

Magicity evolution toward dripline and its impact on electron capture rates during core-collapse

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Overview

- **Introduction:** electron capture rates in stellar matter at finite T (post core Si burning in massive stars, core-collapse)
- **Matter composition and EC rates in n-rich environments:** late stage evolution of core collapse, unconstrained nuclear structure input, scenarios of magicity quenching, consequences for $\langle \lambda^{(NSE)} \rangle$
- **Conclusions:** extra mass measurements for n-rich N=50, 82 nuclei

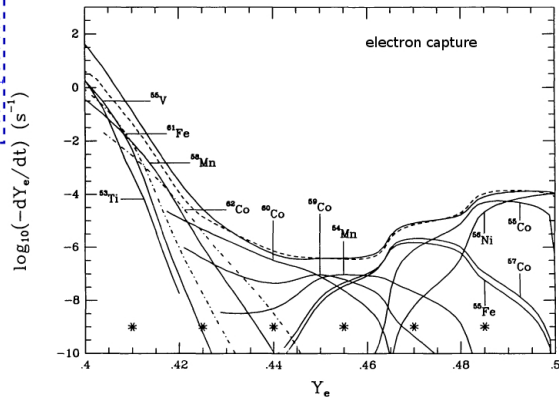
Annual NewCompStar Conference, 25-29 April 2016, Istanbul

Weak interaction rates in the iron core prior to collapse

[Aufderheide et al, ApJS 91,389(1994)]

Thermo conditions for $15M_{\odot}$, $25M_{\odot}$ progenitors:

$7.5 \leq \rho \leq 12 \text{ g/cc}$, $2 \leq T \leq 10 \text{ GK}$, $0.4 \leq Y_e \leq 0.5$

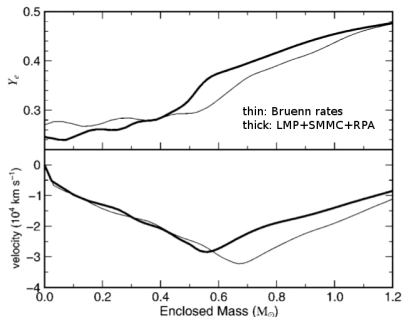
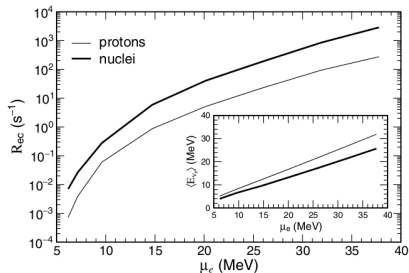


$$\langle \lambda^{(NSE)} \rangle = \frac{\sum \lambda(A, Z)n(A, Z)}{\sum n(A, Z)}$$

- folded up effect of many nuclei, not necessarily the most abundant nor the most reactive
 - $\lambda(A, Z)n(A, Z)(\rho, Y_e, T)$
 - accurate rates are needed
- similarly for β^- -decay

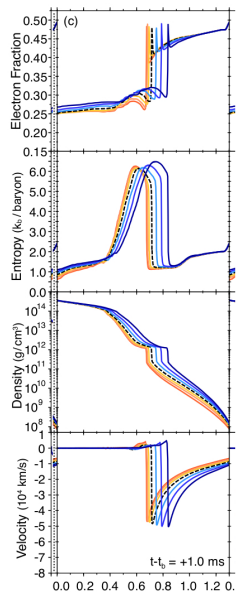
Electron capture rates during core-collapse

[Langanke et al., PRL 90, 241102 (2003)]



- $\lambda_{EC}^{(nuclei)} \gg \lambda_{EC}^{(p)}$
- accurate λ_{EC} needed for dynamics and deleptonization

Electron capture rates during core-collapse



[Sullivan et al., ApJ 816, 44 (2016)]

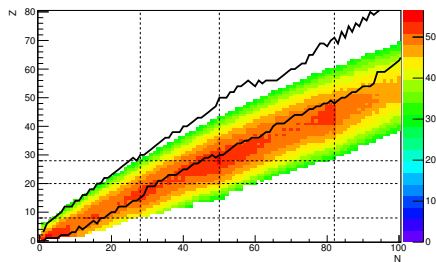
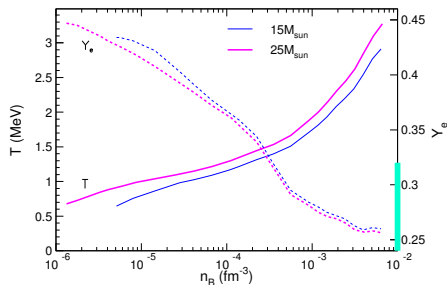
- present accuracy on EC is not sufficient
- CC evolution depend more on EC than on EoS and progenitor models
- systematic modif. of λ_{EC} within present error bars lead to modif. of $+16/-4\%$ on the inner core at bounce and $\pm 20\%$ on $\nu_e = \text{peak luminosity}$
- statistical modif. of λ_{EC} produce smaller effects

increased accuracy on key nuclei (^{78}Ni , ^{79}Cu , ^{79}Zn) might help

Extreme neutron-rich matter is populated in CC

most abundant nuclei are out of the stability valley,
their structure is **not known**

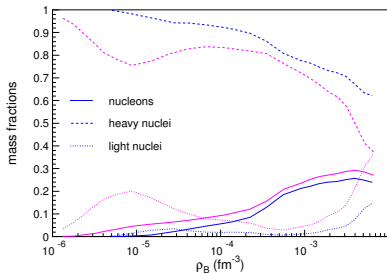
$$n_B = 1.18 \cdot 10^{-3} \text{ fm}^{-3}, Y_e = 0.275, T = 2 \text{ MeV}$$



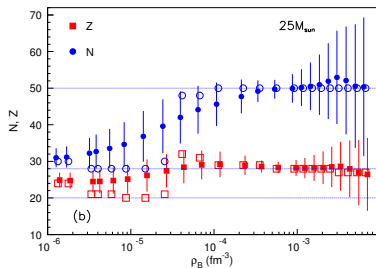
[Juodagalvis et al., NPA848, 454 (2010)]

- similar pattern, slight progenitor dependence
- more massive progenitors lead to more exotic matter, higher T

Matter composition along the CC trajectories



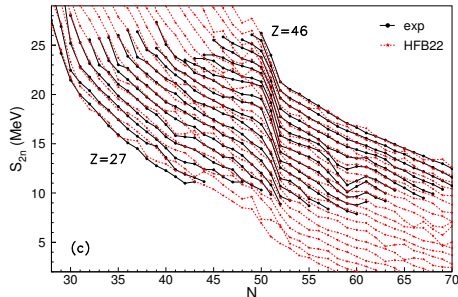
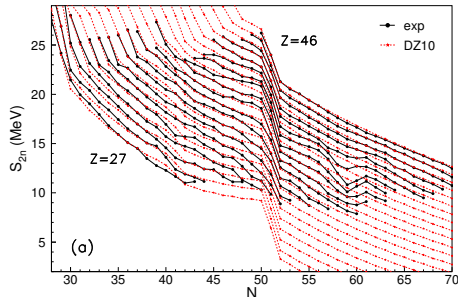
- because of finite T , many nuclei are populated
- $n(A, Z)$ distrib. are multi-peaked
- $X_{A \geq 20} \geq 0.4$



- $\langle N \rangle \neq N_{prob.}, \langle Z \rangle \neq Z_{prob.}$
- $\sigma_{N,Z}$ is large
- $Z_{prob.} = 20, N_{prob.} = 50$
- $\sigma_N \approx 20$, competition of a second magic number

[AR, Gulminelli, Dertel, PRC93, 025803 (2016)]

Magicity far from stability



- beyond stability, binding energies are not known

- predictions of phenomenological or microscopic mass models are used

- correlations and reduced n-p residual interaction, quench magicity in asymmetric nuclei (experimental data exist for $N = 20$)

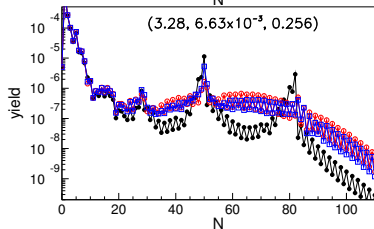
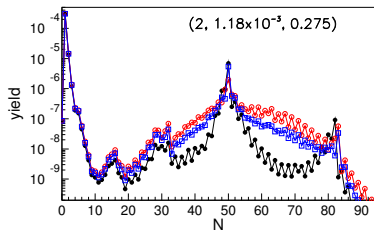
- magicity quenching might occur also for $N = 50$ and $N = 82$

Magicity quenching far from stability

$$B_m(A, Z) = B_{LDM}(A, Z) + f(\alpha, \Delta Z) [B_{DZ}(A, Z) - B_{LDM}(A, Z)]$$

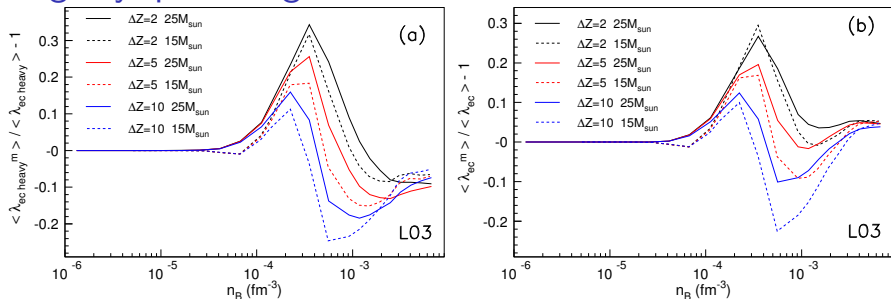
$$f(x, \Delta Z, \alpha) = \exp[\alpha x / \Delta Z], \alpha < 0$$

$$\Delta Z = 10, \Delta Z = 5, \alpha = \log(10^{-2})$$



- magic peaks are much reduced;
- production of non-magic nuclei is much increased

Magicity quenching and EC rates



$$\lambda_{EC} = \frac{\ln 2 \cdot \mathcal{B}}{K} \left(\frac{T}{m_e c^2} \right)^5 [F_4(\eta) - 2\chi F_3(\eta) + \chi^2 F_2(\eta)]$$

[Langanke et al, PRL90, 241102 (2003)]

- structure beyond drip impacts up to 30% on EC;
 - exact values depend of EC rates and assumed scenario of magicity quenching
- enhanced ν -cooling, accelerated collapse, higher inner core at bounce

[AR, Gulminelli, Oertel, PRC93, 025803 (2016)]

Conclusions

- the consequences of a possible quenching of the $N = 50$ and $N = 82$ shell closures on electron capture rates during core-collapse have been examined
- two trajectories corresponding to the pre-bounce evolution of the central element of CC progenitors with $15M_{\odot}$ and $25M_{\odot}$ are considered
[Juodagalvis et al., NPA848, 454 (2010)]
- we found that the properties of very exotic nuclei around $N = 50$ and $N = 82$ represent a key microscopic information

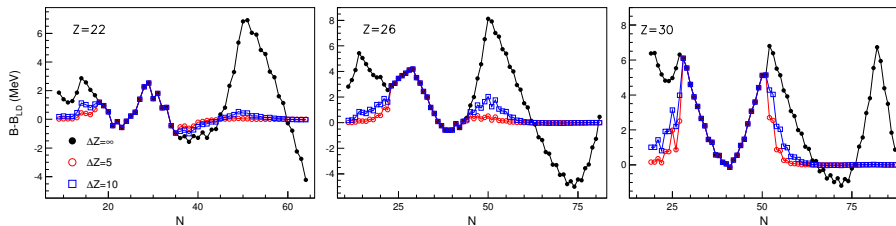
Setup

- exp. masses + Duflo-Zuker

exp. masses + “magicity quenched” Duflo-Zuker

$$B_m(A, Z) = B_{LDM}(A, Z) + f(\alpha, \Delta Z) [B_{DZ}(A, Z) - B_{LDM}(A, Z)]$$

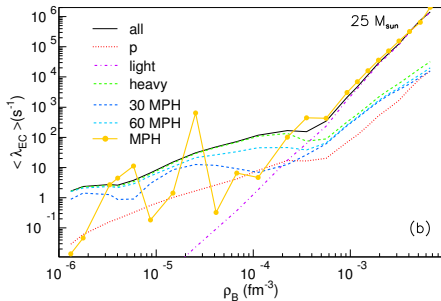
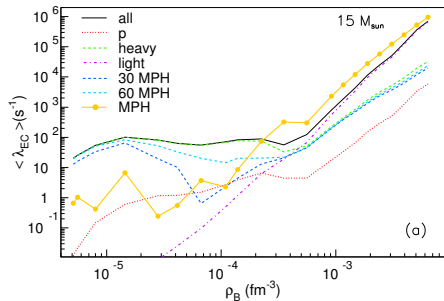
$$f(x, \Delta Z, \alpha) = \exp[\alpha x / \Delta Z], \alpha < 0$$



large/small $\Delta Z \Rightarrow$ slow/steep quenching

EC rates

$$\bar{\lambda}_{EC} = \frac{\sum_{A,Z} n(A,Z) \lambda_{EC}(A,Z)}{\sum_{A,Z} n(A,Z)}$$



- EC by Langanke et al., PRL 2003
- many nuclei contribute to the EC
- SNA approx. is not good