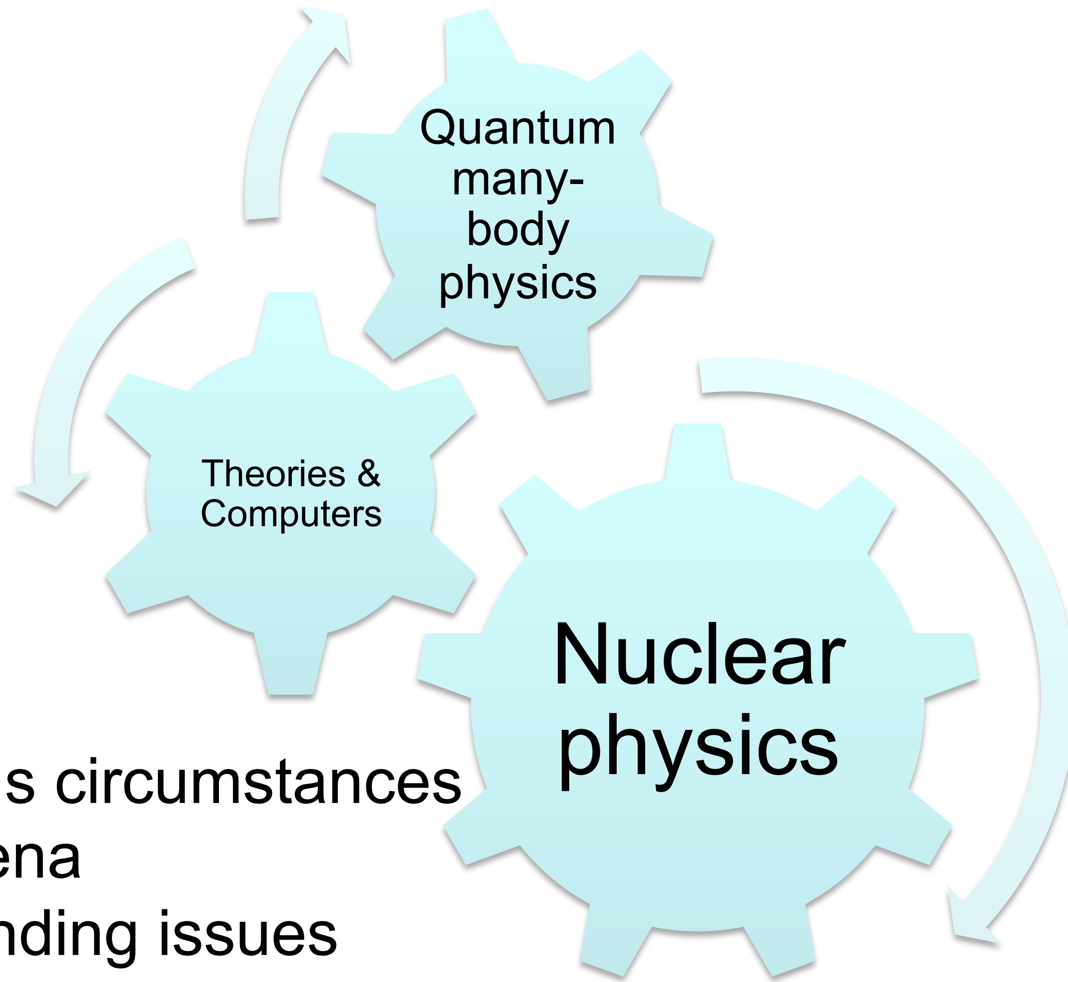
Division of Astrophysics and Nuclear Physics: Nuclear Physics Group (2)

Takashi Nakatsukasa

@CCS, Univ. of Tsukuba, 2014.2.18

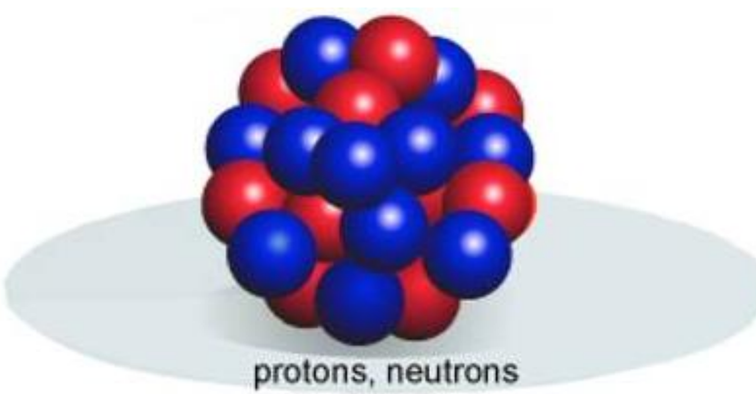
Goals of our researches



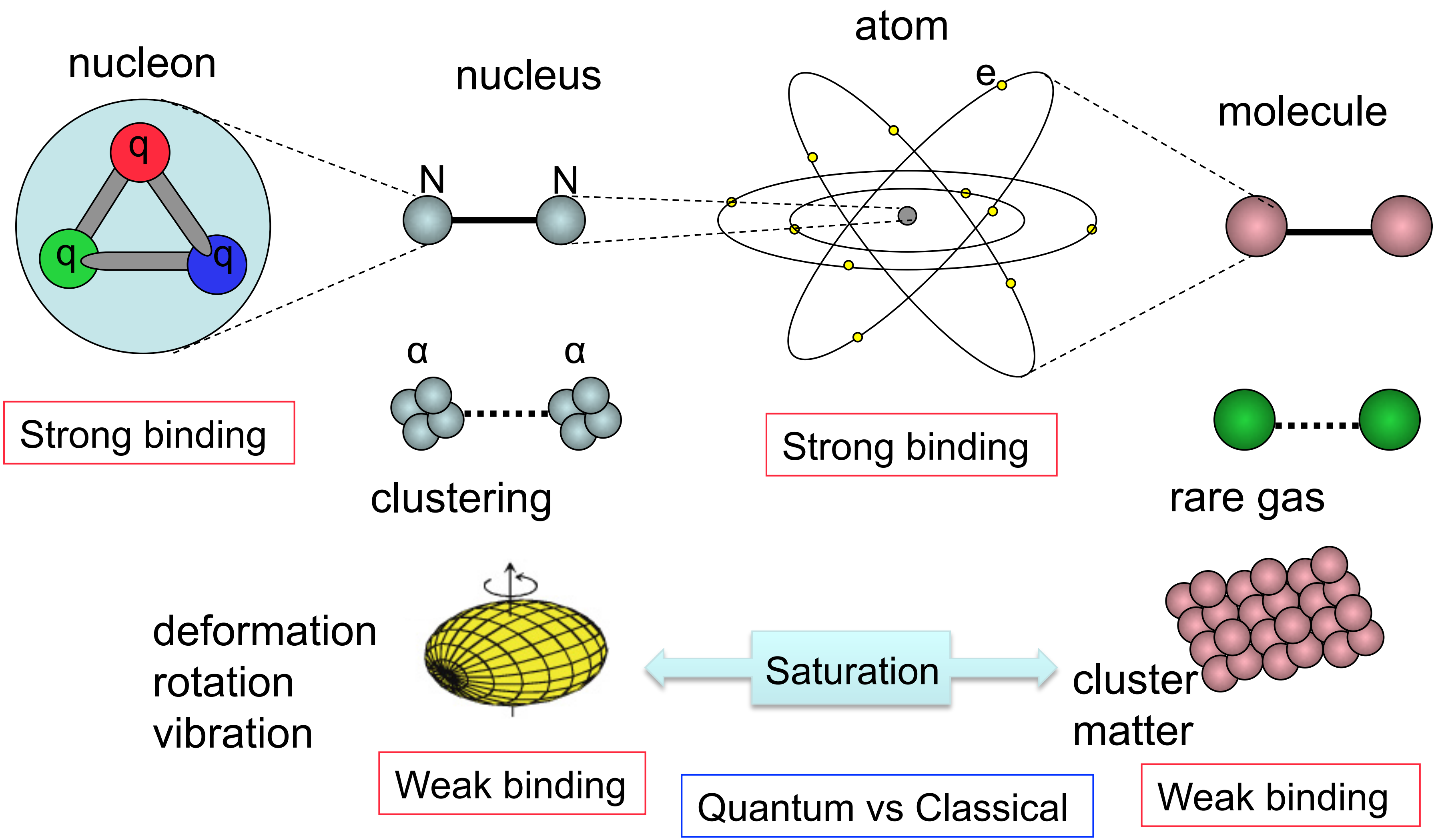
- Compute nuclei in various circumstances
- Predict nuclear phenomena
- Solve current & long-standing issues
- Reach new concepts for nuclei and finite quantum many-body systems

Keywords for nuclei

- Weak binding and saturation
- Quantum nature
- Different scales

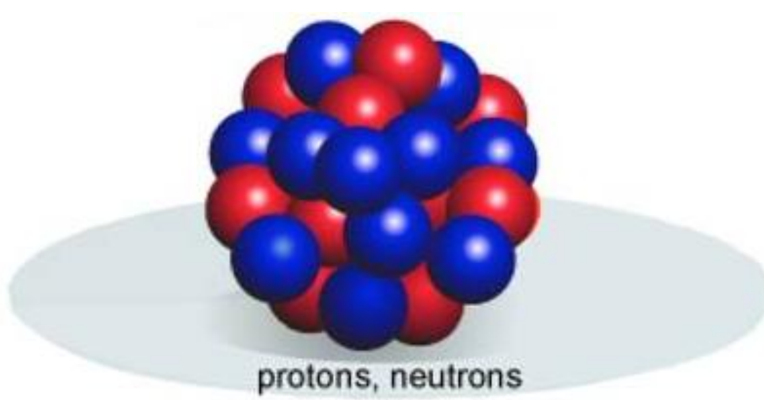


Quarks ➔ nucleons ➔ nuclei & electrons ➔ atoms ➔ molecules

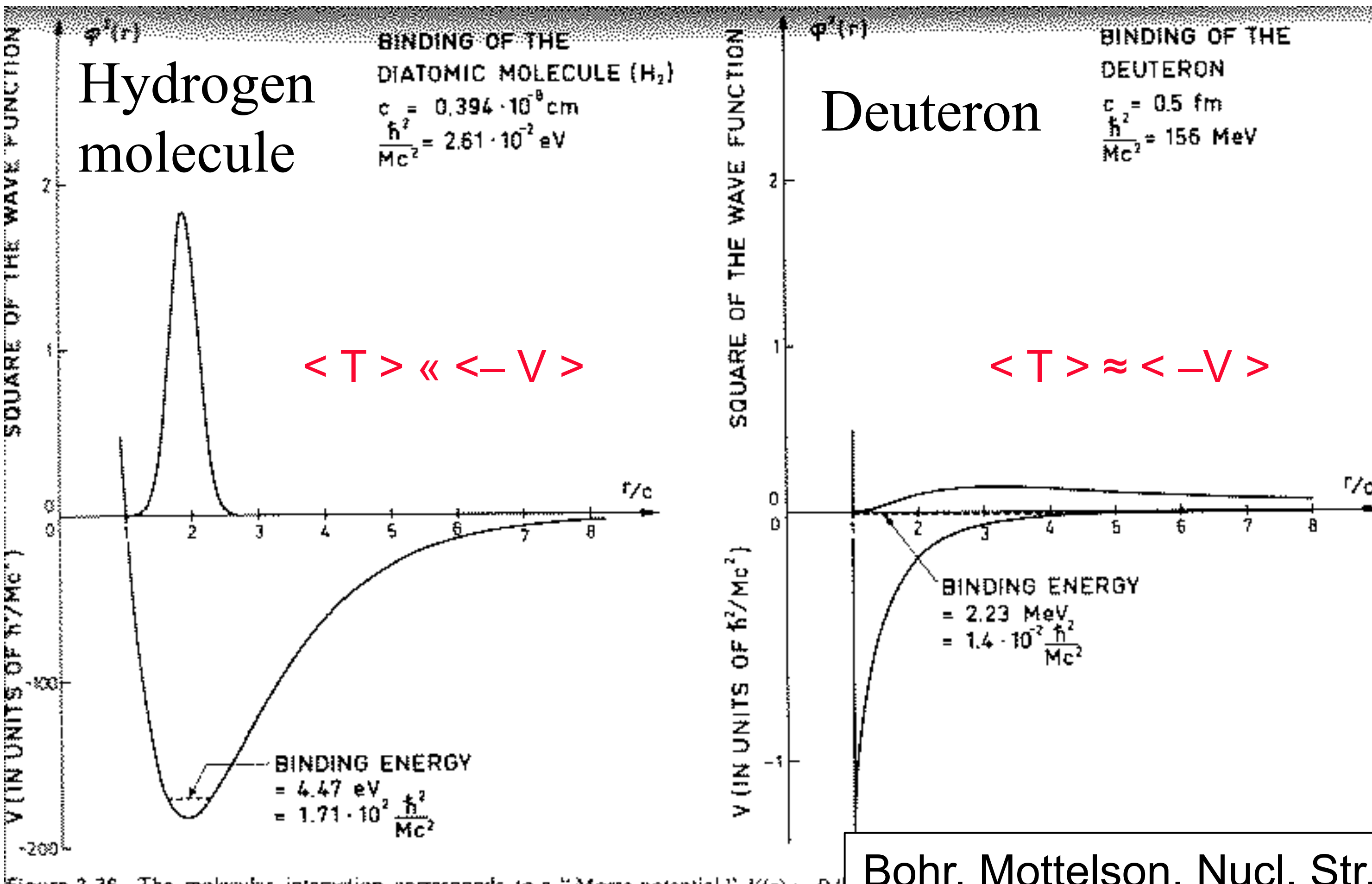


Keywords for nuclei

- Weak binding and saturation
- Quantum nature
- Different scales



Atomic vs nucleonic interaction



Bohr, Mottelson, Nucl. Str. Vol.1

Crystalized at low temperature

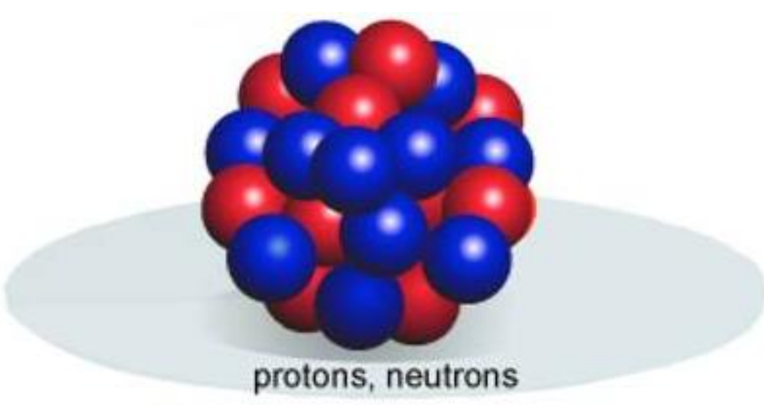
"Classical" many-body system

Liquid at low temperature

"Quantum" many-body system

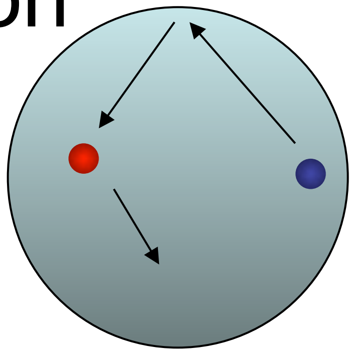
Keywords for nuclei

- Weak binding and saturation
- Quantum nature
- Different scales

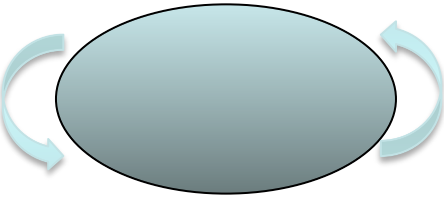


Different time scales in nuclei

- Time period of nucleonic Fermi motion
  - $\tau_F \sim R/v_F \sim 10^{-22}\,\mathrm{s}$



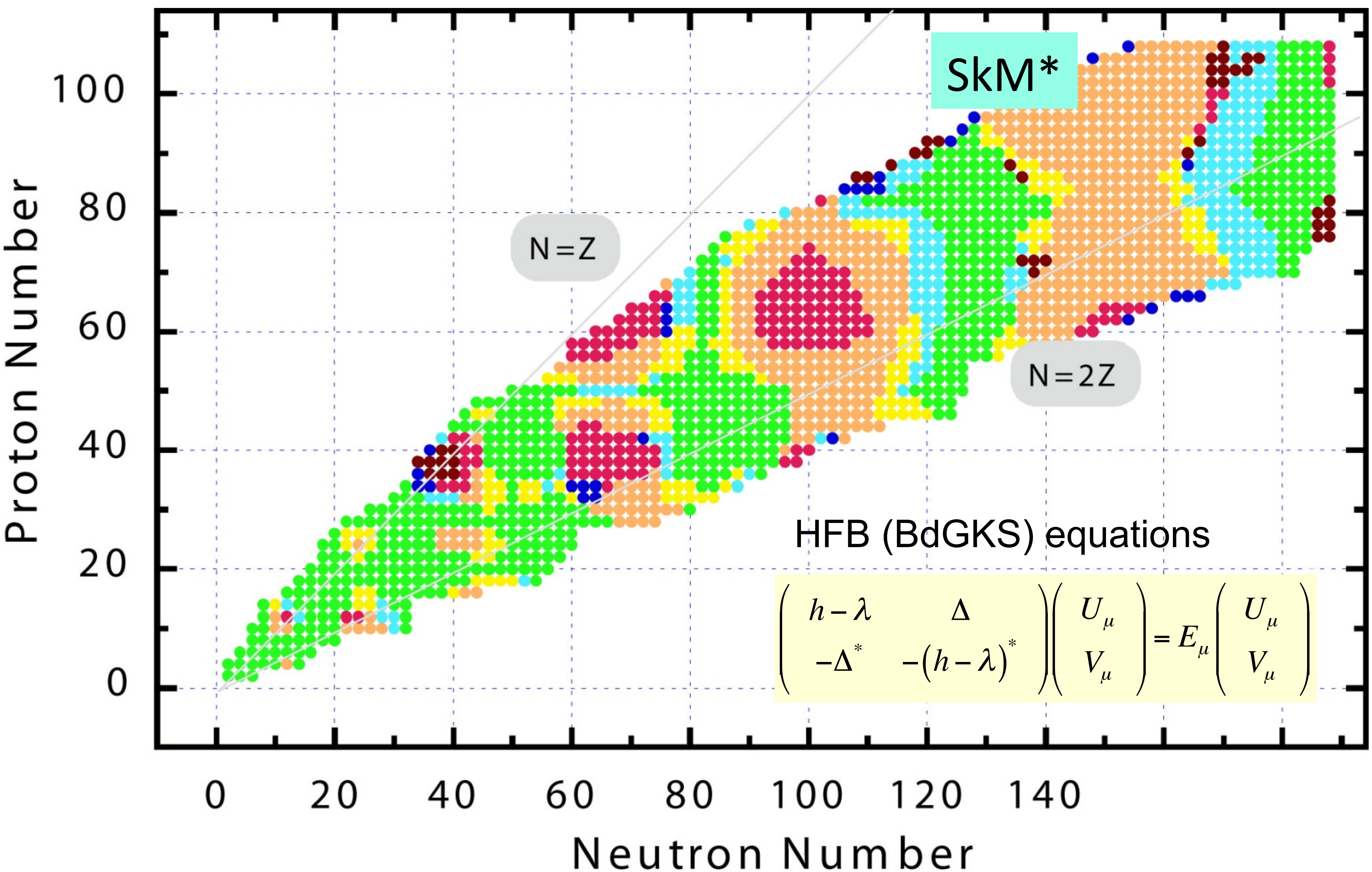
- Slow collective motion
  - "Spontaneous symmetry breaking"
  - Nuclear deformation : $\tau_{\mathrm{rot}} >> \tau_F$



Independent-particle motion

Collective motion

Nuclear deformation predicted by DFT

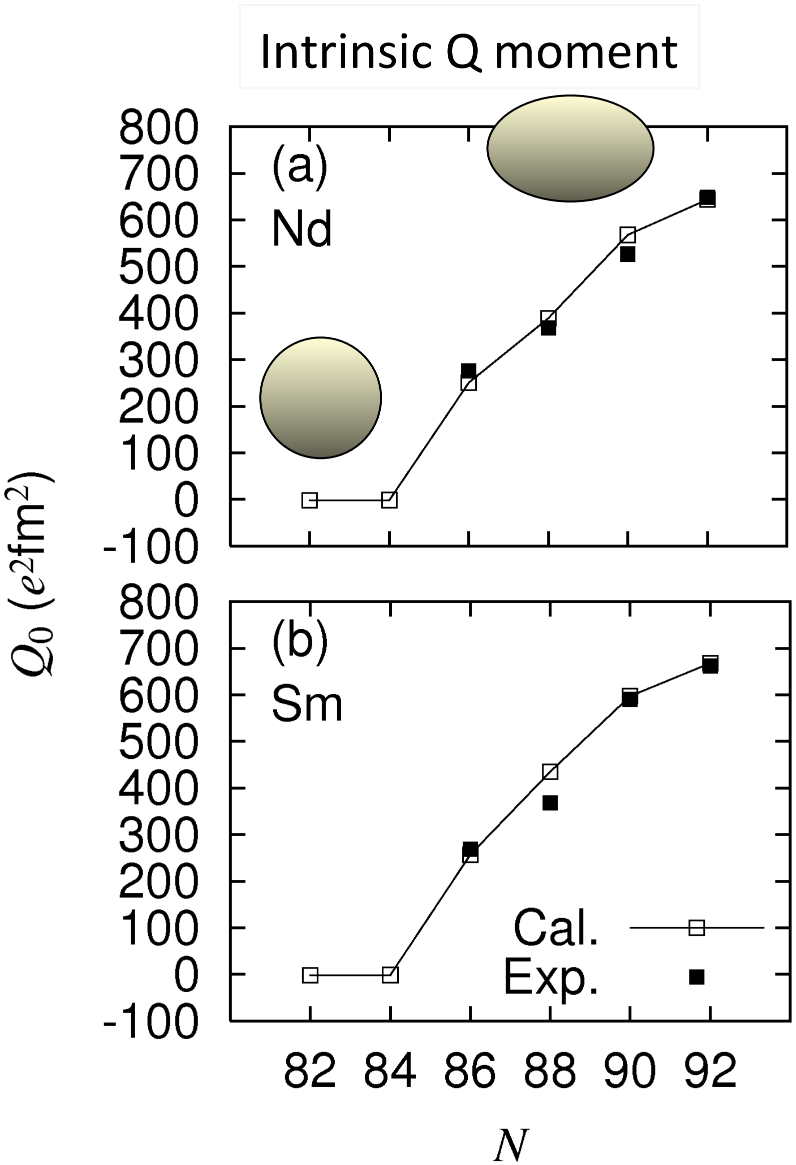


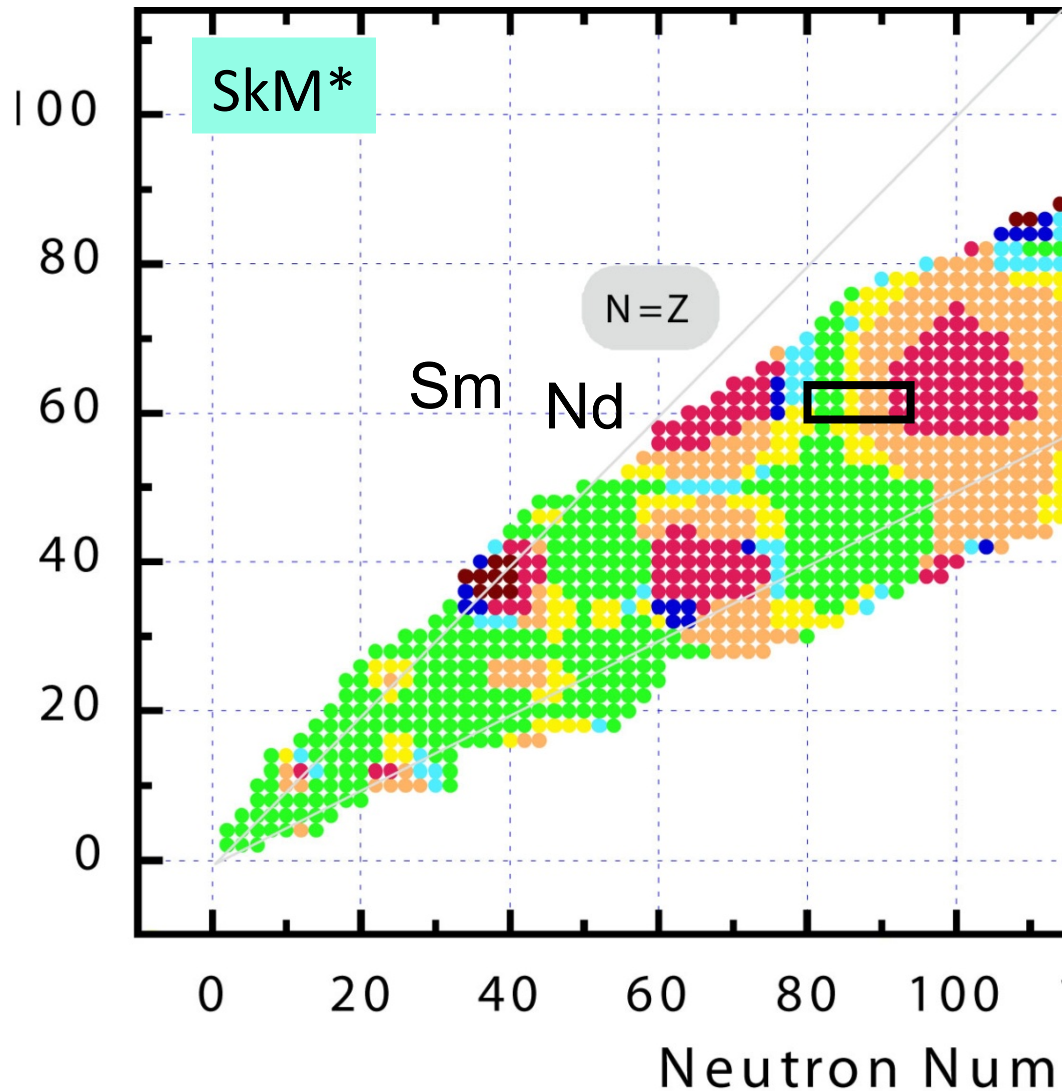
$$\begin{pmatrix} h-\lambda & \Delta \\ -\Delta^* & -(h-\lambda)^* \end{pmatrix} \begin{pmatrix} U_\mu \\ V_\mu \end{pmatrix} = E_\mu \begin{pmatrix} U_\mu \\ V_\mu \end{pmatrix}$$

M.V. Stoitsov *et al.*, Phys. Rev. C68(2003) 054312

Shape transition produced by DFT

Yoshida, Nakatsukasa, PRC PRC 83, 021304(R) (2011)





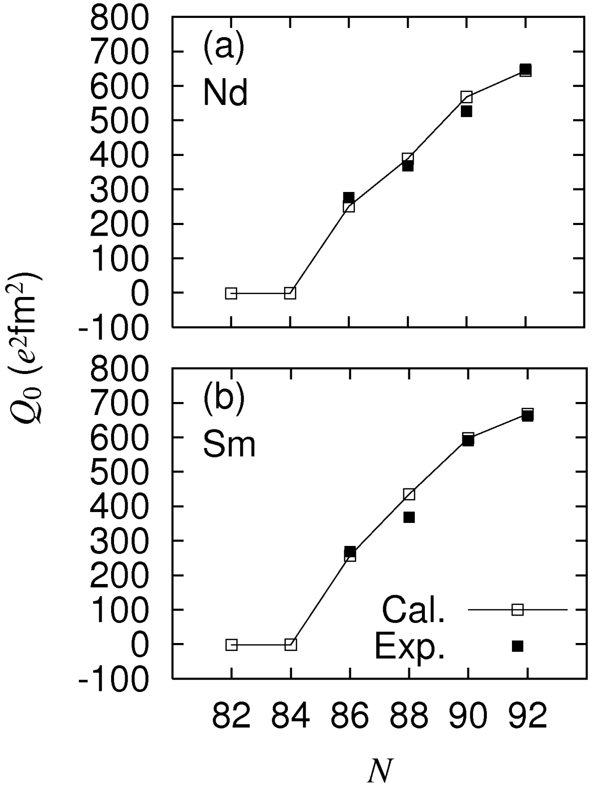
Linear response and photoabsorption cross section

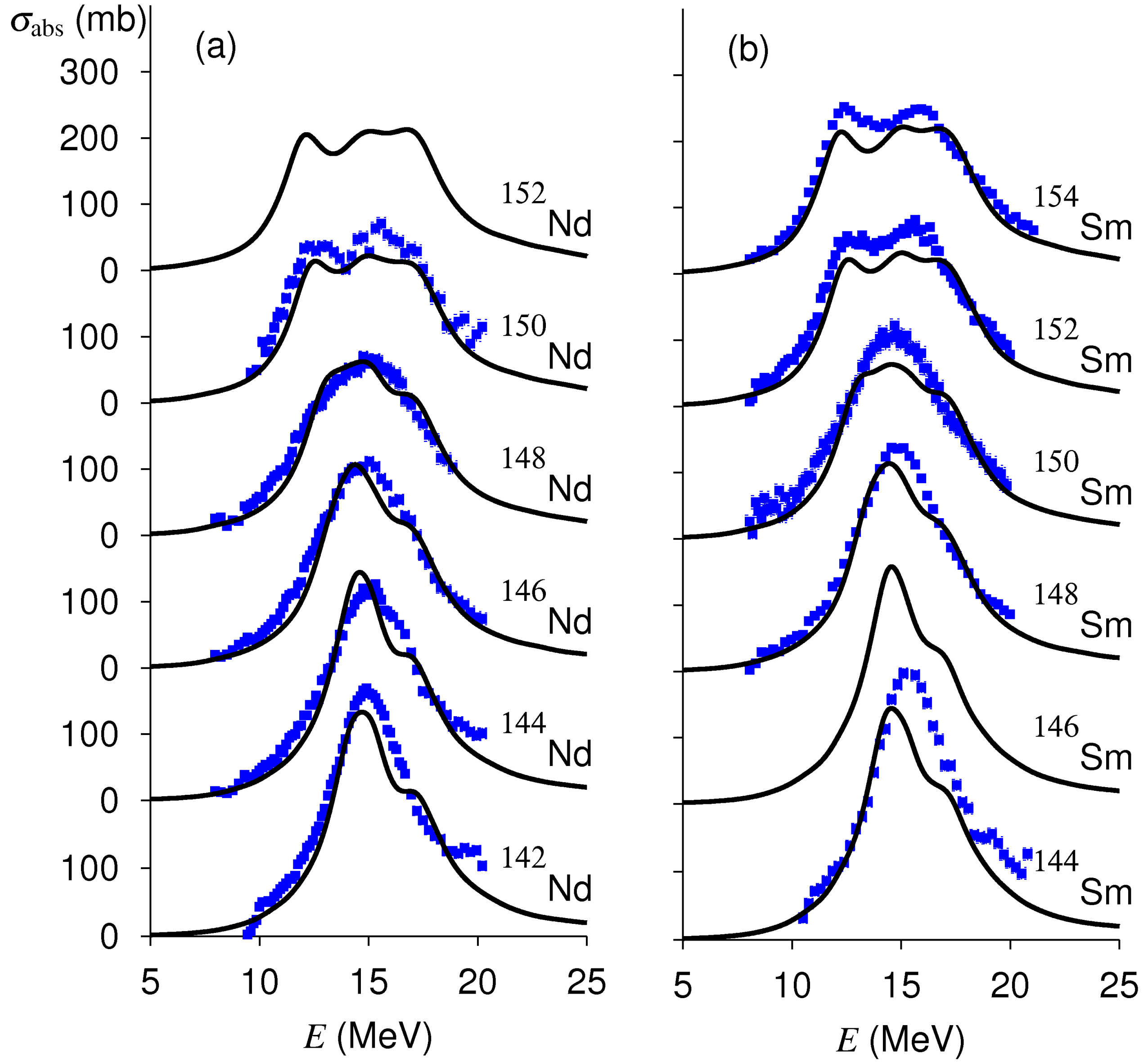
Yoshida, Nakatsukasa, PRC 83, 021304(R) (2011)

SkM* functional

Intrinsic Q moment

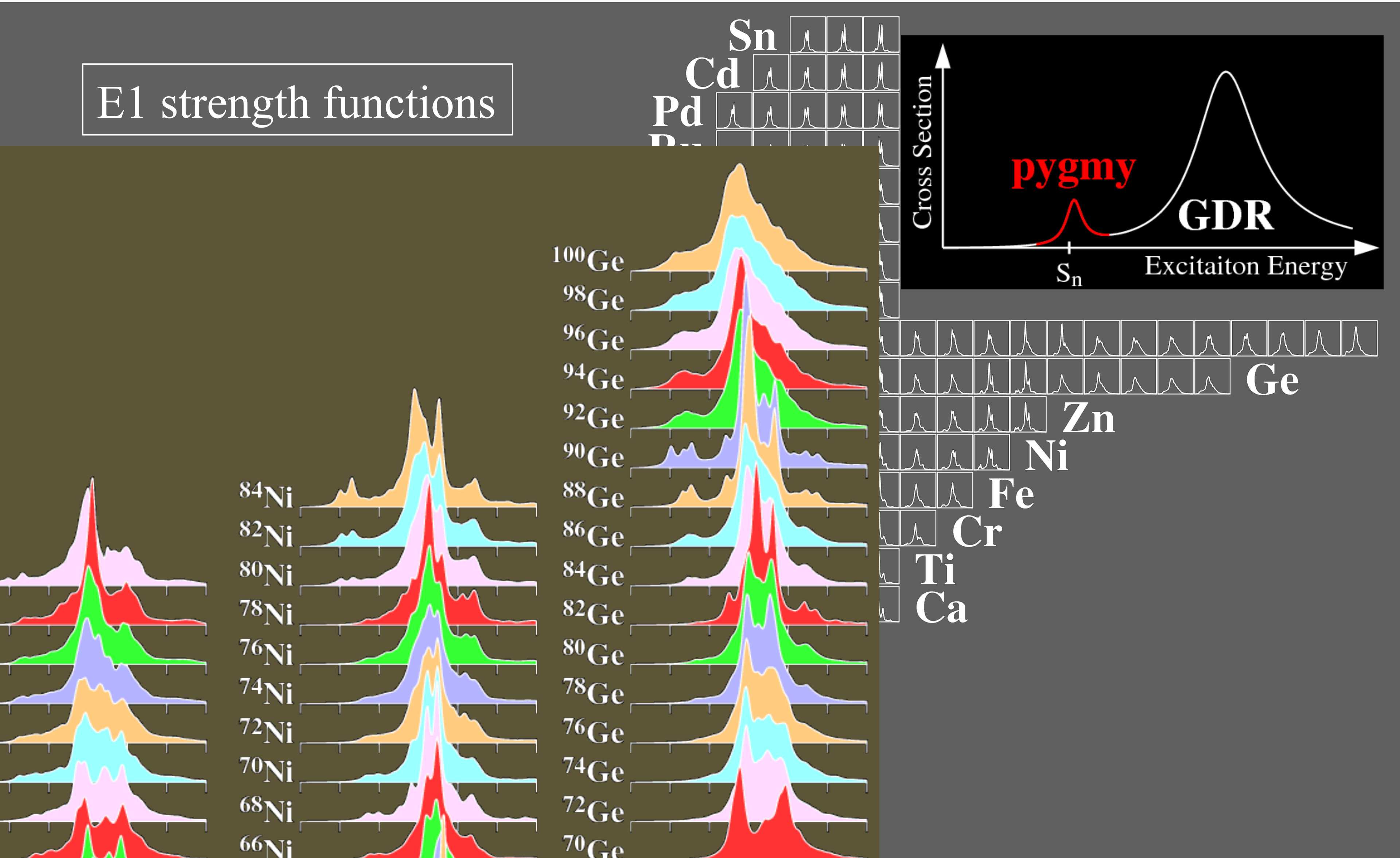
$\langle \hat{Q}_{20} \rangle$





Photoabsorption cross sections

Inakura, T.N., Yabana, PRC 84, 021302 (R) (2011); PRC 88, 051305(R) (2013)

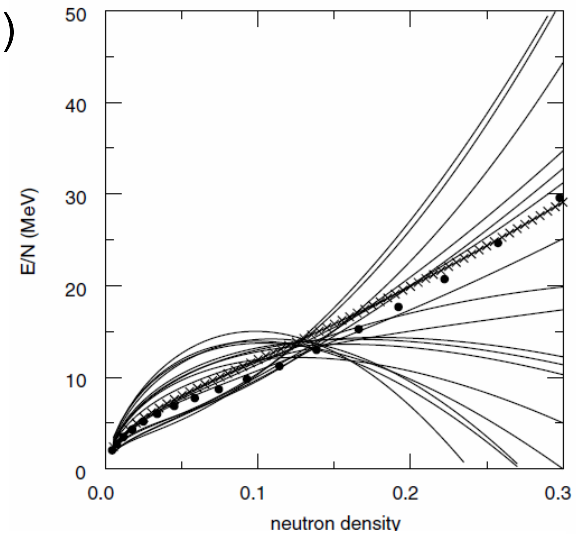


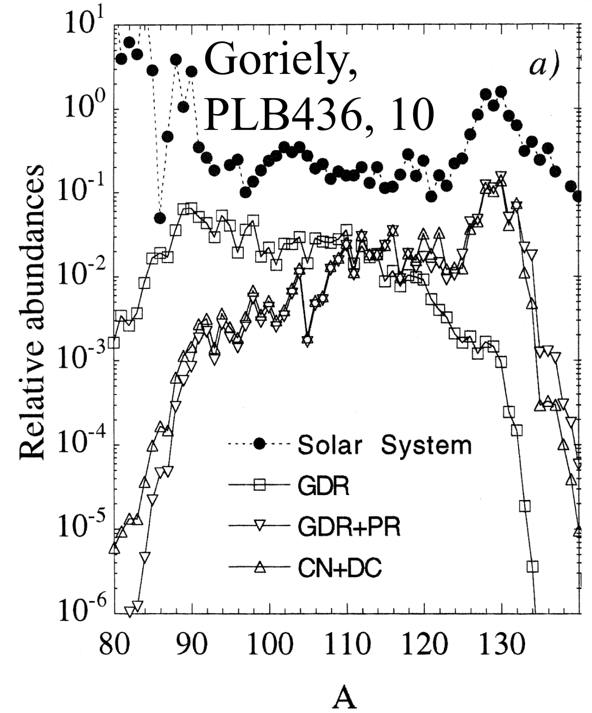
Low-energy *E1* strength in exotic nuclei

Inakura, Nakatsukasa, Yabana, PRC 84, PRC 88, 051305(R) (2013)

Ebata, Nakatsukasa, Inakura, in preparation.

- Constrain the neutron skin thickness and the NM EOS?
  - Yes, but better in very neutron rich!
  - Data on ^{84}Ni are better than ^{68}Ni
- Influence the r-process?
  - Significantly influence the direct neutron capture process near the neutron drip line
  - We need calculation with a proper treatment of the continuum.





Beyond the linear regime
Future subjects

- Nuclear reaction involving a large shape change, such as fission, fusion, etc.
- Problems
  - Numerical cost for solution of TDHFB eq.

$$i\frac{\partial}{\partial t}\begin{pmatrix} U_\mu(t) \\ V_\mu(t) \end{pmatrix} = \begin{pmatrix} h(t)-\lambda & \Delta(t) \\ -\Delta^*(t) & -\left(h(t)-\lambda\right)^* \end{pmatrix}\begin{pmatrix} U_\mu(t) \\ V_\mu(t) \end{pmatrix}$$

  - How to obtain quantum spectra?

Time-dependent Hartree-Fock-Bogoliubov (TDHFB) calculations with Gogny interaction (Y. Hashimoto)

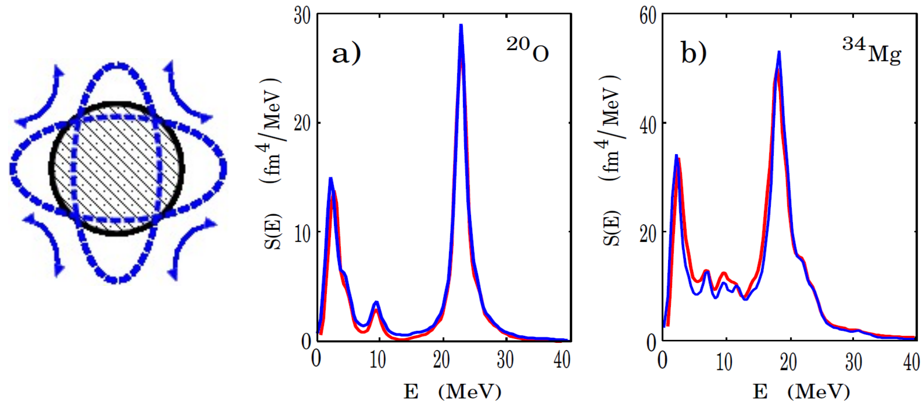
1. Aim:

The aim of the TDHFB calculations is to understand the dynamical role of the pairing correlation in the large-amplitude collective motions including the reaction processes.

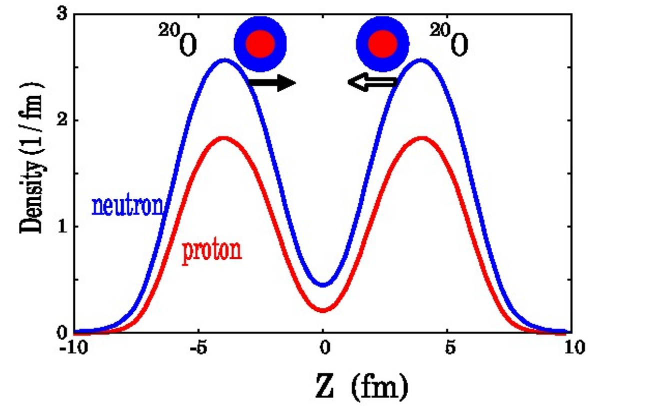
2. Method :

i) A new method of carrying out the Gogny-TDHFB calculations was proposed with the three-dimensional harmonic oscillator basis (3DHO).

ii) The program codes were extended to make use of the **spatial grids** (Lagrange mesh) instead of the 3DHO . At present, two-dimensional harmonic oscillator + one-dimensional Lagrange mesh (2DHO+LM) is used.



Strength functions of quadrupole vibrations in superconducting nuclei ^{20}O and ^{34}Mg.



Colliding superconducting nuclei ^{20}O + ^{20}O.

EPJ A48:55 (2012) PRC88, 034307 (2013)

(calculations are in progress on a computer)

Physics
spotlighting exceptional research

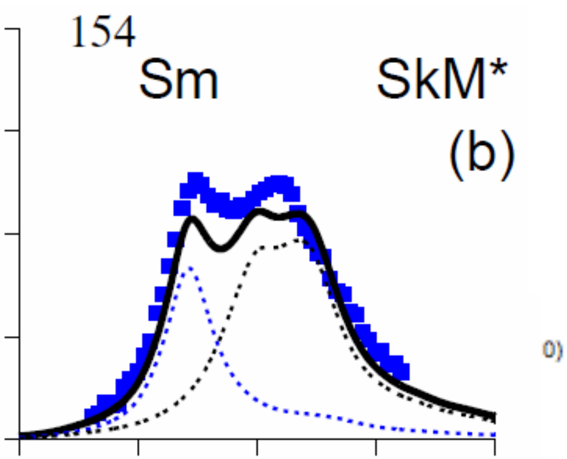
Home | About | Browse | APS Journals

$$i\frac{\partial}{\partial t}|k(t)\rangle = \left(h(t)-\eta_k(t)\right)|k(t)\rangle$$

$$i\frac{\partial}{\partial t}\rho_k(t) = \Delta_k^*(t)K_k(t) - \text{c.c.}$$

$$i\frac{\partial}{\partial t}K_k(t) = \left(\eta_k(t)+\eta_{\bar{k}}(t)\right)K_k(t) + \Delta_k(t)\left(2\rho_k(t)-1\right)$$

Synopsis: Time-saving steps

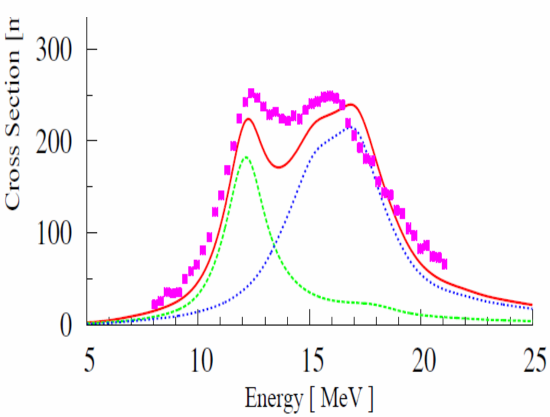


Canonical-basis time-dependent Hartree-Fock-Bogoliubov theory and linear-response calculations

Shuichiro Ebata, Takashi Nakatsukasa, Tsunenori Inakura, Kenichi Yoshida, Yukio Hashimoto, and Kazuhiro Yabana

Phys. Rev. C **82**, 034306 (2010)

Published September 9, 2010



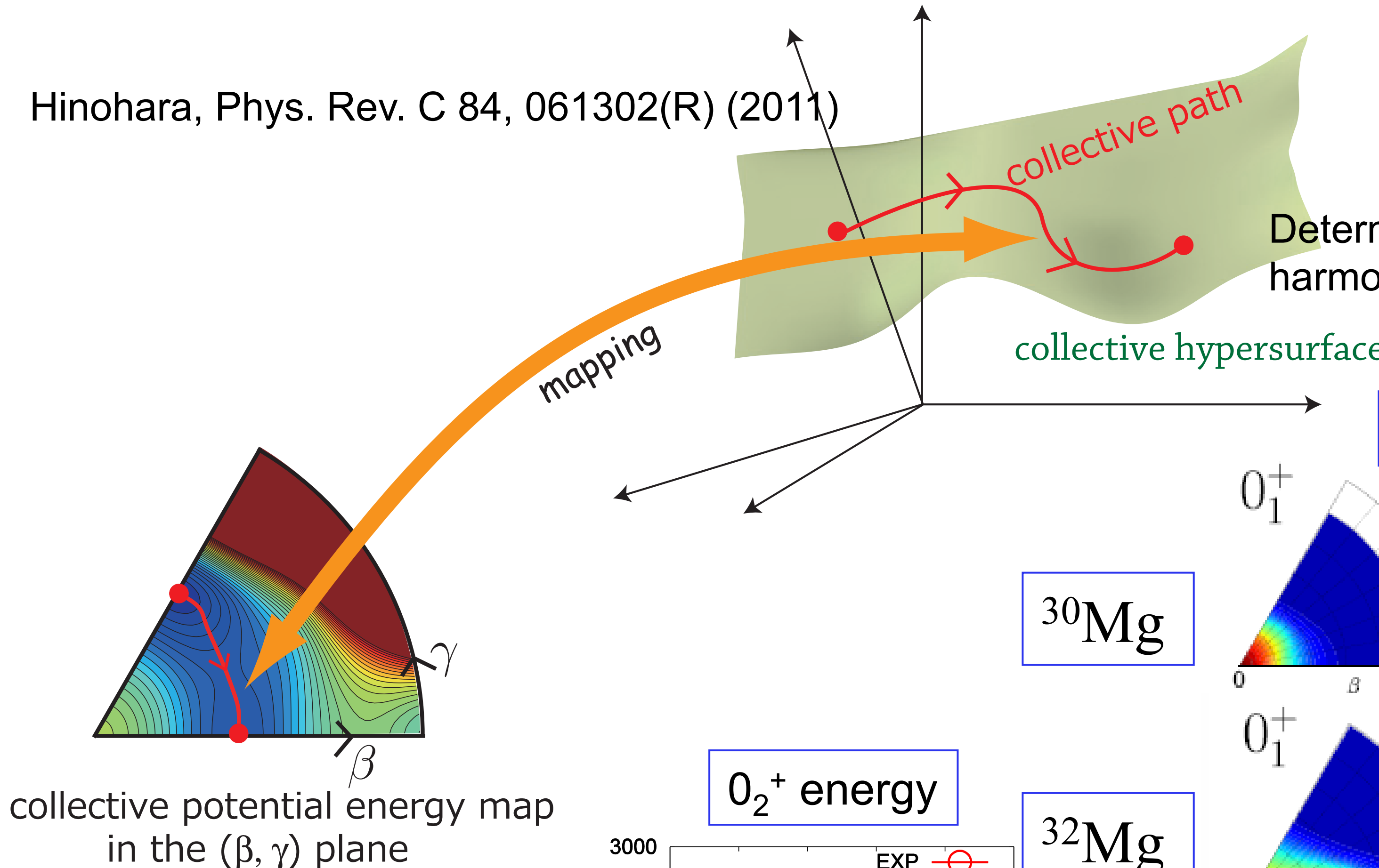
2D cal. w/o Coulomb	→	3D cal. w Coulomb
~1000 CPU h		~ 20 CPU hours

Canonical-basis real-time method may significantly reduces computational task.

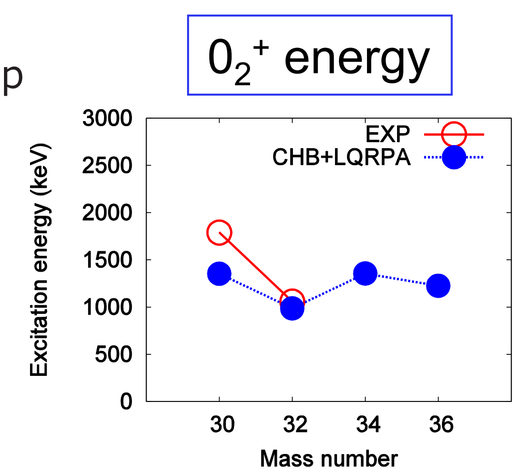
Applicable to nuclear dynamics beyond the liner regime: fusion and fission reactions.

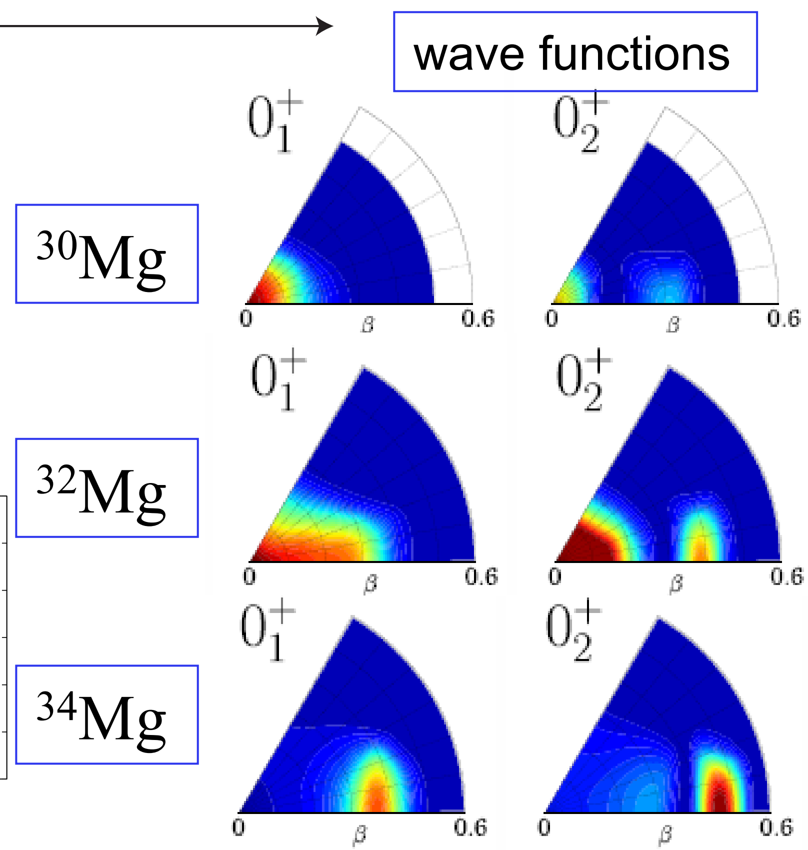
Collective subspace

Hinohara, Phys. Rev. C 84, 061302(R) (2011)



Determined by the local harmonic equation (LHE)





Next stage: Applications to fission problems

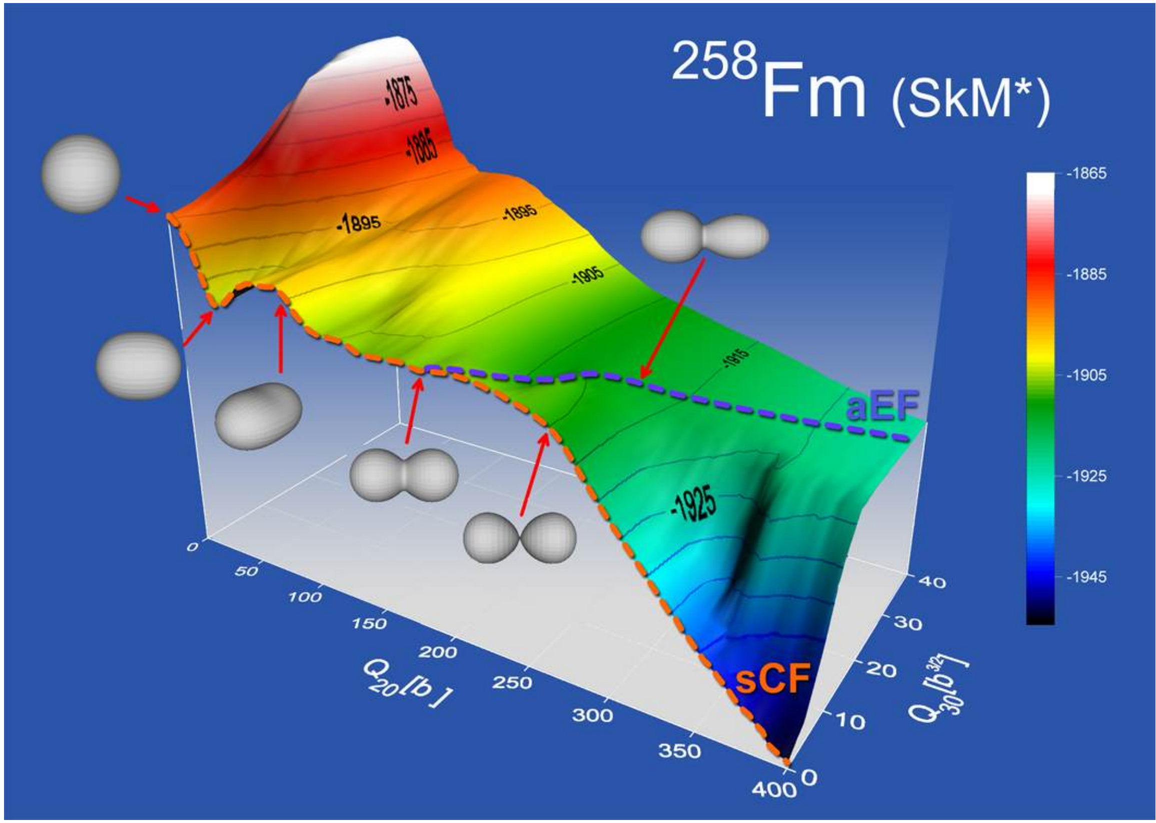
- Constrained Hamiltonian

$$H = H - \lambda q$$

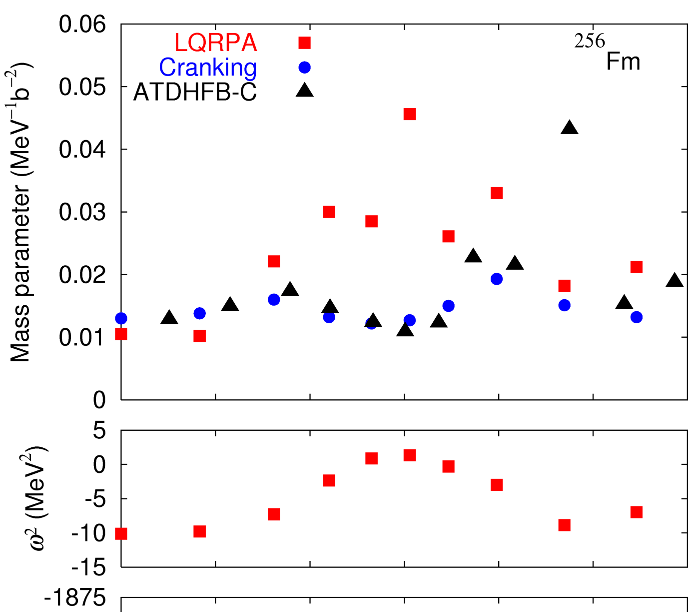
- Constrained operator

  q Solution of LHE

- Collective mass parameters



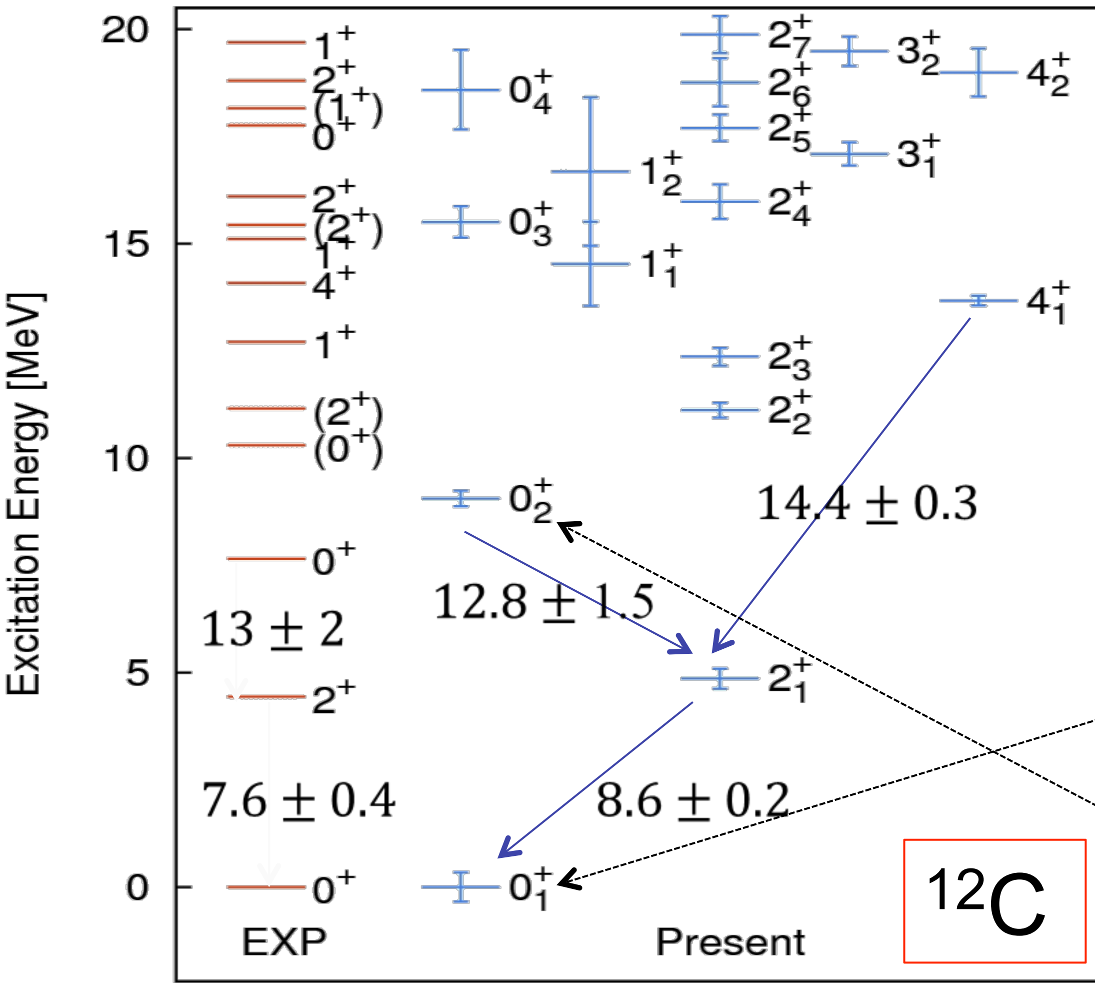
Test calculation

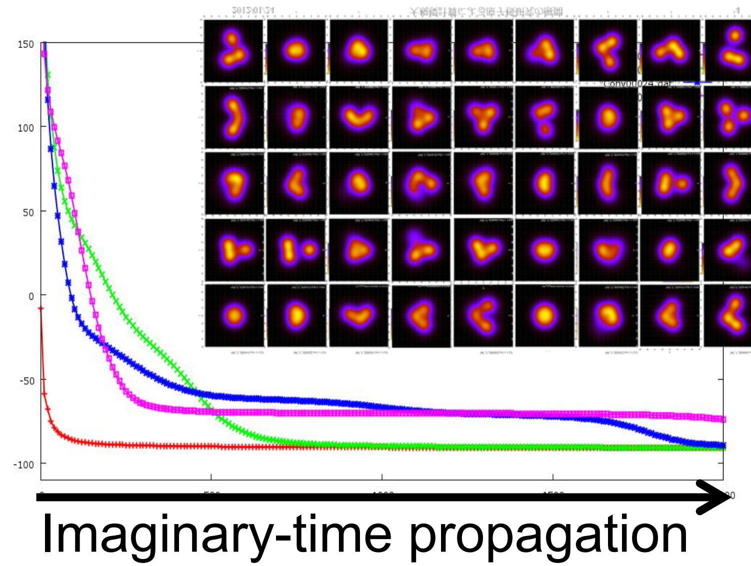


Local Harmonic Equation (LHE) is able to calculate the collective mass parameters including dynamical effect by the time-odd mean fields.

Stochastic generation and IT propagation of multi-reference states

Fukuoka, et al. PRC 88, 014321 (2013)





The ground state is well described by a single SD.

The Hoyle state requires many SD's with 3-alpha cofigurations.

Tilted axis rotation (TAR) in osmium ^{182}Os

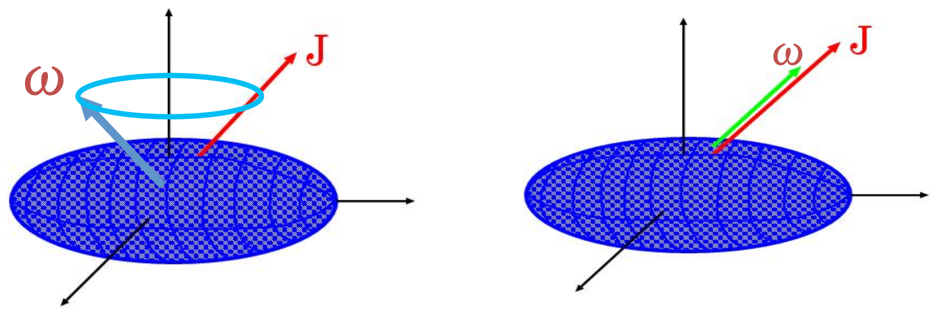
(Y. Hashimoto)

1. Aim:

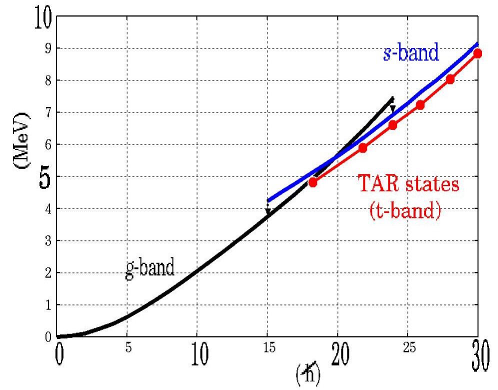
There is a possibility of three-dimensional nuclear rotational motion, where the nucleus rotates about an axis which is away from any of the principal axes. The aim of this work is to understand the microscopic mechanism of the three-dimensional nuclear rotational motions of the wobbling and the tilted axis rotation (TAR).

2. Method :

The constrained Hartree-Fock-Bogoliubov (HFB) and the generator coordinate method (GCM) are used.



Schematic pictures of wobbling (left) and TAR (right) of a deformed nuclei on body-fixed frame.



Calculated TAR states come below the s-band.

Results (in osmium ^{182}Os):

I. Stability of the s-band with respect to the tilt angle is related with the appearance of the t-band. (Eur. Phys. J. A42, 571 (2009))

II. The energy splitting in the t-band is calculated by combining the tilted-axis cranked HFB and the GCM. (INFORMATION Vol.13(2010), 569., Vol,10, No.2(2007), 199. , AIP Conf. Proc. Vol.1235(2010), 91.)

Summary

- Researches associated with nuclear TDDFT
  - Recent progress
  - Code developments for massively parallel computing
- Future directions
  - Microscopic theory for nuclear fission with TDDFT
  - Multi-reference DFT toward ab-initio-type cal.
  - Collaborative works with RIKEN's groups