Nuclear Structure using Deep Inelastic and Transfer Reactions

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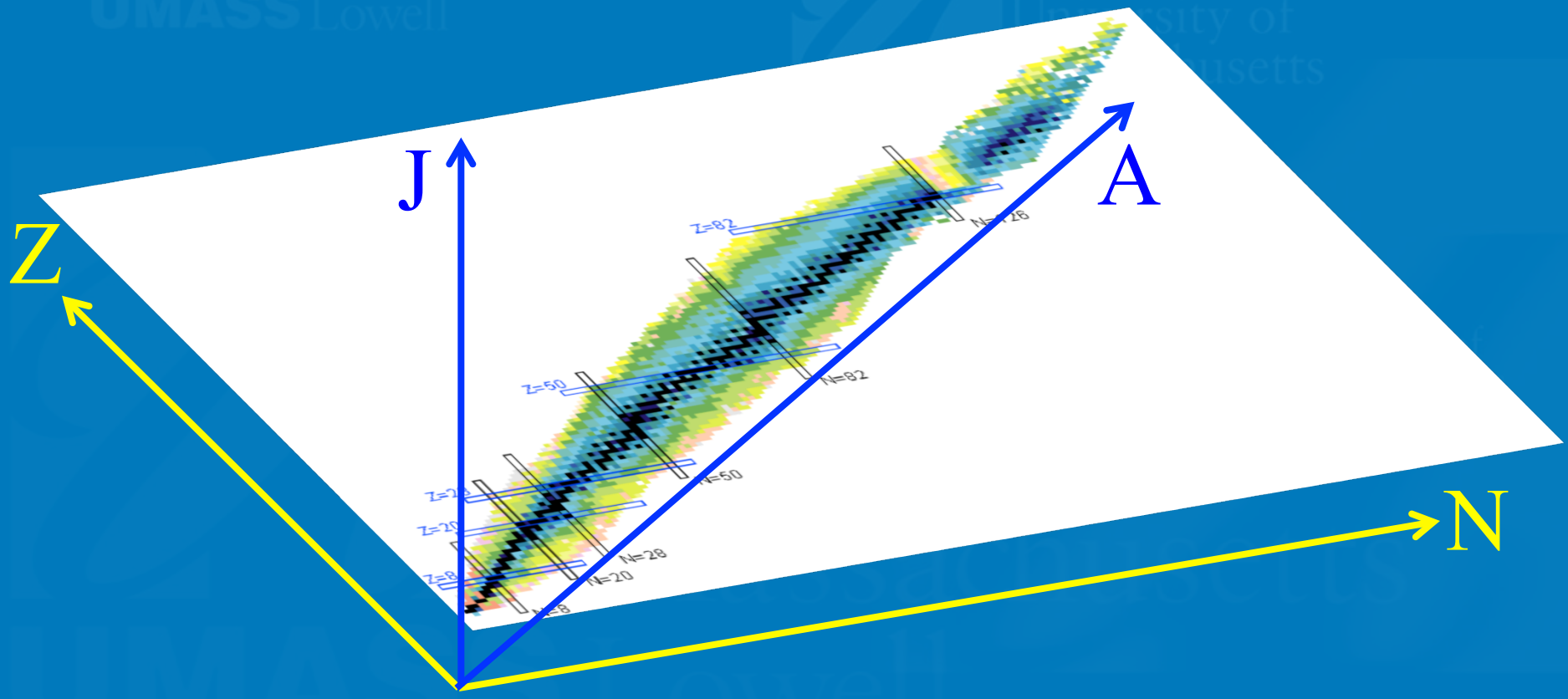
outline

- Technique
- Physics
- Challenges
- Progress
- Status
- Outlook

the spectroscopic frontiers



technique

Complementarity :

(in high-spin population with stable beam and target)

-fusion-evaporation preferentially populates neutron-deficient nuclei

-inelastic and transfer access stable to neutron-rich

Characteristics :

-populates a wide variety of nuclei

-Cross-sections competitive (or better) than fusion

-complementary fragment provides identification

Physics with inelastic/transfer reactions

- Rich pioneering history at ATLAS
- (narrow and personally biased recent examples here)
- heavy and very heavy nuclei
- A~180 region
- yrast traps, K-isomers, limits of approximate symmetries, soft potentials, shape transitions
- A~250 region
- K-isomers, highest neutron orbitals, reduced pairing, higher order multipole shapes

Neutron-rich nuclei 170<A<190 : courtesy Greg Lane (ANU)

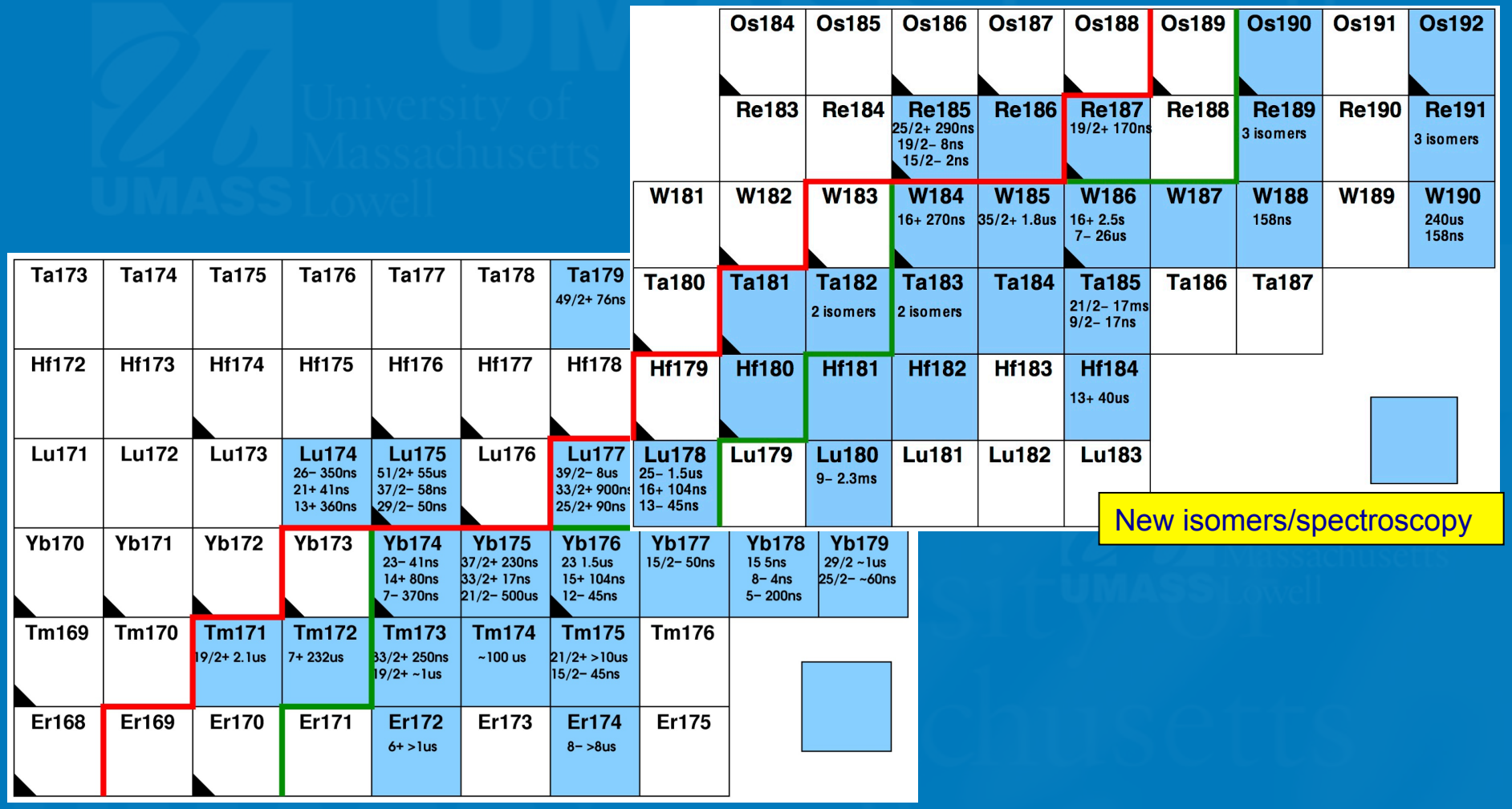
- Deep-inelastic collisions with pulsed ^{136}Xe beams from ATLAS.
- Various thick targets across four experiments (one more approved)
  - ^{170}Er, ^{174}Yb, ^{175}Lu, ^{176}Lu, ^{185}Re, ^{186}W, ^{187}Re and ^{192}Os.
- γ-γ-γ-time: 1/825 ns pulsing
- γ-γ-clock: from 10/40μs up to 1/4s slow chopping.

- neutron-rich nuclei are only weakly populated
- huge backgrounds
  - many (many!) products
  - intense target excitation

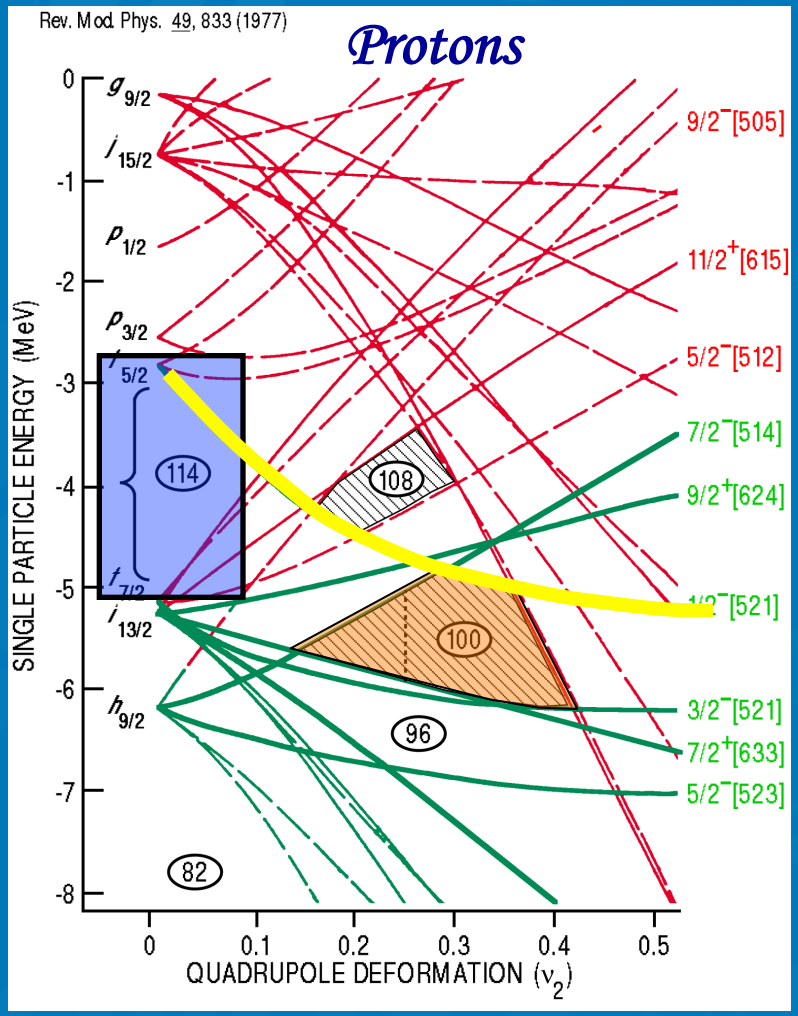
Requires Gammasphere and time correlations to pull them out.

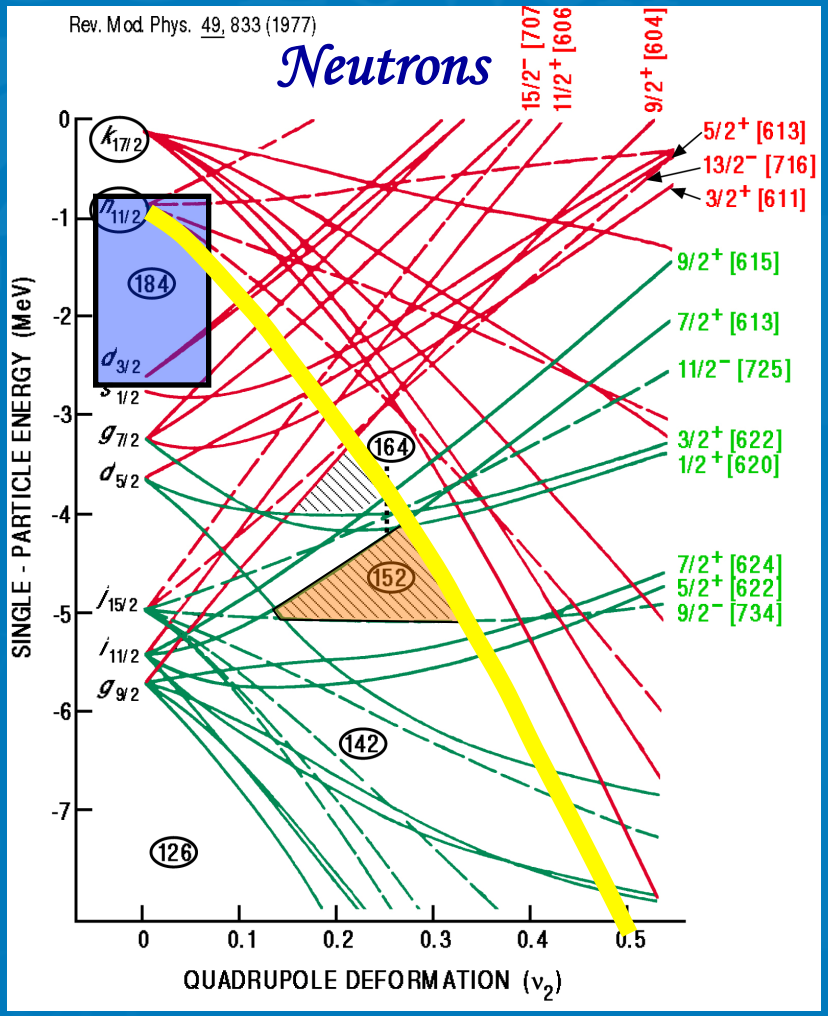
- Focus on high-K isomers - purity of the K quantum number
- Shape changes/transitions – triaxiality/hexadecapole
- Astrophysical implications - ^{176}Lu/^{180}Ta, other fortuitous discoveries?

A~180 overview : courtesy Greg Lane (ANU)



A~250 : connecting very heavy to superheavy





R.R. Chasman and I. Ahmad, Rev. Mod. Phys. 49, 833 (1977) **Woods-Saxon**

complementary reaction mechanisms

Inelastic and transfer reactions with radioactive targets
Complement fusion-evaporation studies of Z>100 nuclei
Follow same neutron orbitals into lower-Z isotones

^{209}Bi (1450 MeV) on ^{248}Cm
^{207}Pb (1430 MeV) on ^{249}Cf
^{208}Pb (1430 MeV) on ^{244}Pu

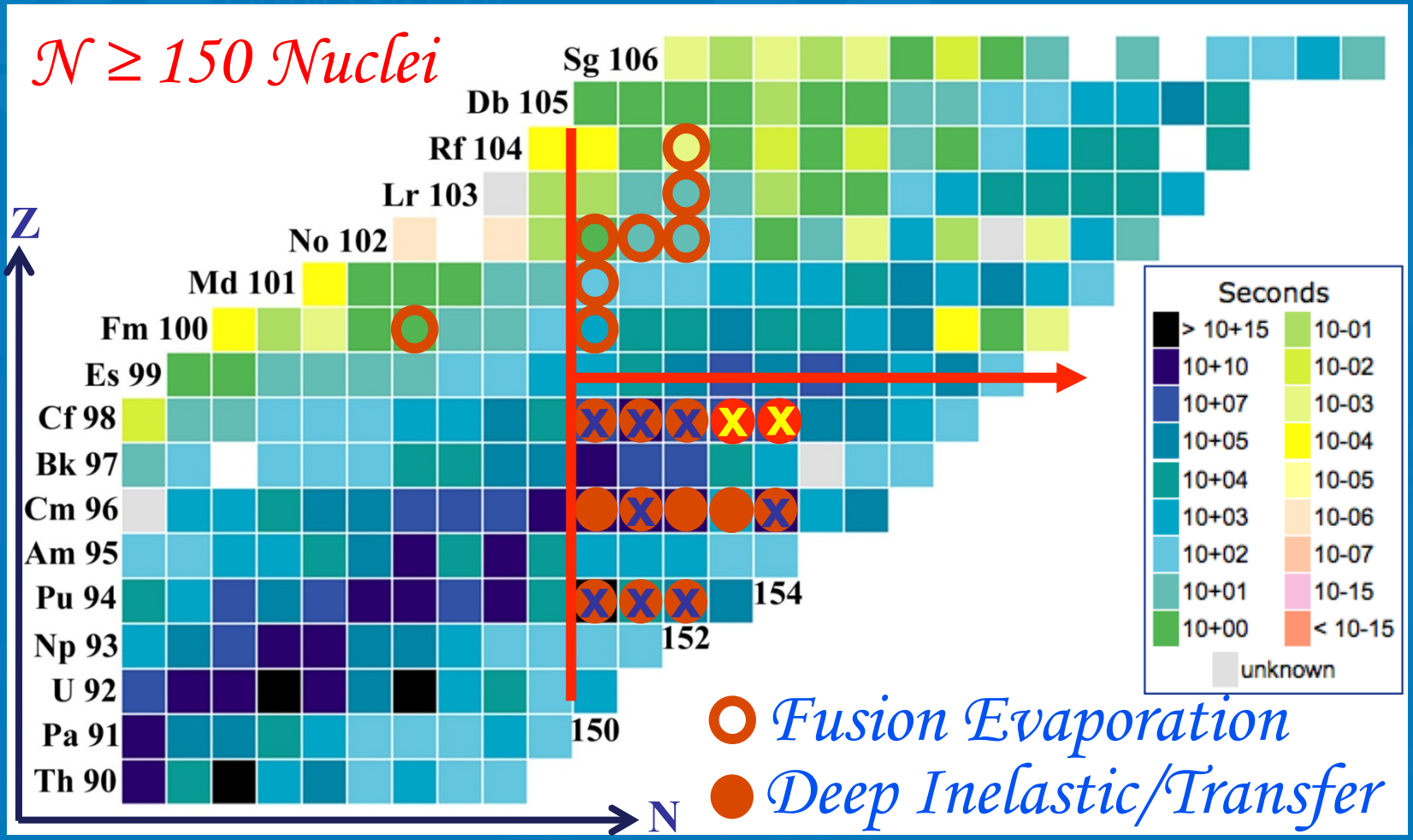
~15% above Coulomb barrier
ATLAS + Gammasphere backed targets

Prior prompt spectroscopy in Cm, Pu using these techniques

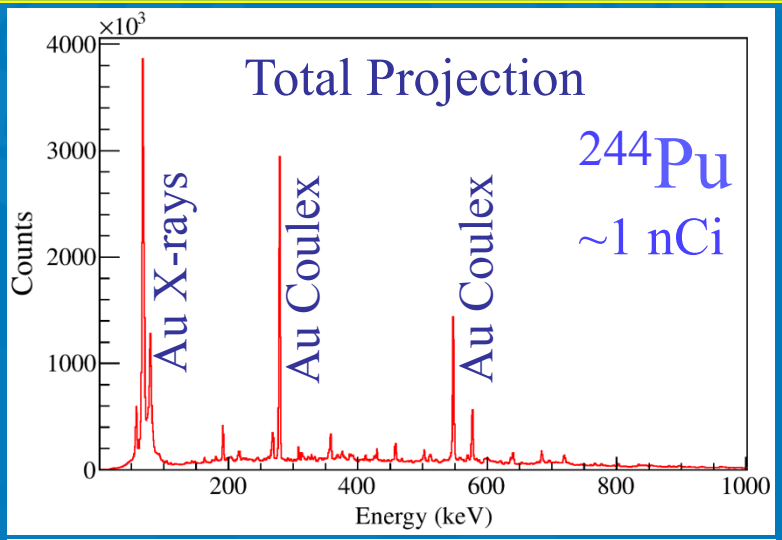
Current program targets both prompt and delayed spectroscopy

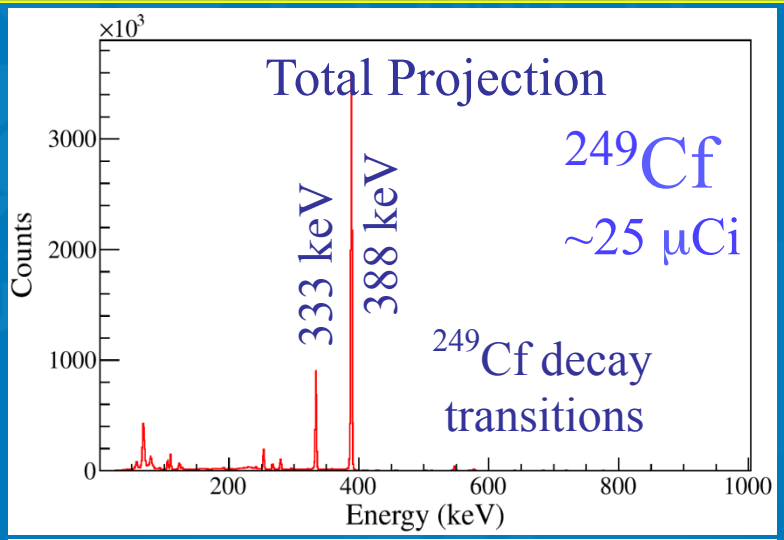
G. Hackman et. al., Phys. Rev. C 57, R1056 (1998)
I. Wiedenhoever et al., PRL 83, 2143 (1999)
K. Abu Saleem, Ph.D. thesis, Illinois Inst. of Tech. (2002)

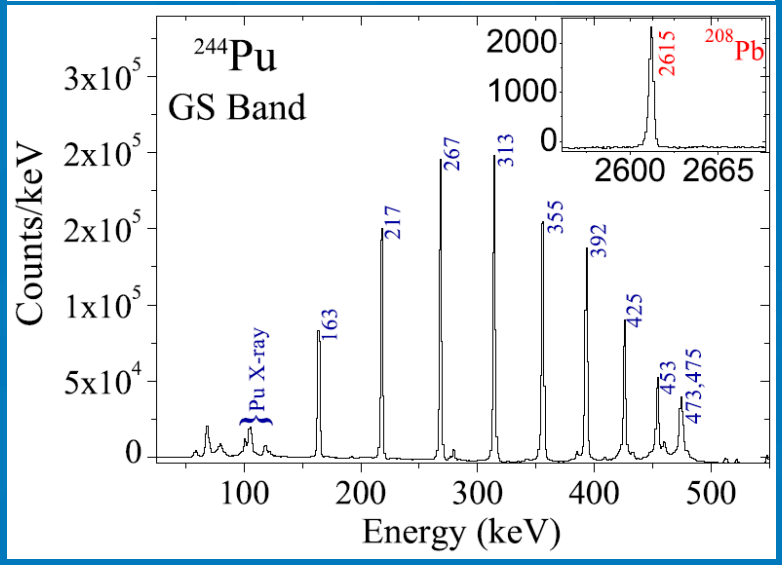
the highest neutron orbitals

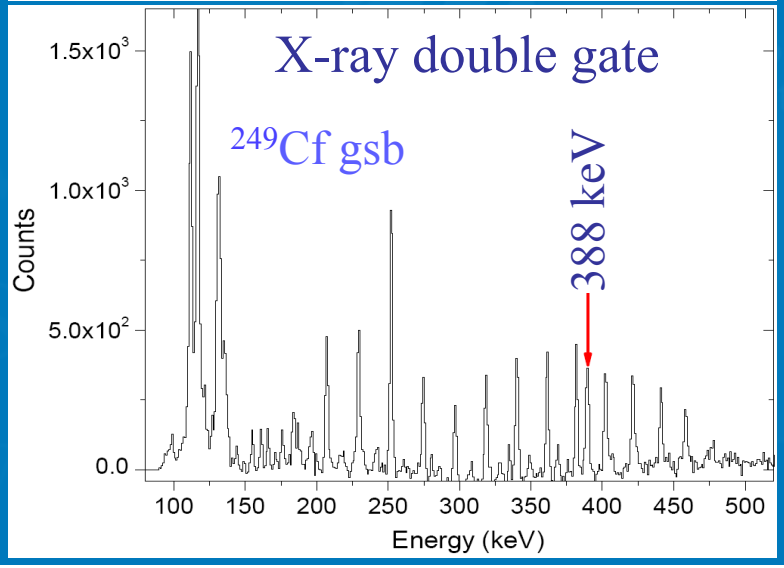


spectroscopic challenges : radioactive targets



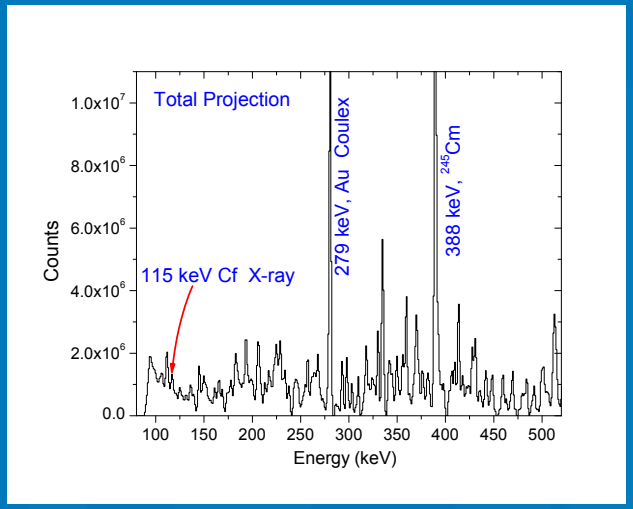


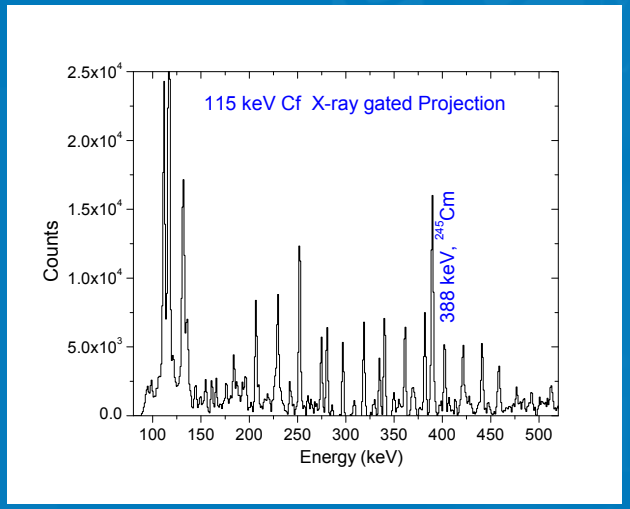


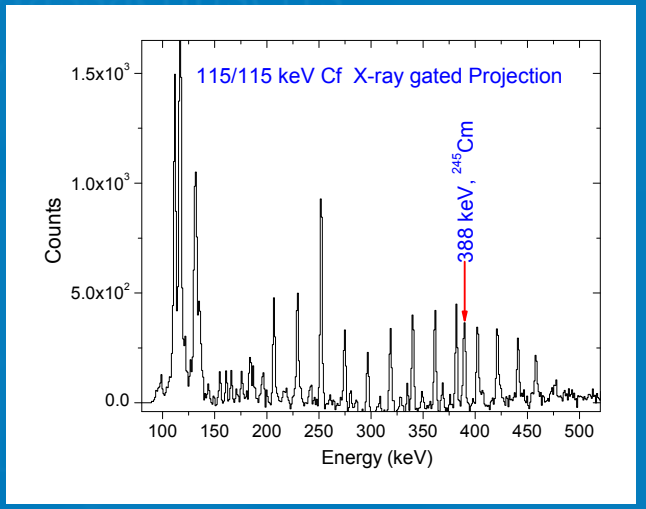


spectroscopic challenges : radioactive targets

$^{208}Pb + ^{249}Cf$ and Gammasphere







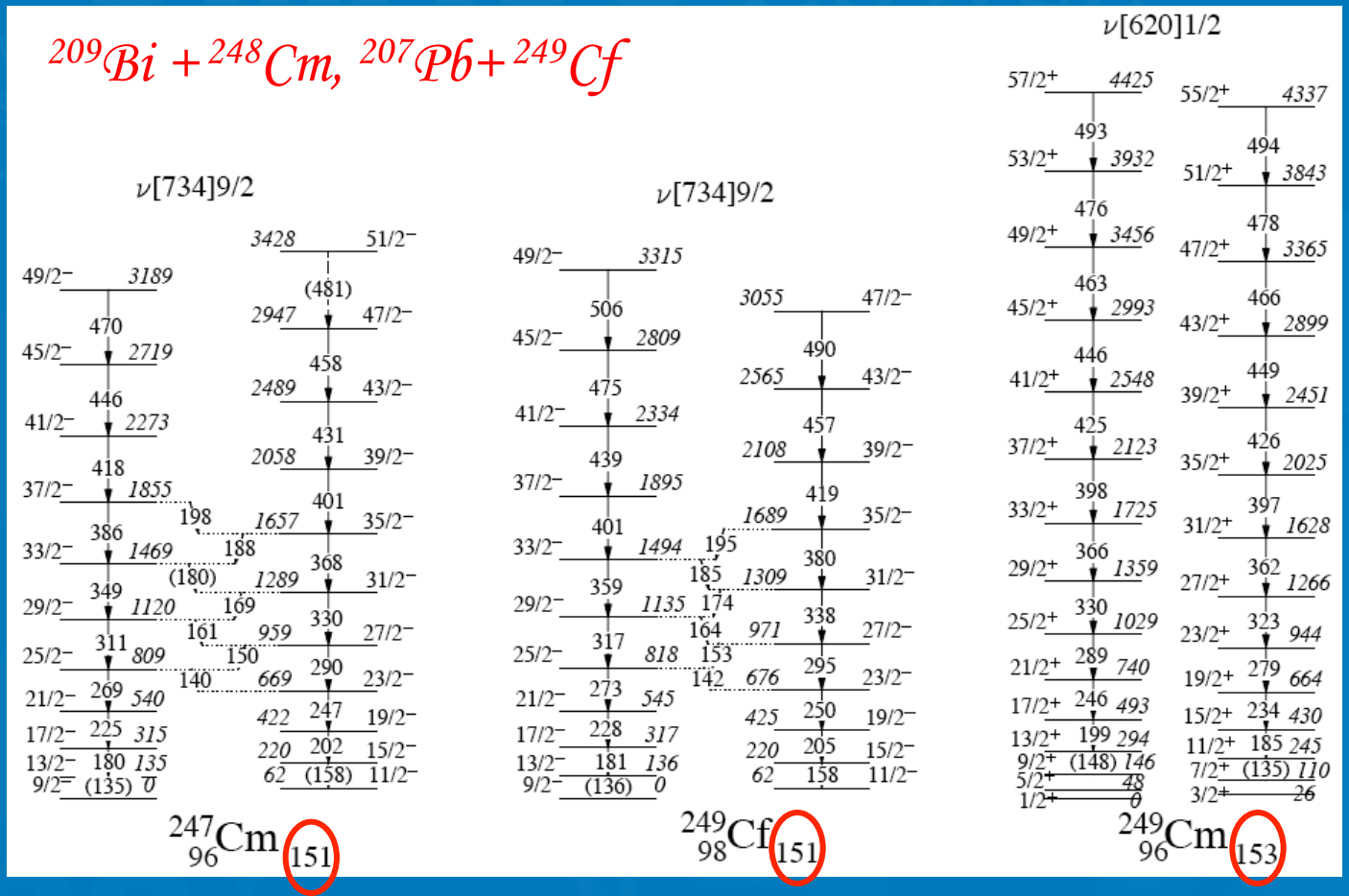
Acknowledgments: John Greene and Irshad Ahmad for target prep and ANL in-house collaborators for ensuring beam was hitting target

odd-A Cm (Z=96) and Cf (Z=98)

X-γ and cross-coincidences with binary reaction partner

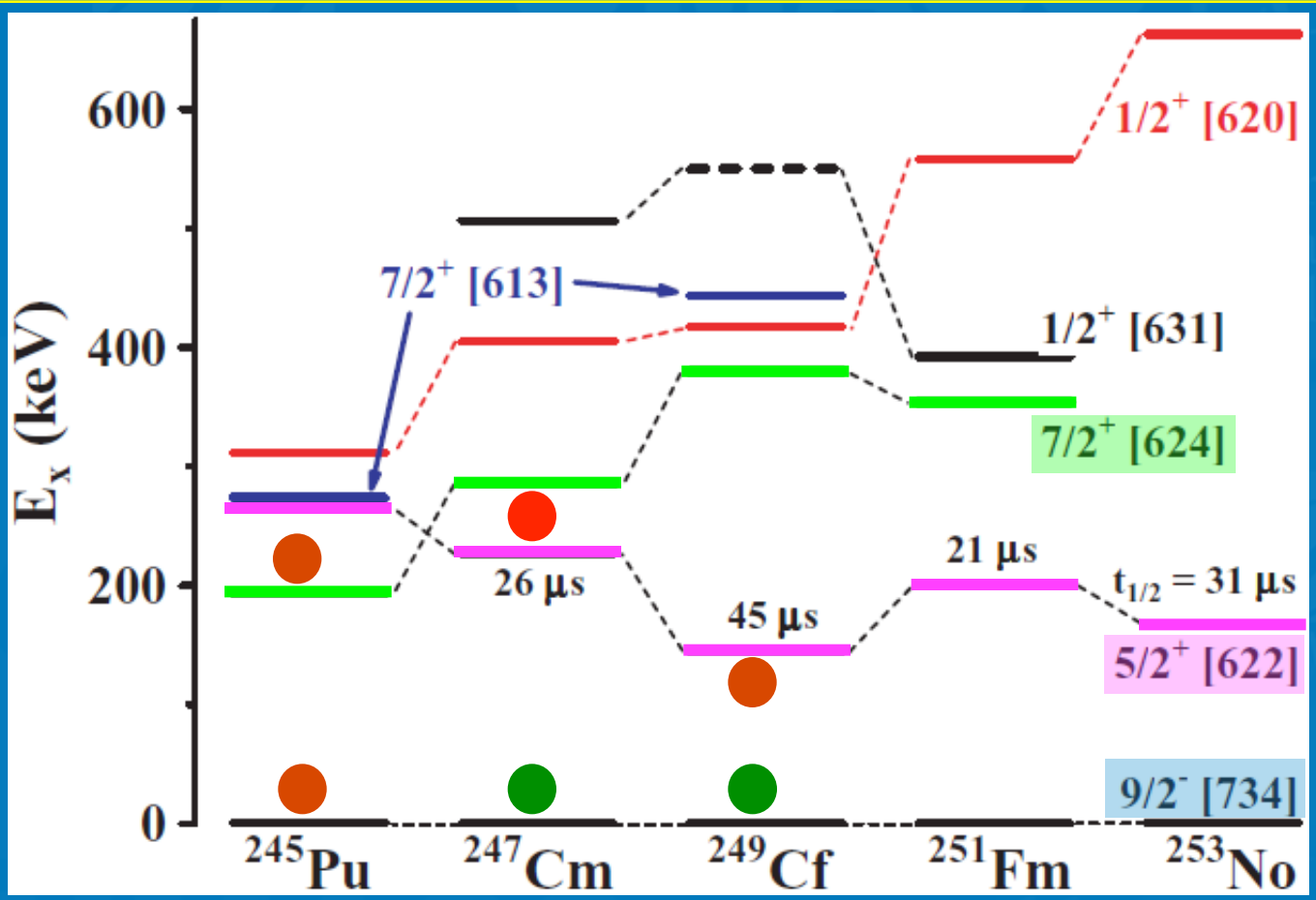
High-spin studies at the highest oscillator shells

$^{209}Bi + ^{248}Cm$, $^{207}Pb + ^{249}Cf$



S.K. Tandel et al., Phys. Rev. C 82, 041301 (R) (2010)

Bands built on single-particle orbitals (N=151)



Rotational Bands

S.K. Tandel et al., PRC 82, 041301 (R) (2010)

S.S. Hota (Ph.D. thesis, 2012) to be published

Single-particle orbitals
H. Makii et al., PRC 76, 081301(R) (2007)

emerging systematics: N=151

Bands built on ground state and excited states

Configurations from M1/E2 branching ratios

$\pi i_{13/2}$ and $\nu j_{15/2}$ align at comparable frequencies

$\nu j_{15/2}$ alignments blocked and unblocked

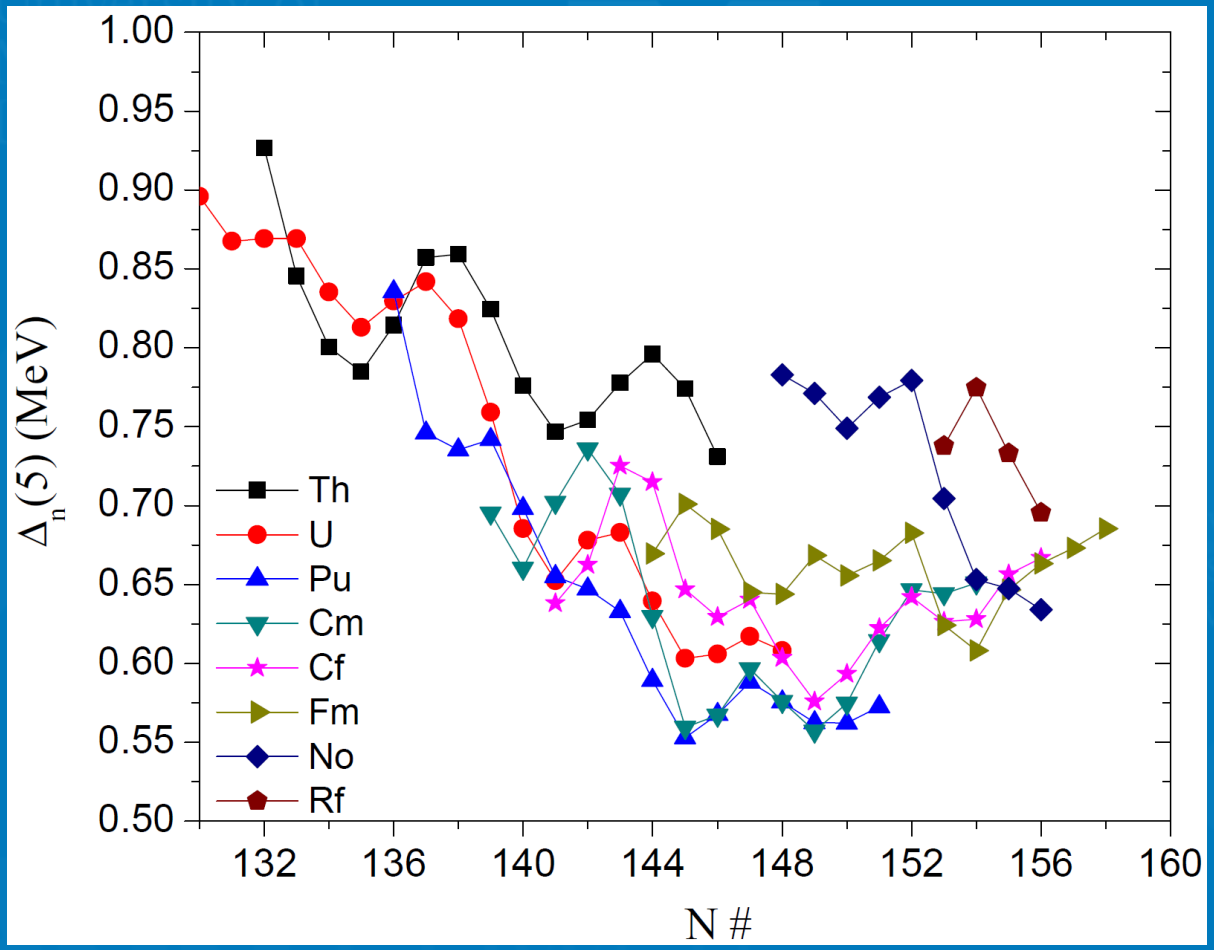
Experiments say protons align first

Cranking calculations say neutrons align first!

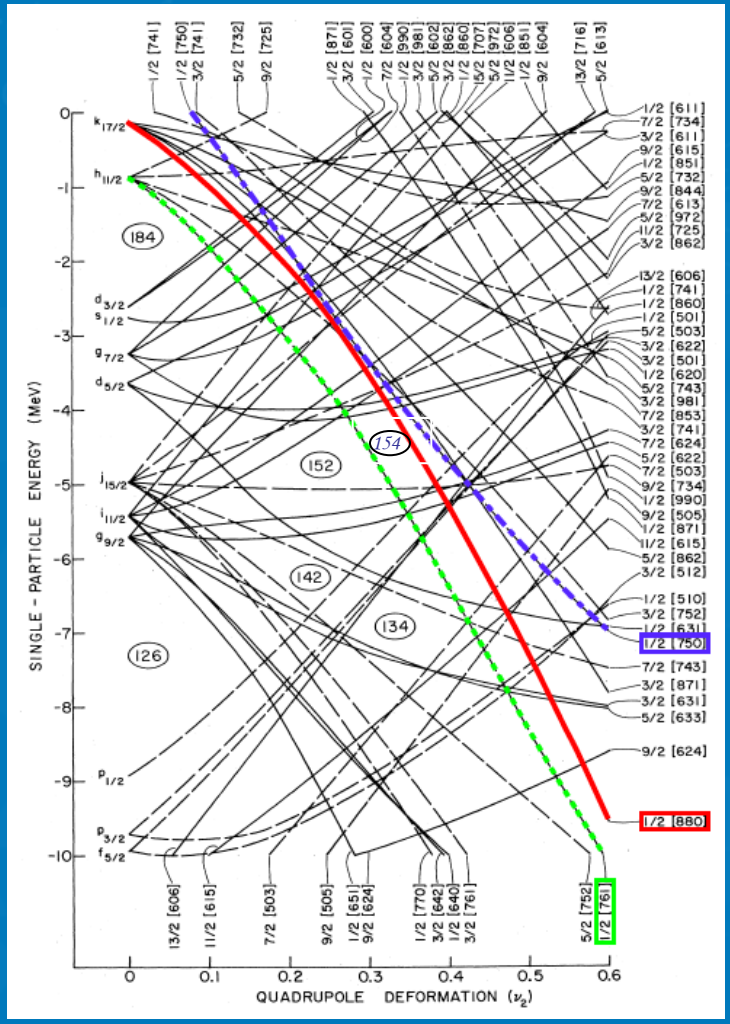
Inclusion of β_6 deformation is important

comprehensive data now available for N=150-154

reduced neutron pairing

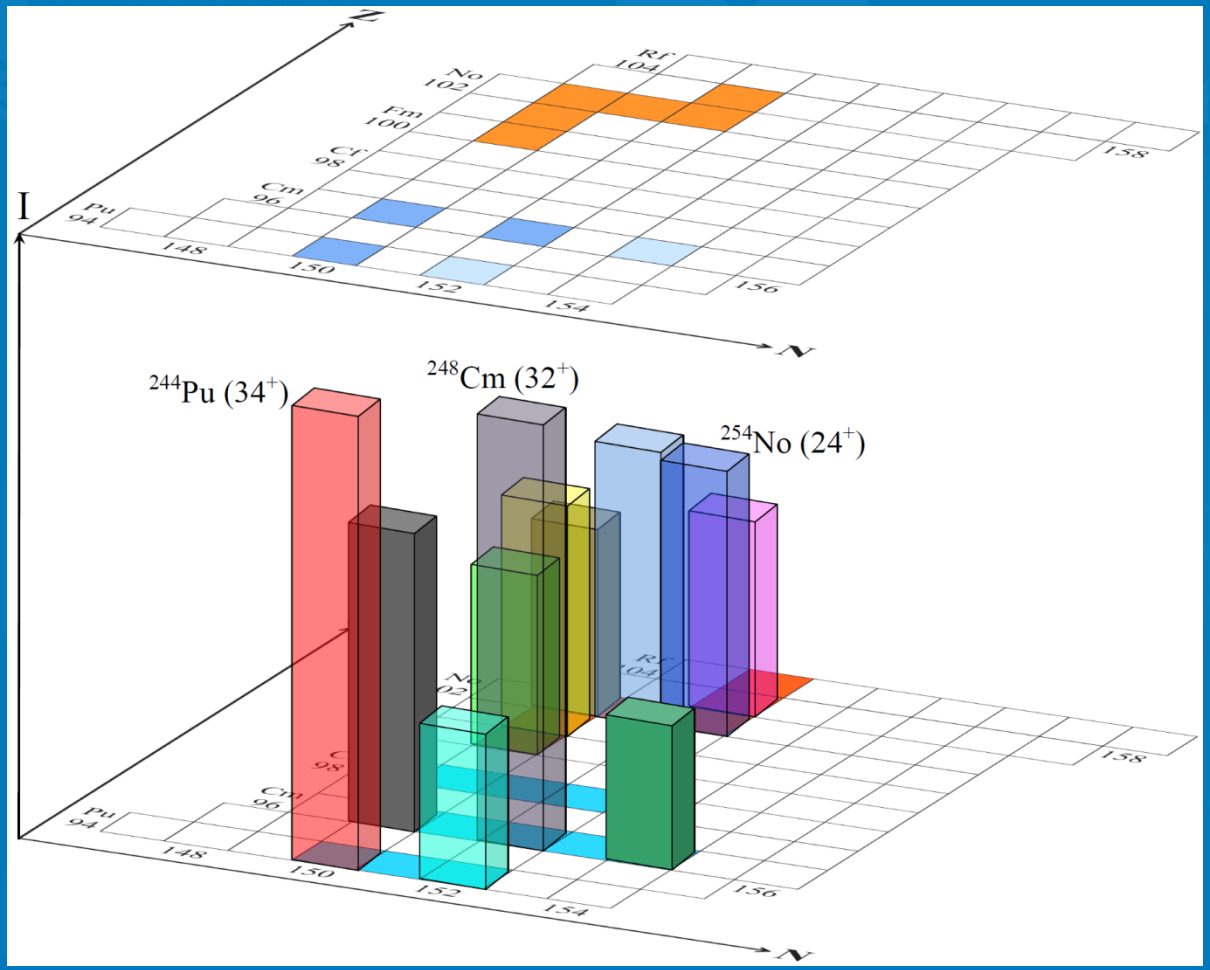


orbitals from above the N=184 shell gap?



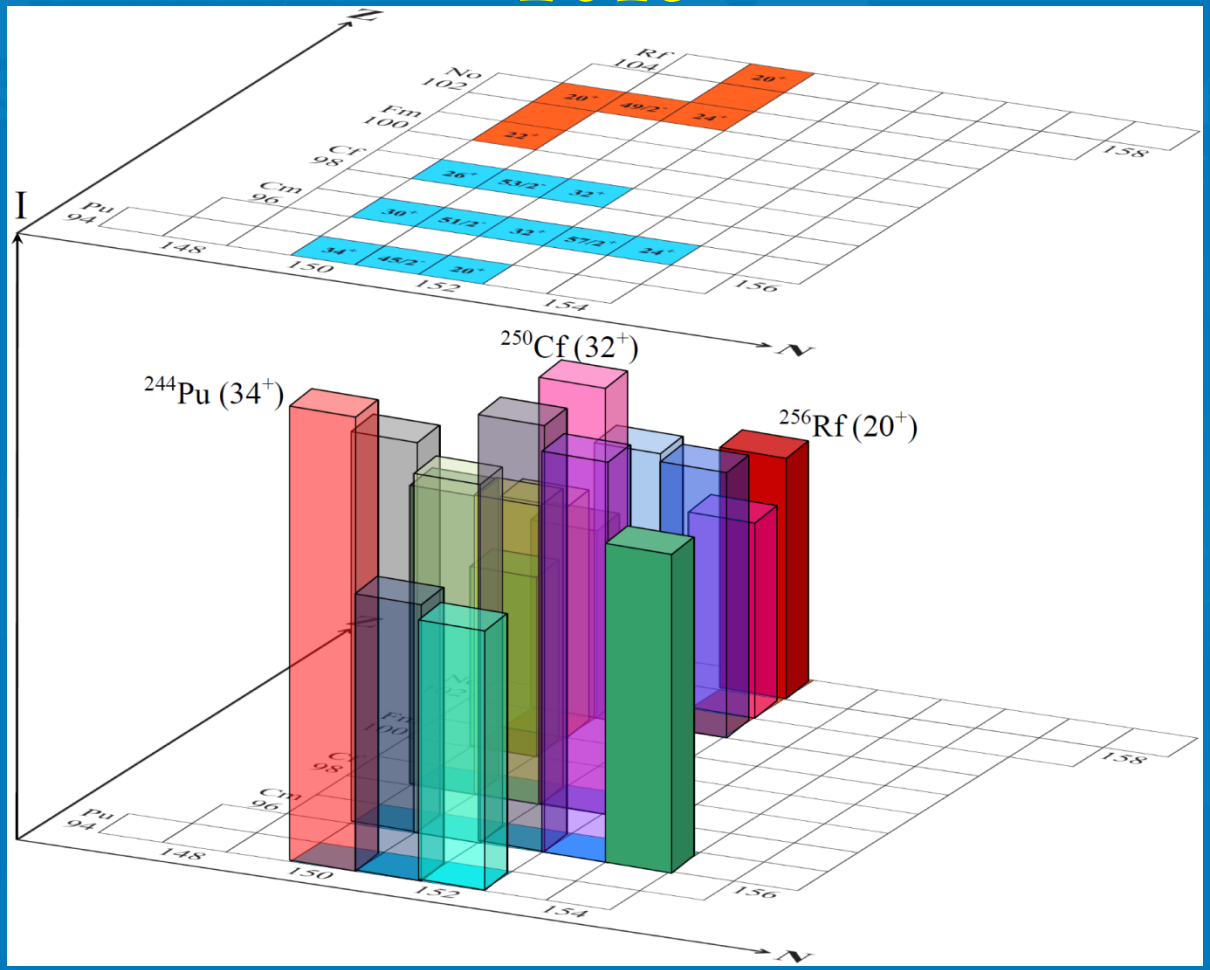
evolving landscape : A~250 region

2009



evolving landscape : A~250 region

2013



status summary

- nuclear structure via inelastic/transfer reactions
- powerful technique complements fusion
- accesses high spins in neutron-rich nuclei
- radioactive targets and heavy beams for A~250 studies
- K-Isomer physics (not focused on here)
- emerging systematics of highest neutron orbitals
- competing nucleon alignments
- higher order multipole deformation
- reduced neutron pairing at the N=152 gap
- orbitals from above the N=184 spherical gap?

near future outlook

- data on odd-proton nuclei sorely lacking
- (both for inelastic/transfer as well as fusion)
- A~250 proton transfer yields much lower than in A~180
- explore limits of radioactive target experiments
- heavy radioactive beams ??
- N~150 factory ???

Collaborators for A~250 experiments

S. S. Hota.[1], P. Chowdhury[1], T.L. Khoo[2], M.P. Carpenter[2], R.V.F. Janssens[2], I. Ahmad[2], J. Greene[2], S.K. Tandel[1,3], D. Seweryniak[2], S. Zhu[2], P. Bertone[2], C.J. Chiara[2,4], A. Y. Deo[1], N. D' Olympia[1], C. J. Guess[1], G. Henning[2], C.R. Hoffman[2], E. G. Jackson[1], F.G. Kondev[2], S. Lakshmi[1], T. Lauritsen[2], C.J. Lister[1], E.A. McCutchan, V. S. Prasher[1], Y. Qiu[1], V. Shirwadkar[1], I. Stefanescu[2]

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