Nuclear Structure of the N=20 Island of Inversion and Its Shore with Large-Scale Shell-Model Calculations

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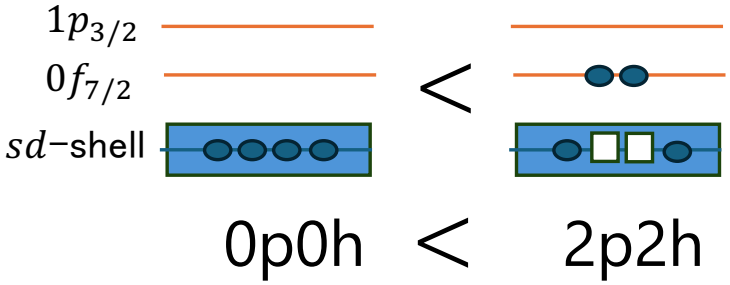
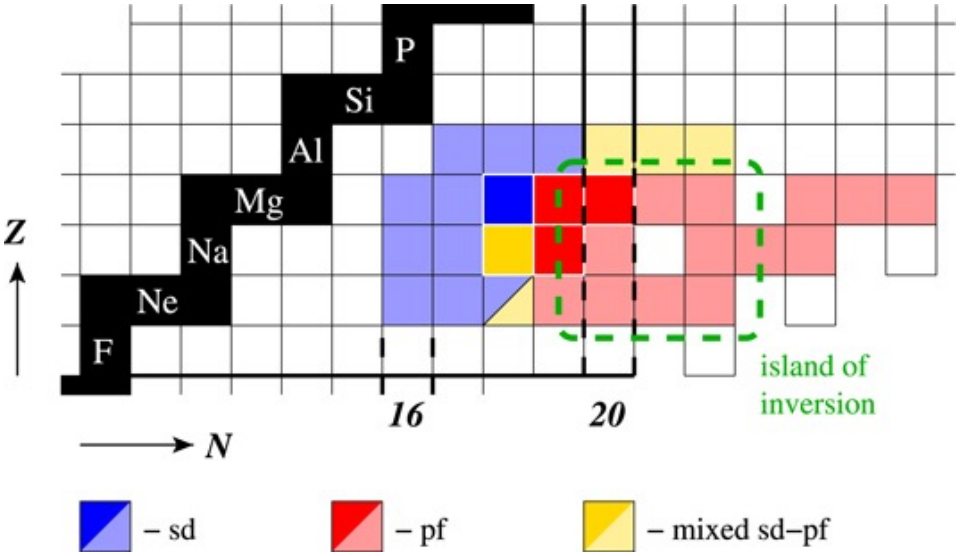
Island of inversion

- The island of inversion (IoI) is a region where the low-lying states are dominated by intruder configurations.

P. A. Butler *et. al.* 2017 J. Phys. G: Nucl. Part. Phys. **44** 044012





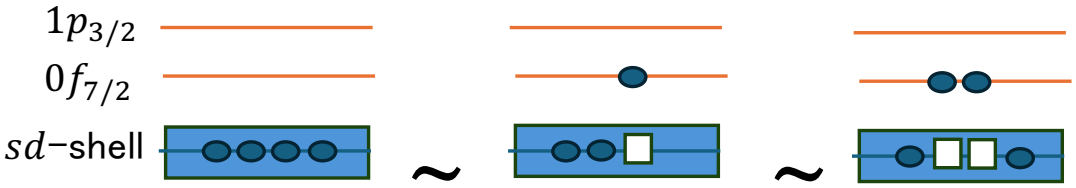
- Shell model studies for IoI
  - SDPF-M [1]

    The first interaction to successfully describe the IoI
  - FSU [2]
  - SDPF-U-MIX [3]

[1] Y. Utsuno *et al.*, PRC **60**, 054315 (1999)
[2] Lubna *et al.*, PRR **2**, 043342 (2020)
[3] Caurier *et al.*, PRC **90**, 014302 (2014).

The shore of the island of inversion

- Role of odd nuclei on the shore of the IoI.



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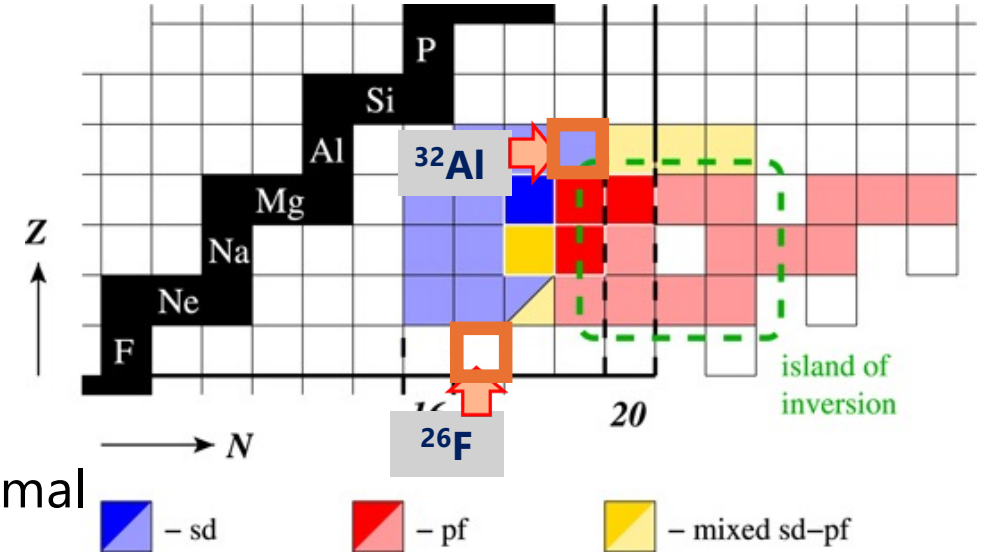


These states play a key role in connecting normal and intruder configurations.

We found that the SDPF-M interaction has difficulty reproducing negative-parity states for odd-mass nuclei in the shore of the IoI.

Shell model interaction

- USD [4]/USDB [5]

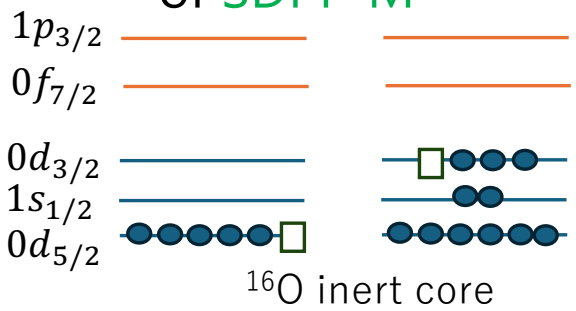
  defined in the sd-shell model space.
  USDB is an improved version of USD.

- SDPF-M [1]

  Its model space is defined by 16O inert core, with the sd-shell+$f_{7/2}$ and $p_{3/2}$ orbitals as valence orbital
  The sd-shell, pf-shell, and sd–pf cross-shell components are constructed by combining existing effective interactions.
  The sd-shell part is based on the USD interaction.

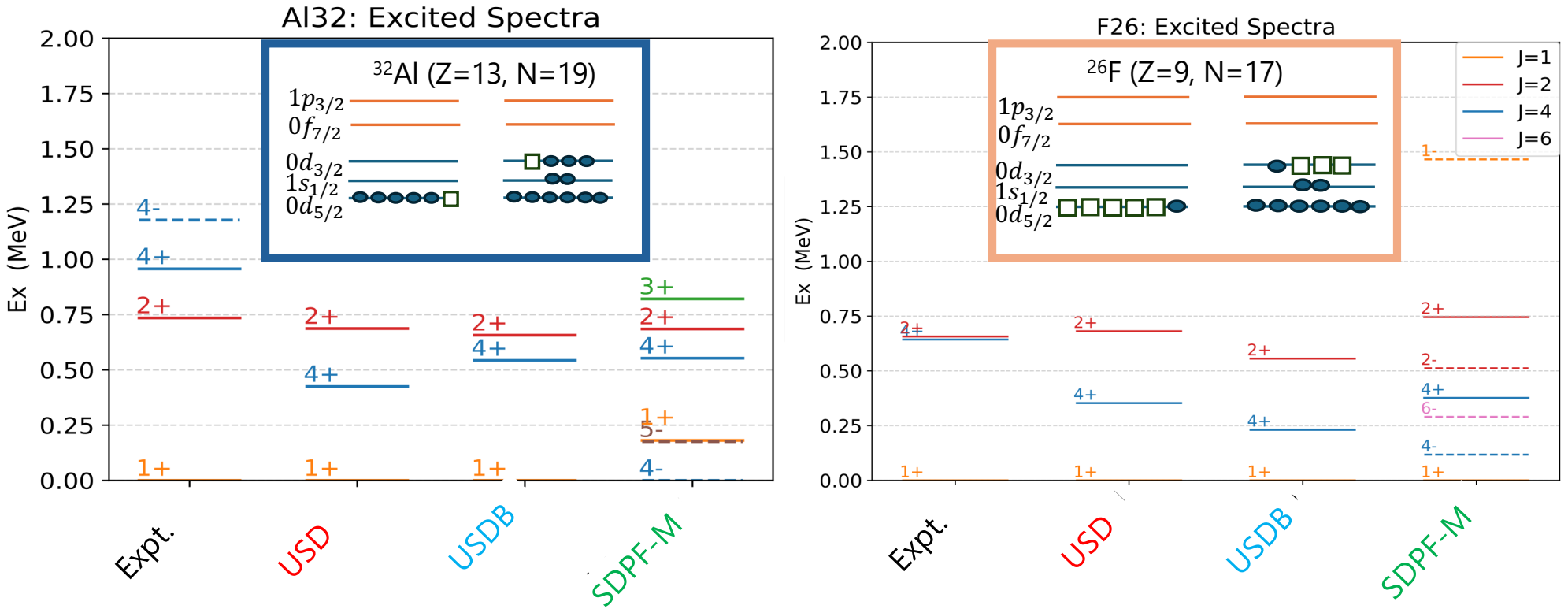
[4] B. A. Brown et al. Rev. Nucl. Part. Sci. **38**, 29 (1988)
[5] W. A. Richter et al. Phys. Rev. C **78**, 064302 (2008)

Model space of SDPF-M



We performed shell-model calculations using these interactions with the **KSHELL** code.

Results of previous work



- The excitation energies of the 4^+ states are underestimated by all effective interactions in both nuclei
- With the SDPF-M interaction, the negative-parity state is predicted too low.

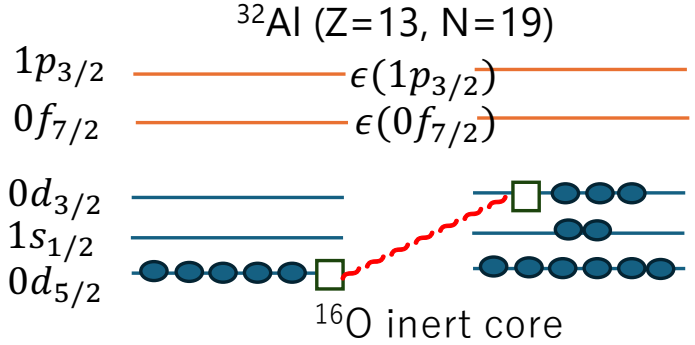
Revision of the SDPF-M with USDB and GXPF1A

We constructed a hybrid interaction in the same model space as SDPF-M.

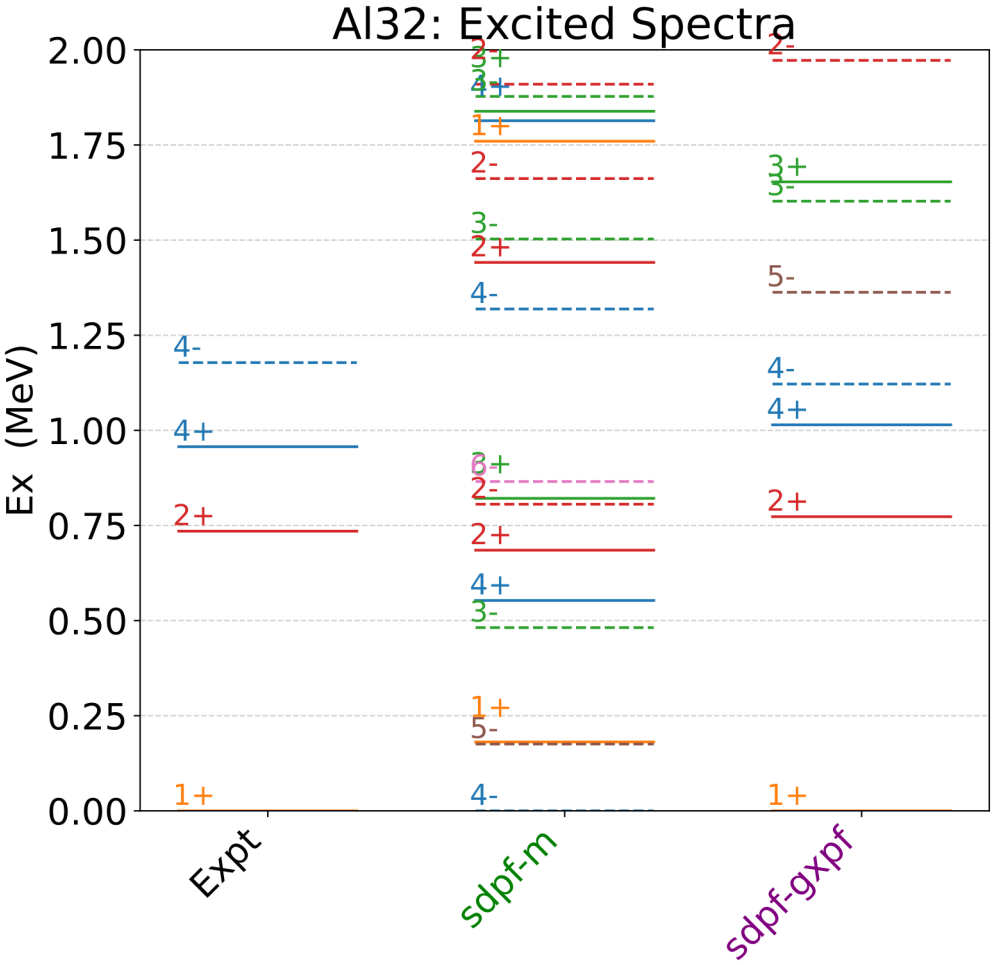
- sd-shell part: USDB, pf-shell part: GXPF1A[6]
  sd-pf cross-shell part: Millener–Kurath interaction used in SDPF-M
- We optimized following 5 parameters
  $\langle (0d_{5/2})(0d_{3/2})| V |(0d_{5/2})(0d_{3/2})\rangle^{T=0}_{J=1,2,4}$, ε(1p3/2) and ε(0f7/2) ,
  to minimize the chi-square for excitation energies of the 1+, 2+, 4+, and 4− of ^{32}Al and those of the 7/2− and 3/2− of ^{35}Si.
- The monopole interaction is fixed to that of USDB

$$\bar{V}^{T}_{ab} = \frac{\sum_{J}(2J+1)\langle ab; J_o T_o \,|\, V \,|\, ab; J_o T_o\rangle}{\sum_{J}(2J+1)}$$

We named this interaction SDPF-GXPF

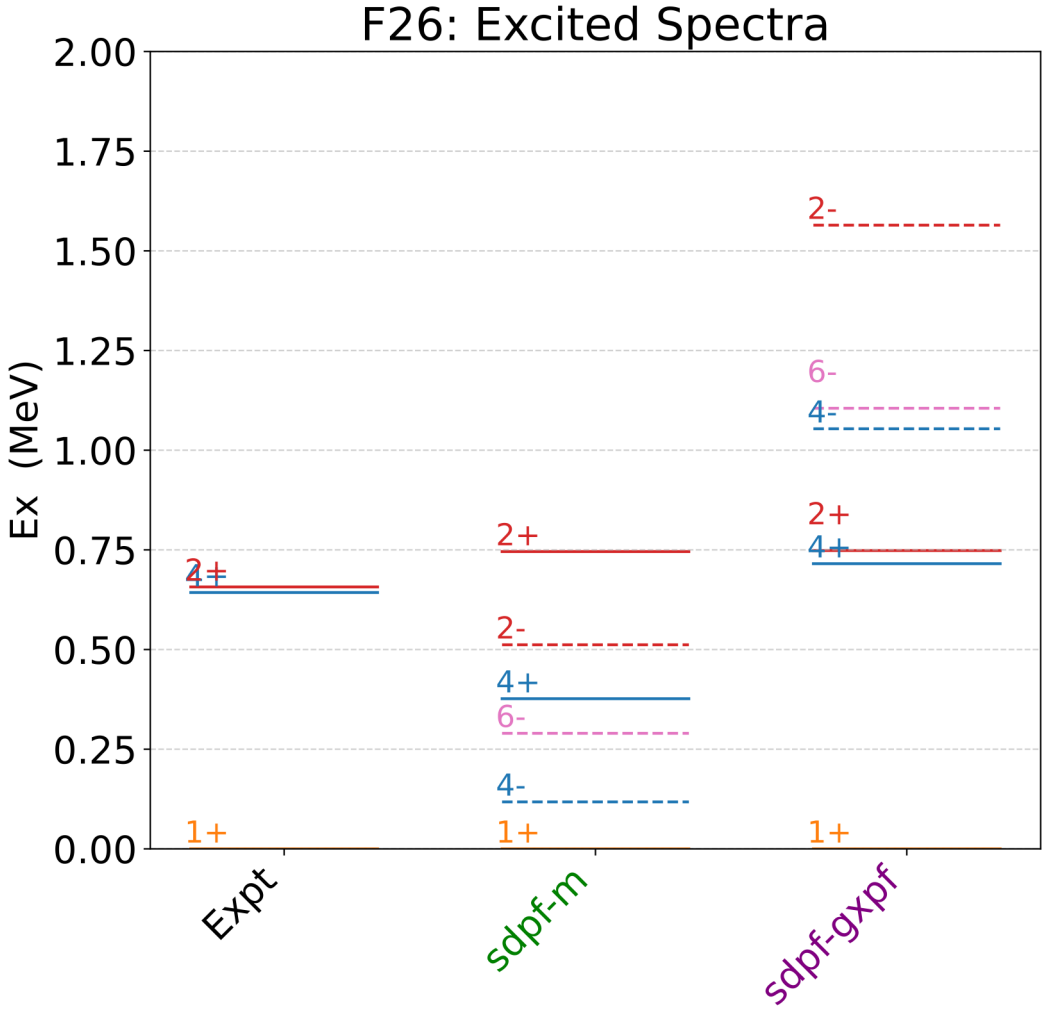


Results of SDPF-GXPF



- Excited spectrum of ^{32}Al
  - The spectrum of ^{32}Al is reproduced.
  - The negative parity of ^{32}Al is reproduced by modifying SPEs of SDPF-M interaction.

Results of SDPF-GXPF



- Results of ^{26}F

- The spectrum of ^{26}F is reproduced.

- The result of ^{26}F is agreement with experimental data without including any ^{26}F data in the fitting procedure.

Root-mean-square (RMS)

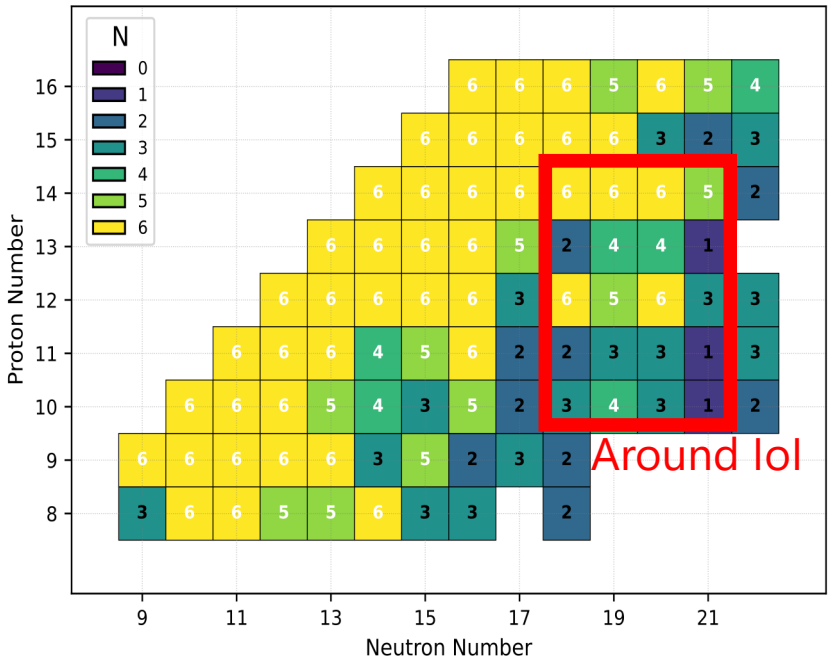
- Root-mean-square (RMS)

The RMS deviation was calculated as

$$\mathrm{RMS} = \sqrt{\frac{1}{N_d}\sum_{i=1}^{N_d}\left(E_i^{\mathrm{cal}} - E_i^{\mathrm{exp}}\right)^2}. \qquad E_i = \begin{cases} S_n, & i = \mathrm{g.s.}, \\ E_x(i), & i \neq \mathrm{g.s.}. \end{cases}$$

Interaction	Total (MeV) (N_d=402)	Around IoI (MeV) (N_d=84)
SDPF-M	0.536	0.747
SDPF-GXPF	0.504	0.650

States included in RMS evaluation



Selected states: max. 6 per nucleus; positive parity only for N < 18, and up to 3 positive and 3 negative parity states for 18 ≤ N ≤ 22, if experimental data exist.

Summary and Future plan

- We performed shell-model calculations near the island of inversion with USD/USDB/SDPF-M interactions.
  - ➡ We found some disagreements for ^{26}F and ^{32}Al.
- To address this problem, we propose a new interaction, SDPF-GXPF, defined in the model space of the sd shell and the p3/2 and f7/2 orbitals.
  - ➡ we improved the description of excited spectra near the Island of Inversion.
- Improvement of SDPF-GXPF interaction.
- Providing information to experimentalists
  - ➡ Tomorrow's talk by Matsuda-san (Univ. of Osaka)