A presentation supported by the JSPS Core-to-Core Program "International Research Network for Exotic Femto Systems (EFES)"

First EMMI-EFES workshop on neutron-rich exotic nuclei EENEN 09

- Realistic effective nuclear forces for neutron-rich nuclei -

9 -11 February 2009, GSI Darmstadt

Why forces ?

What forces ?

Takaharu Otsuka
University of Tokyo / RIKEN / MSU

18時21分

Previous workshops on nuclear structure and astrophysics

2004 Dec GSI in Germany

2006 Oct. 4~7 RIKEN in Japan
(2rd in Google for "Japanese-German workshop")

2007 Sep. 29 ~ Oct. 2 Frauenchiemsee in Bavaria

ExtreMe Matter Institute has been established at the site of GSI.

A central goal of the Alliance is the creation of the "ExtreMe Matter Institute (EMMI)' on GSI grounds. With EMMI Europe will get a unique infrastructure for interdisciplinary investigations of matter under extreme conditions (from extremely hot matter of the big bang to ultra-cold quantum gases). This institute will also serve as a think tank for the just officially started International FAIR facility.

Areas covered:

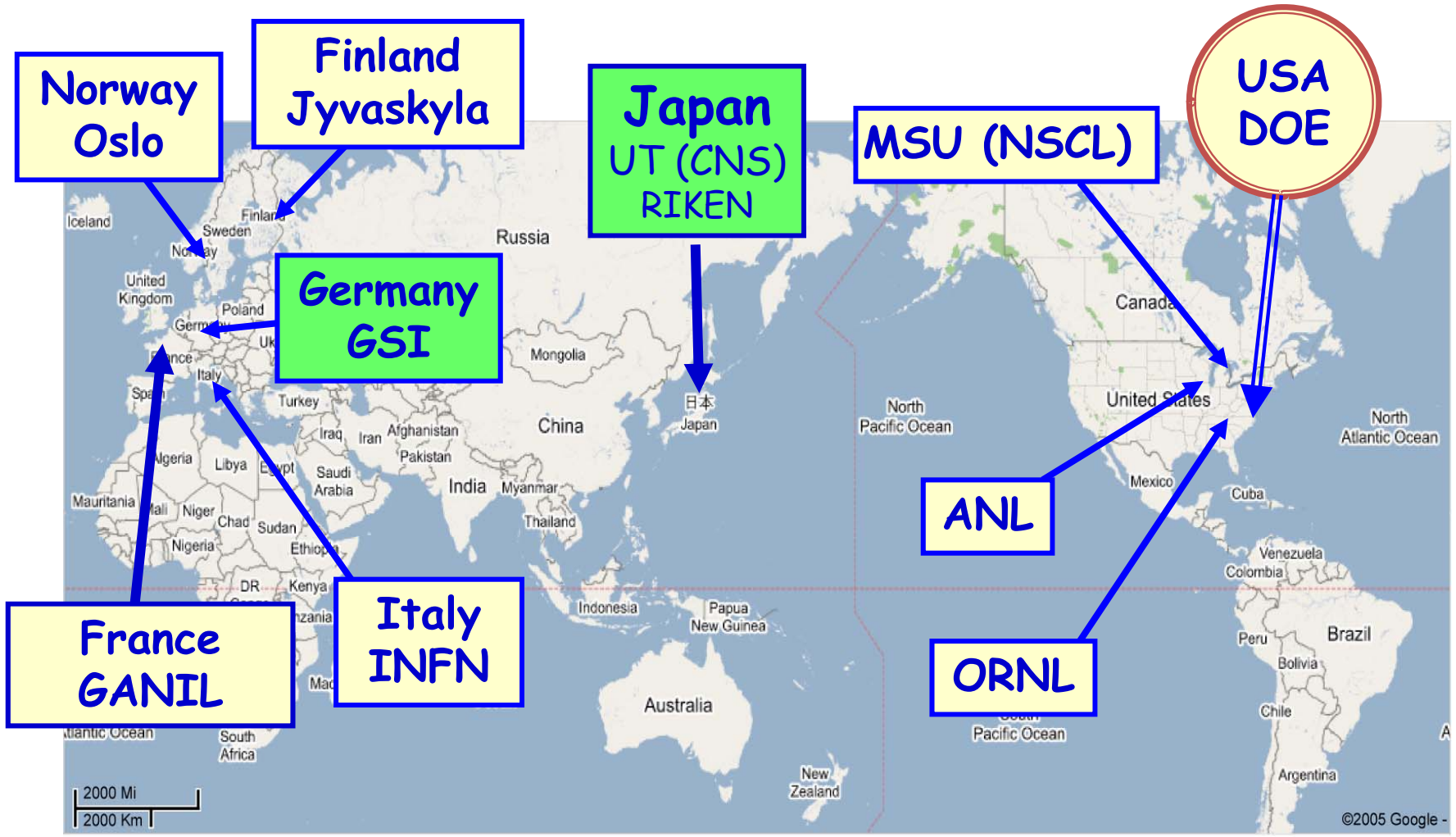
- Quark-Gluon-Matter
- Neutron Matter → This workshop is the first scientific meeting under this subject.
- Plasmas of High Energy Density
- Atomic Physics - Extreme States of Matter

International collaboration:

From Japan, Univ. Tokyo and RIKEN.

→This workshop is a Japanese contribution to EMMI.
There is significant support also from EMMI.

EFES : A Japanese program by JSPS to promote international collaboration in the area of physics of exotic nuclei



Based on this tradition, EMMI-EFES workshops

First EMMI-EFES workshop (EENEN 09) on
neutron-rich exotic nuclei
- Realistic effective nuclear forces for neutron-rich nuclei -

More emphasis on discussions and initialization of collaborations

More focus on specific subjects
→ *Nuclear forces in nuclear structure* this time

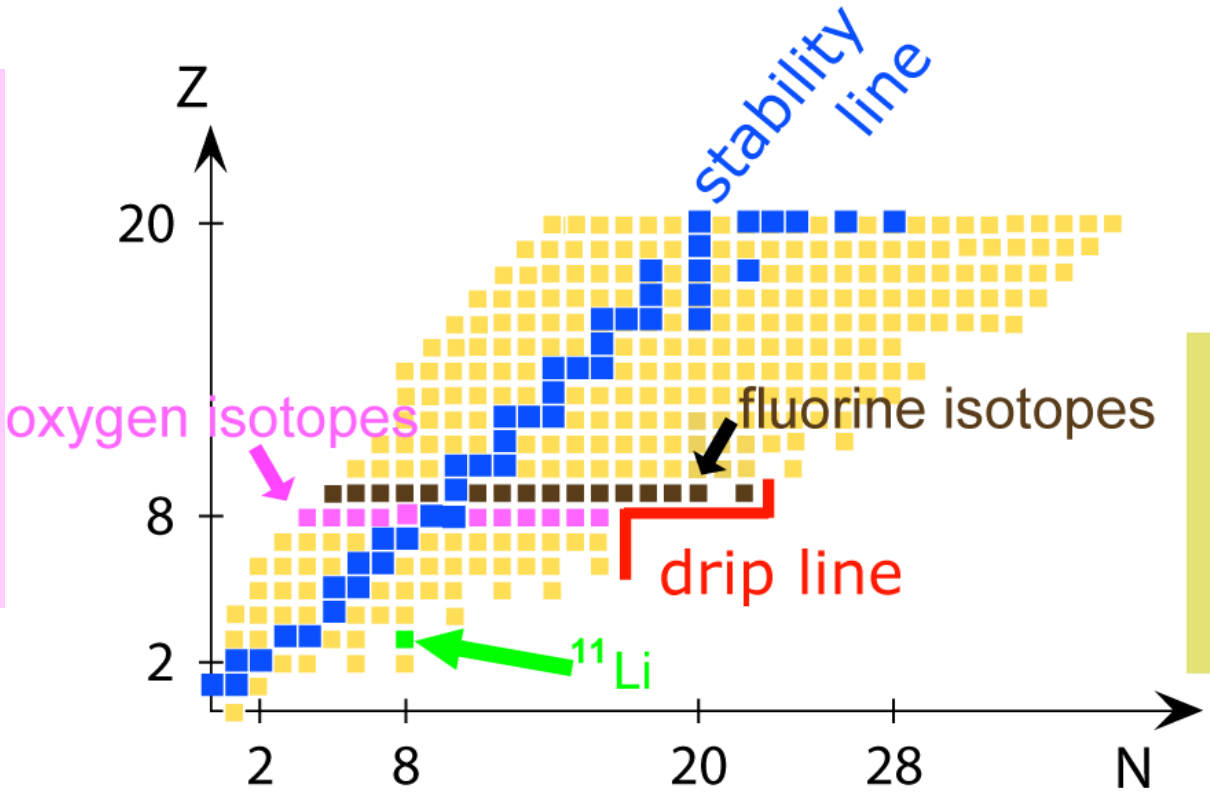
In the future, we may have workshops on broader scopes possibly including the help from DFG.

Why forces ? What forces ?

An example

Nuclear Chart
- Left Lower Part -

Stable nuclei
Exotic nuclei
Fluorine isotopes
Oxygen isotopes



Proton number →

Neutron number →

Why is the drip line of Oxygen so near ?

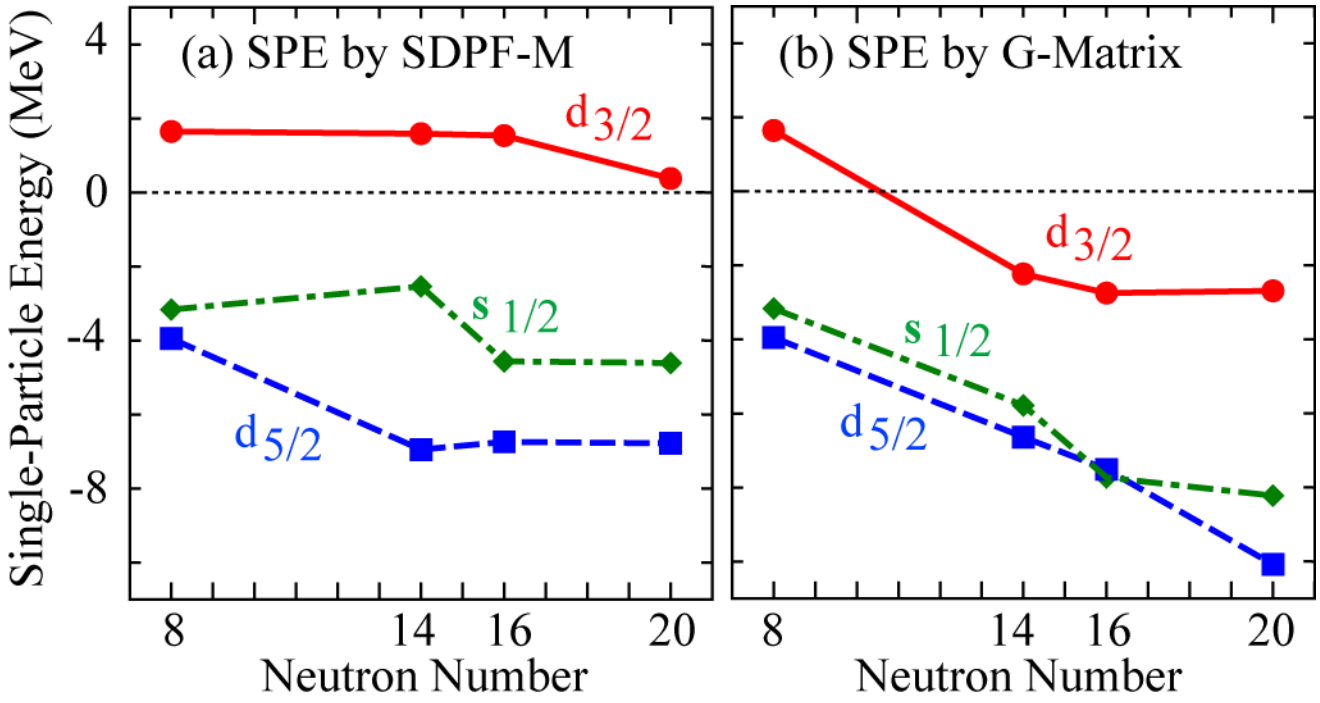
Single-Particle Energy for Oxygen isotopes

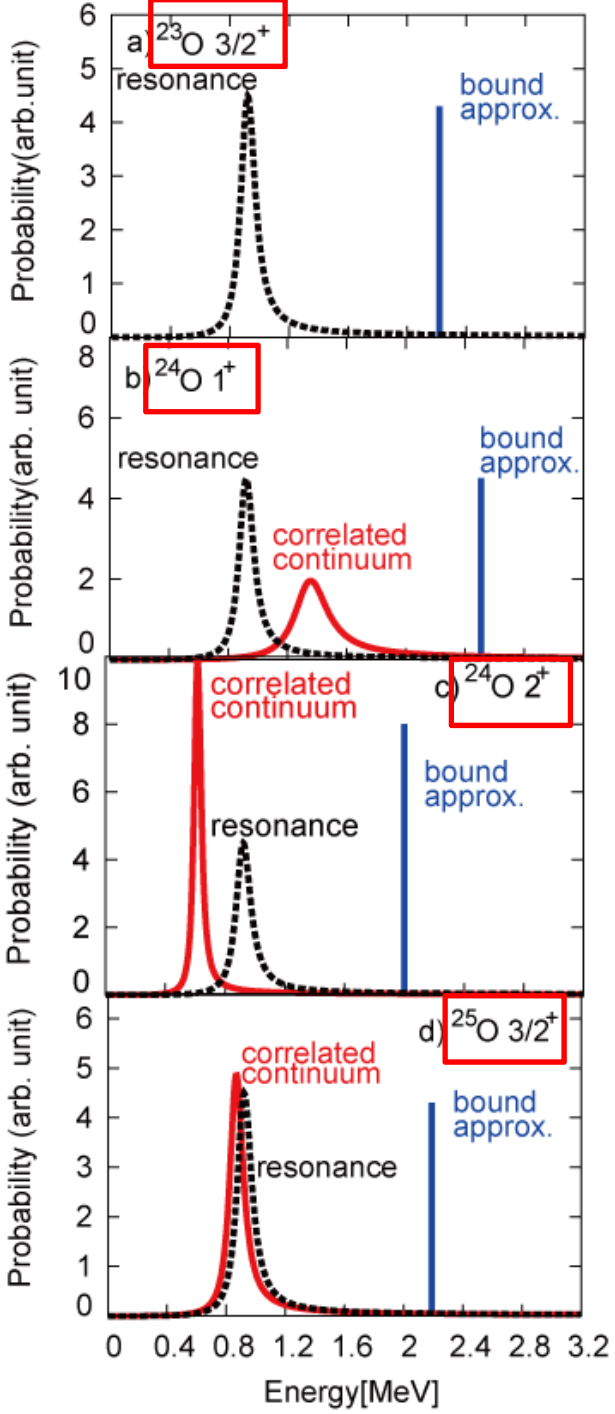
SDPF-M

G-matrix + fit
(USD +)

Y. Utsuno, T.O., T. Mizusaki, and M. Honma,
Phys. Rev. C **60**, 054315 (1999).

Kuo-Brown
G-matrix
+ core-pol.





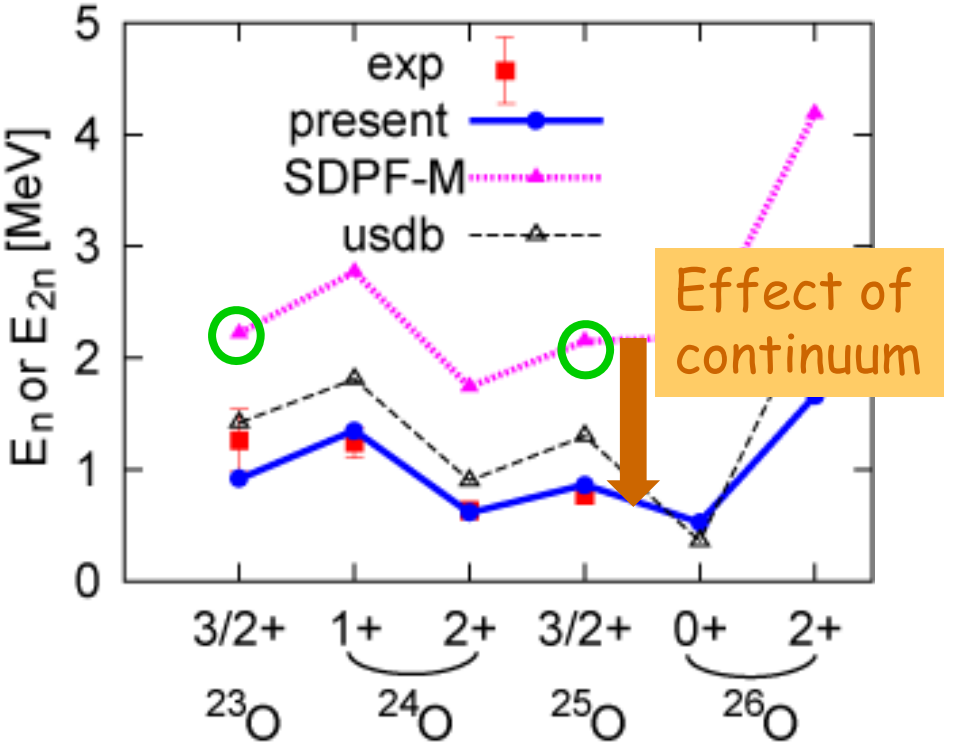
SDPF-M interaction appears to be consistent with continuum-couplings

Spectrum of emitted neutrons from exotic O isotopes created by knockout reactions

theory : **Continuum-Coupled Shell Model**

Tsukiyama, Otsuka, Fujimoto

2008, submitted



What is the origin of

the *repulsive modification* of

T=1 monopole matrix elements ?

The same puzzle as in the pf shell

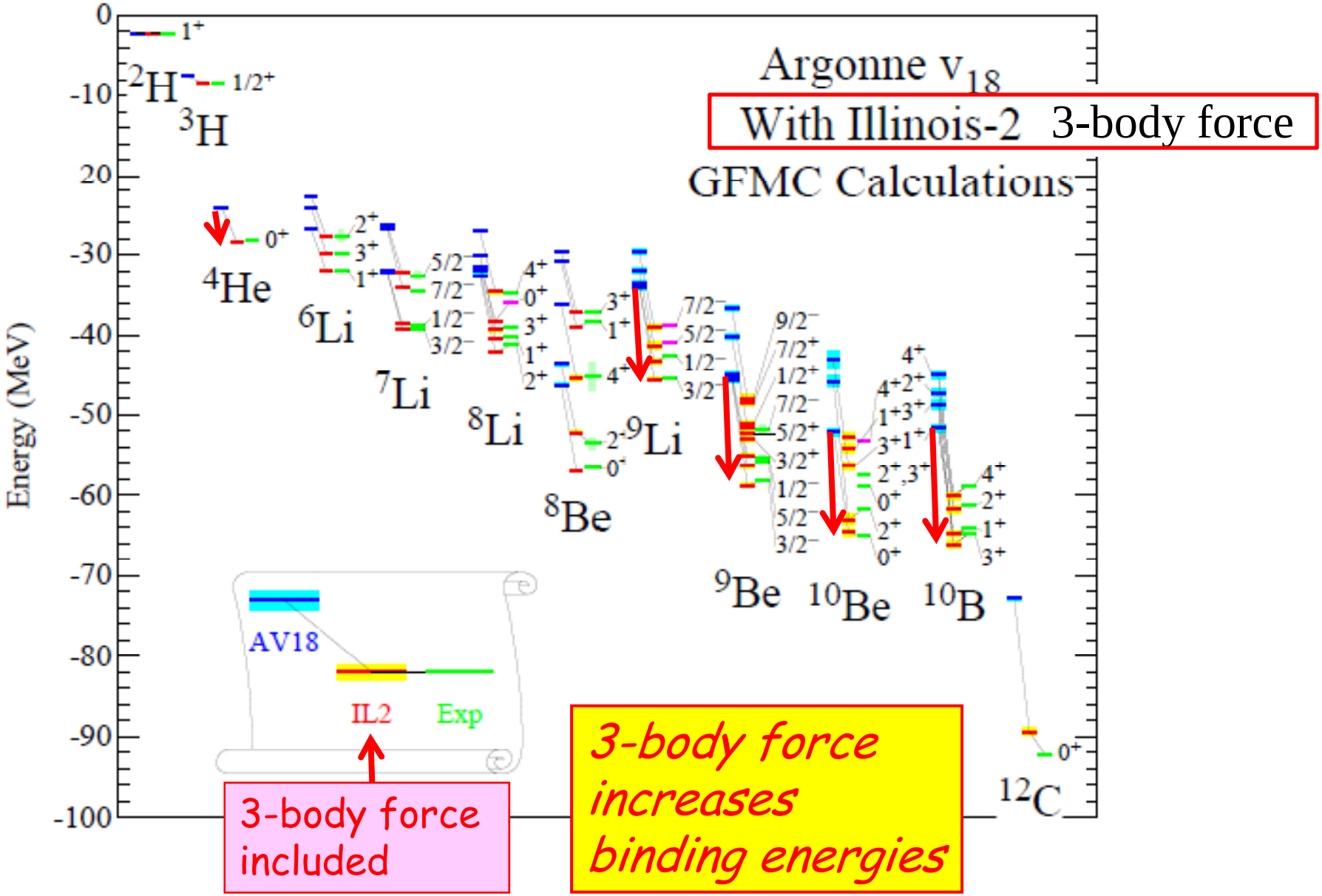
A solution within *bare* 2-body interaction
is very unlikely
(considering efforts made so far)

→ 3-body interaction

3NF -> attractive effects

systematics in results of GFMC, NCSM
CC (Hagen et al., Phys. Rev. C76, 034302 (2007)

GFMC (Green Function Monte Carlo) by Argonne group



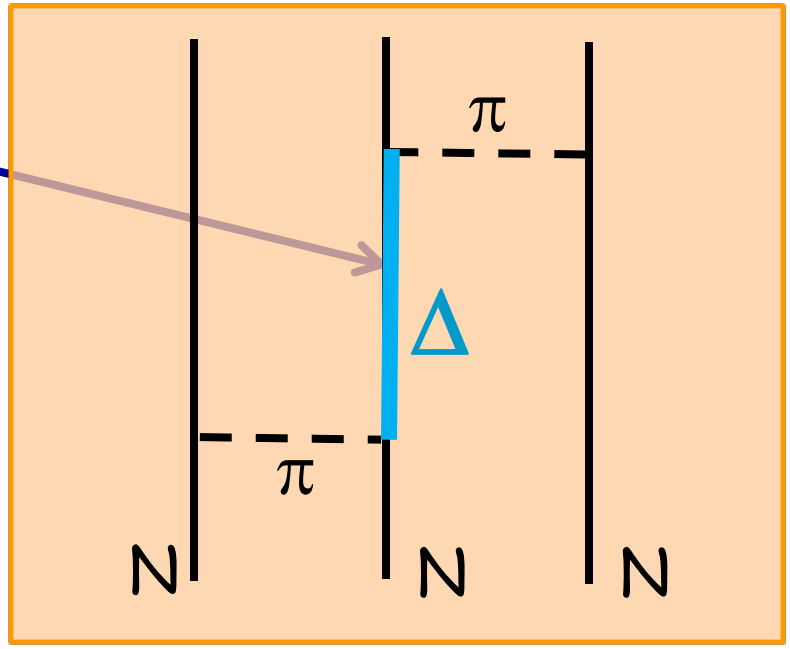
The key : Fujita-Miyazawa 3N mechanism (Δ-hole excitation)

Progress of Theoretical Physics, Vol. 17, No. 3, March 1957

Pion Theory of Three-Body Forces

Jun-ichi FUJITA and Hironari MIYAZAWA

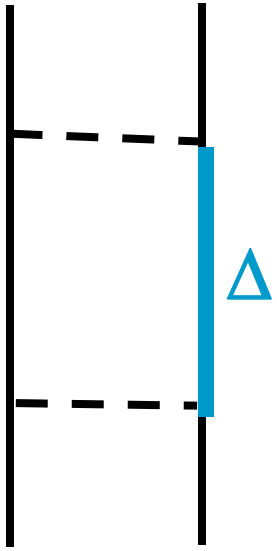
Δ particle
m=1232 MeV
S=3/2, I=3/2



Oset, Toki and Weise

Phys. Rep. 83, 281 (1982)

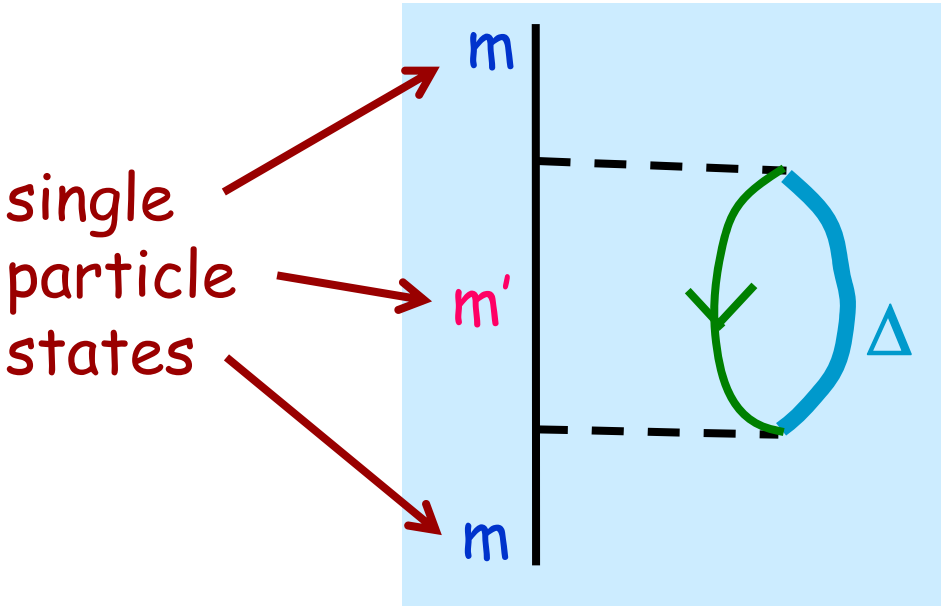
Renormalization of *NN* interaction due to Δ **excitation** in the intermediate state



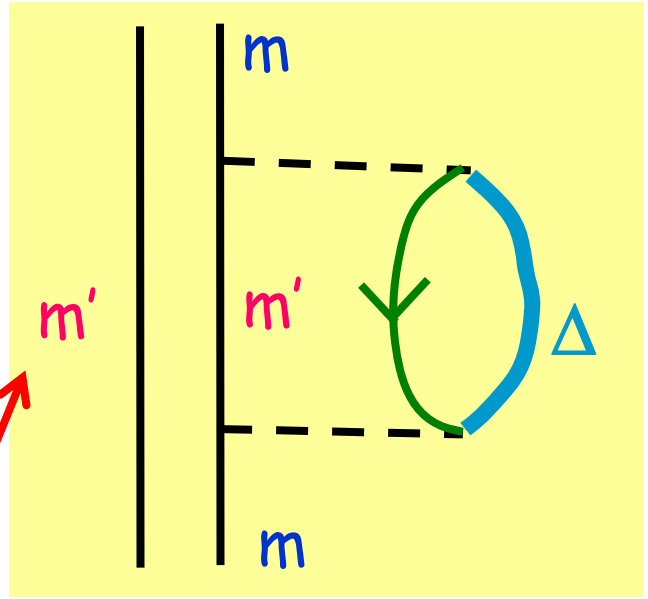
T=1 attraction between *NN* effectively

Modification to bare *NN* interaction (for *NN* scattering)

Pauli blocking effect on the renormalization of single-particle energy



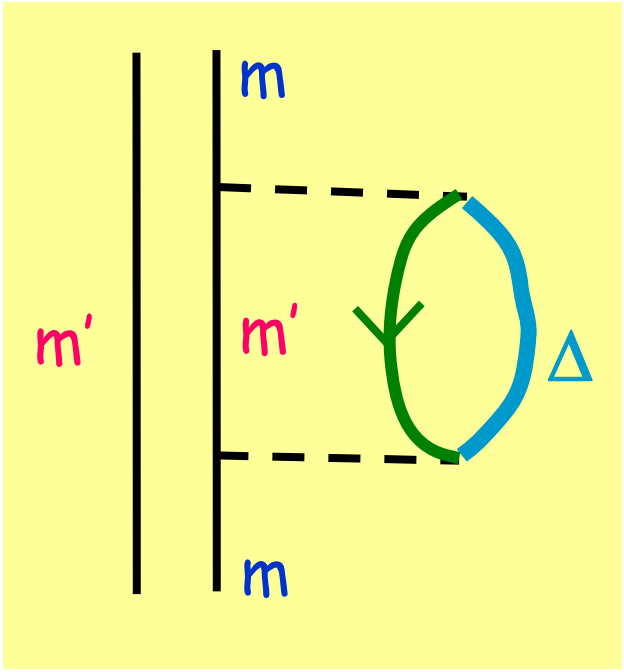
Renormalization of single particle energy due to Δ-hole excitation
→ more binding (attractive)

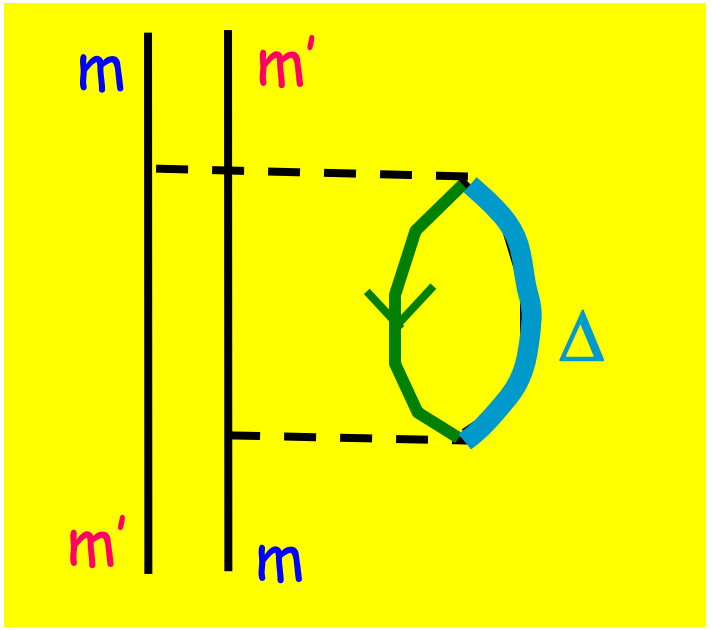


Another valence particle in state m'

Pauli Forbidden
→ *The effect is suppressed*

Inclusion of Pauli blocking

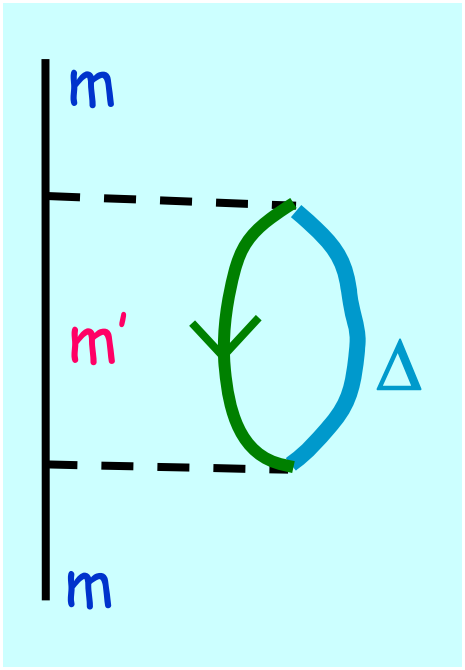




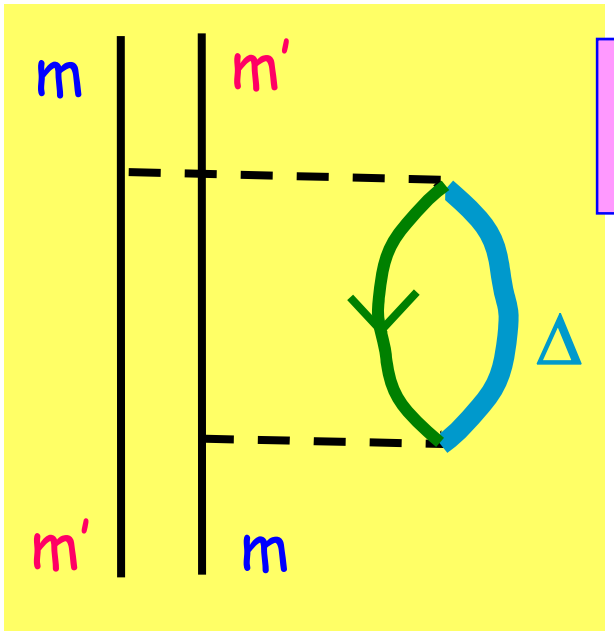
Pauli forbidden
(from previous page)

This Pauli effect is included automatically by the exchange term.

Most important message with Fujita-Miyazawa 3NF



+

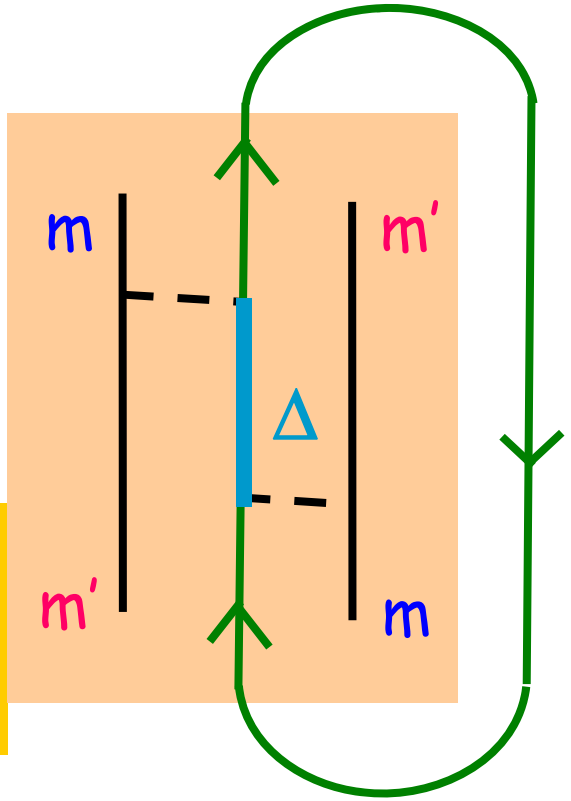


Effective monopole repulsive interaction

Renormalization of single particle energy

Pauli blocking

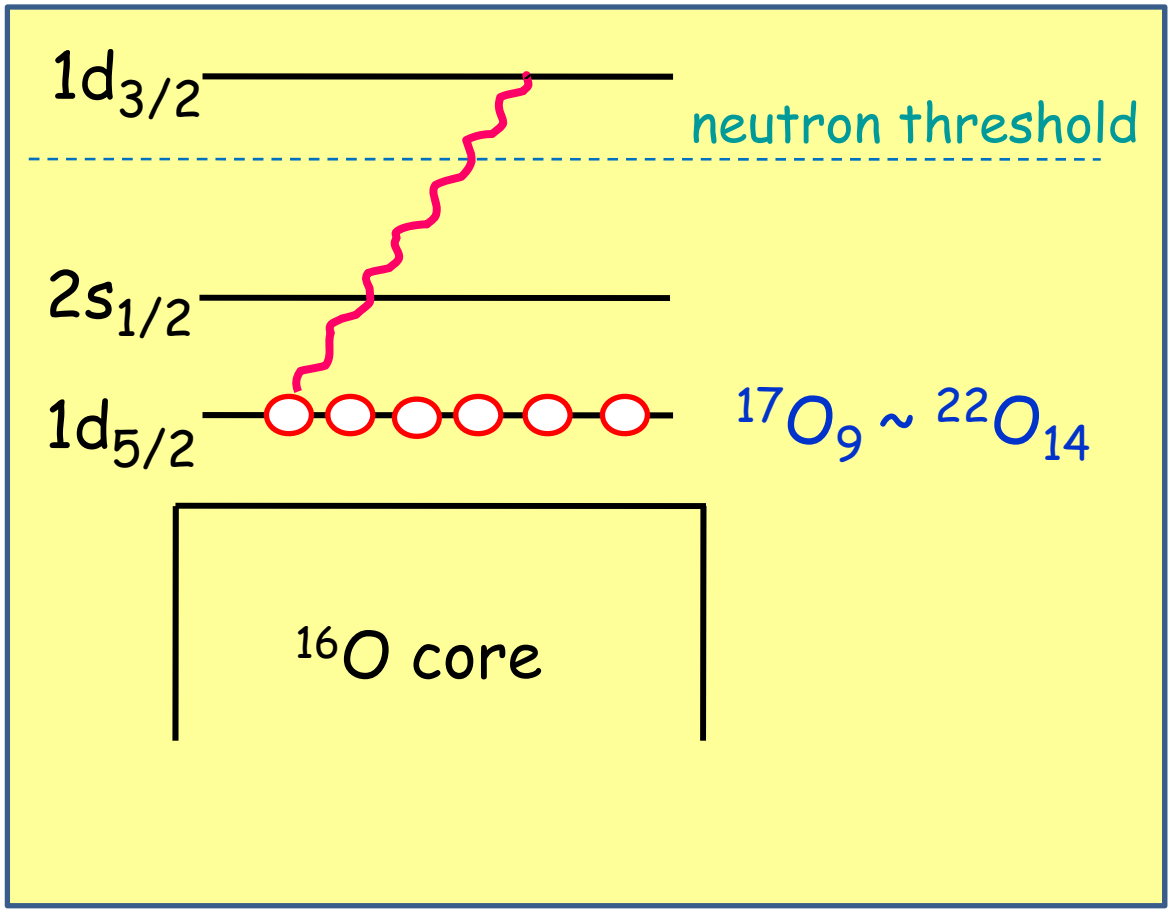
same



Monopole part of Fujita-Miyazawa 3-body force

Back to the question of high-lying $d_{3/2}$

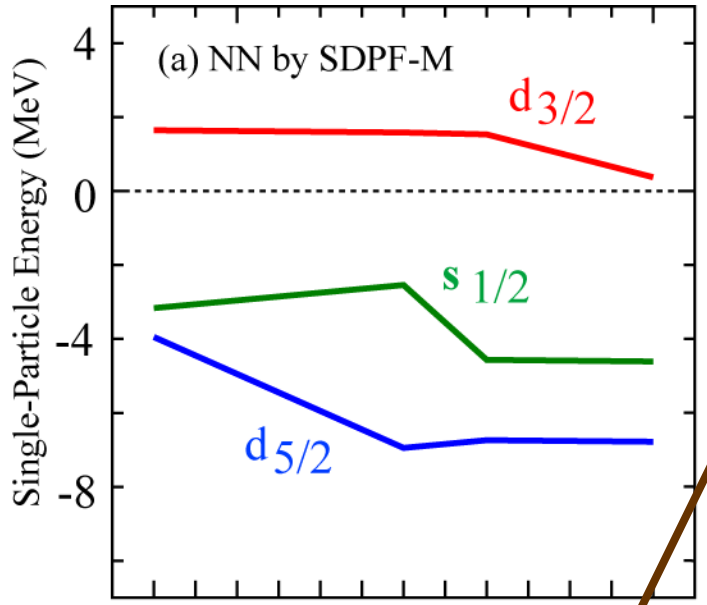
Neutron orbits
in Oxygen isotopes

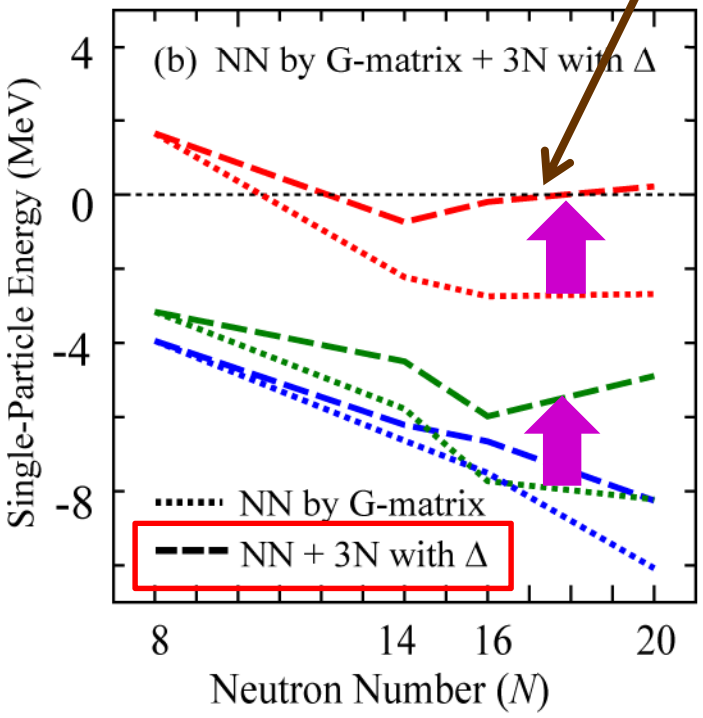


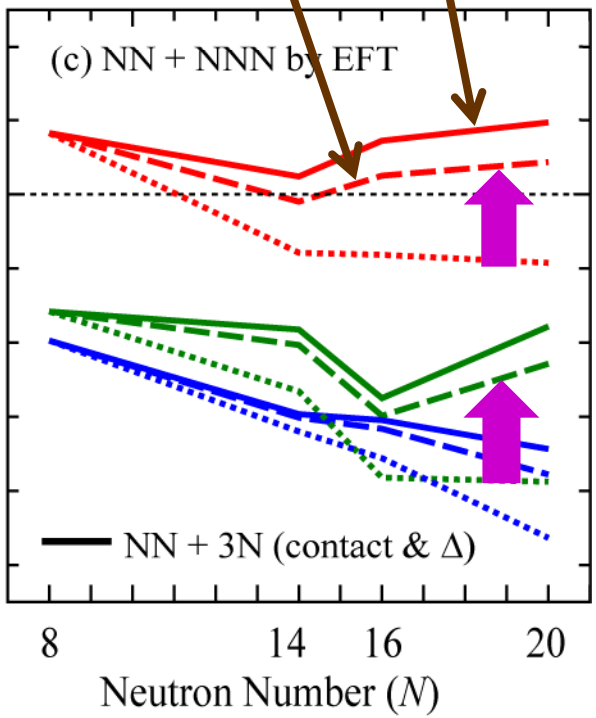
Central :
attractive
(generally)

Tensor :
attractive
- 0.9 MeV
(next page)

Δ-hole induced
repulsion
(> tensor)
Next page







Theoretical calculations

(i) Δ-hole excitation in a conventional way

(ii) EFT with Δ included

(iii) EFT incl. contact terms

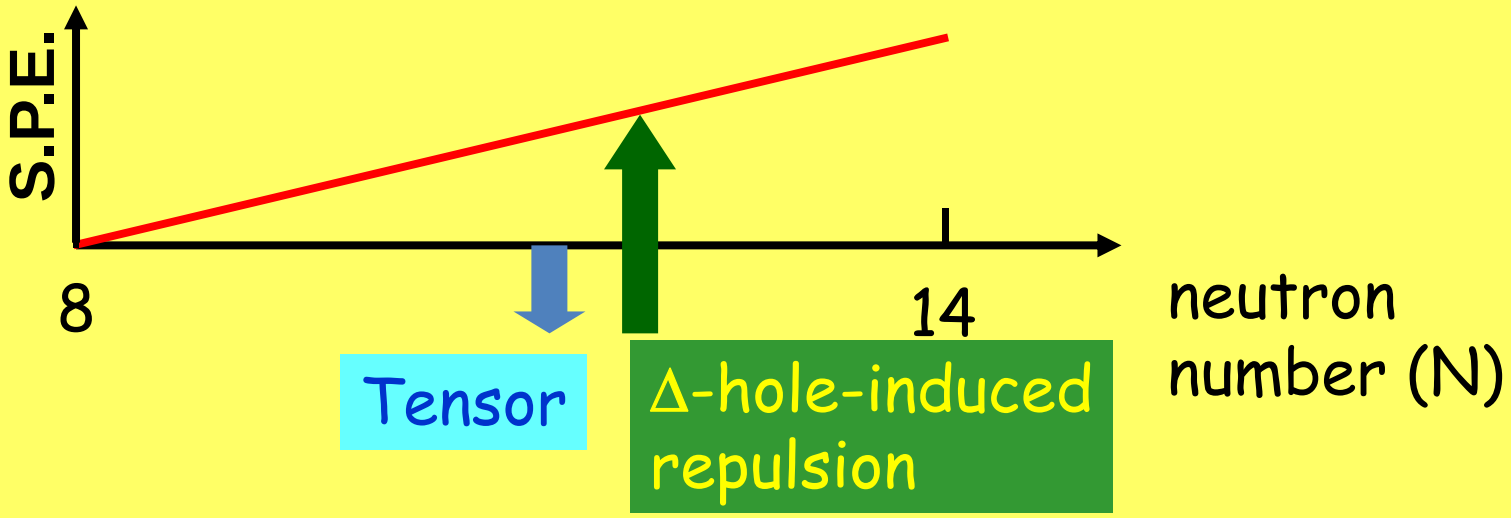
Δ-hole dominant role in determining oxygen drip line

Repulsive effective monopole interaction assuming ^{16}O core

π exchange with radial cut-off at 0.7 fm , ΔE =293 MeV
f_{πNΔ}/f_{πNN} = ¥sqrt{9/2}

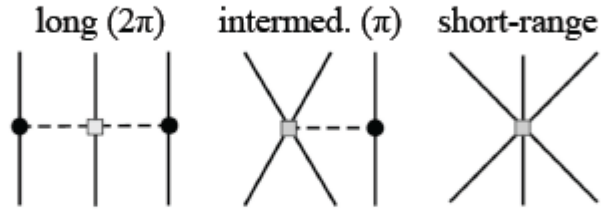
j	j'	Monopole interaction pion tensor
$d_{5/2}$	$d_{3/2}$	250 keV

$d_{3/2}$ single-particle energy relative to N=8



Low-momentum 3N interactions

from leading N^{2}LO chiral EFT ~ $(Q/\Lambda)^3$ van Kolck (1994), Epelbaum et al. (2002)



c_i from πN, consistent with NN $c_1 = -0.9^{+0.2}_{-0.5}$, $c_3 = -4.7^{+1.2}_{-1.0}$, $c_4 = 3.5^{+0.5}_{-0.2}$

Meissner (2007)

c_3,c_4 important for structure, large uncertainties at present

NN for smooth cutoff Vlowk (n_exp=4) from N3LO(500)

3N with c_1, c_3, c_4
(from piN/NN, somewhat different from one Delta)

D, E terms fitted to E(3H) and radius(4He)

Summary

Nuclear forces should play dominant roles in the structure of exotic nuclei.

As an example, even 3-body force seems to have characteristic effects on their existence and properties.

Collaborators

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