组态相互作用壳模型研究进展

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2024.11.17@Shenzhen

Outline

- Introduction to Configuration-Interaction Shell Model (CISM)
- Towards Unified Force for Medium and Heavy Mass Nuclei
- Isomeric Study on Exotic Nuclei
- Summary

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Recent progress in configuration–interaction shell model

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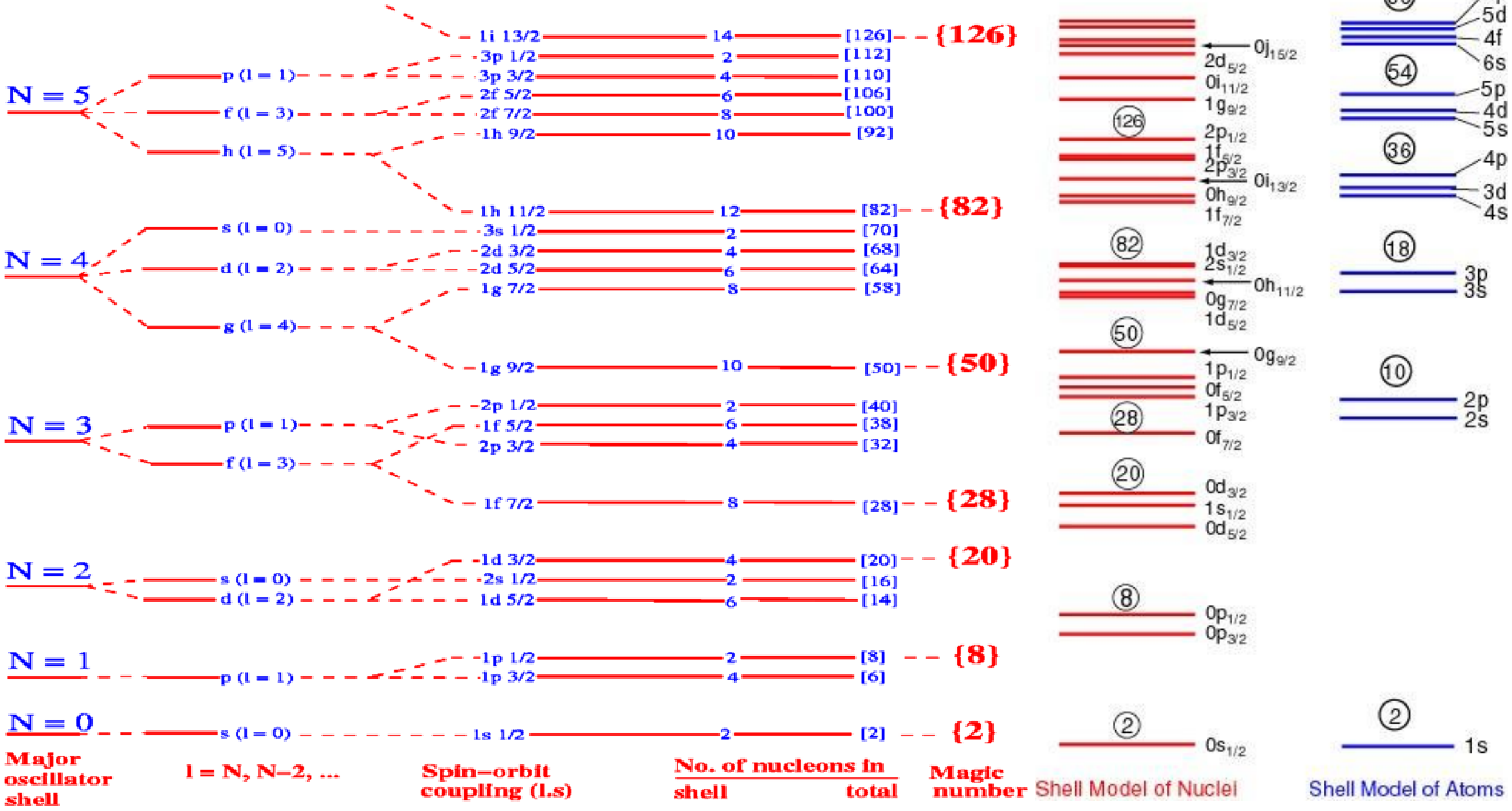
Since Mayer and Jensen employed the single-particle shell model to interpret the magic numbers, various microscopic nuclear models have been developed to study the nuclear force and structure. The configuration–interaction shell model (CISM), performed in truncated model space with the inclusion of the residual interaction, is one widely-used nuclear structure model. In the last decade, CISM has progressed in investigating the cross-shell excitation in exotic light nuclei, the similarity and difference in mirror nuclei, and the isomerism and seniority conservation in medium and heavy nuclei. Additionally, researchers have attempted to construct effective Hamiltonians for nuclei near ^{132}Sn and ^{208}Pb through a unified way in the CISM framework. In parallel, related models, including the nucleon-pair approximation (NPA) approach, the Monte Carlo shell model (MCSM), the projected shell model (PSM), the Gamow shell model (GSM), etc., have also been extensively developed and validated in the last decade. This paper reviews the recent progress in CISM and some related models.

Keywords: Configuration–interaction shell model; nuclear structure; effective Hamiltonian.

PACS Number(s): 21.60.Cs, 21.10. -k, 21.30.-x

Independent-Particle (Shell) Model

Magic Numbers for Nucleons: 2, 8, 20, 28, 50, 82, 126 (neutrons)

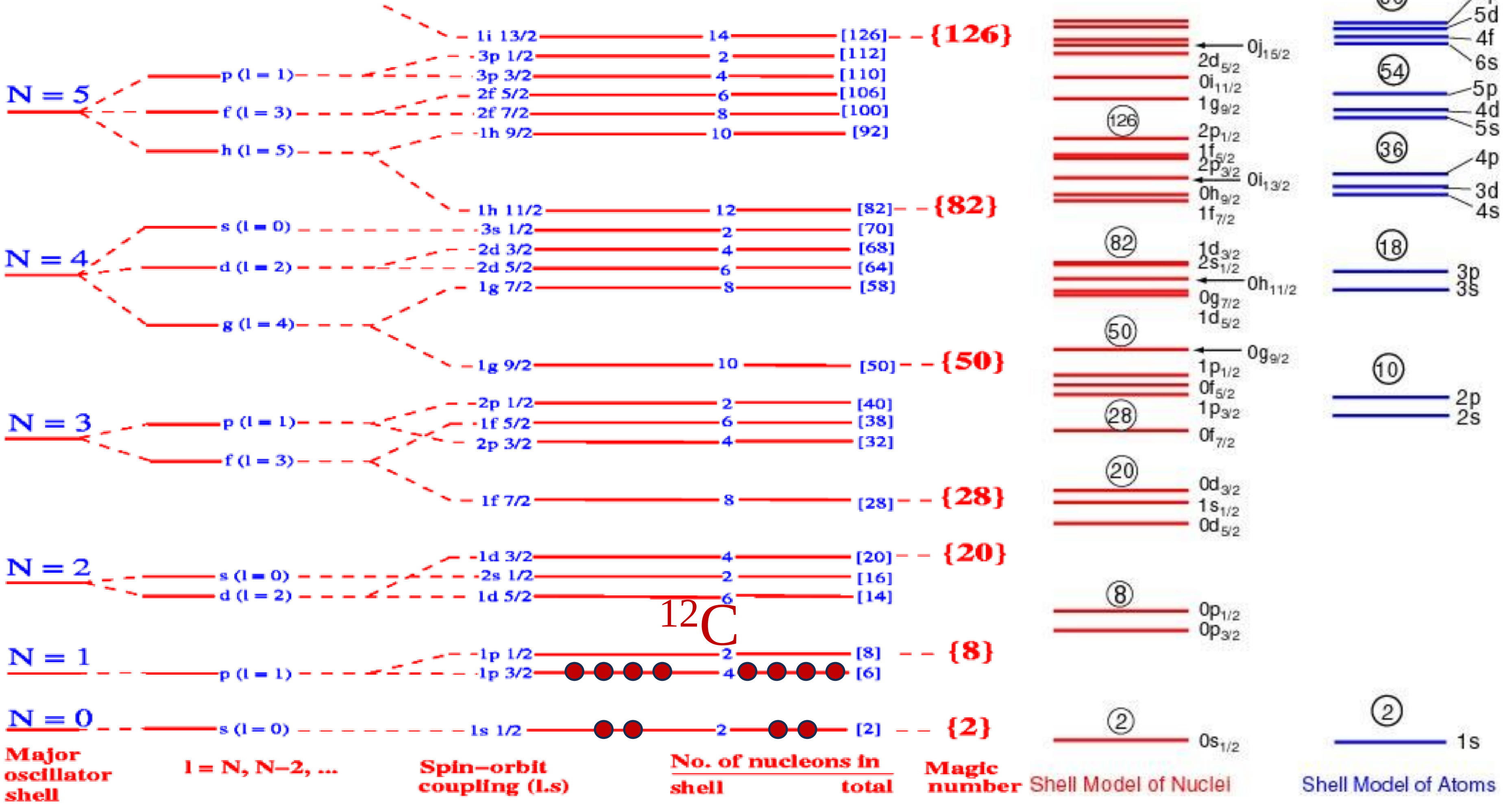


Occupied from Lowest Orbitals **Configuration Mixing**

Classic Shell VS Dynamic Shell

Independent-Particle (Shell) Model

Magic Numbers for Nucleons: 2, 8, 20, 28, 50, 82, 126 (neutrons)



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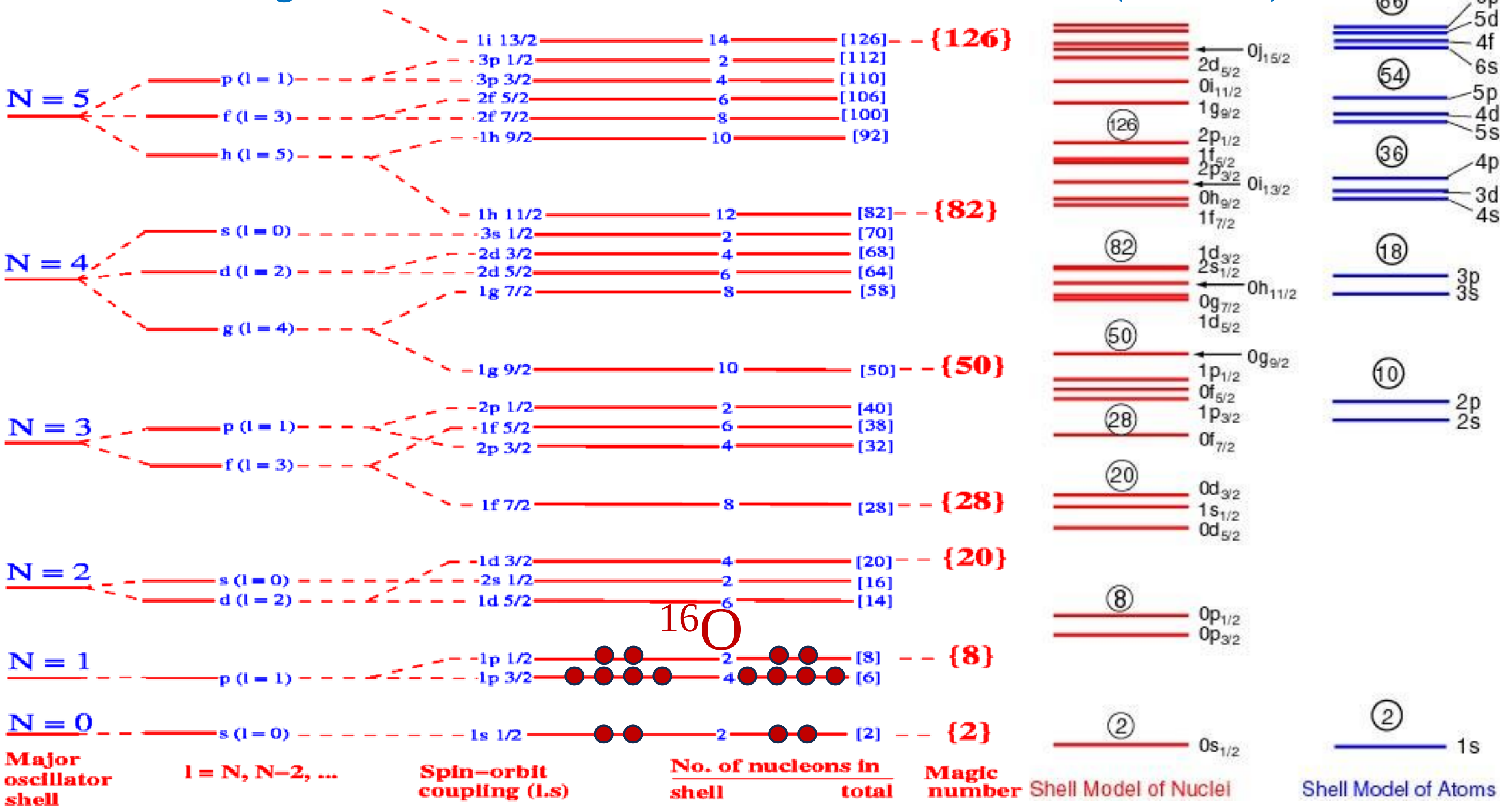

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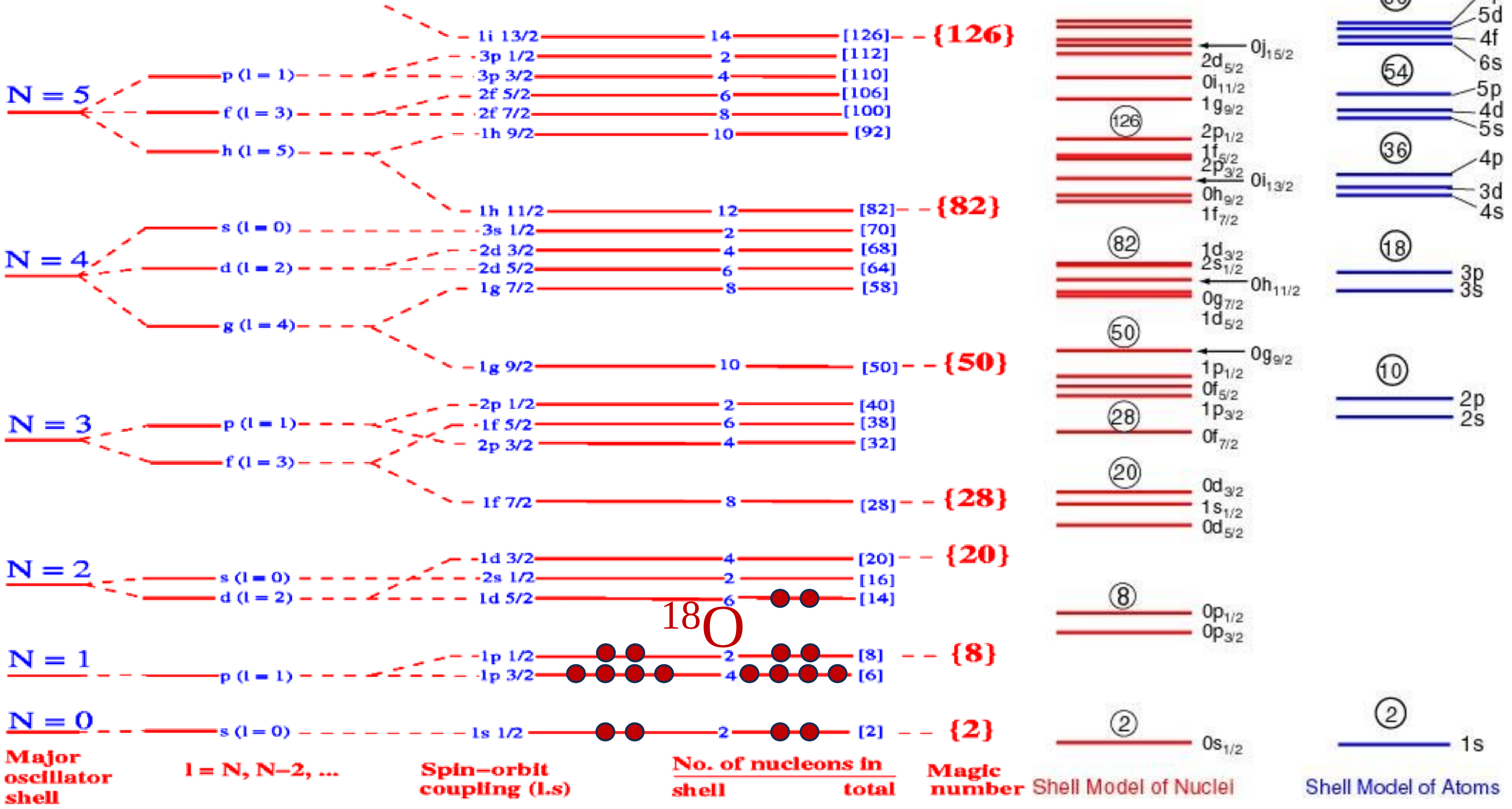
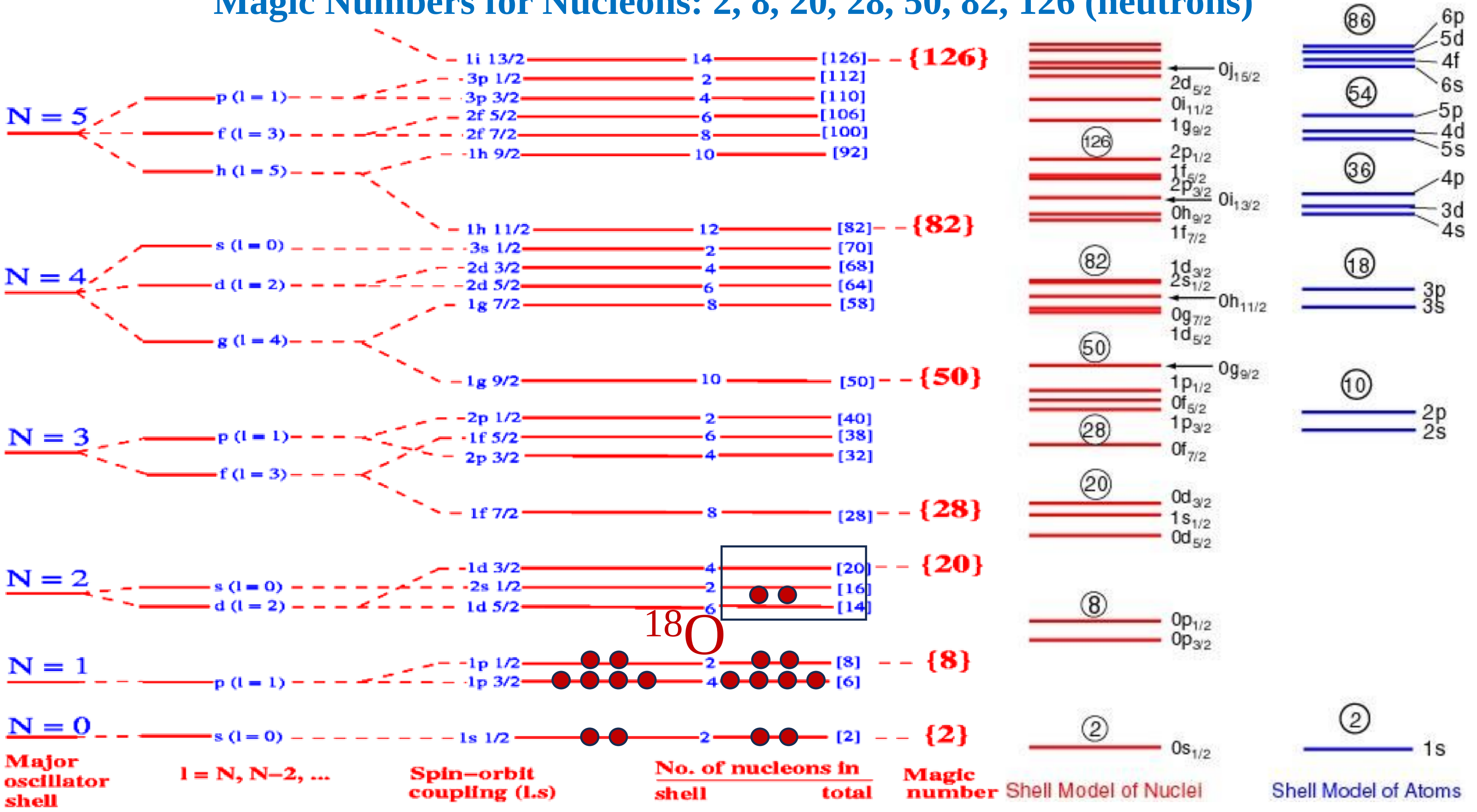


Occupied from Lowest Orbitals **Configuration Mixing**

Classic Shell VS Dynamic Shell

Configuration Mixing

Magic Numbers for Nucleons: 2, 8, 20, 28, 50, 82, 126 (neutrons)



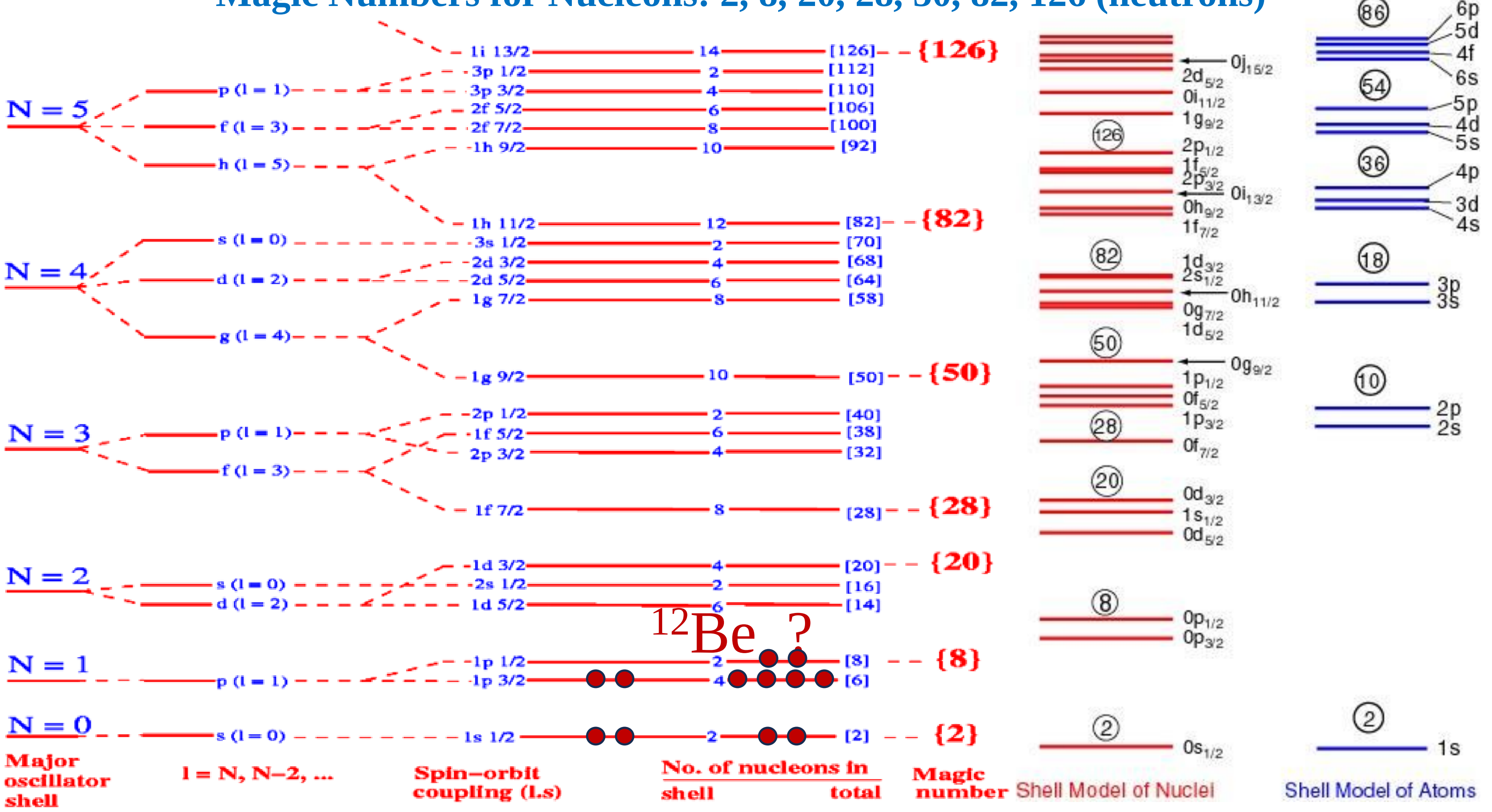
Occupied from Lowest Orbitals

Configuration Mixing

Classic Shell VS Dynamic Shell

Dynamic Shell Structure

Magic Numbers for Nucleons: 2, 8, 20, 28, 50, 82, 126 (neutrons)



Occupied from Lowest Orbitals

Configuration Mixing

Classic Shell VS Dynamic Shell

Phenomenological Force: deduce force from data, such as BE, level, EM, β

Single Particle Basis (normally H.O.) → Model Space

Model Space → Effective Hamiltonian

Effective Hamiltonian

$$H = \sum_i \epsilon_i n_i + \sum_{i,j,k,l} v_{ij,kl} a_i^\dagger a_j^\dagger a_l a_k,$$

Effective Hamiltonian → Wave Functions (configuration mixing)

Wave Functions (configuration mixing) → Solve Schrödinger Equation (energies, wave functions)

Solve Schrödinger Equation (energies, wave functions)

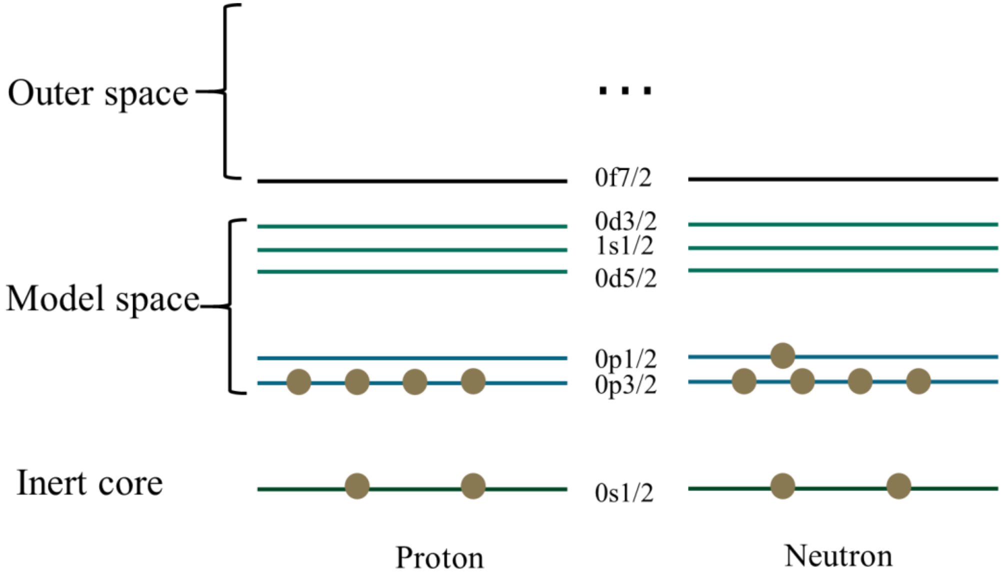
$$\boldsymbol{H}\Psi = E\Psi \rightarrow \boldsymbol{H}_{\text{eff}}\Psi_{\text{eff}} = E\Psi_{\text{eff}}$$

Solve Schrödinger Equation → Other Properties: EM, β, SF…

Three Key Factors of CISM: Model Space, Effective Hamiltonian, Code (Caurier.RMP.05)

Model Space

Hilbert Space: Core, Model Space (1 or 2 major shells), Outer Space



Single: p, sd, pf
Two: psd, sdpf
Three: psdpf

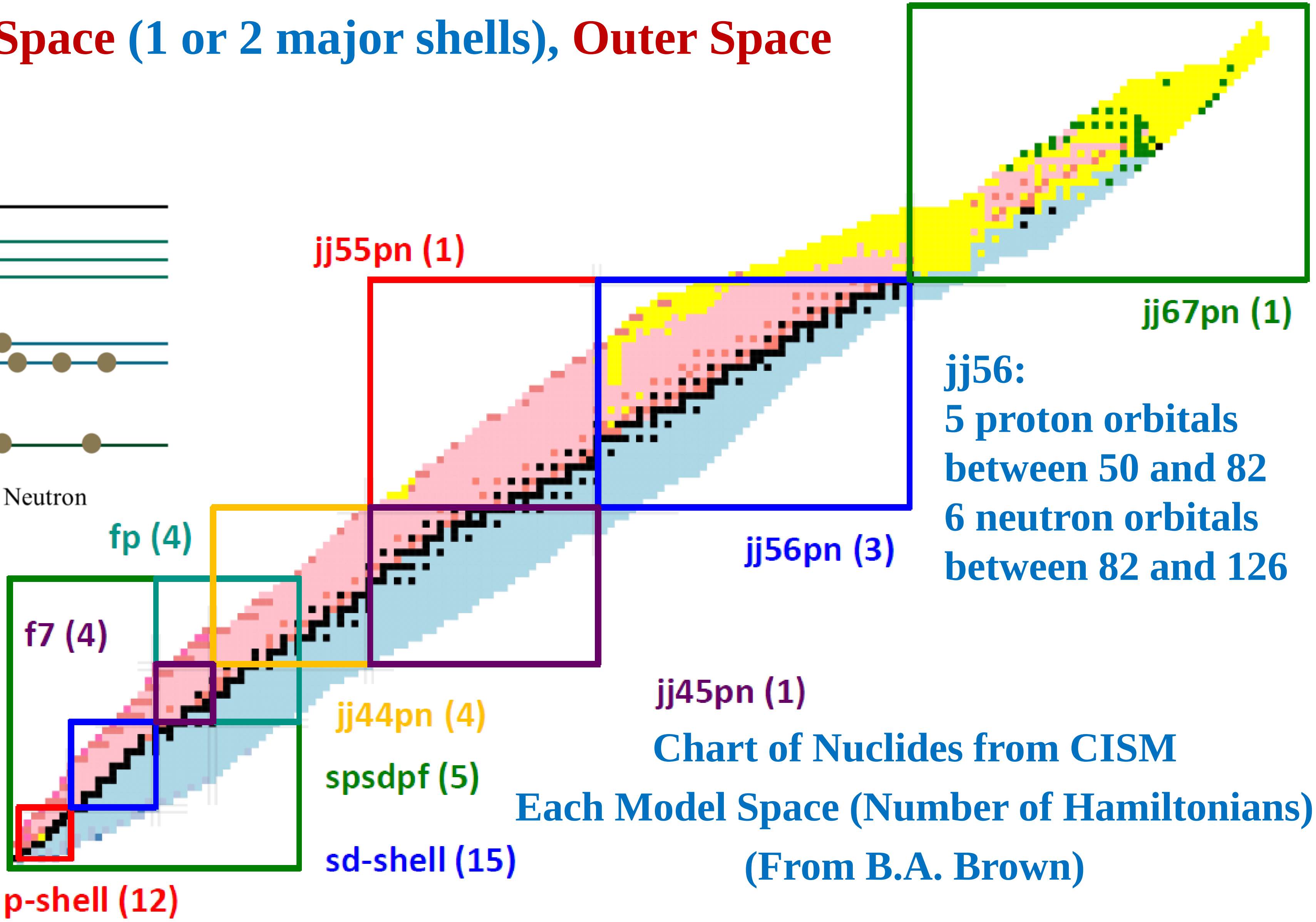


Chart of Nuclides from CISM
Each Model Space (Number of Hamiltonians)
(From B.A. Brown)

Model space	Frozen core	Orbits	Proton number range	Neutron number range
jj44	^{56}Ni	$\pi 0f_{5/2}$, $\pi 1p_{3/2}$, $\pi 1p_{1/2}$, $\pi 0g_{9/2}$ $\nu 0f_{5/2}$, $\nu 1p_{3/2}$, $\nu 1p_{1/2}$, $\nu 0g_{9/2}$	28–50	28–50
jj45	^{78}Ni	$\pi 0f_{5/2}$, $\pi 1p_{3/2}$, $\pi 1p_{1/}$, $\pi 0g_{9/2}$ $\nu 0g_{7/2}$, $\nu 1d_{5/2}$, $\nu 1d_{3/2}$, $\nu 2s_{1/2}$, $\nu 0h_{11/2}$	28–50	50–82
jj46	^{110}Ni	$\pi 0f_{5/2}$, $\pi 1p_{3/2}$, $\pi 1p_{1/2}$, $\pi 0g_{9/2}$ $\nu 0h_{9/2}$, $\nu 1f_{7/2}$, $\nu 1f_{5/2}$, $\nu 2p_{3/2}$, $\nu 2p_{1/2}$, $\nu 0i_{13/2}$	28–50	82–126
jj55	^{100}Sn	$\pi 0g_{7/2}$, $\pi 1d_{5/2}$, $\pi 1d_{3/2}$, $\pi 2s_{1/2}$, $\pi 0h_{11/2}$ $\nu 0g_{7/2}$, $\nu 1d_{5/2}$, $\nu 1d_{3/2}$, $\nu 2s_{1/2}$, $\nu 0h_{11/2}$	50–82	50–82
jj56	^{132}Sn	$\pi 0g_{7/2}$, $\pi 1d_{5/2}$, $\pi 1d_{3/2}$, $\pi 2s_{1/2}$, $\pi 0h_{11/2}$ $\nu 0h_{9/2}$, $\nu 1f_{7/2}$, $\nu 1f_{5/2}$, $\nu 2p_{3/2}$, $\nu 2p_{1/2}$, $\nu 0i_{13/2}$	50–82	82–126
jj57	^{176}Sn	$\pi 0g_{7/2}$, $\pi 1d_{5/2}$, $\pi 1d_{3/2}$, $\pi 2s_{1/2}$, $\pi 0h_{11/2}$ $\nu 0i_{11/2}$, $\nu 1g_{9/2}$, $\nu 1g_{7/2}$, $\nu 2d_{5/2}$, $\nu 2d_{3/2}$, $\nu 3s_{1/2}$, $\nu 0j_{15/2}$	50–82	126–184
jj66	^{164}Pb	$\pi 0h_{9/2}$, $\pi 1f_{7/2}$, $\pi 1f_{5/2}$, $\pi 2p_{3/2}$, $\pi 2p_{1/2}$, $\pi 0i_{13/2}$ $\nu 0h_{9/2}$, $\nu 1f_{7/2}$, $\nu 1f_{5/2}$, $\nu 2p_{3/2}$, $\nu 2p_{1/2}$, $\nu 0i_{13/2}$	82–126	82–126
jj67	^{208}Pb	$\pi 0h_{9/2}$, $\pi 1f_{7/2}$, $\pi 1f_{5/2}$, $\pi 2p_{3/2}$, $\pi 2p_{1/2}$, $\pi 0i_{13/2}$ $\nu 0i_{11/2}$, $\nu 1g_{9/2}$, $\nu 1g_{7/2}$, $\nu 2d_{5/2}$, $\nu 2d_{3/2}$, $\nu 3s_{1/2}$, $\nu 0j_{15/2}$	82–126	126–184

Effective Hamiltonian

$$H\Psi = E\Psi \to H_{\mathrm{eff}}\Psi_{\mathrm{eff}} = E\Psi_{\mathrm{eff}}$$

$$\begin{pmatrix} PHP & PHQ \\ QHP & QHQ \end{pmatrix} \begin{pmatrix} P\Psi \\ Q\Psi \end{pmatrix} = E \begin{pmatrix} P\Psi \\ Q\Psi \end{pmatrix}$$

$$P = \sum_{i=1}^{D} |\Phi_i\rangle\langle\Phi_i|, \quad Q = \sum_{i=D+1}^{\infty} |\Phi_i\rangle\langle\Phi_i|.$$

$$P\{H + H\frac{1}{E - QHQ}QH\}P\Psi = EP\Psi.$$

H: full space Hamiltonian

H_{eff}: model space Hamiltonian (effective interaction)

P, Q: projection operator

Realistic: from realistic NN (+NNN) force, need to be renormalized for short range and in-medium effect

Phenomenological: fit to experimental data, such as binding energies and levels

TBME fit (USD) or potential fit (V_{MU}+LS) or combination

Effective Nuclear Force

$$V = V_c + V_{LS}(\mathbf{L}\cdot\mathbf{S}) + V_T S_{12},$$

$$\hat{S}_{12} = \left(\frac{\hat{\boldsymbol{r}}}{r}\cdot\hat{\boldsymbol{\sigma}}_1\right)\left(\frac{\hat{\boldsymbol{r}}}{r}\cdot\hat{\boldsymbol{\sigma}}_2\right) - \frac{1}{3}(\hat{\boldsymbol{\sigma}}_1\cdot\hat{\boldsymbol{\sigma}}_2)$$

Effective Hamiltonian

V_{MU}+LS (monopole-based universal interaction + spin-orbit force)

$$V_C(\mathrm{Gauss}) = \sum_{T=0,1.S=0,1} f_{T,S} P_{T,S} exp\left(-\left(\frac{r}{\mu}\right)^2\right)$$

$$V_{MU} = V_C(\mathrm{Gauss}) + V_T(\pi + \rho)$$

$$V_{MU} + LS = V_{MU} + V_{LS}(\mathrm{M3Y})$$

G. Bertsch *et al.*, Nucl. Phys. A 284, 399 (1977).

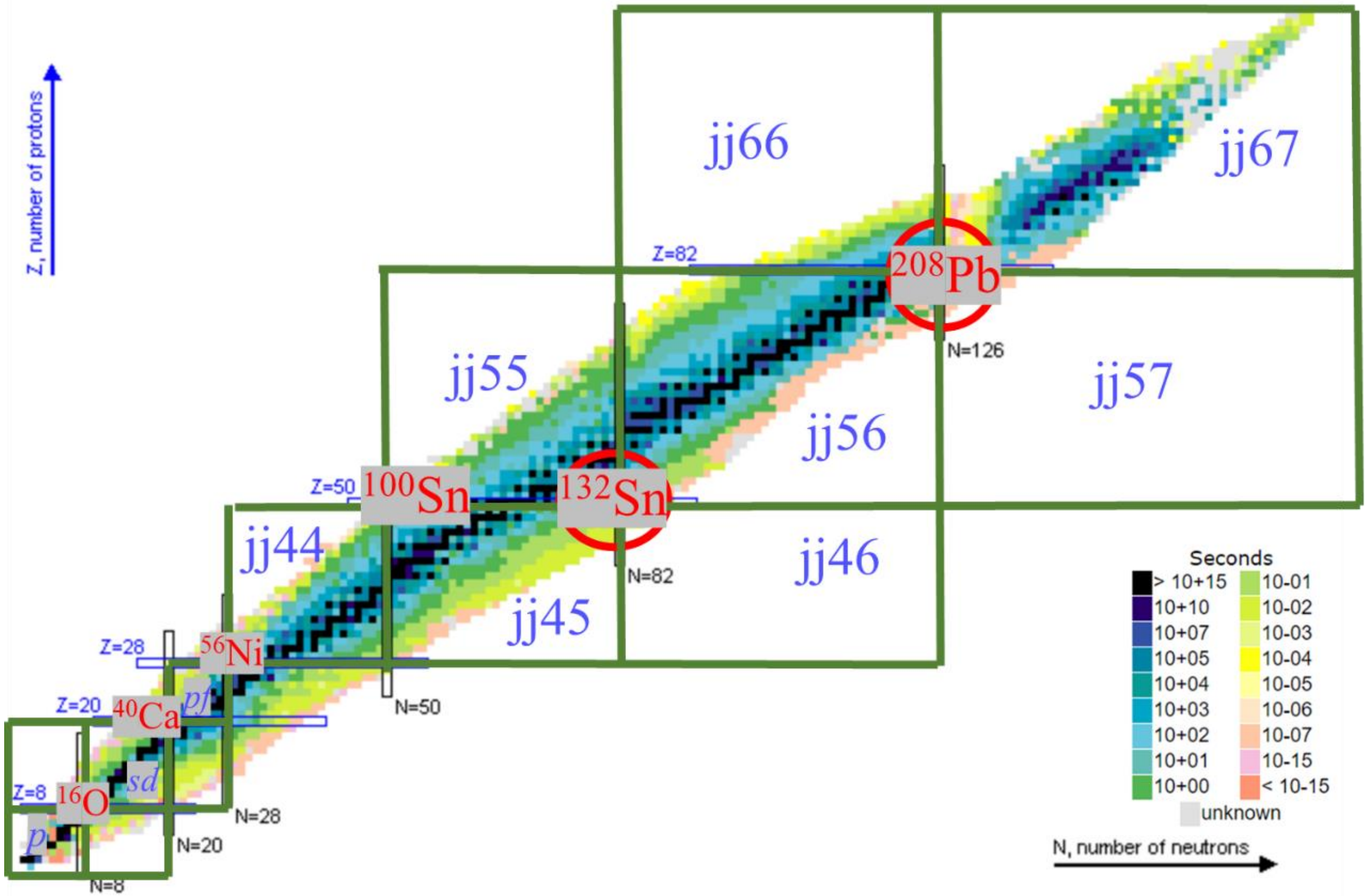
$$\begin{aligned}
\langle k_a k_b | V | k_c k_d \rangle_{JT} &= 2\left[\frac{(2j_a+1)(2j_b+1)(2j_c+1)(2j_d+1)}{(1+\delta_{ab})(1+\delta_{cd})}\right]^{1/2} \\
&\times \sum_{\Lambda\Lambda' S} (-1)^{\Lambda-\Lambda'}(2\Lambda+1)(2\Lambda'+1)(2S+1) \\
&\times \begin{Bmatrix} l_a & \frac{1}{2} & j_a \\ l_b & \frac{1}{2} & j_b \\ \Lambda & S & J \end{Bmatrix} \begin{Bmatrix} l_c & \frac{1}{2} & j_c \\ l_d & \frac{1}{2} & j_d \\ \Lambda' & S & J \end{Bmatrix} \\
&\times \sum_{nln'l'NL} \langle nlNL | n_a l_a n_b l_b \rangle_\Lambda \delta^{odd}_{l+S+T} \\
&\times \langle n'l'NL | n_c l_c n_d l_d \rangle_{\Lambda'} \delta^{odd}_{l'+S+T} \\
&\times \sum_j (2j+1) \begin{Bmatrix} L & l & \Lambda \\ S & J & j \end{Bmatrix} \begin{Bmatrix} L & l' & \Lambda' \\ S & J & j \end{Bmatrix} \\
&\times \langle nlS; j | V | n'l'S; j \rangle
\end{aligned}$$

Monopole interaction:

$$V_{jj'} = \sum_J (1+\delta(jj')) \frac{(2J+1)}{(2j+1)(2j'+1)} \langle jj' | V | jj' \rangle_J$$

V_{MU}+LS describe well the monopole properties
Construct effective Hamiltonian for any model space
Verified in many region as effective Hamiltonian or parts of it

Effective Hamiltonian



V_{MU}+LS as cross-shell part
p-sd (YSOX)
sd-pf (sdpf-mu)
pf-jj44
^{132}Sn jj46
^{208}Pb jj57, jj5_67, jj56_67, jj66

V_{MU}+LS as effective Hamiltonian
^{132}Sn and ^{208}Pb region (red circle)
jj45, jj46, jj55, jj56
jj56, jj57, jj66, jj67

Effective Hamiltonian

VMU+LS Applications

psd

PHYSICAL REVIEW C **85**, 064324 (2012)

Shell-model study of boron, carbon, nitrogen, and oxygen isotopes with a monopole-based universal interaction

Cenxi Yuan,[1,2,*] Toshio Suzuki,[3,4,†] Takaharu Otsuka,[2,5,6,‡] Furong Xu,[1,7,§] and Naofumi Tsunoda[2]

sdpf

PHYSICAL REVIEW C **86**, 051301(R) (2012)

Shape transitions in exotic Si and S isotopes and tensor-force-driven Jahn-Teller effect

Yutaka Utsuno,[1,2] Takaharu Otsuka,[2,3,4,5] B. Alex Brown,[4,5] Michio Honma,[6] Takahiro Mizusaki,[7] and Noritaka Shimizu[2]

pfsdg

PHYSICAL REVIEW C **91**, 024320 (2015)

Large-scale shell-model calculations for unnatural-parity high-spin states in neutron-rich Cr and Fe isotopes

Tomoaki Togashi,[1,*] Noritaka Shimizu,[1] Yutaka Utsuno,[1,2] Takaharu Otsuka,[1,3,4] and Michio Honma[5]

jj45

PHYSICAL REVIEW LETTERS **122**, 212502 (2019)

Proton Shell Evolution below ^{132}Sn: First Measurement of Low-Lying β-Emitting Isomers in ^{123,125}Ag

Z. Q. Chen,[1] Z. H. Li,[1,*] H. Hua,[1,†] H. Watanabe,[2,3] C. X. Yuan,[4] S. Q. Zhang,[1] G. Lorusso,[3,5,6] S. Nishimura,[3] H. Baba,[3] F. Browne,[3,7] G. Benzoni,[8] K. Y. Chae,[9] F. C. L. Crespi,[8,10] P. Doornenbal,[3] N. Fukuda,[3] G. Gey,[3,11,12] R. Gernhäuser,[13] N. Inabe,[3] T. Isobe,[3] D. X. Jiang,[1] A. Jungclaus,[14] H. S. Jung,[15,16] Y. Jin,[1] D. Kameda,[3] G. D. Kim,[17] Y. K. Kim,[17,18] I. Kojouharov,[19] F. G. Kondev,[20] T. Kubo,[3] N. Kurz,[19] Y. K. Kwon,[17] X. Q. Li,[1] J. L. Lou,[1] G. J. Lane,[21] C. G. Li,[1] D. W. Luo,[1] A. Montaner-Pizá,[22] K. Moschner,[23] C. Y. Niu,[1] F. Naqvi,[24] M. Niikura,[25] H. Nishibata,[26] A. Odahara,[26] R. Orlandi,[27,28] Z. Patel,[6] Zs. Podolyák,[6] T. Sumikama,[3] P.-A. Söderström,[3] H. Sakurai,[3] H. Schaffner,[19] G. S. Simpson,[11] K. Steiger,[13] H. Suzuki,[3] J. Taprogge,[3,14,29] H. Takeda,[3] Zs. Vajta,[3,30] H. K. Wang,[31] J. Wu,[1,20] A. Wendt,[23] C. G. Wang,[1] H. Y. Wu,[1] X. Wang,[1] C. G. Wu,[1] C. Xu,[1] Z. Y. Xu,[25,32] A. Yagi,[26] Y. L. Ye,[1] and K. Yoshinaga[33]

Effective Hamiltonian

VMU+LS Applications

jj46

Physics Letters B 762 (2016) 237–242

Isomerism in the "south-east" of ^{132}Sn and a predicted neutron-decaying isomer in ^{129}Pd

Cenxi Yuan [a,*], Zhong Liu [b,*], Furong Xu [c,d], P.M. Walker [e], Zs. Podolyák [e], C. Xu [f], Z.Z. Ren [f], B. Ding [b], M.L. Liu [b], X.Y. Liu [b], H.S. Xu [b], Y.H. Zhang [b], X.H. Zhou [b], W. Zuo [b]

jj5_56

PHYSICAL REVIEW C **107**, 054306 (2023)

Shell-model-based investigation on level density of Xe and Ba isotopes

Jinbei Chen (陈进北),[1,2,*] Menglan Liu (刘梦兰),[1,*] Cenxi Yuan (袁岑溪),[1,†] Shengli Chen (陈胜利),[1,‡] Noritaka Shimizu (清水則孝),[3] Xiaodong Sun (孙小东),[2] Ruirui Xu (续瑞瑞),[2] and Yuan Tian (田源)[2]

jj5_67

PHYSICAL REVIEW C **106**, 044314 (2022)

Shell-model study on spectroscopic properties in the region "south" of ^{208}Pb

Cenxi Yuan,[1,*] Menglan Liu,[1] Noritaka Shimizu,[2] Zs. Podolyák,[3] Toshio Suzuki,[4,5] Takaharu Otsuka,[6,7,8,9] and Zhong Liu[10,11]

jj66

PHYSICAL REVIEW LETTERS **126**, 152502 (2021)

Editors' Suggestion Featured in Physics

New α-Emitting Isotope ^{214}U and Abnormal Enhanc
Lightest Uranium Isot

Z. Y. Zhang (张志远),[1,2] H. B. Yang (杨华彬),[1] M. H. Huang (黄明辉),[1]
C. Qi (亓冲),[4] A. N. Andreyev,[5,6] M. L. Liu (柳敏良),[1,2] L. Ma (马龙)
Y. S. Wang (王永生),[1,2,7] J. G. Wang (王建国),[1] C. L. Yang (杨春莉
W. Q. Yang (杨维青),[1] R. F. Chen (陈若富),[1] H. B. Zhang (张宏斌
L. M. Duan (段利敏),[1,2] H. R. Yang (杨贺润),[1,2] W. X. Huang (黄文学
Y. H. Zhang (张玉虎),[1,2] H. S. Xu (徐瑚珊),[1,2] N. Wang (王宁),[8]
S. Huang (黄山),[8] W. Hua (滑伟),[3] L. Zhu (祝龙),[3] X. Wang (王翔)
S. Y. Wang (王守宇),[12] W. Z. Xu (许文政),[12] H. W. Li (李弘伟),[12] Z. Z

PHYSICAL REVIEW C **105**, L051302 (2022)

Letter

New isotope ^{207}Th and odd-even staggering in α-decay energies for nuclei with $Z > 82$ and $N < 126$

H. B. Yang (杨华彬),[1,2] Z. G. Gan (甘再国),[1,3,*] Z. Y. Zhang (张志远),[1,3] M. H. Huang (黄明辉),[1,3] L. Ma (马龙),[1] M. M. Zhang (张明明),[1] C. X. Yuan (袁岑溪),[4,†] Y. F. Niu (牛一斐),[5,‡] C. L. Yang (杨春莉),[1,3] Y. L. Tian (田玉林),[1,3] L. Guo (郭亮),[5] Y. S. Wang (王永生),[1] J. G. Wang (王建国),[1] H. B. Zhou (周厚兵),[6] X. J. Wen (温小江),[6] H. R. Yang (杨贺润),[1,3] X. H. Zhou (周小红),[1,3] Y. H. Zhang (张玉虎),[1,3] W. X. Huang (黄文学),[1,3] Z. Liu (刘忠),[1,3] S. G. Zhou (周善贵),[7,3] Z. Z. Ren (任中洲),[8] H. S. Xu (徐瑚珊),[1,3] V. K. Utyonkov,[2] A. A. Voinov,[2] Yu. S. Tsyganov,[2] A. N. Polyakov,[2] and D. I. Solovyev[2]

Shell-model code

- Oak Ridge Rochester Multi-Shell code (J. B. French et al., 1969)
- Glasgow group (R. R. Whitehead et al., 1977)
- OXBASH/NUSHELLX (B.A. Brown et al., 1986)
- Drexel University shell model code (M. Vallieres et al.. 1988-1997)
- ANTOINE : amelioration of the code of the Glasgow group (E. Caurier et al., 1999)
- NATHAN (E. Caurier et al.. 1999)
- EICODE (J. Toivanen, 2006)
- KSHELL (N. Shimizu et al, 2013)
- MFDn (P. Maris et al., 2013)
- REDSTICK, BIGSTICK (C.W. Johnson et al.)
- GSM (2021)

N. Shimizu, arXiv:1310.5431(2013);
N. Shimizu *et al.*, *Comput. Phys. Commun.* 244, 372 (2019)

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Recent progress in configuration–interaction shell model

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Since Mayer and Jensen employed the single-particle shell model to interpret the magic numbers, various microscopic nuclear models have been developed to study the nuclear force and structure. The configuration–interaction shell model (CISM), performed in truncated model space with the inclusion of the residual interaction, is one widely-used nuclear structure model. In the last decade, CISM has progressed in investigating the cross-shell excitation in exotic light nuclei, the similarity and difference in mirror nuclei, and the isomerism and seniority conservation in medium and heavy nuclei. Additionally, researchers have attempted to construct effective Hamiltonians for nuclei near ^{132}Sn and ^{208}Pb through a unified way in the CISM framework. In parallel, related models, including the nucleon-pair approximation (NPA) approach, the Monte Carlo shell model (MCSM), the projected shell model (PSM), the Gamow shell model (GSM), etc., have also been extensively developed and validated in the last decade. This paper reviews the recent progress in CISM and some related models.

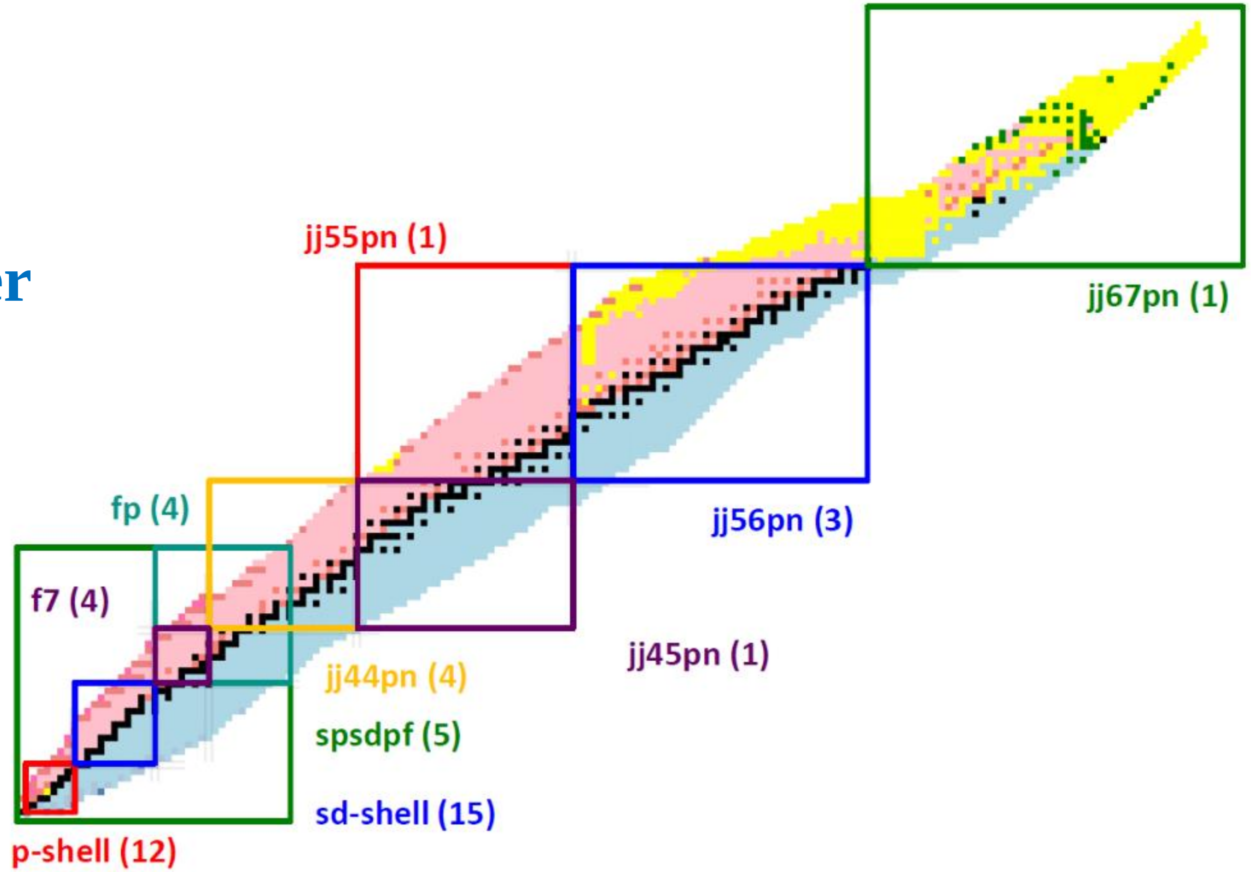
Keywords: Configuration–interaction shell model; nuclear structure; effective Hamiltonian.

PACS Number(s): 21.60.Cs, 21.10.-k, 21.30.-x

- **Nice results on BE, level, EM, β**

VS

- **Different H, quality of predicted power**



- **One effective force for all possible nuclei (RMS for BE, level, EM, GT)**

中山大學中法

Institut franco-chinois de l'én

The effective interaction between nucleons deduced from nuclear spectra*

John P. Schiffer

Argonne National Laboratory, Argonne, Illinois 60439
and University of Chicago, Chicago, Illinois 60637

William W. True

University of California, Davis, California 95616

Two-body matrix elements of the residual nucleon–nucleon interaction are extracted from experimental data throughout the periodic table and are used to determine the ranges and well depths of various components of a local interaction. The $T=1$ even and odd components of the central interaction both definitely require two wells with different ranges; a shorter-range attractive well with a longer-range repulsive one. The need for a tensor interaction and a two-body spin–orbit interaction is also explored and their inclusion improves the fit slightly.

Configuration mixing

V_{MU}+LS(M3Y)

Isospin-Spin

C10 C11 C01 C00

T1 T0 LS1 LS0

$$V_{CEN} = U_{SO}(r)P^{SO} + U_{SE}(r)P^{SE} + U_{TO}(r)P^{TO} + U_{TE}(r)P^{TE},$$

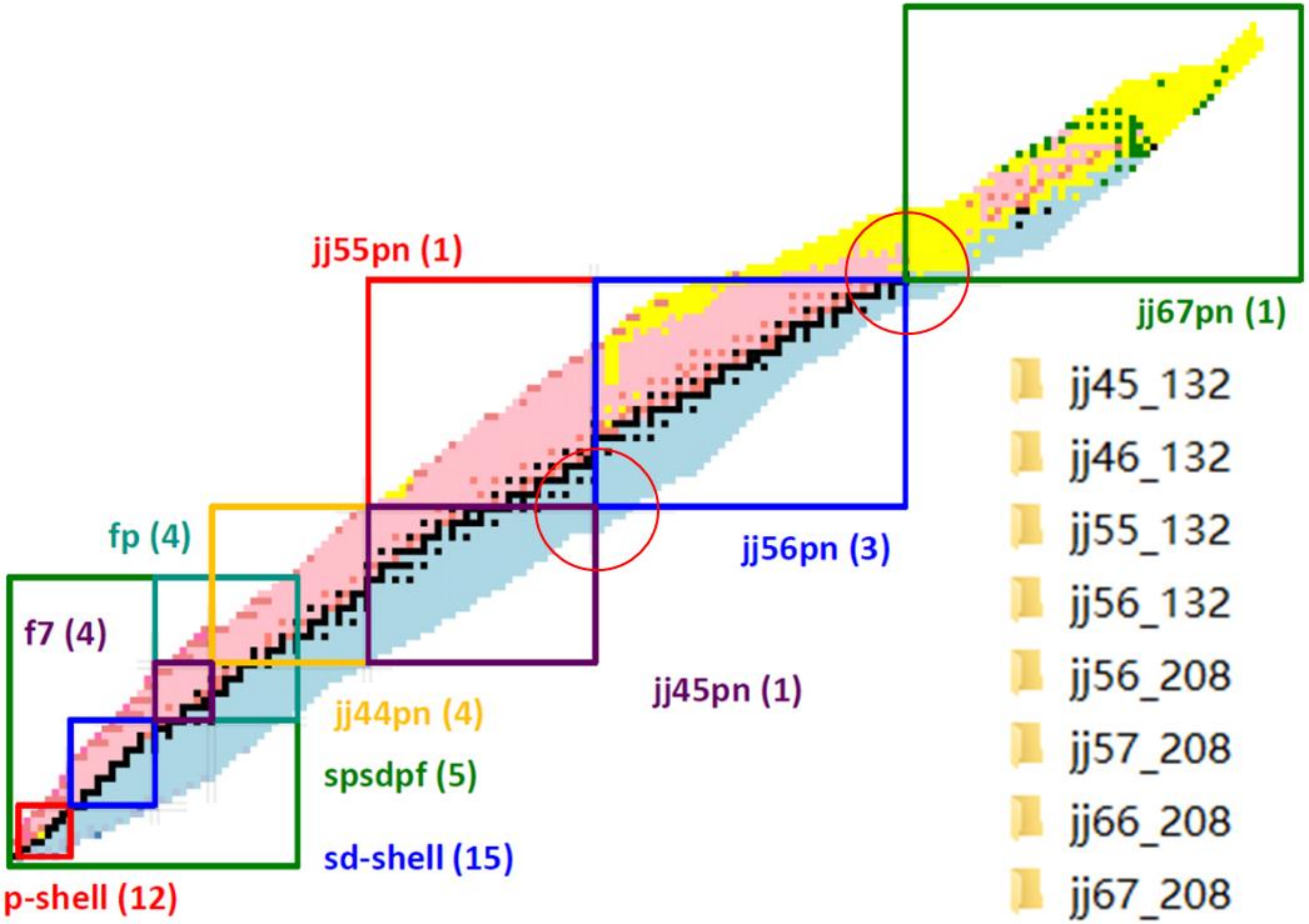
$$V_{LS} = U_{LS}(r)\vec{L}\cdot\vec{S}$$

$$V_{Tensor} = U_{Tensor}(r)\left[\frac{3(\vec{\sigma}_1\cdot\vec{r})(\vec{\sigma}_2\cdot\vec{r}) - r^2(\vec{\sigma}_1\cdot\vec{\sigma}_2)}{r^2}\right]$$

TABLE XV. Typical errors in the interaction strengths in MeV with $r_1 = 1.415$ fm and $r_2 = 2.0$ fm for a 1% change in χ^2.

$T=0$					
S. O.$_A$	S. O.$_B$	Tr. E.$_A$	Tr. E.$_B$	Tens. E.	LS. E.
3.7 ± 9	122 ± 73	−56 ± 2	−63 ± 20	−43 ± 10	−0.4 ± 2
$T=1$					
S. E.$_A$	S. E.$_B$	Tr. O.$_A$	Tr. O.$_B$	Tens. O.	LS. O.
−13.5 ± 1.2	−36 ± 13	15.2 ± 1.1	−171 ± 12	−6.1 ± 1.4	3.4 ± 0.8

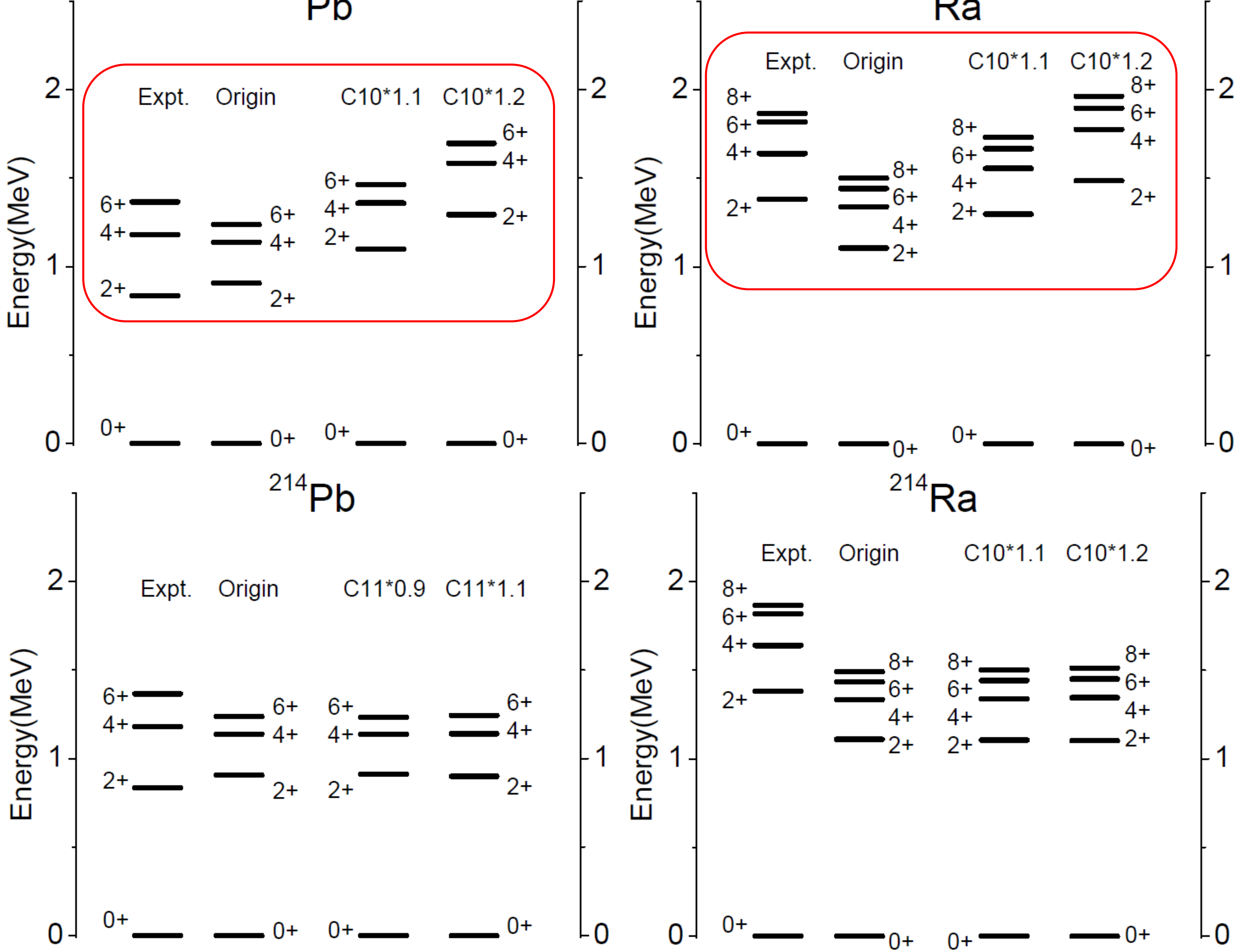
- Use **one effective nuclear force** to deduce Hamiltonians for model spaces around ^{132}Sn and ^{208}Pb.
- Focus on the **strengths** of different force components.
- Describe the **excitation energies** of 725 levels in 136 nuclei .



Overall progress:

No. Nuclei	136	98	38 (semi-magic)
No. States	725	505	220
RMS (MeV)	0.139	0.138	0.141
Mean (MeV)	0.031	0.038	0.015

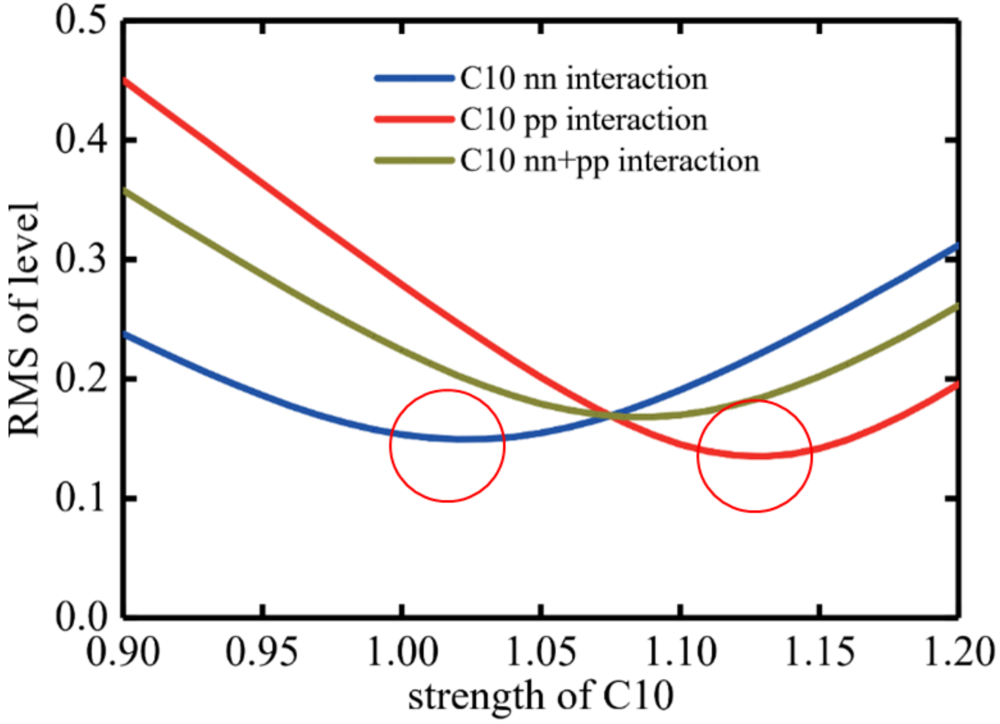
“Mirror” difference?



CXY, TX Du, NPR35.4(2018)537

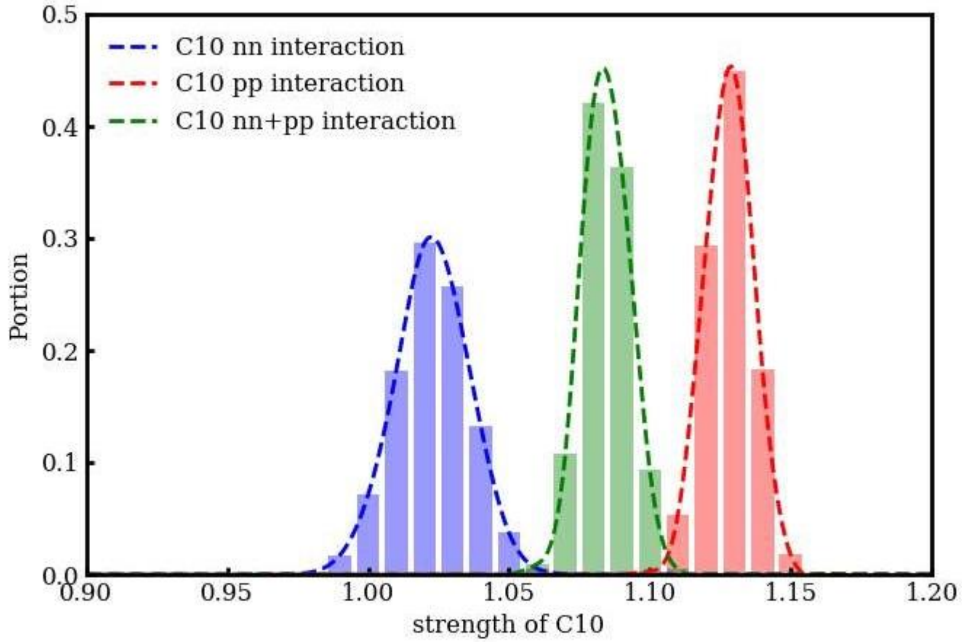
CXY, et al., ND2019 proceedings
EPJ Web of Conf. 239, 04002 (2020)

RMS for nuclei around ^{208}Pb and ^{132}Sn



- nn: 101 levels in Pb and Sn isotopes, $^{201-214}$Pb, $^{125-138}$Sn
- pp: 97 levels in N=126 and N=82 isotones, ^{204}Pt-^{214}Ra, ^{128}Pd-^{139}La

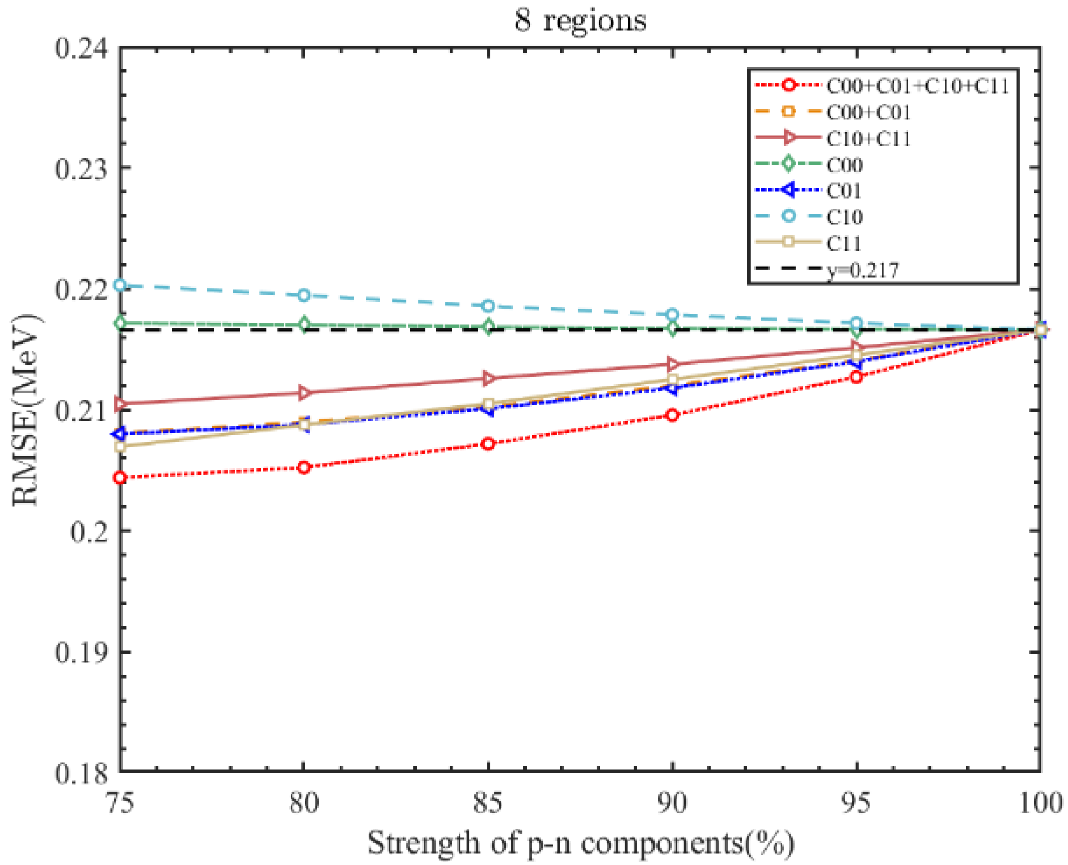
Uncertainty of strength of C10 from bootstrap method

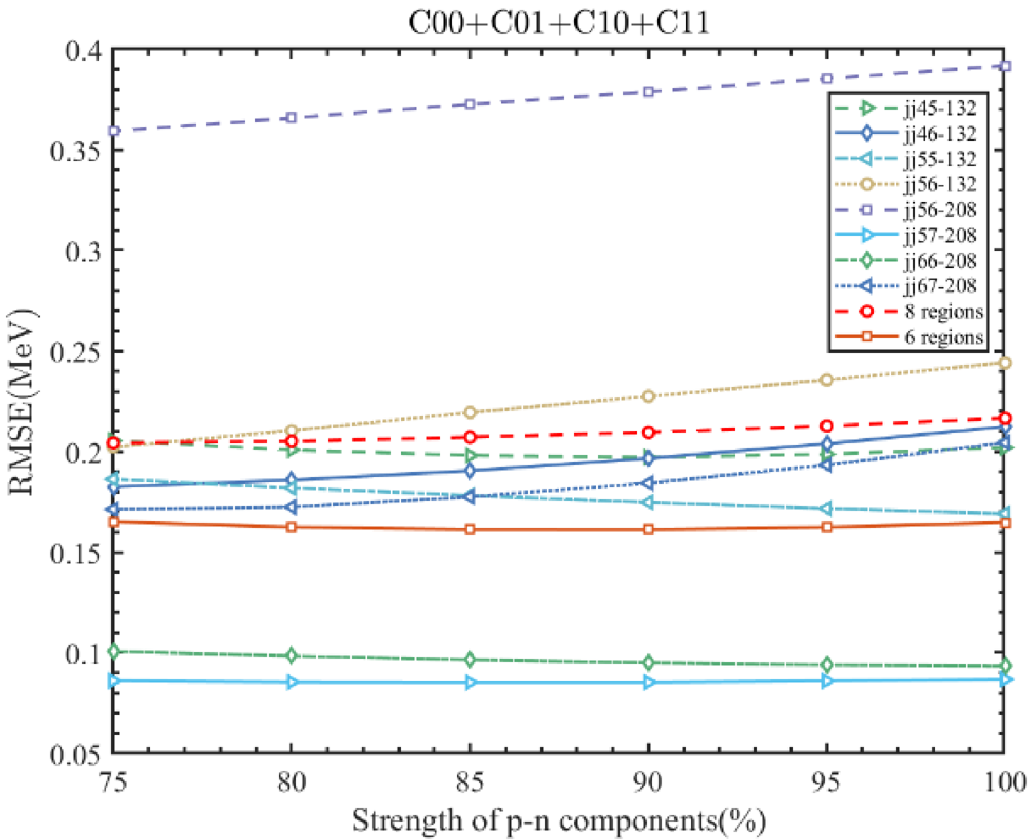


Comparing with 88 levels in 15 nuclei, the RMS of levels are 0.17, 0.27, and 0.47 for V_{MU}+LS, jj45pnm, and jj45pna, respectively. Simple nuclear force V_{MU}+LS gives

nucleus	Jπ	Expt.	V_{MU}+LS	jj45pnm	jj45pna
RMS			0.17	0.27	0.47

RMS for other nuclei

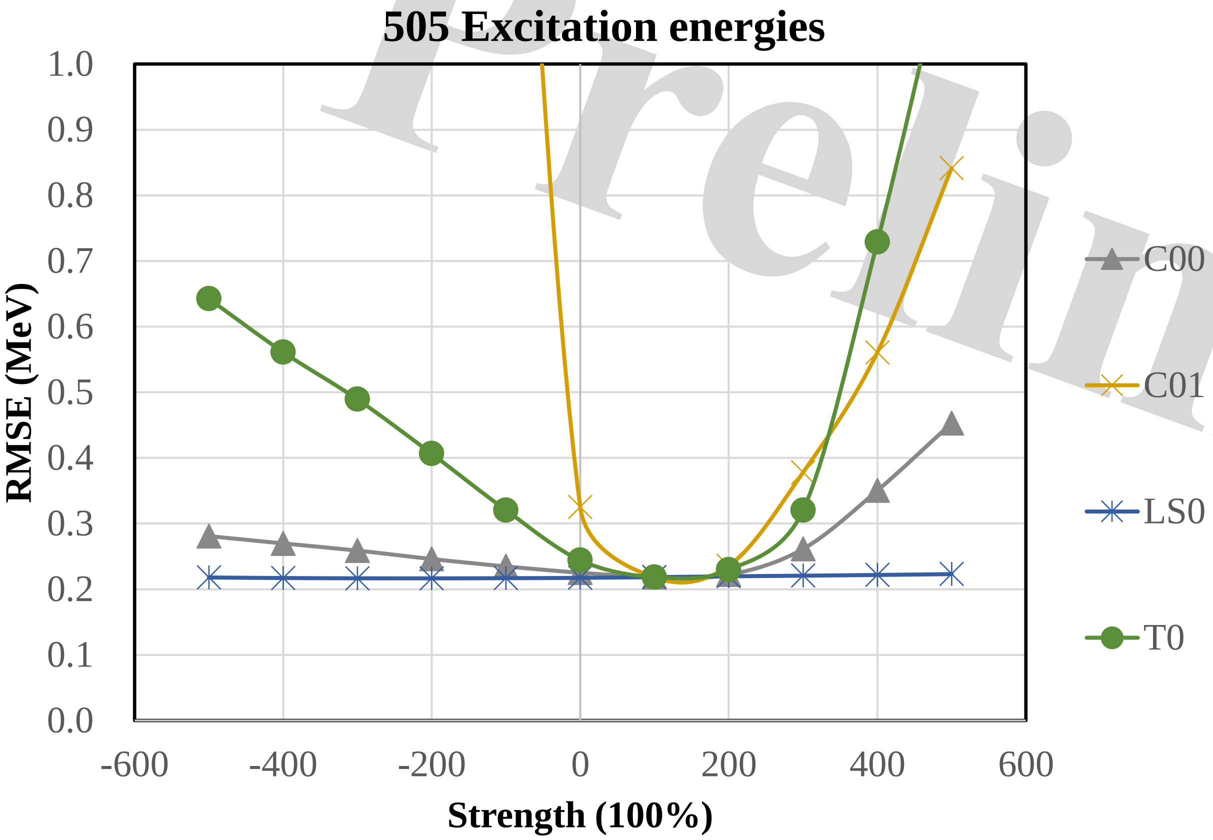


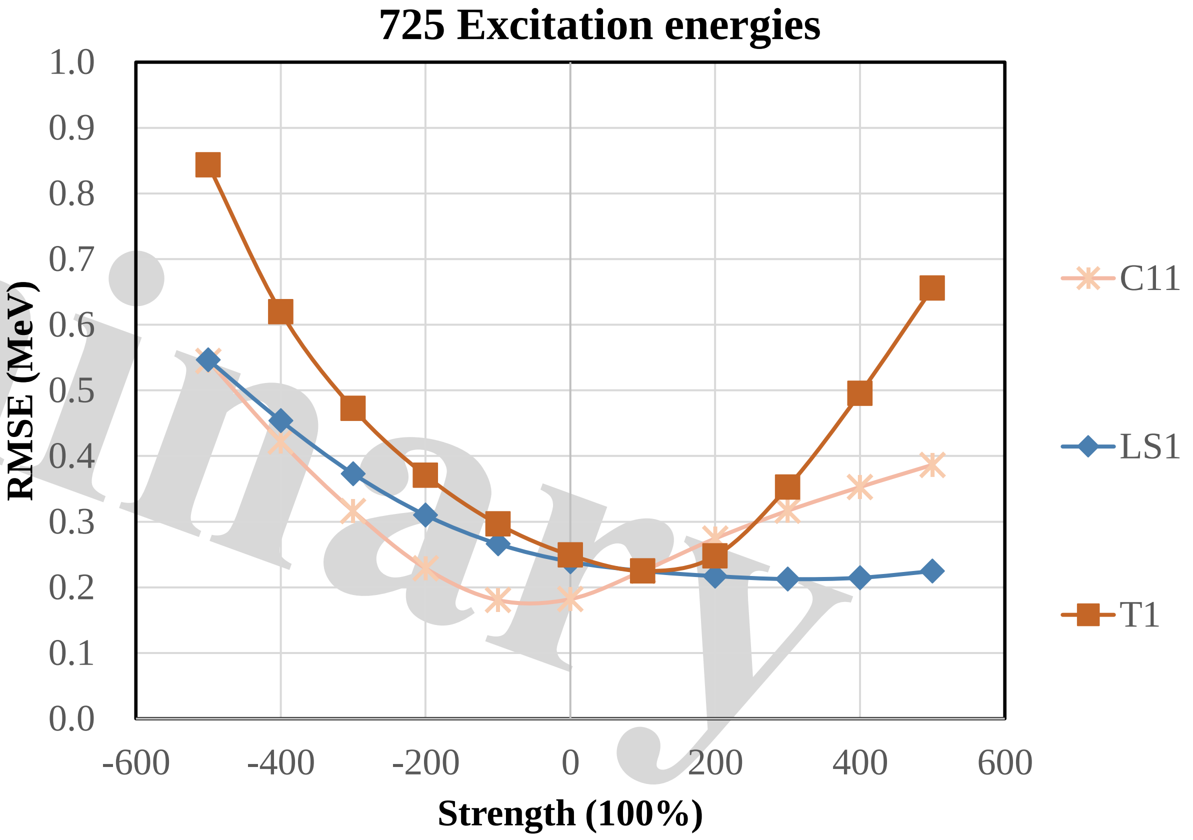


- pn: more than 500 levels
- RMS slightly sensitive to the pn components

- Different tendency for different regions

RMS for other nuclei-Excitation energy

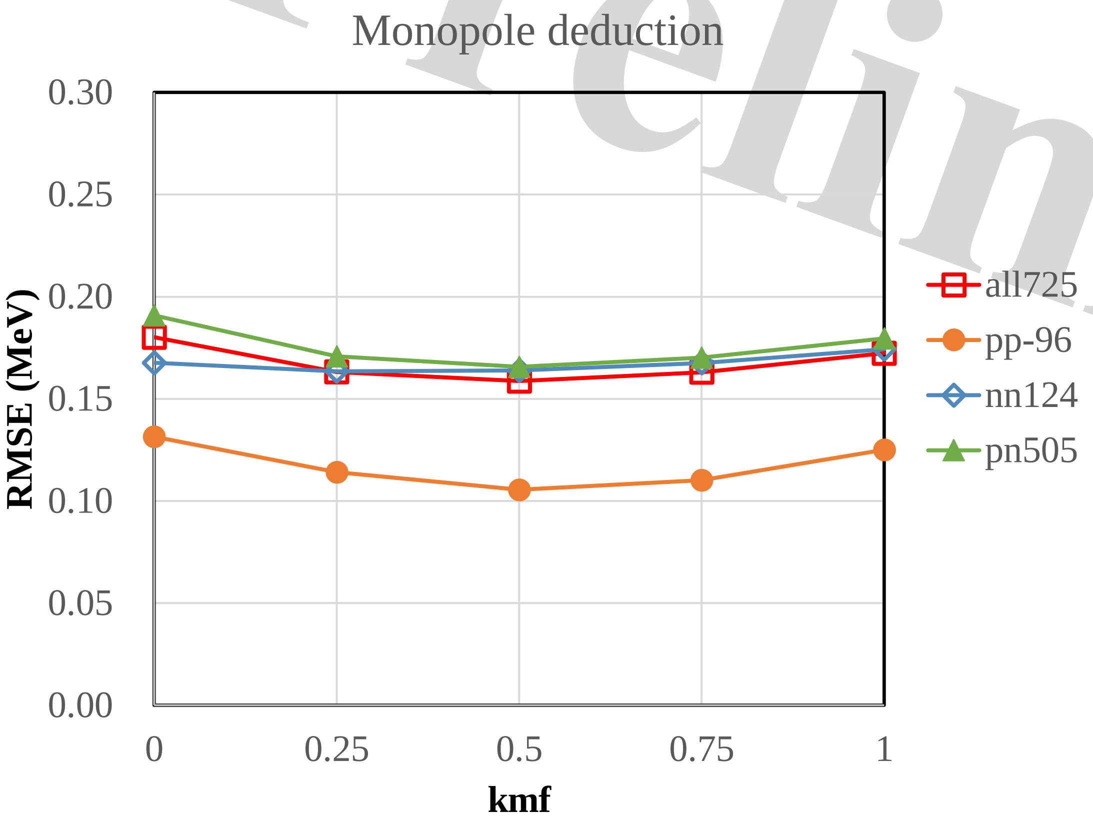


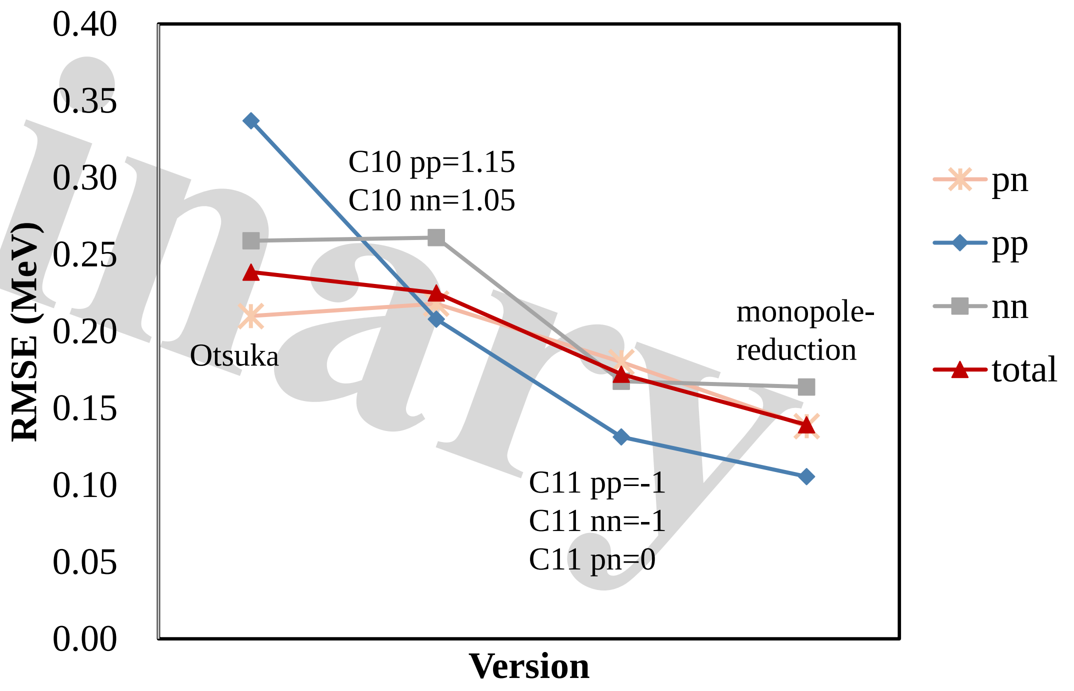


- pn: more than 500 level
- C00, C01,T0 and T1 are relatively well-determined
- Spin-orbital forces to be further considered

RMS for other nuclei

< ij | V | ij> (new)= < ij | V | ij> (old) – kmf* Vij(monopole)

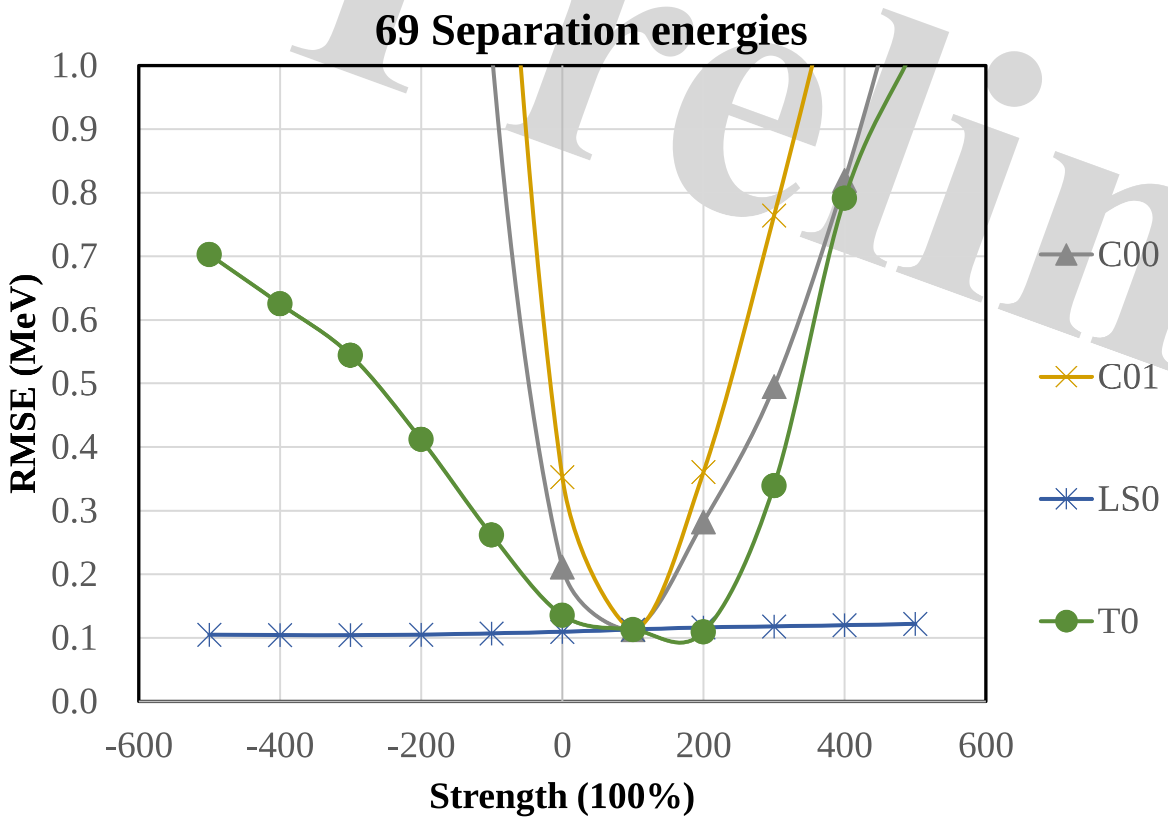


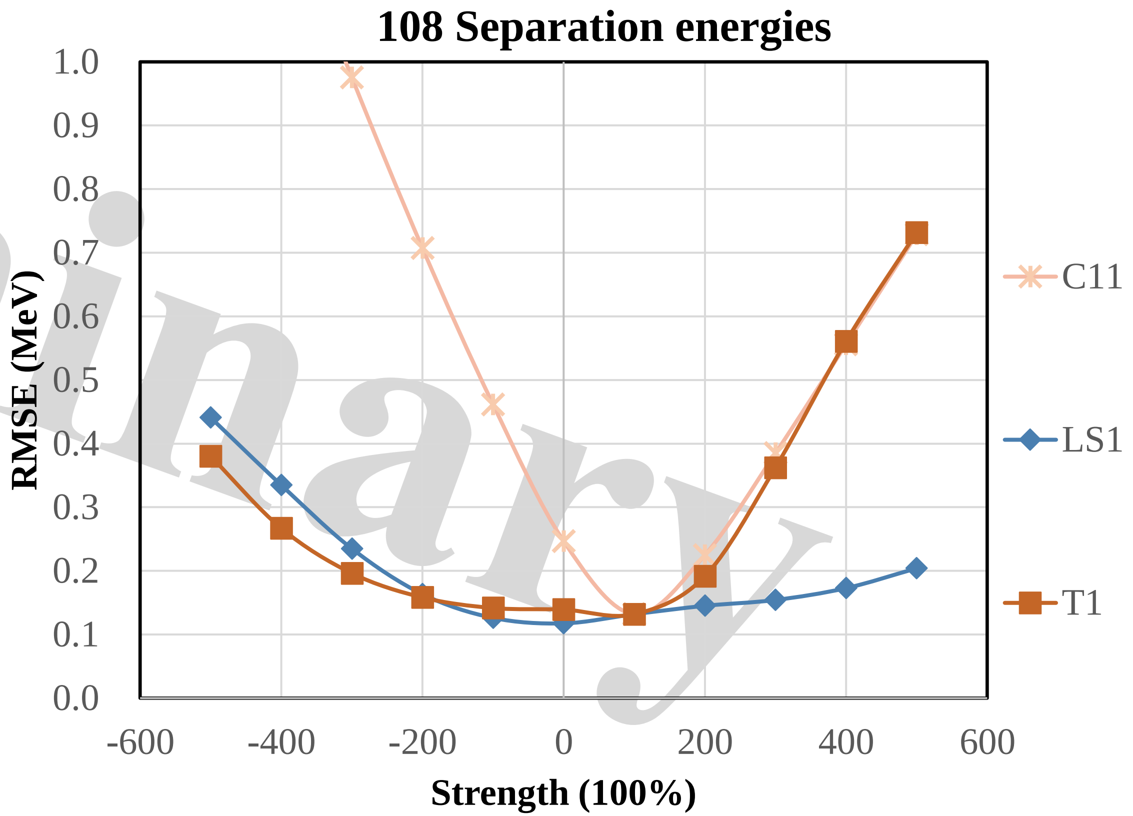


➢ **monopole deduction or semi-frozen of monopole interaction is suggested.**

中山大學中法核工程与技术学院
Institut franco-chinois de l'énergie nucléaire université Sun Yat-sen

RMS for other nuclei-Neutron separation energy

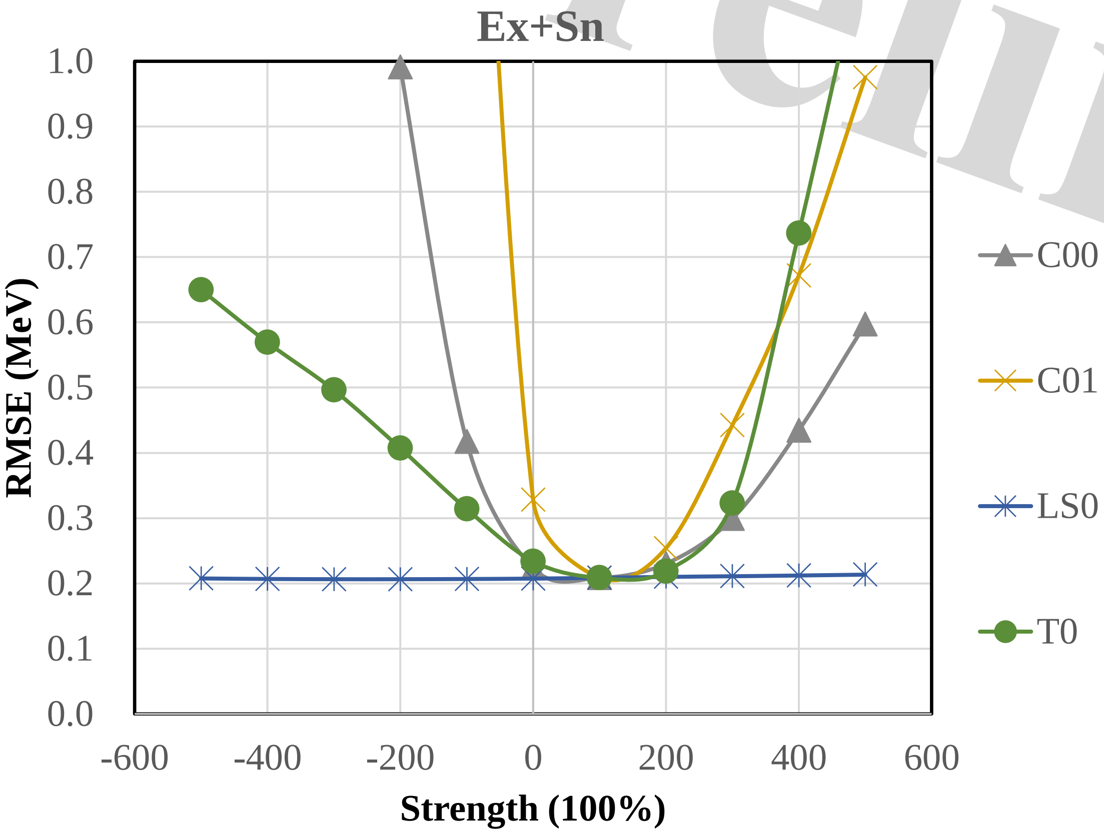


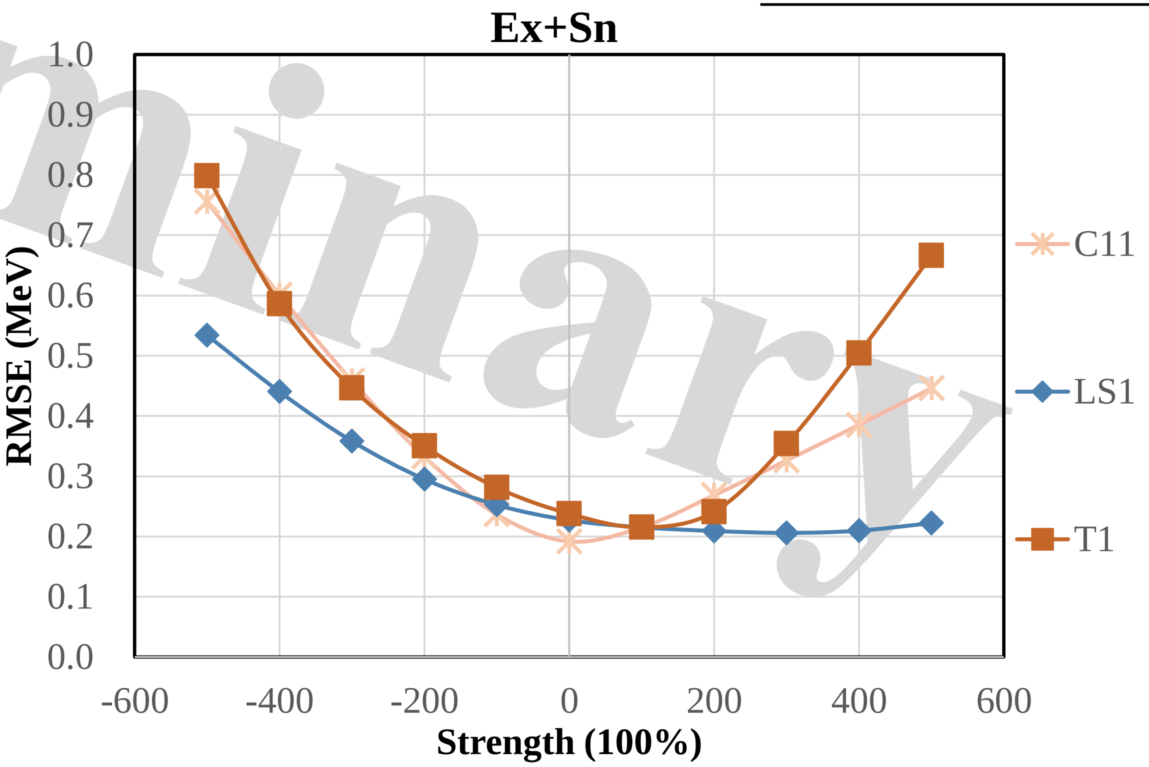


RMS for other nuclei-Excitation energy + Neutron separation energy

The optimized strengths

	Ex	Sn	Ex+Sn
C11	-1	1	0
LS1	3	0	3
T0	1	2	1





Outline

- Introduction to Configuration-Interaction Shell Model (CISM)
- Towards Unified Force for Medium and Heavy Mass Nuclei
- Isomeric Study on Exotic Nuclei
- Summary

International Journal of Modern Physics E
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Recent progress in configuration–interaction shell model

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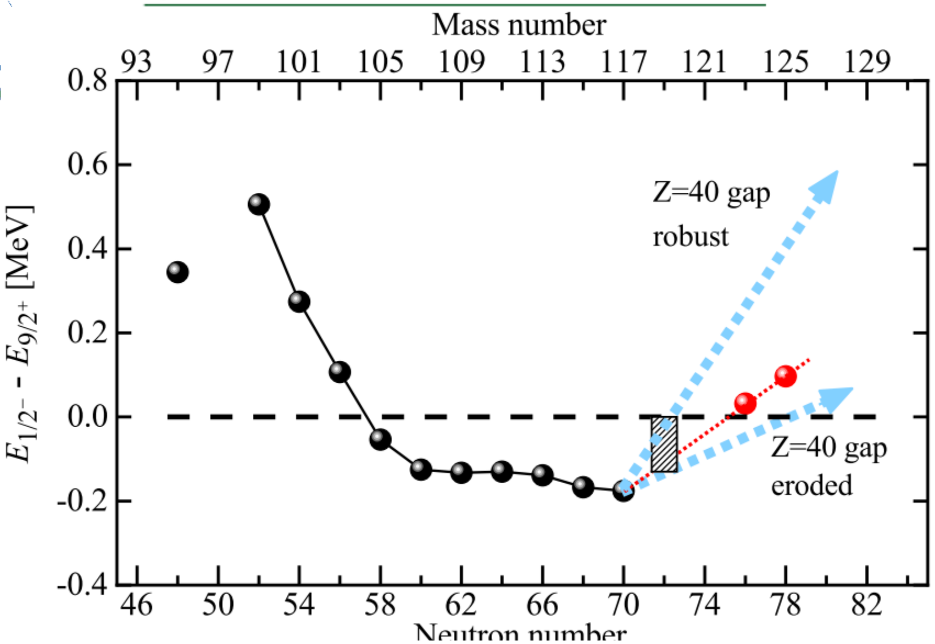
Since Mayer and Jensen employed the single-particle shell model to interpret the magic numbers, various microscopic nuclear models have been developed to study the nuclear force and structure. The configuration–interaction shell model (CISM), performed in truncated model space with the inclusion of the residual interaction, is one widely-used nuclear structure model. In the last decade, CISM has progressed in investigating the cross-shell excitation in exotic light nuclei, the similarity and difference in mirror nuclei, and the isomerism and seniority conservation in medium and heavy nuclei. Additionally, researchers have attempted to construct effective Hamiltonians for nuclei near ^{132}Sn and ^{208}Pb through a unified way in the CISM framework. In parallel, related models, including the nucleon-pair approximation (NPA) approach, the Monte Carlo shell model (MCSM), the projected shell model (PSM), the Gamow shell model (GSM), etc., have also been extensively developed and validated in the last decade. This paper reviews the recent progress in CISM and some related models.

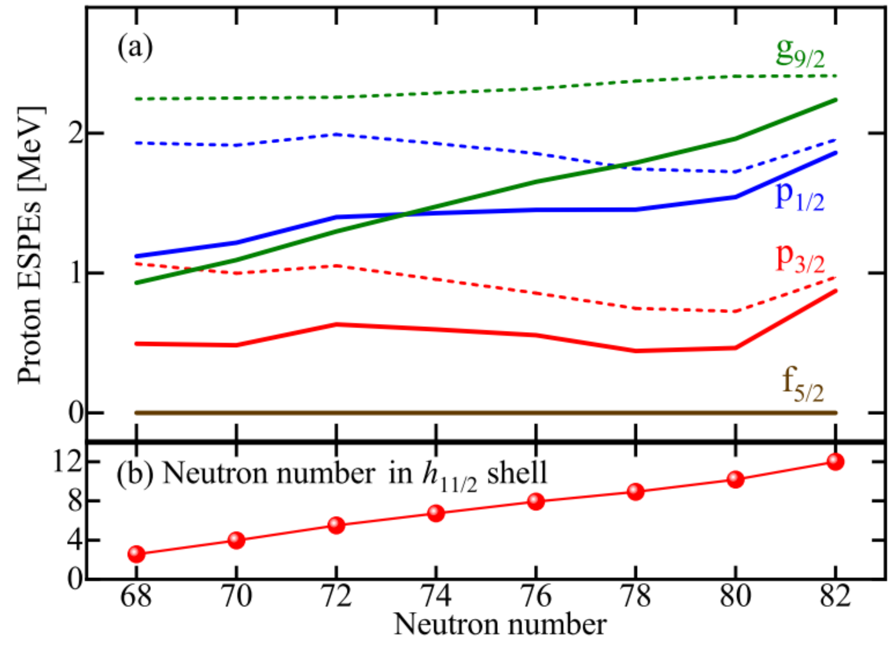
Keywords: Configuration–interaction shell model; nuclear structure; effective Hamiltonian.

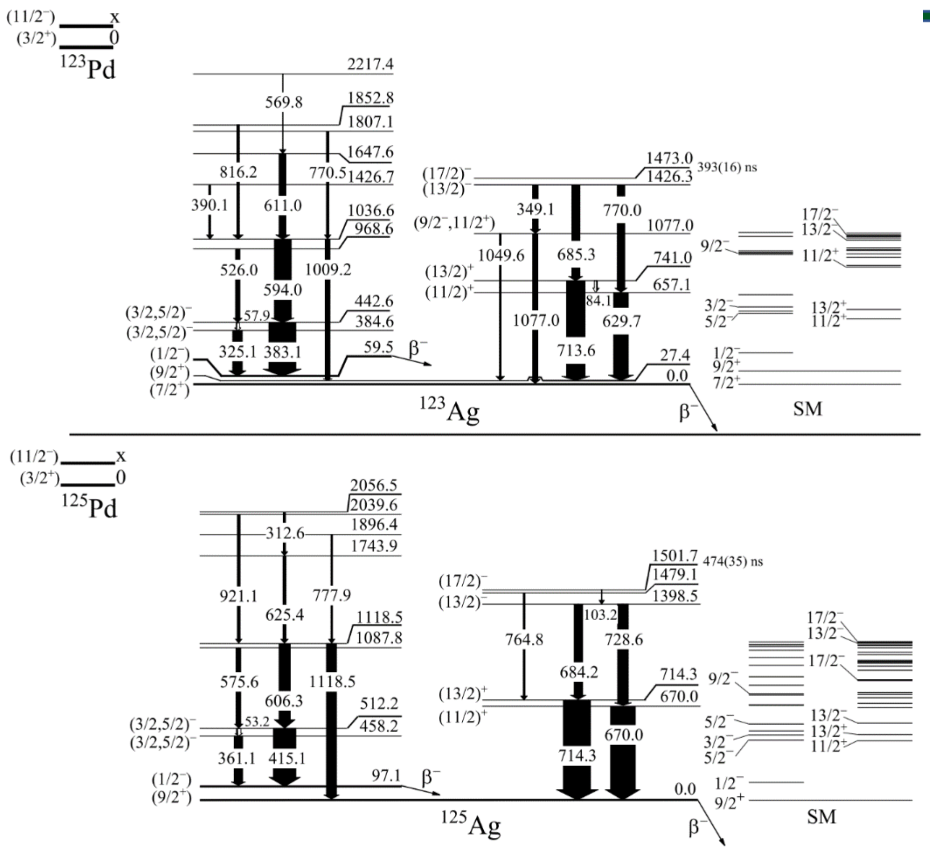
PACS Number(s): 21.60.Cs, 21.10. -k, 21.30.-x

中山大學中法核工程与技术学院

Type I shell evolution







Such simple nuclear force give both nice description on levels, ESPE, and the mechanism of shell evolution

ZQ Chen, et al., PRL, 122, 212502 (2019)

Possible Isomers

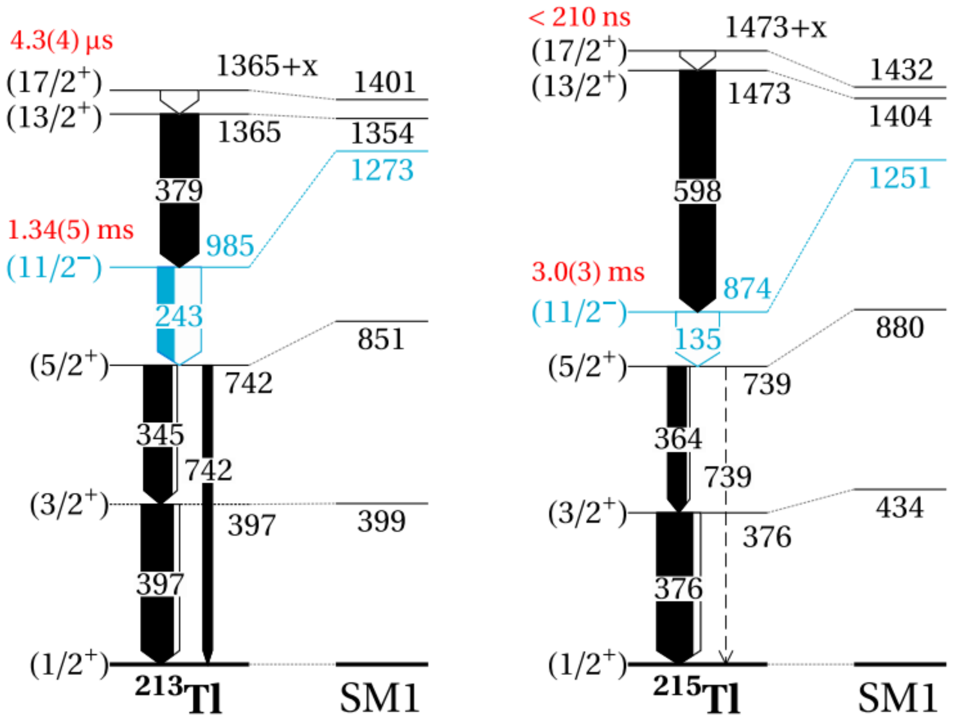
PHYSICAL REVIEW C **106**, 044314 (2022)

Shell-model study on spectroscopic properties in the region "south" of ^{208}Pb

Cenxi Yuan,[1,*] Menglan Liu,[1] Noritaka Shimizu,[2] Zs. Podolyák,[3] Toshio Suzuki,[4,5]
Takaharu Otsuka,[6,7,8,9] and Zhong Liu[10,11]

Nuclide	J_i^π	J_f^π	δE (MeV)	$B(E2)$ (e^2 fm^4)	Half-life (μs)
^{215}Pb	$17/2^+$	$13/2^+$	0.33	28.08	0.0047
	$21/2^+$	$17/2^+$	0.12	31.44	0.18
^{213}Pb	$17/2^+$	$13/2^+$	0.29	33.46	0.0069
	$21/2^+$	$17/2^+$	0.12	0.45	12.13
^{213}Tl	$13/2^+$	$9/2^+$	0.09	0.01	1812.75
	$17/2^+$	$13/2^+$	0.05	0.03	444.55
^{212}Tl	11^+	9^+	0.11	2.27	2.93
^{211}Tl	$13/2^+$	$9/2^+$	0.09	66.27	0.14

	Type of interaction	Source of interaction
PO5-PO5	proton-proton	KHHE (modified)
NO6-NO6	neutron-neutron	KHHE
NO7-NO7	neutron-neutron	KHPE
PO5-NO6	proton-neutron	KHHE
PO5-NO7	proton-neutron	V_{MU}+LS
NO6-NO7	neutron-neutron	V_{MU}+LS

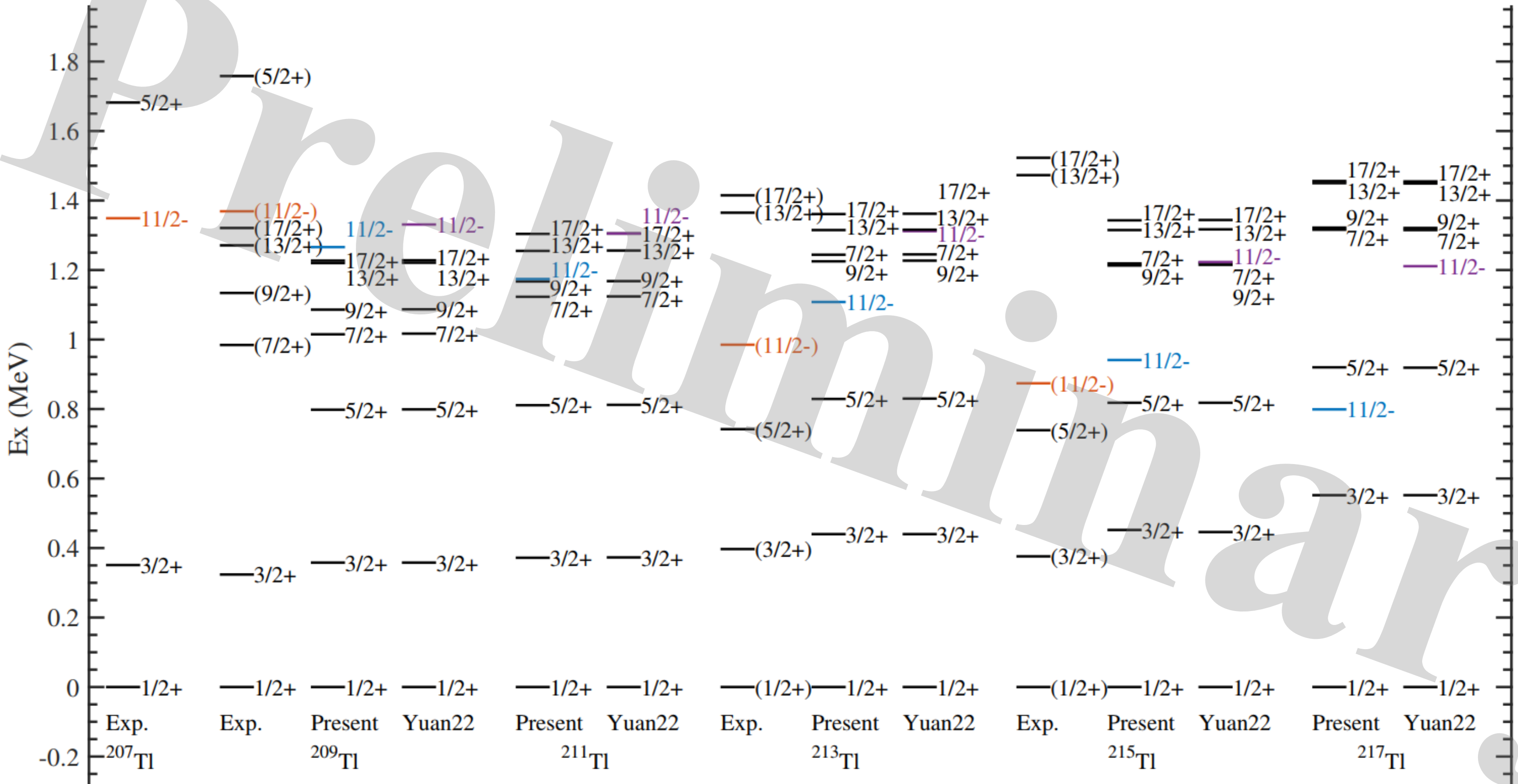


Yeung et al., PRL, 133, 072501 (2024)

submitted

Shell-model investigation on the isomerism in the "south-east" of ^{208}Pb induced by the $\pi 0h_{11/2}$ hole

Menglan Liu (刘梦兰),[1] Cenxi Yuan (袁岑溪),[1,*] Guangxin Zhang (张广鑫),[1] Yinu Zhang (张一怒),[1] and Chong Qi (亓冲)[2,1]



β-decaying isomers candidates in Tl isotopes

Based on *Yuan2022:*

- Modification of proton-proton elements in *Steer2008:*

$\langle \pi 1d_{3/2}\pi 0h_{11/2}|V|\pi 1d_{3/2}\pi 0h_{11/2}\rangle_{7-}$ +0.135 MeV,

$\langle \pi 2s_{1/2}\pi 1d_{5/2}|V|\pi 2s_{1/2}\pi 1d_{5/2}\rangle_{2+,3+}$ +0.250 MeV,

$\langle \pi 2s_{1/2}\pi 0h_{11/2}|V|\pi 1d_{3/2}\pi 0h_{11/2}\rangle_{6-}$ = 0.260 MeV .

- $\langle \pi 0h_{11/2}\pi 0h_{11/2}|V|\pi 0h_{11/2}\pi 0h_{11/2}\rangle_{10+}$ +0.1 MeV.
- $\langle \pi 0h_{11/2}\upsilon 1g_{9/2}|V|\pi 0h_{11/2}\upsilon 1g_{9/2}\rangle$ +0.045 MeV.

submitted

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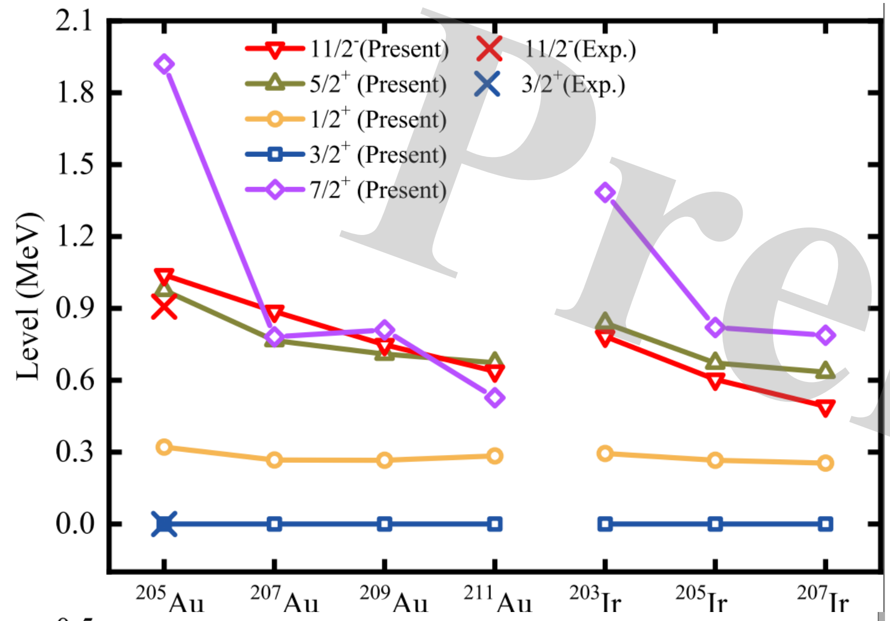
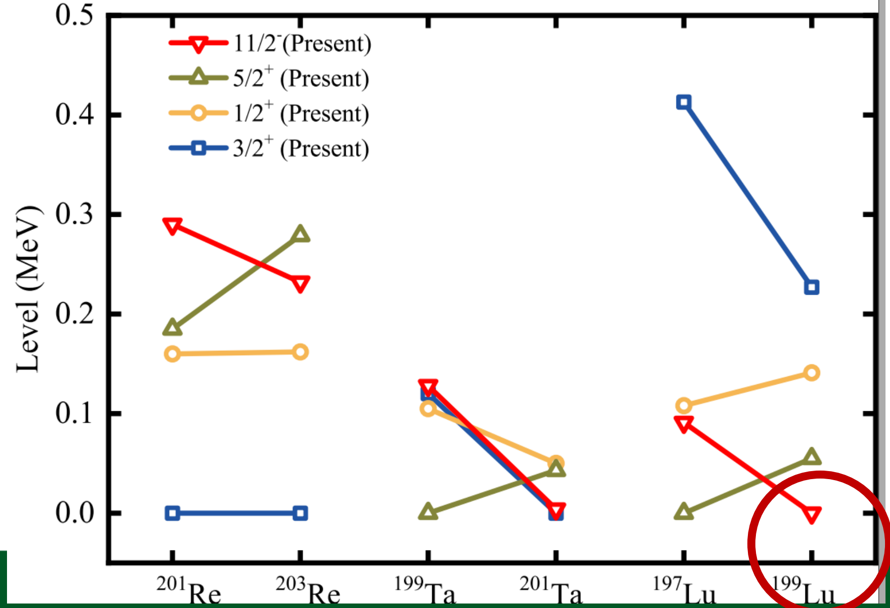


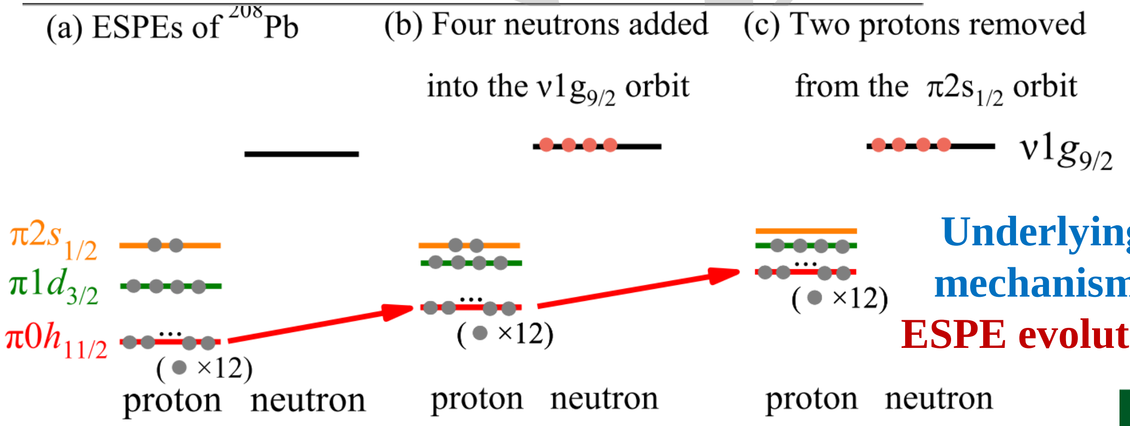


11/2- is predicted to be the ground state in 199Lu, a waiting point candidate.

TABLE I. Prediction on the most probable γ decay of the first $11/2^-$ states.

Nucleus	Final state	Decay mode
^{217}Tl	$3/2^+$	$M4$
^{205}Au	$5/2^+$	$E3$
^{207}Au	$7/2^+$	$M2$
^{209}Au	$3/2^+$	$M4$
^{211}Au	$3/2^+$	$M4$
^{203}Ir	$3/2^+$	$M4$
^{205}Ir	$3/2^+$	$M4$
^{207}Ir	$3/2^+$	$M4$
^{201}Re	$5/2^+$	$E3$
^{203}Re	$3/2^+$	$M4$
^{199}Ta	$5/2^+$	$E3$
^{201}Ta	$3/2^+$	$M4$
^{197}Lu	$5/2^+$	$E3$

β-decaying isomers candidates in odd-even isotopes



Underlying mechanism: ESPE evolution

submitted

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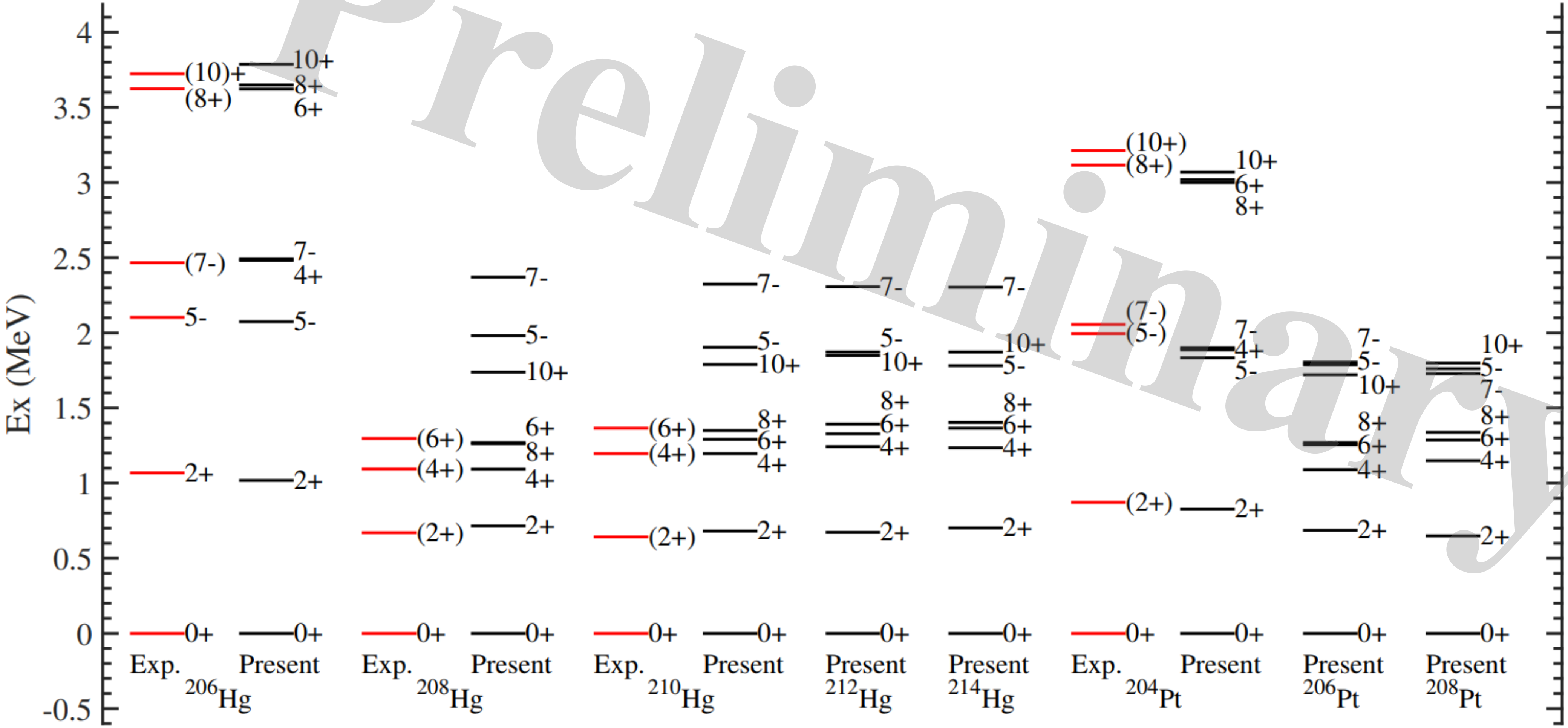
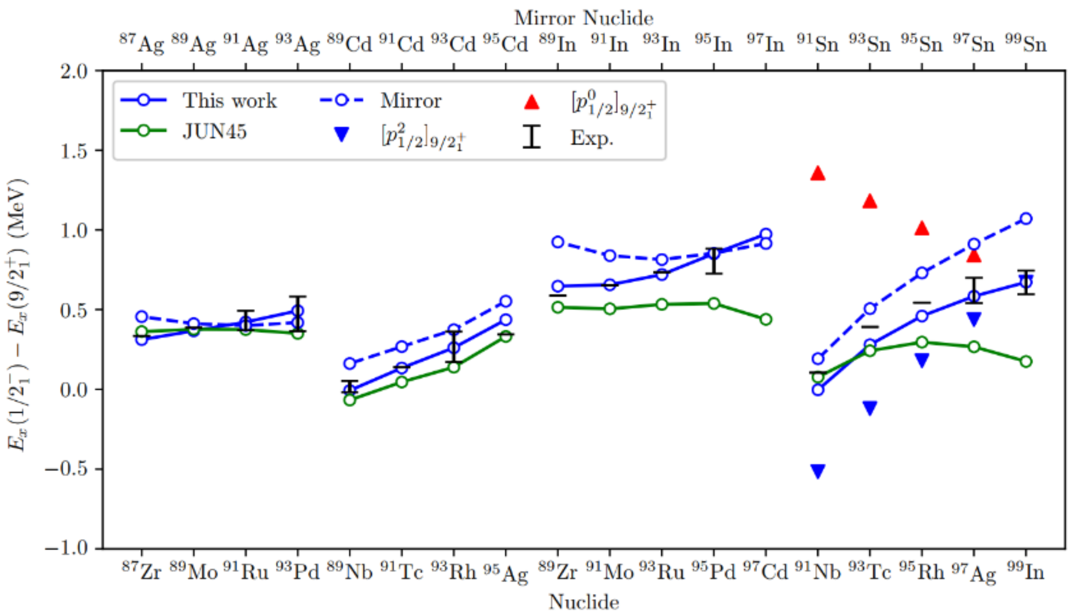
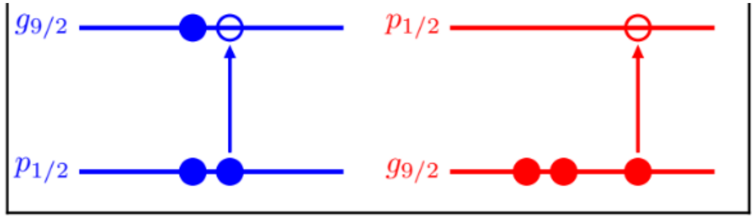
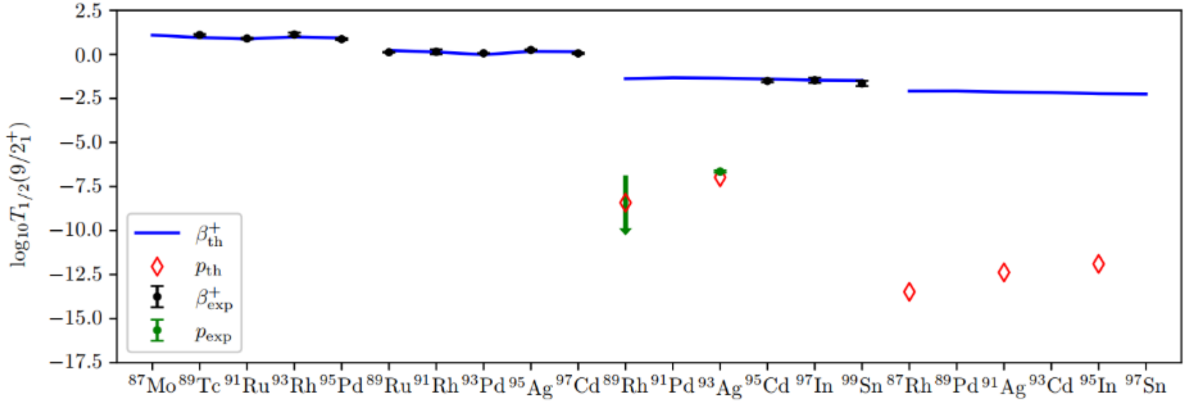
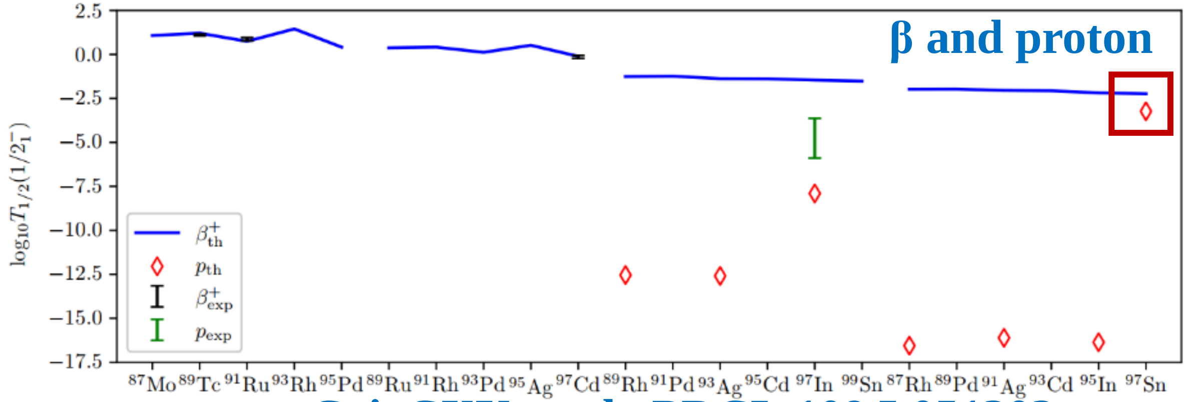


Drip Line Isomer









Cai, CXY, et al., PRCL.109.L051302

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Recent progress in configuration–interaction shell model

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Since Mayer and Jensen employed the single-particle shell model to interpret the magic numbers, various microscopic nuclear models have been developed to study the nuclear force and structure. The configuration–interaction shell model (CISM), performed in truncated model space with the inclusion of the residual interaction, is one widely-used nuclear structure model. In the last decade, CISM has progressed in investigating the cross-shell excitation in exotic light nuclei, the similarity and difference in mirror nuclei, and the isomerism and seniority conservation in medium and heavy nuclei. Additionally, researchers have attempted to construct effective Hamiltonians for nuclei near ^{132}Sn and ^{208}Pb through a unified way in the CISM framework. In parallel, related models, including the nucleon-pair approximation (NPA) approach, the Monte Carlo shell model (MCSM), the projected shell model (PSM), the Gamow shell model (GSM), etc., have also been extensively developed and validated in the last decade. This paper reviews the recent progress in CISM and some related models.

Keywords: Configuration–interaction shell model; nuclear structure; effective Hamiltonian.

PACS Number(s): 21.60.Cs, 21.10.-k, 21.30.-x

- **Summary and Perspective**
  - **Systematic study from medium to heavy nuclei**
  - **CISM with one effective nuclear force (better for extrapolation) for Spectroscopic Properties**

Collaboration

Menglan Liu, Boshuai Cai, Shengli Chen, Guangxin Zhang, Jun Su, Long Zhu, Wei Hua, Bo Mei (SYSU)

Furong Xu, Yanlin Ye, Hui Hua, Zhihuan Li, Jianling Lou, Zaihong Yang, Xiaofei Yang (PKU)

Chong Qi (KTH), Takaharu Otsuka (Todai), Noritaka Shimizu (Tsukuba), Toshio Suzuki (Nihon U)

Zhong Liu, Yuhu Zhang, Meng Wang, Zaiguo Gan, Xinxing Xu, Huabin Yang, Zhiyuan Zhang, Shitao Wang, Xing Xu, Yuanming Xing, Jiajian Liu, Jianguo Li (IMP)

Chengjian Lin, Huiming Jia, Xiaoguang Wu (CIAE), Phil Walker, Zsolt Podolyak (Surrey), Jenny Lee (HKU)

Gaolong Zhang, Danyang Pang, Hiroshi Watanabe (Beihang), He Wang (RIKEN)

Many others …

Thanks for your Time!

Welcome to SYSU and IFCEN!

Collaborations and Applications Welcome!

Contact: Cenxi YUAN, yuancx@mail.sysu.edu.cn