Shapes, softness, and non-yrast collectivity in ^{186}W

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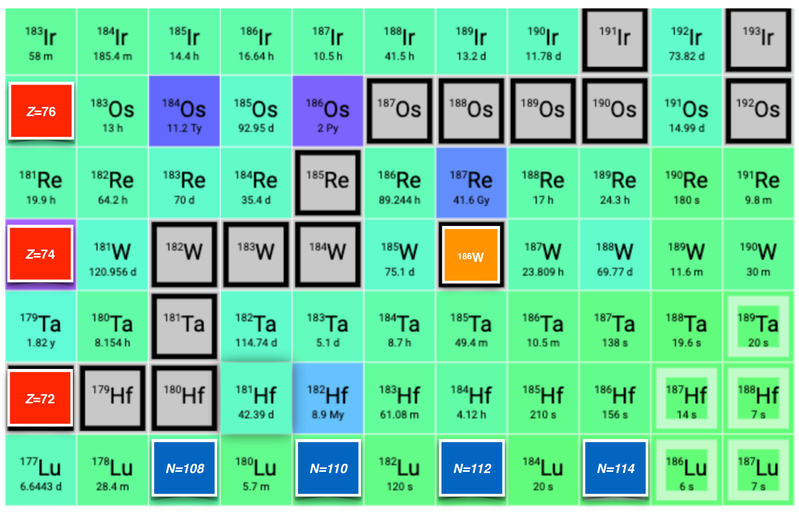
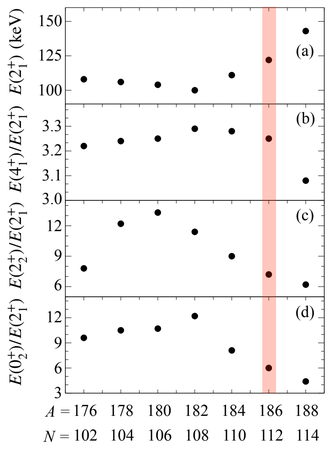
Nuclear shapes near ^{186}W

Figure modified from 'The Colourful Nuclide Chart': https://people.physics.anu.edu.au/~ecs103/chart/

Atomic nuclei in rare-earth and transition elements, between axially symmetric, prolate-deformed ^{170}Dy at mid-shell and spherical, doubly magic ^{208}Pb, have long been predicted to pass through a region of soft, triaxial shapes that evolve into oblate deformation as *Z* and/or *N* increase.

In the W isotopes, shape transitions and *K*-isomers associated with axially symmetric shapes have been identified. Energy systematics and $B(E2;2^+_1 \rightarrow 0^+_1)$ values indicate that ^{186}W, the focus of this work, lies beyond maximum axial deformation and is softening.





Energy systematics in some even-even W isotopes.

Tungsten-186 is the heaviest stable W isotope. Its low-lying structure has been investigated; however, experimental data on the non-yrast, higher-spin states are sparse due to the lack of any suitable heavy-ion fusion-evaporation reaction.

While level spacings and lifetimes of ground-state-band members reveal the overall shape and collectivity, rotational side bands contain more nuanced information on softness to vibrations and axial asymmetry.

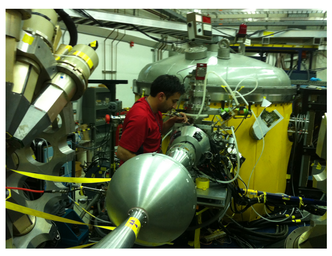
Gammasphere + CHICO2, ATLAS Facility, Argonne National Laboratory USA

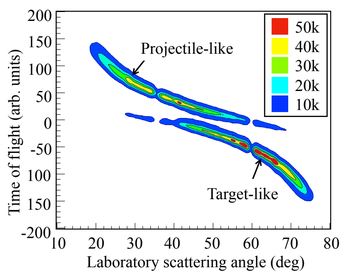
Gammasphere: https://www.anl.gov/phy/gammasphere. CHICO2: C. Y. Wu, *et al.* Nucl. Instrum. Meth. A 814, 6 (2016).

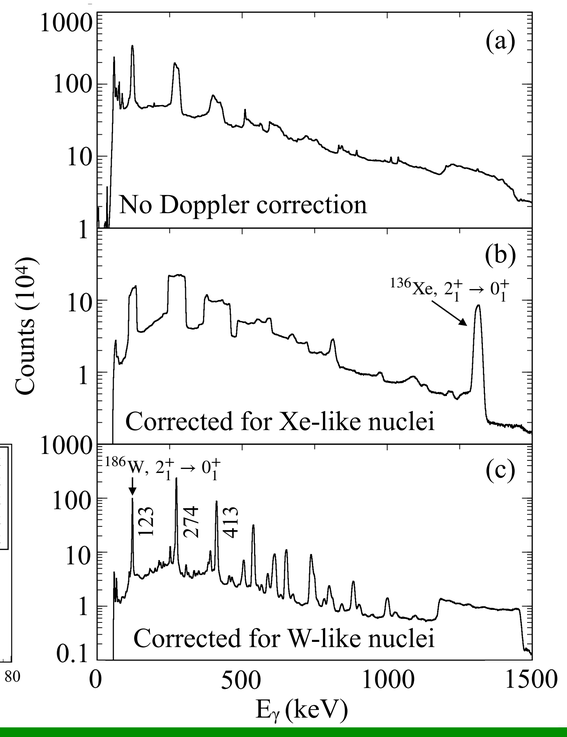
Inelastic scattering of ^{136}Xe beams at 725 and 800 MeV (10 and 20% above the Coulomb barrier, respectively).

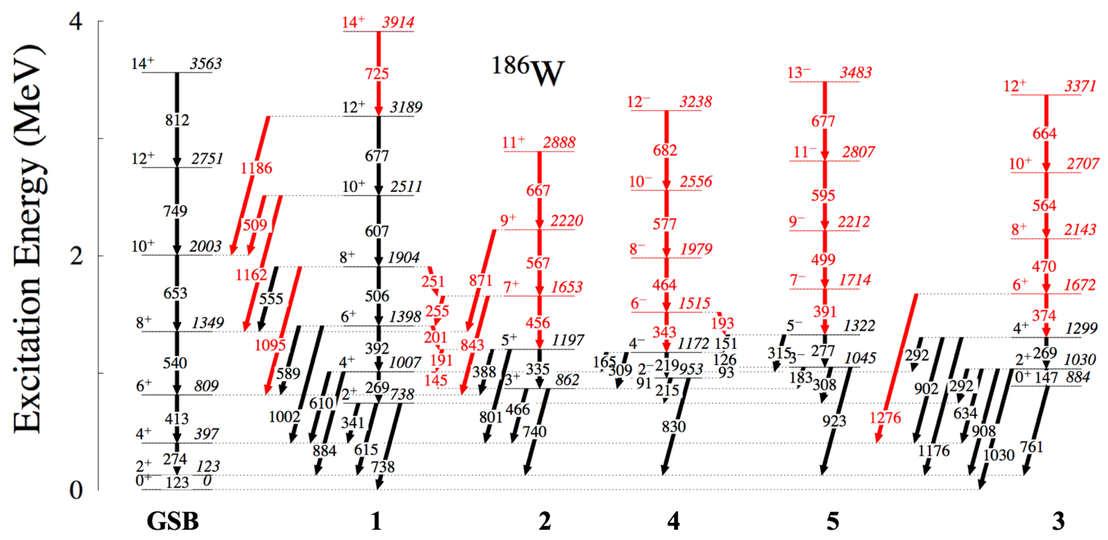
Beams impinged upon a thin target of ^{186}W (99.8% enriched), 250-μg/cm² thick and backed by a 110-μg/cm² thick, carbon foil.

Scattered beam- and target-like ions were detected and identified with the upgraded Rochester-Livermore 4π compact heavy-ion counter, CHICO2. Gamma-rays were detected by Gammasphere.









Level scheme from this work. Expansion of the rotational bands shown in red.

Band staggering

E. A. McCutchan *et al.*, Phys. Rev. C 76, 024306 (2007); A. Davydov and G. Filippov, Nucl. Phys. 8, 237 (1958); L. Wilets and M. Jean, Phys. Rev. 102, 788 (1956).

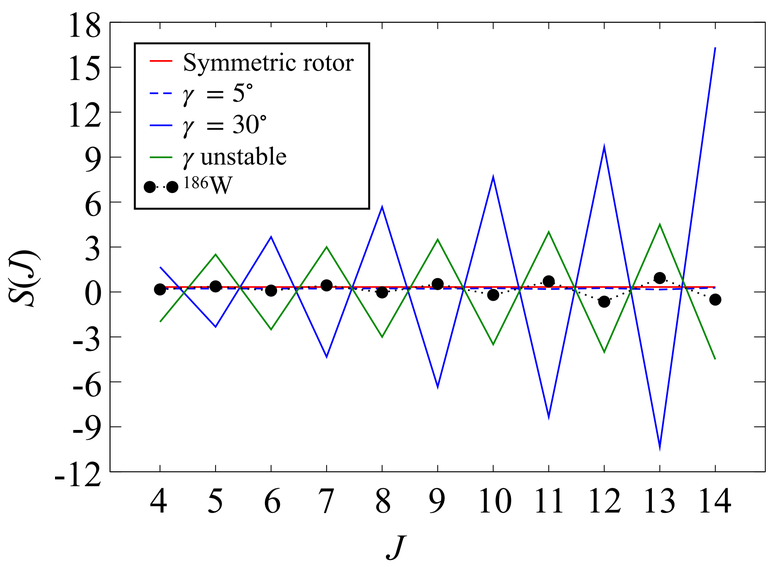
By finding and extending the odd-spin members of the γ band, the issue of rigid deformation versus triaxial softness can be explored through examination of the so-called even- and odd-spin staggering:

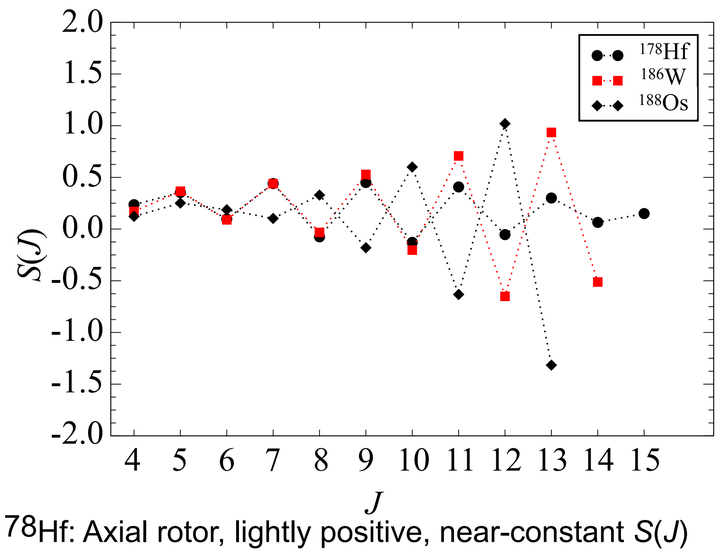
$$S(J) = \frac{[(E(J) - E(J-1)] - [E(J-1) - E(J-2)]}{E(2^+_1)}$$

where the staggering parameter *S*(*J*) is determined from the energy differences between levels with ΔJ = 1 within the rotational band.

Staggering patterns predicted for a variety of nuclear shapes are shown to the right.

- **Axial** shapes have small, **positive constant** values.
- **Rigid triaxial** shapes have **positive** values for **even *J*.**
- ***γ*-soft** shapes have **positive** values for **odd *J*.**





^{178}Hf: Axial rotor, lightly positive, near-constant *S*(*J*)

^{186}W: γ-soft, with positive *S*(*J*) values for odd-*J* spins

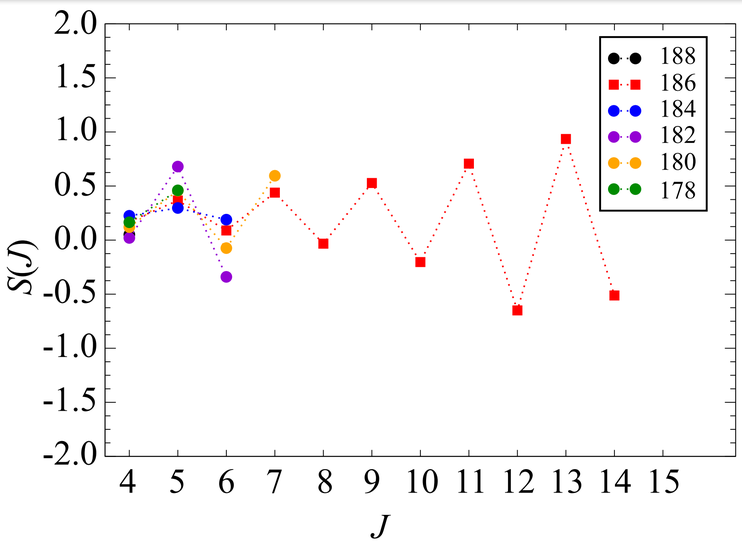
^{188}Os: axial at low spin, small positive *S*(*J*) values, but transitions to large, positive *S*(*J*) for a rigid, triaxial shape.

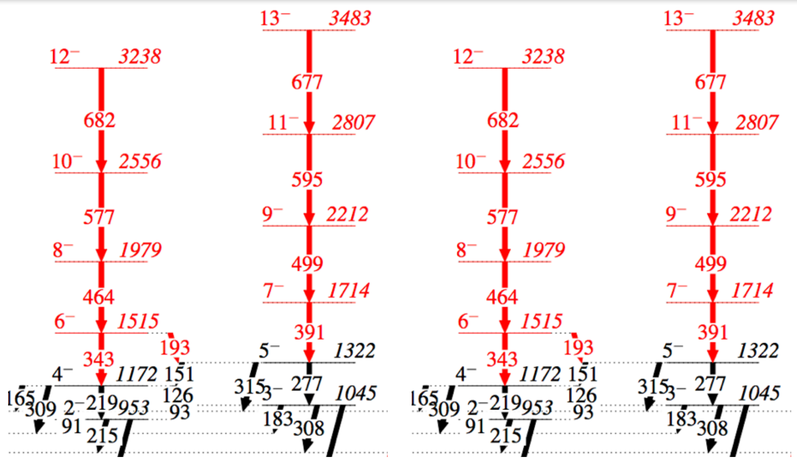
The $K^\pi = 2^+$ band… … and the $K^\pi = 2^-$ band

F. K. McGowan, W. T. Milner, R. O. Sayer, R. H. Robin- son, and P. H. Stelson, Nucl. Phys. A 289, 253 (1977); G. Alaga, K. Alder, A. Bohr, and B. R. Mottelson, Dan. Mat. Fys. Medd. 29, 1 (1955).

Staggering patterns observed in the W isotopes:

- ^{186}W staggering phase consistent with a γ-soft potential (+ve values for odd *J*).
- Other isotopes have limited data.
- Further experiments needed to locate the oblate shape transition predicted in ^{186}W





$K^\pi = 2^-$ signature partners? OR $K^\pi = 2^-$ and $K^\pi = 3^-$ bands?

Can use Alaga rules to check:

$$R = \frac{Br_\gamma(3^-_1 \rightarrow 2^+_2) \times E_\gamma(3^-_1 \rightarrow 3^+_1)^3}{Br_\gamma(3^-_1 \rightarrow 3^+_1) \times E_\gamma(3^-_1 \rightarrow 2^+_2)^3}.$$

	R(*K*=2)	R(*K*=3)	Expt.
J = 3⁻	0.71	2.86	0.66(2)
J = 4⁻	1.66	1.66	1.50(8)
J = 5⁻	2.86	1.28	<5

Measured γ-decay branching ratios consistent with signature partners of a strongly coupled, $K^\pi=2^-$ octupole vibrational band.

This material is based upon work supported by the U.S. Department of Energy, Office of Science, Office of Nuclear Physics under Grants No. DE-FG02-94ER40848 (UML), No. DE- FG02-97ER41041 (UNC), No. DE-FG02-97ER41033 (TUNL) and DE-FG02-94-ER40834 (UMCP), and Contracts No. DE-AC02-06CH11357 (ANL) and No. DE-AC52-07NA27344 (LLNL), the International Technology Center Pacific (ITC-PAC) under Contract No. FA520919PA138 (ANU), and the National Science Foundation. The research used resources of ANL's ATLAS facility, which is a DOE Office of Science user facility.

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