

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

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2 Introduction

- Nuclear Shapes

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**.

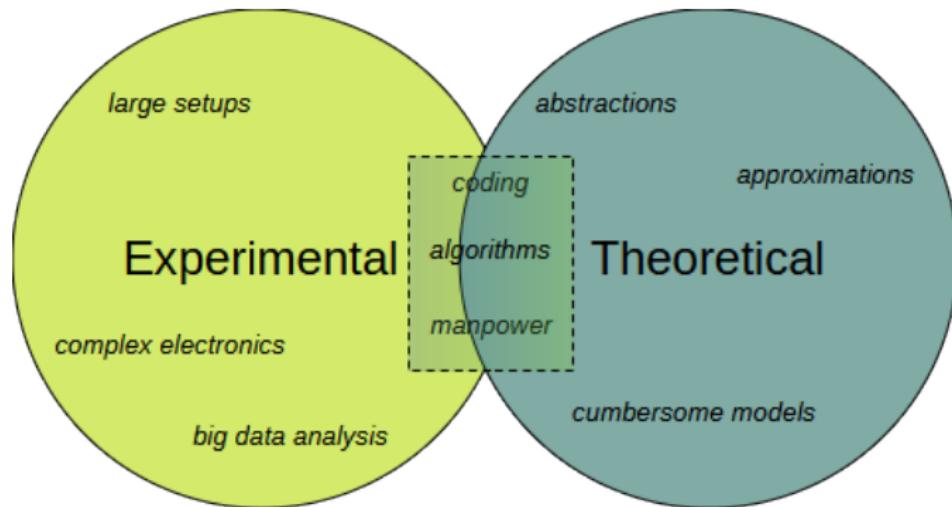


Objectives exclusive to the thesis

- 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.



Fingerprints of Triaxiality

Evidence

- Currently, there are **only two** well-established phenomena uniquely attributed to triaxial deformation.
 - ① **Wobbling Motion** WM (*Bohr and Mottelson, 1950s*)
 - ② **Chiral Motion** χ M (*Frauendorf, 1997*)
- These two can be measured/detected experimentally.

Experimental observations

First experimental evidence for **nuclear wobbling motion** in 2001.

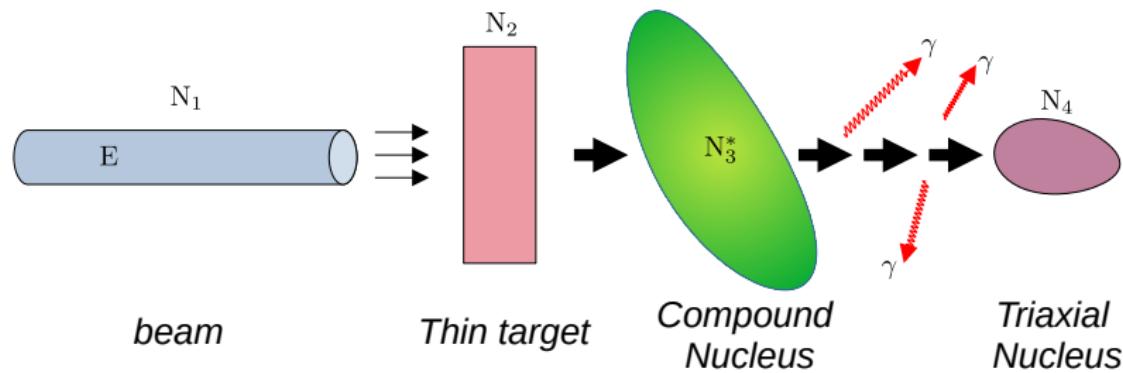
Goal

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

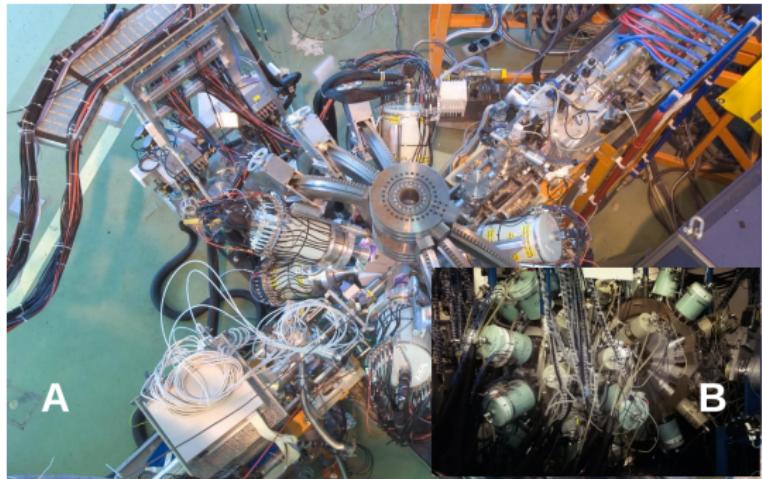


Figure: a) IDS detector, CERN. Source: isodel.web.cern.ch b) JUROGAM II, Finland. Source: twitter.com

Nuclear Shapes (in the context of WM)

Nuclear Radius

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

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

Quadrupole deformations

- **For us:** Most relevant modes are the **quadrupole vibrations** $\lambda = 2$
 \Rightarrow *Play a crucial role in the rotational spectra of nuclei:*

Axial shapes

Collective coordinates

- Most of the nuclei are either **spherical** or **axially symmetric** in their ground-state (Budaca, 2018).
- Coordinates $\alpha_{2\mu}$ can be reduced to only two *deformation parameters*: β_2 (*eccentricity*) and γ (*triaxiality*).
- Moments of inertia: $\mathcal{I}_{1,2,3}$: two are equal, one is different.

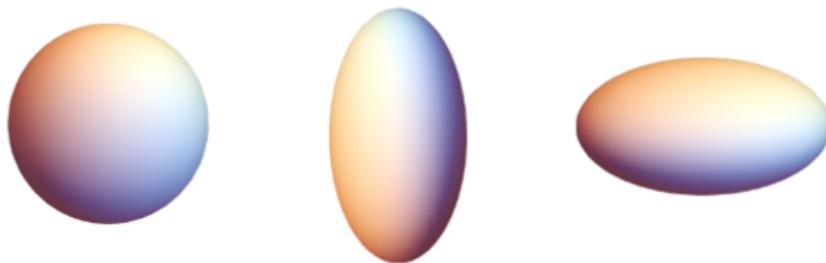
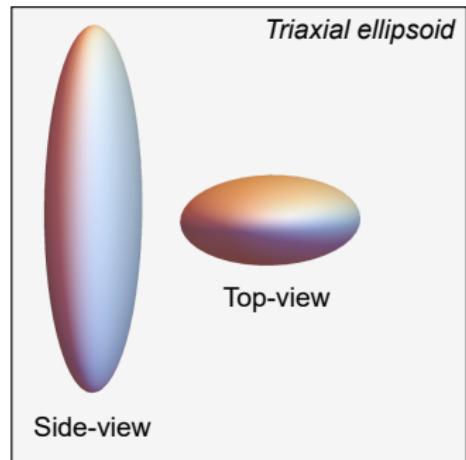
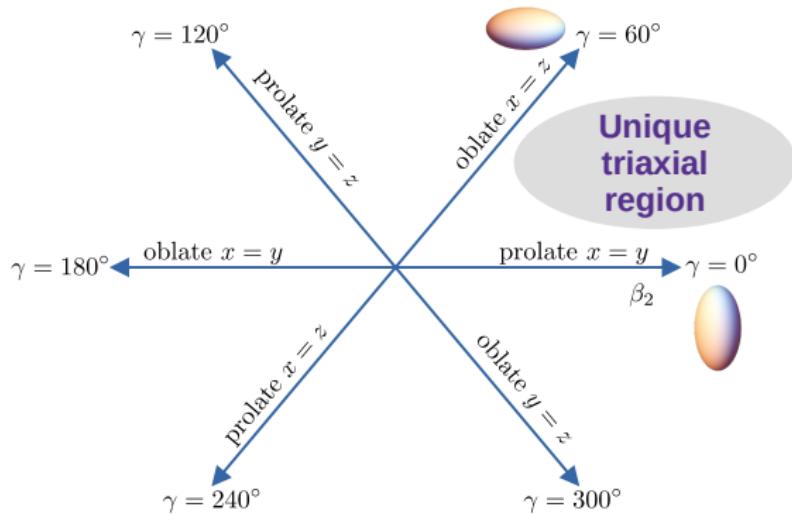


Figure: **spherical**: $\beta_2 = 0$ **prolate**: $\beta_2 > 0$ **oblate**: $\beta_2 < 0$. ($\gamma = 0^\circ$).

Non-axial (triaxial) shapes

- The triaxiality parameter γ (Bohr, 1969): departure from axial symmetry.
- Moments of inertia: $I_1 \neq I_2 \neq I_3$.



Wobbling Motion

Characteristics

- $\gamma \neq 0^\circ \rightarrow$ MOI anisotropy \rightarrow the *main rotation* around \mathcal{J}_{\max} is disturbed by the other two axes \rightarrow **resulting motion of the rotating nucleus has an oscillating behavior**
- The **total angular momentum** (a.m.) **precesses** and **wobbles** around \mathcal{J}_{\max}
- Tilting by an energy quanta \sim *vibrational character* \rightarrow **wobbling phonon** $n_w = 0, 1, 2\dots$

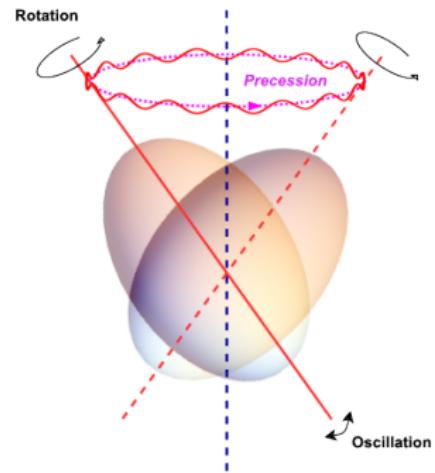
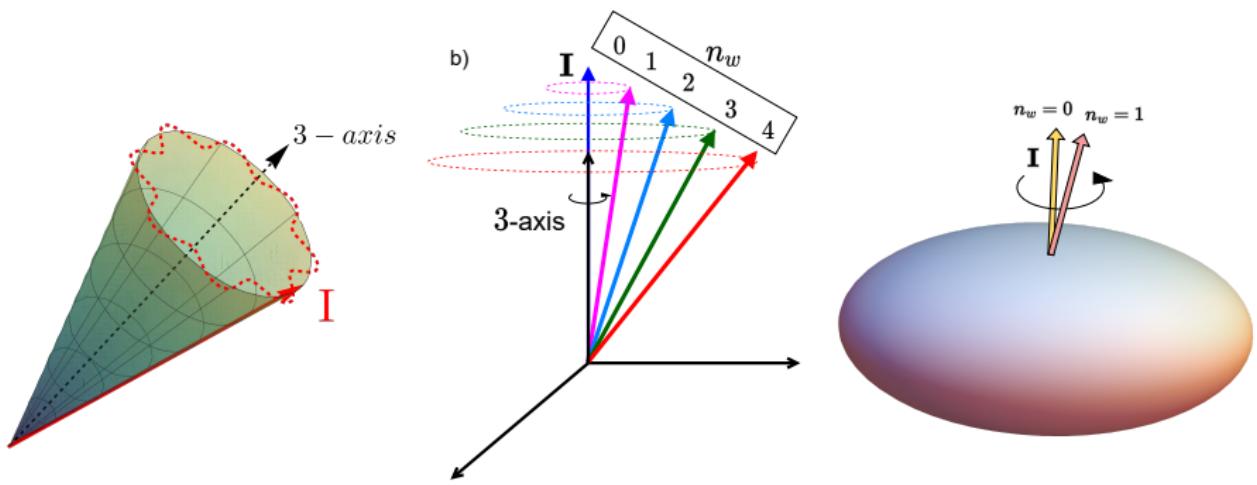


Figure: Geometrical interpretation of a wobbling triaxial nucleus: *rotation + precession + oscillation.* R. Poenaru, PhD Thesis (WIP)

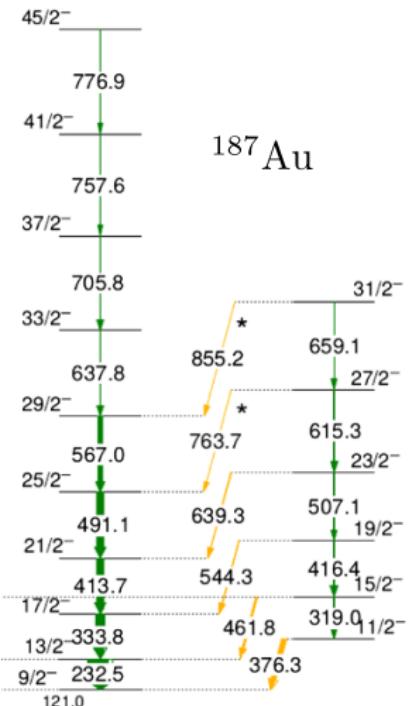
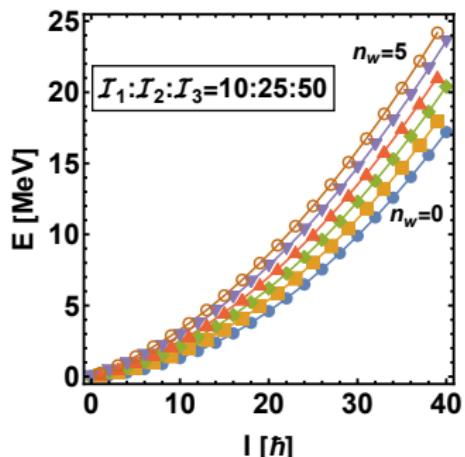
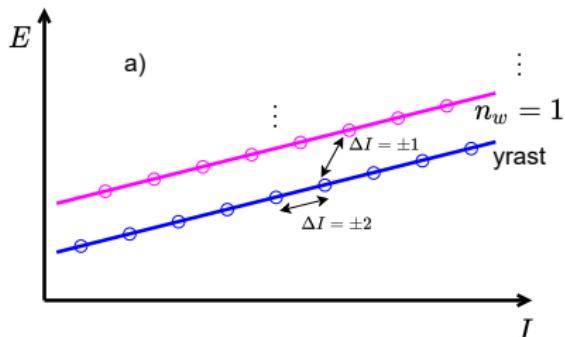
Wobbling Motion

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

Thank you for your attention ❤