Beta-decay of very neutron-rich nuclei in N=126 region

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Continuum QRPA framework
based
on the self-consistent g.s. from EDF theory.

DF+CQRPA

A quest for spin-current part of (universal) NDF

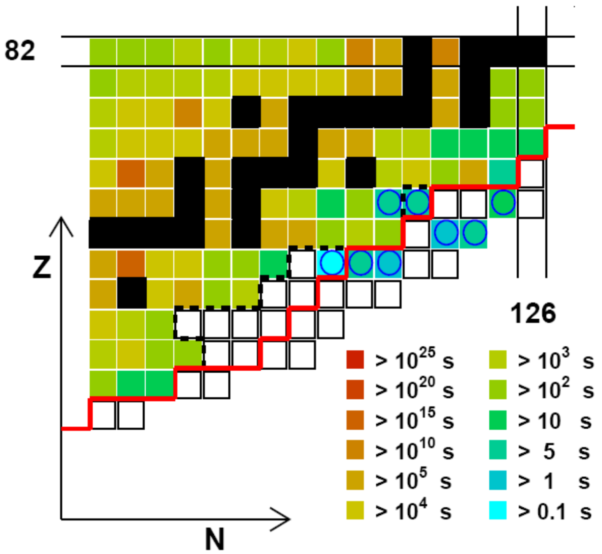
Nuclear structure at the limit of a high (N-Z).

Important applications:

- ☐ RNB experiments on beta-decay of short-lived neutron-rich nuclei.
- ☐ Astrophysical R-process modeling (masses, beta-rates, (n,γ)- rates…).
- ☐ Accelerator Driven Systems (1GeV p + 208Pb and 238U targets).

GSI experiments near N=126

The experimental technique used for the production of heavy neutron-rich nuclei was the in-flight fragmentation of relativistic heavy projectiles. In these collisions, the fragmentation process can populate a reaction channel refered to as 'cold fragmentation', where only protons are removed from the projectile and the excitation energy of the resulting projectile pre-fragment is so low that no neutron evaporation follows fragmentation. When using a ^{208}Pb beam, this reaction mechanism allows to produce heavy neutron-rich nuclei along the closed shell N=126.



GSI 2007
8 nuclides: 75 Re, 76 Os, 77 Ir …

Colour scale: the known half-lives (NuBase).

Circles: T. Kurtukian-Nietto , J.Benlliure et al. Nucl-exp.0711.0101v1.
Empty boxes: identified with no half-life information.

GSI 2010
213Tl , 221,222 Po, 224At, 236Ac

L. Chen et al. Nucl-exp.0110.
Identified with the half-life information

Large-scale explorations of the nuclear mass-surface and beta-decay " landscape".

Gamow-Teller vs first-forbidden decays near closed shell N=126

EDF. Self-Consistent Ground State

$$E_{Kohn-Sham}[\rho,\nu] = Tr\left(\frac{p^2}{2M}\rho\right) + E_{\text{int}}[\rho,\nu]$$

$$E_{\text{int}} = \sum_{main,Coul,sl} \varepsilon_n[\rho] + \frac{1}{2}\,\nu^*\;F^{\xi}[\rho]\nu$$

$$"main" \propto volume + fin.range\ surface$$

$$F^{\xi} \propto volume + surface$$

$$H = \begin{pmatrix} h-\mu & -\Delta \\ -\Delta & \mu-h \end{pmatrix}$$

$$h = \frac{p^2}{2m} + \frac{\delta E}{\delta\rho} \sim \rho$$

$$\Delta = \frac{\delta E_{\text{int}}}{\delta\nu}$$

$$\rho_0,\nu_0 \Rightarrow h_0,\Delta_0 \Rightarrow \rho_1,\nu_1 \Rightarrow h_1,\Delta_1$$

- Energy Density functional

S.A. Fayans, S.V. Tolokonnikov,E.Trykov, D. Zawischa, Nucl.Phys. A676 (2000) 49.
I.N. Borzov, S.A. Fayans, E. Kromer, D. Zawischa Z. Phys. A335(1996) 117

- DF3

Fenomenological (local) energy-density functional by **S.A. Fayans** et al.,
δ-function + density dependent (volume+surface) pairing.

Fitted to the g.s. properties of very neutron-rich nuclei near “magic cross” Z=50/N=82 at ^{132}Sn.

CQRPA. Effective spin-isospin NN-interaction

$$F^{\omega}_{\tau\tau} = \frac{\delta^2 E}{\delta\rho^{\tau}\delta\rho^{\tau}} \qquad F^{\xi}_{\tau\tau} = \frac{\delta^2 E}{\delta\nu^{\tau}\delta\nu^{\tau}}$$

The ground state properties are less sensitive to spin-isospin components of EDF.
The spin-isospin (time odd) parts of the effective NN-interaction can be defined independently of the scalar (time-even) parts.

***Continuum QRPA* based on the self-consistent ground state.**

Universal effective NN-interaction (A-independent).
Universal quenching $e_q^2=(0.9)^2$ ***(A, E-independent).***

T=1, ph

T=0, pp

$$F^{\omega}_{\tau\tau} \propto g'_{LM}\delta_{r-r'} + \pi + \rho \qquad F^{\xi}_{\tau\tau} \propto g'_{pp}\delta_{r-r'}$$

Q_β – values: maximal beta-decay energy releases

Accurate description of the Q_β-values is crucial for beta-decay studies.
Q_β is correlated with the qp-energies, as both are obtained from the same DF framework.

DFs with m*/M~1 reproduce Q_β–values well enough :

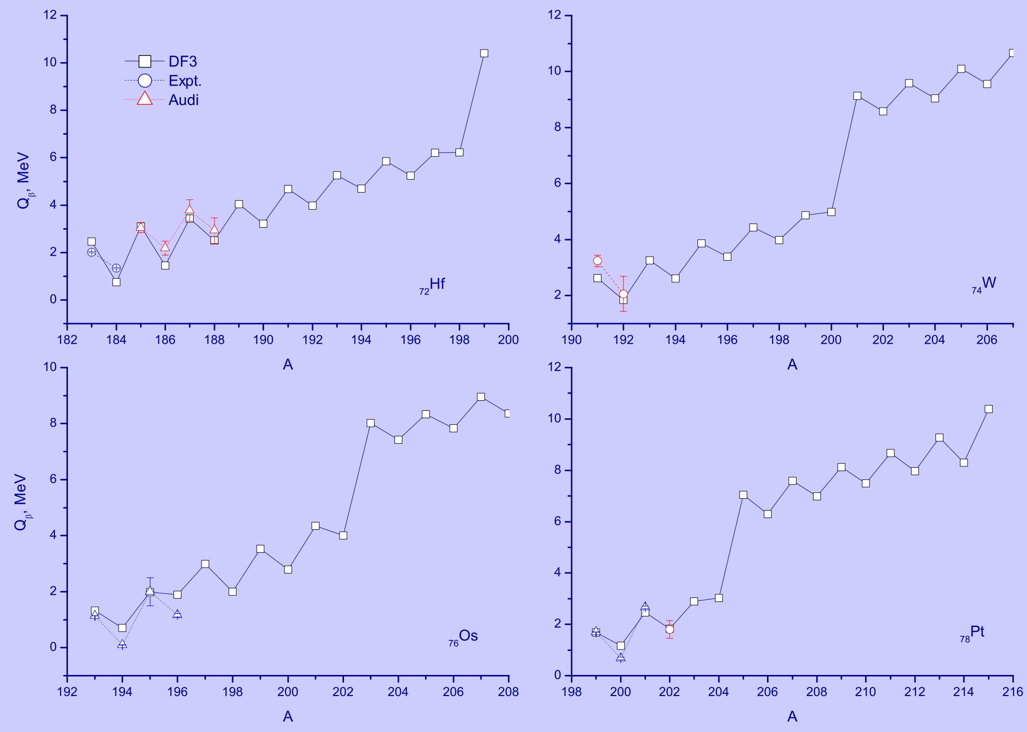
For N=82

Typical deviation from the data is 0.5 - 1.5 MeV

For N=126

Deviation is 0.5 - 0.6 MeV

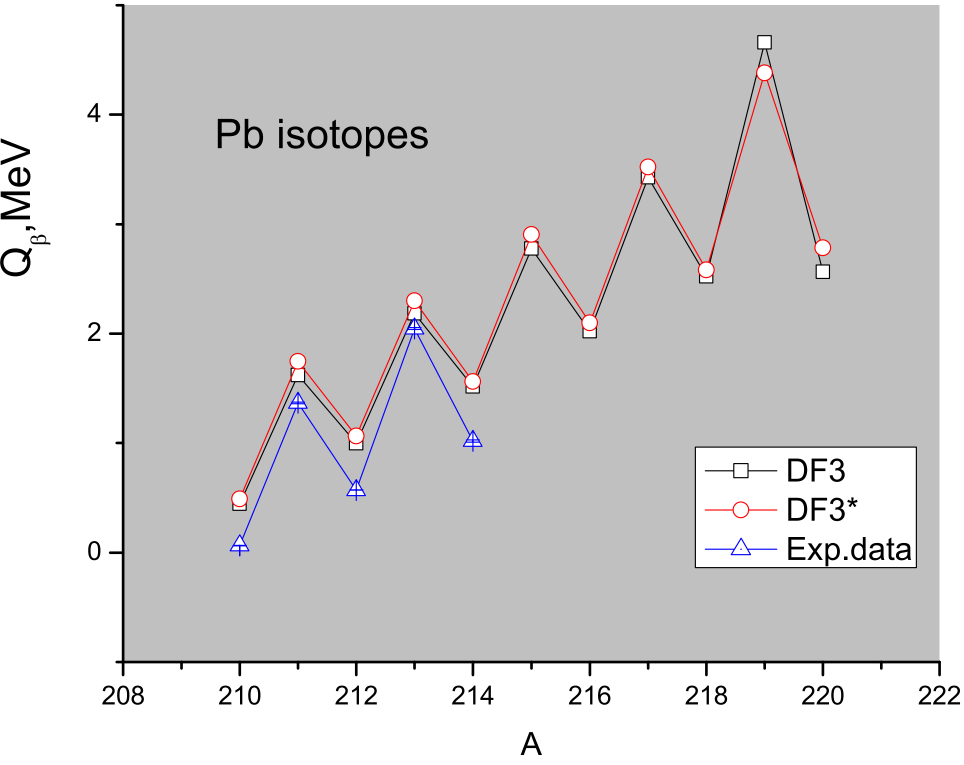
(Recent RDFs underestimate the phase-space, overshooting T1/2)

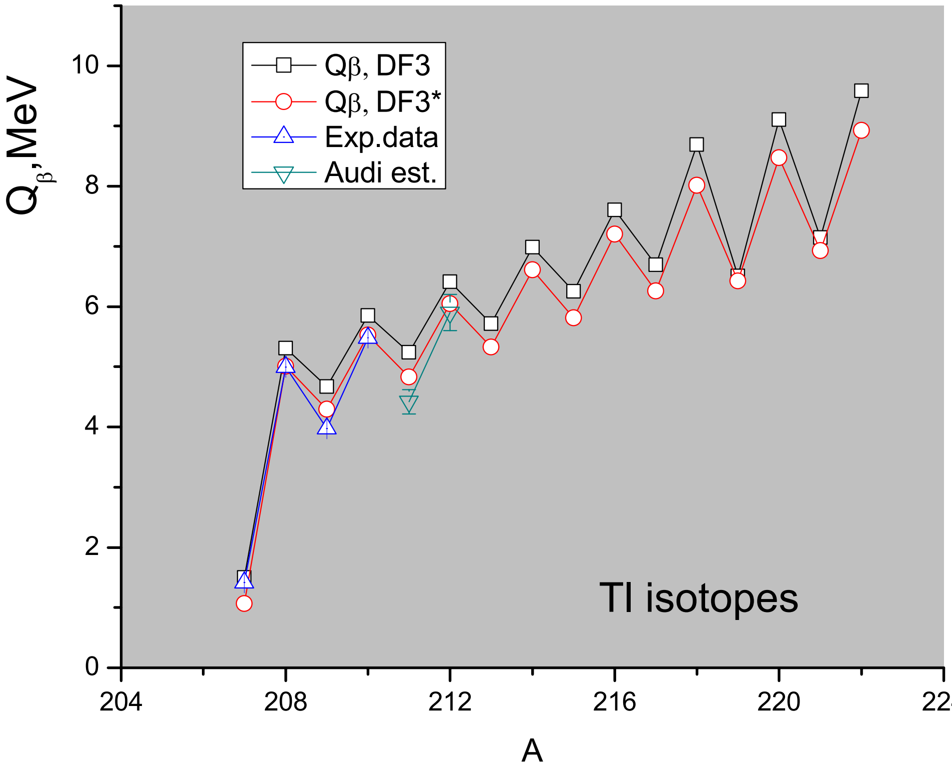


Extended mass measurements at N=126 are of high value for improving the DF

Possible improvements: ***Spin-orbital part of the Df3***

Example: Qbeta-values sensitivity to the velocity dependent interaction ($g1_{np}$)

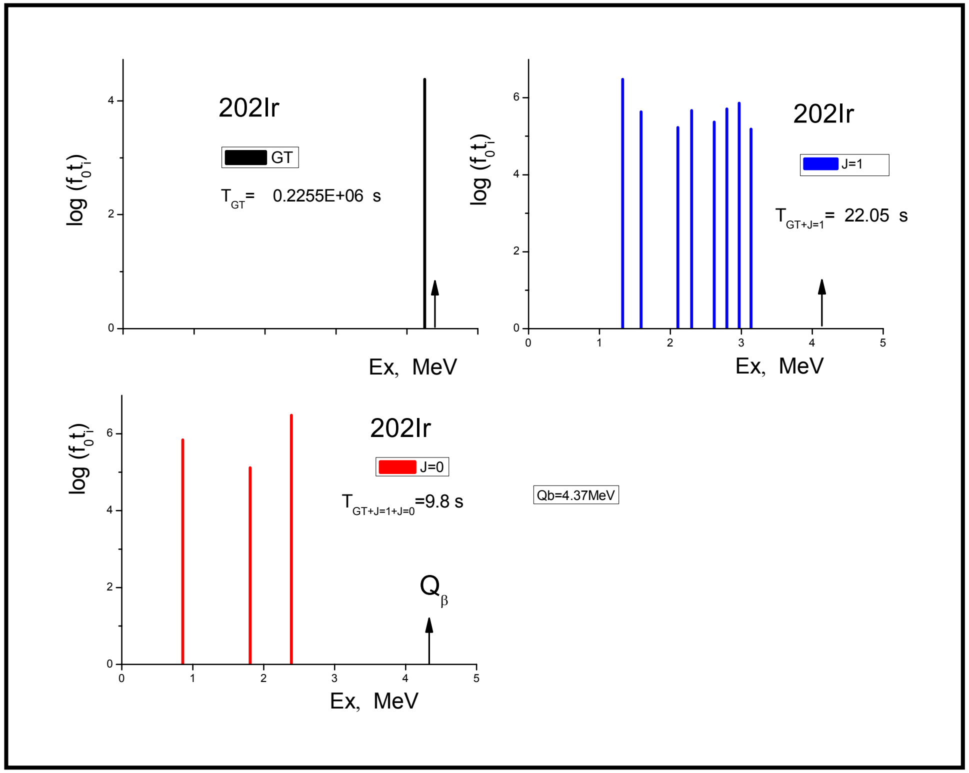




Spin-orbital splitting needs re-adjustment in a wide A-region (especially for the nuclei with high spin-orbital density , Z=80-90 region)

The GT and FF strength-functions are calculated within the single DF3+CQRPA framework

GT
n1h9/2→p1h11/2



FF
n1i13/2→p1h11/2

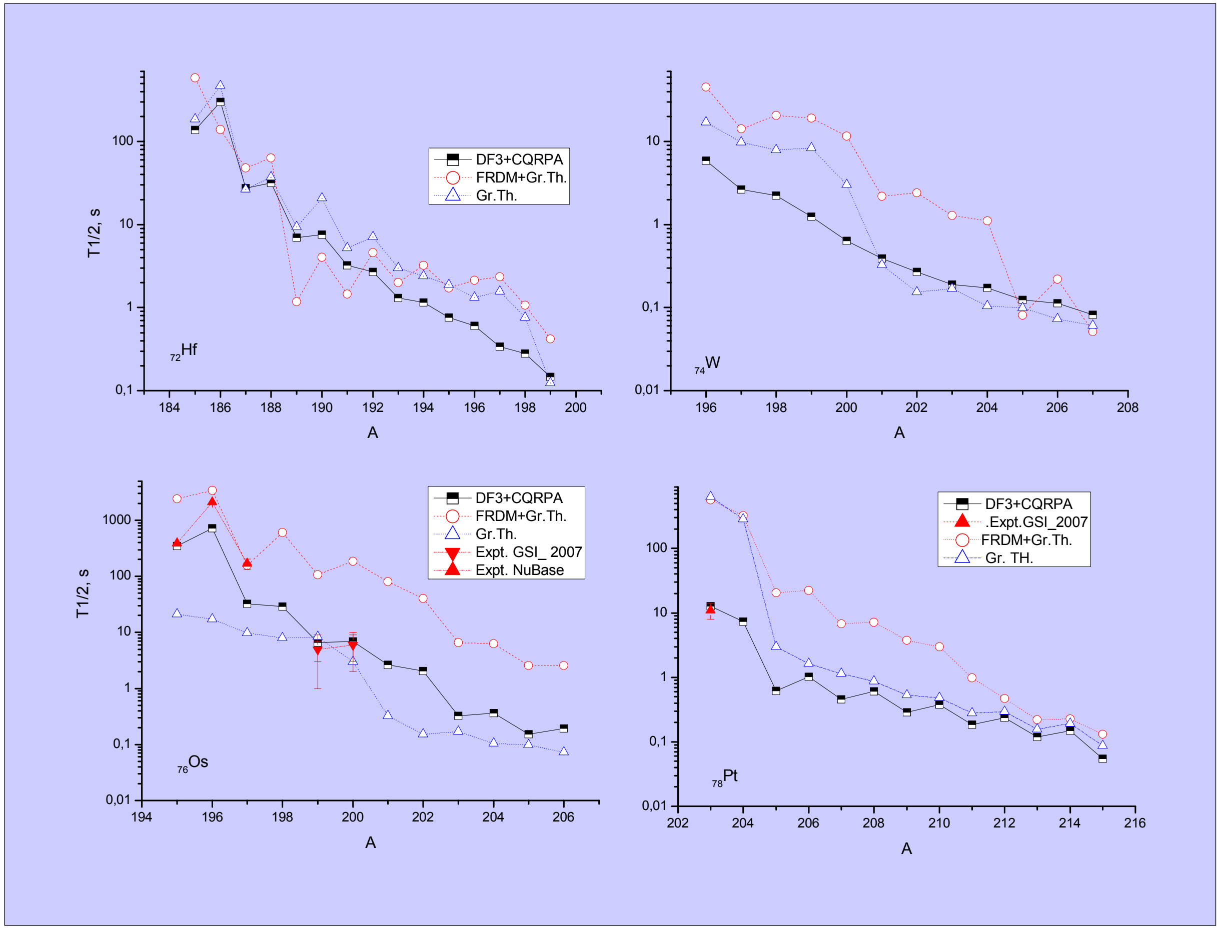
n3p3/2→ p3d3/2
n3p1/2→ p3s1/2

The GT decays are retarded by

- the low “phase-space” factors f(Qb-Ex)
- high occupancy factor of the 1ph11/2 orbital.

The high-energy FF decays compete with the low transition energy GT decays.

72Hf - 78Pt.



Half-lives approaching N=126

Typical deviation from the exp. data

FRDM = 30

DF3 = 1 - 2

A,Z	T1/2 (s)	DF3	FRDM
199Os	5 +4-2	6.6	106.8
200Os	6+4-3	6.9	187.1

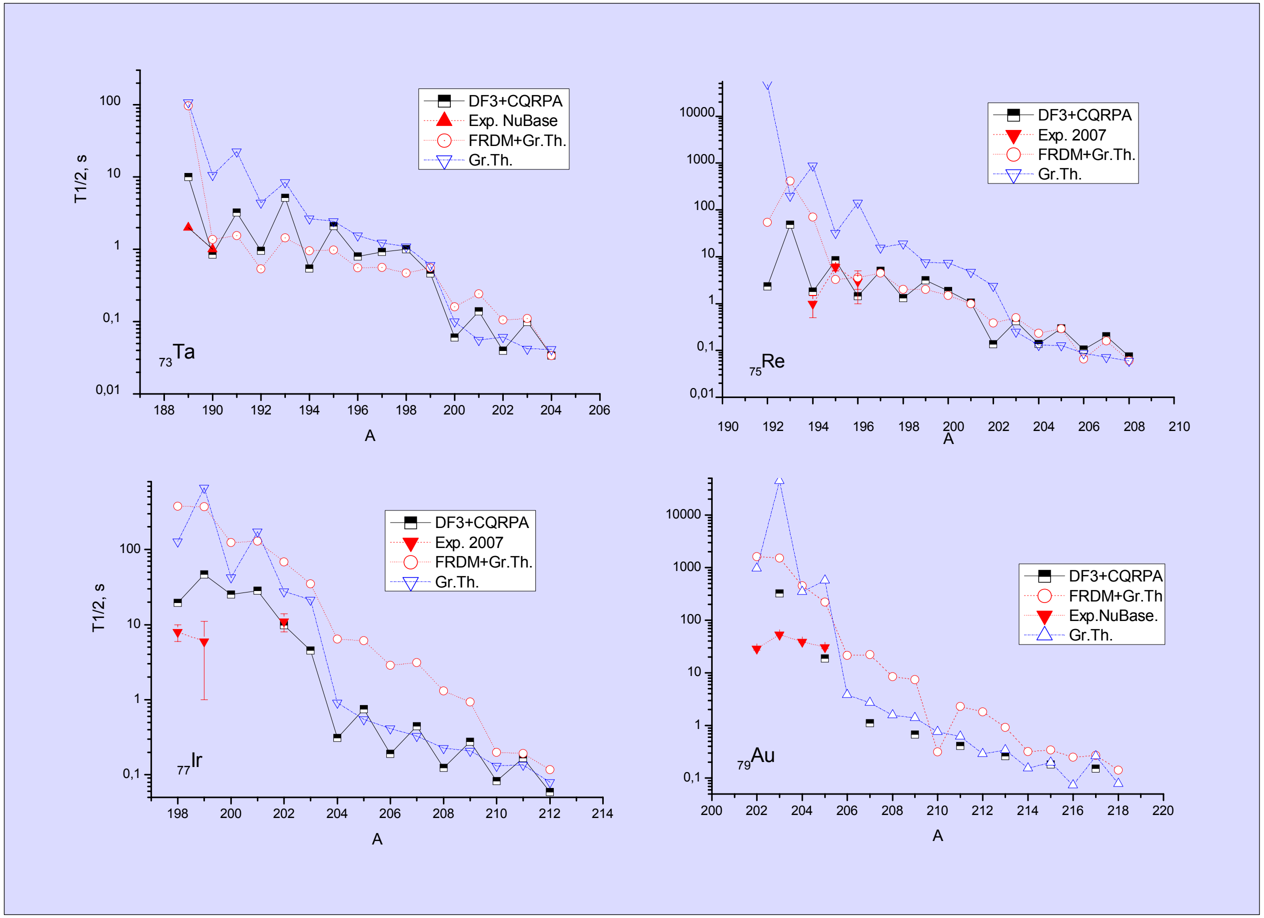
New GSI FRS-ESR campaigns

TRIAC, KEK Japan, Proposal 09

These Proposals are aimed to pin down the r-process waiting point nuclei

198Hf, 200W, 202Os, 204Pt

73Ta - 79Au.



Half-lives of odd-Z nuclides approaching N=126

Typical deviation from the exp. data

FRDM = up to 70

DF3 = up to 8

A,Z	**T1/2 (s)**	**DF3**	**FRDM**
194Re	**1 +- 0.5**	**2.1**	**70.8**
195Re	**6+-1**	**8.5**	**3.3**
196Re	**3+1-2**	**1.4**	**3.6**

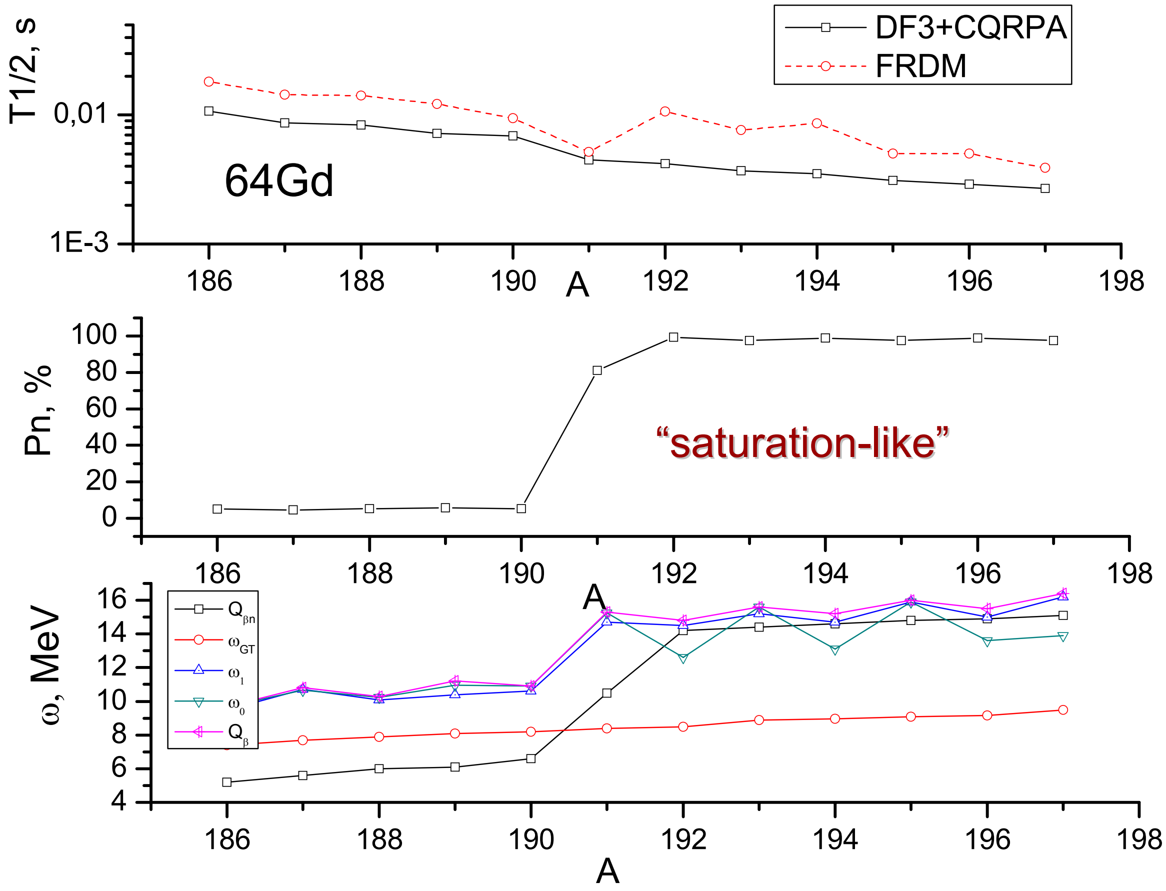
205Au

Exp. 31+/- 2 (s)

FRDM = 221,0 s (7)

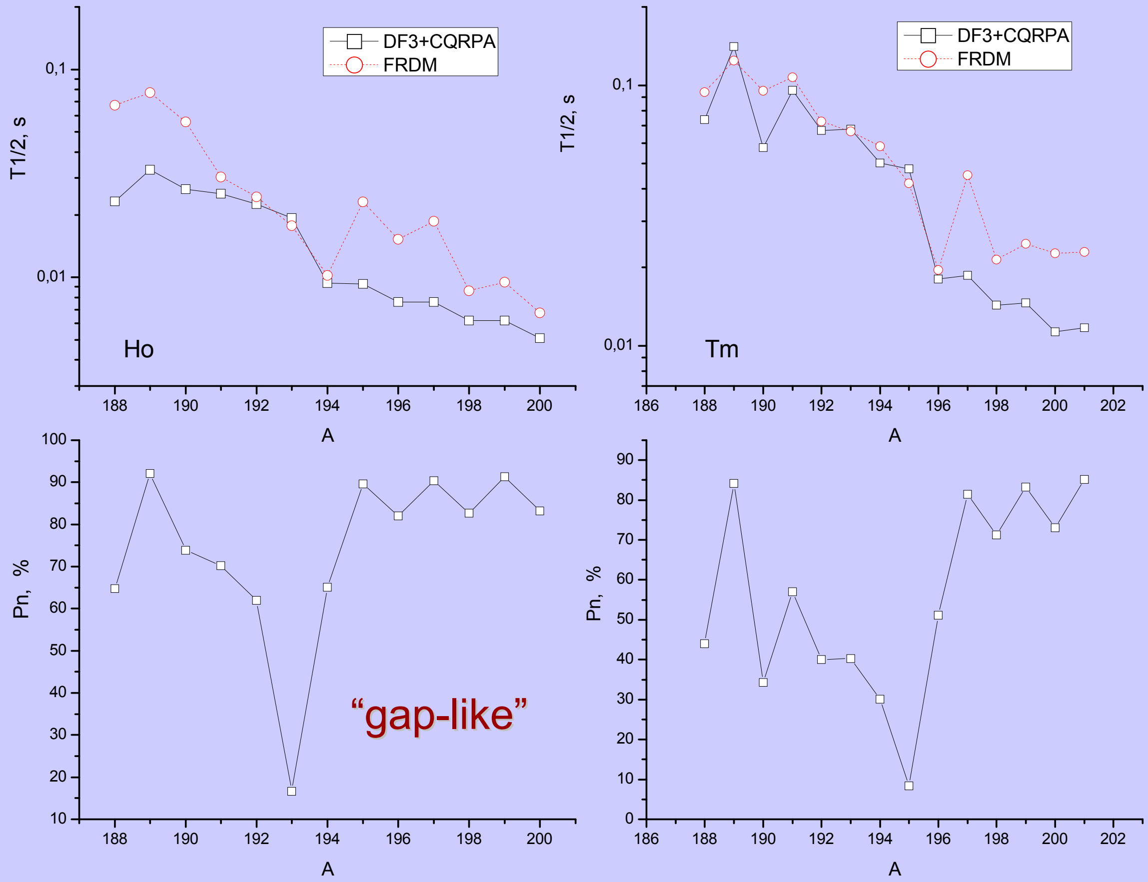
DF3 = 18.7 s (1.6)

64Gd isotopes near N=126.



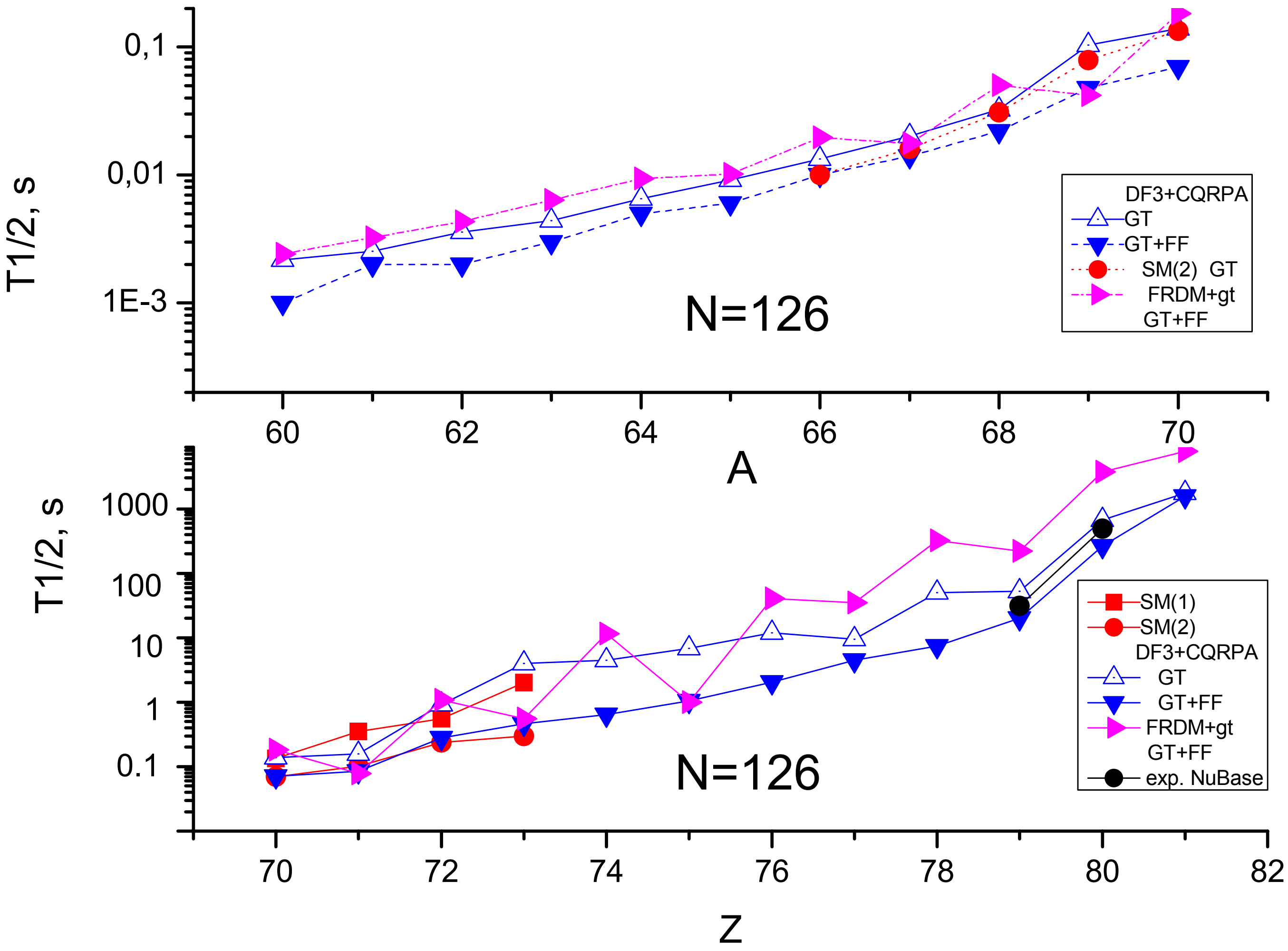
67Ho,69Tm isotopes near N=126.

Z=67, 69, N ~ 126



“gap-like”

N=126 waiting point nuclei

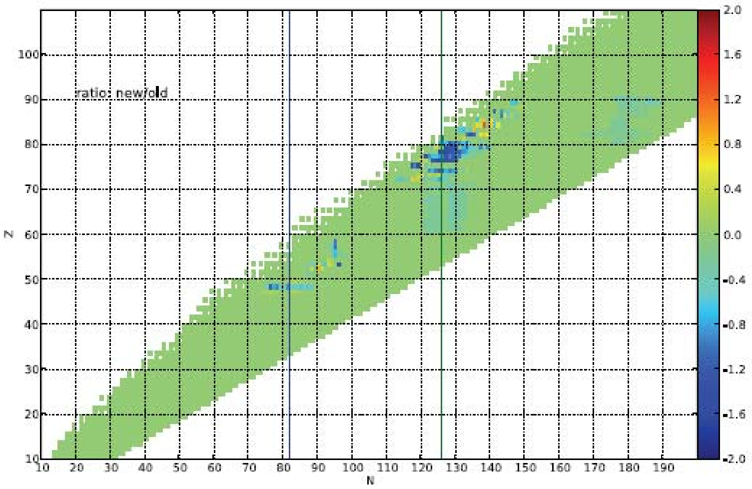


Impact of the half-lives on R-process abundances at N=126

(A.Arcones e.a. 2010)

FRDM half-lives were replaced by the DF3 ones for the nuclides near N=126 only.

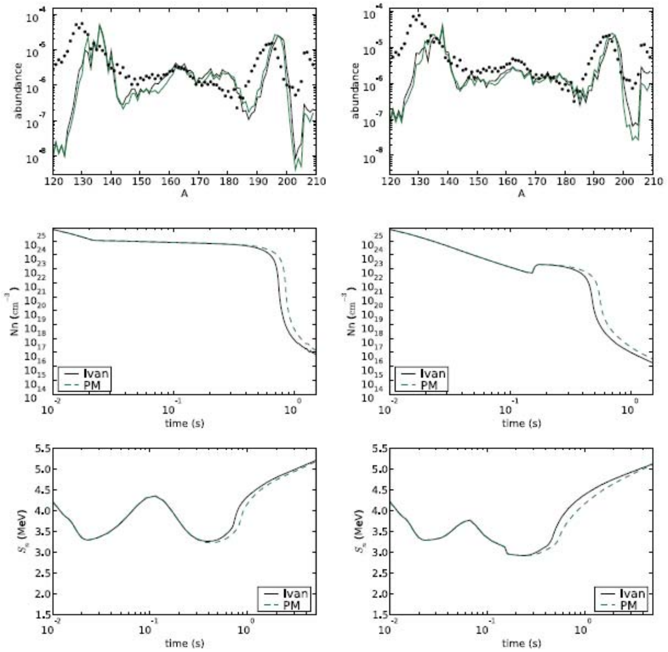
Changes the abundances near the third peak (A~195) and for fissioning nuclei



The colors represent $\log(t_{1/2}(I)/t_{1/2}(PM))$. One can easily see which rates are updated.

Hot

Cold r-process



The main effect occurs at N=126, where the new half-lives are smaller. This produces a faster evolution after reaching this region and it is visible in the figure of the average neutron separation. We have identified the minima of Sn with the moments when the path reaches N=82 and 126. Since the evolution is faster neutrons are consumed more rapidly and neutron density starts to drop early. Therefore, this could have some consequence for the freeze-out.

I. Summary (Beta-decay)

- Global calculations of the β-decay half-lives.
  Systematic studies in a wide (Z=15 – 92) region:
  Table I. Spherical nuclei. Used for new experiments
  at GSI, KEK, HRIBF

- GT decay dominates for Z~ 28, 50 for $N<N_{mag}=50, 82$
  Competition of GT and high-energy FF decays
  for heavier Z = 60 - 82 , N approaching Nmag=126.

- Signatures of the GT/FF competition: “saturation-like” and
  “saw-like’ patterns in Pn(A) behavior.

- The shorter half-lives make evolution faster , break through
  the N=126 waiting points faster. The matter flow to heavier
  (fissioning) nuclei should be also faster in DF3+CQPRA.

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Acknowledgments

Partially supported by DFG

Discussions are acknowledged with

K. Schmidt *GSI, Darmstadt*
J. Benlluire *USC, Santiago de Compostella*
K. Rykaczewski*, HRIBF, Oak Ridge*

thanks to
Yu. Litvinov (*GSI*)
H. Ishiyama (*TRIAC, KEK Japan)*
N. Costiris, (*PYTHAIM Collaboration*)
for their interest in DF+CQRPA results

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I.N.B, K. Langanke, G. Martinez-Pinedo, F. Montes Nucl.Phys. A814,159,2008
J.A.Winger … INB et al., HRIBF Collaboration Phys.ReV.Lett 102 (2009) 142502
T.Kurtukian-Nietto, J.Benlluire, .INB…et al.GSI Collaboration. nucl-ex 0711.0101v1, (→Phys.Lett B, 2010)