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Microscopic description of β-decay rates of r-process nuclei

Diana Alvear Terrero[1,2,3]

In collaboration with

Gabriel Martínez-Pinedo[1,2,3] **Caroline E. P. Robin**[4,3] **Ante Ravlić**[5] **Thomas Neff**[3]

[1]Helmholtz Forschungsakademie Hessen für FAIR. [2]Technische Universität Darmstadt.
[3]GSI Helmholtzzentrum für Schwerionenforschung. [4]Fakultät für Physik, Universität Bielefeld.
[5]Facility for Rare Isotope Beams, Michigan State University.

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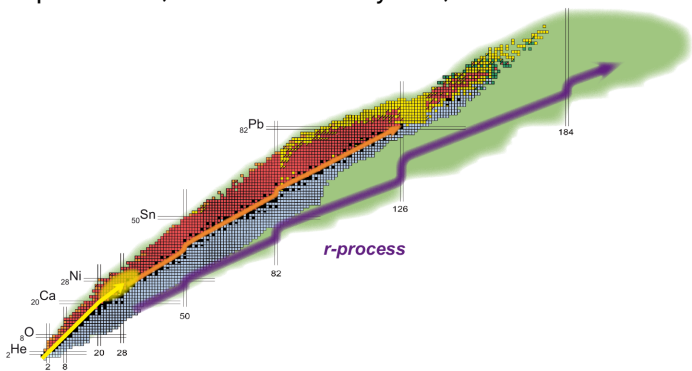
The r-process.

- Astrophysical environment should provide enough neutrons per seed
- Path not fully accessible to experiments → theoretical predictions
- Inputs: β-decay half-lives, neutron-capture rates, fission rates and yields, …

Determine the nuclear timescale for the r-process: competition with expansion timescale.



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β-decay rates of r-process nuclei.

g.s.

$$(Z,N) \xrightarrow{\beta^-} (Z+1,N-1) \; + \; e^- + \bar{\nu}_e$$

L, J, S:

$J_i^{\pi_i}$ $\qquad$ $J_f^{\pi_i}$

$L = 0$: allowed (GT: $\Delta S = 1$)

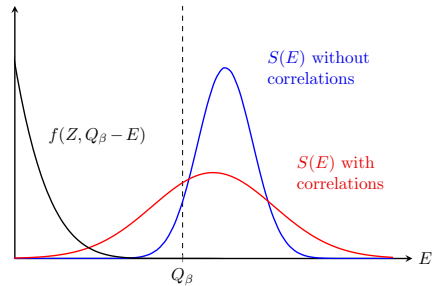
$L > 0$: forbidden (FF: $L = 1$, $\pi_i \neq \pi_f$)

- Allowed decays (GT):

$$\lambda = \frac{\ln 2}{T_{1/2}} \propto \int^{Q_\beta} f(Z, Q_\beta - E) S(E) dE$$

$$S(E) = \sum_f |\langle f|\hat{F}|i\rangle|^2 \delta(E - E_f + E_i)$$

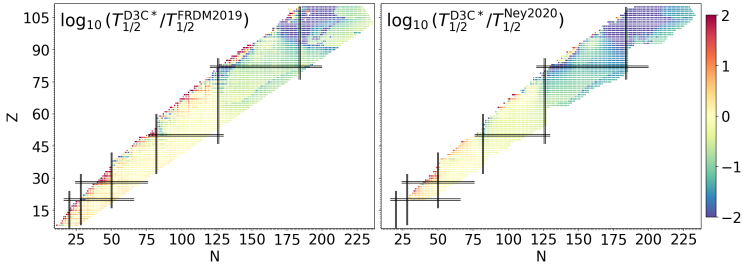
- Correlations relevant to the low-lying strength.

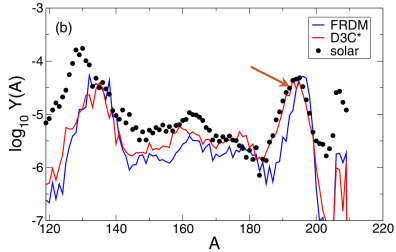


Global β-decay calculations within QRPA.

- **FRDM** + gross theory for FF[1]
- relativistic spherical approach with **D3C*** [2]

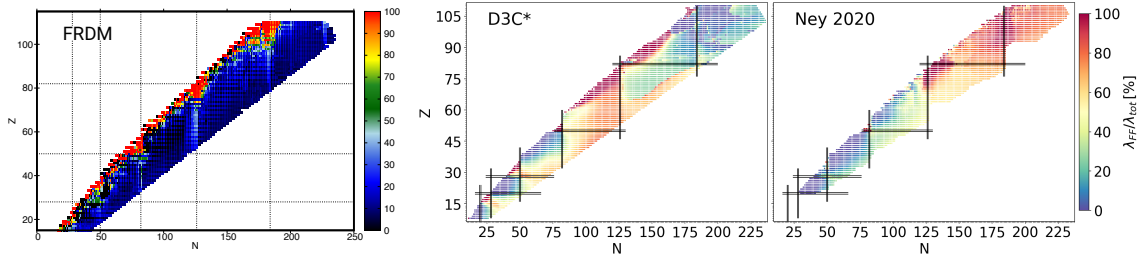
  shorter half-lives for $N > 126 \Rightarrow$ shift of the third abundance peak ($A \sim 195$)
- non-relativistic deformed approach with SKO' (**Ney 2020**)[3]





[1] P. Möller et al., Phys. Rev. C **67**, 055802 (2003), P. Möller et al., Atomic Data and Nuclear Data Tables **125**, 1–192 (2019).
[2] T. Marketin et al., Phys. Rev. C **93**, 025805 (2016), M. Eichler et al., The Astrophysical Journal **808**, 30 (2015).
[3] E. M. Ney et al., Phys. Rev. C **102**, 034326 (2020).

Global β-decay calculations within QRPA.



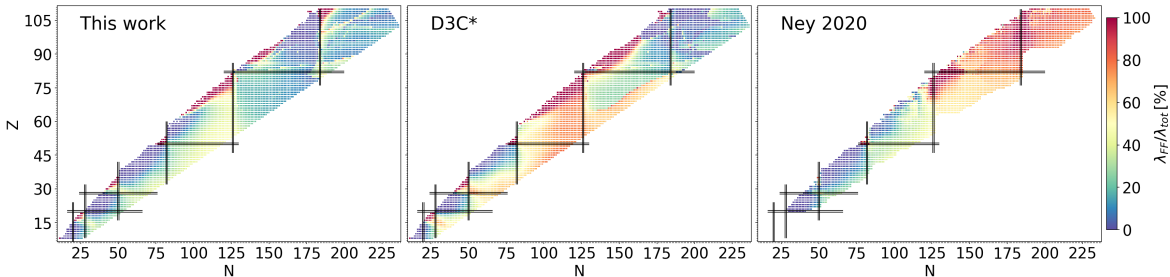
Very different predictions of the FF contribution to the rates

[4] P. Möller et al., Phys. Rev. C **67**, 055802 (2003), P. Möller et al., Atomic Data and Nuclear Data Tables **125**, 1–192 (2019).
[5] T. Marketin et al., Phys. Rev. C **93**, 025805 (2016).
[6] E. M. Ney et al., Phys. Rev. C **102**, 034326 (2020).

Global β-decay calculations within QRPA.

FF contribution to the rates

$\rightarrow$ After some recent corrections to the code for the RMF approach with **D3C*** functional[7]



[7] C. E. P. Robin and G. Martínez-Pinedo, arXiv:2403.17115 (2024).

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Global β-decay calculations within QRPA.

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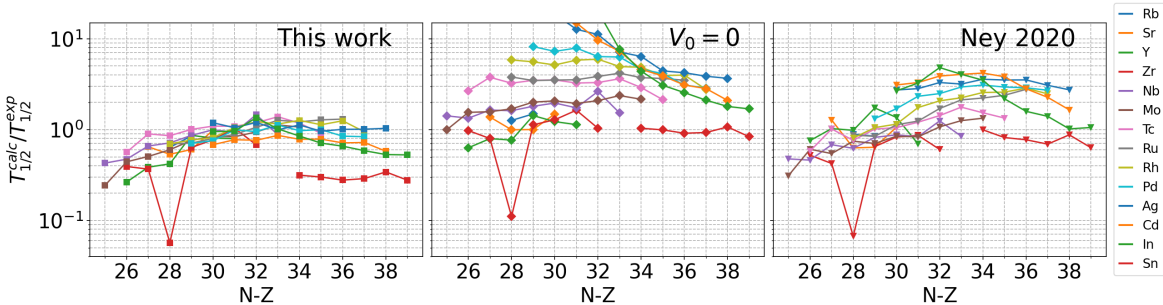
Sensitivity to isoscalar pairing strength (V_0) and comparison with experiment[8]

- For constant V_0, the effect along one chain depends on the single particle states being filled.

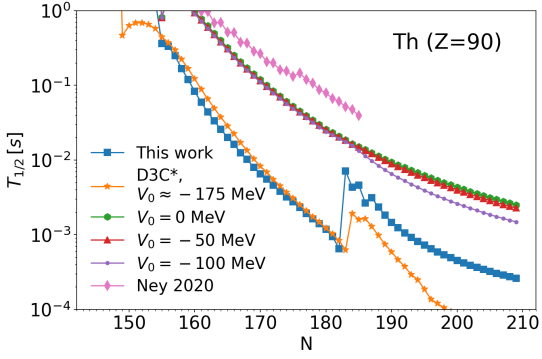


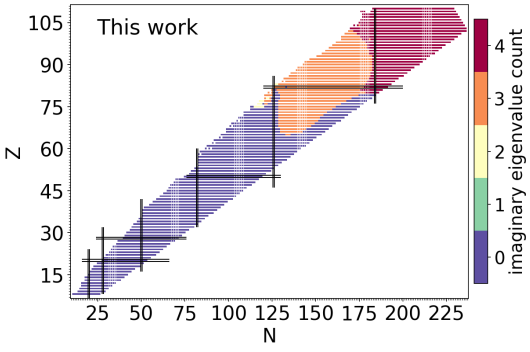
Within QRPA scheme, the inclusion of V_0 is needed.

[8] G. Lorusso et al., Phys. Rev. Lett. **114**, 192501 (2015).

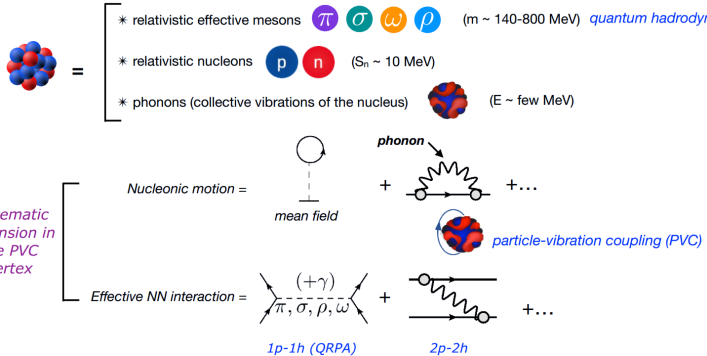
Global β-decay calculations within QRPA.

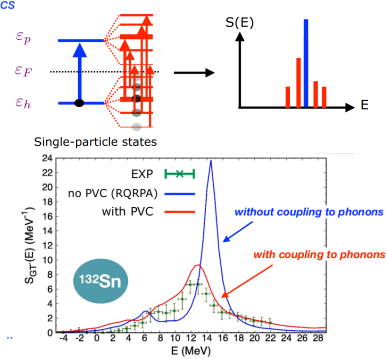
- Large V_0 values can produce problems in the QRPA when moving to the heavy and superheavy region $\rightarrow$ need better prescription for V_0 $\rightarrow$ missing correlations.





Extensions: proton-neutron pairing[9]

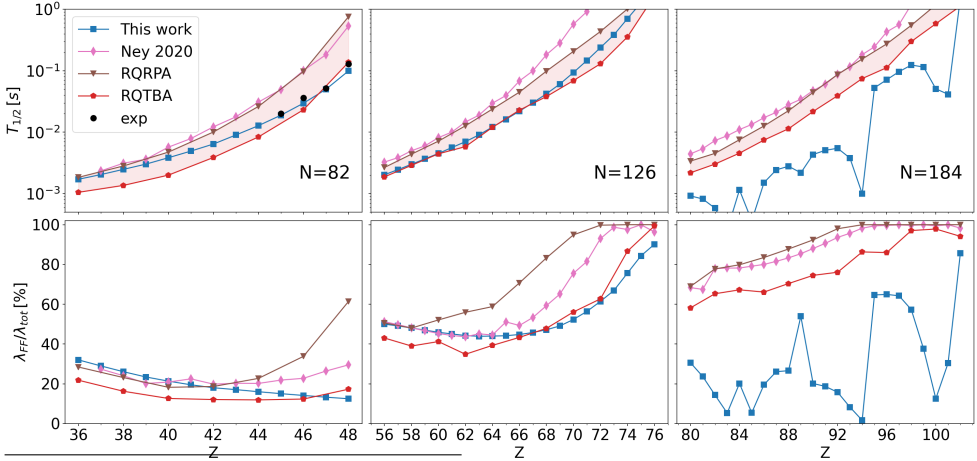




- No adjustable proton-neutron pairing.
- So far limited to spherical systems.

[9] C. Robin and E. Litvinova, Phys. Rev. C **98**, 051301 (2018), C. Robin and E. Litvinova, European Physical Journal A **52**, 205 (2016).

Extensions: proton-neutron pairing.[10]



[10] C. E. P. Robin and G. Martínez-Pinedo, arXiv:2403.17115 (2024).

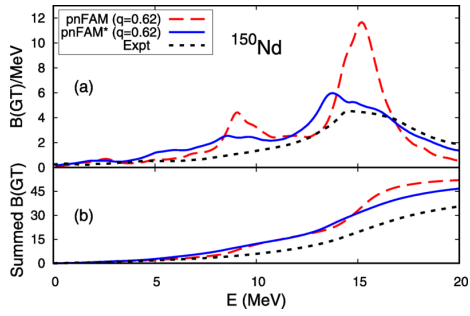
Extensions: proton-neutron pairing and deformation.

Procedure:[11,12]

- Extract phonon vertices from like-particle FAM-QRPA[13] for all multipole excitations
- Add the vertices to the deformed β-decay calculation[14] (in collaboration with A. Ravlić)

In progress

Effects on the GT strength[2]



[11] E. Litvinova and Y. Zhang, Phys. Rev. C **104**, 044303 (2021), Y. Zhang et al., Phys. Rev. C **105**, 044326 (2022).
[12] Q. Liu et al., Phys. Rev. C **109**, 044308 (2024).
[13] A. Bjelčić and T. Nikšić, Computer Physics Communications **287**, 108689 (2023).
[14] A. Ravlić et al., Phys. Rev. C **110**, 024323 (2024).

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Summary and outlook.

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- Towards improvement of global β-decay rates calculations within relativistic description taking into account the particle-vibration coupling and deformation of the nuclei.
- At QRPA level:
  - Corrections and update of previous relativistic QRPA β-decay rates calculation *(in progress)*.
  - Need a prescription for the isoscalar pairing strength that does not introduce artefacts.
- Beyond QRPA:
  - Inclusion of the phonons reduces the half-lives, bringing them closer to the experiment without the need for adjustable proton-neutron pairing.
  - Calculation of the deformed like-particle phonon matrices and implementation in the deformed β-decay code *(in progress)*

Thank you for your attention!