Pair-truncation for particle-hole configuration spaces

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International Symposium of Nuclear Science:

Simplicity, Symmetry and Beauty

In honor of the Rice Age of Professor Akito Arima

Shanghai, September 26th-28th, 2018

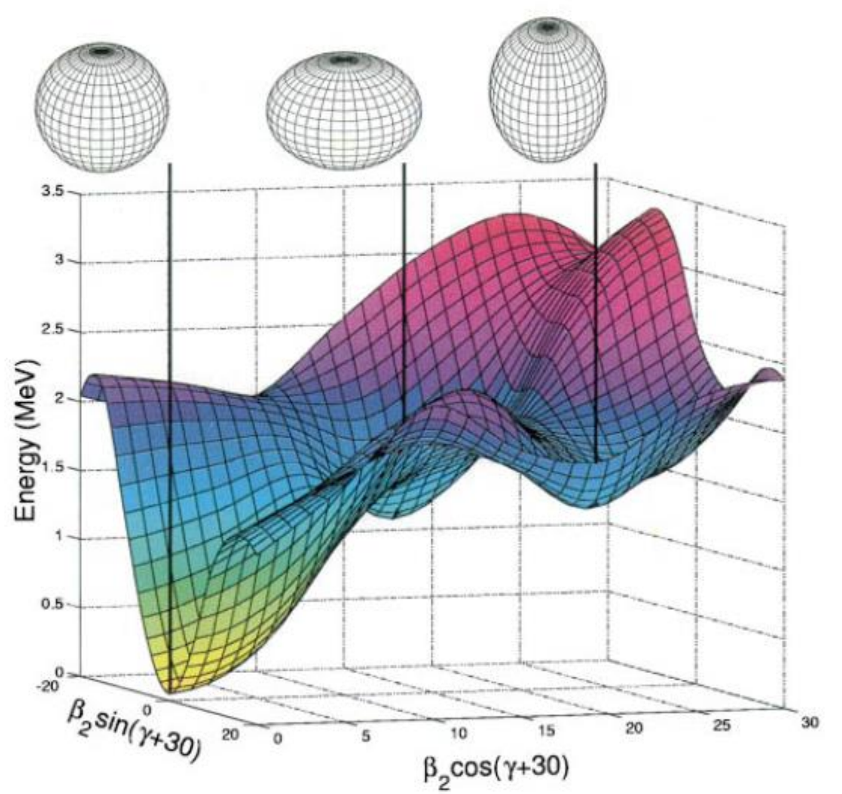
HAPPY HAPPY Rice-Age Birthday

to

Arima Sensei !

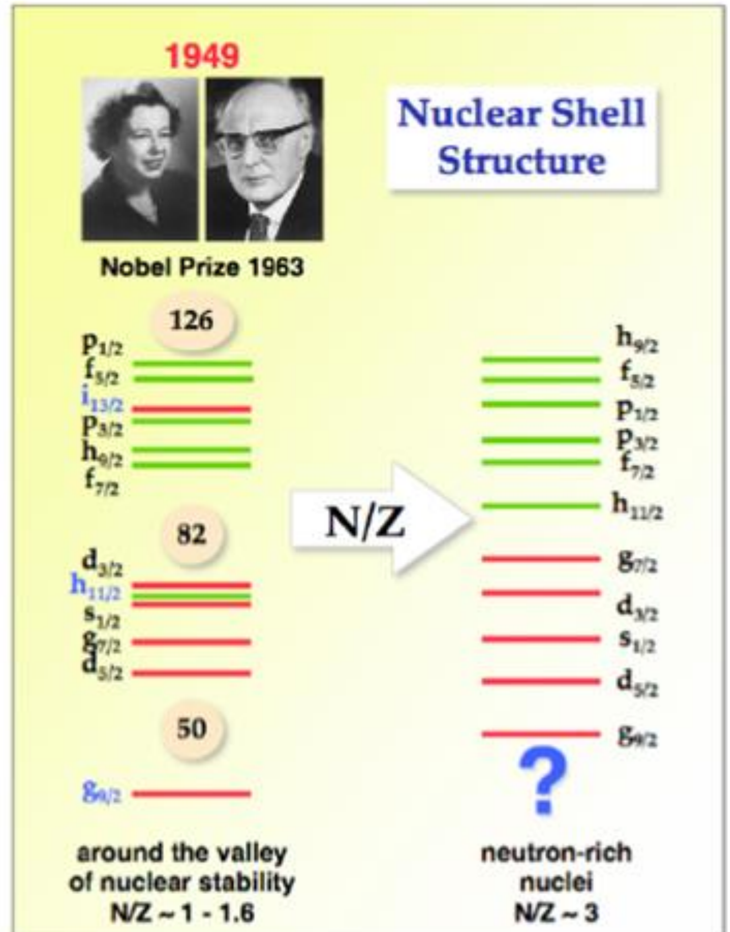
WHY particle-hole configurations

Shape coexistence



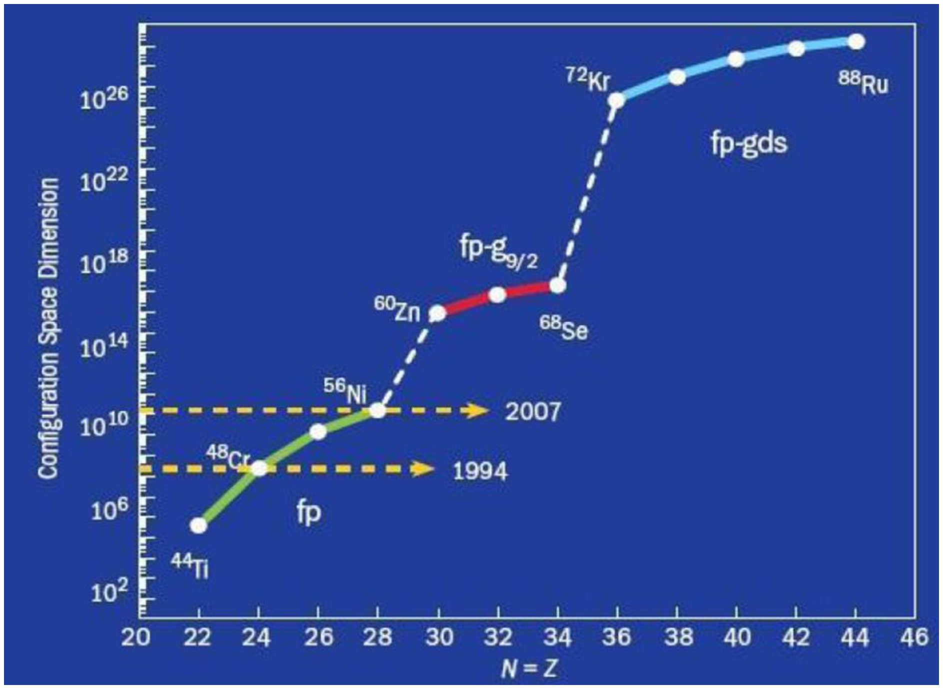
A. N. Andreyev et al., Nature 405 (2000).

Shell evolution

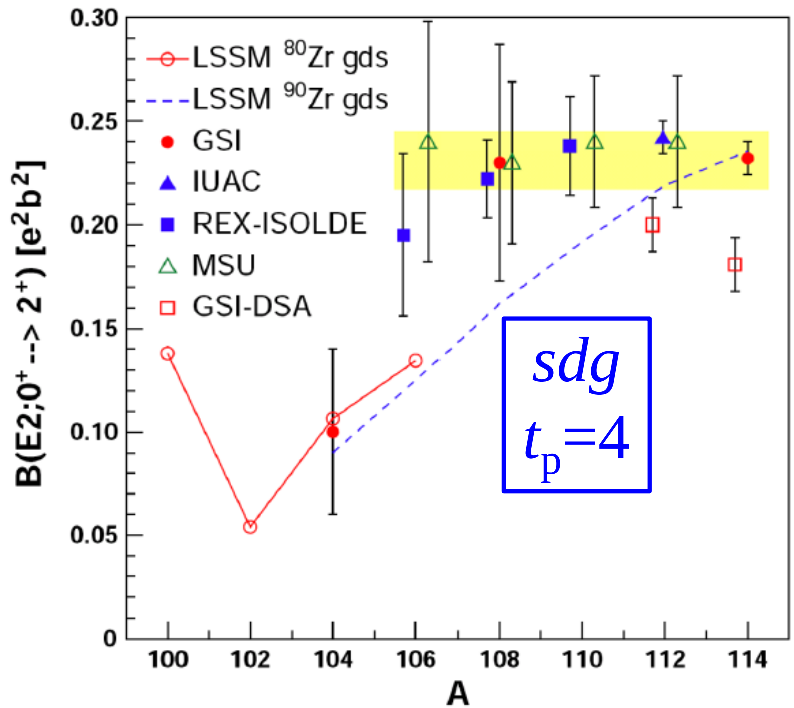


WHY truncation

Shell-Model dimensions



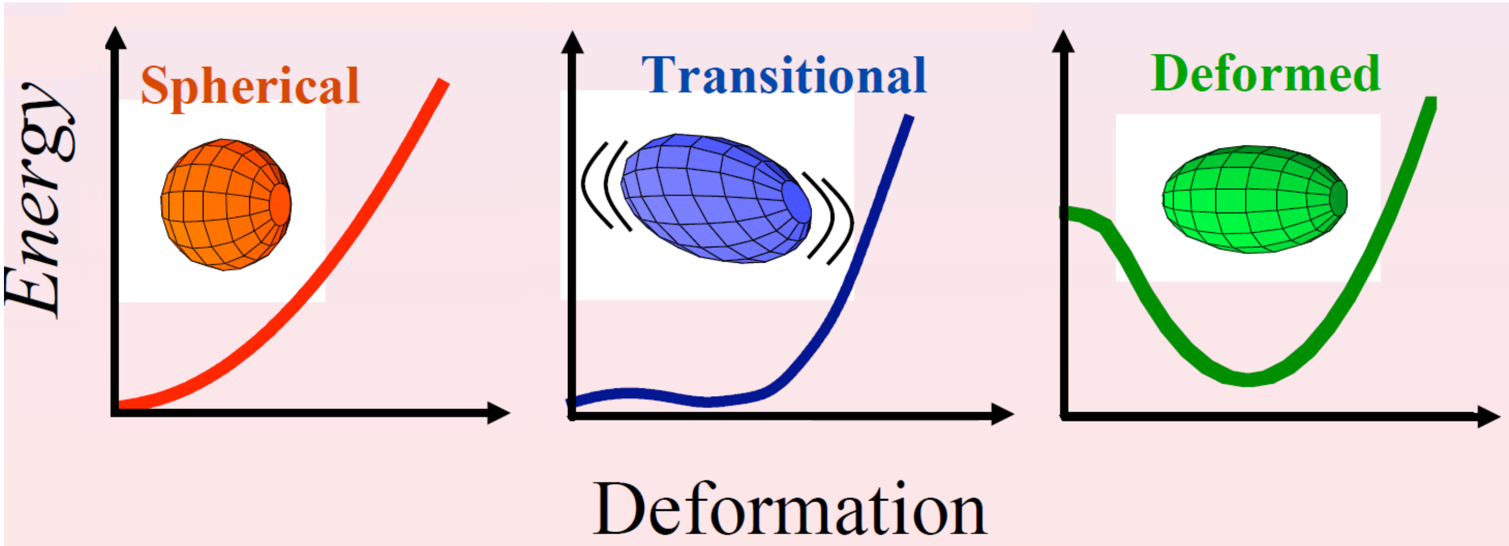
LSSM cal. for Sn isotopes



Guastalla et al.

Phys. Rev. Lett. 110, 172501 (2013)

WHY truncation



To describe Shape Coexistence:

HUGE space when using spherical s.p. basis

Deformed nuclei: Deformed DFT + angular momentum projection 

Spherical nuclei: Spherical s.p. basis

Transitional nuclei: Spherical s.p. basis

+ truncation ! 

HOW to truncate

"A crucial step is to truncate the shell-model basis into a subspace that allows us to treat **low-lying quadrupole excitations** and **intruder excitations moving across closed shells (or subshells)**." ---- Heyde and Wood, Rev. Mod. Phys. 83, 1467 (2011)

Interacting Boson Model

VOLUME 35, NUMBER 16 PHYSICAL REVIEW LETTERS 20 OCTOBER 1975

Collective Nuclear States as Representations of a SU(6) Group*

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and

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Kernfysisch Versneller Instituut, University of Groningen, Groningen, The Netherlands†, and Argonne National Laboratory, Argonne, Illinois 60439
(Received 11 August 1975)

We propose a description of collective quadrupole states in even-even nuclei in terms of representations of a boson SU(6) group. We show that within this model both the vibrational and the rotational limit can be recovered.

P. D. Duval, and B. R. Barrett, Phys. Lett. B 100, 223 (1981).
P. D. Duval, and B. R. Barrett, Nucl. Phys. A 376, 213 (1982).

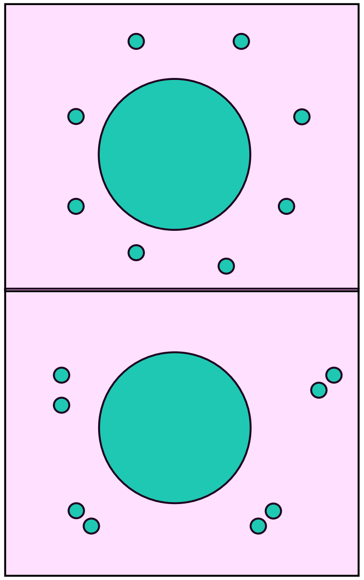
K. Heyde, C. De Coster, J. Jolie, and J. L. Wood, Phys. Rev. C 46, 541 (1992).

……

Nucleon-pair approximation

Shell-model basis (m-scheme):

$$|\phi\rangle = a^{+}_{j_1 m_1} a^{+}_{j_2 m_2} \cdots a^{+}_{j_n m_n} |0\rangle$$



nucleon pair：

$$A^{(r)+} = \sum_{j_1 j_2} y(j_1 j_2 r) A^{(r)+}(j_1 j_2), \quad A^{(r)+}(j_1 j_2) = (a^{+}_{j_1} \times a^{+}_{j_2})^{(r)}$$

pair basis (J-scheme):

$$|\varphi\rangle = \left(\cdots \left(\left(A^{(r_1)+} \times A^{(r_2)+} \right)^{(J_2)} \times A^{(r_3)+} \right)^{(J_3)} \cdots \times A^{(r_N)+} \right)^{(J_N)}_{M_N} |0\rangle$$

J. Q. Chen, Nucl. Phys. A 626, 686 (1997).

Y. M. Zhao and A. Arima, Physics Reports 545, 1 (2014).

PHYSICAL REVIEW C **97**, 024303 (2018)

Nucleon-pair approximation with particle-hole excitations

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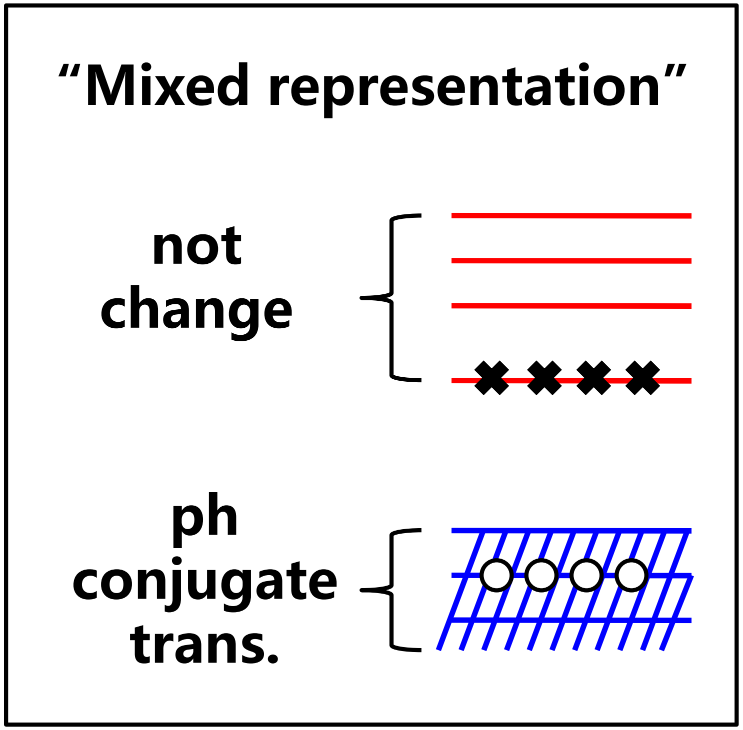
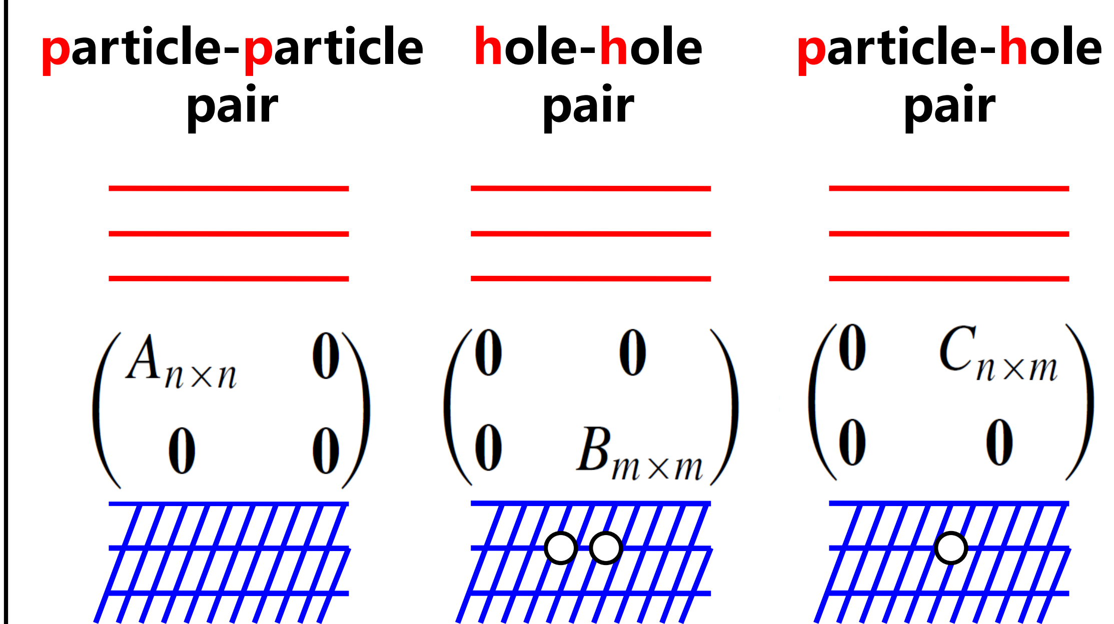




Two types of excitations across closed shell can be flexibly included.

Calculation of ^{100}Sn

1. Space

holes : 28-50 major shell , particles : 50-82 major shell

up to 4-particle-4-hole

2. Shell-model Hamiltonian

$$H = H_{\rm SM} + \beta\left(H_{\rm CM} - \frac{3}{2}\hbar\omega\right), \qquad H_{\rm CM} = \frac{\tilde{P}^2}{2mA} + \frac{1}{2}mA\omega^2\tilde{R}^2.$$

$$H_{\rm SM} = \sum_j \varepsilon_j N_j + \sum_{j_1 \leqslant j_2}\sum_{j_3 \leqslant j_4}\sum_{JM}\sum_{TM_T} \frac{V_{JT}(j_1 j_2 j_3 j_4)}{\sqrt{(1+\delta_{j_1 j_2})(1+\delta_{j_3 j_4})}} A^{JT\dagger}_{MM_T}(j_1 j_2) A^{JT}_{MM_T}(j_3 j_4)$$

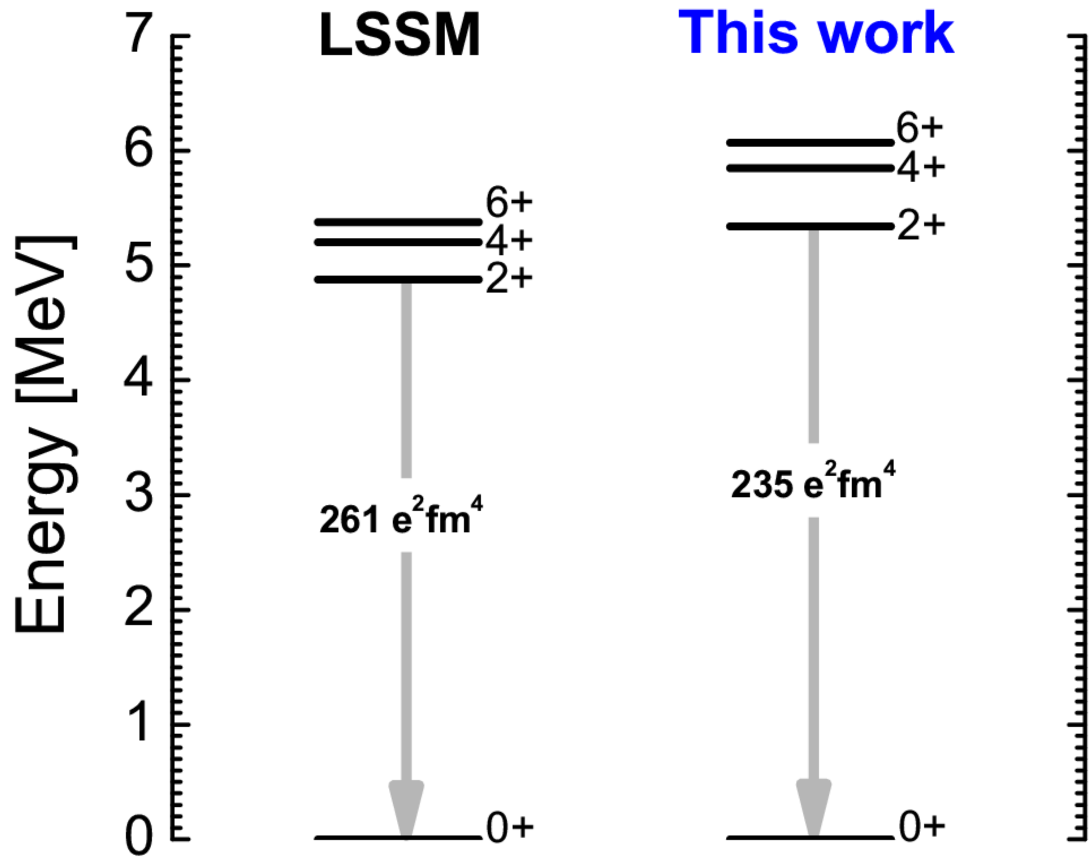
TBME : CD-Bonn + $V_{\text{low-k}}$ (given by Prof. T. T. S. Kuo)

3. Pair truncation

SD pairs of both pp and hh types

& ph pairs (phonons) with spin-2, 4, 6

Calculation of ^{100}Sn



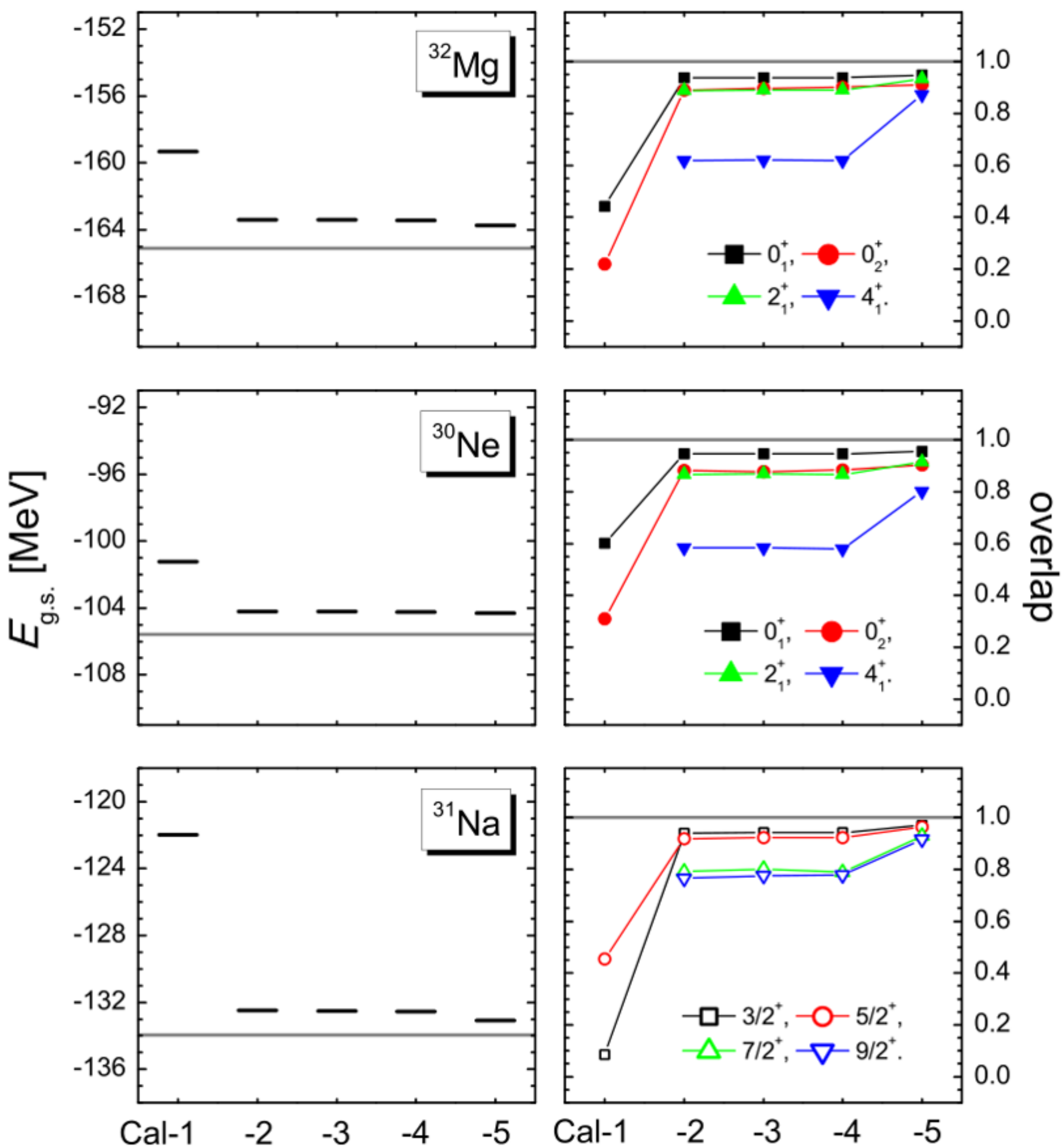
LSSM:

holes in $0g_{9/2}$, particles in $0g_{7/2}1d_{5/2}1d_{3/2}2s_{1/2}$, up to 4p4h

CD-Bonn + G-matrix

Faestermann et al., Prog. Part. Nucl. Phys. 69, 85 (2013)

Inversion-island nuclei: validity study



particle-hole excitations across N=20 shell

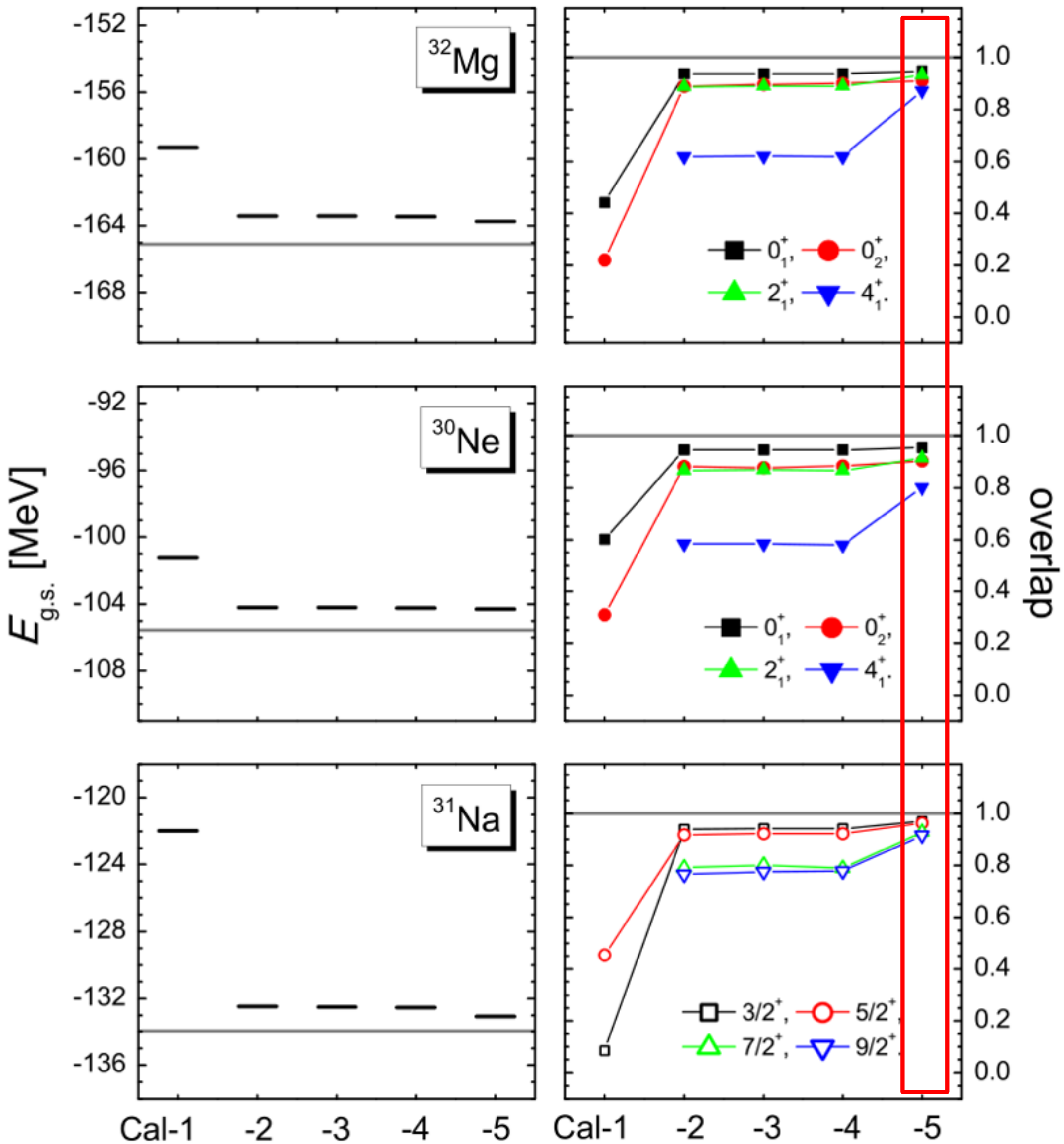
sdpf-M interactions of Utsuno et al.

to fix structure coeff.

$$\frac{\delta}{\delta y_i} E_{g.s.} = 0$$

YYC et al., preliminary

Inversion-island nuclei: validity study



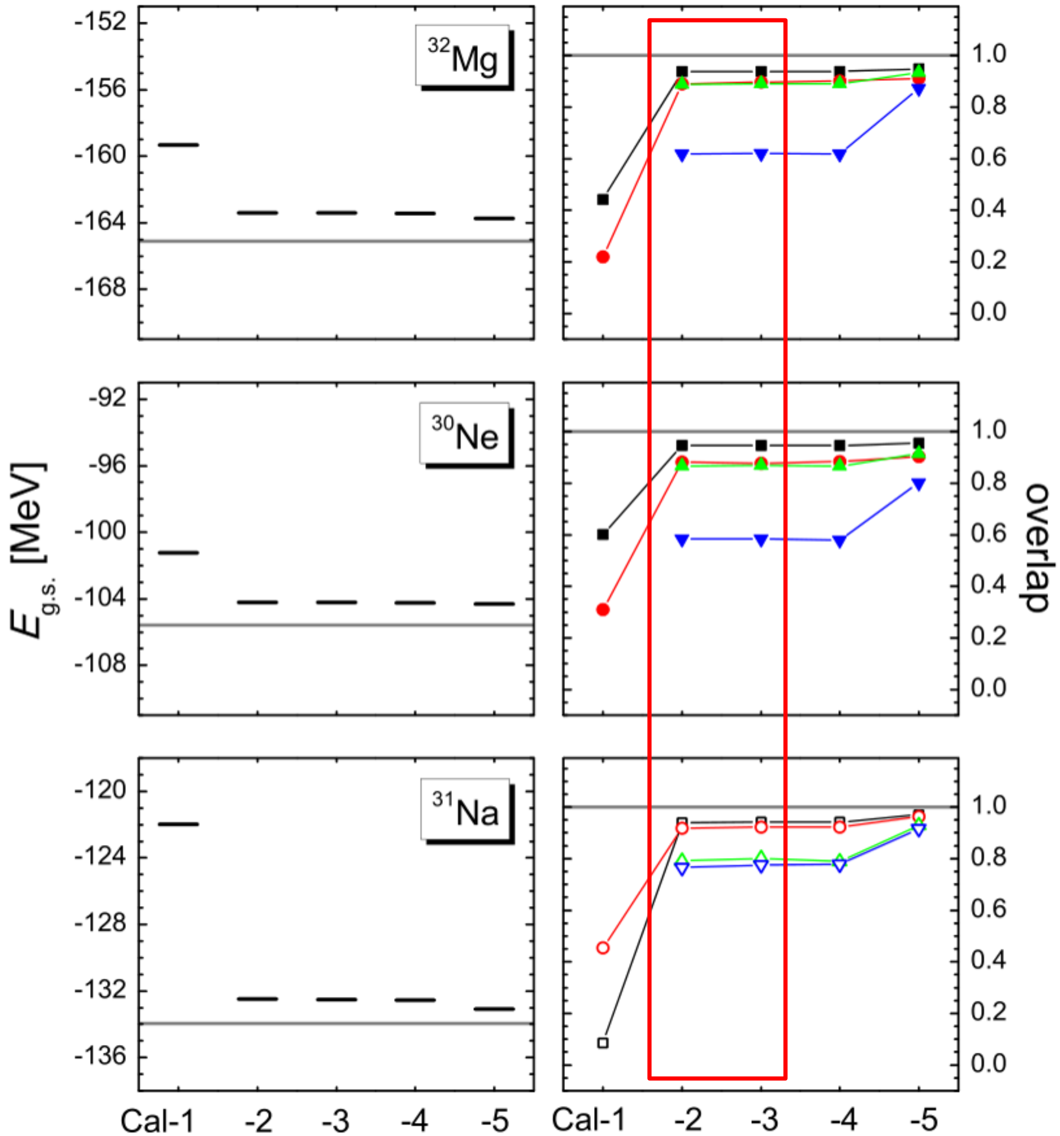
0^+_1, 2^+_1, 4^+_1, $3/2^+_1$, $5/2^+_1$, $7/2^+_1$, $9/2^+_1$

particle-hole config. dominant

0^+_2

shape-coexisting state; consistent with the result of two-neutron transfer reaction for Mg-32 (PRL 105, 252501)

Inversion-island nuclei: validity study



Cal-1: pp and hh *S* pairs

Cal-2: pp and hh *SD* pairs

Cal-3: Cal-2+ph *F* pair

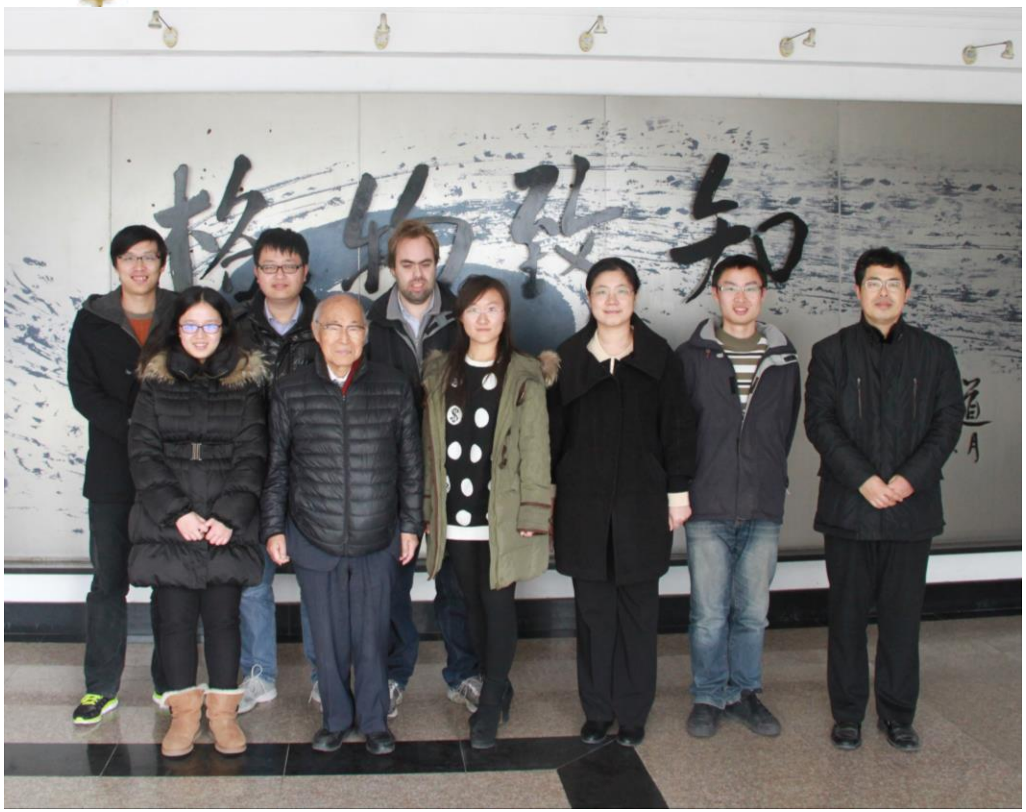
Cal-4: Cal-2+*D'* pair

Cal-5: Cal-2+*G* pair

Next plans

- **Effects of particle-hole configurations and effective operators in descriptions of magnetic moments and E2-transition probabilities in heavy nuclei**

- **Descriptions for collectivity in transitional nuclei from perspective of a pair-truncated particle-hole configuration space**



MANY…MANY Gratitudes to Arima Sensei !