Impact of nuclear masses on the r-process nucleosynthesis

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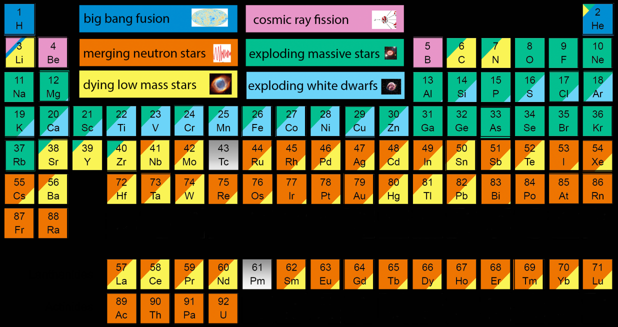
The Origin of the Solar System Elements



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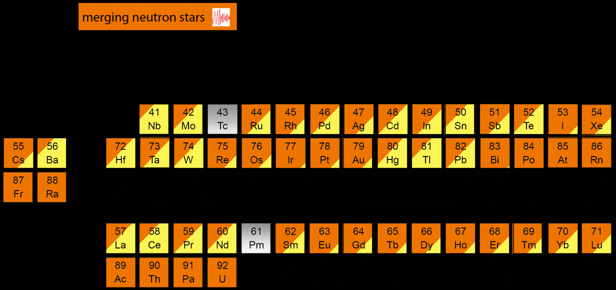

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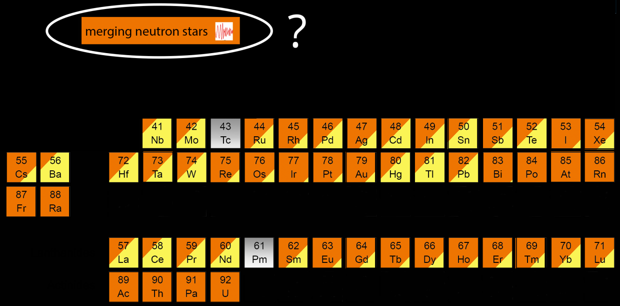

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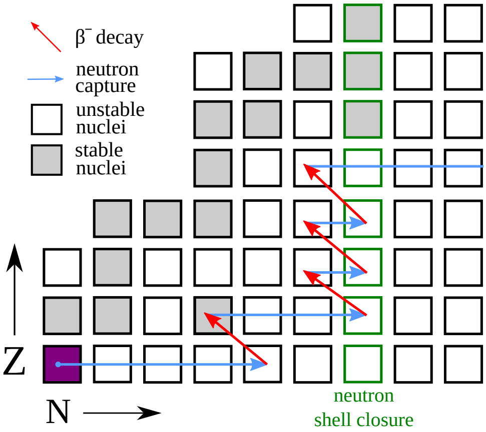
The r process

B[2]FH, Rev. Mod. Phys. 29, 547 (1957) ; A. Cameron, Report CRL-41 (1957)

$\tau_{(n,\gamma)} \ll \tau_{\beta-}$

$A_{\text{final}} \approx A_{\text{initial}} + \frac{\text{neutrons}}{\text{seed}}$

$Y_e = \frac{n_e}{n_b}$



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- Astrophysical site with **high neutron fluxes** → transient object (e.g., **neutron star mergers**).

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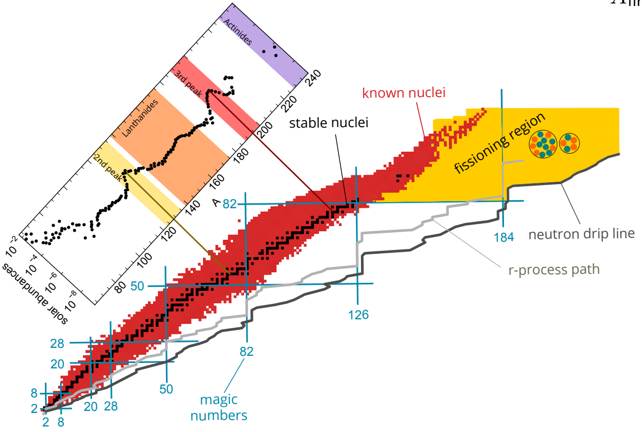

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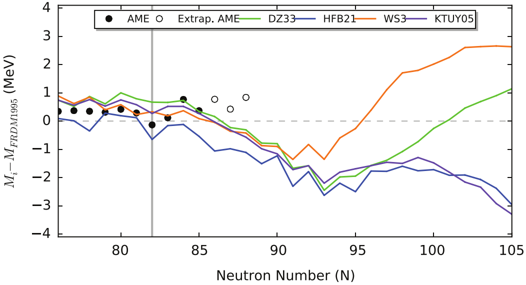
M. R. Mumpower et al., PPNP 86 (2016)



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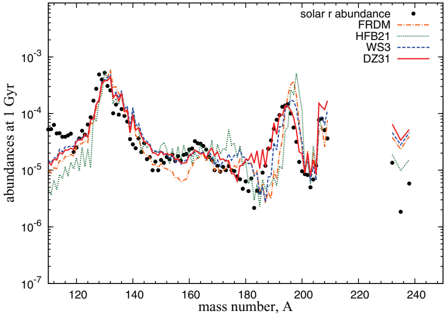
J. J. Mendoza-Temis et al., PRC 92 (2015)



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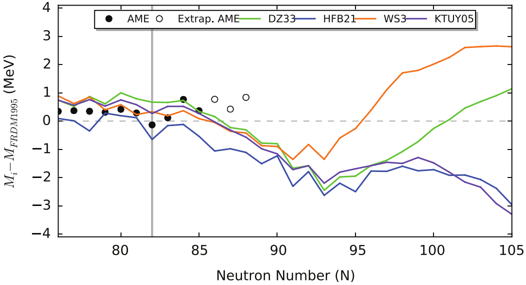

What are the most relevant nuclear mass differences for the r-process abundances?

Nuclear masses - Global and local contributions

Binding energies can be decomposed into **two contributions**:

$$E = E_{\mathrm{bulk}} + E_{\mathrm{shell}}$$

E_{bulk}: **homogeneous, bulk part**. Determines the global properties, depends smoothly on A. It can be described using the liquid drop model (LDM):

$$\begin{aligned}\frac{E^{\mathrm{LDM}}}{A} &= a_{\mathrm{vol}} + a_{\mathrm{sur}} A^{-1/3} + a_{\mathrm{cur}} A^{-2/3} \\ &+ a_{\mathrm{sym}} I^2 + a_{\mathrm{ssym}} A^{-1/3} I^2 + a_{\mathrm{sym}}^{(2)} I^4 \\ &+ a_{\mathrm{Coul}} Z^2 A^{-4/3} + a_{\mathrm{pai}} \delta\end{aligned}$$

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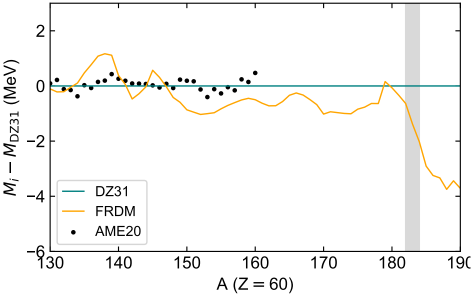
This talk: r-process abundances are insensitive to global changes in masses.

Nuclear masses - Global and local changes



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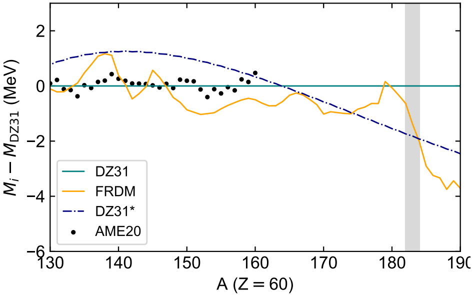

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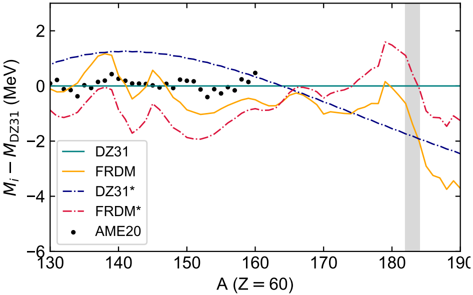

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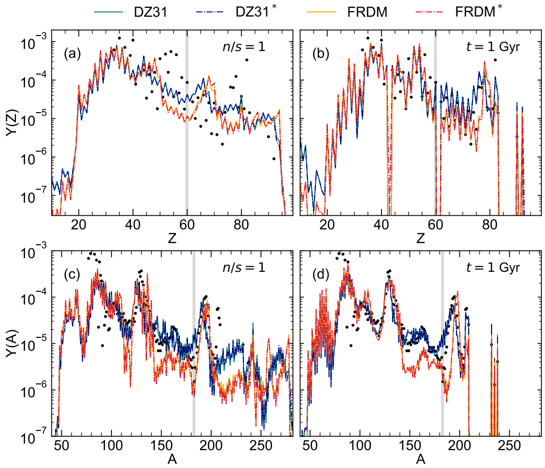
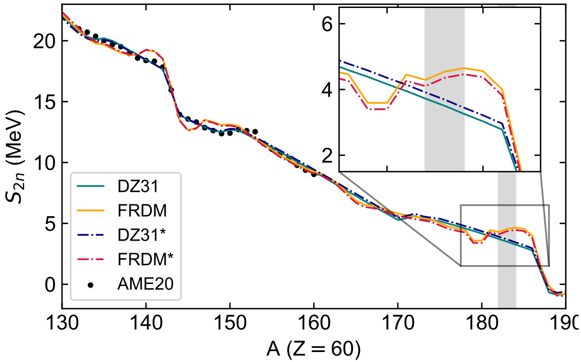
Masses and r process

~2000 NSM trajectories from Collins *et al.*, MNRAS 101093 (2023)



Abundances insensitive to global changes in masses (e.g., symmetry energy).

Nuclear masses - Global and local changes



Abundance mostly related to local changes on S_{2n} (rather than bulk properties of masses) $\rightarrow$ $\Delta_{2n}(N, Z) = S_{2n}(N, Z) - S_{2n}(N + 2, Z)$.

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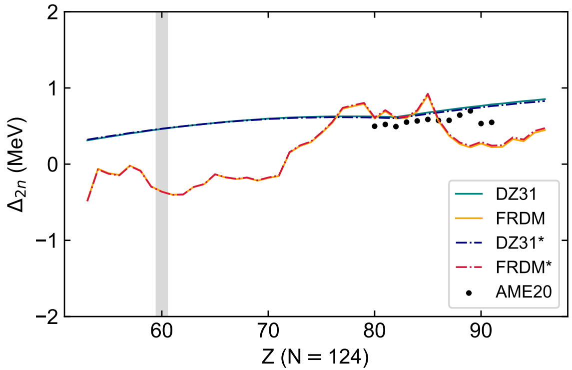

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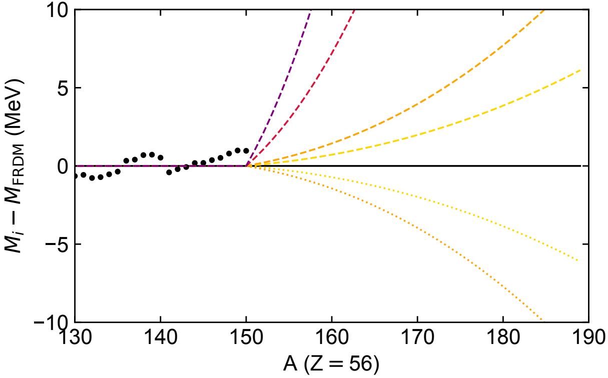

$$\frac{E^{\mathrm{LDM}}}{A} + a_{\mathrm{Nsym}} H(N_{\mathrm{max}}^{\mathrm{exp}}(Z)) I^2 \quad \text{with} \quad I = \frac{N-Z}{N+Z}$$

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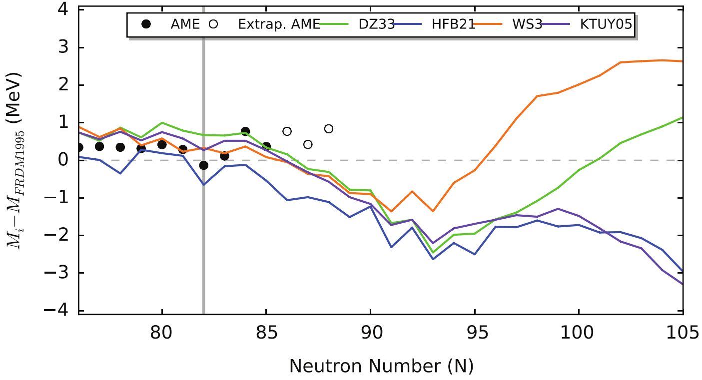

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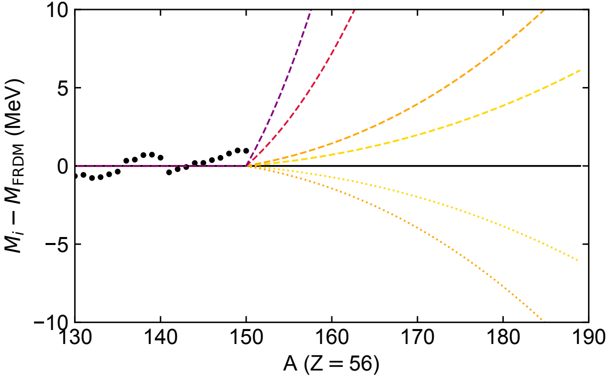

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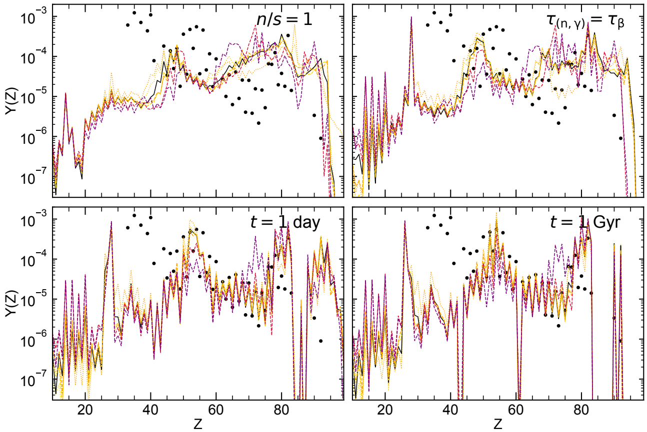

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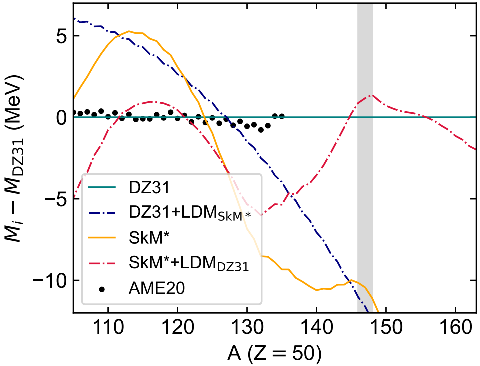

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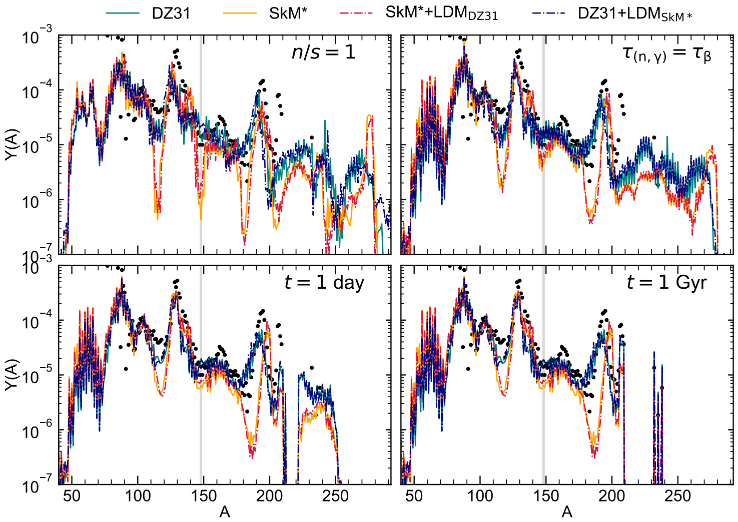
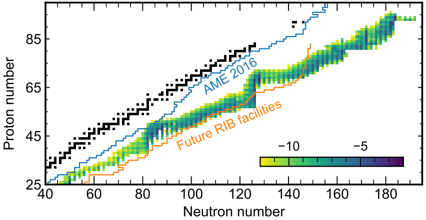


Conclusions

- Understanding the cosmic origin of heavy elements produced by the r-process requires a detailed knowledge of nuclear properties of neutron rich nuclei, being nuclear masses an essential ingredient.
- By separating the bulk behaviour from the quantum shell-correction contribution in different mass tables, we studied the impact of local and global changes in mass surfaces on the r-process.
- We find that global changes on masses have little effect on final r-process abundances, which are mostly determined by shell effects producing local changes in S_n. **All discrepancies are equal, but some are more equal than others.**



- This result allows to better quantify the more impactful changes on nuclear masses, providing further guidance to future experiments.