Description of excitation states in light nuclei with Skyrme interaction employing multiple Slater determinants

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Collaborators

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Introduction

Atomic nuclei show various correlation structures

In light nuclei

clustering state and shell model like structure

Our goal

unified microscopic theory which is capable of describing clustering as well as shell-model-like states simultaneously

- *ab-initio* calculations
  - succeed to describe the ground state
  - Not good for excited state

  ex. no-core shell model for Hoyle state etc.
- anti-symmetrized molecular dynamics

  Gaussian single particle WF

we take another approach to unify description of nuclear structure with various correlations

Our approach

many-body Hamiltonian (Skyrme interaction etc.)

superposing multiple Slater determinants

excited states as well as ground state

advantage of our method

many-body Hamiltonian (Skyrme interaction etc.)

converged solution for many physical quantities

Method 1 : preparation of Slater determinants

1. Prepare many Slater determinants in some way
2. Parity and Angular momentum projection each Slater determinant
3. Configuration mixing (diagonalization of Hamiltonian)

the initial orbitals as a Gaussian wave packet and the center of the Gaussian is taken to be a random number

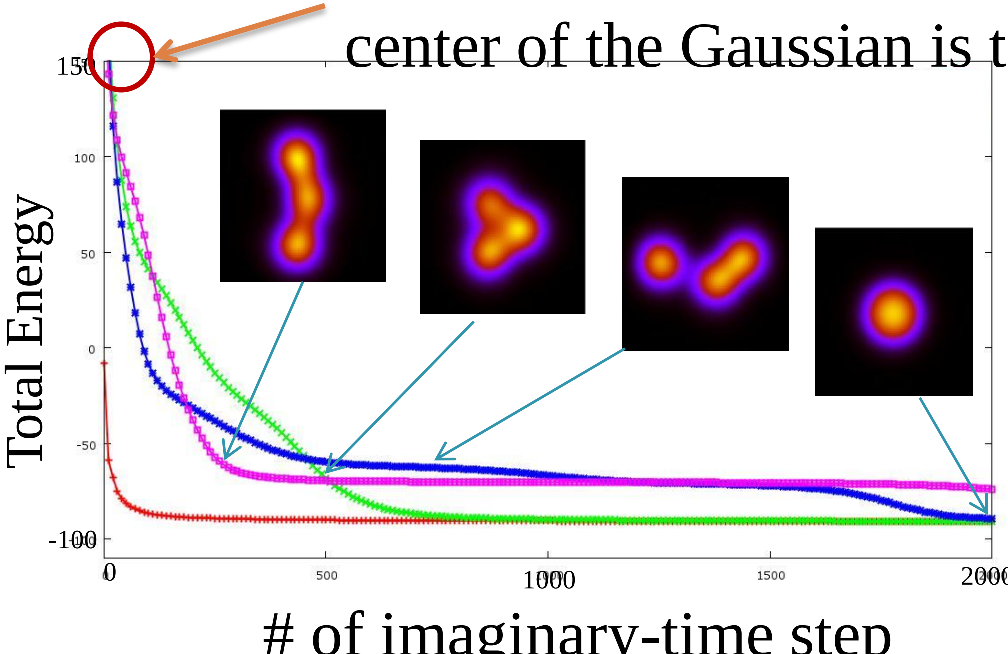


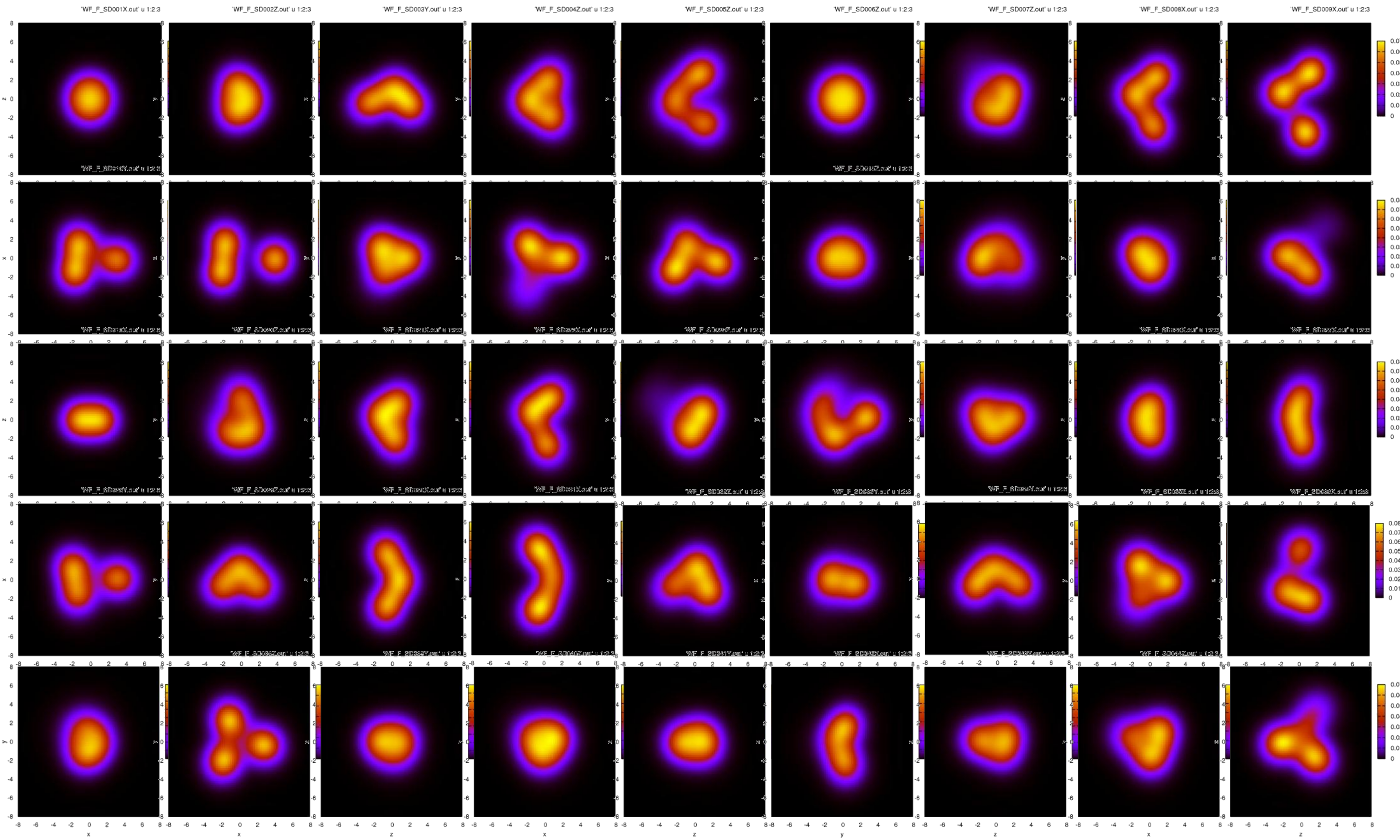
Fig. An example of imaginary-time evolution in ^{12}C

- Imaginary-time method calculate ground state solution in the Hartree-Fock
- number of cluster-like structures during the iteration

S. Shinohara, Ph.D. thesis(2007)

S. Shinohara *et al.*, PRC 74,054315 (2006)

Method 1 : preparation of Slater determinants



Method 2 : Parity and 3D Angular momentum Projection

1. Prepare many Slater determinants in some way

2. Parity and Angular momentum projection each Slater determinant

3. Configuration mixing (diagonalization of Hamiltonian)

Parity & Angular momentum projection

To restore symmetries, we achieve 3D projection of angular momentum and parity for each Slater determinant.

projected state

$$\hat{\mathrm{P}}^J_{MK}\hat{\mathrm{P}}^{\pm}\left|\Phi_n\right\rangle$$

Angular momentum projection operator

$$\hat{\mathrm{P}}^J_{MK}=\frac{2J+1}{8\pi^2}\int d\Omega \mathrm{D}^{J*}_{\mathrm{MK}}\hat{\mathrm{R}}(\Omega)$$

$$(\hat{\mathrm{R}}=e^{-i\alpha\hat{J}_z}e^{-i\beta\hat{J}_y}e^{-i\gamma\hat{J}_z})$$

Parity projection operator

$$\hat{\mathrm{P}}^{\pm}=\frac{1}{2}(1+\hat{\mathrm{P}}_r)$$

Method 3 : Configuration Mixing

1. Prepare many Slater determinants in some way

2. Parity and Angular momentum projection each Slater determinant

3. Configuration mixing

(diagonalization of Hamiltonian)

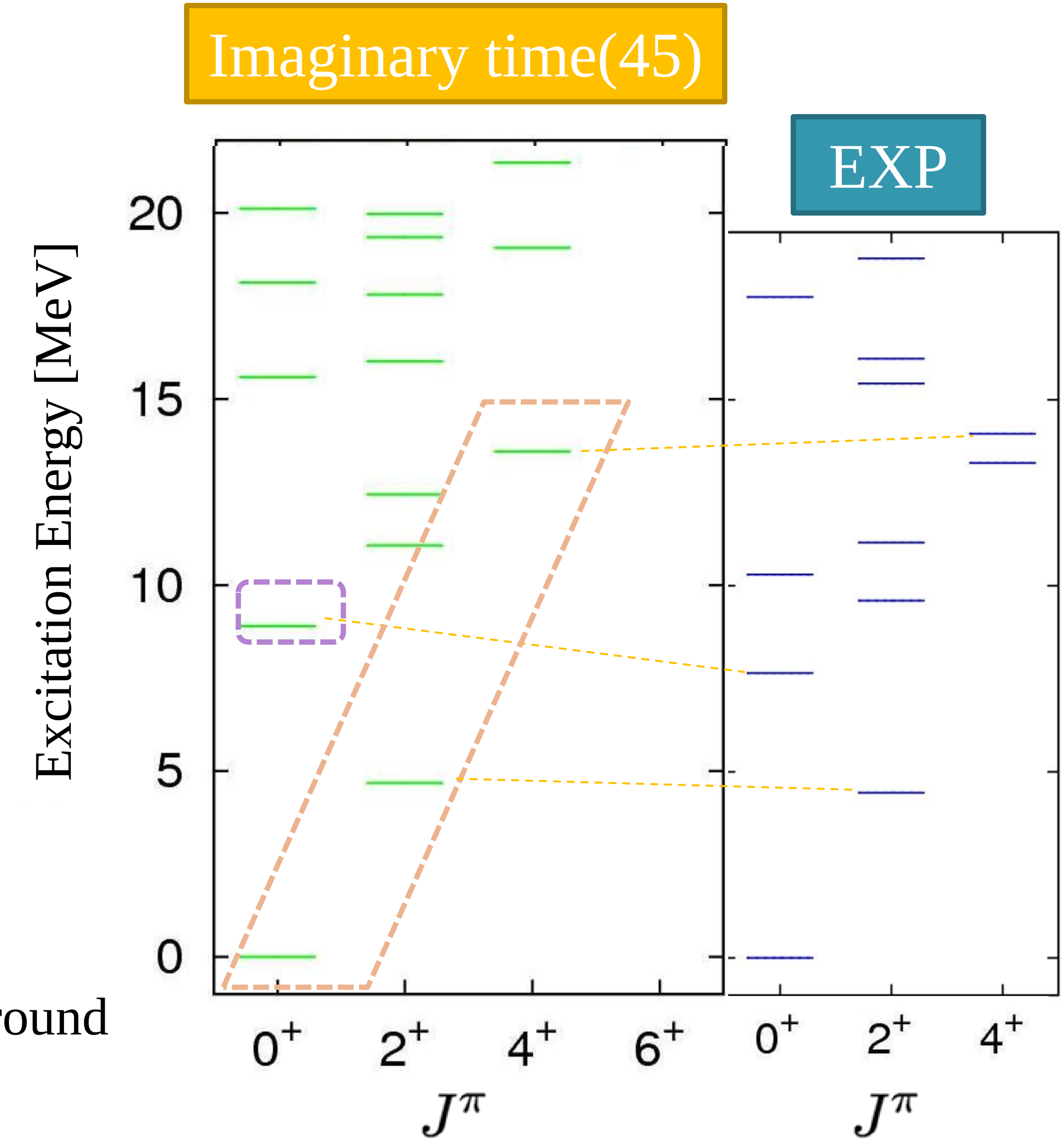
Configuration mixing

diagonalize the Hamiltonian within the projected states

$$|\Psi^{J(\pm)}\rangle = \sum_{n,K} \boxed{g_{nK}} \hat{\mathrm{P}}^{J}_{MK} \hat{\mathrm{P}}^{\pm} |\Phi_n\rangle$$

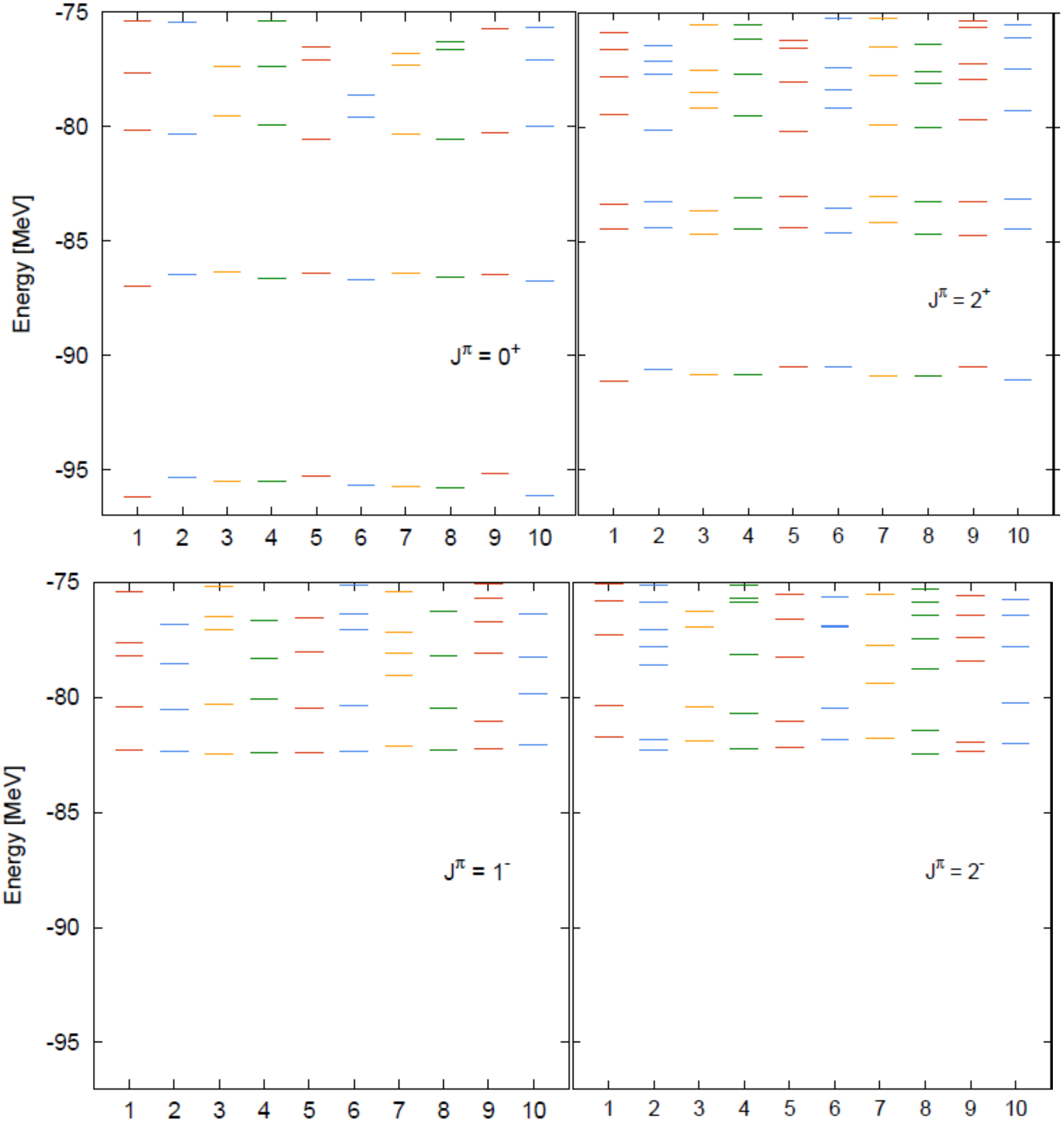
This coefficient can get to diagonalize Hamiltonian.

Energy spectrum for ^{12}C



well for the ground state band

^{12}C Comparison of calculations using ten sets of Slater determinants

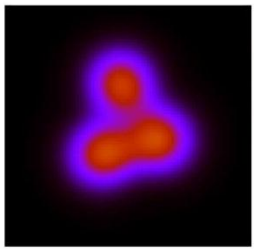


- these figures show that we can obtain a convergent excitation spectra for a given effective Hamiltonian.
- ten sets of Slater determinants, each with 45 Slater-determinants, generated with different random numbers.
- low energy states almost coincide with each other

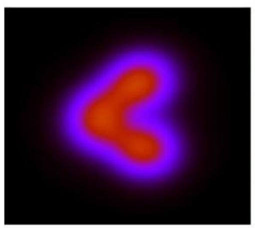
→ our calculation is reliable in low energy states

^{12}C Comparison with measured values

Hoyle state : 0_2^+



41.2%



36.1%

31.7%

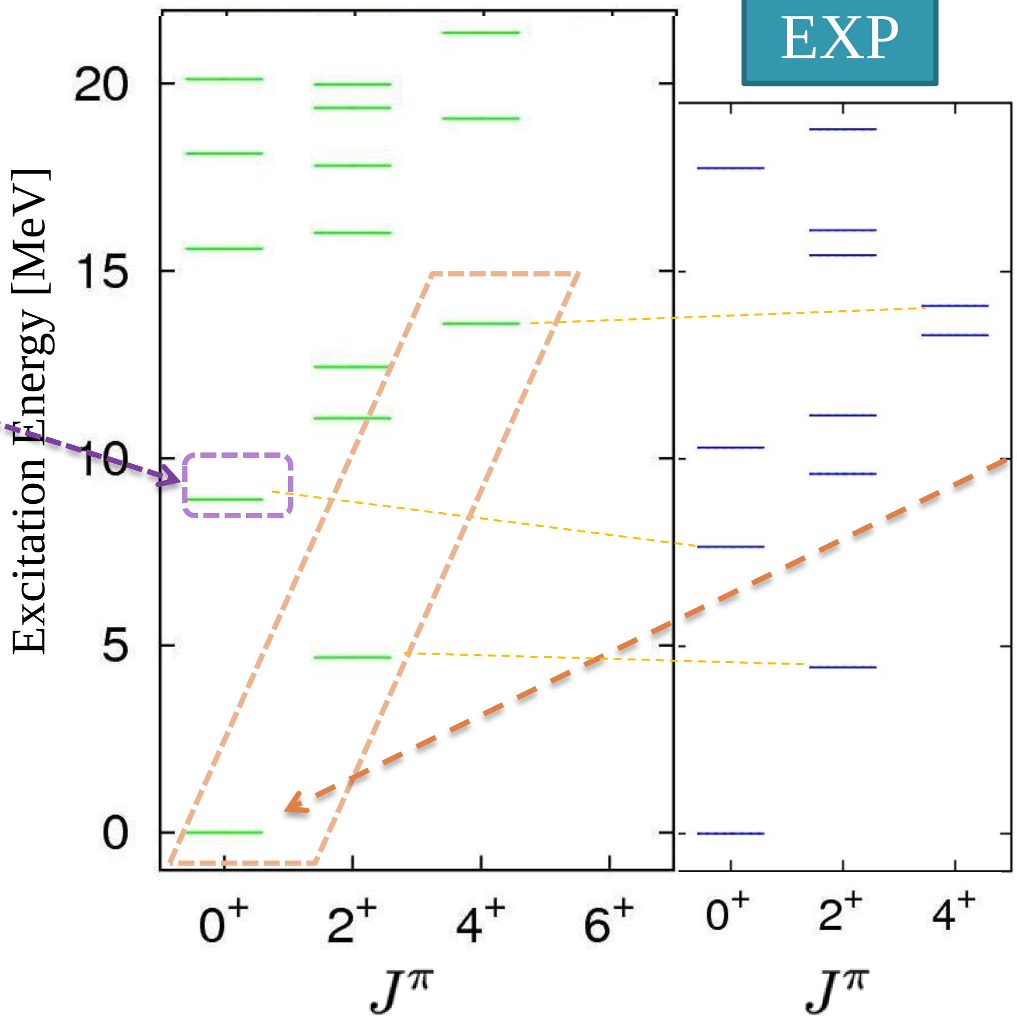
28.9%

⋮

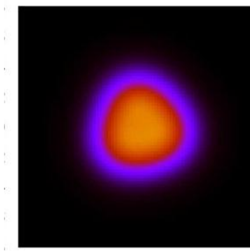
many SD is essential

Imaginary time(45)

EXP



Ground state



0_1^+

89.8%

86.9%

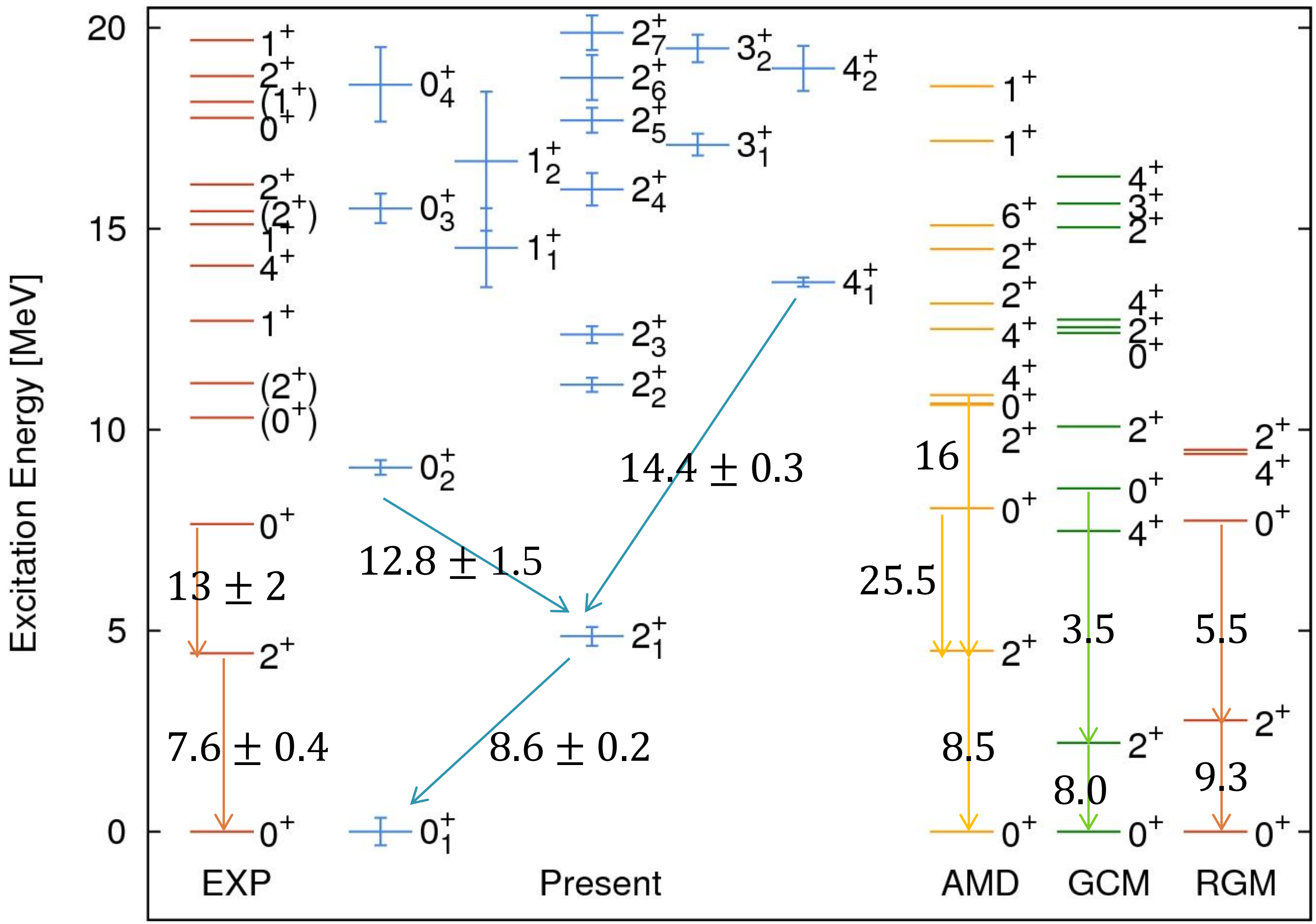
86.2%

84.9%

⋮

single SD

^{12}C Comparison with other theories

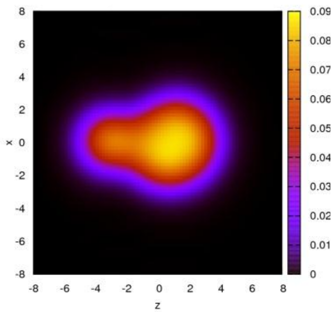


arrow : B(E2) value $(e^2 fm^4)$

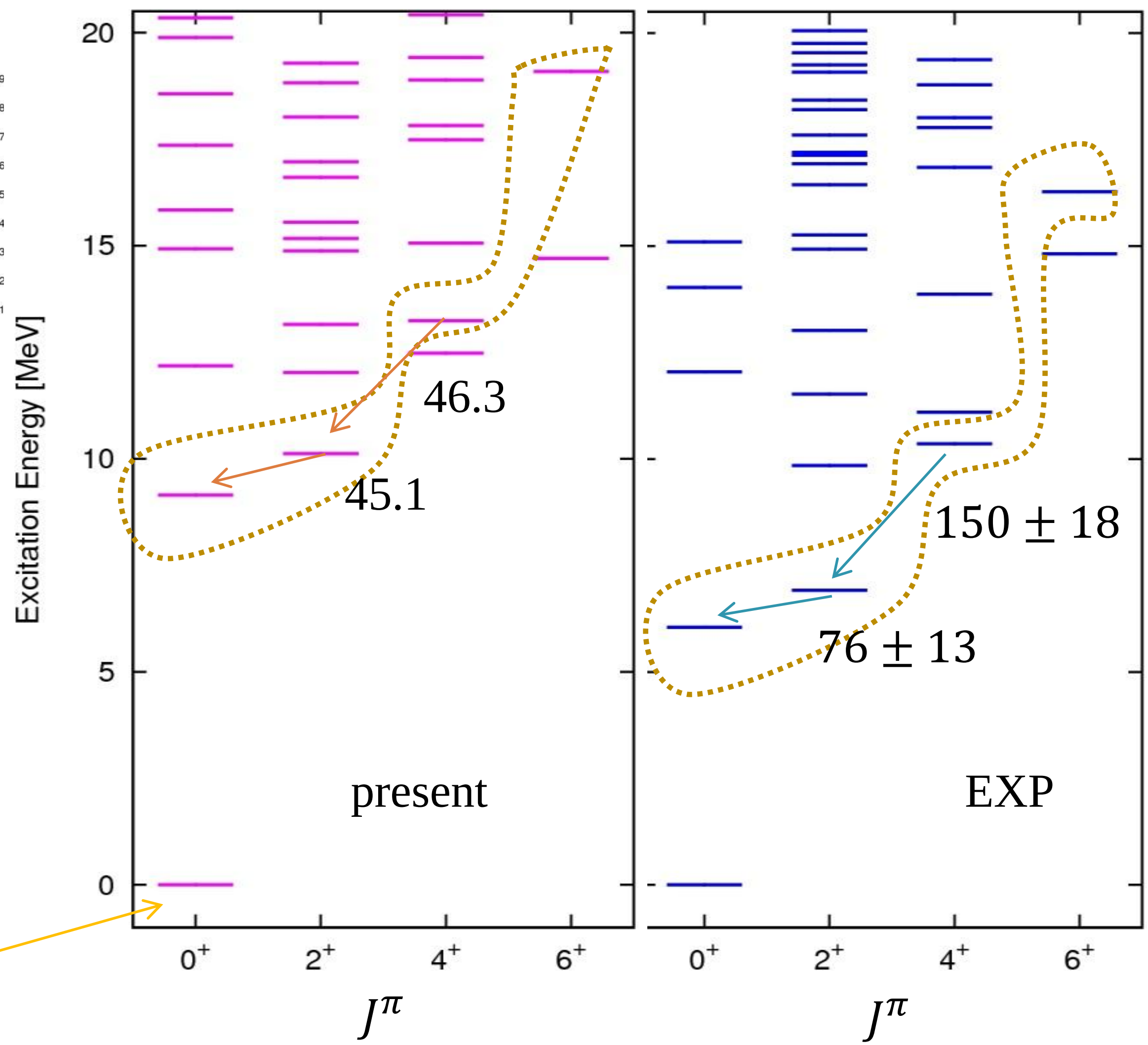
good agreement with experimental value

^{16}O Comparison with measured values

^{12}C + α(?) like



0_2^+ : 67.0%
2_1^+ : 66.4%
4_2^+ : 43.1%



HF state:
80%

The excitation energy is slightly high.
←Model space is small

arrow : B(E2) value (e^2fm^4)

Summary and perspective

- Our goal is unified description of nuclear structure with different correlations. (multiple Slater determinants, Projection)
- ^{12}C
  - Hoyle state is 3-alpha gas like state
  - our calculation get accurate low energy excitation.
- ^{16}O
  - mean field solution amount for 80% in the ground state after the configuration mixing
  - slightly high excitation <- probably caused by a weak coupling nature of α-^{12}C(future work)
- We achieve calculations for some light nuclei, and we succeed to obtain a convergent excitation spectra for a given effective Hamiltonian, which we adopted Skyrme interaction.

We hope to extend our work for many nuclei or an *ab-initio* description starting with more realistic nucleon-nucleon force.