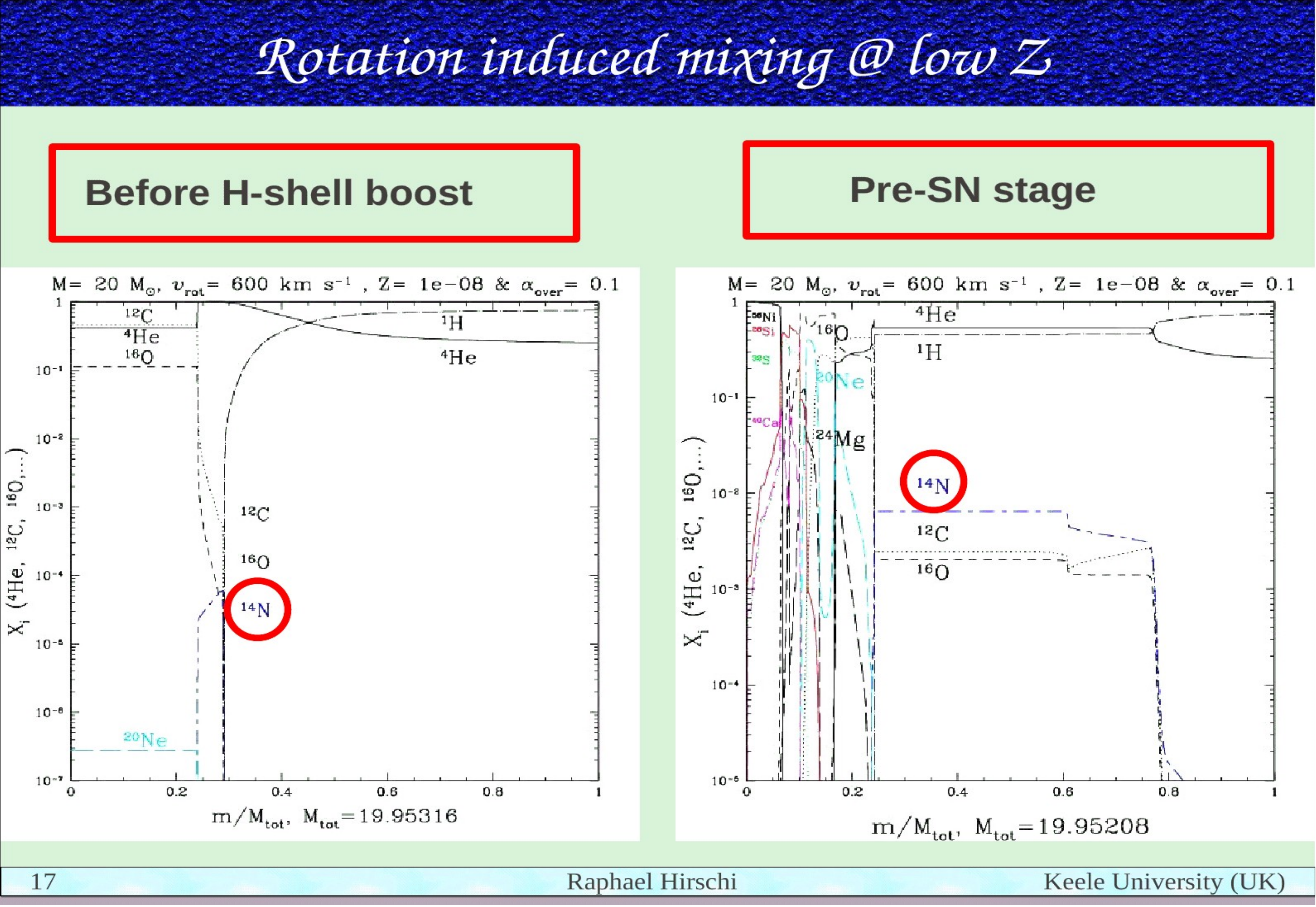
# First & Second Signatures of Fast Rotators in the Early Universe

**Early Universe shows large N/O and C/O ratios**

Chiappini, Hirschi, Meynet, Ekstroem, Maeder, Matteucci (2006a,b)



stellar wind loss from early fast rotating stars!!



# Rotation induced mixing @ low Z

**Before H-shell boost**

**Pre-SN stage**

*rotation produces primary nitrogen and later* $^{22}$*Ne => enhances mass loss and s-process source*

# s-Processing in rotating low-metallicity stars, $Z=10^{-5}$

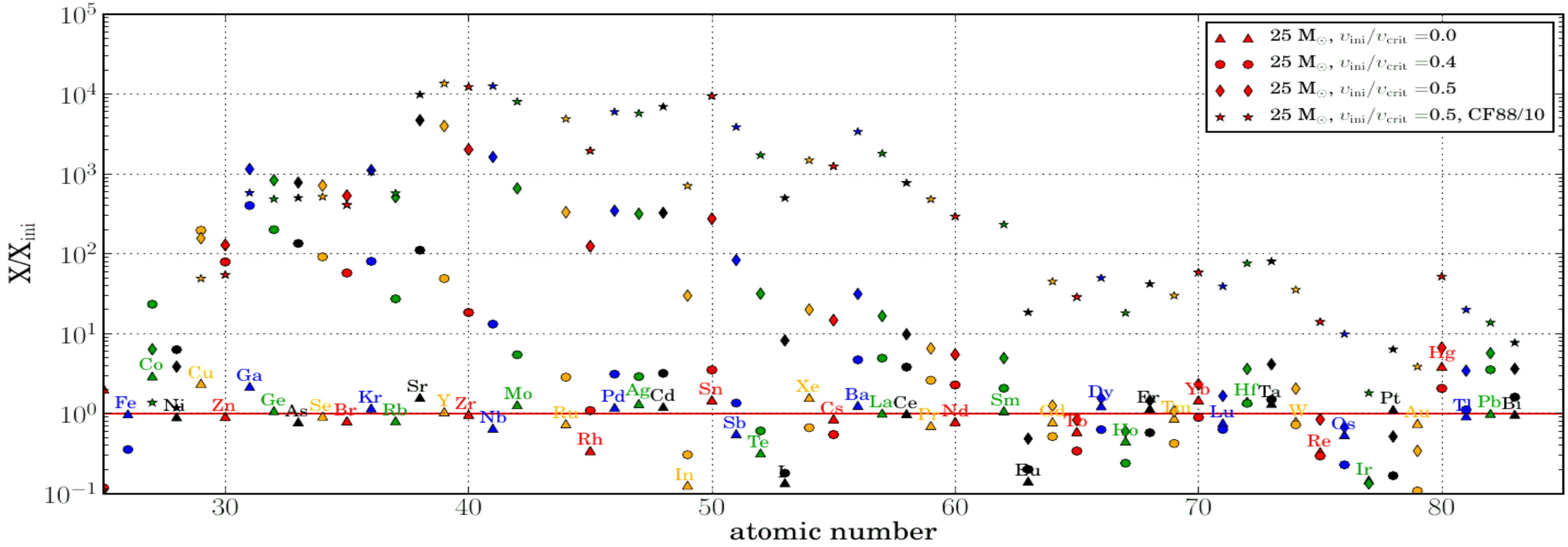
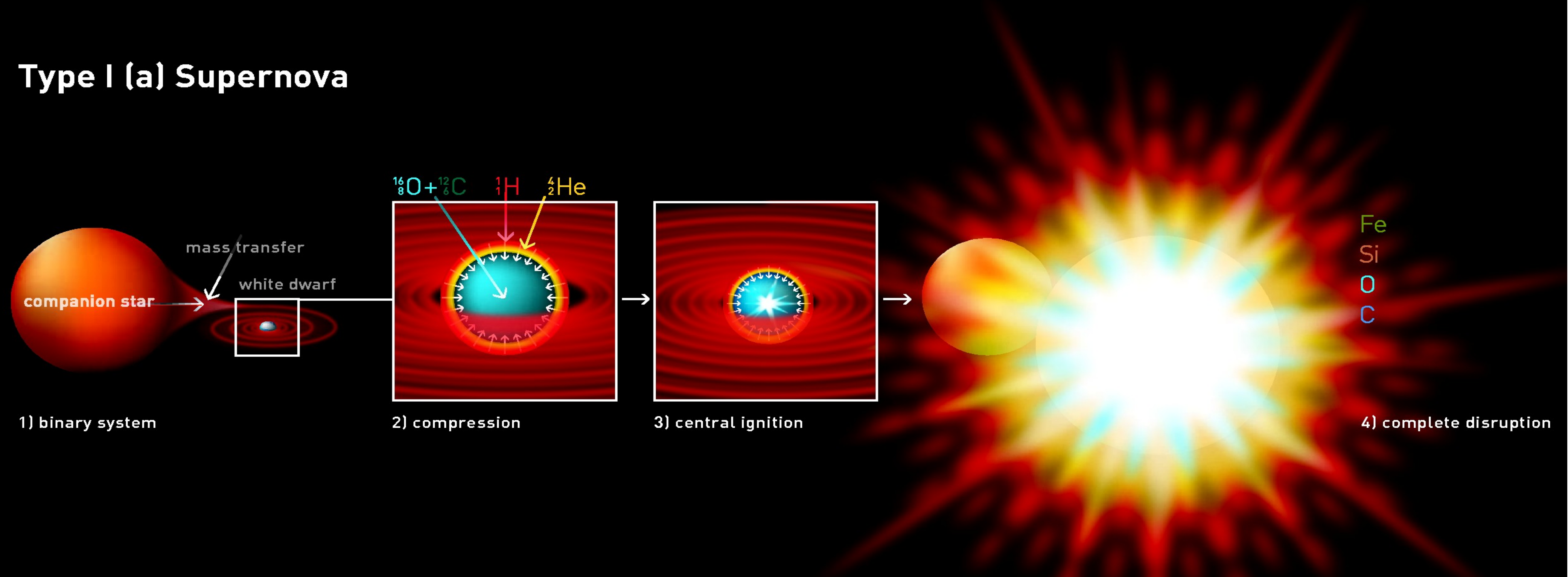


**Fig. 1.** Overproduction factors (abundances divided by their initial values) for the 25 $M_\odot$ models with $Z = 10^{-5}$ after the end of core He-burning. The model without rotation (triangles) does not produce s-process efficiently whereas the rotating models (filled circles, B1 and diamonds, B3) produce significant quantities of s-process. The additional rotating models with reduced $^{17}O(\alpha,\gamma)$ rates (B4, CF88/10) highlights the uncertainty linked to the neutron poison $^{16}O$.

Dependence on rotation and $^{16}O$ neutron poison via $^{16}O(n,\gamma)^{17}O(\alpha,\gamma)$ or $^{17}O(\alpha,n)$ (Frischknecht, Hirschi, Thielemann 2012)

# Explosions caused by accretion in binary stellar systems



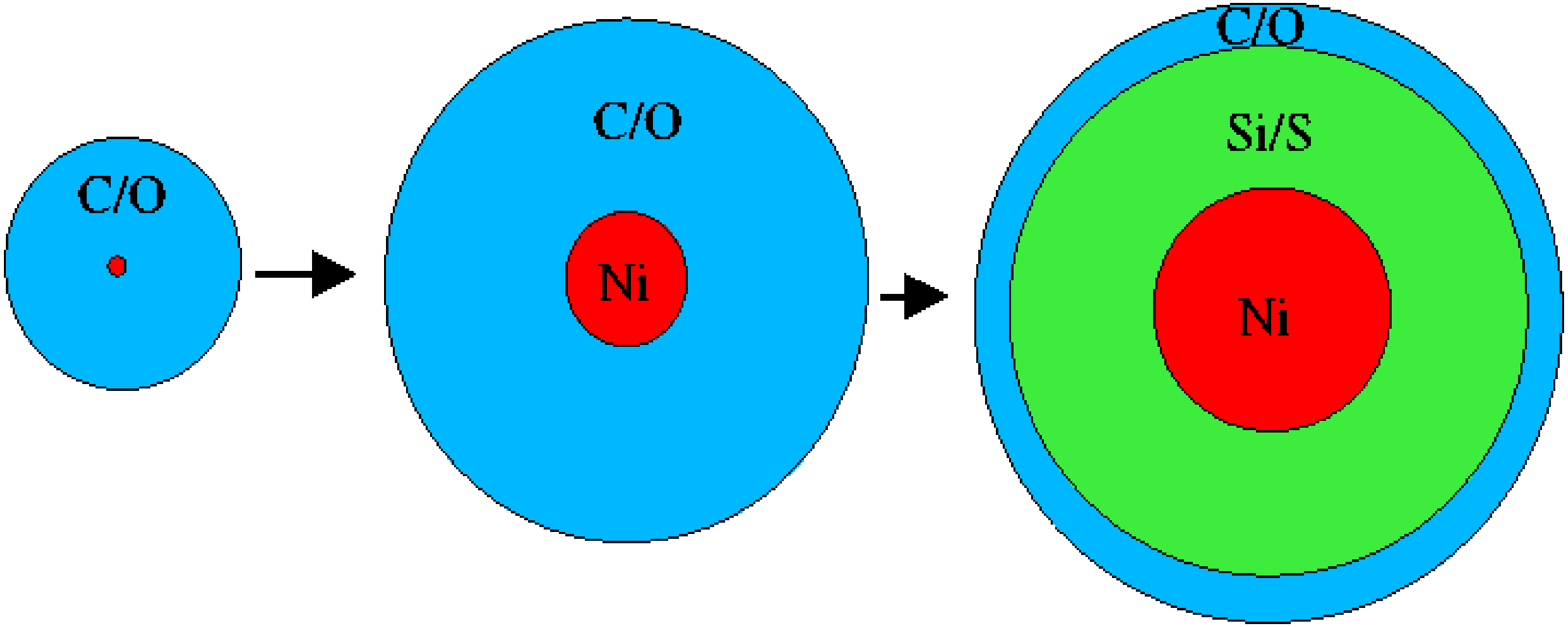
binary systems with accretion onto one compact object can lead (depending on accretion rate) to explosive events with thermonuclear runaway (under electron-degenerate conditions)

- white dwarfs (novae, type Ia supernovae)
- neutron stars (type I X-ray bursts, superbursts?)

Other options:
White Dwarf Mergers (super-Chandrasekhar)
He-accretion on WD (sub-Chandra)

# Back of the Envelope SN Ia

e.g. W7 (Nomoto, Thielemann, Yokoi 1984); delayed detonations (Khokhlov, Höflich, Müller; Woosley et al.)



$M_{ch} \approx 1.4 M_\odot$ of $^{12}C/^{16}O$=1 WD $\rightarrow$ 1.398776 $M_\odot$ $^{56}Ni$

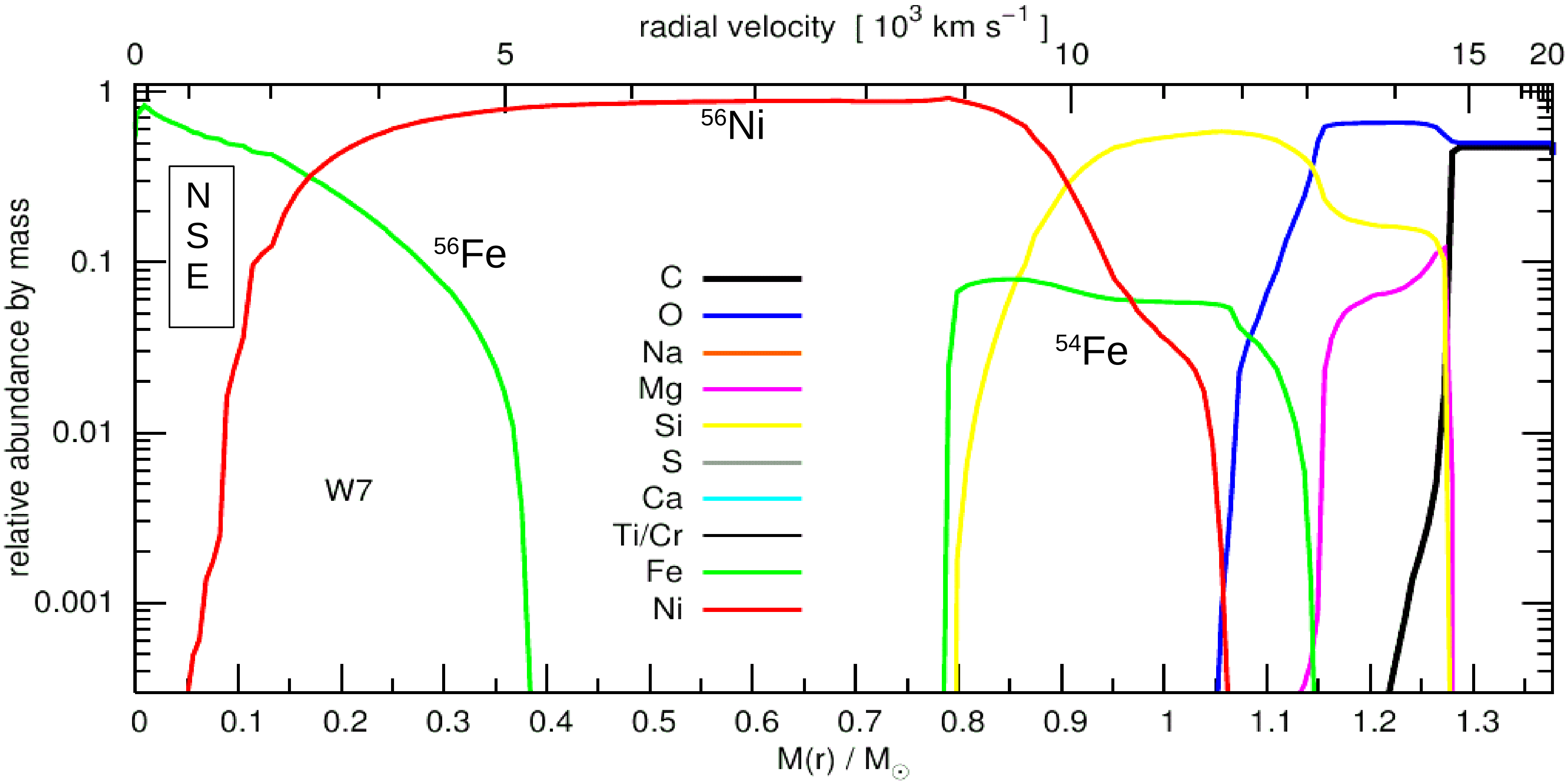
$\rightarrow 2.19 \times 10^{51}$ erg - $E_{grav} \approx (5-6) \times 10^{50}$ erg

reduction due to intermediate elements like Mg, Si, S, Ca

$\rightarrow 1.3 \times 10^{51}$ erg

in spherically symmetric models description of the burning front propagation (with hydrodynamic instabilities) determines outcome!

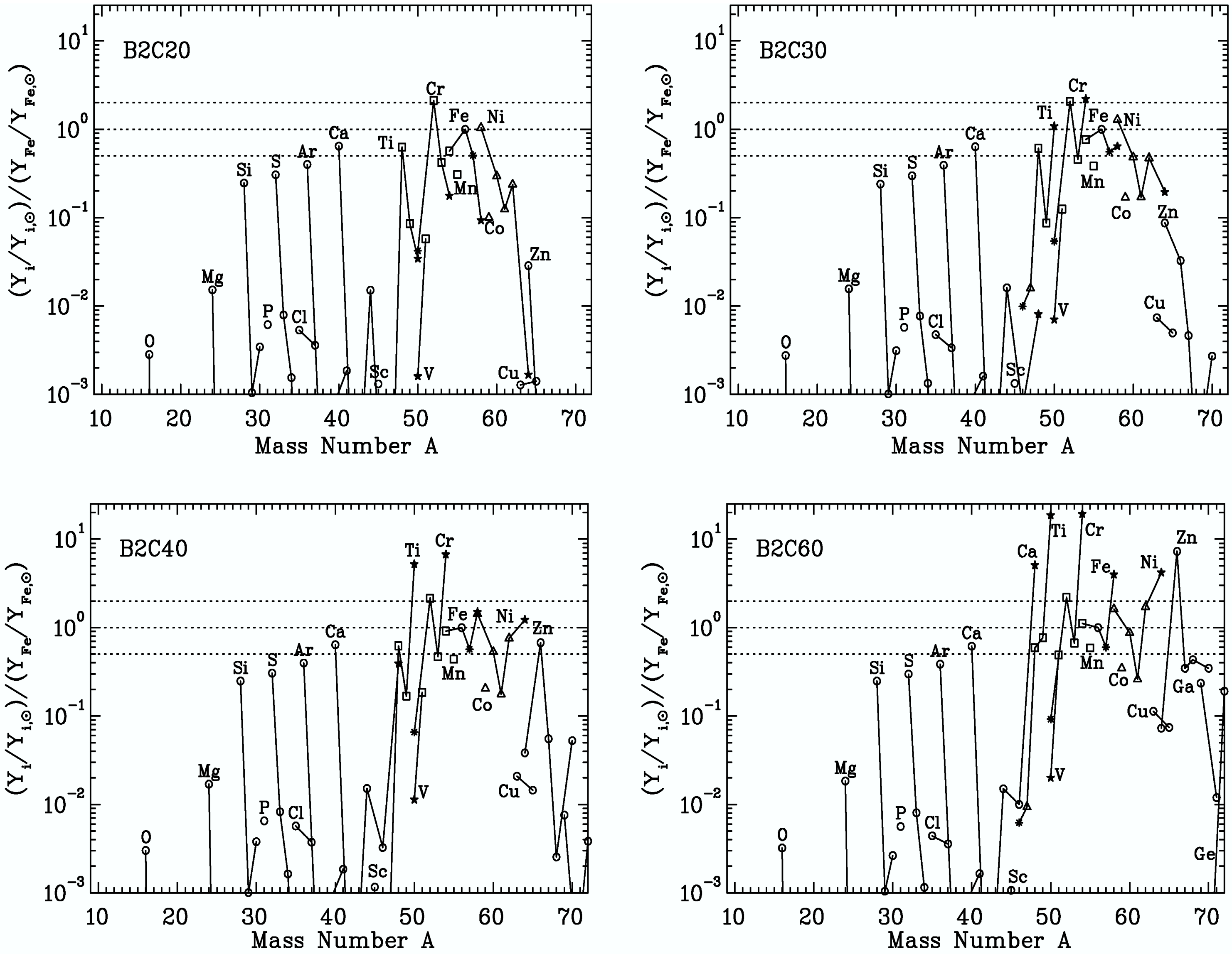
# W7



a deflagration (subsonic burning front) with a propagation speed related to a mixing length in time-dependent mixing length theory of 0.7 times the pressure scale height.

# Ignition density determines Ye and neutron-richness of (60-70% of) Fe-group

FKT et al. (2004, spher. sym. explosions with parametrized burning front)



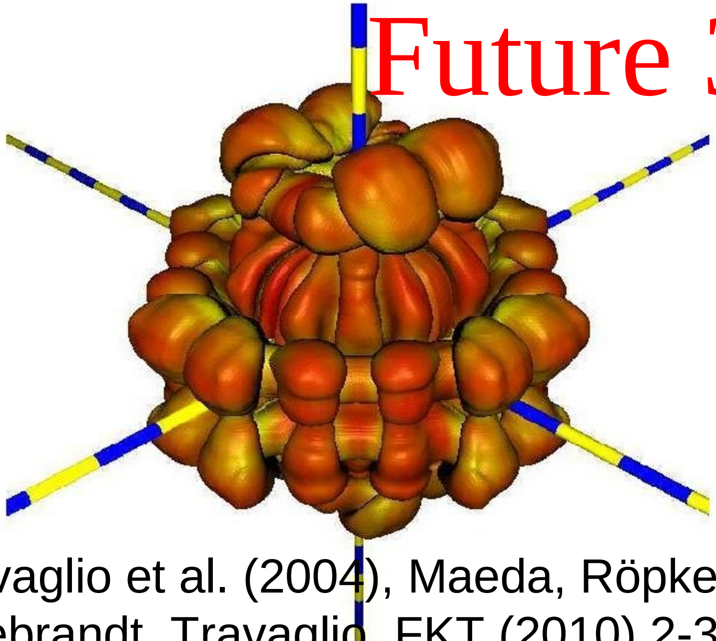
results of explosive C, Ne, O and Si-burning:
Fe-group to alpha-elements 2/1-3/1

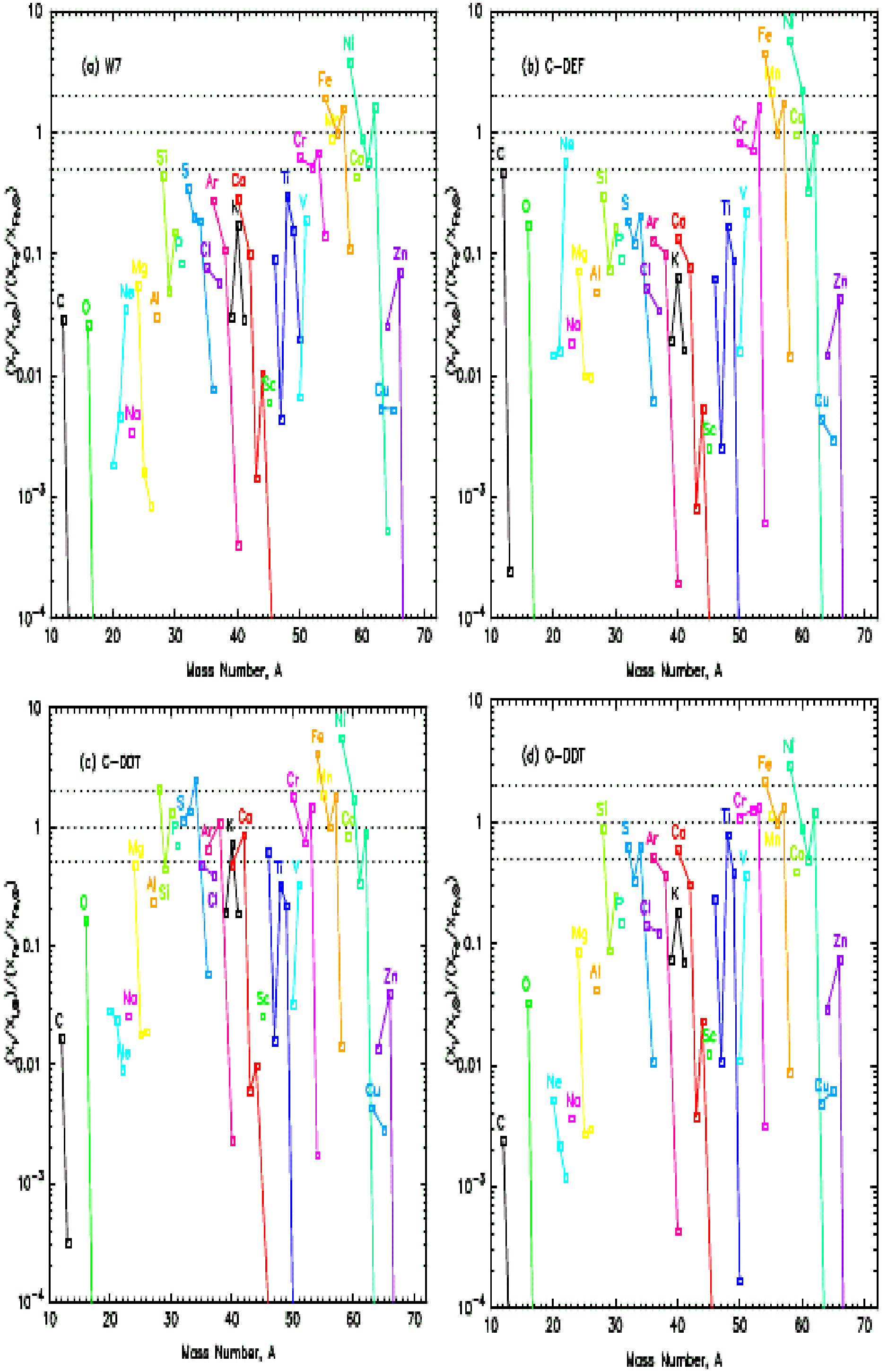
SNe Ia dominate Fe-group, over-abundances by more than factor 2 not permitted

maximum central density 3 $10^{9}$ gcm$^{-3}$ →

***$^{48}$Ca, $^{50}$Ti, $^{54}$Cr .. strong indicators!!***

# Future 3D Models





Travaglio et al. (2004), Maeda, Röpke, Fink, Hillebrandt, Travaglio, FKT (2010),2-3D nucleosynthesis with tracer particles)

consistent treatment needed instead of parametrized spherical propagation,

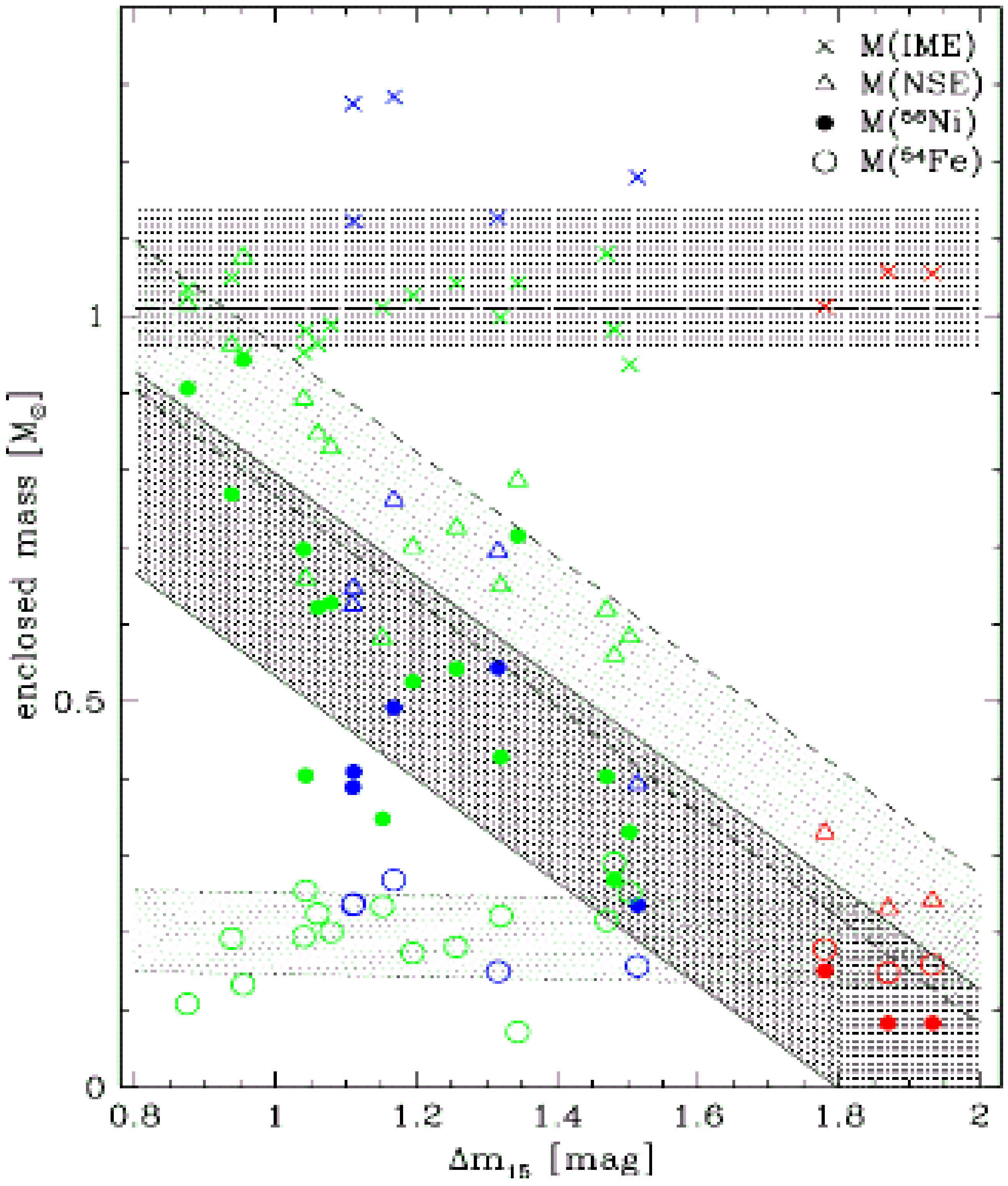
MPA Garching (Röpke et al.), U. Chicago/ SUNY Stony Brook (Calder et al.)

*- distribution of ignition points uncertain (deflagration, centrally ignited delayed detonation, off-center delayed detonation)*

*- hydrodynamic instabilities determine propagation of burning*

*- deflagration/detonation transition*

Other options:
White Dwarf Mergers (super-Chandrasekhar)
He-accretion on WD (sub-Chandra)

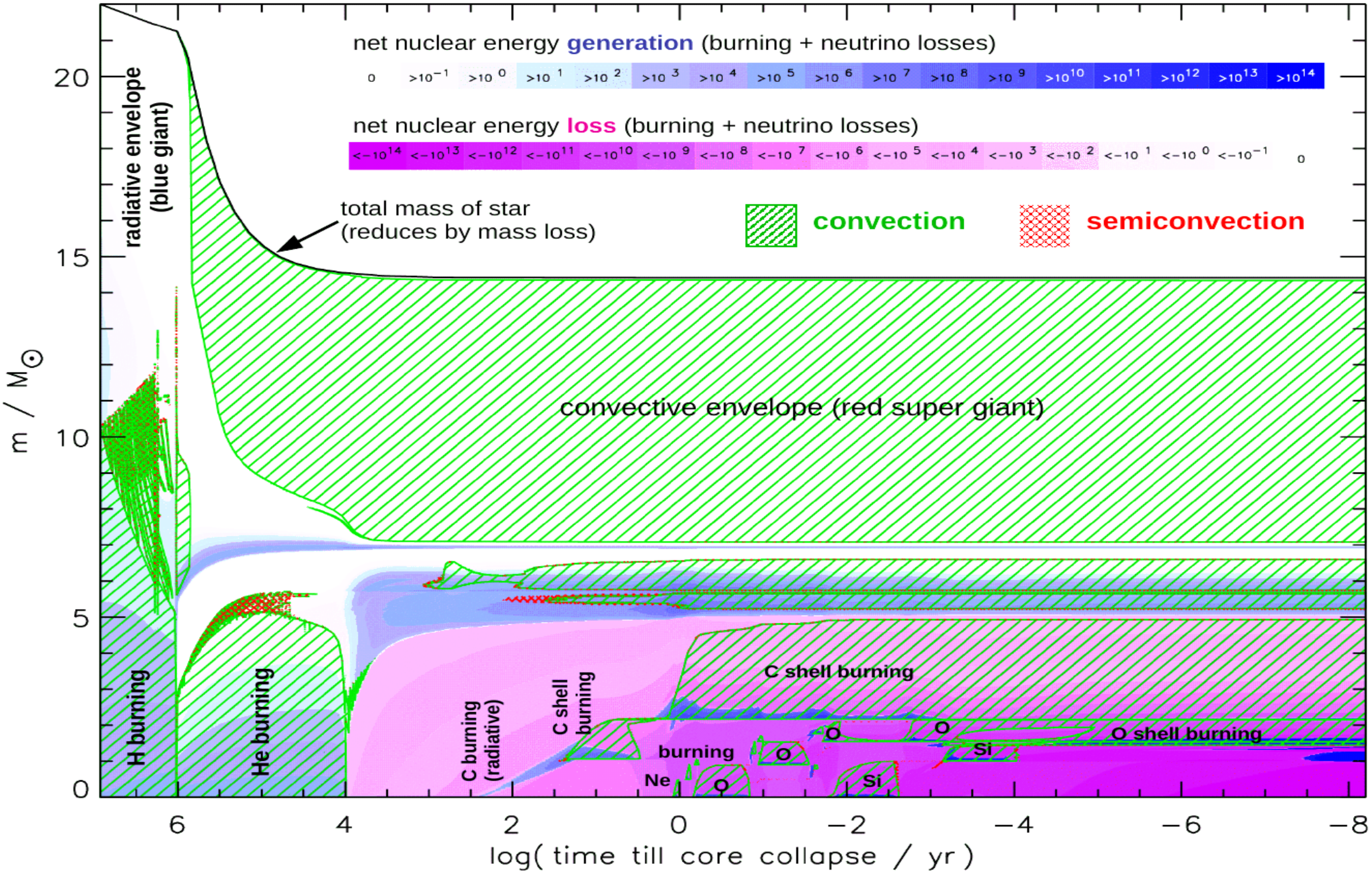


# Zorro diagram

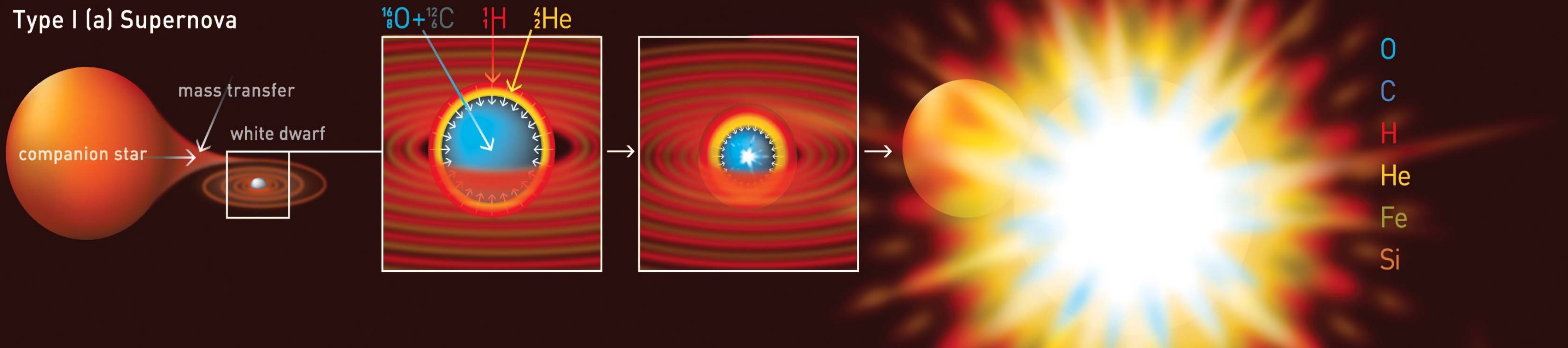
*The distribution of the main abundance groups in a sample of SNe Ia. The enclosed mass of different burning products is plotted vs. Δm15 (B).*
*Open circles refer to stable $^{54}$Fe and $^{58}$Ni; solid circles to $^{56}$Ni, and open triangles to the sum of these.*
*Crosses show the mass enclosed inside the layer of intermediate mass elements (IME), i.e., the total mass burned.*
*$^{54}$Fe and $^{58}$Ni in the SN core are roughly constant over all luminosities,while $^{56}$Ni determines the luminosity and correlates with Δm15 (B).*
*The mass enclosed by the position of IME's is inferred to be similar for all SNe of the sample, and the explosion energy seems constant (from Mazzali et al. 2007).*

**Alex Heger :** A huge number of models with mass loss and full reaction networks for varying metallicities and their explosive nucleosynthesis in initiated explosions

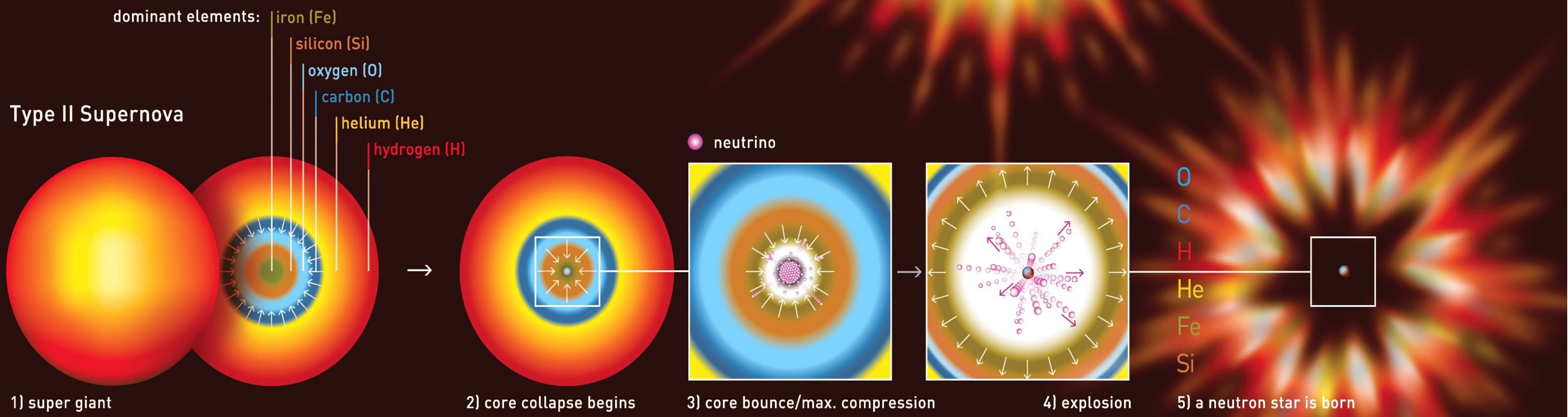
*But what is the role of rotation (mixing creates „metallicities“, i.e. opacities and mass loss Hirschi et al. 2012)*

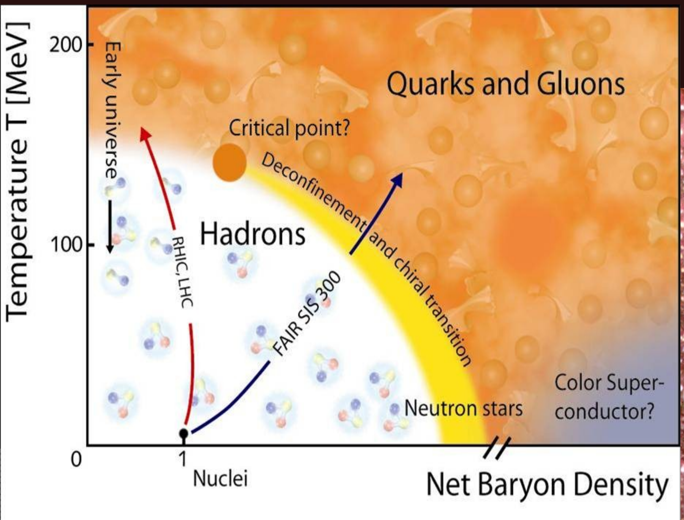


## Type I (a) Supernova

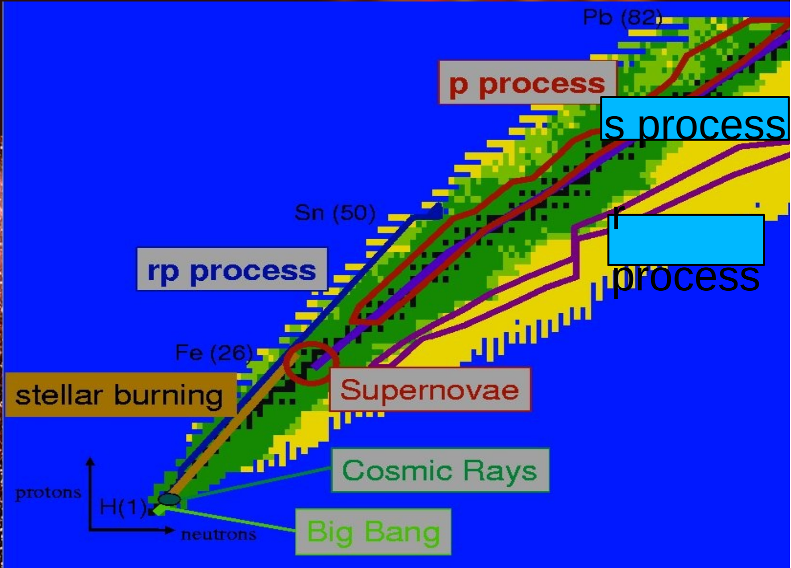


## Type II Supernova

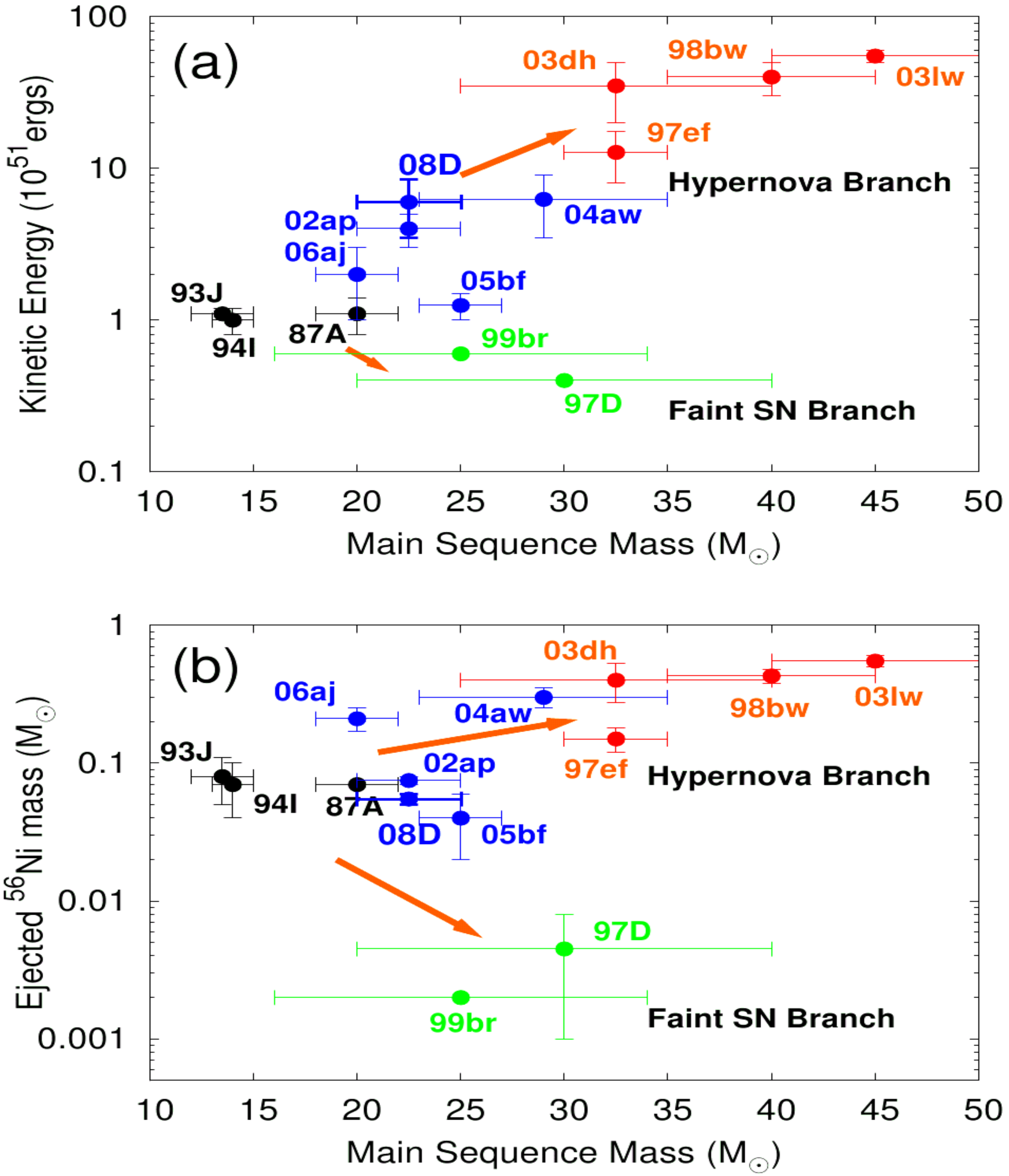




## SN 1987A

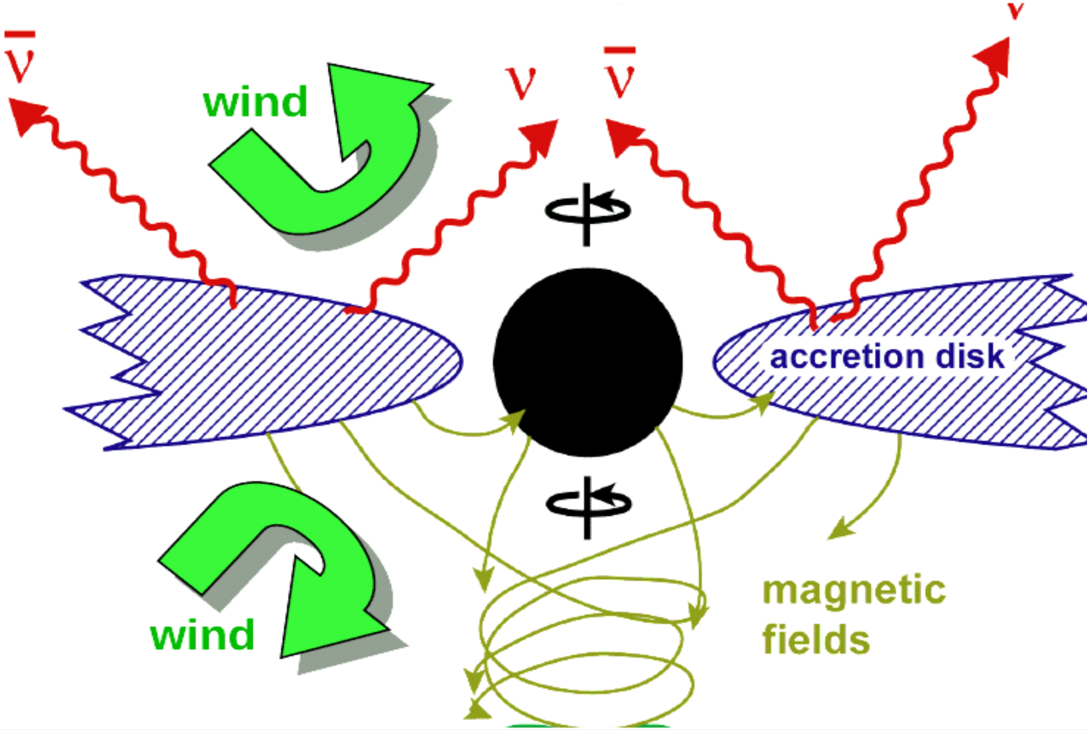


# End Stages of Massive Stars (Nomoto et al. 2011)



- *8 - 10 $M_\odot$ super-AGB stars when O+Ne+Mg core collapses due to electron capture, produce little α-elements and Fe-peak elements*
- ***10 - 90 $M_\odot$ undergo Fe-core collapse. Nucleosynthesis in aspherical explosions might be important,***
- *90 - 140 $M_\odot$ stars undergo pulsational nuclear instabilities at various nuclear burning stages, including O and Si-burning → BH.*
- *140 - 300 $M_\odot$ stars become pair-instability supernovae, **if the mass loss is small enough**.*
- *> 300$M_\odot$ Very massive stars undergo core-collapse to form intermediate mass black holes.*

Partial or complete failure of neutrino powered SN explosion



a. partial fallback
(faint supernova)

b. complete fallback

Leads to rotating stellar cores.
If J> 3 x $10^{16}$ $cm^2/sec$

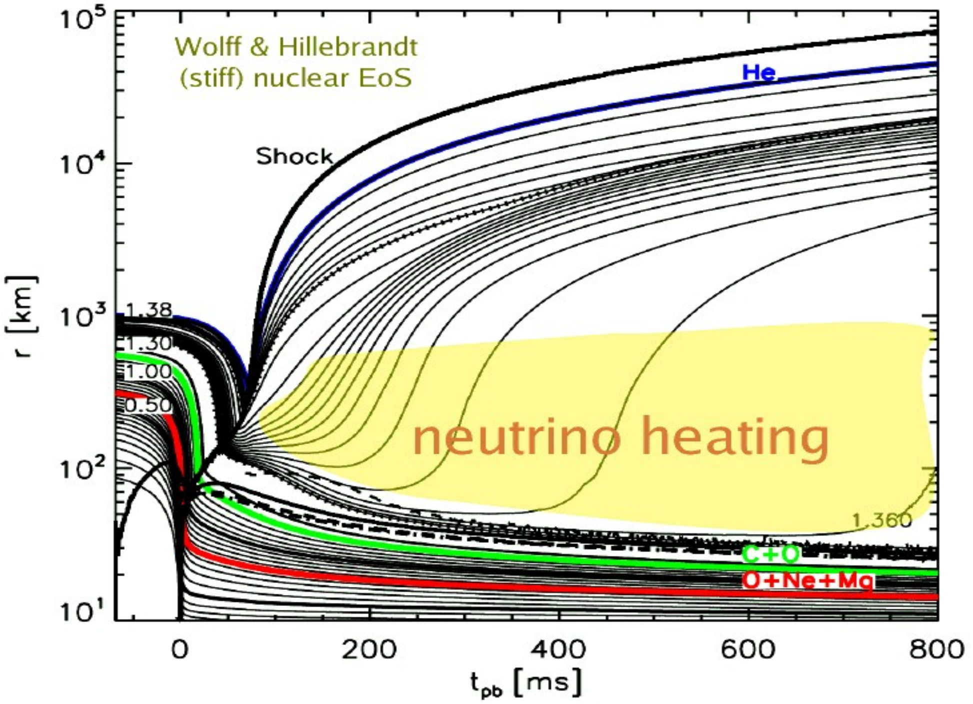
and a rapidly accreting black hole forms (M $\simeq 0.1 M_\odot/s$)
Fed by the collapsing star ($t_{dyn} \simeq 446 s/ \rho^{1/2} \approx 10 s$)
Accretion disk releases gravitational energy,
this plus winds of hot disk eplode the star
=> Collapsar/hypernova/GRB

*from Heger, Fryer, MacFadyen 2011*

# Supernovae in 1D

## SN Simulations: $M_{star} \sim 8...10\, M_{sun}$

"Electron-capture supernovae"
or "ONeMg core supernovae"

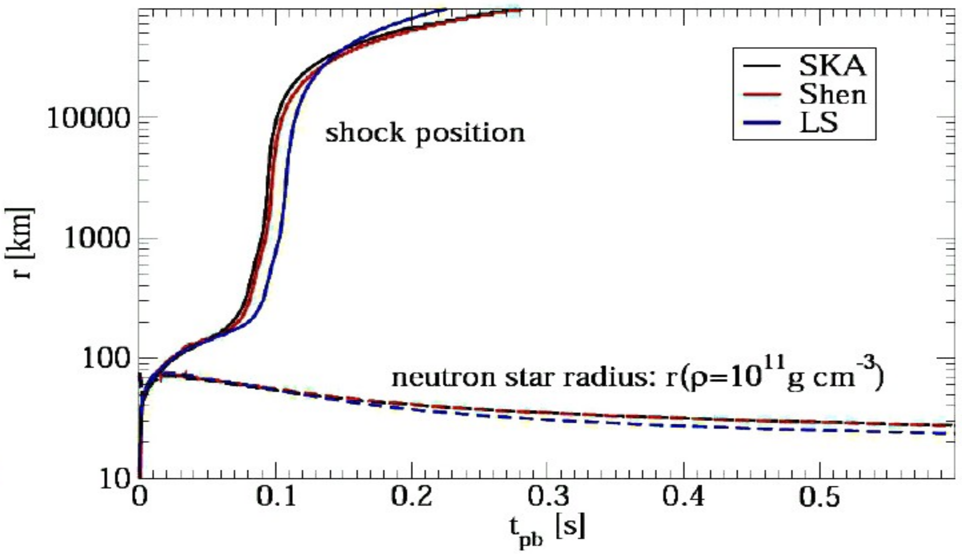


Kitaura et al., A&A 450 (2006) 345;
Janka et al., A&A 485 (2008) 199

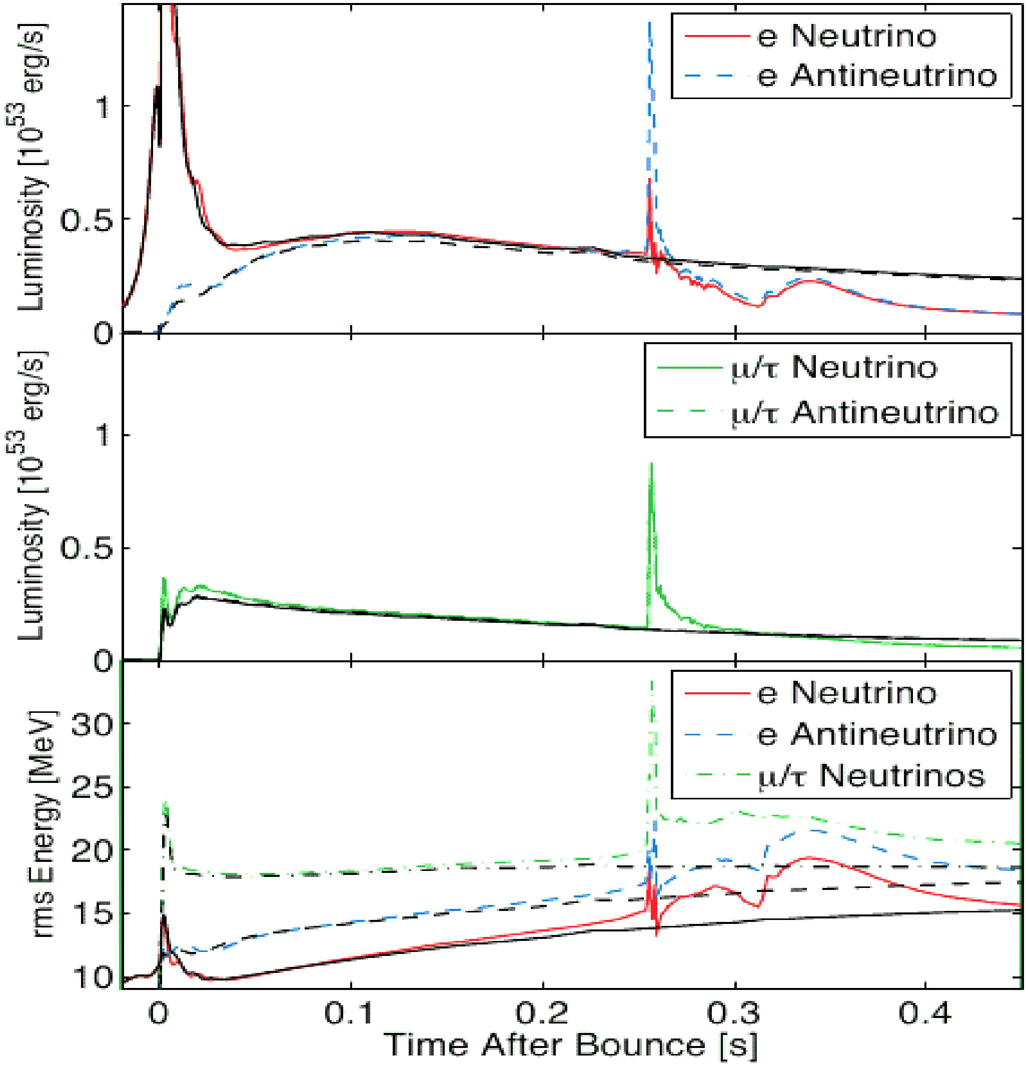
Fischer et al. 2010

Convection is not necessary for launching explosion but occurs in NS and in neutrino-heating layer

- No prompt explosion !
- Mass ejection by "neutrino-driven wind"
  (like Mayle & Wilson 1988
  and similar to AIC of WDs;
  see Woosley & Baron 1992, Fryer et al. 1999;
  Dessart et al. 2006)
- Explosion develops in similar way for soft nuclear EoS (i.e. compact PNS) and stiff EoS (less compact PNS)

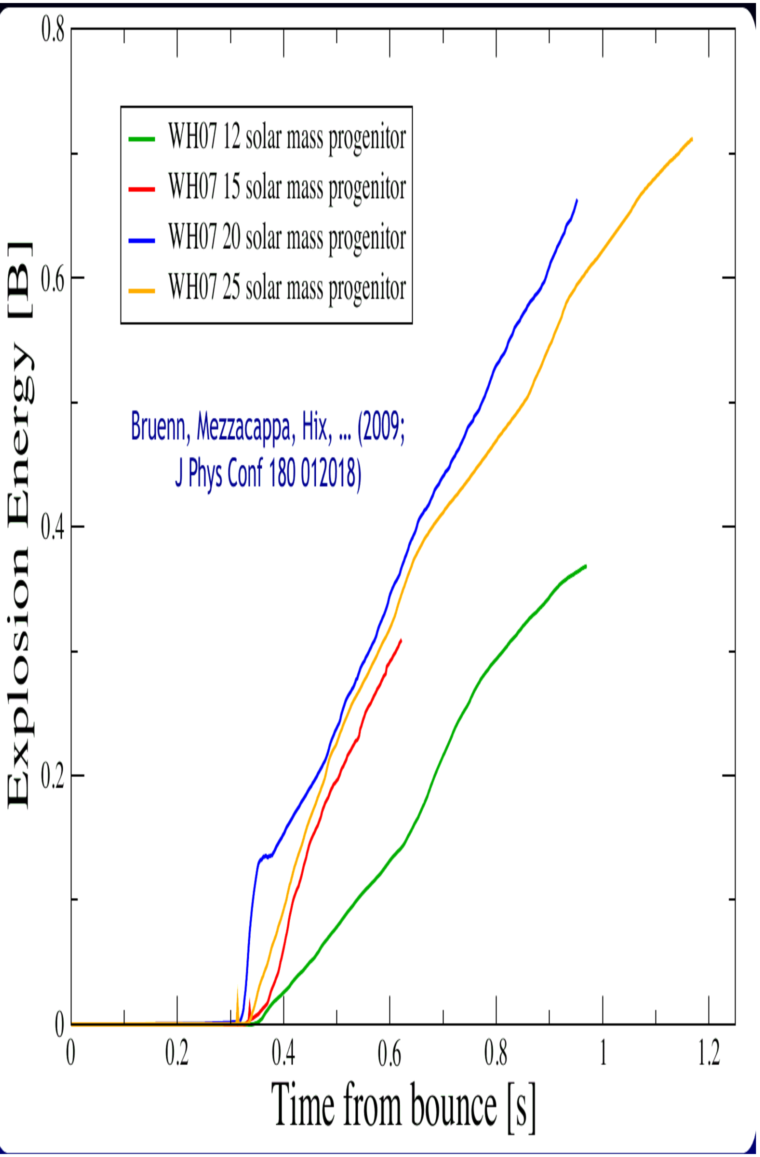


# Core Collapse with EOS utilizing MIT Bag Model (Sagert et al. 2009, Fischer et al. 2010b)



Shown is a simulation of a $10M_{sun}$ star containing ($B^{1/4}$ =162) quark matter compared to one with hadronic matter only (black lines)

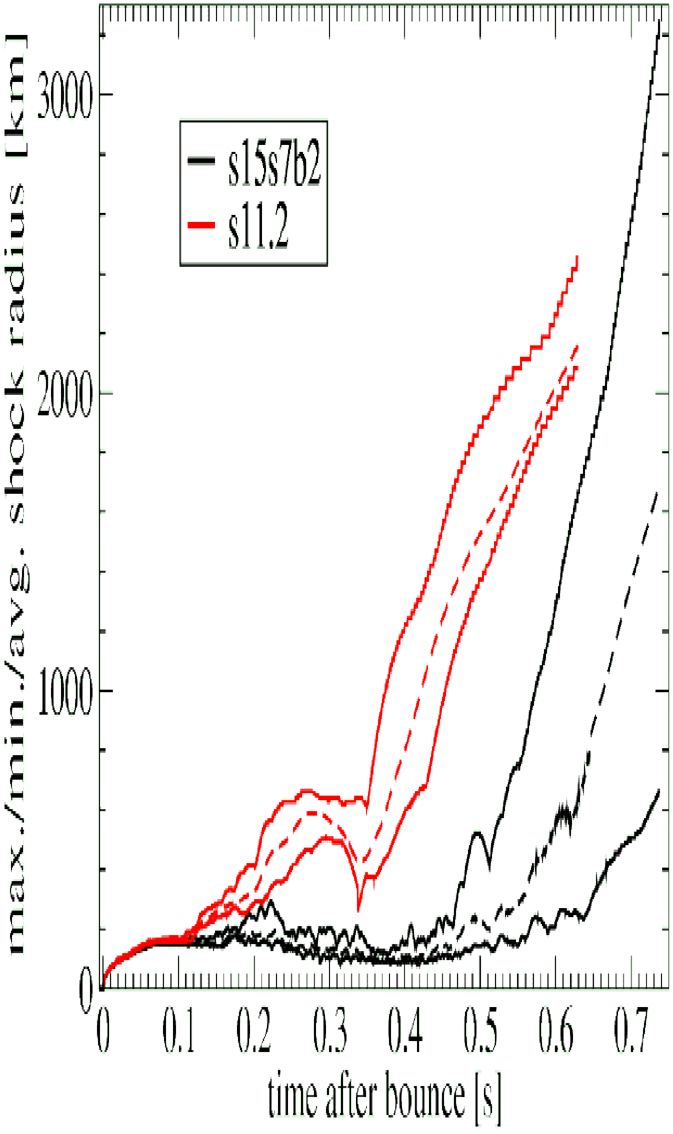
# 2D and 3D simulations



Bruenn, Mezzacappa, Hix, ... (2009; J Phys Conf 180 012018)

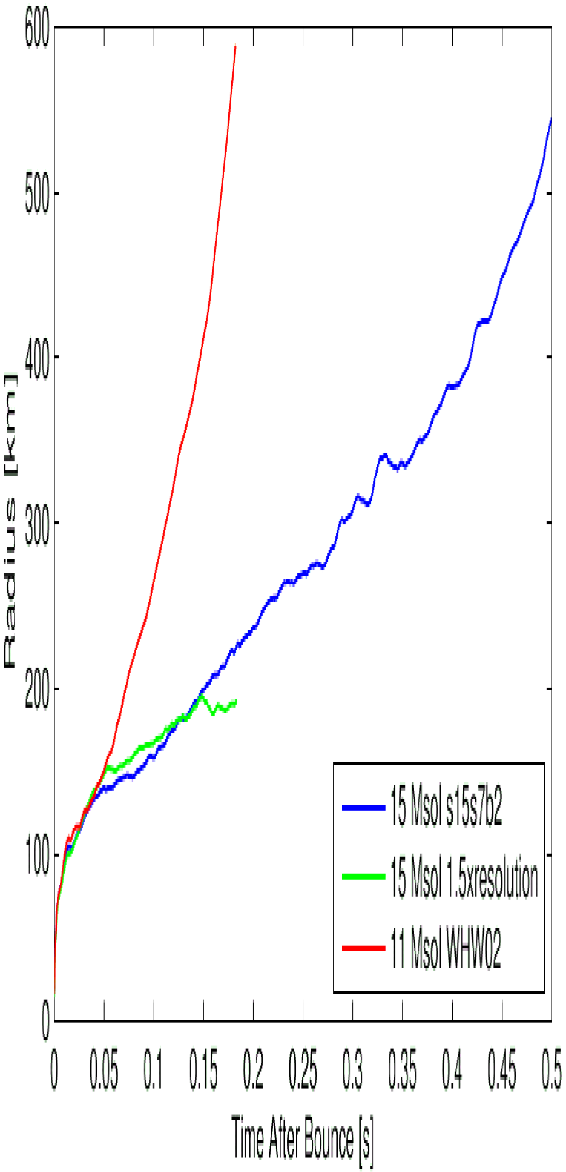
Oak Ridge

Shock radii



Garching

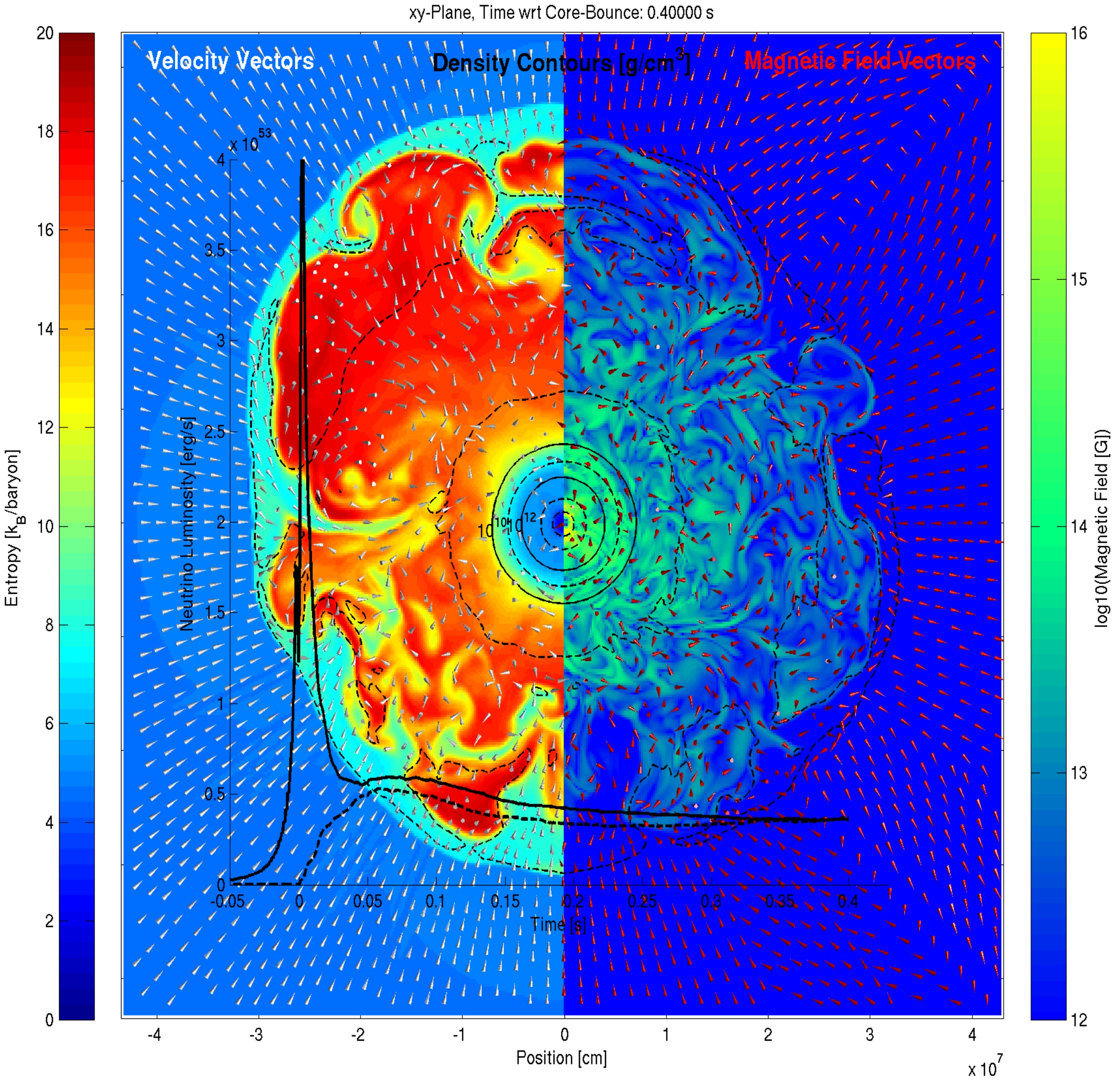
*can we be optimistic?*

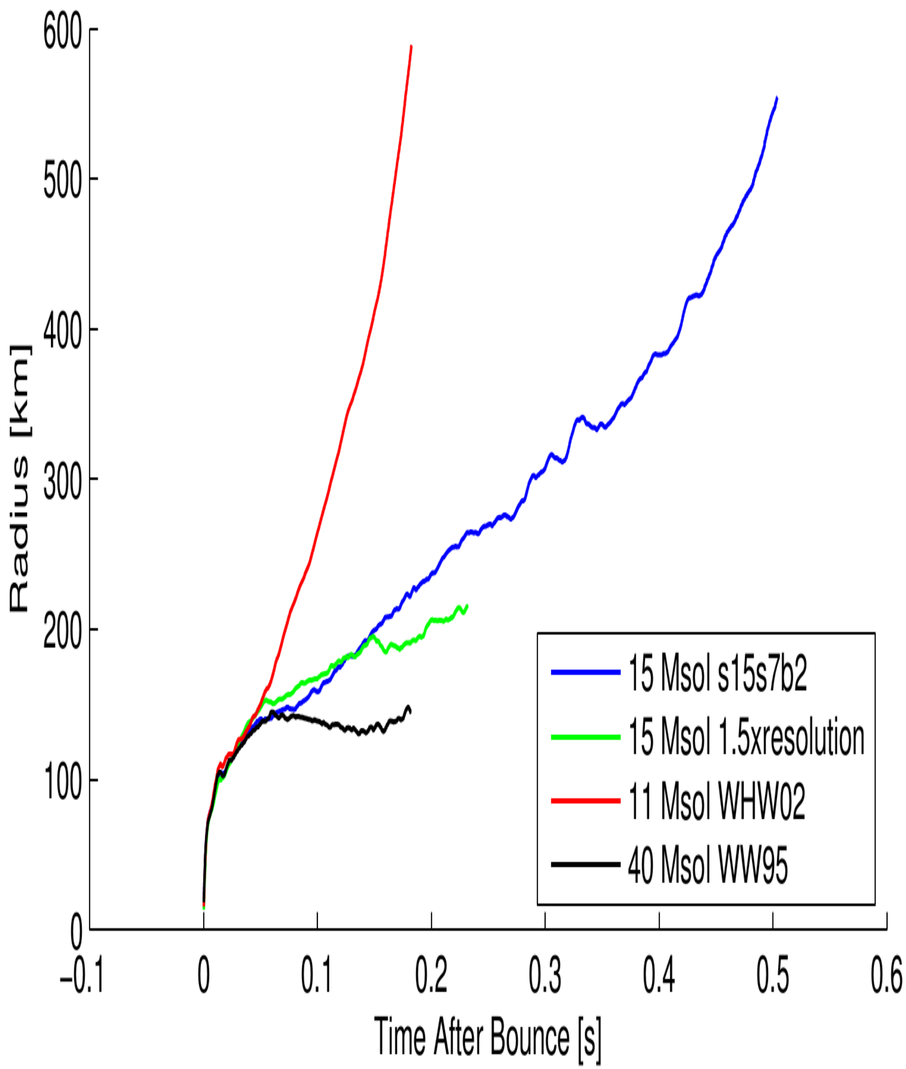


Basel

# Simulations in 3D

Liebendörfer et al. 2012



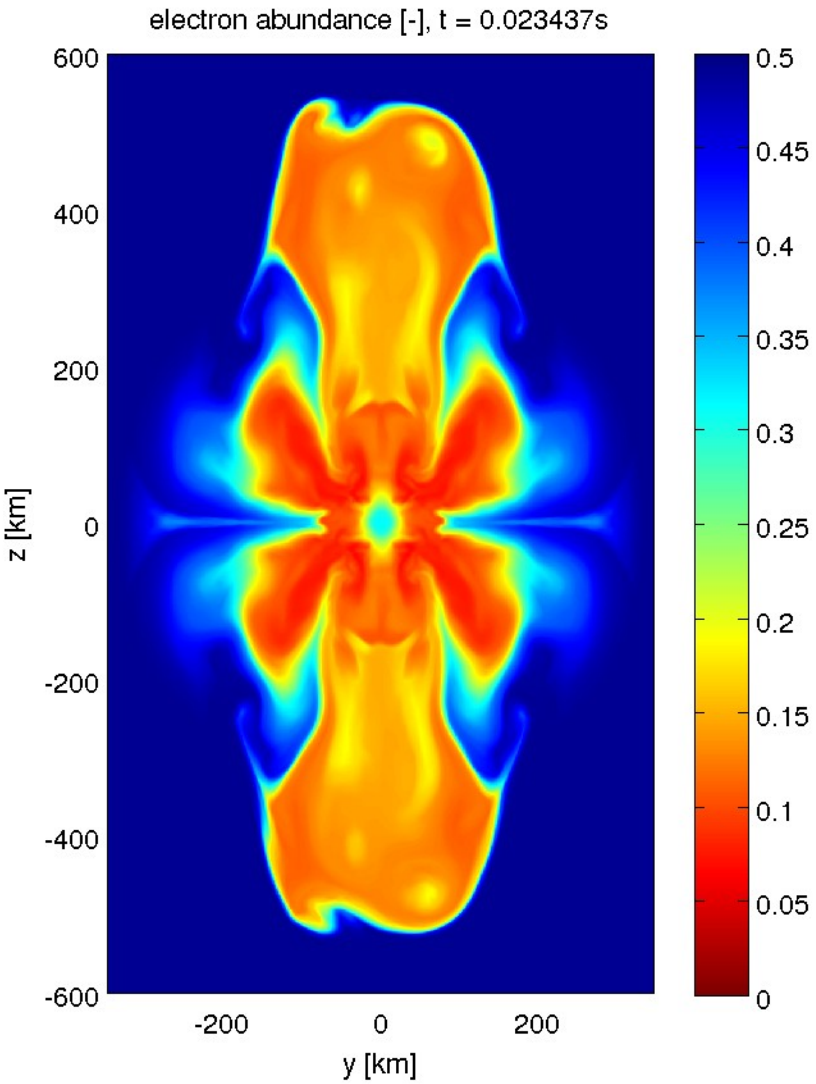


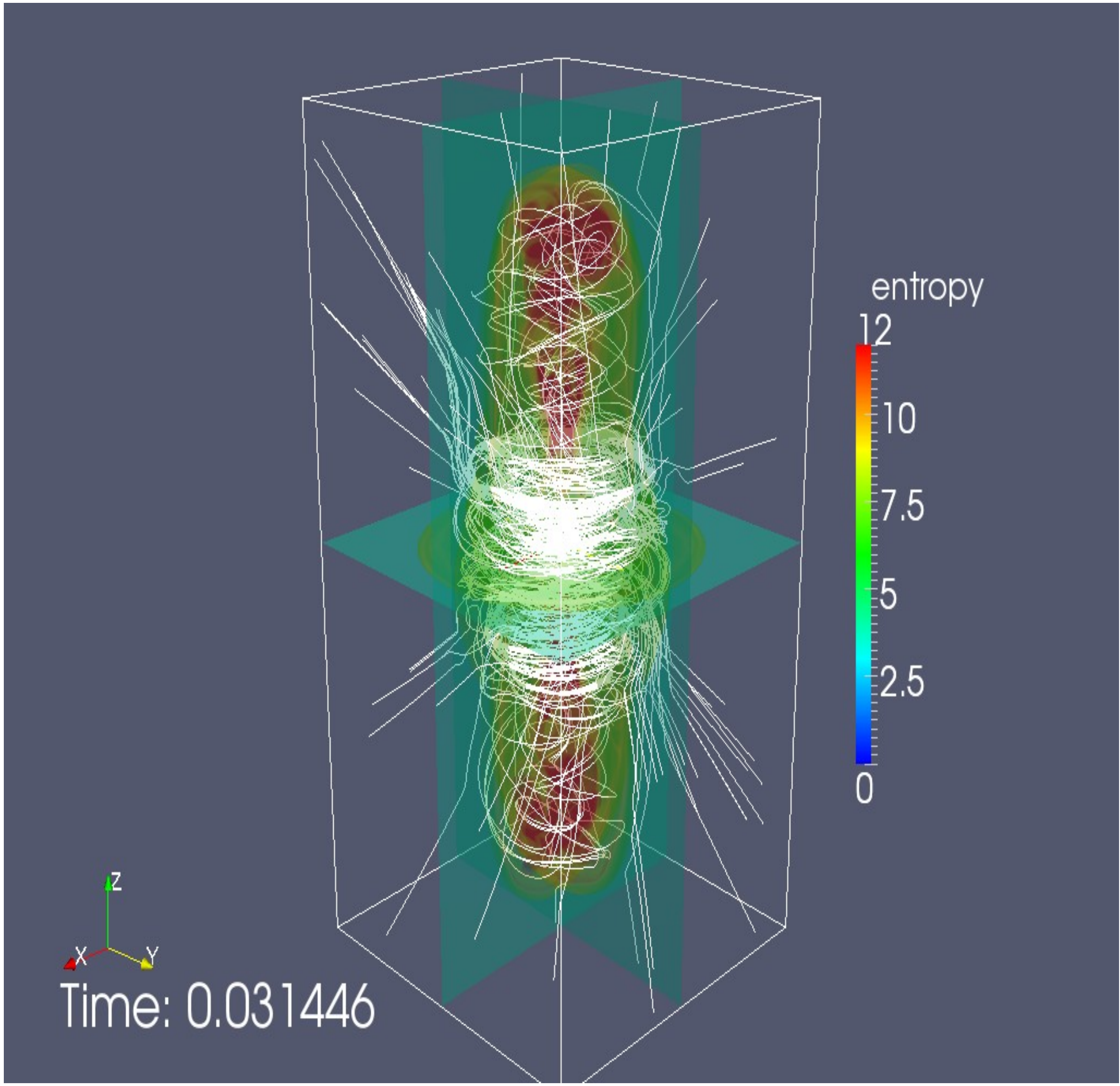
*Multi-D explosion calculations are optimistic! (but EoS dependence, 2M$_{sol}$ neutron star)*

*When do we understand transition from regular core collapse SNe with neutron star formation - to faint SNe with fall back and BH formation - BH formation and hypernovae???*

# 3D Collapse of Fast Rotator with Strong Magnetic Fields:

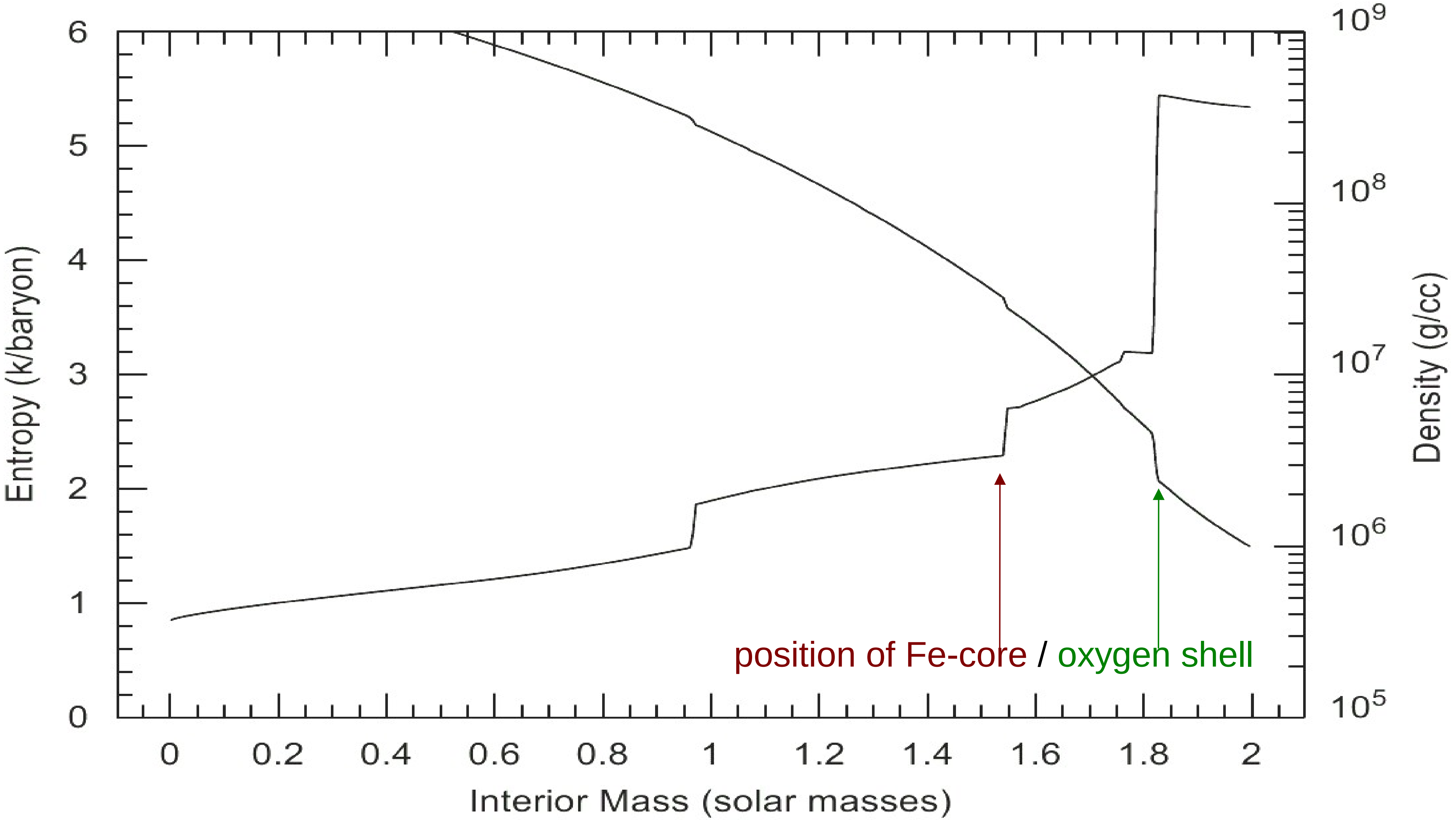
15 $M_{sol}$ progenitor (Heger Woosley 2002), shellular rotation with period of 2s at 1000km, magnetic field in z-direction of 5 x$10^{12}$ Gauss





*3D simulations by Winteler, Käppeli et al. 2012*

# How to invoke induced explosions for nucleosynthesis purposes?

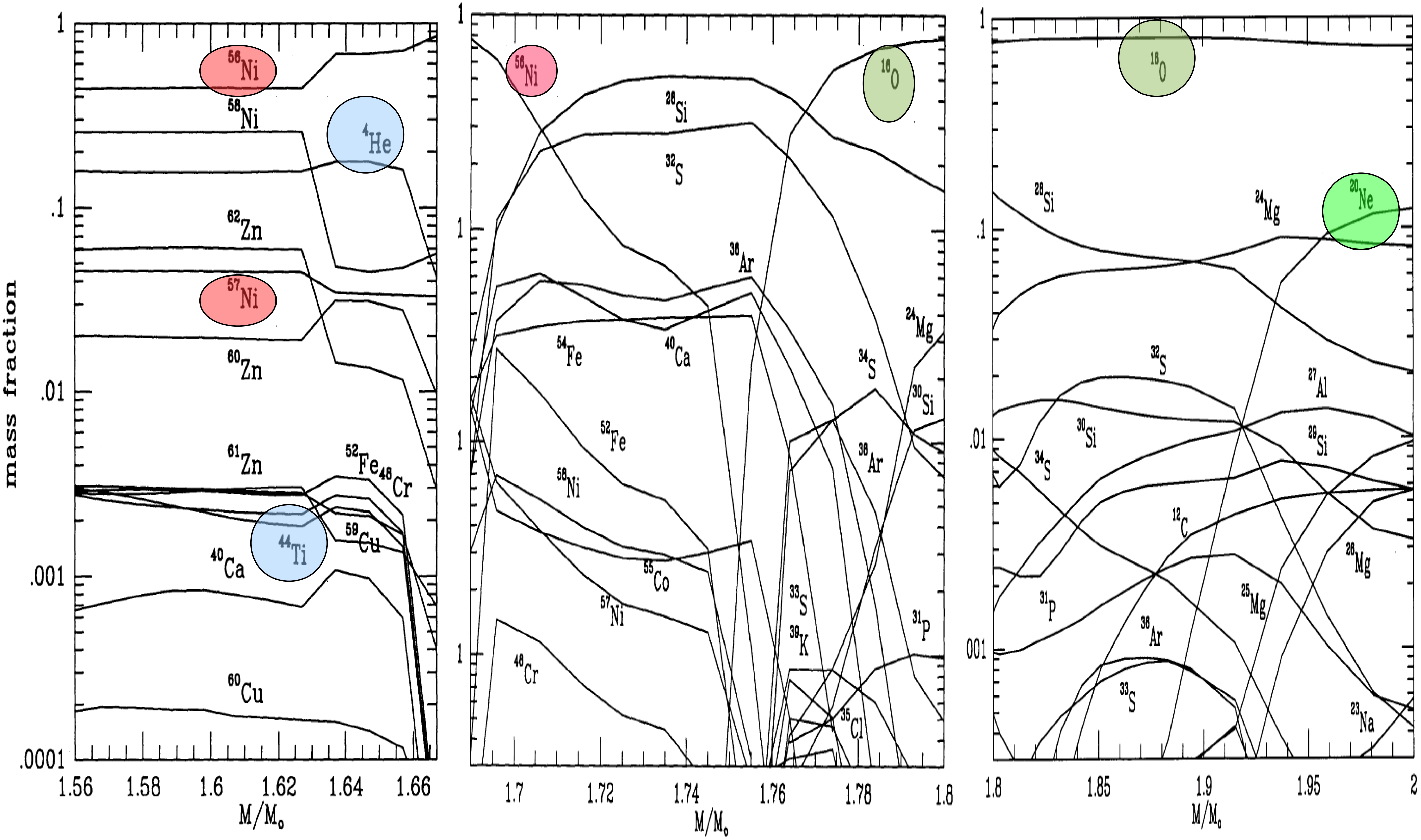


*without a self-consistent mechanism nucleosynthesis can only be calculated with induced explosions. Woosley & Heger position a piston with 1.2B at $S=4k_B/b$,*

*Nomoto/Umeda/Thielemann applied thermal bomb and integrate from outside until expected $^{56}$Ni-yield.*

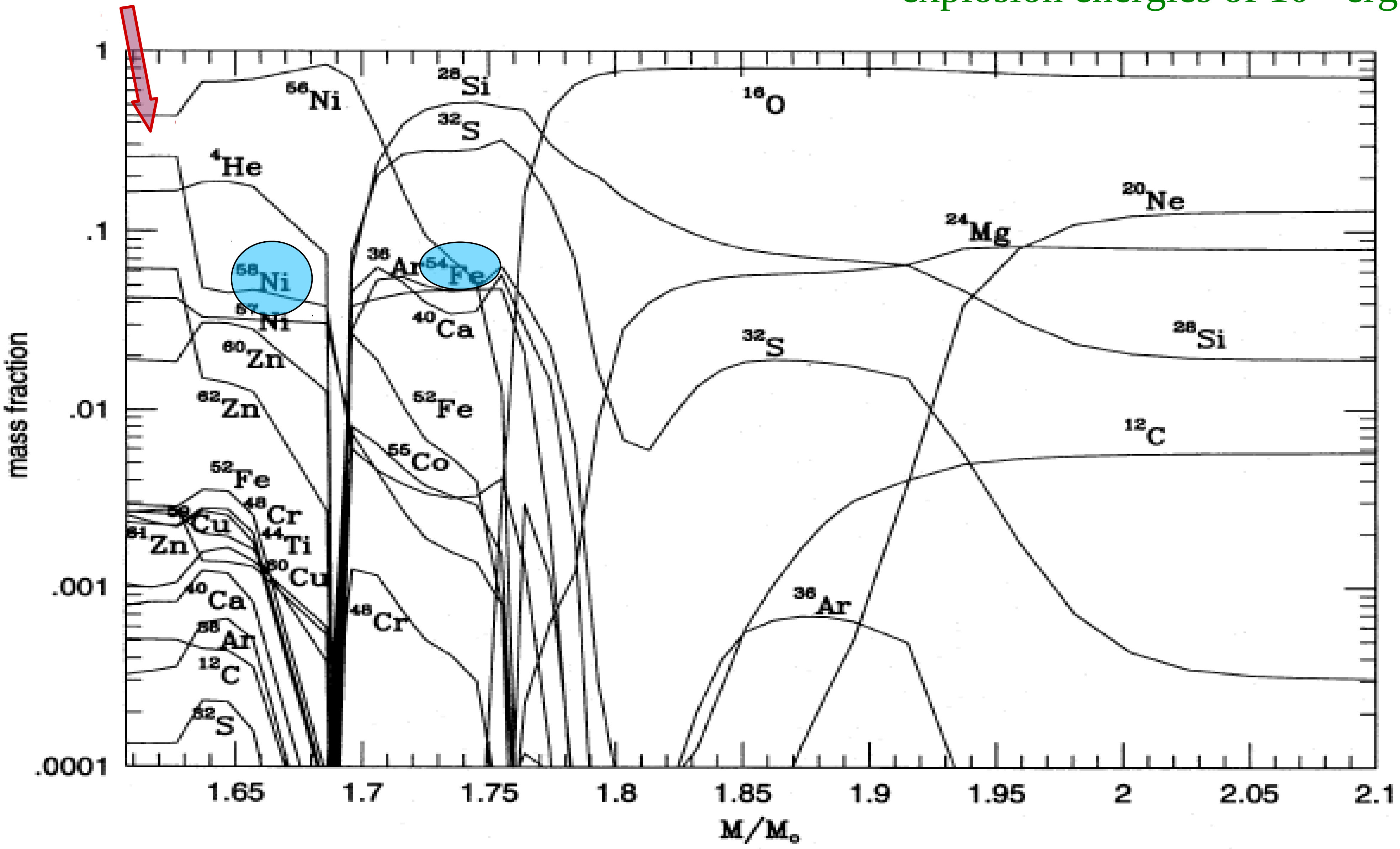
# Products of Explosive Burning (20Msol)

Fe-group composition depends on $Y_e$ and entropy (alpha-rich freeze-out)



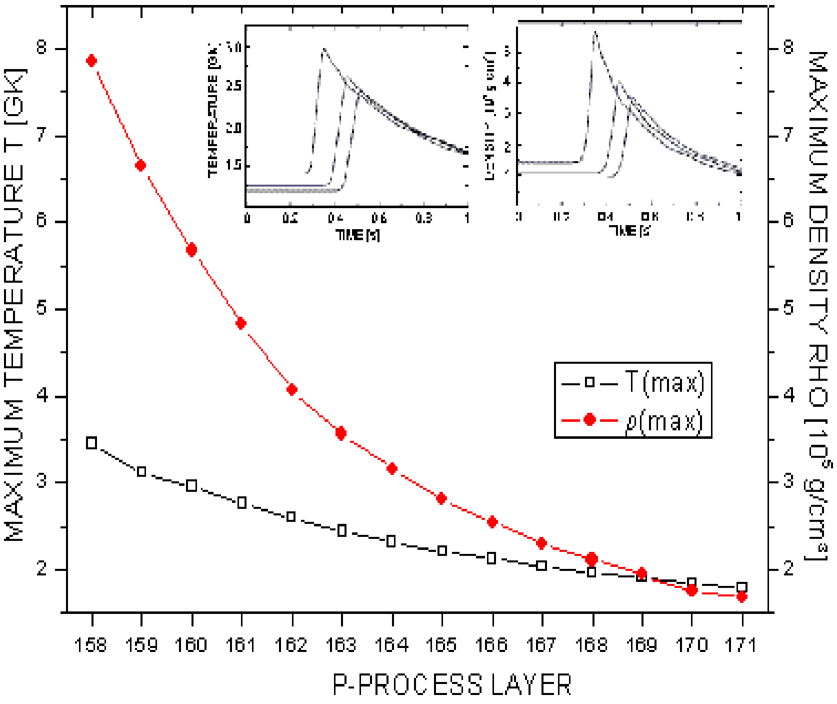
*explosive Si-burning (alpha-rich, incomplete), O-burning, Ne-burning*

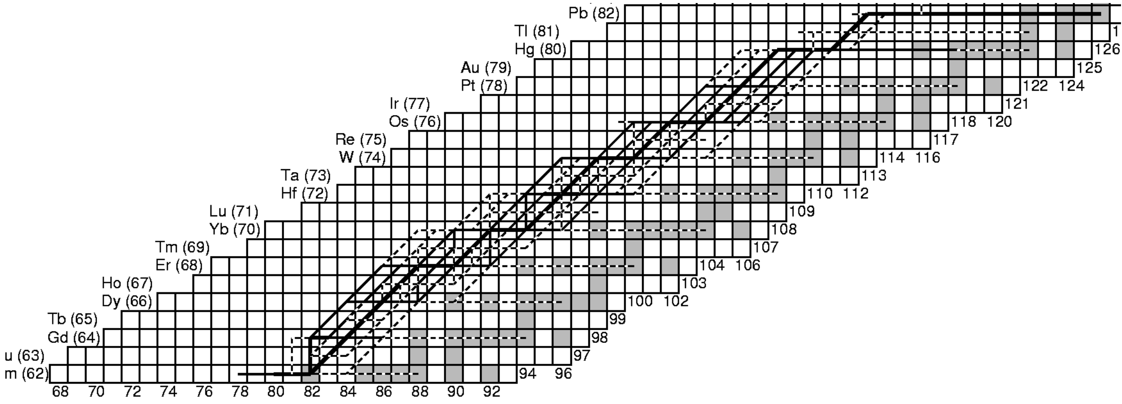
# Nucleosynthesis problems in “induced” piston or thermal bomb models utilized up to present to obtain explosive nucleosynthesis yields with induced explosion energies of $10^{51}$ erg

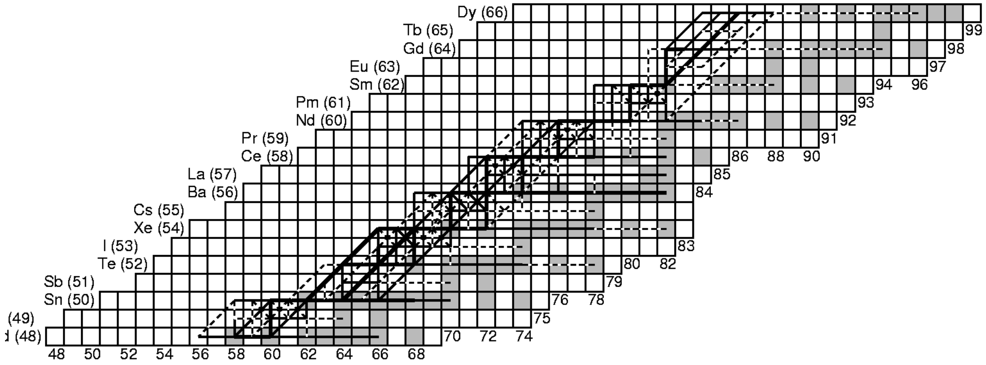


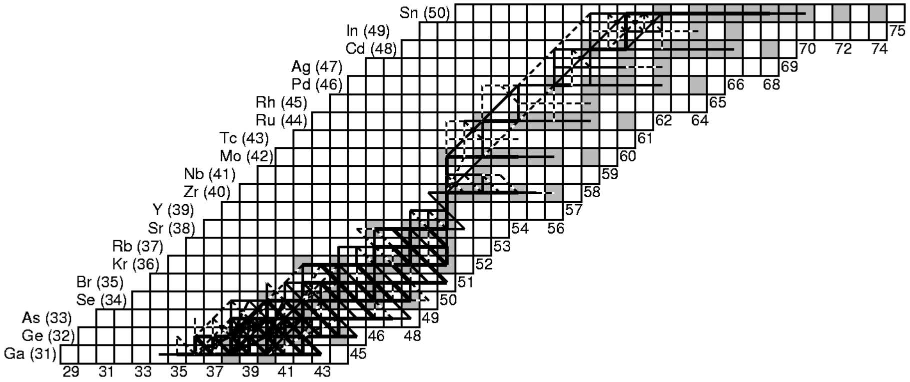
prior results made use of initial stellar structure (and $Y_e$!) when inducing artificial explosion. This neglects the effect of the explosion mechanism on the innermost zones, causes strange overproductions of Ni isotopes and does not go much beyond Ni!

# p-process in explosive Ne/O-Burning zones



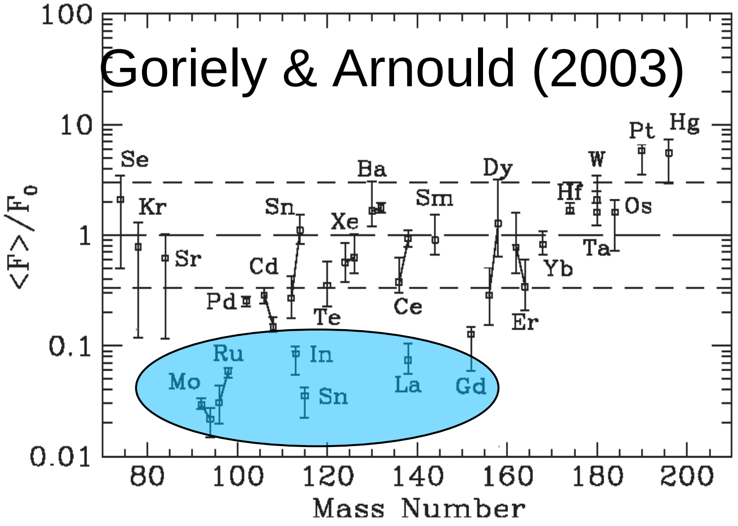


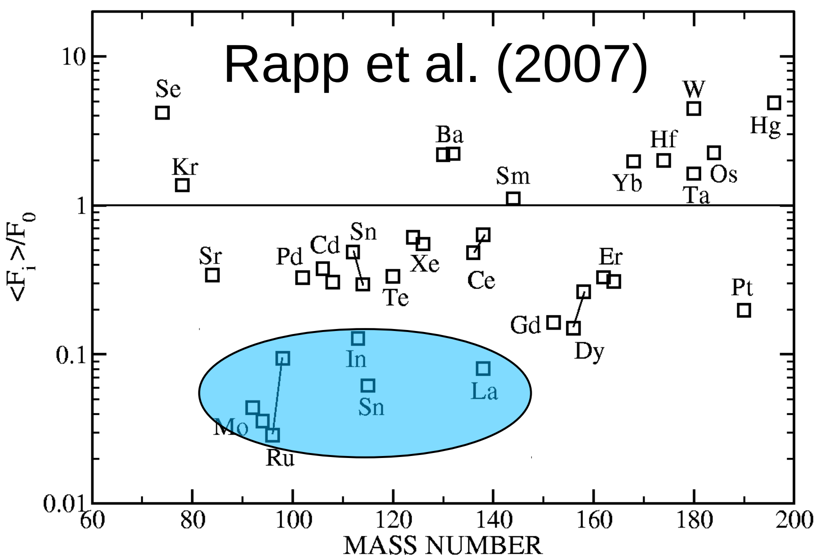


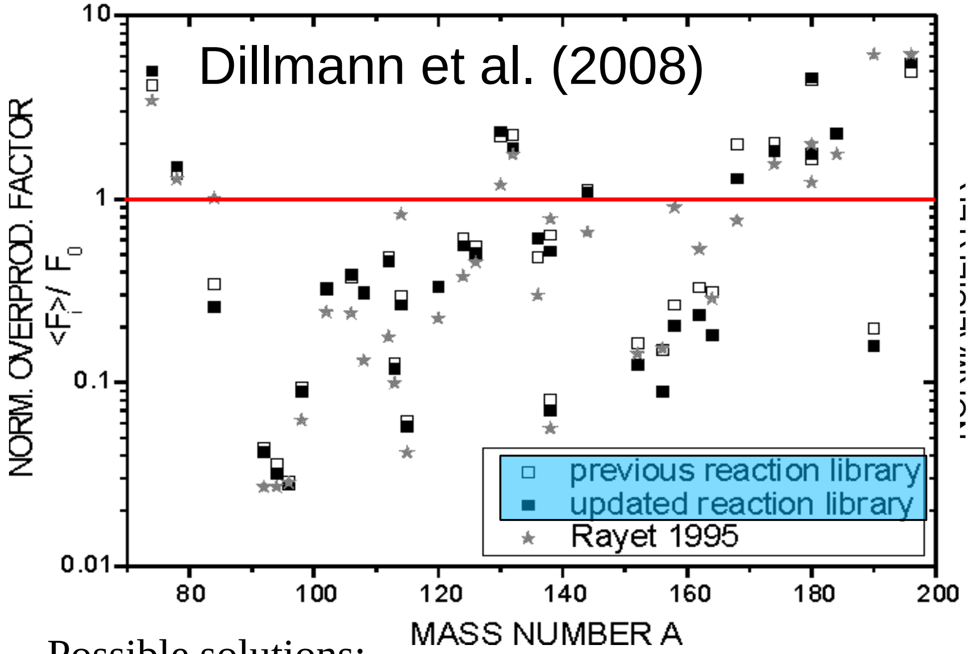


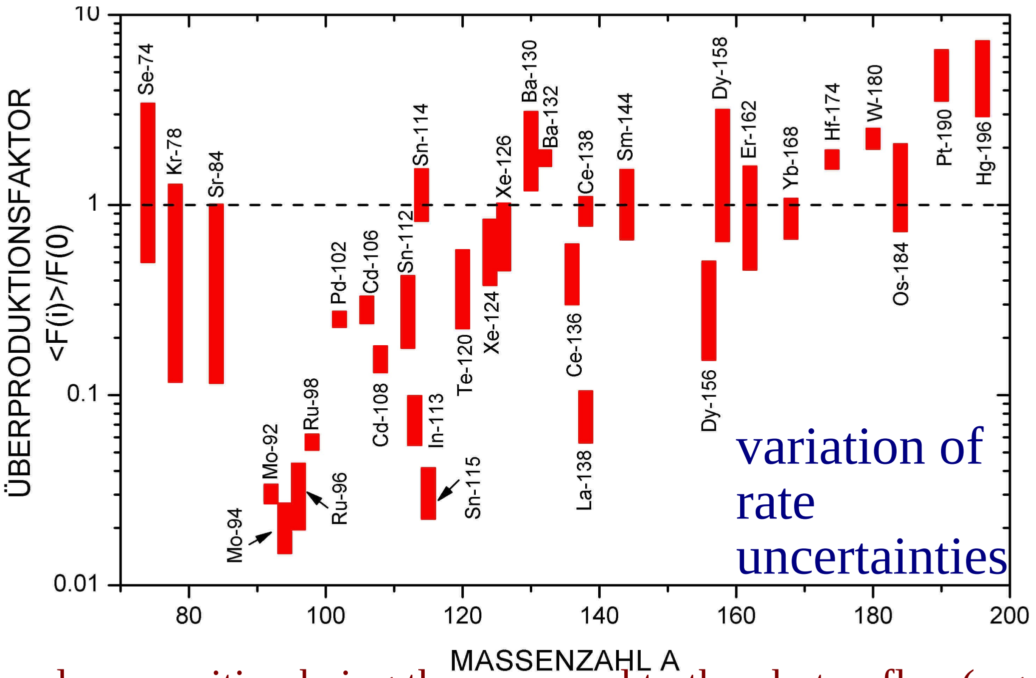
Rapp et al. (2007), following p-(gamma)-process calculations within the framework of Rayet et al. (1995) for a 25M$_{sol}$ star of Yoshida et al. (2002) to verify the impact of nuclear uncertainties.

# Comparison with solar p-only nuclei


Goriely & Arnould (2003)


Rapp et al. (2007)


Dillmann et al. (2008)



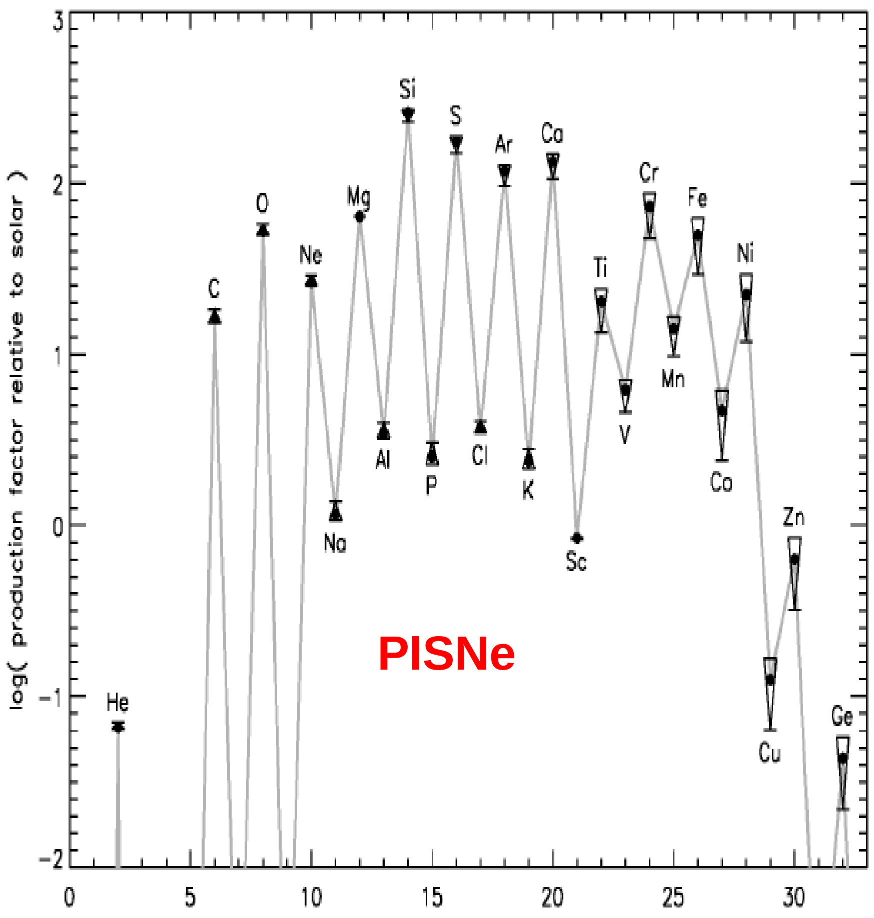
variation of rate uncertainties

Possible solutions:

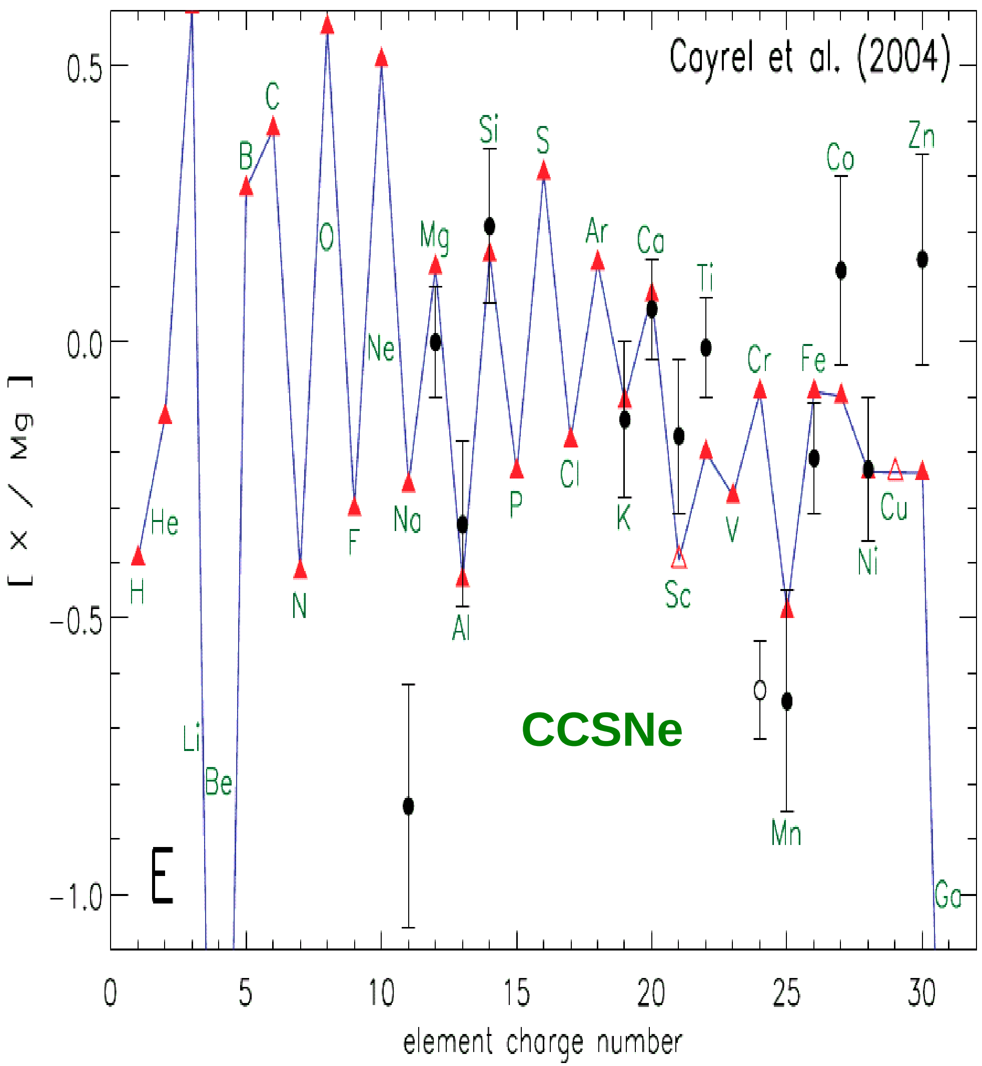
(a) analyze environments which start with a different seed composition being then exposed to the photon flux (e.g. extent of prior s-processing as possibly found in the accreted He-burning layers of SNe Ia, Howard et al. 1991, Kusakabe et al. 2009, Travaglio et al. 2010, but not a solution for LEPP elements at low metallicities!)

(b) invent different environment with capture reactions for light p-isotopes.

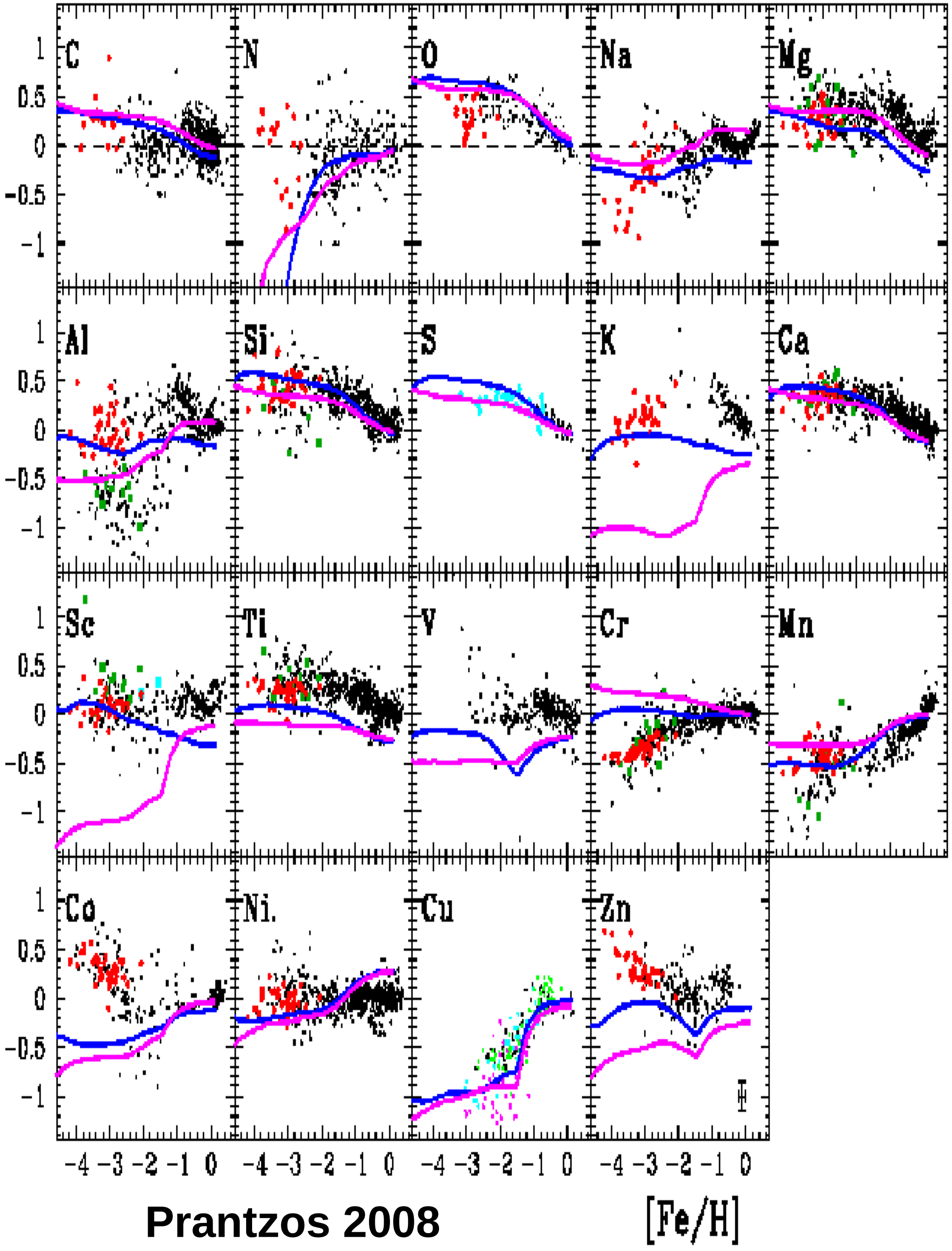
# Pop III yields (Heger & Woosley 2003, 2010)
# Evolution of metal-free stars



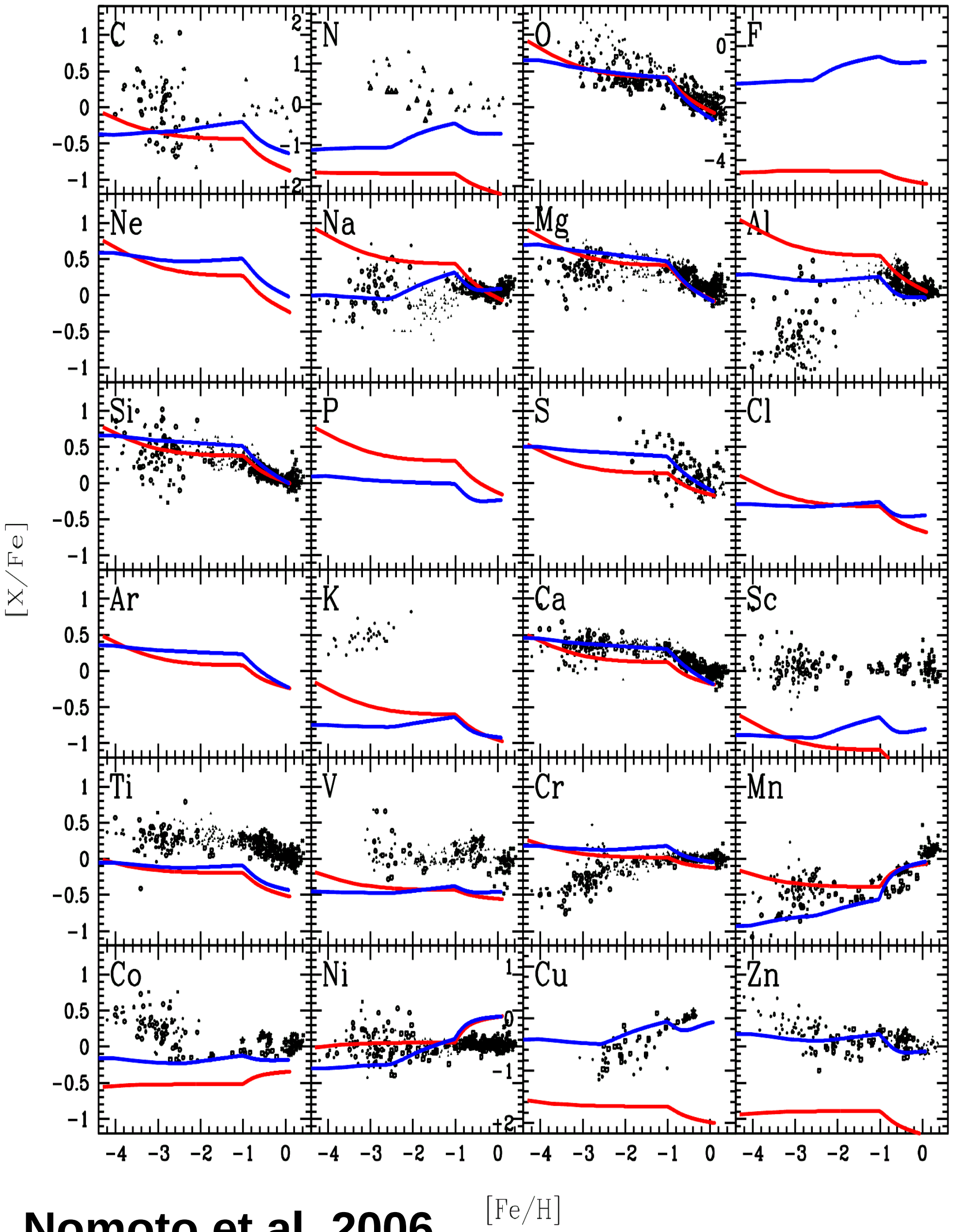
PISNe yields, too large odd-even Z scatter, not observed in low metallicity stars



Cayrel et al. (2004). taken as representative sample for low metallicity stars (representing type II supernova yields). E: “Standard” IMF integration of yields from M = 10 − 100 $M_\odot$, explosion energy E = 1.2 B (underproduction of Sc, Ti, Co and Zn).



**Prantzos 2008**



**Nomoto et al. 2006**

Joint problems for K, Sc, Ti, V, Cr, Co, Zn

**Chemical evolution calculations** Prantzos 2008 and Nomoto et al. 2006 with Weaver& Woosley, and Limongi&Chieffi yields vs. Nomoto et al. yields with and without hypernovae (50% of IMF)

# In exploding models matter in innermost ejected zones becomes proton-rich ($Y_e$>0.5)

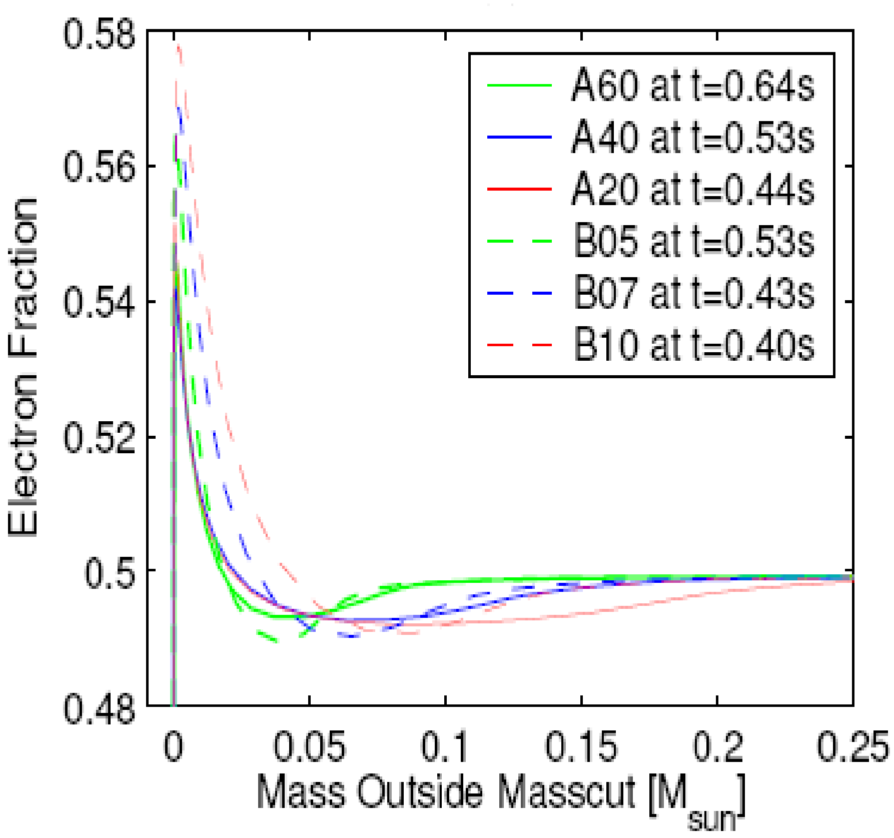
if the neutrino flux is sufficiant (scales with $1/r^2$)! :

$Y_e$ dominantly determined by $e^{\pm}$ and $\nu_e, \bar{\nu}_e$ captures on neutrons and protons

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

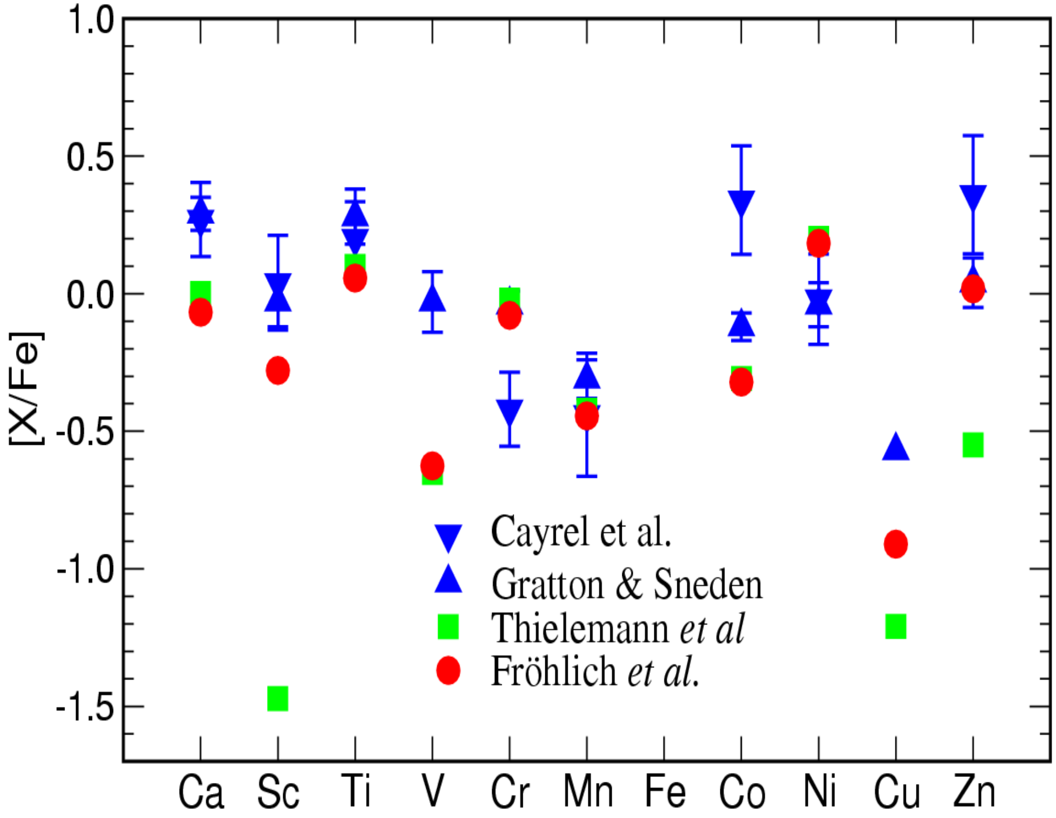
$$\bar{\nu}_e + p \leftrightarrow n + e^+$$

- high density / low temperature → high $E_F$ for electrons → e-captures dominate → n-rich composition
- if el.-degeneracy lifted for high T → $\nu_e$-capture dominates → due to n-p mass difference, p-rich composition
- in late phases when proto-neutron star neutron-rich, $\bar{\nu}_e$'s see smaller opacity → higher luminosity, dominate in neutrino wind → neutron-rich ejecta



Liebendörfer et al. (2003), Fröhlich et al. (2006a), Pruet et al. (2005)

# Improved Fe-group composition



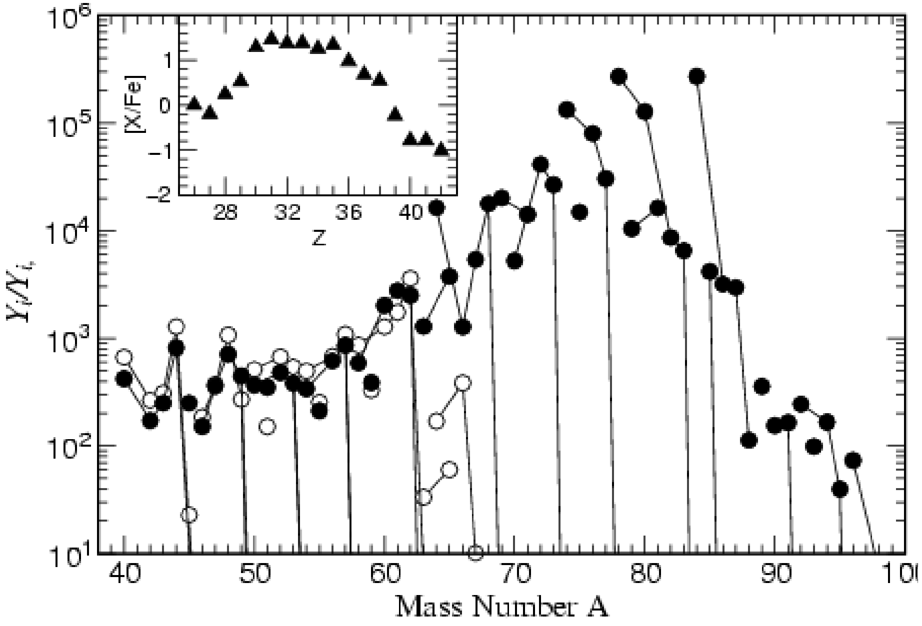
Models with $Y_e$>0.5 lead to an alpha-rich freeze-out with remaining protons which can be captured similar to an rp-process. This ends at $^{64}$Ge, due to (low) densities and a long beta-decay half-life (decaying to $^{64}$Zn).

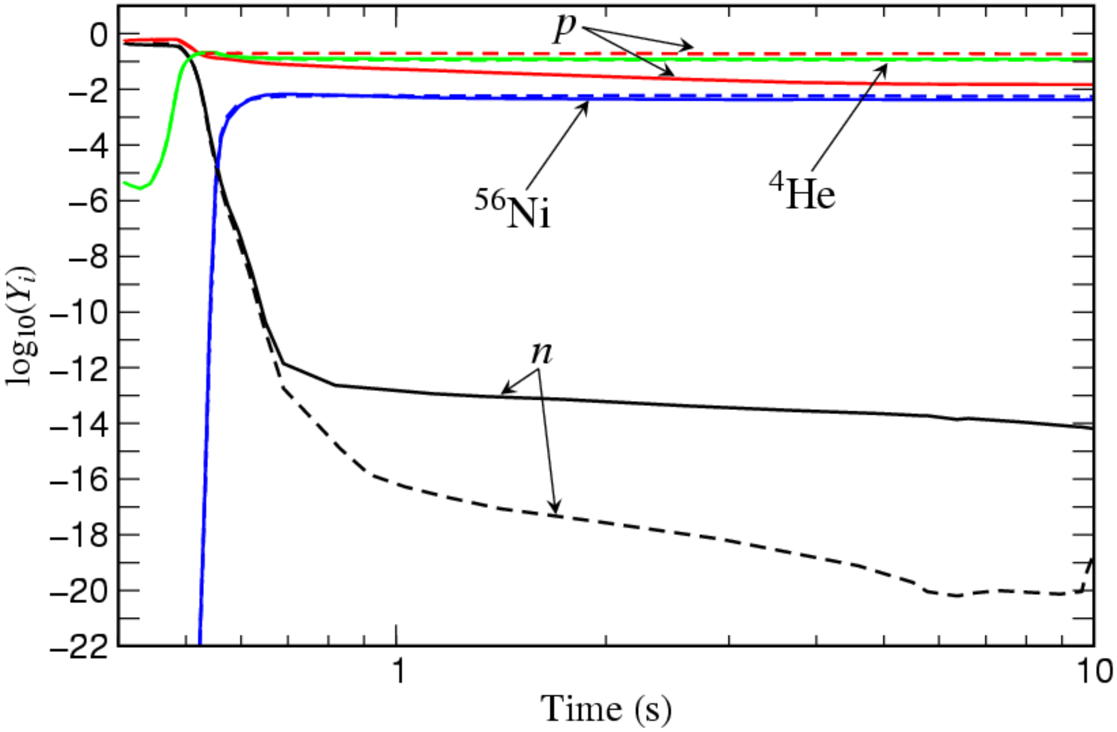
This effect improves the Fe-group composition in general (e.g. Sc) and extends it to Cu and Zn!

Fröhlich et al. (2004, 2006a), see also Pruet et al. (2005), Fröhlich et al. (2012)
*but see also Izutani & Umeda (2010) for hypernova conditions; main question:*
*which fraction of massive stars have to become hypernovae in order to produce solar Zn???*

# *νp*-process

$$\bar{\nu}_e + p \rightarrow e^+ + n; \quad n + {}^{64}\mathrm{Ge} \rightarrow {}^{64}\mathrm{Ga} + p; \quad {}^{64}\mathrm{Ga} + p \rightarrow {}^{65}\mathrm{Ge}; \ldots$$

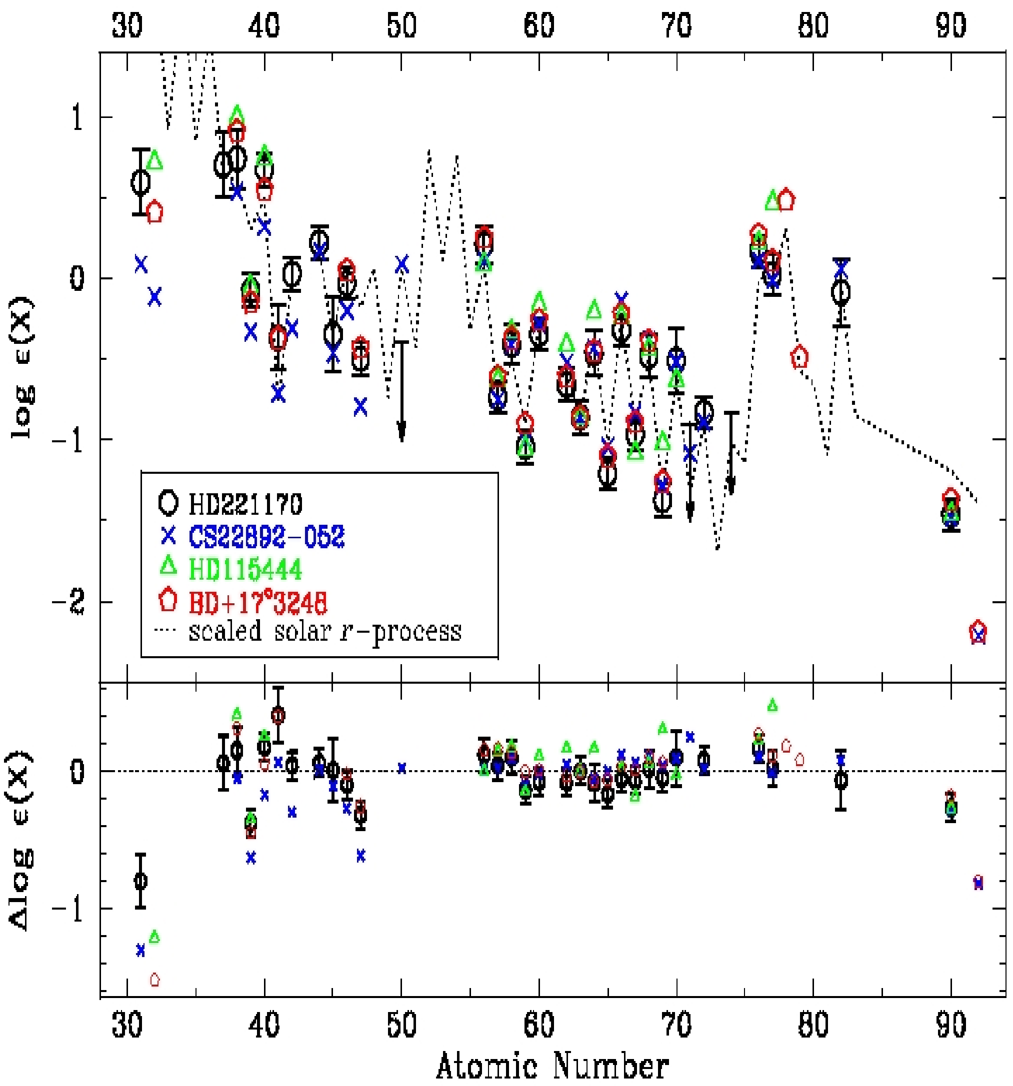




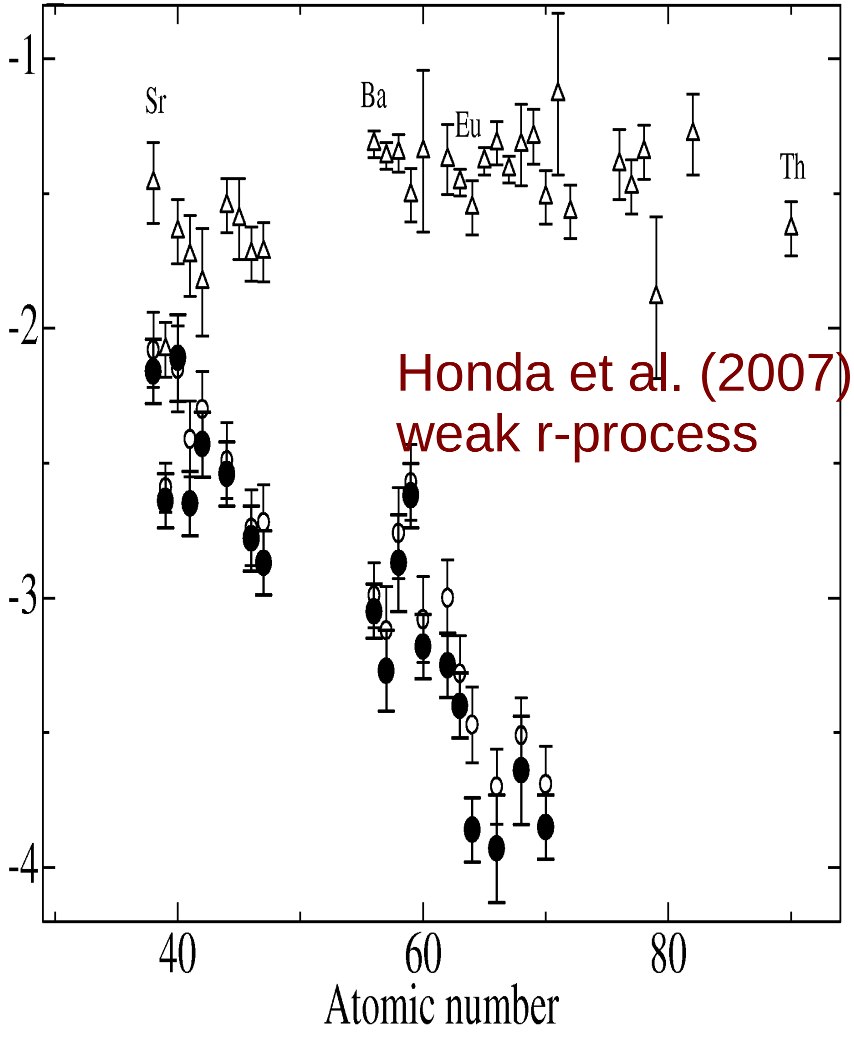
Fröhlich et al. (2006b);
also strong overabundances can be obtained up to Sr and beyond (light p-process nuclei) see also Pruet et al. (2006), Wanajo (2006).
Recent analysis by Wanajo, Janka, Kubono (2010) and Fröhlich et al. (2012) with variation of neutron star masses and reverse shock position

A new process, which could solve some observational problems of Sr, Y, Zr in early galactic evolution and the problem of light p-process nuclei.
Anti-neutrino capture on protons provides always a small background of neutrons which can mimic beta-decay via (n,p)-reactions.

# Almost identical behavior of heavy r-element abundances, variations in light r-elements, often underabundances in comparison to solar r-abundances



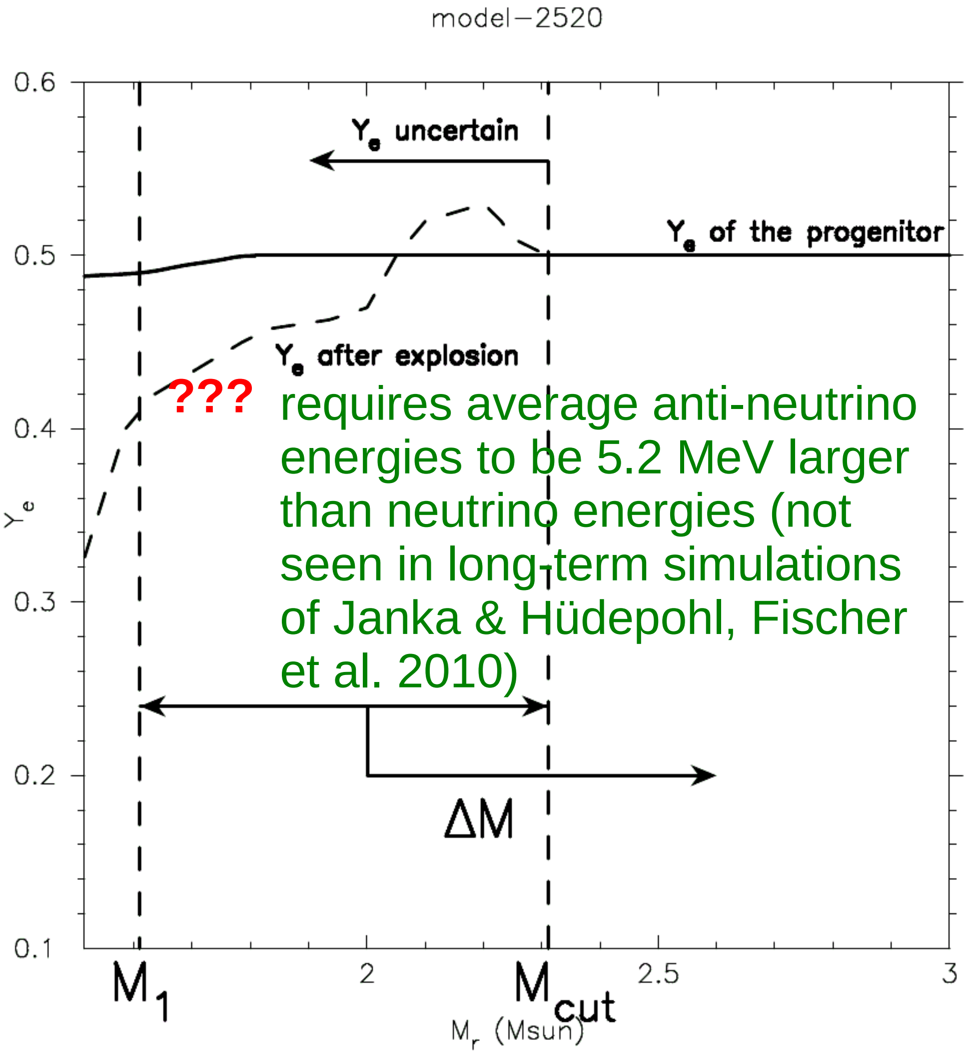
Ivans et al. (2006)



Honda et al. (2007)
weak r-process

Fig. 5.— Logarithmic differences from the solar system r-process pattern ($\log\varepsilon_{\rm object} - \log\varepsilon_{\rm solar-r}$). The open triangles mean CS 22892-052, the open circles mean HD 122563, and the filled circles mean HD 88609.

# Possible Variations in Explosions and Ejecta



??? requires average anti-neutrino energies to be 5.2 MeV larger than neutrino energies (not seen in long-term simulations of Janka & Hüdepohl, Fischer et al. 2010)

Izutani et al. (2009)

- *massive stars experience fallback and delayed black hole formation: small amount of Fe-group ejecta (e.g. Moriya et al. 2010, faint supernovae)?*
- *regular explosions with neutron star formation, neutrino exposure, $\nu p$-process, moderately neutron-rich neutrino wind and weak r-process**??** (see e.g. Arcones & Montes 2011, Roberts et al. 2010)*
- *under which (special?) conditions can very high entropies or very neutron-rich ejecta be obtained which produce the main r-process nuclei?*

*(Wanajo et al. 2010, neutron-rich lumps in EC-Supernovae?? jets: e.g. Cameron 2003, Fujimoto et al. 2008?; very high entropy and neutron-rich neutrino wind?)*

# What is the site of the r-process(es)?

- **Electron Capture Supernovae ?** ***Wanajo (weak!)***

- **Neutron Star Mergers? Freiburghaus, Goriely,** ***Panov, Arcones, Martinez-Pinedo***

- **Black Hole Accretion Disks?** ***MacLaughlin, Wanajo, Janka***

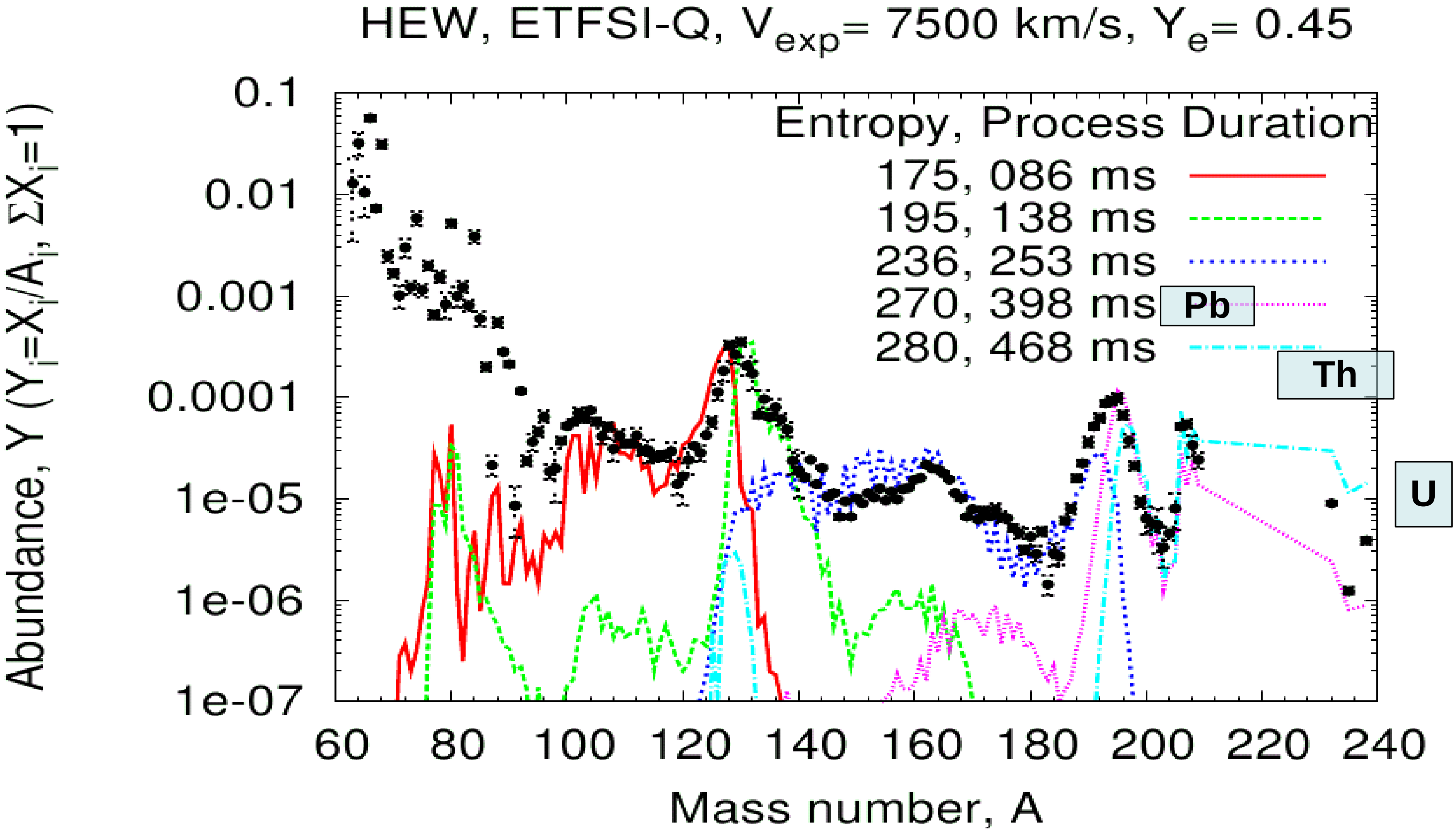
- **Neutrino-driven Winds (in supernovae?) ?** ***Arcones (no!)***

- **CC Neutrino Interactions in the Outer Zones of Supernovae** ***Haxton, Qian (abundance pattern ?)***

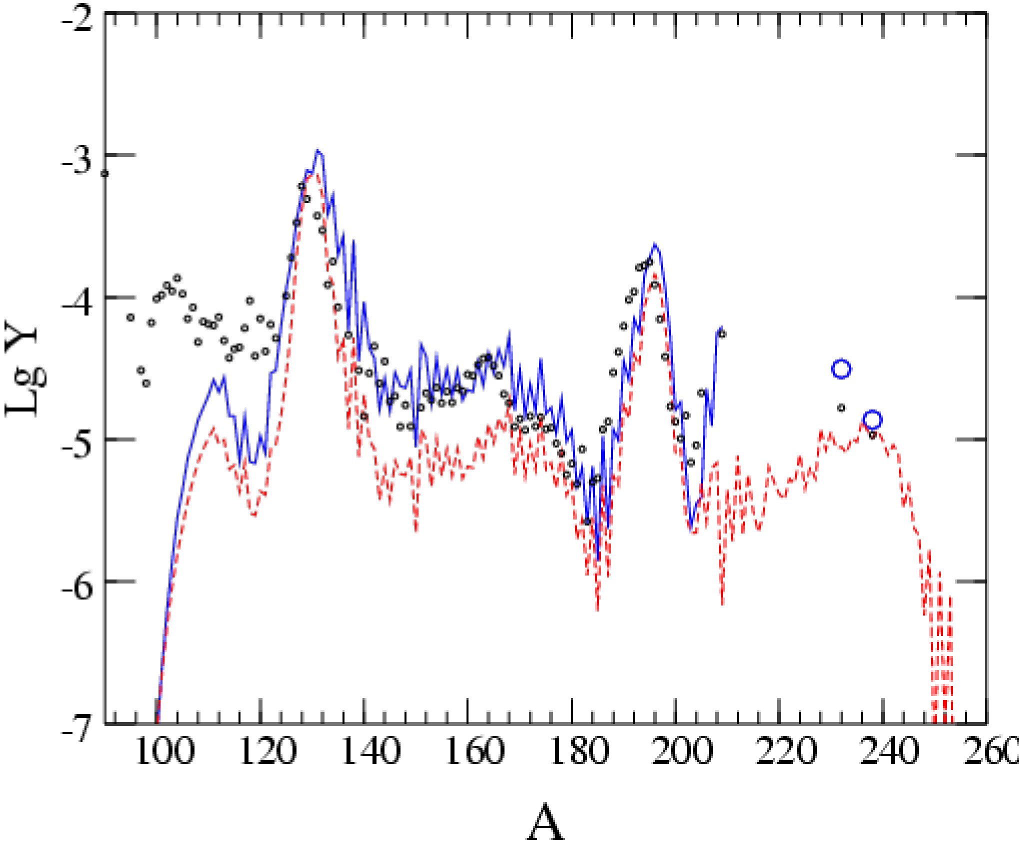
- **Polar Jets from Rotating Core Collapse?** ***Winteler, Nishimura***

# Individual Entropy Components

Farouqi et al. (2010), above S=270-280 fission back-cycling sets in

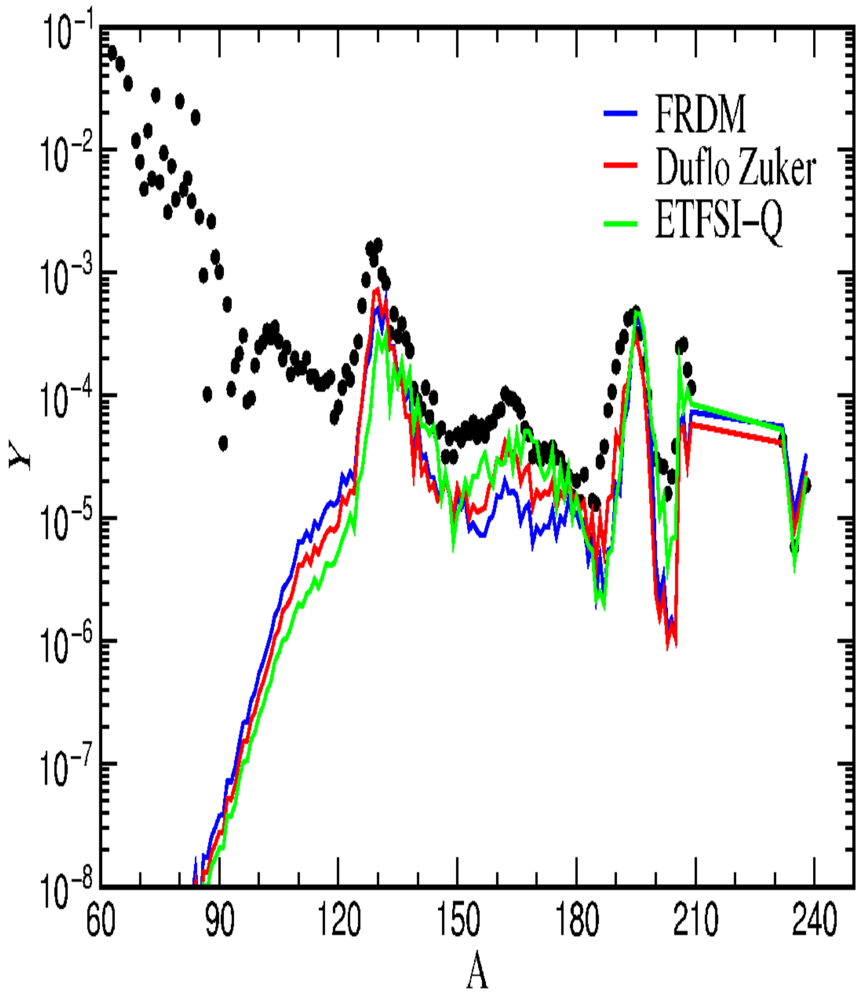


# Fission Cycling in Neutron Star Mergers



Panov, Korneev and Thielemann (2007, 2009) with parametrized fission yield contribution (see also Goriely, Bauswein, Janka 2011)

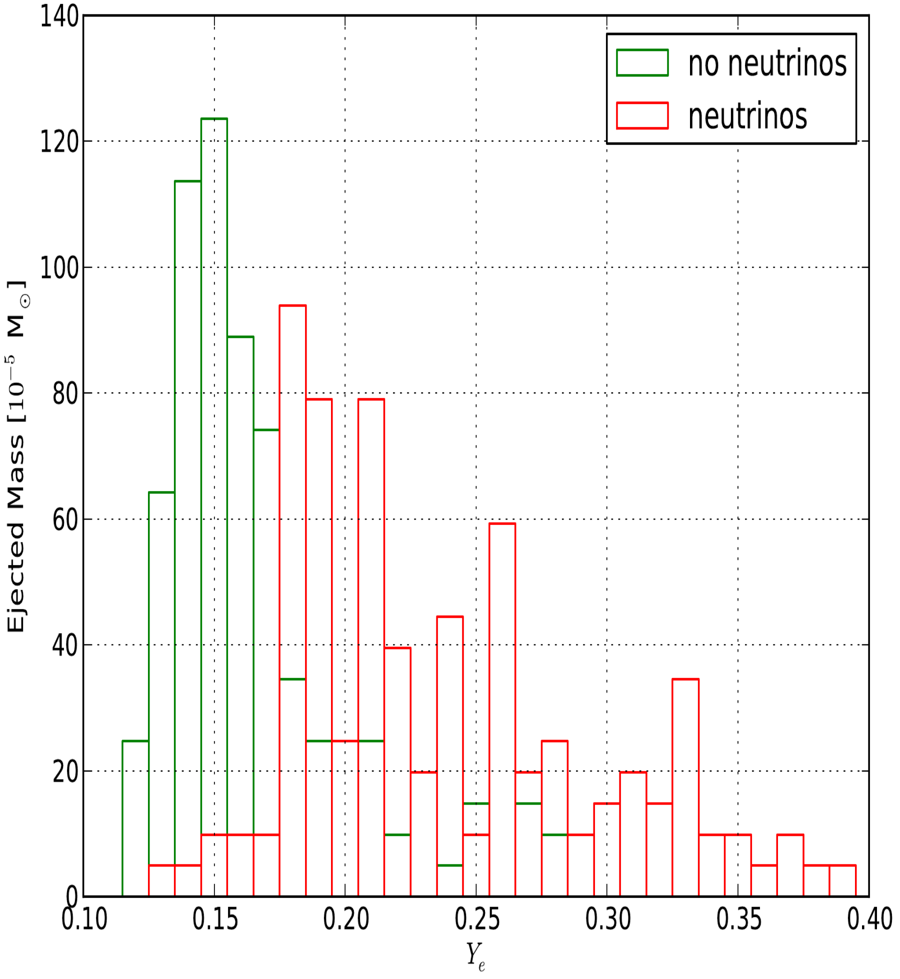
Trajectory from Freiburghaus, Rosswog, and Thielemann 1999 ($Y_e = 0.1, n/Seed = 238$).

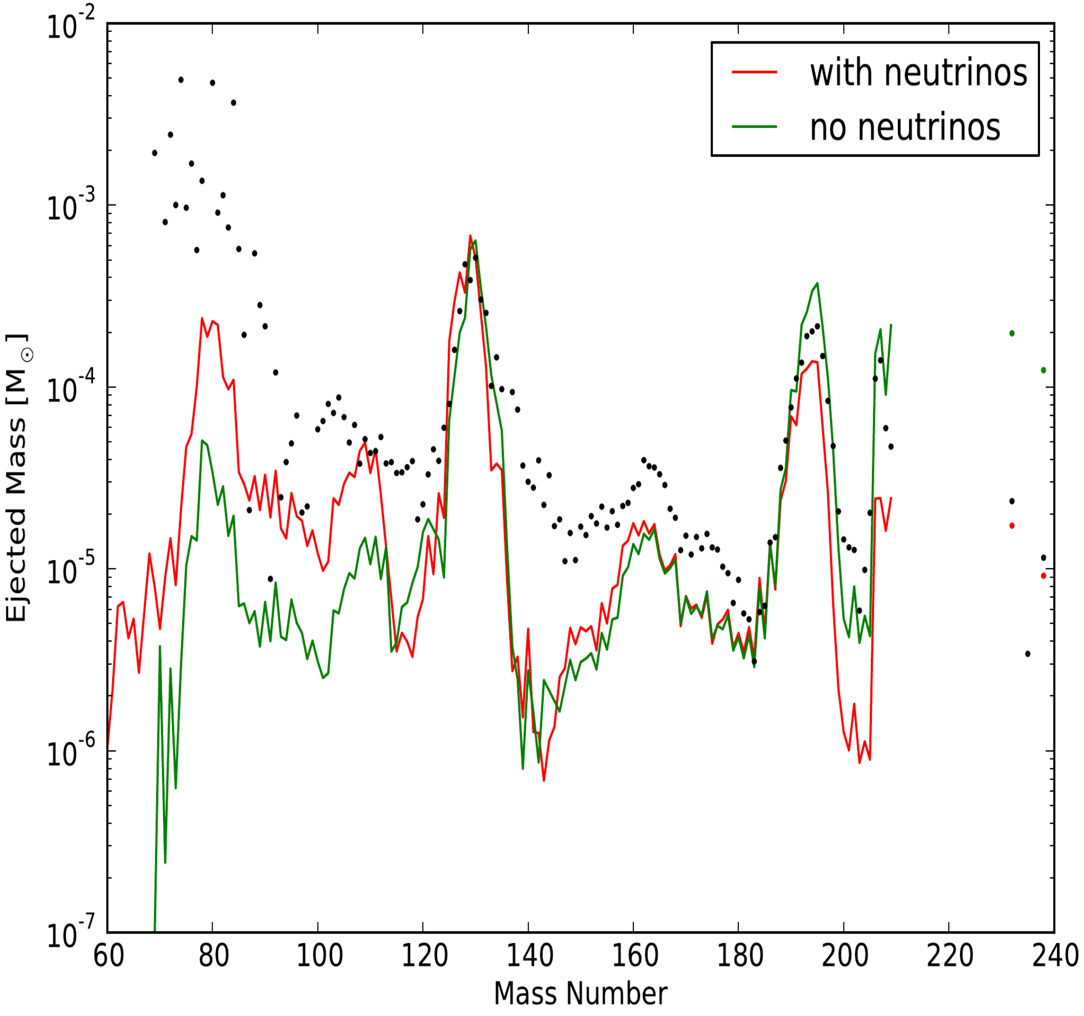


Martinez-Pinedo et al. (2006)

in principle contradicted from gal. evol. calc. (however, see Ishimura & Wanajo 2010), but similar conditions in SN polar jets? (Cameron 2003, Fujimoto 2008)

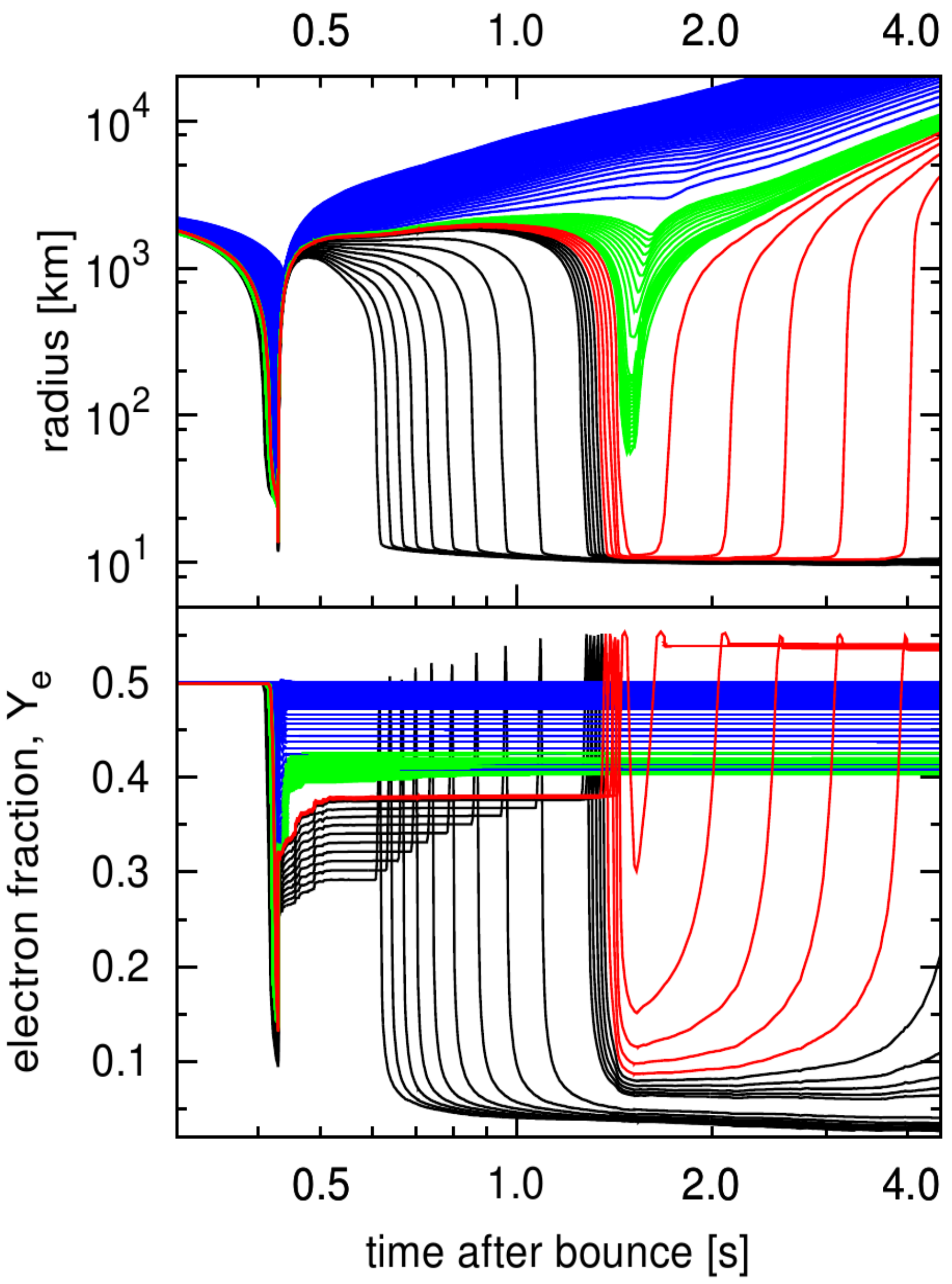
# Results of Jet Ejection from fast rotating collapse with large magnetic fields

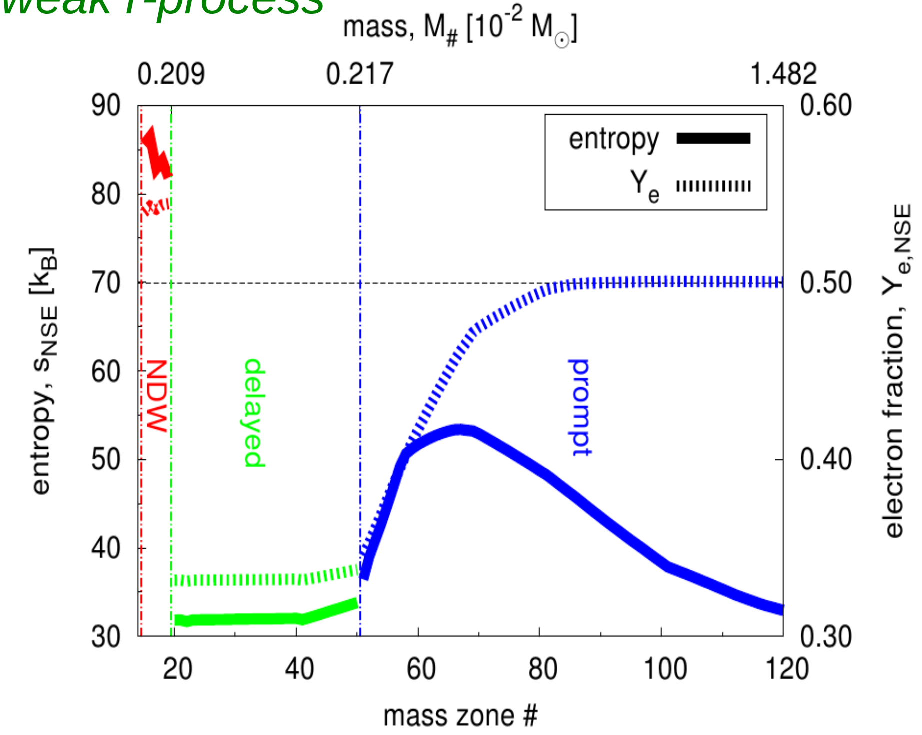


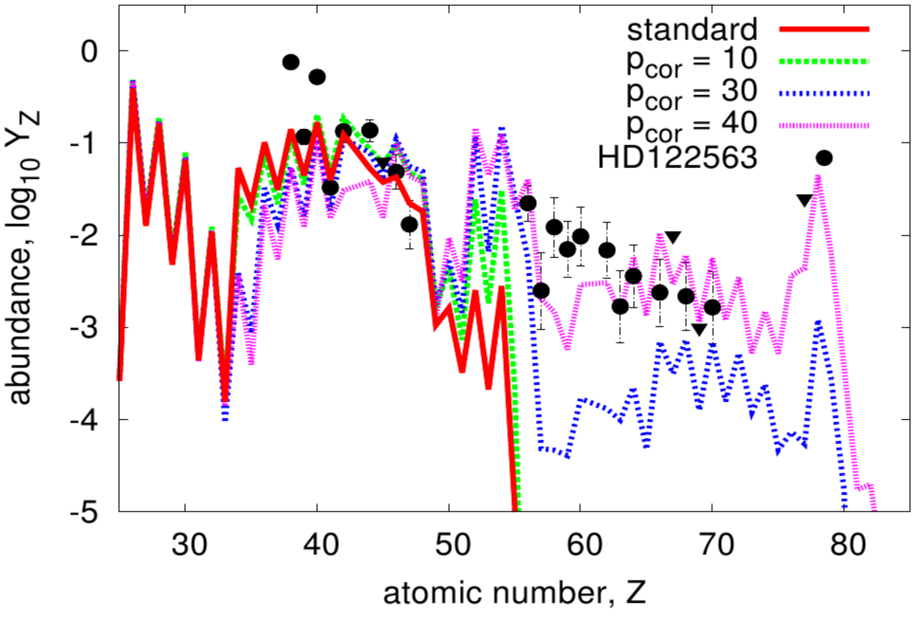


*total ejected mass: few times $10^{-3}$ Msol; C. Winteler, R. Käppeli et al. 2012,, final abundances depend on extrapolated expansion after end of present hydro simulation.*

# Results: Quark-Hadron EoS Explosion (Nishimura, Fischer, Thielemann et al. 2011), *ejection of initially neutronized matter, but only weak r-process*







# Summary

*The explanation of solar system abundances up to Fe reasonably well understood, if one knows SN explosion energies*

*Fe-group composition depends on $Y_e$ dialed in the explosion*

*Neutrino wind seems always to lead to proton-rich conditions and νp-process*

*Nucleosynthesis beyond Fe more complicated than originally envisioned (r- and p-process), s-process still depends on parametrized intershell mixing.*

*The classical p/γ-process cannot reproduce the light p-isotopes and another process has to contribute these nuclei (νp-process) and/or p/γ-process in different locations..*

*Also the r-process comes in at least two versions (weak-main/strong). Weak r-process possible in EC SNe and Quark-Hadron EoS SNe. Any chance to become neutron-rich in the late neutrino wind?*

*The main/strong r-process comes apparently in each event in solar proportions, but the events are rare. The site is not found, yet. Speculations include rotating core collapse events with jet ejection, neutron star mergers and accretion disks around black holes.*