

# A Systematic Description of the Wobbling Motion in Odd-Mass Nuclei Within a Semi-Classical Formalism

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*A presentation for the degree of Doctor of Philosophy*

May 12, 2023

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2 Nuclear Shapes

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# Aim



## Research Objectives

- Extend the current interpretation of the **nuclear triaxiality** in the context of its unique fingerprint: **Wobbling Motion**
- Adopt a framework that is as close as possible to **classical physics**.
- Provide new formalisms for the phenomena related to **nuclear deformation**.

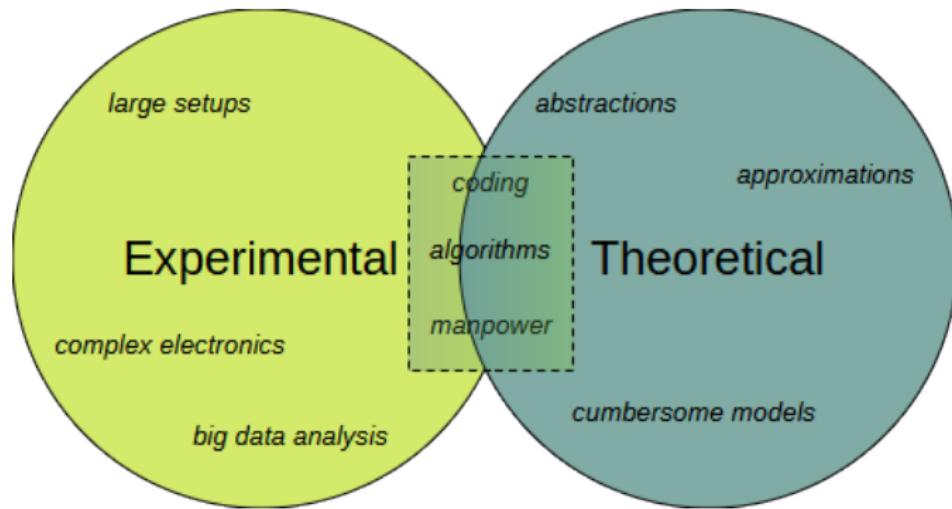


## Objectives exclusive to the thesis

- Give the reader enough context towards a better understanding of the underlying concepts, methods, and results.
- Create a completely *open-source* project.

# Motivation

- **Nuclear Triaxiality** has become a *hot topic* within the scientific community.
- Identifying nuclei with triaxial deformations represents a real **experimental** and **theoretical** challenge.



# Nuclear Deformation

## Nuclear Radius

The **shape** of the nucleus is most generally described in terms of the *nuclear radius*:

$$R(\theta, \varphi) = R_0 \left( 1 + \sum_{\lambda=0}^{\infty} \sum_{\mu=-\lambda}^{\lambda} \alpha_{\lambda\mu} Y_{\lambda}^{\mu}(\theta, \varphi) \right) \quad (1)$$

## Quadrupole deformations $\lambda = 2$

- **For us:** Most relevant modes are the **quadrupole vibrations**  $\lambda = 2$   
 $\implies$  Play a crucial role in the rotational spectra of nuclei:
- *Bohr, 1969:* Coordinates  $\alpha_{2\mu}$  can be reduced to only two *deformation parameters*:  $\beta_2$  (**eccentricity**) and  $\gamma$  (**triaxiality**).

# Axial shapes

## Collective coordinates

- Most of the nuclei are either **spherical** or **axially symmetric** in their ground-state (*Budaca, 2018*).
- Moments of inertia:  $\mathcal{I}_{1,2,3}$ : two are equal, one is different.

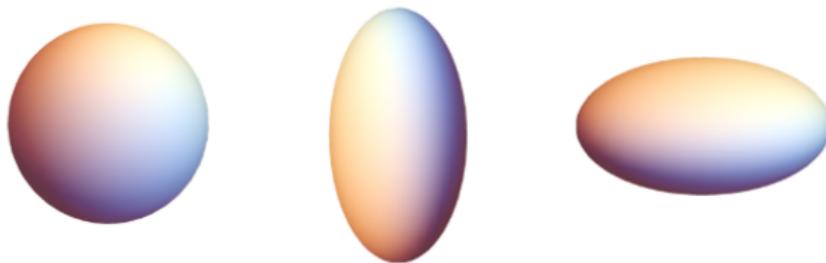
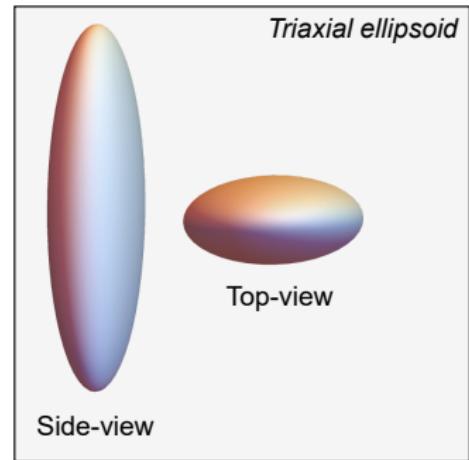
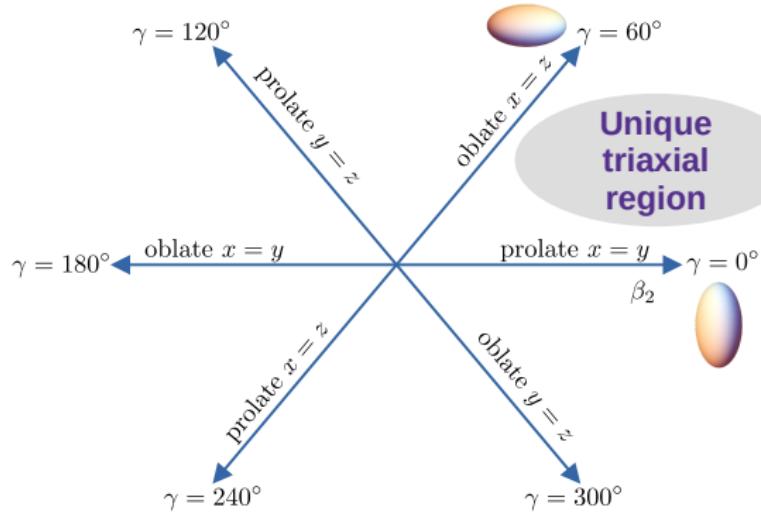


Figure: **spherical**:  $\beta_2 = 0$  **prolate**:  $\beta_2 > 0$  **oblate**:  $\beta_2 < 0$ . ( $\gamma = 0^\circ$ ).

# Non-axial shapes

- The triaxiality parameter  $\gamma \neq 0^\circ$ : departure from axial symmetry.
- Moments of inertia:  $I_1 \neq I_2 \neq I_3$ .



# Fingerprints of Triaxiality

## Evidence

- Currently, there are **only two** well-established phenomena uniquely attributed to triaxial deformation.
  - ① **Wobbling Motion** - WM (*Bohr and Mottelson, 1970s*)
  - ② Chiral Motion -  $\chi$ M (*Frauendorf, 1997*)
- These two can be measured/detected experimentally.

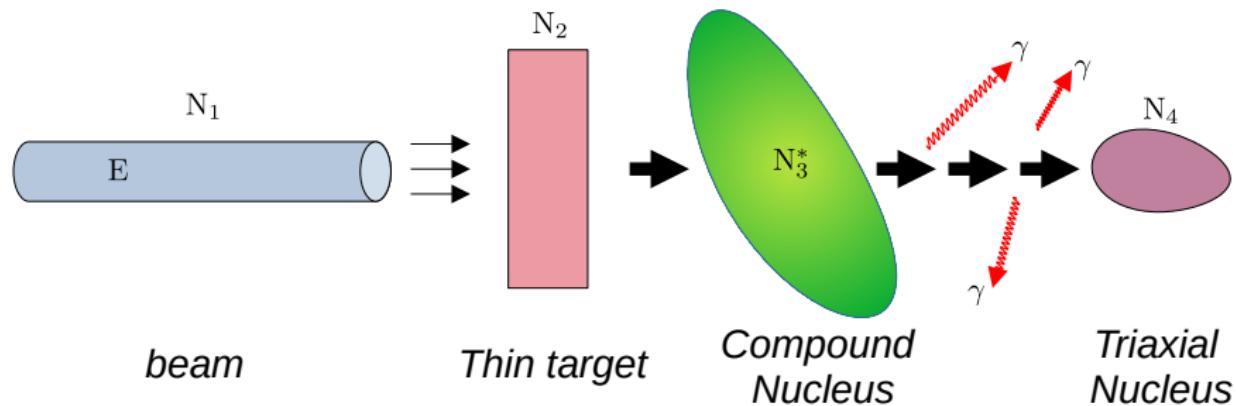
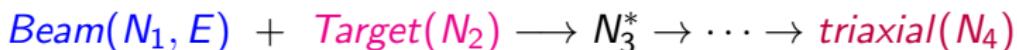
## Goal

**Describe the elusive character of Wobbling Motion in the context of nuclear triaxiality.**

# Q Probing triaxiality in nuclei

Triaxial nuclei can be observed/obtained in several experiments:

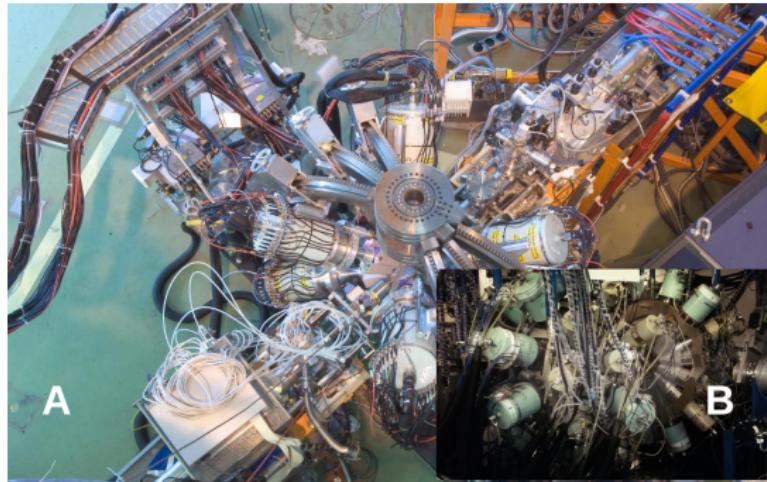
- Nuclear fission:  $A \rightarrow B + C$
- Nuclear fusion:  $X + Y \rightarrow Z$
- **Fusion-evaporation reactions:** Long-lived + enhanced deformation



# Q Nuclear facilities

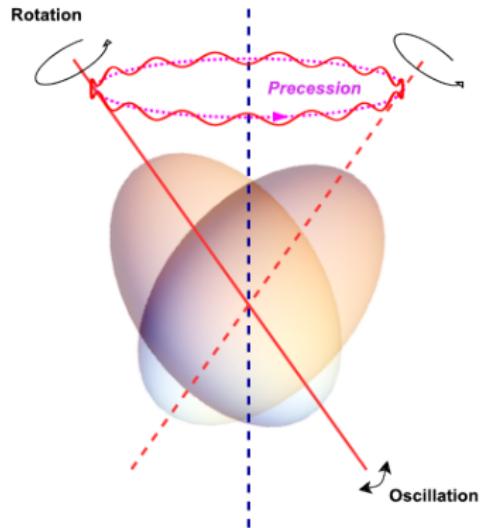
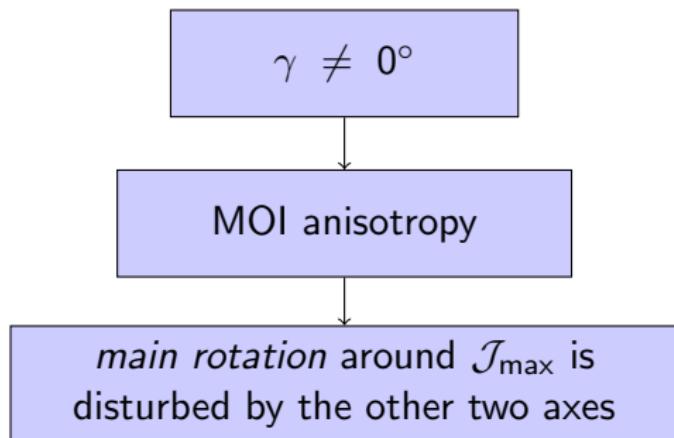


**Figure:** Gammasphere detector, ANL-ATLAS USA. *Source: aps.org*



**Figure:** a) IDS detector, CERN. *Source: isolde.web.cern.ch* b) JUROGAM II, Finland. *Source: twitter.com*

# Wobbling Motion



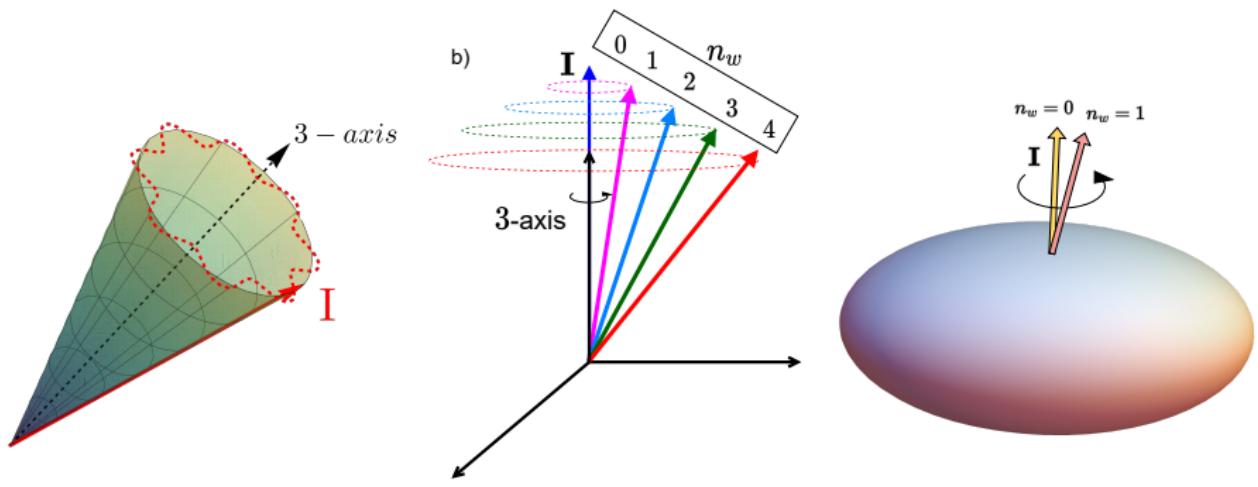
## Wobbling Effect

- The **total angular momentum** of the nucleus **precesses** and **oscillates** around  $\mathcal{J}_{\max}$ .

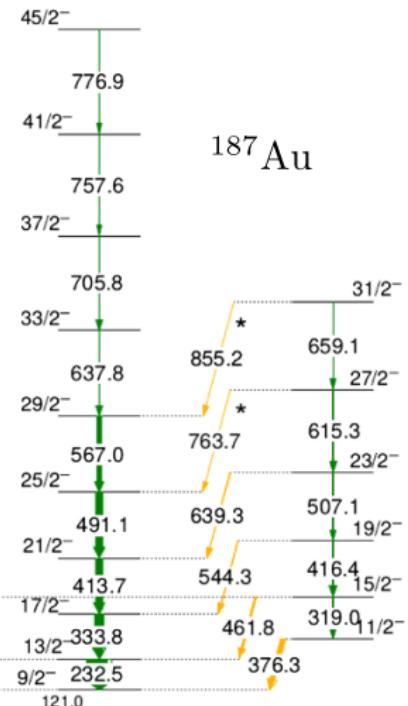
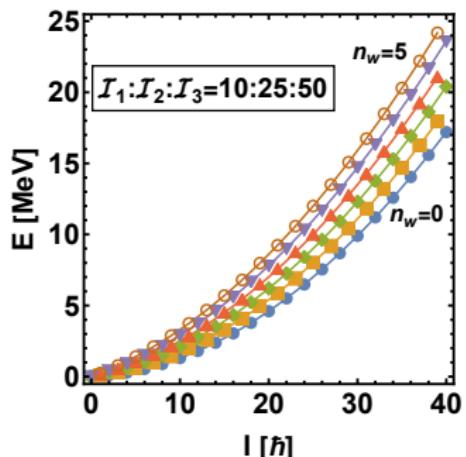
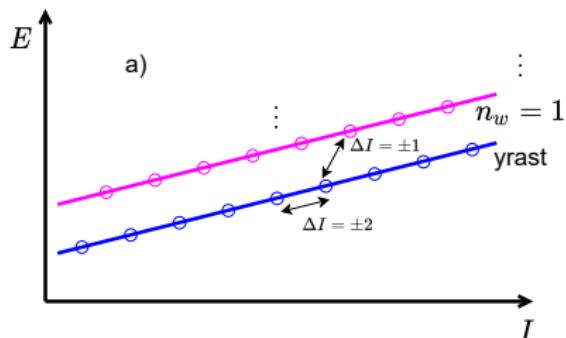
## Wobbling Motion

## Harmonic oscillation

- Precession of  $\mathbf{I}$  is affected by **rotational frequency** and/or **tilting**
  - Tilting only by "specific" amount  $\rightarrow$  **harmonic character**  $\rightarrow$  **wobbling phonon**:  $n_w = 0, 1, 2, \dots$



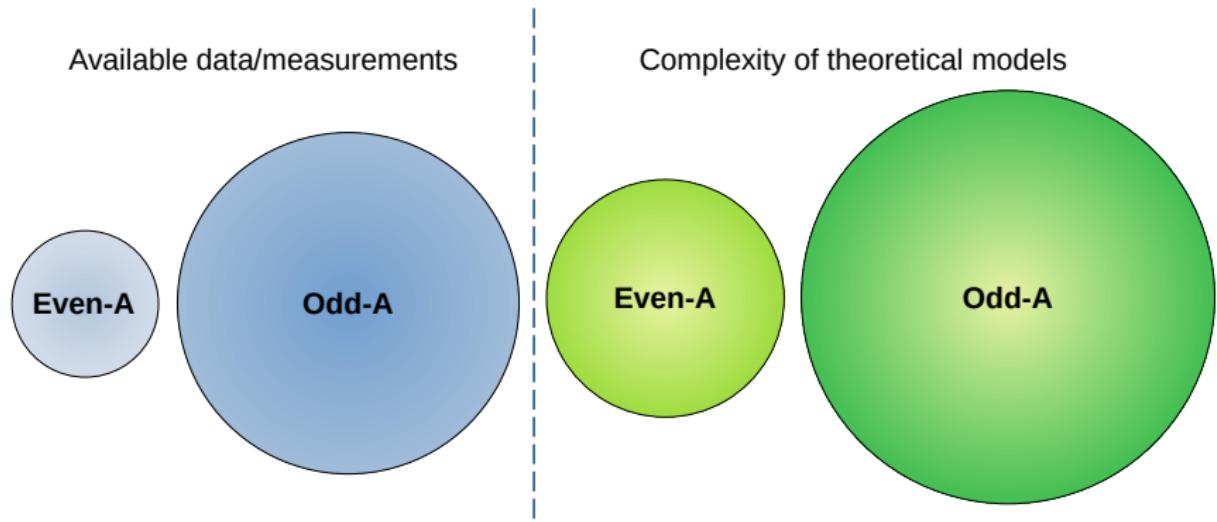
# Wobbling Motion II

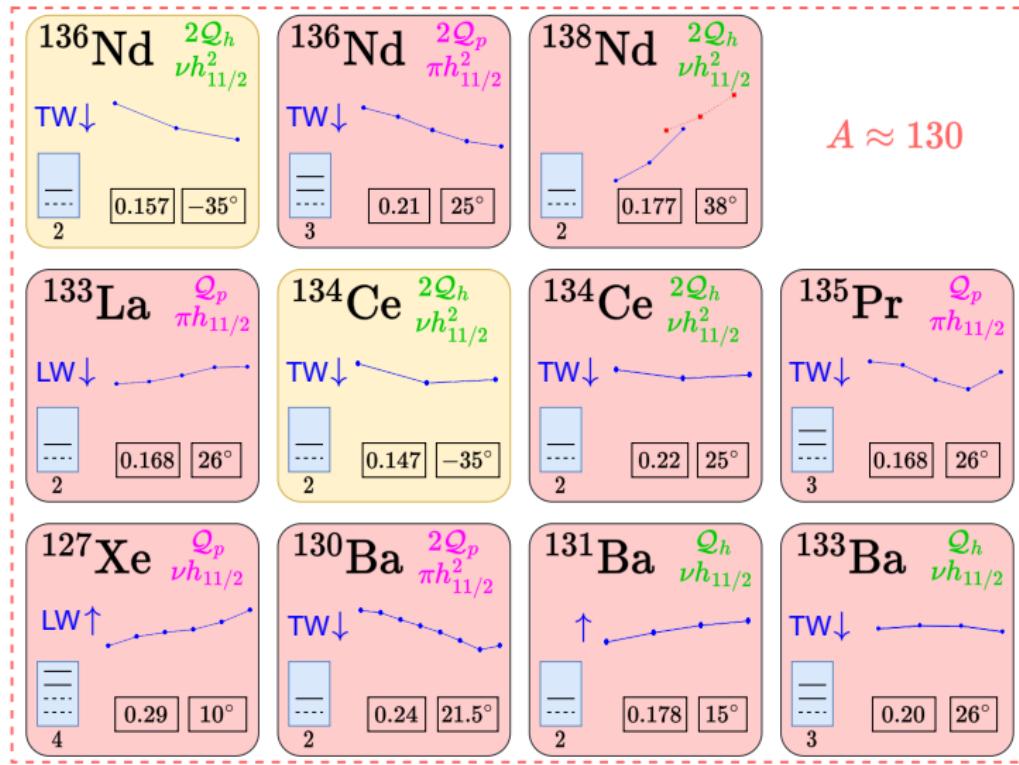


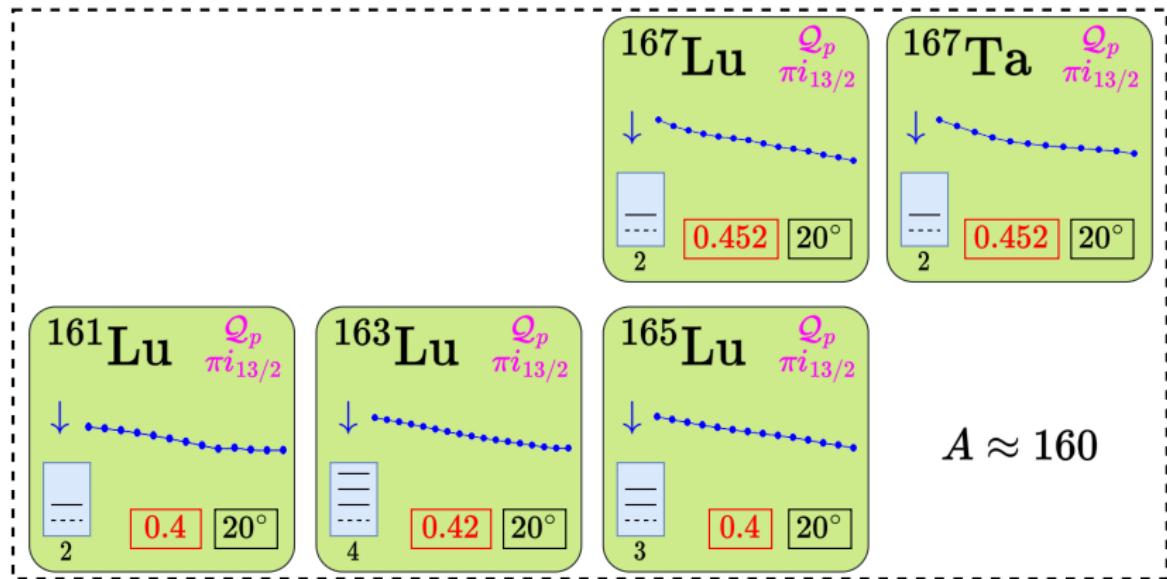
Sensharma, 2020.

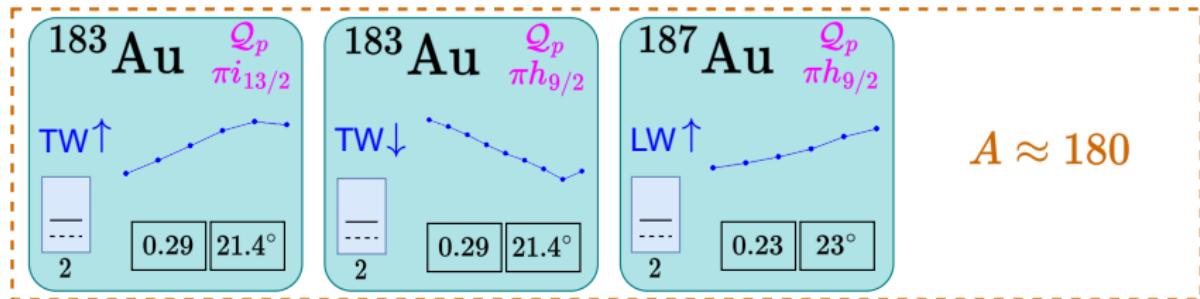
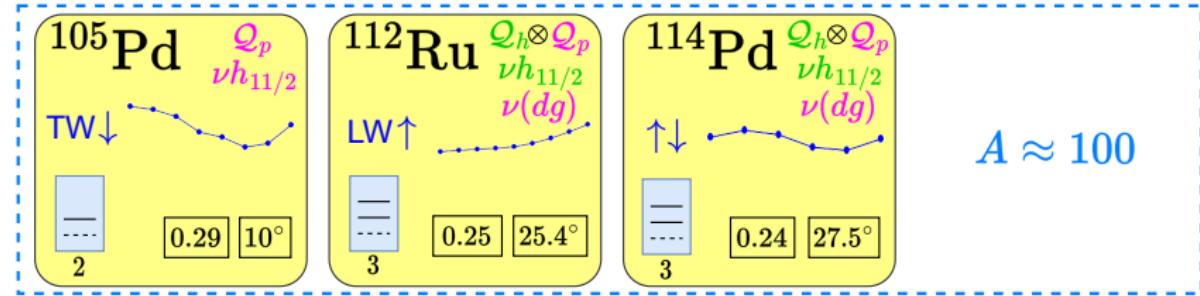
# Even- $A$ vs. Odd- $A$ Picture

- First experimental evidence for **nuclear wobbling motion** in 2001.
- Current mass-regions for wobblers:  $A = 130, 160, 180$ .



Latest wobblers  $A=130$ 

Latest wobblers  $A=160$ 

Latest wobblers  $A=180$ Recent progress around  $A \approx 100$  (?)

Thank you for your attention ❤