Alpha Decay and Fission of K-Isomers

Rod Clark

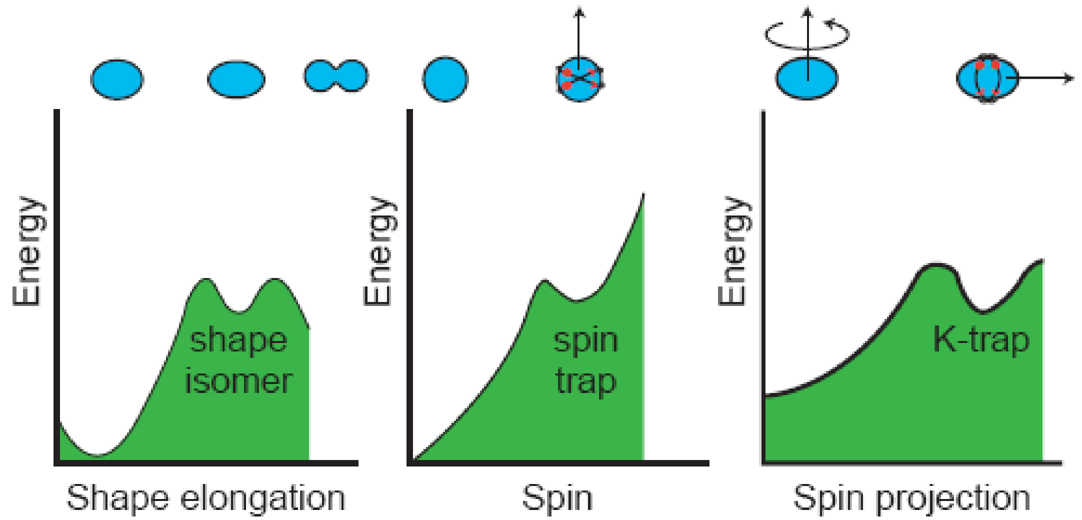
Outline

Alpha Decay

- stability of excited metastable states (isomers)
- superfluid tunneling model
- role of pairing, excitation energy, angular momentum

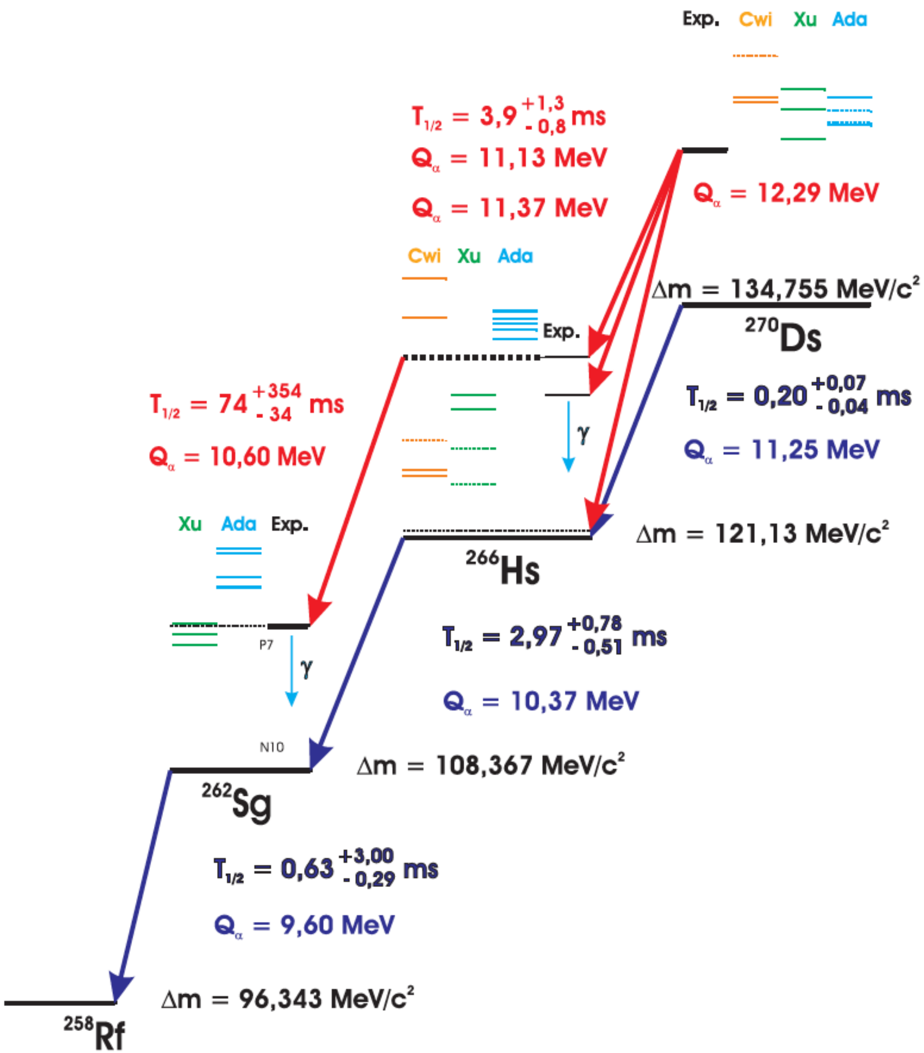
Fission

- stability against fission
- hindrances of isomers
- expectations for hindrance factors



P. Walker and G. Dracoulis
Nature 399 (1999) 35

Alpha Decay of K-Isomers: ^{270}Ds (Z=110)



Observation of alpha-decaying K-isomers with half-lives significantly longer than the ground state.

Implications for stability/survivability

Three major factors influencing alpha decay multi-QP states:

- Larger Q_α means shorter $T_{1/2}$
- Large ΔL means longer $T_{1/2}$
- Reduced pairing means longer $T_{1/2}$

Superfluid tunneling model used to estimate influence of these factors on alpha decay of multi-QP states.

J. Rissanen et al., PRC 90 044324 (2014)
R.M. Clark and D. Rudolph, PRC 97 02433 (2018)

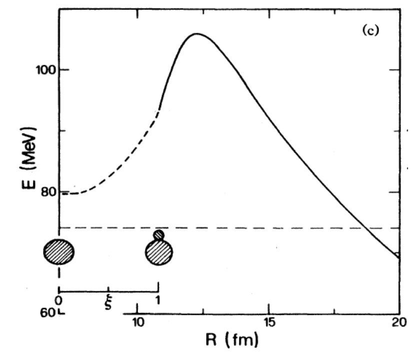
S. Hofmann et al., Eur. Phys. J. A 10 5 (2001), D. Ackermann, Prog. Theor. Phys. Suppl. 196 255 (2012)

Superfluid Tunneling Model (STM)

The Hamiltonian of the model is:

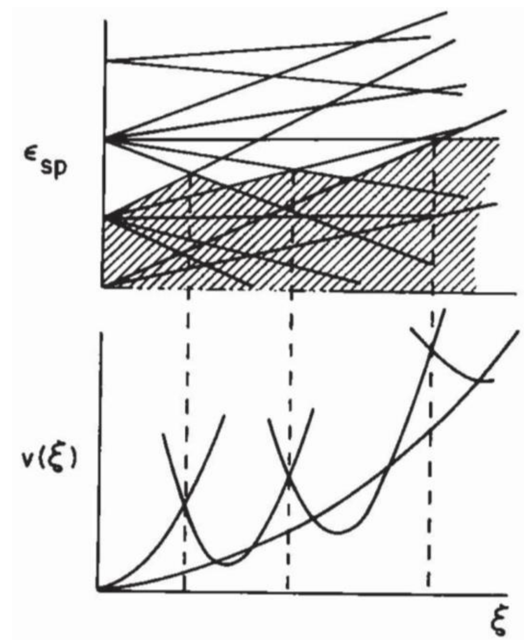
$$\left[-\frac{\hbar^2}{2D}\frac{\partial^2}{\partial\xi^2}+V(\xi)\right]\psi_n(\xi)=E_n\psi_n(\xi)$$

ξ = generalized deformation variable
D = inertial mass (depends on Δ)
Δ = pairing gap = $12/\sqrt{A}$ MeV



Calculation of decay constant:
λ = f . P . T

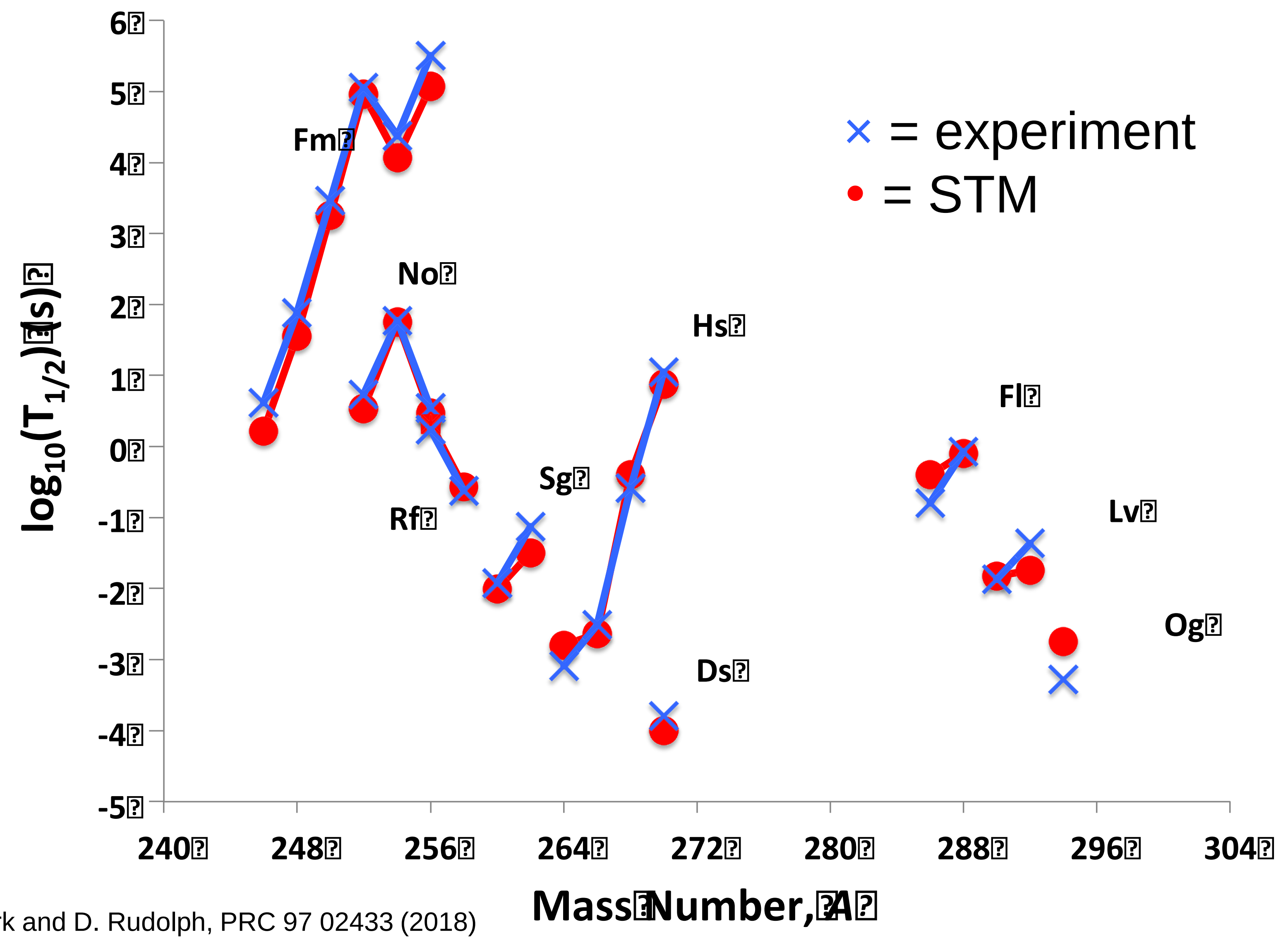
P= preformation of decay configuration
f = frequency of hitting barrier
T = transmission coefficient through barrier



"Nuclear Superfluidity: Pairing in Finite Systems"
David M. Brink and Ricardo A. Broglia
Cambridge University Press, 2005

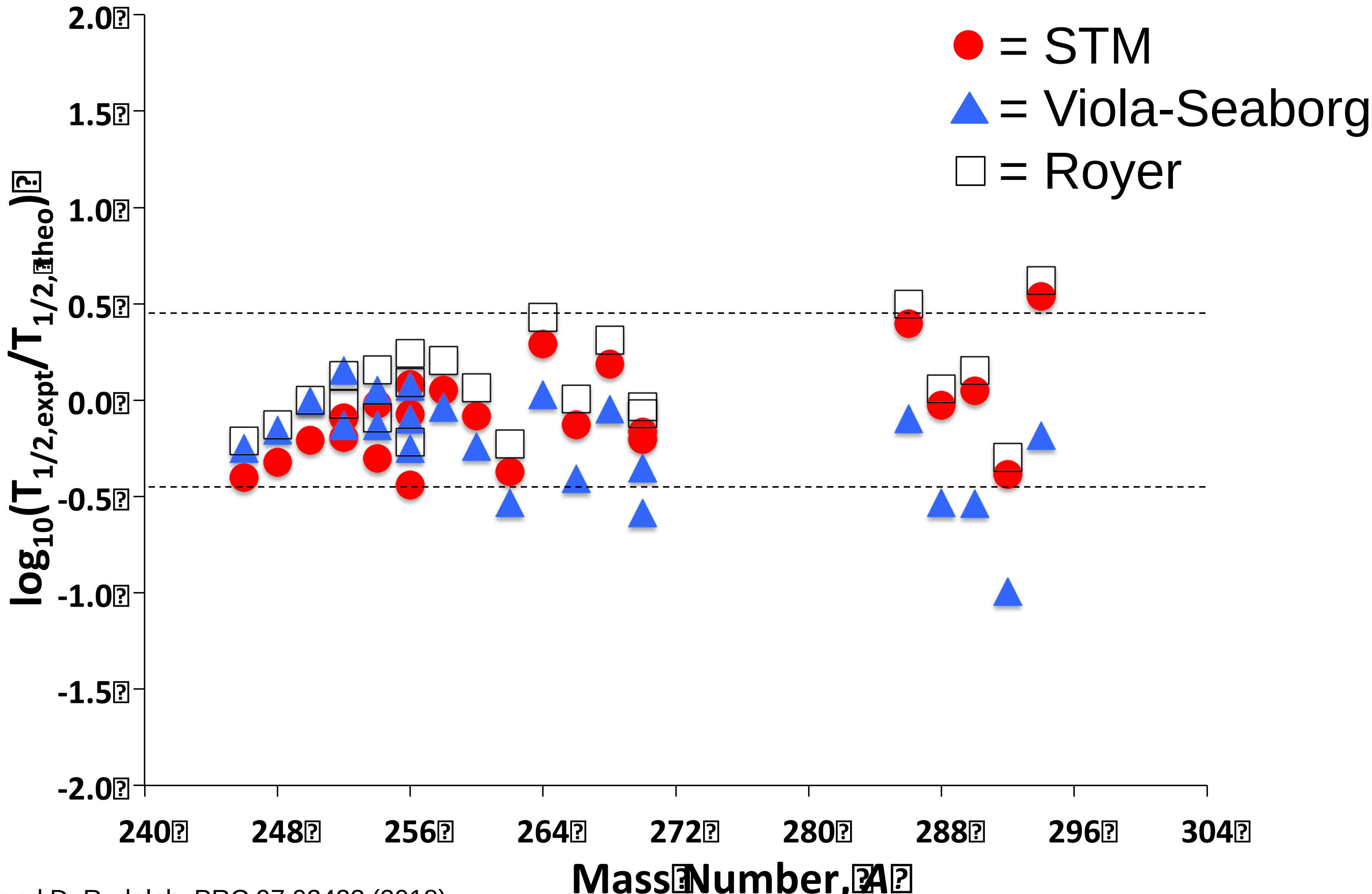
F. Barranco, G.F. Bertsch, R.A.Broglia, E.Vigezzi,
NPA 512 253 (1990)

Alpha Decay of Even-Even Isotopes: Fm to Og



R.M. Clark and D. Rudolph, PRC 97 02433 (2018)

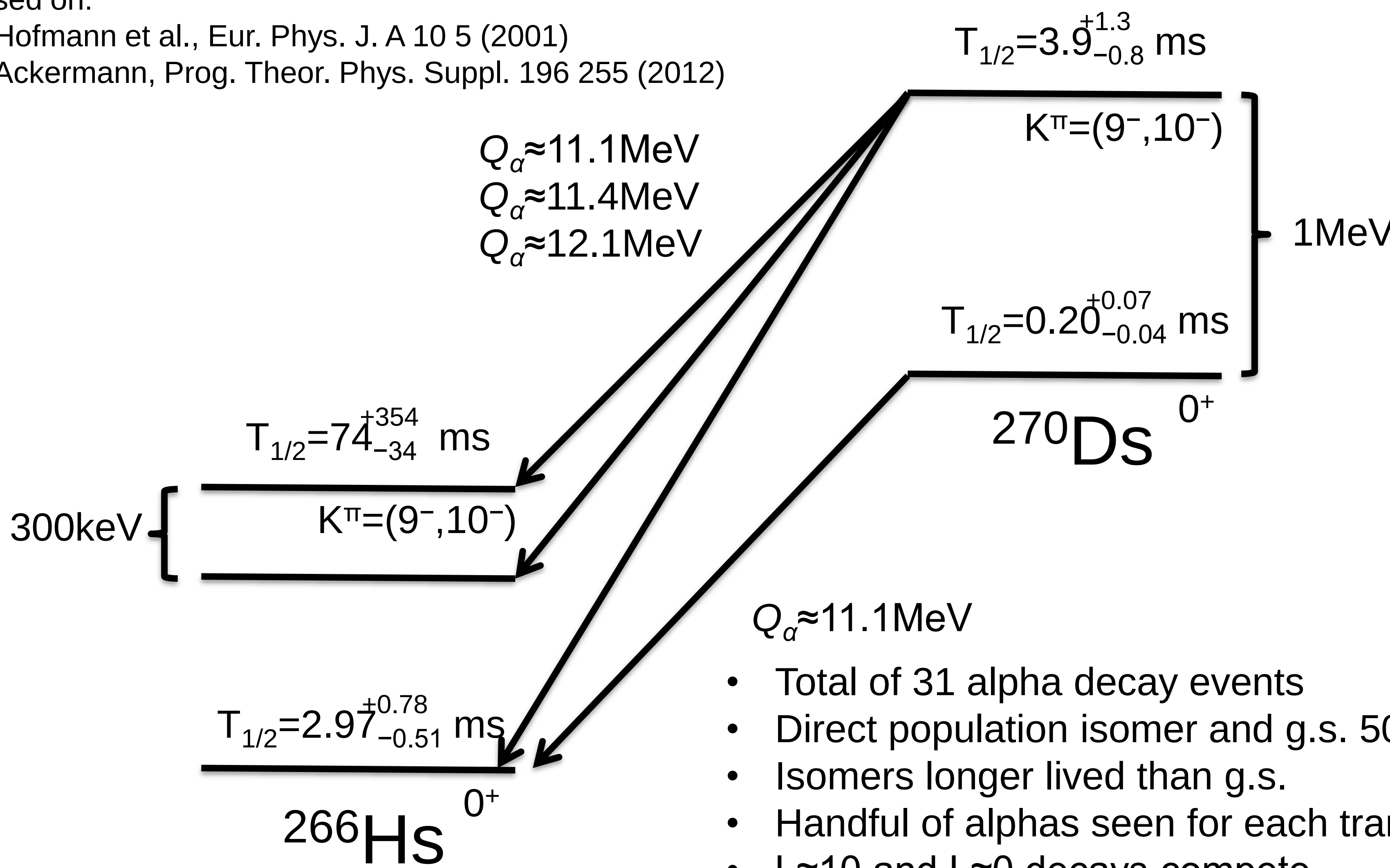
Reproducing Ground State Alpha Decays of SHN



R.M. Clark and D. Rudolph, PRC 97 02433 (2018)

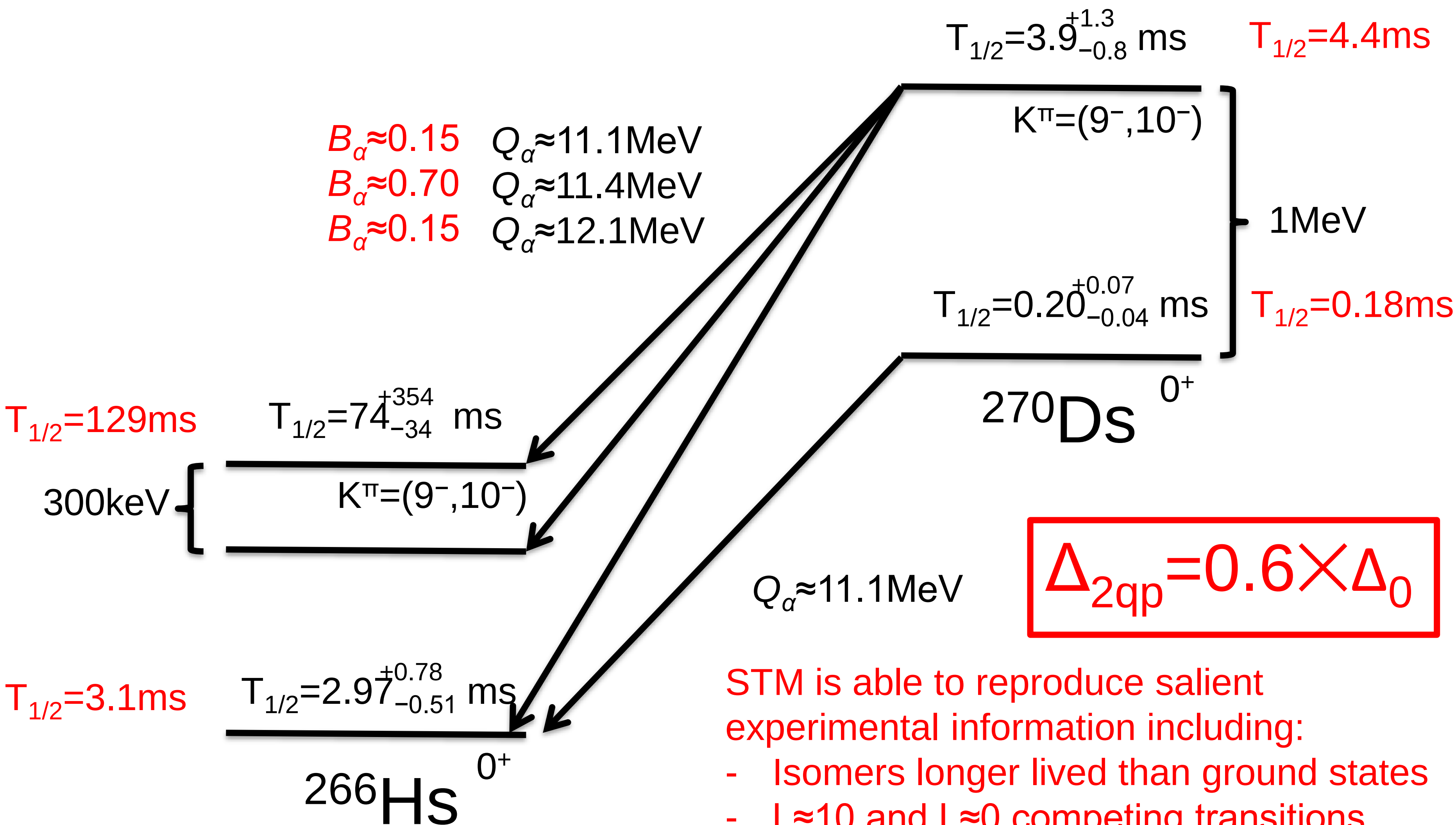
Alpha Decay of K Isomers in ^{270}Ds: Experiment

Based on:
S. Hofmann et al., Eur. Phys. J. A 10 5 (2001)
D. Ackermann, Prog. Theor. Phys. Suppl. 196 255 (2012)



- Total of 31 alpha decay events
- Direct population isomer and g.s. 50:50
- Isomers longer lived than g.s.
- Handful of alphas seen for each transition
- L≈10 and L≈0 decays compete

Reproducing Alpha Decays of K Isomers in ^{270}Ds



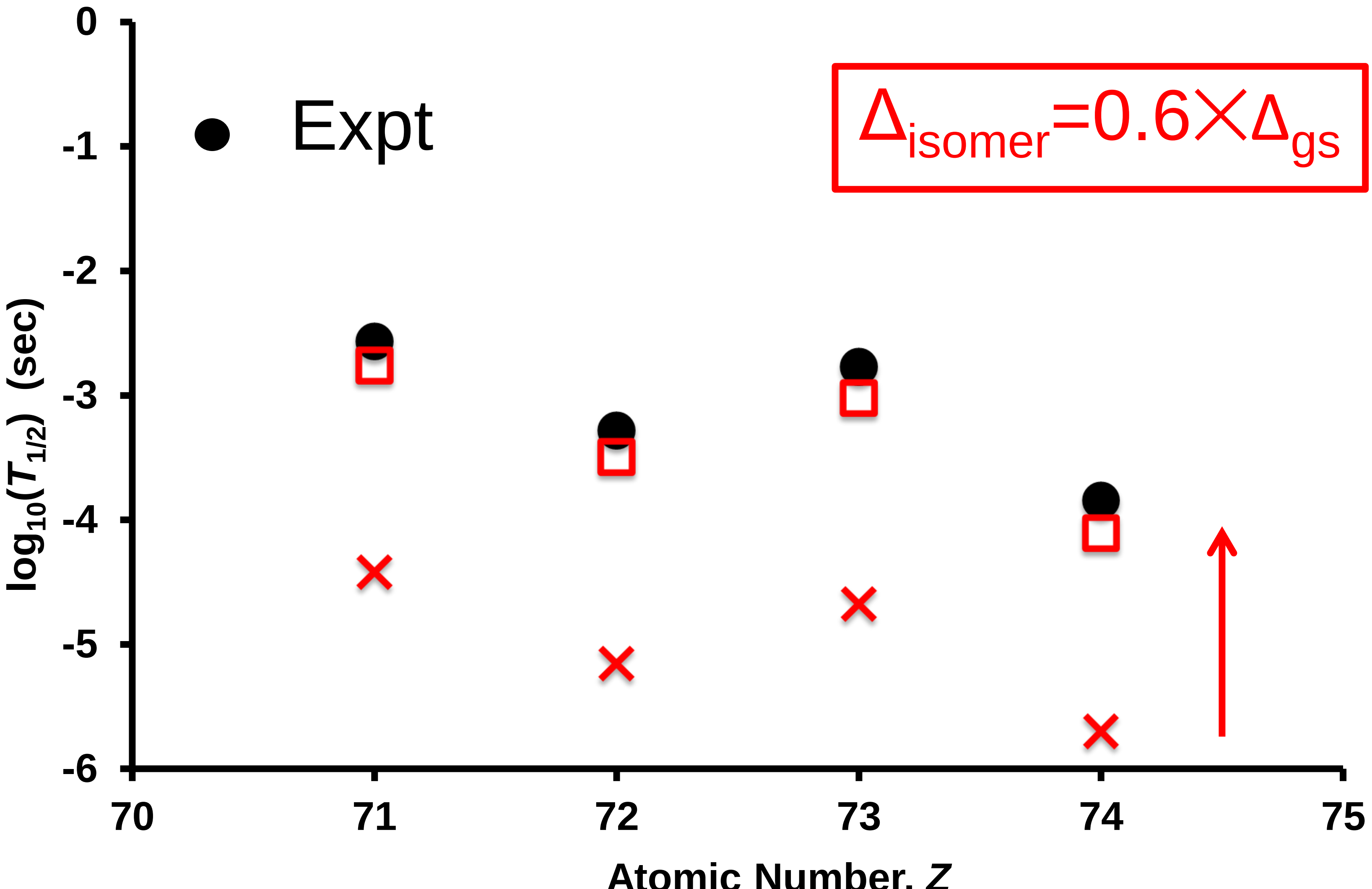
$$\Delta_{2qp}=0.6\times\Delta_0$$

STM is able to reproduce salient experimental information including:

- Isomers longer lived than ground states
- L≈10 and L≈0 competing transitions

R.M. Clark and D. Rudolph, PRC 97 02433 (2018)

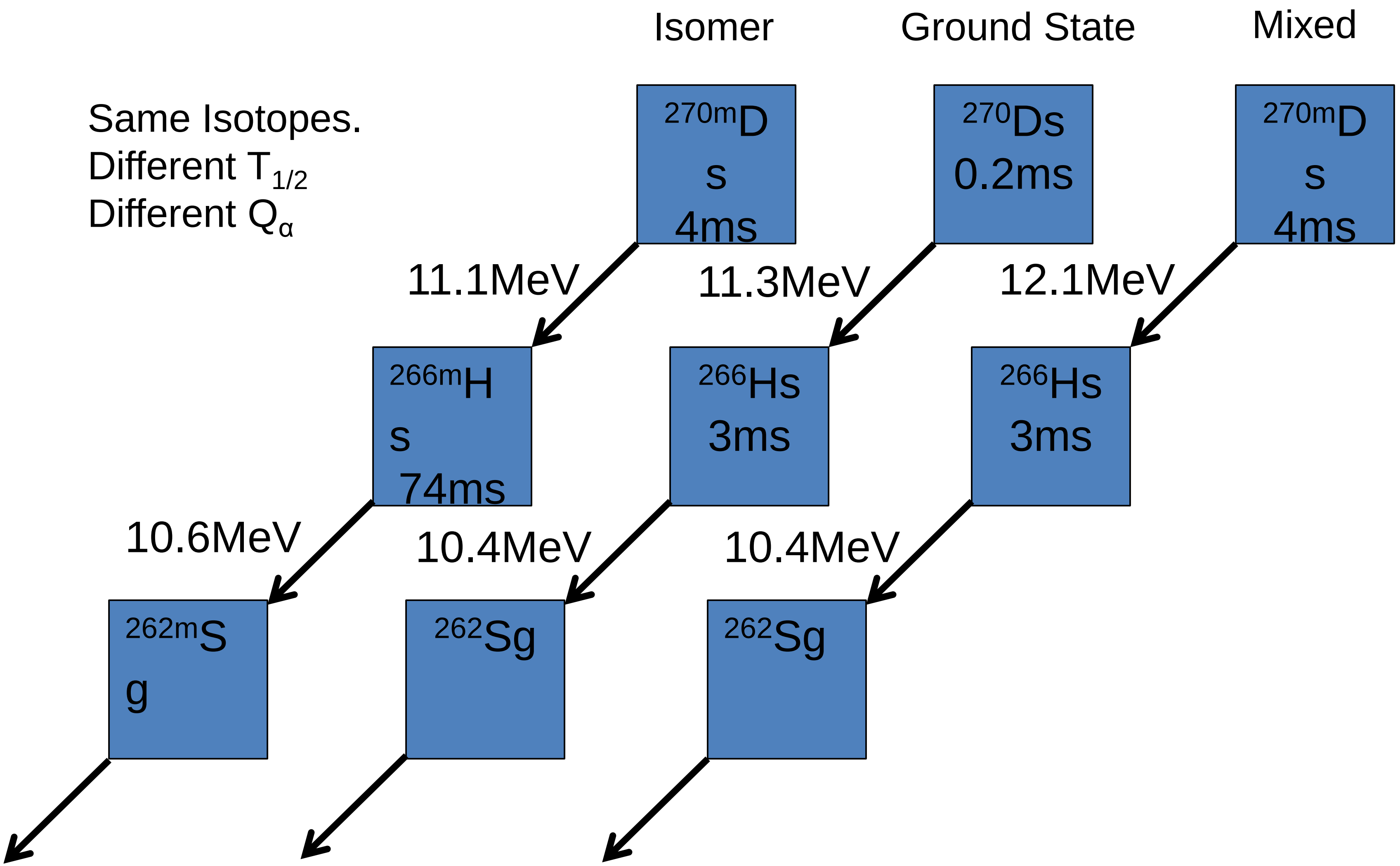
α Decay of High-Spin Isomers in N=84 Isotones



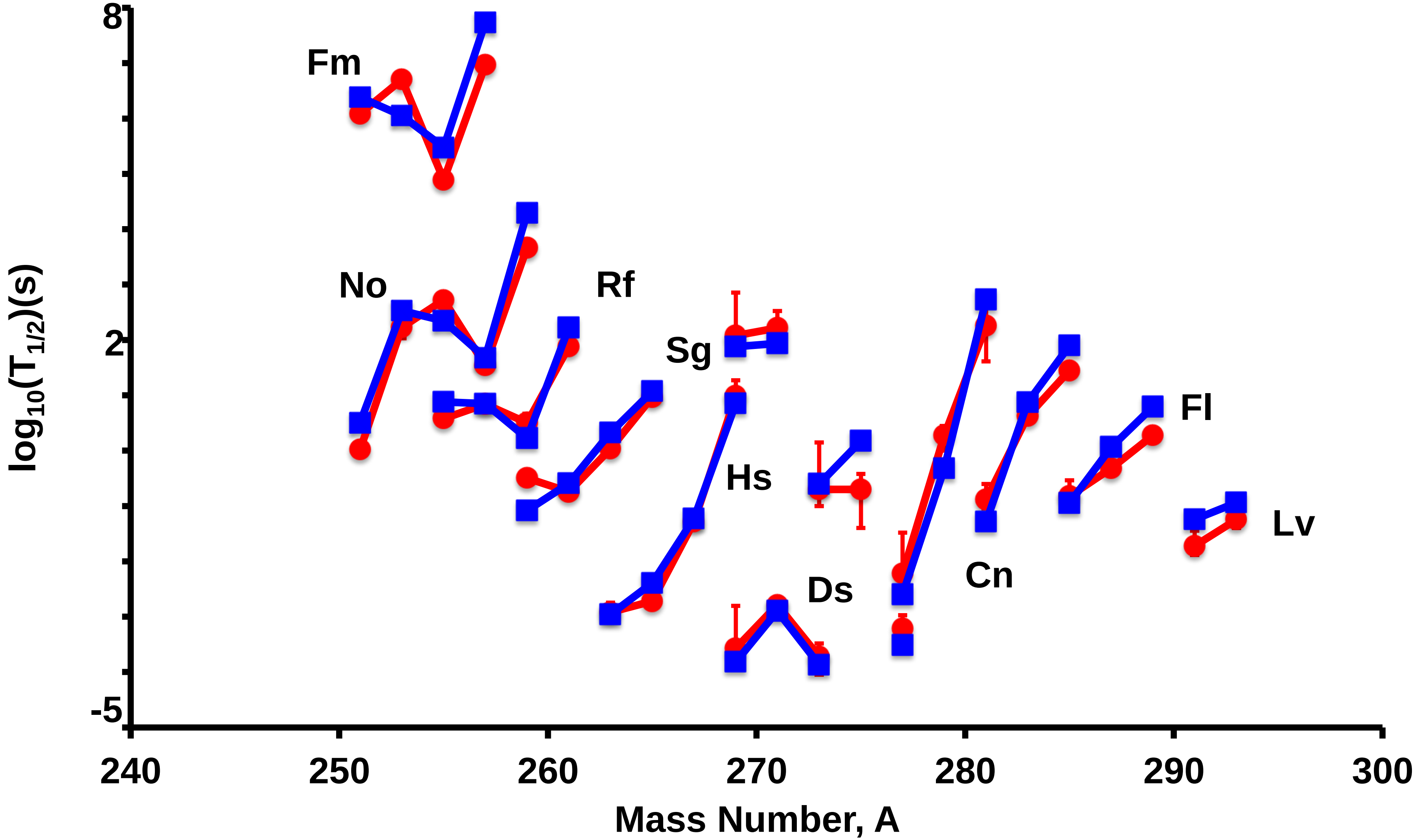
R.M. Clark et al., Phys. Rev. C 99 024325 (2019).

Ambiguities in Decay Chains

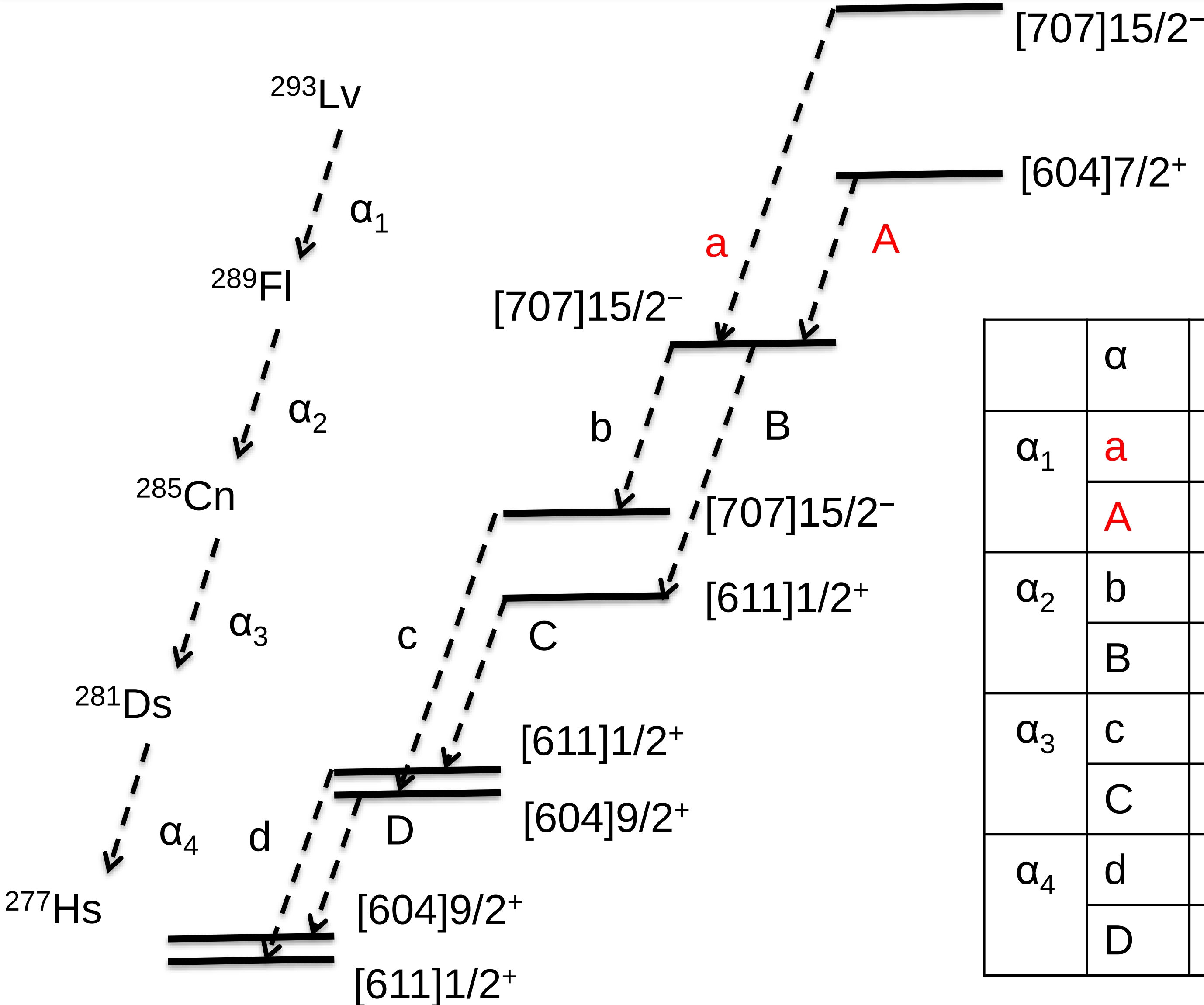
Same Isotopes.
Different $T_{1/2}$
Different Q_{α}



Even-Z, Odd-N SHN



^{293}Lv Decay Chains



Calculations from:
Cwiok, Nazarewicz, Heenen,
PRL 83 1108 (1999)

	α	Q_α(MeV)	L	$T_{1/2}$(s)
α_1	a	11.40	0	1.2×10^{-3}
	A	10.47	5	1.3×10^{0}
α_2	b	9.02	0	1.5×10^{3}
	B	9.64	7	5.3×10^{2}
α_3	c	9.50	3	1.9×10^{1}
	C	8.76	0	1.8×10^{0}
α_4	d	9.44	0	2.8×10^{0}
	D	9.28	0	8.6×10^{0}

Fission

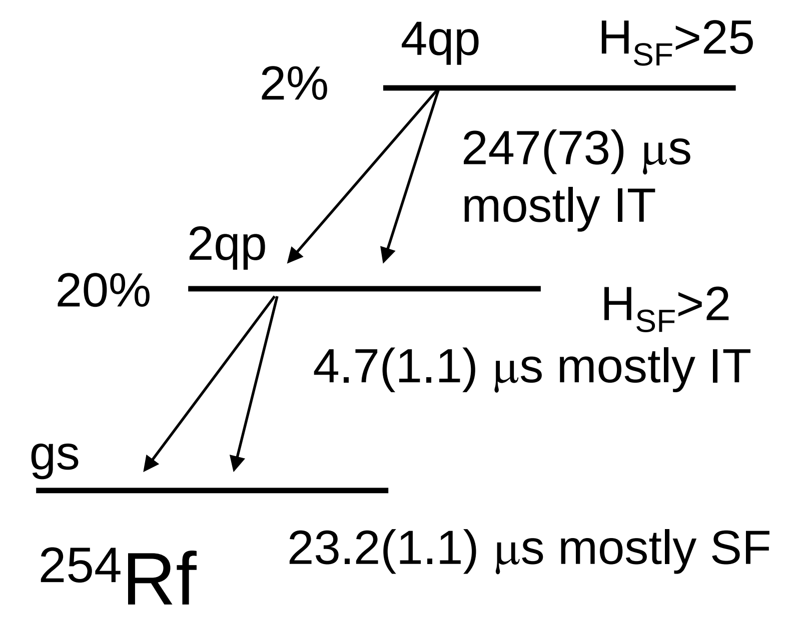
Expectations of Fission Hindrance

Ground-state decay mode is 100% SF with half-life of ~23μs.

Possibility of long-lived isomers that may also have significant SF branch?

The excitation energy of the high-K 2-qp isomer is ~1 MeV (or the fission barrier height, B_f, is ~ 1MeV less for the isomer relative to the ground state).

This will result in a shorter fission half-life



H.M.David et al., Phys. Rev. Lett. 115 132502 (2015)

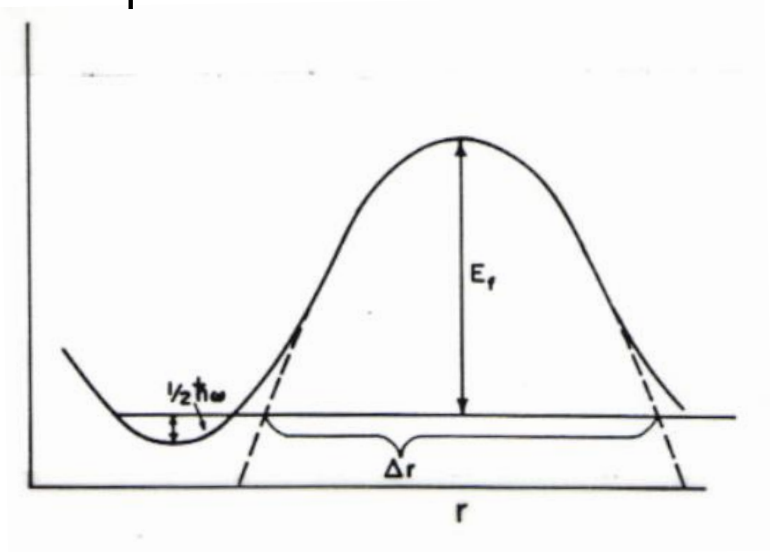
The high-K state will involve broken pairs and it could "look" more like the configuration of the ground state of the odd-odd neighbor

This will result in a longer fission half-life

What do we expect for the fission hindrance of such a high-K isomer?

The Effect from Changing B_f

Simple Parabolic Fission Barrier



R. Vandenbosch and J.R. Huizenga, Nuclear Fission, Academic Press 1973

Loveland, Morrissey, and Seaborg, Nuclear Chemistry, Wiley and Sons 2006

The fission half life can be expressed as:

$$t_{1/2}=2.77\times10^{-21}\exp[2\pi(B_f)/\hbar\omega]$$

Barrier height, Bf = 6 MeV

Barrier curvature = 0.5 MeV

➔ $t_{1/2} = 1.5 \times 10^{12}$ s

Barrier height, Bf = 5 MeV

Barrier curvature = 0.5 MeV

➔ $t_{1/2} = 5.4 \times 10^{6}$ s

One expects the decay of the isomer to be ~3×10^{5} faster

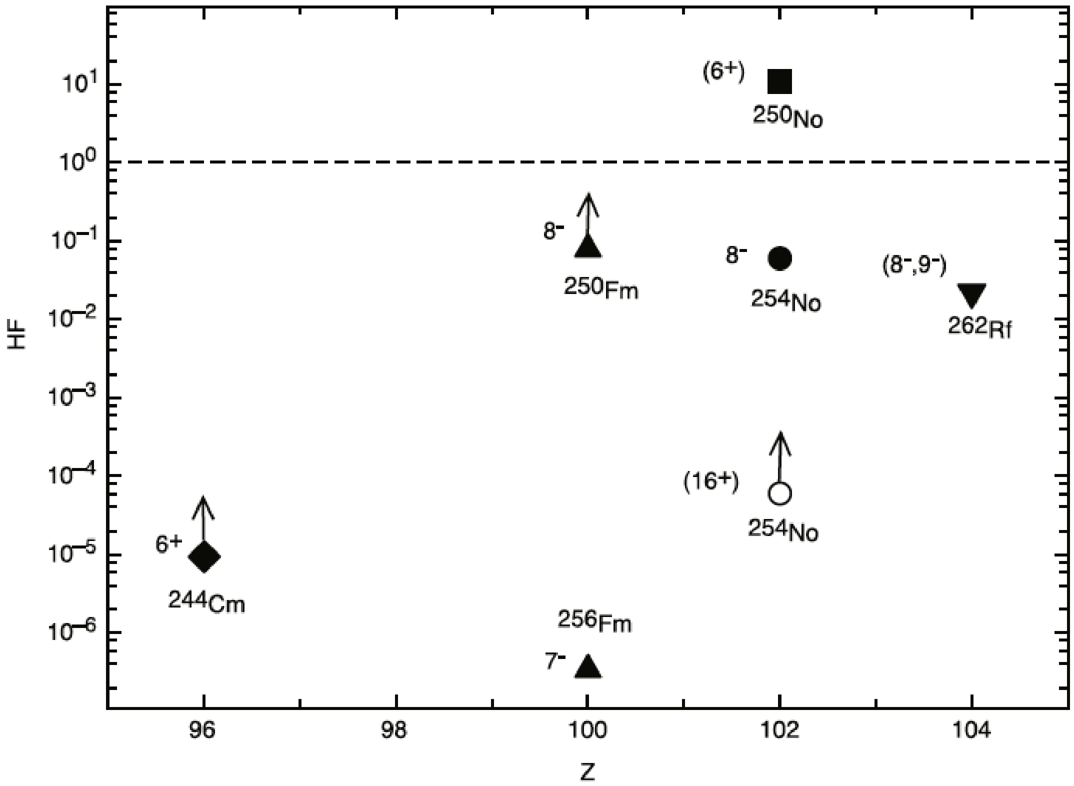
The Effect from Odd-Odd Character

$^{255}_{105}Db_{150}$ ~20% SF, $t_{1/2}$=1.6(5)s HF=3.5×10^{5}	$^{256}_{105}Db_{151}$ ~0.02% SF, $t_{1/2}$ = 1.9(4)s HF=4.1×10^{8}
$^{254}_{104}Rf_{150}$ ~100% SF, $t_{1/2}$=23(3)μs	$^{255}_{104}Rf_{151}$ ~48% SF, $t_{1/2}$=2.3(7)s HF=2.1×10^{5}

One expects the decay of the isomer to be ~4×10^{8} slower due to odd particles

Fission Hindrances of Multi-QP Isomers

I'd expect K-isomer HF~10^3-10^5



F.G.Kondev, G.D.Dracoulis, T.Kibedi,
Atomic Data and Nuclear Data Tables 103-104 (2015) 50

Changing B_f by 1MeV gives HF of ~10^{-5}

Odd-Odd "character" gives HF of ~10^8-10^{10}

Available data does not indicate such hindrances

^{244}Cm, ^{250}Fm, ^{254}Rf all lower limits (no positive identification of a fission branch from isomer).

^{250}No story changing (EM-decay branch reported at TAN15)

^{262}Rf likely misassigned
(M. Murakami et al., PRC 88 (2013) 024618)

Leaves ^{256}Fm and ^{254}No cases needing to be confirmed

Summary

- Alpha decay is probing stability of states in heaviest nuclei
- Clear indications of isomers providing extra stability
- All ingredients (Q_α, L, pairing) essential to understanding
- Superfluid Tunneling Model is able to reproduce known data

- Fission decay from isomeric states has yet to be confirmed
- It will provide a new tool to understand fission process
- Pairing (dynamic), Specialization (role of odd particles, K purity)

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ありがとうございます。

Thank you very much.