Implications of Nuclear Mass Models for the Astrophysical Origin of Heavy r-Process Elements

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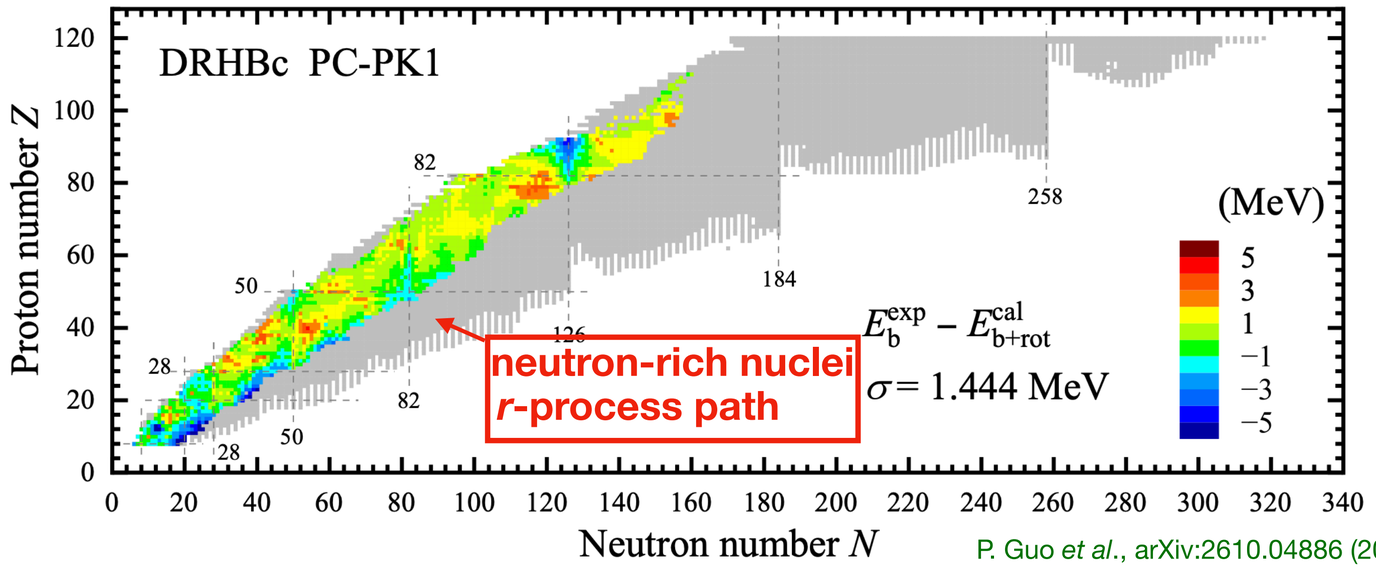
Contents

- Brief introduction to DRHBc theory
- Implications of DRHBc and FRDM2012 on r-process nucleosynthesis in magnetohydrodynamically driven jet (MHDJ), collapsar and neutron star merger (NSM)
- Comparison with solar abundance and Universality

DRHBc mass table project

Deformed **R**elativistic **H**artree-**B**ogoliubov theory in **c**ontinuum

DRHBc project: to describe the ground state of $8 \leq Z \leq 120$



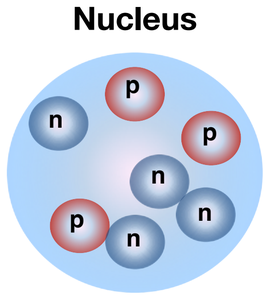
Model	Density functional	$\sigma(E_b)$	$\sigma(S_{2n})$	$\sigma(S_{2p})$	$\sigma(S_n)$	$\sigma(S_p)$	Data number
DRHBc$^{w/o\ E_{rot}}$	PC-PK1	**2.434**	**0.920**	**0.891**	**0.669**	**0.686**	2380
DRHBc$^{w/\ E_{rot}}$	PC-PK1	**1.444**	**0.939**	**0.998**	**0.700**	**0.777**	2380
RCHB	PC-PK1	8.143	1.477	1.527	0.865	0.886	2347
RMF+BCS	TMA	2.040	0.861	1.071	0.644	0.802	2381
HFB	SkM*	6.894	1.092	1.736	0.682	0.979	2354
HFB	SLy4	5.172	0.875	0.774	0.634	0.609	2382
HFB	SV-min	3.324	0.689	0.719	0.520	0.538	2382
HFB	UNEDF1	1.983	0.672	0.751	0.492	0.543	2387

P. Guo *et al.*, arXiv:2610.04886 (2026).

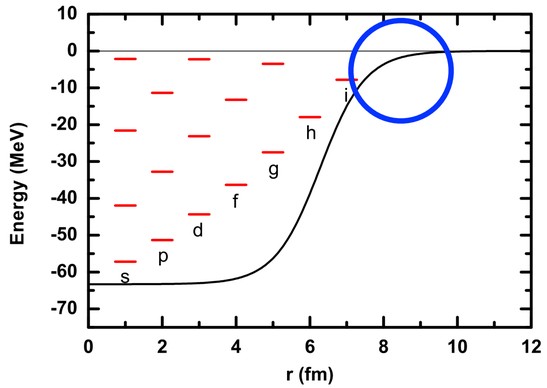
- DRHBc was developed to describe deformed, weakly bound exotic nuclei by treating deformation, pairing correlations, and continuum effects self-consistently.
- The DRHBc mass table provides a systematic description of nuclear mass across the nuclear chart, including neutron-rich nuclei relevant to the *r*-process.

Features of DRHBc with PC-PK1

Deformed **R**elativistic **H**artree-**B**ogoliubov theory in **c**ontinuum

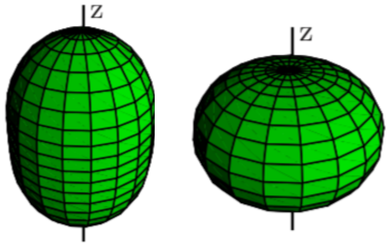


- Contact interactions between nucleons using PC-PK1 are used in the Lagrangian.



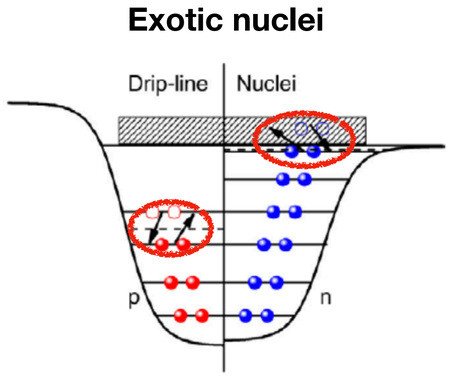
H. Liang *et al,* Phys. Rev. C **87**, 014334 (2013).

- Dirac Woods-Saxon basis is adopted; continuum is well included.



prolate $\beta_2 > 0$ **oblate** $\beta_2 < 0$

- Axial deformation degrees of freedom are included.



J. Meng *et al,* Prog. Part. Nucl. Phys. **57**, 470 (2006).

- Pairing potential is consistently included and solved together with mean field using HB equation.

Setup for r-process nucleosynthesis calculation

- Tool: NucNet Tool (Clemson code)
  Meyer, B. S., & Adams, D. C. 2007, M&PSA, 42, 5215
  https://sourceforge.net/u/mbradle/blog/?page=4
- Default Data: JINA Reaclib Database + Fission data
  Cyburt, R. H., Amthor, A. M., Ferguson, R., et al. 2010, ApJS, 189, 240 Shibagaki, S., Kajino, T., Mathews, G. J., et al. 2016, ApJ, 816, 79
- Investigated Astrophysical environments: NSM, MHDJ SN, Collapsar
  Korobkin, O., Rosswog, S., Arcones, A., & Winteler, C. 2012, MNRAS, 426, 1940
  Nakamura, K., Kajino, T., Mathews, G. J., Sato, S., & Harikae, S. 2013, IJMPE, 22, 1330022
  Shibagaki, S., Kajino, T., Mathews, G. J., et al. 2016, ApJ, 816, 79
- How to apply nuclear masses and reactions from DRHBc?
  1. Apply nuclear masses M from the preliminary DRHBc mass table, replacing FRDM.
  2. Update theoretical (n,γ) reaction and β^- decay rates.

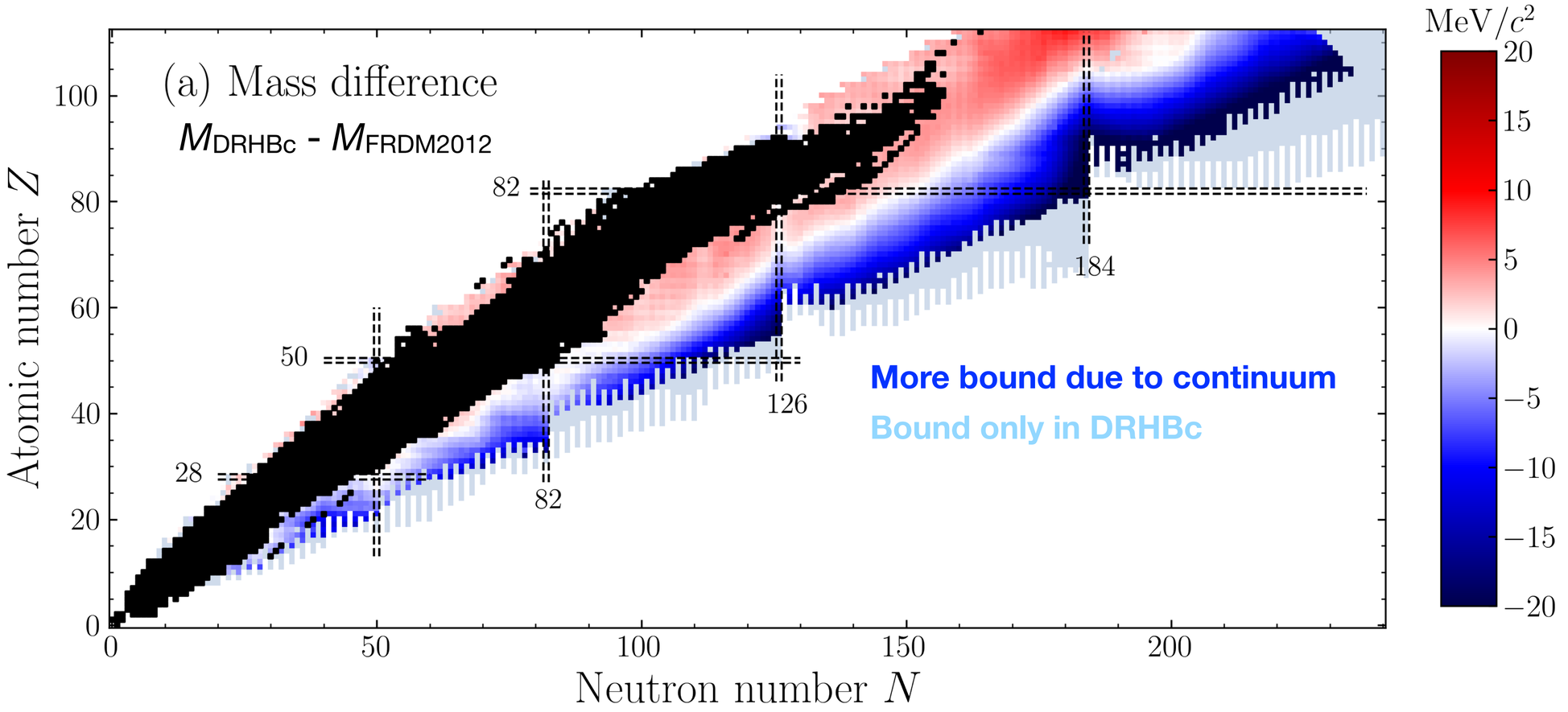
  Courtesy: Peng Guo (PKU) & DRHBc Collaboration

  For example, if the mass changes by $\triangle m$ MeV/c^2,

  β-decay rate $\propto [(Q_\beta + \triangle m)/Q_\beta]^5$ $(=[Q_{\beta,\mathrm{DRHBc}}/Q_\beta]^5)$

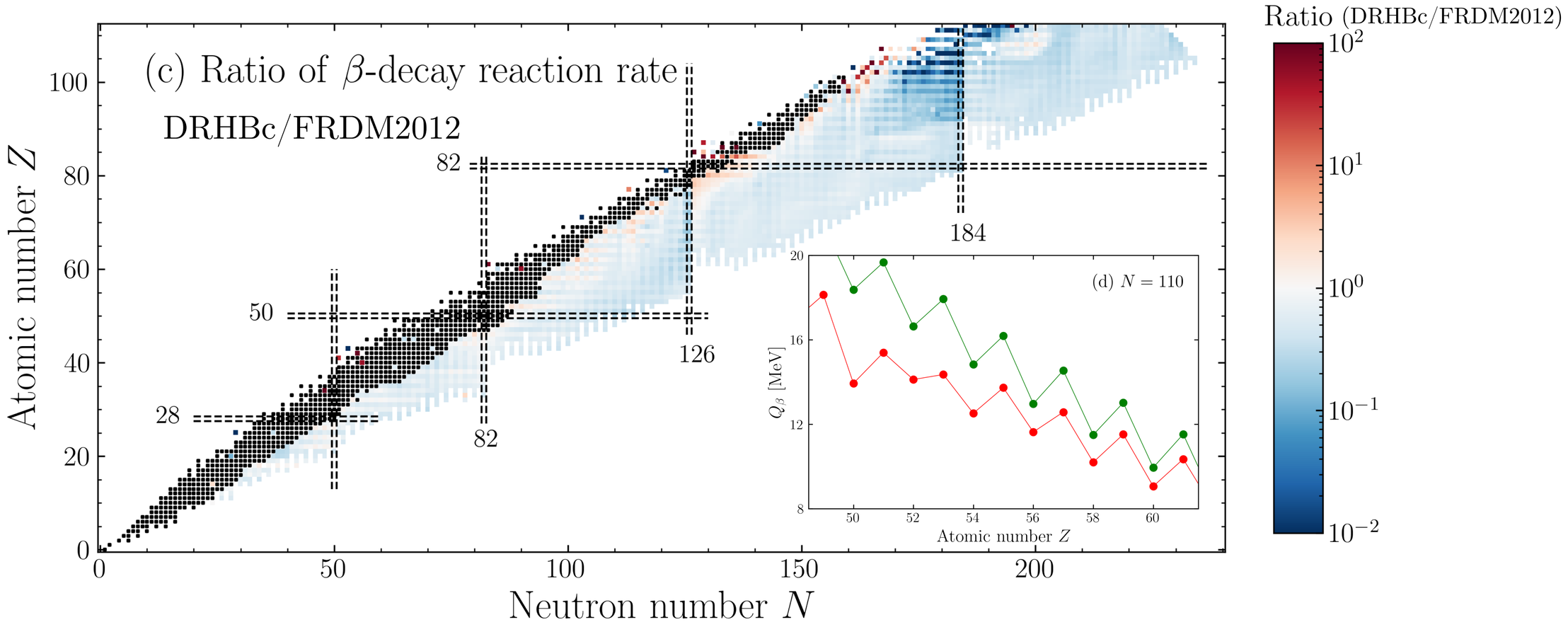
  neutron-capture rate $\propto [(Q_{(n,\gamma)} + \triangle m)/Q_{(n,\gamma)}]^3$ $(=[Q_{(n,\gamma),\mathrm{DRHBc}}/Q_{(n,\gamma)}]^3)$

Mass differences between DRHBc and FRDM2012



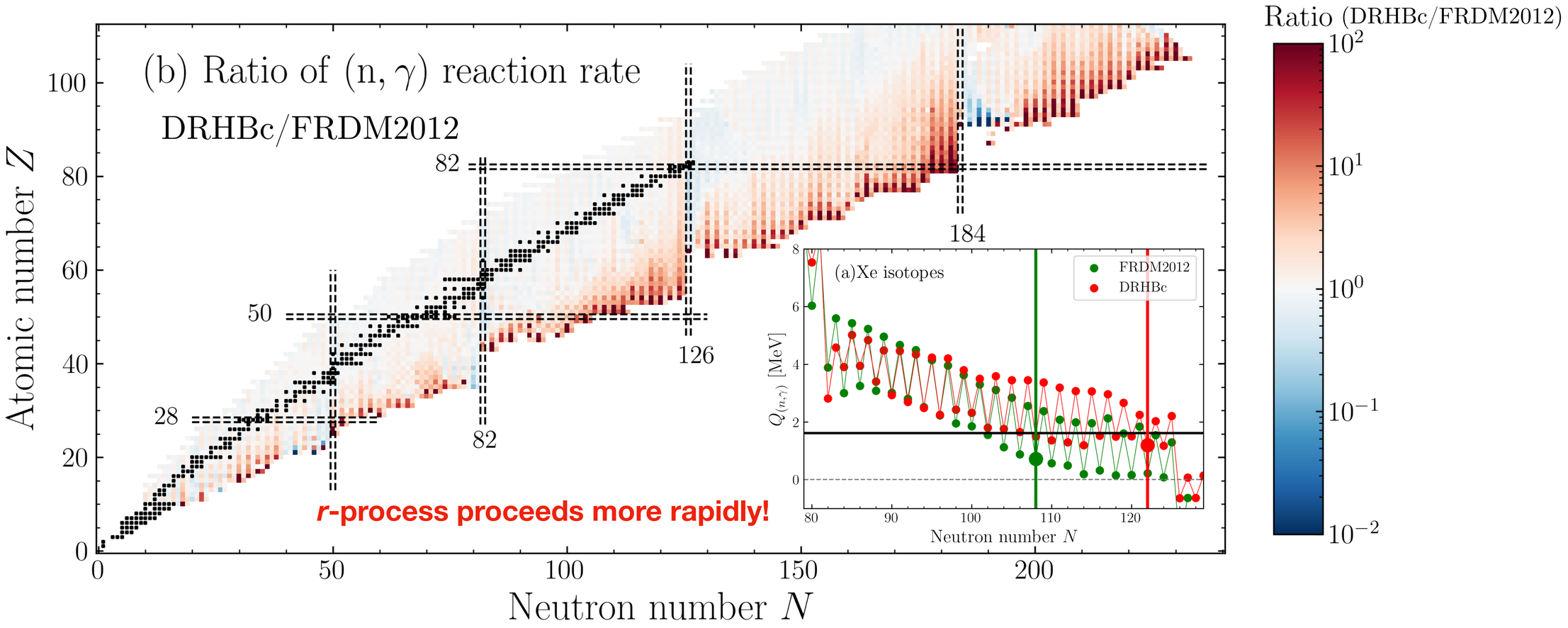
- DRHBc predicts lower masses than FRDM2012 in neutron-rich region.
- These mass differences affect reaction Q-values and, consequently, r-process.

Impact of nuclear masses on reaction Q-values



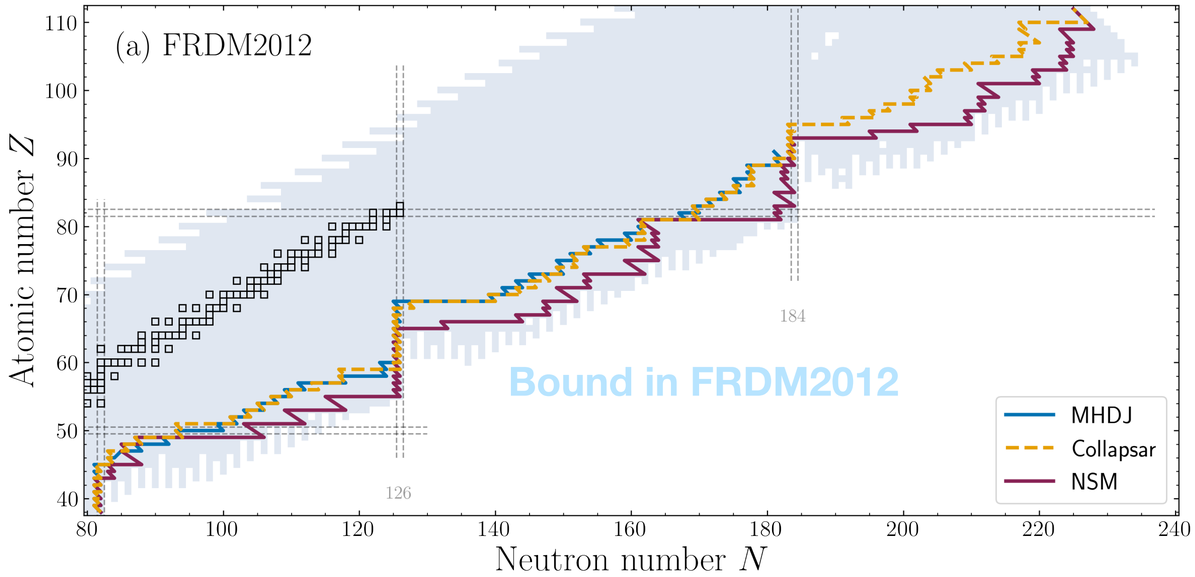
- DRHBc generally predicts lower β-decay rates in the neutron-rich region.
- The impact on β-decay rates is smaller than that of neutron-capture rates.

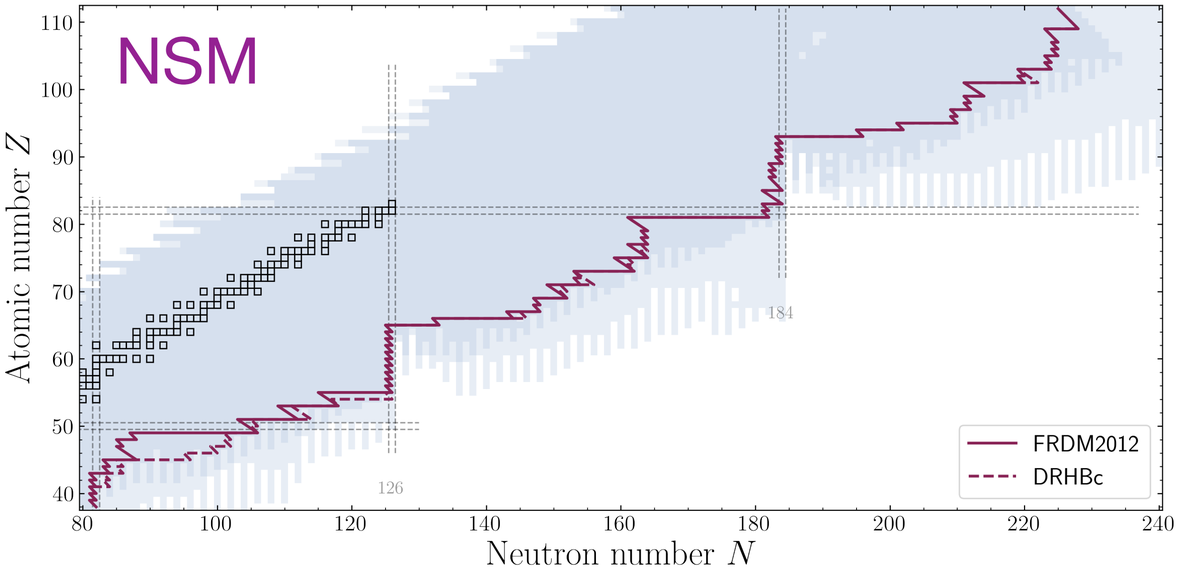
Impact of nuclear masses on reaction Q-values

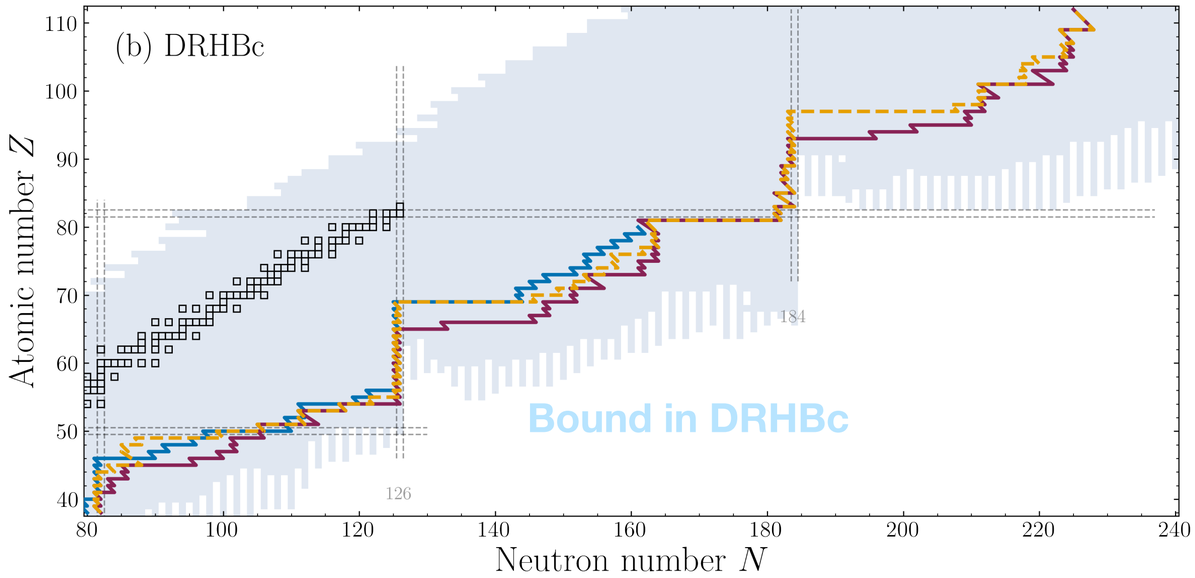


- DRHBc generally enhances neutron-capture rates in the neutron-rich region.
- The relatively small neutron-capture Q-values of odd-N nuclei highlight the importance of nuclear pairing.

Impact of nuclear masses on r-process paths





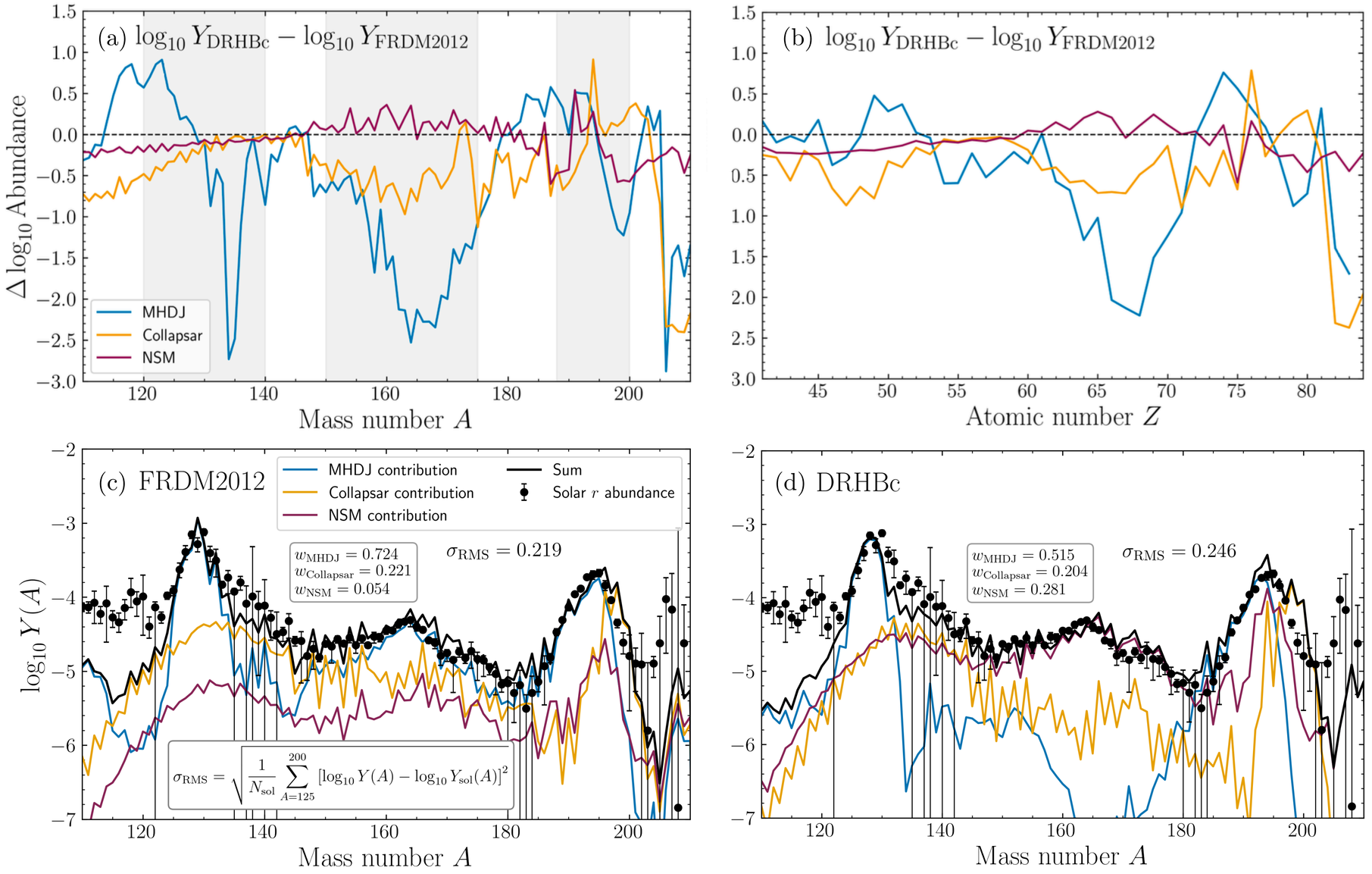


- With DRHBc, the r-process paths lie closer to the neutron drip line across the three astrophysical environments.

$$\left(\frac{S_n}{k_{\rm B}T}\right) \simeq 2.30\left[35.68 + \frac{3}{2}\log_{10}\left(\frac{k_{\rm B}T}{\rm MeV}\right) - \log_{10}\left(\frac{n_n}{\rm cm^{-3}}\right)\right]$$

Kajino, T., & Mathews G. J. 2017, Reports on Progress in Physics, 80 084901

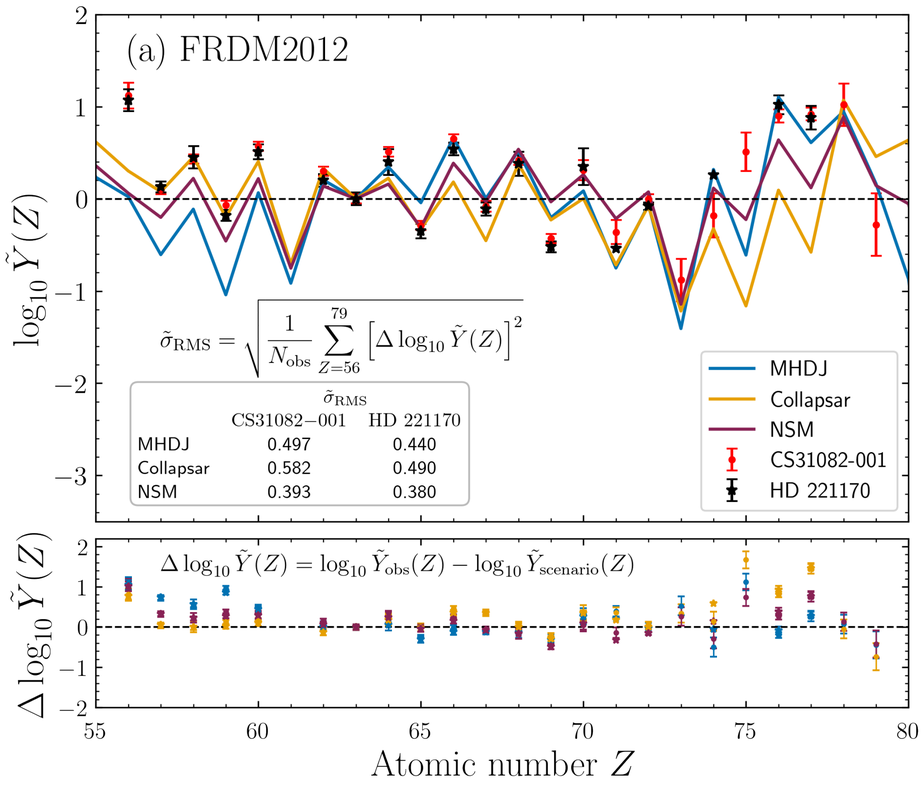
Impact of nuclear masses on final abundances

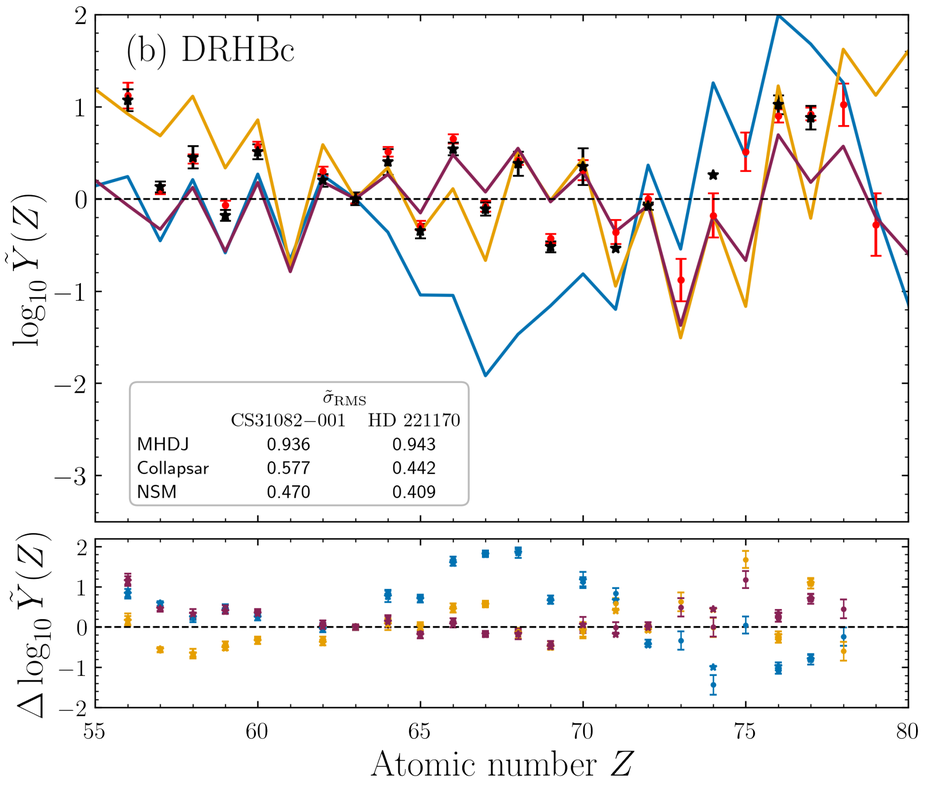


- The sensitivity of the abundance pattern to the nuclear mass model depends strongly on the astrophysical site.
- The inferred contributions to the solar r-process could vary by the adopted mass model.

Comparison with r-process-enhanced stars

Motivated by a comment from Prof. Kanji Mori





- Nuclear physics helps us understand the origin of heavy r-process elements, while observed r-process abundances may constrain nuclear models for neutron-rich nuclei.

Summary

- ✓ We investigated the impact of DRHBc nuclear masses on r-process nucleosynthesis in MHDJ, collapsar, and NSM environments, in comparison with FRDM2012.

- ✓ DRHBc masses shift the r-process path toward more neutron-rich nuclei and modify the final abundance patterns, particularly in the MHDJ case.

- ✓ The sensitivity of the r-process abundance pattern to the nuclear mass model varies considerably across astrophysical environments.

- ✓ Observed r-process abundances may constrain nuclear properties, while nuclear mass uncertainties limit constraints on their astrophysical origins.

Thank you for your attention!