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Mean-field derivation of the interacting boson model for exotic nuclear shapes



Kosuke Nomura U. Zagreb





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Microscopic study of IBM

- from shell model
 - OAI mapping (1978)
- applied to vibrational and yunstable nuclei
- general cases (stronglydeformed nuclei) ?
- new development (2008):



PRL 101, 142501 (2008)	PHYSICAL REVIEW LETTERS	week ending 3 OCTOBER 2008
Mean-Field Derivation of the Interacting Boson Model Hamiltonian and Exotic Nuclei		
Kosuke Nomura, ¹ Noritaka Shimizu, ¹ and Takaharu Otsuka ^{1,2,3,4}		

Self-consistent mean field: DFT

... universal, microscopic description of intrinsic properties of arbitrary nuclei



Calculation of **spectra** within DFT is demanding \rightarrow Construct IBM from DFT?

DFT-to-IBM mapping

Potential energy surface
obtained from constrained
SCMF (HFBCS, HFB)

2. ... mapped to expectation value of the IBM Hamiltonian \rightarrow IBM parameters



3. Diagonalise the mapped IBM Hamiltonian in **lab. frame** \rightarrow **Observables** (energies, electromagnetic transitions, etc)

Derived parameters for Sm isotopes

$$\hat{H}_{\rm IBM} = \epsilon (\hat{n}_{d\nu} + \hat{n}_{d\pi}) + \kappa \hat{Q}_{\nu}^{\chi_{\nu}} \cdot \hat{Q}_{\pi}^{\chi_{\pi}}$$



Energies



... Problem with deformed rotor

Physica Scripta, Vol. 22, 468-474, 1980

Features of Nuclear Deformations Produced by the Alignment of Individual Particles or Pairs

Aage Bohr and Ben R. Mottelson

The Niels Bohr Institute and Nordita, Blegdamsvej 15, DK-2100 Copenhagen, Denmark

... some properties of deformed rotational nuclei are not satisfactorily accounted for by the IBM

... which is due to the SD truncation

... validity of (sd-)IBM for rotational nuclei?

Boson mapping for deformed nuclei



Moment of inertia of deformed nuclei is underestimated → some correlation is missing

To correct the difference, rotational LL term is introduced:

$$\hat{H}'_{\rm IBM} = \hat{H}_{\rm IBM} + \alpha \hat{L} \cdot \hat{L}$$

Parameters determined from PES

Coefficient a determined from cranking calculation

K.N., T. Otsuka, N. Shimizu, L. Guo, Phys. Rev. C 83, 041302(R) (2011)

Microscopic formulation of the IBM covering deformed nuclei is now complete!



Recent progress (1/4): Triaxial nuclei

Microscopically implemented three-body boson terms; addressed relation between y-rigid and y-unstable pictures

(2012) PHYSICAL REVIEW LETTERS



Robust Regularity in γ-Soft Nuclei and Its Microscopic Realization K. Nomura,¹ N. Shimizu,² D. Vretenar,³ T. Nikšić,³ and T. Otsuka^{1,2,4}



Recent progress (2/4): octupole-deformed nuclei

Editors' Suggestion

39 citatio

Microscopic description of octupole shape-phase transitions in light actinide and rare-earth nuclei

K. Nomura, D. Vretenar, T. Nikšić, and Bing-Nan Lu Phys. Rev. C **89**, 024312 (2014) – Published 24 February 2014



The authors present a systematic analysis of low-lying quadrupole and octupole collective states based on the microscopic energy density functional framework. Consistent with the empirical trend, the resulting nuclear structure characteristics show evidence of a shape transition between stable octupole deformation and octupole softness. Mapping from relativistic DFT to sdf-IBM; first DFT-based calculation



ex: Th isotopes



Recent progress (3/4): Shape coexistence

Developed a new IBM code incl. particle-hole excitations: extend the frontier of microscopic study of shape coexistence



Phys. Rev. C 98, 024303 (2018) - Published 1 August 2018



The cadmium isotopes have been a classic testing ground for vibrational models with various multiphonon states identified. The present calculation follows a well-defined prescription in which the potential energy surface (PES) from a microscopic calculation is input to an interacting boson model calculation by matching that PES. This reduces the number of parameters and allows one to distinguish the vibrational states from cross-shell intruder states.

ex2: identified intruder states out of "vibrational" spectra of Cd isotopes (2018)

Recent progress (4/4): Odd-mass systems

 Using DFT calc. as input, number of free parameters in the interacting boson-fermion model is dramatically reduced;
overcome one of the theoretical challenges



K.N., T. Niksic, D. Vretenar, Phys. Rev. C 93, 054305 (2016) + 7 others

Mean-field derivation of IBM – summary

- IBM is derived for general cases, and attains predictive power;
- IBM and DFT mean-field can be "friends" (a brand new DFT-based approach to nuclear spectroscopy is developed);
- an accurate, systematic, and computationally feasible prediction of exotic nuclear shapes and spectroscopy (octupole, shape coexistence, etc.)

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> For more information please visit: http://bela.phy.hr/quantixlie/hr/ https://strukturnifondovi.hr/

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