Isomerism and Nuclear Structure of Heavy Elements

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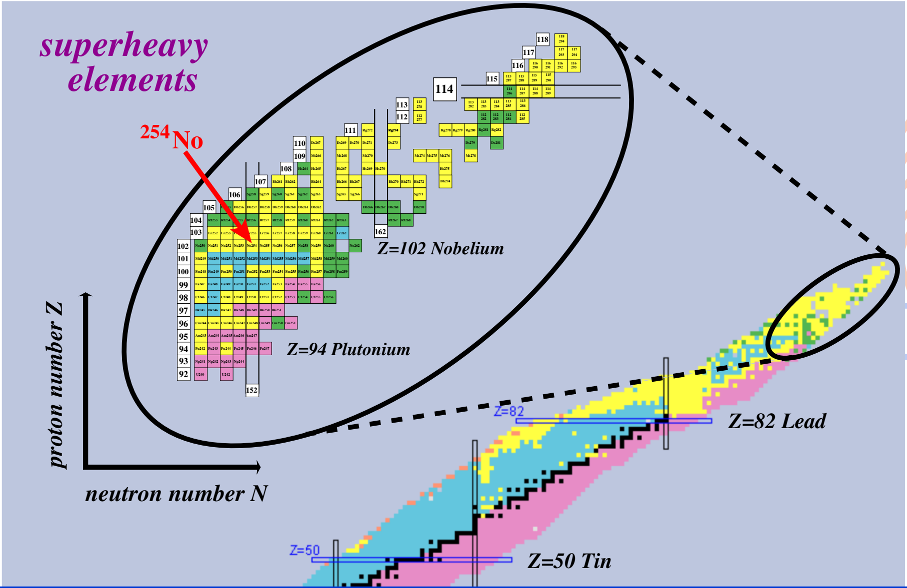
Collaborators

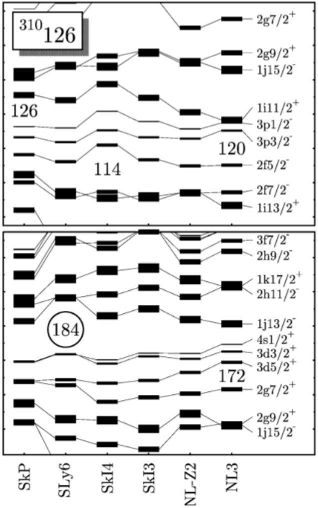
Shapes and Symmetries in Nuclei: from Experiment to Theory
6.-11.10.2017
Saclay, France

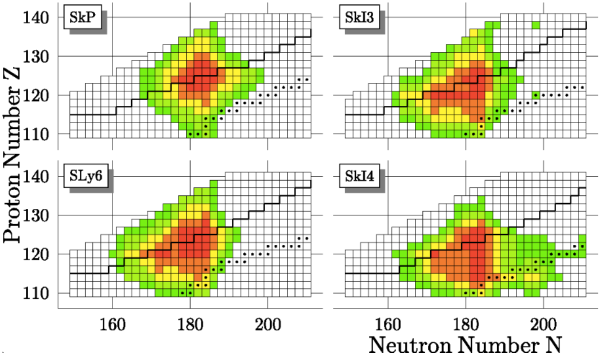
Outline

Superheavy Elements - Current Status



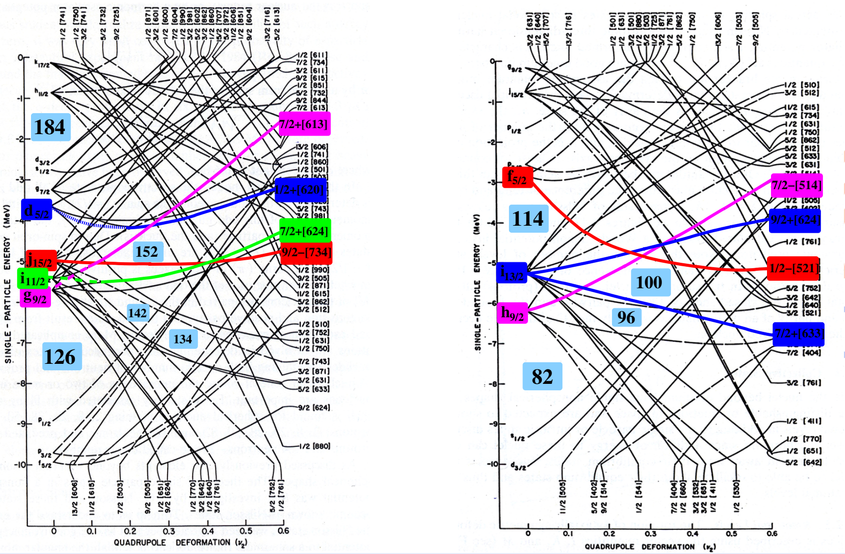
SHE - Shell Correction and Single-Particle Levels





M. Bender, W. Nazarewicz, P.-G. Reinhard, PLB **515**, 42 (2001)

Single-Particle Orbitals in Region of ^{254}No



R.R. Chasman et al., Rev. Mod. Phys. 49, 833 (1977)

K-Isomerism in ^{254}No and ^{250}Fm

PHYSICAL REVIEW C VOLUME 7, NUMBER 5 MAY 1973

Isomeric States in ^{250}Fm and ^{254}No†

Albert Ghiorso, Kari Eskola,* Pirkko Eskola,* and Matti Nurmia
Lawrence Berkeley Laboratory, University of California, Berkeley, California 94720
(Received 30 November 1972)

- Isomeric states in ^{254}No and ^{250}Fm first postulated by Ghiorso et al., PRC7 (1973) 2032
- *The transfer of the ^{250}Fm atoms from the wheel onto the movable detectors must then be caused by the feeble recoil resulting from the isomeric transition or other accompanying γ rays and conversion electrons in the cascade that leads to the ground state. For a 500 keV γ ray the recoil energy of a ^{250}Fm atom is about 0.5 eV.*

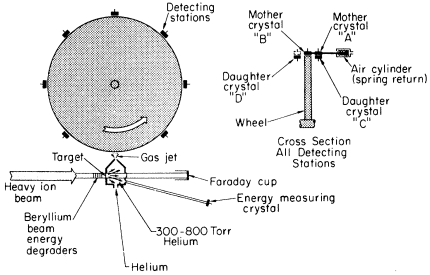
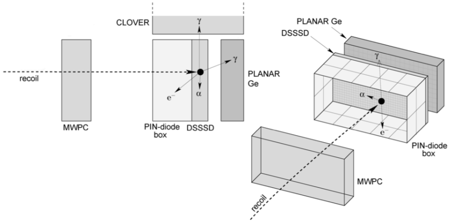


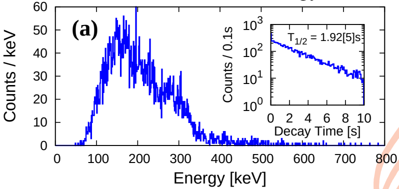
FIG. 1. A schematic diagram of the seven-detector-station system. The cross section at right shows the arrangement of the two movable mother detectors and the two stationary daughter detectors.

Studies of K-Isomerism - Calorimetric Method

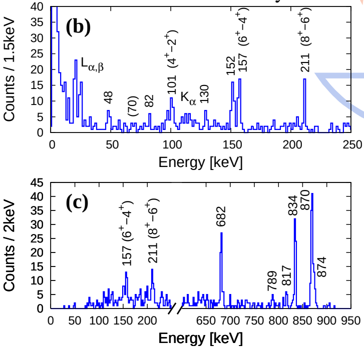
- Powerful method proposed by Jones, NIM A488 (2002) 471
- Low-energy transitions highly converted, look for Recoil-electron-α correlated chains in DSSSD
- Information on pairing gap, Δ and single-particle energies, ϵ_i, ϵ_j
- $E = \sqrt{(\epsilon_i - \lambda)^2 + \Delta^2} + \sqrt{(\epsilon_j - \lambda)^2 + \Delta^2}$



Correlated Electron Energy

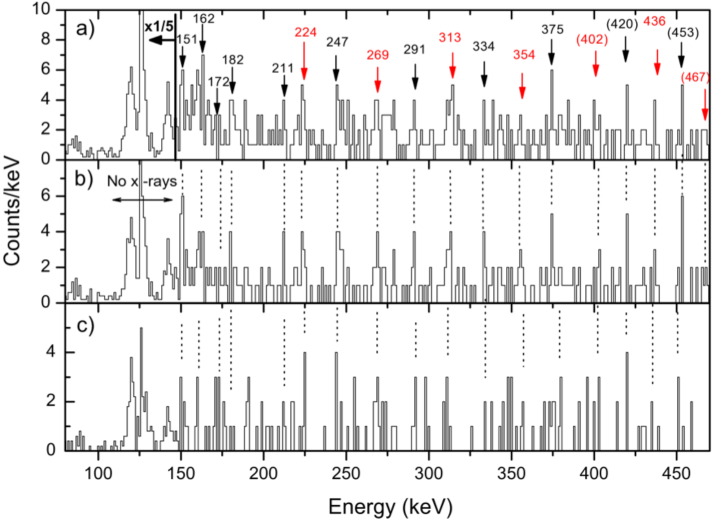


Focal Plane Gamma Rays



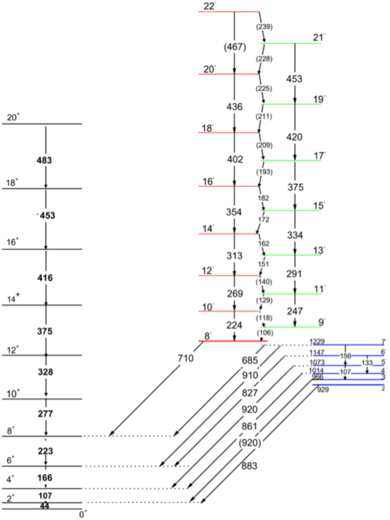
K-Isomerism in ^{252}No

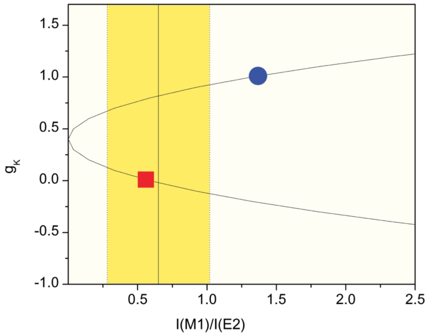
^{48}Ca + ^{206}Pb $\Rightarrow$ ^{252}No + 2n JUROGAM/RITU/GREAT B.Sulignano et al., PRC , 044318 (2012)



K-Isomerism in ^{252}No

B.Sulignano et al., PRC , 044318 (2012)

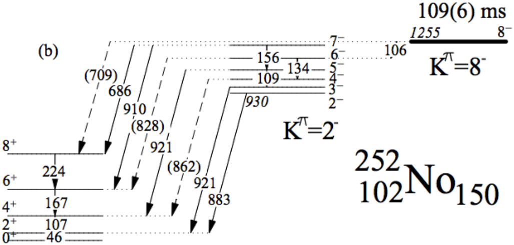


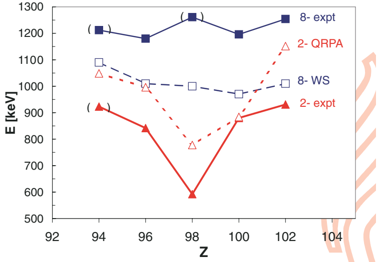


Configuration Assignment:

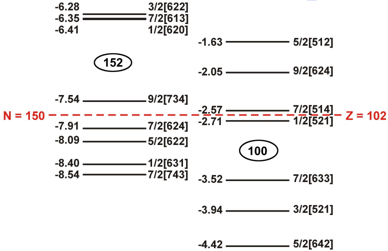
8^- - $\nu[624]7/2^+ \otimes \nu[734]9/2^-$

Systematics of 2 quasi-particle states: N=150



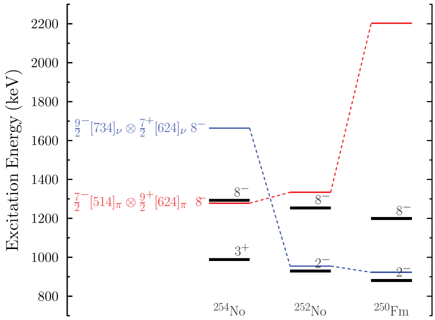


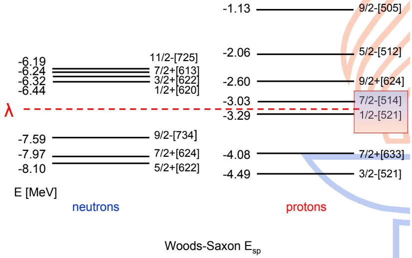
A.Robinson et al., PRC **78**, 034308 (2008)
B.Sulignano et al., PRC , 044318 (2012)



Systematics of 2 quasi-particle states: N=150/152

N=150/152: P.T.Greenlees et al., PRC **78**, 021303(R) (2008)
N=152: R.-D. Herzberg et al., Nature **442**, 896-899 (2006)





Systematics of 2 quasi-particle states: N=152, ^{254}No

R.-D. Herzberg et al., Nature **442**, 896-899 (2006)
S.K. Tandel et al., PRL **97**, 082502 (2006)
F.P. Hessberger et al., EPJA **43**, 55 (2010)

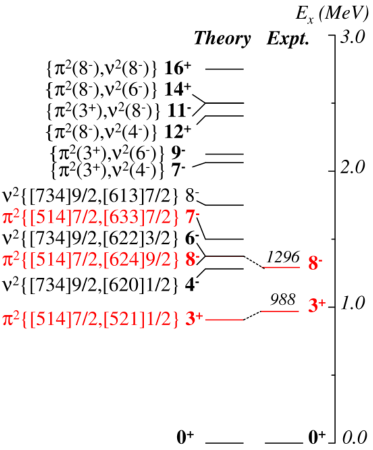
Assigned Configurations:

3^+ - ($\pi[514]7/2^- \otimes \pi[521]1/2^-$)
8^- - ($\pi[514]7/2^- \otimes \pi[624]9/2^+$)
53keV E1 ΔK=5: f_ν = 804

R.M.Clark et al., PLB **690**, 19 (2010)

Assigned Configurations:

3^+ - ($\pi[514]7/2^- \otimes \pi[521]1/2^-$)
8^- - ($\nu[734]9/2^- \otimes \nu[624]7/2^+$)
or 8^- - ($\nu[734]9/2^- \otimes \nu[613]7/2^+$)
10^+ - ($\nu[734]9/2^- \otimes \nu[725]11/2^-$)
16^+ - ($\pi[514]7/2^- \otimes \pi[624]9/2^+$) +
($\nu[734]9/2^- \otimes \nu[613]7/2^+$)



S.K. Tandel et al., PRL **97**, 082502 (2006)

Systematics of 2 quasi-particle states: N=152, ^{256}Rf

H.B.Jeppesen et al., PRC **79**, 031303(R) (2009)

Assigned Configurations:

Lowest isomer 2QP K=6,7
Second isomer 2QP K=10-12:
possibly 10^+ - $\nu[734]9/2^- \otimes \nu[725]11/2^-$
Highest isomer? - not discussed

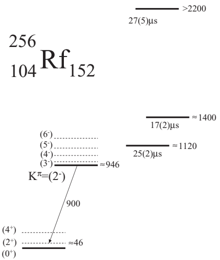


FIG. 3. Proposed decay scheme for ^{256}Rf. Energies are given in keV. Half-lives are written beneath each isomer.

J.Rissanen et al., PRC **88**, 044313 (2013)

(Re-) Assigned Configurations:

5^- - $(\pi[521]1/2^- \otimes \pi[624]9/2^+)$
8^- - $(\pi[514]7/2^- \otimes \pi[624]9/2^+)$

TABLE VII. Calculated 2-QP configurations for ^{256}Rf.

Configuration	K^π	$E_x^{calc.}$
$\pi^2(1/2^-[521] \otimes 9/2^+[624])$	5^-	1062
$\pi^2(7/2^-[514] \otimes 9/2^+[624])$	8^-	1102
$\pi^2(7/2^-[514] \otimes 5/2^-[512])$	3^+	1346
$\nu^2(9/2^-[734] \otimes 1/2^+[620])$	5^-	1350
$\nu^2(9/2^-[734] \otimes 7/2^+[613])$	8^-	1390
$\pi^2(7/2^+[514] \otimes 5/2^-[512])$	6^+	1411
$\pi^2(7/2^+[514] \otimes 1/2^+[521])$	4^+	1425
$\nu^2(9/2^-[734] \otimes 3/2^+[622])$	6^-	1446
$\nu^2(9/2^-[734] \otimes 11/2^-[725])$	10^+	1455
$\pi^2(9/2^+[624] \otimes 5/2^-[512])$	7^-	1507

Observation of 3 isomeric states confirmed JYFL

Interesting case: N=148 ^{250}No

Previous studies:

Oganessian DGFRS 2001

^{204}Pb(^{48}Ca,2n) $t_{1/2}$=46μs

^{206}Pb(^{48}Ca,4n) $t_{1/2}$=26μs

Belozerov VASSILISSA 2003

^{204}Pb(^{48}Ca,2n) $t_{1/2}$=5.9μs 42 events

^{206}Pb(^{48}Ca,4n) $t_{1/2}$=54μs 22 events (^{249}No?)

Possible isomeric state in ^{250}No

Peterson FMA 2006

Mass Selection

^{204}Pb(^{48}Ca,2n) A=250

$t_{1/2}$=3.7μs g.s.

$t_{1/2}$=43μs isomeric state

Assigned as 6^+ - ($\nu[622]5/2^- \otimes \nu[624]7/2^+$)

Direct fission or electromagnetic branch to g.s.?

D. Peterson et al., PRC **74**, 014316 (2006)

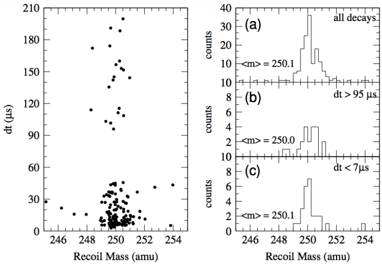


FIG. 3. Mass numbers of the residues associated with spontaneous fission decays. (Left panel) Decay time versus mass. (Right panels) Projections to the mass axis for all decays (a), purely long decays (b), and primarily short decays (c). See text and Table II for more details.

Latest study in JYFL (RITU + GREAT)

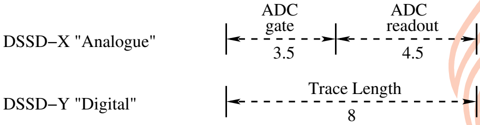
Experimental Details:

Spokespersons:
B. Sulignano (CEA), P.T. Greenlees (JYFL)

^{204}Pb(^{48}Ca,2n) E_{beam}=220 MeV
Typical I_{beam} $\simeq$100 pnA
Around 6 days beam on target

DSSD-Y (80 strips) "digital" electronics
DSSD-X (120 strips) "analogue" electronics
3 Clovers + Planar Ge
Low thresholds (80-100 keV)

Search for electromagnetic branch



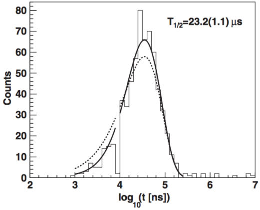
Signals separated by more than 8μs in different events
Pile-up marker in data for first 3.5μs of analogue
Traces cover "dead" readout period in analogue

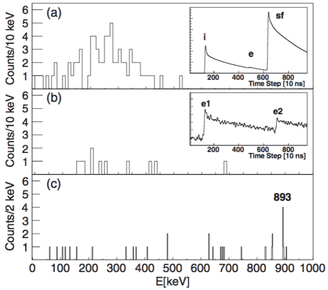
K-isomerism in ^{254}Rf

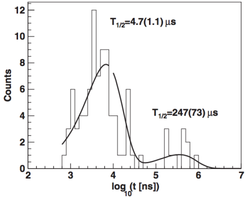
PRL 115, 132502 (2015) PHYSICAL REVIEW LETTERS week ending 25 SEPTEMBER 2015

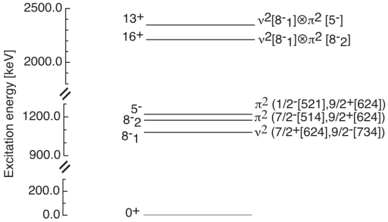
Decay and Fission Hindrance of Two- and Four-Quasiparticle *K* Isomers in ^{254}Rf

H. M. David,[1] J. Chen,[1,‡] D. Seweryniak,[1,†] F. G. Kondev,[1] J. M. Gates,[2] K. E. Gregorich,[2] I. Ahmad,[1] M. Albers,[1,§] M. Alcorta,[1,∥] B. B. Back,[1] B. Baartman,[2] P. F. Bertone,[1,¶] L. A. Bernstein,[3] C. M. Campbell,[2] M. P. Carpenter,[1] C. J. Chiara,[4,1] R. M. Clark,[2] M. Cromaz,[2] D. T. Doherty,[5,**] G. D. Dracoulis,[6,*] N. E. Esker,[2] P. Fallon,[2] O. R. Gothe,[2] J. P. Greene,[1] P. T. Greenlees,[7] D. J. Hartley,[8] K. Hauschild,[9] C. R. Hoffman,[1] S. S. Hota,[10,††] R. V. F. Janssens,[1] T. L. Khoo,[1] J. Konki,[7] J. T. Kwarsick,[2] T. Lauritsen,[1] A. O. Macchiavelli,[2] P. R. Mudder,[2] C. Nair,[1] Y. Qiu,[10] J. Rissanen,[2] A. M. Rogers,[1,‡‡] P. Ruotsalainen,[7,‡‡] G. Savard,[1] S. Stolze,[7] A. Wiens,[2] and S. Zhu[1]

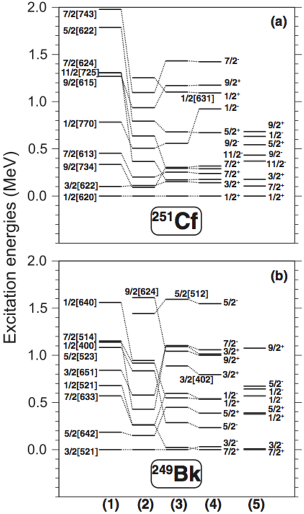


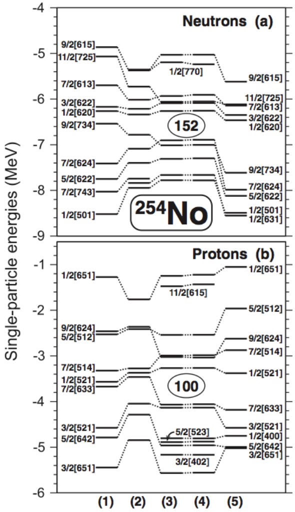






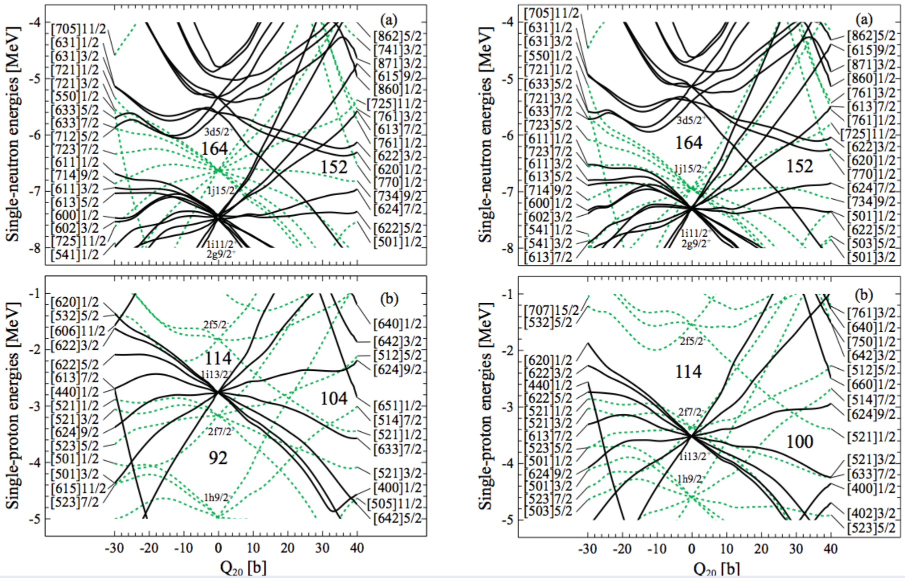
Theory - Skyrme UNEDF1^{SO}



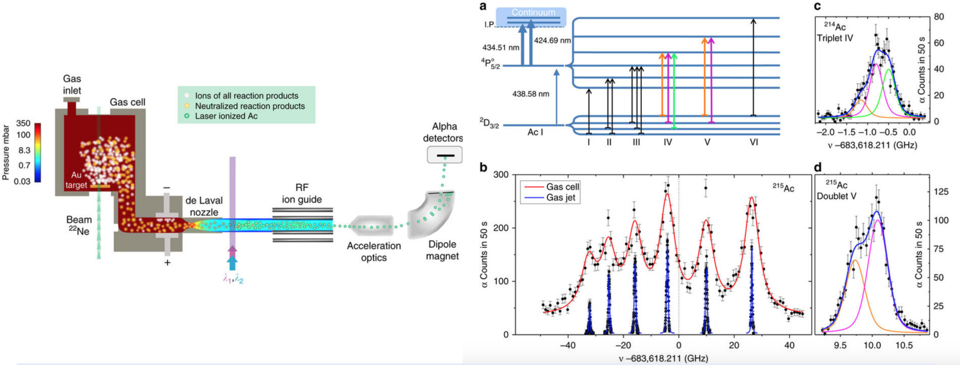


- Based on Skyrme UNEDF1 functional (Kortelainen et al., PRC **85**, 024304 (2012))
- Re-adjustment of pairing strengths and spin-orbit coupling constants
- Pairing first adjusted to experimental 3-point mass differences of ^{249}Bk and ^{251}Cf
- Second adjustment to reproduce low-frequency MoI of ^{252}No
- Spin-orbit coupling constants adjusted to better reproduce ^{249}Bk and ^{251}Cf spectra
- Increased pairing strength needed to reproduce MoI
- Cannot simultaneously reproduce 3-point mass differences and MoI
- Yue Shi et al., PRC **89**, 034309 (2014)

Theory - Skyrme UNEDF1^{SO}

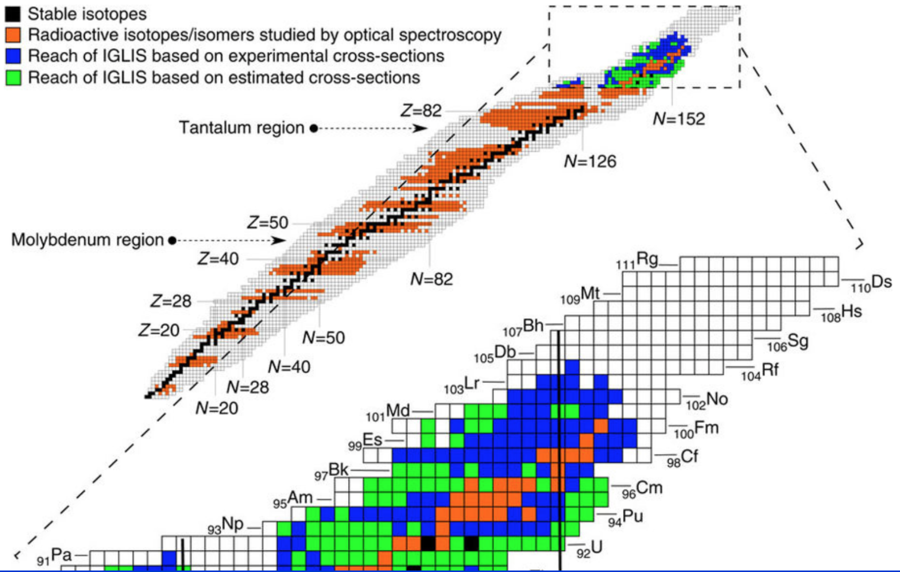


Future - in-gas jet laser spectroscopy

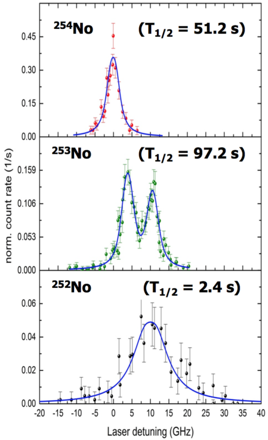


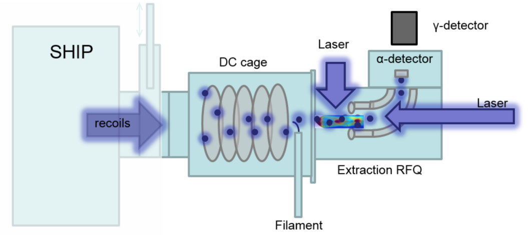
R. Ferrer et al., Nature Comm. **8**, 14520 (2017)

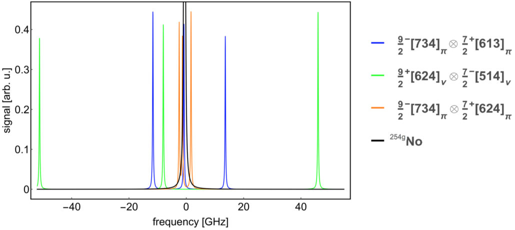
Future - in-gas jet laser spectroscopy



Future - ^{254}No at GSI-FAIR







M. Laatiaoui et al., Nature **538**, 495 (2016

R. Ferrer, S. Raeder, G-PAC proposal U314

Summary

- K-isomers provide powerful tool to locate single-particle states in heavy nuclei
- Interpretation of N=150 K-isomers seems clear
- ^{256}Rf K-isomer data from JYFL seems to be consistent with data from Berkeley
- Interpretation of N=152 K-isomers still open
- Upgraded electronics enabled new studies of isomerism in ^{250}No, ^{254}Rf
- Large body of experimental data has highlighted deficiencies in modern-mean field calculations
- May have consequences for the prediction of properties of SHE
- Attempts to understand these deficiencies have been started
- High-resolution laser spectroscopy studies will be a powerful tool in the future

Collaboration

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