Nuclear studies with FSU Hamiltonian

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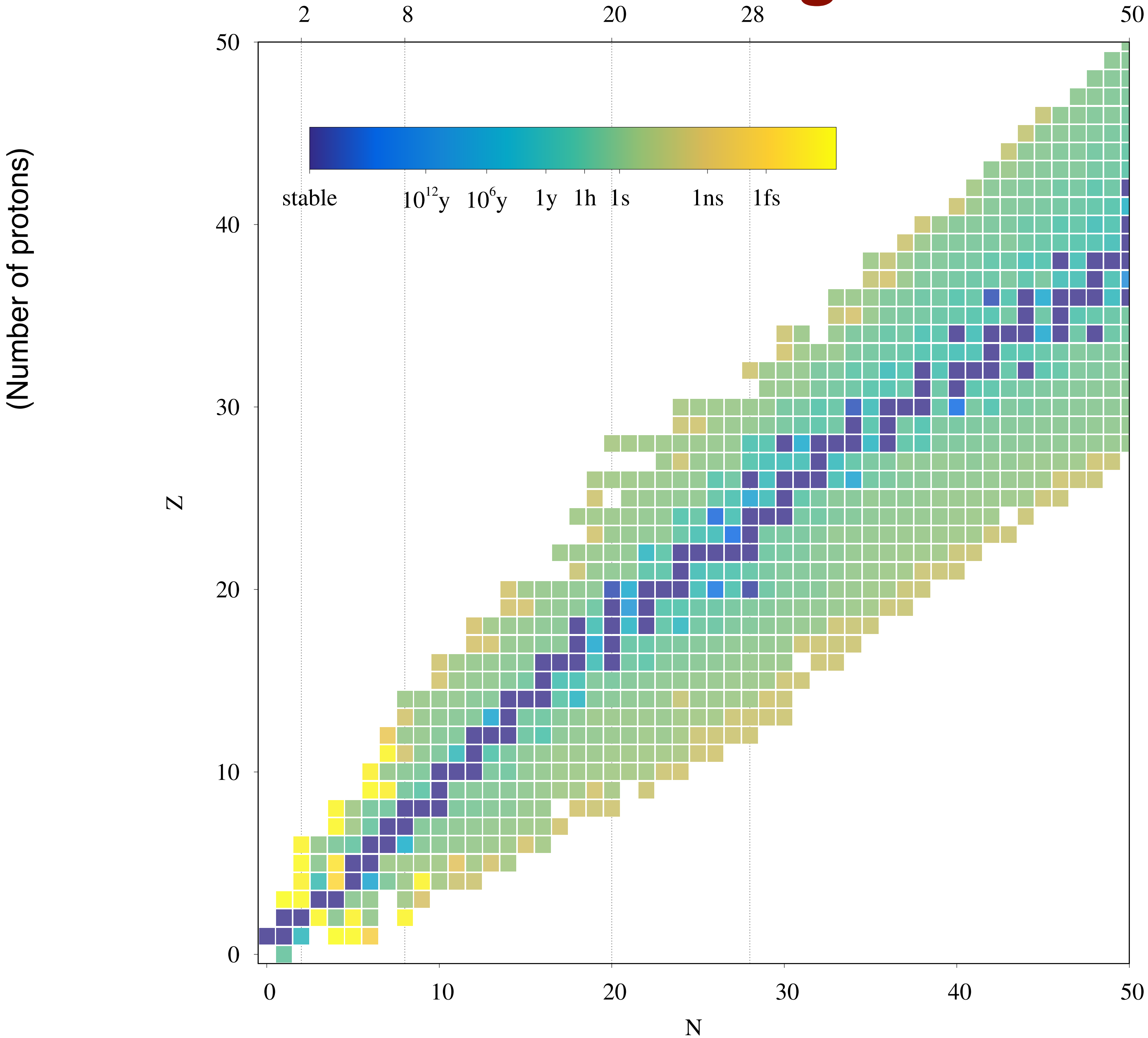
Nuclear shell model

- Phenomenological component is an intrinsic part of theory, theory takes guidance from experiment related to models and parameters.
    - Understanding of complex and collective phenomena
    - Path to ab-initio understanding of nuclear forces and their role
    - Guidance for experimental studies
- Nuclear shell model has been a powerful tool in nuclear studies for many decades
- Innovations: configuration interactions, clustering, RGM, reactions, time dependent dynamics

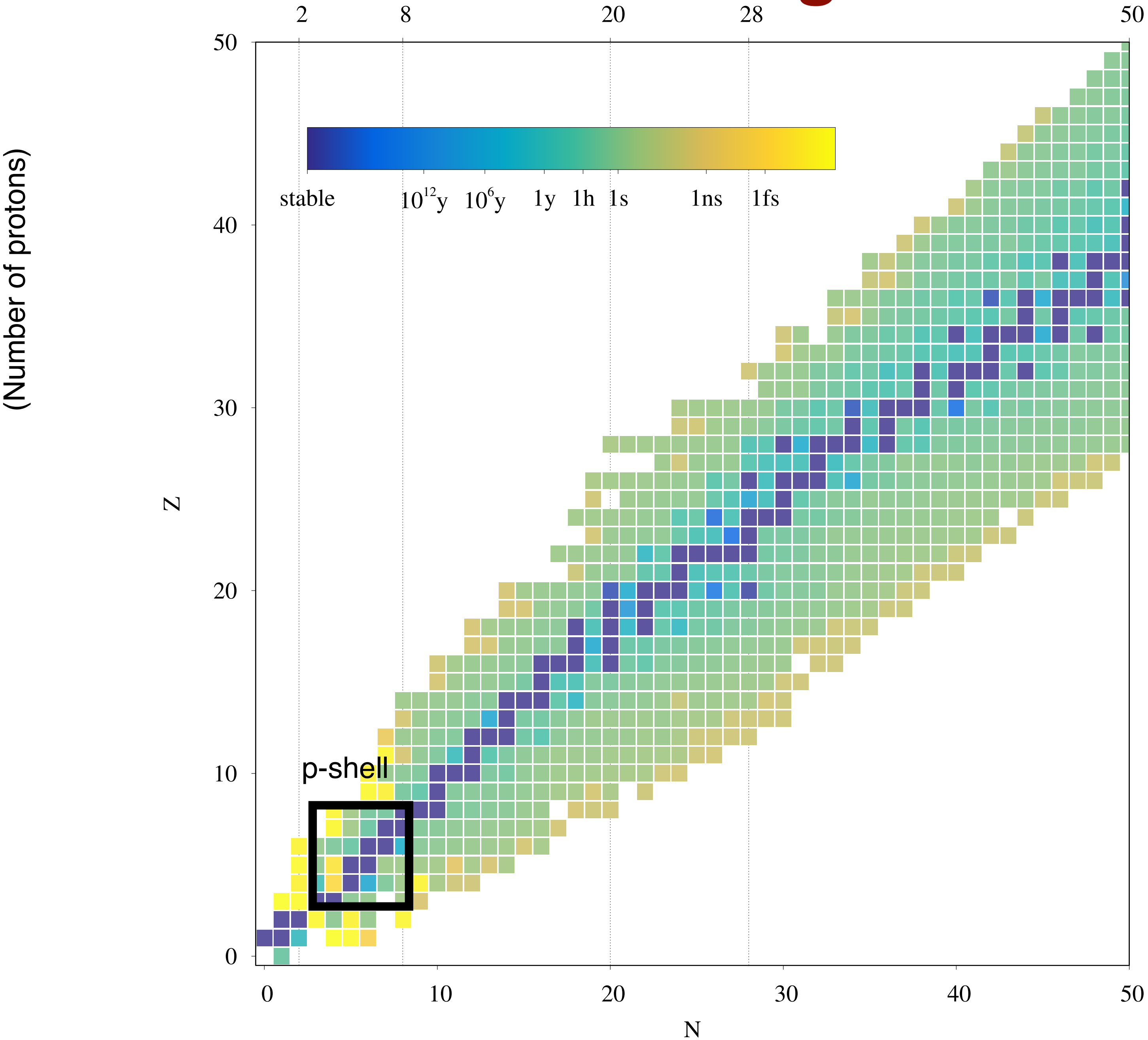
B. A. Brown, "The nuclear shell model towards the drip lines," Progress in Particle and Nuclear Physics, **47**, 517 (2001)

S. R. Stroberg, H. Hergert, S. K. Bogner, and J. D. Holt, "Nonempirical Interactions for the Nuclear Shell Model: An Update," Annu. Rev. Nucl. Part. Sci., **69,** 307 (2019)

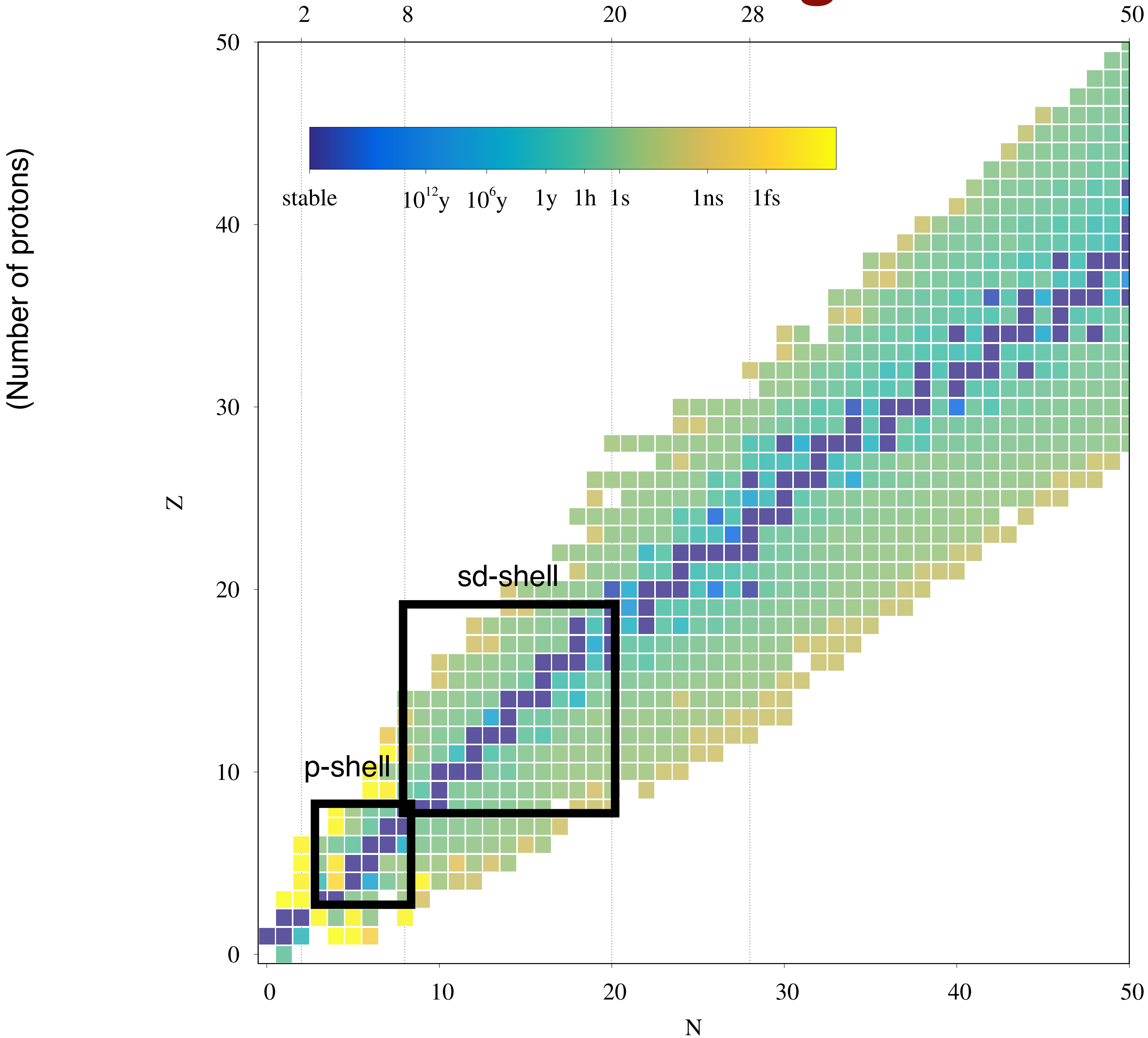
Nuclear regions



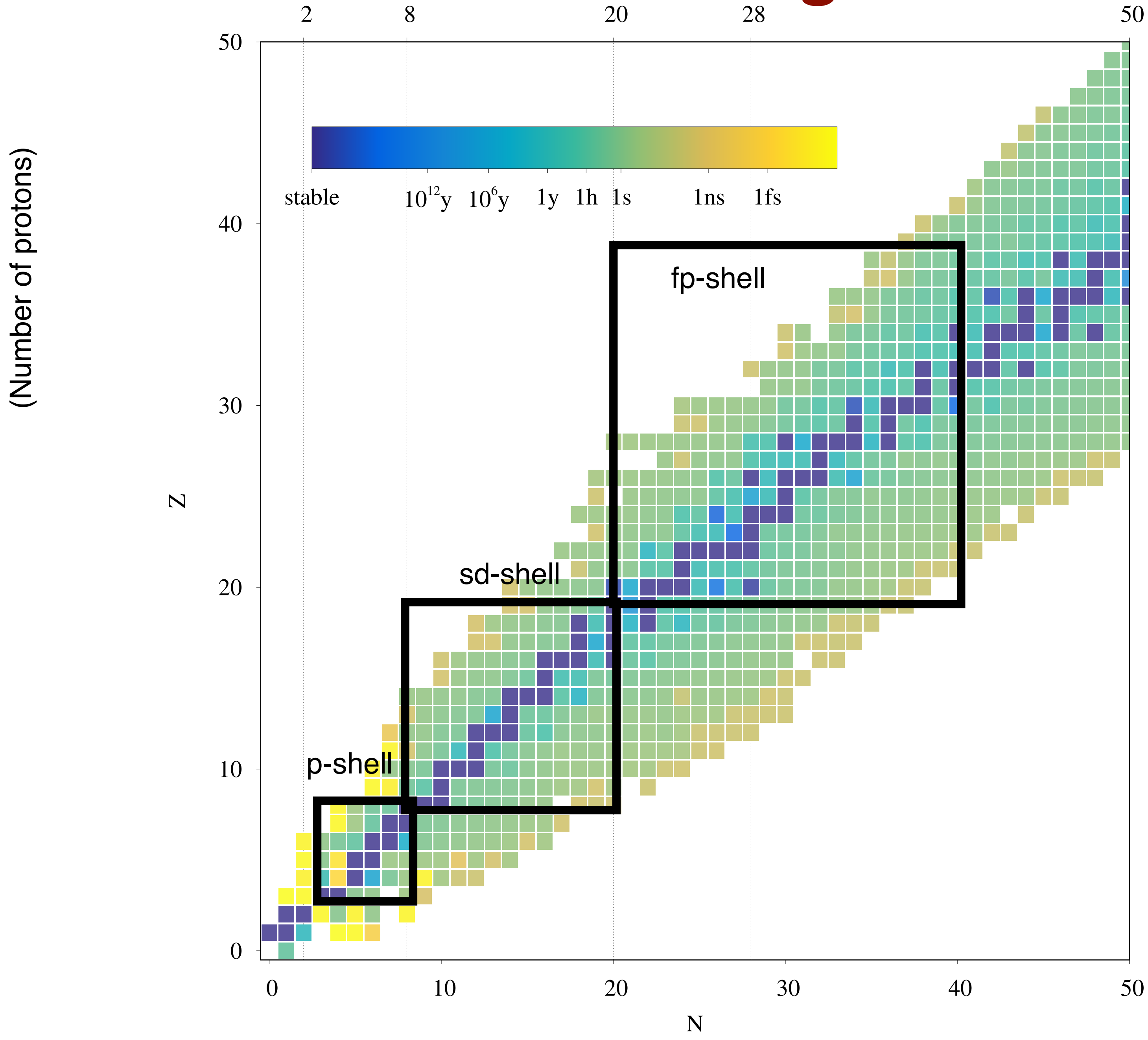
Nuclear regions



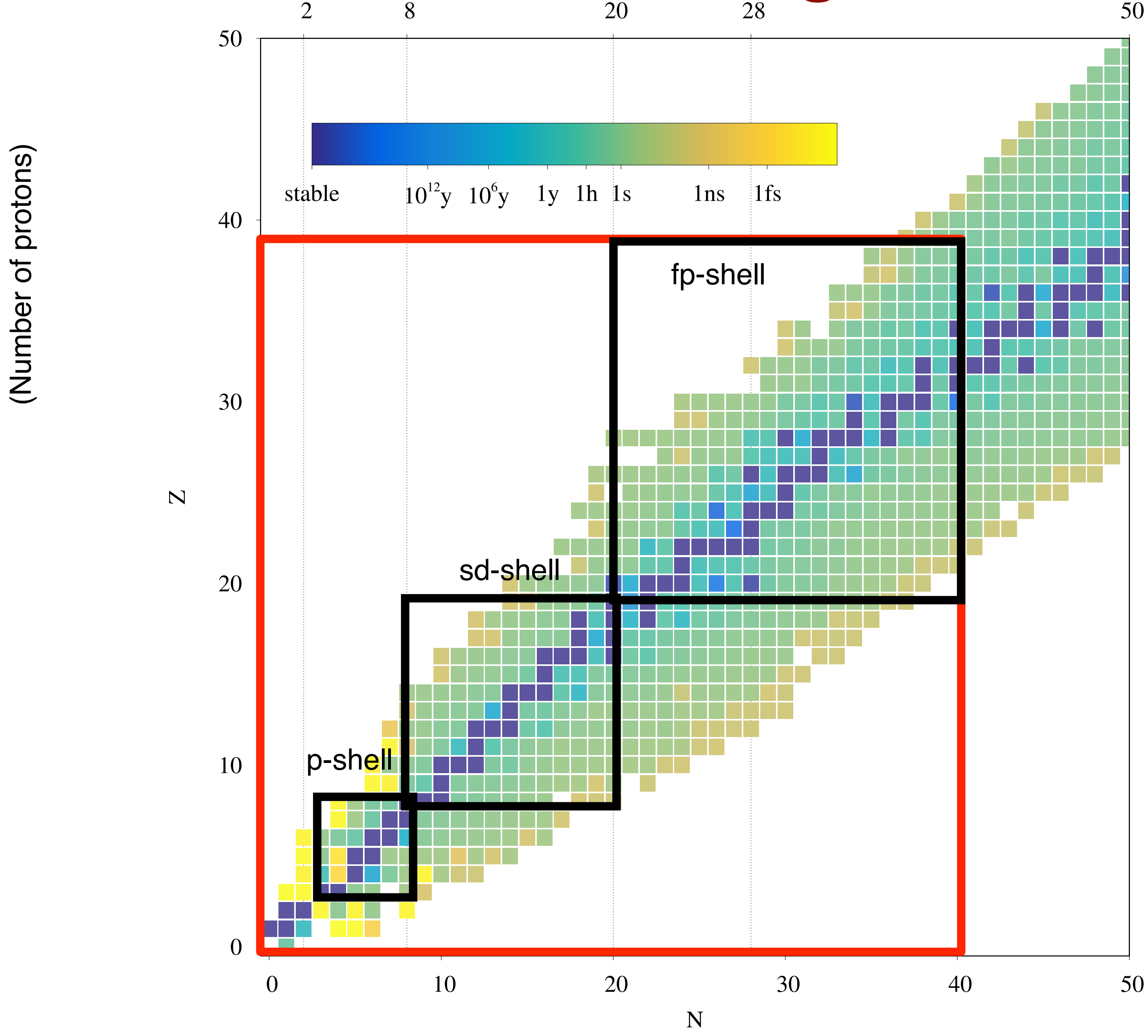
Nuclear regions



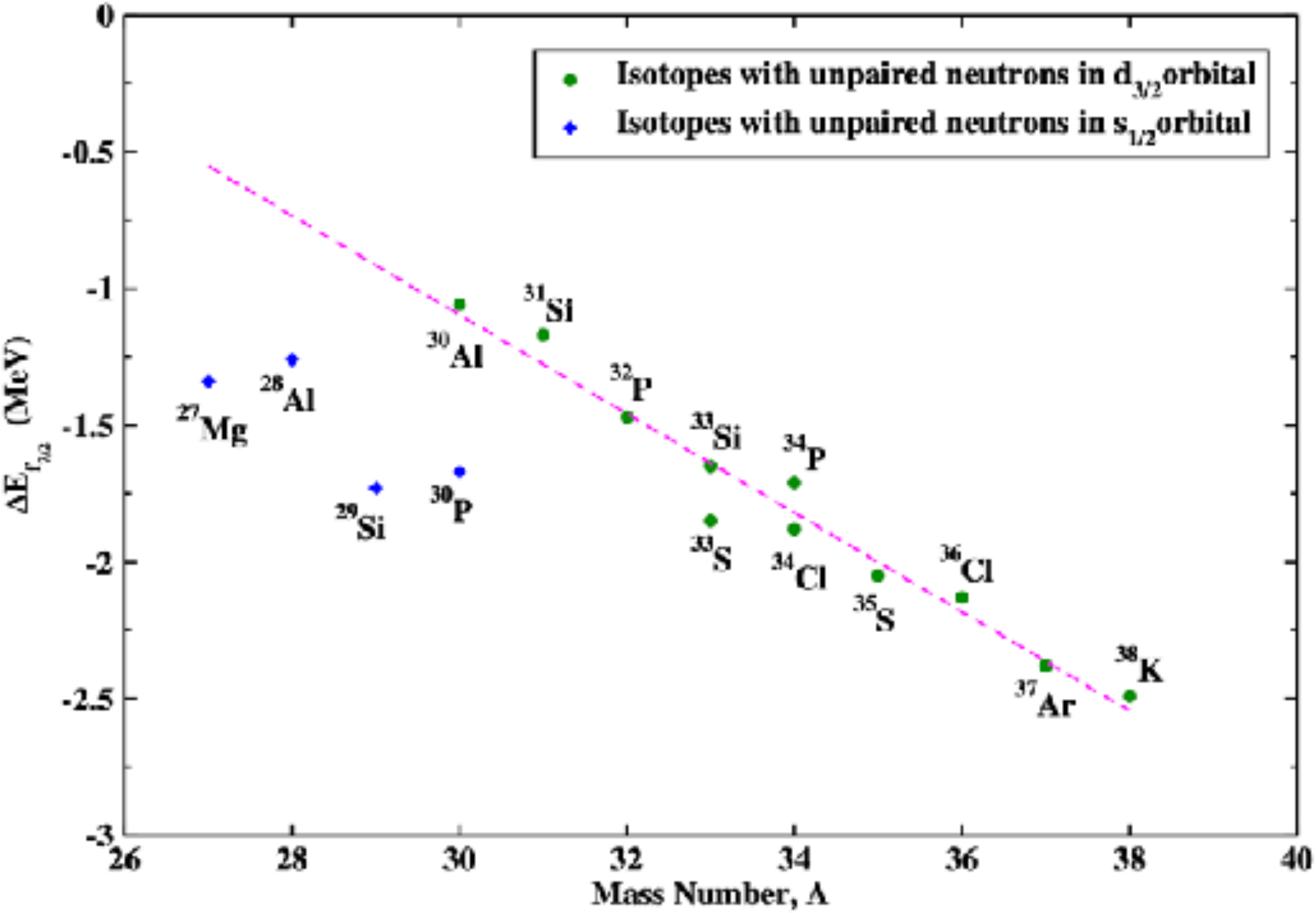
Nuclear regions



Nuclear regions



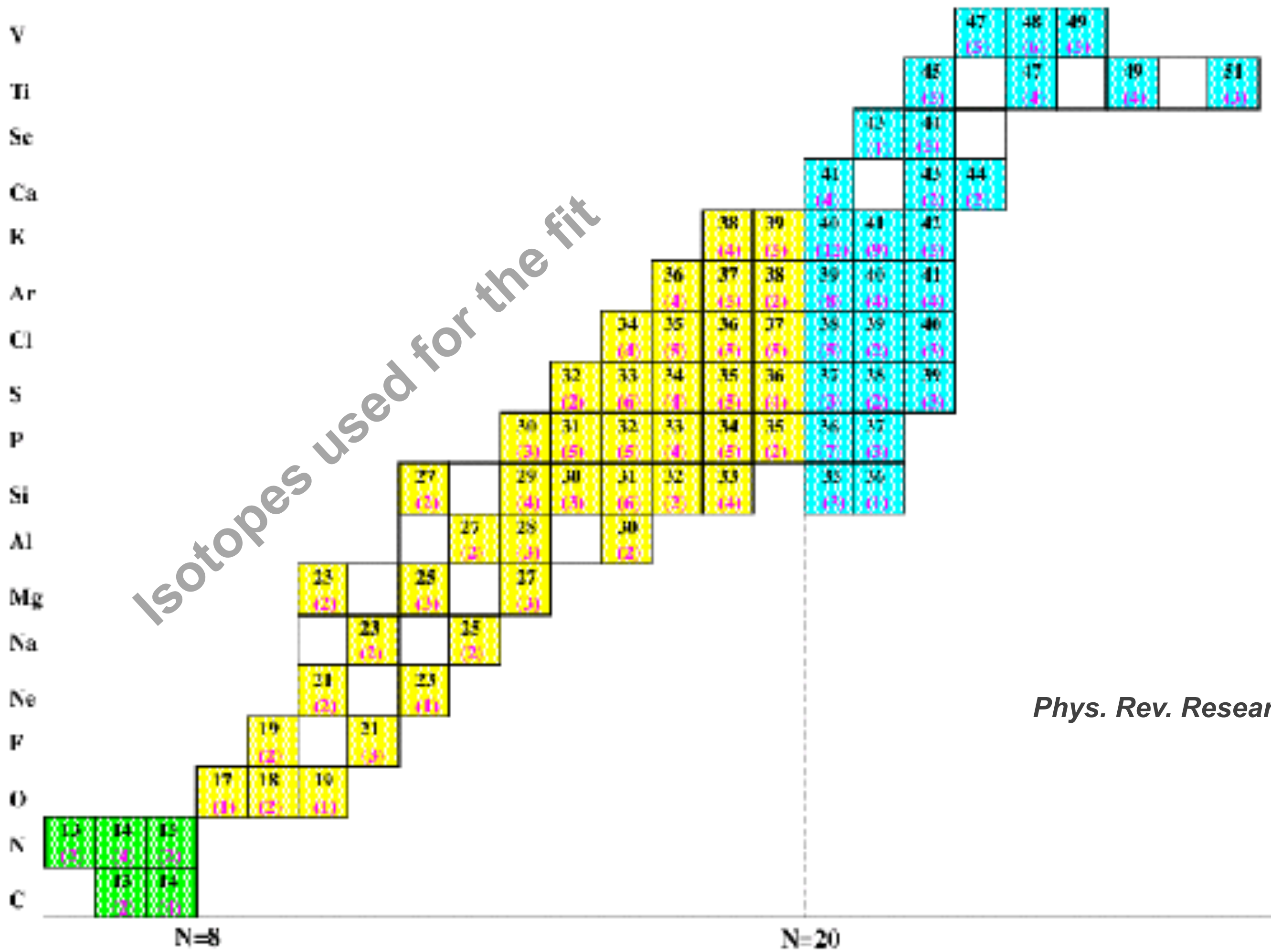
Motivations for a new fit



The reduction of $0f_{7/2}$ SPE needed (within WBP Hamiltonian) to reproduce experimental data within sd shell.

R. Lubna, Ph.D. Thesis, Florida State University (2019)

Phenomenological Shell Model



Phys. Rev. Research 2, 043342 (2020)

- Fit within *spsdfp* model-space
- Use existing models, (cki, usdb, wbp, gx1a) as starting point
- Concentrate on effectively 4 types of states, 270 experimental levels
- Reduce fit to 70 free parameters, and χ^2 minimization further to 40

Phenomenological Shell Model

^{34}Si (N= 20, Z= 14)

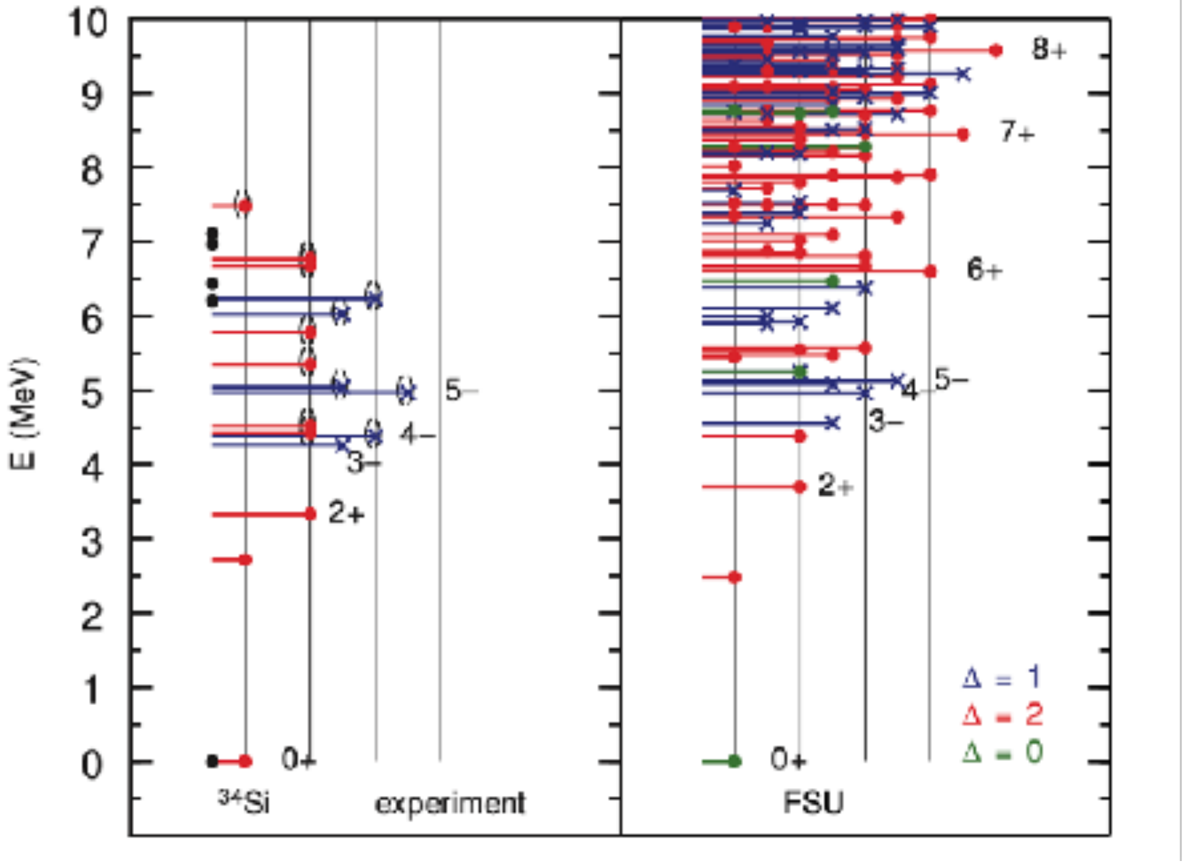


Figure from review paper
B. A. Brown, The Nuclear Shell Model Towards The Drip Lines, Physics 4, 525--547 (2022).

Phenomenological Shell Model

^{32}Mg (N= 20, Z= 12)

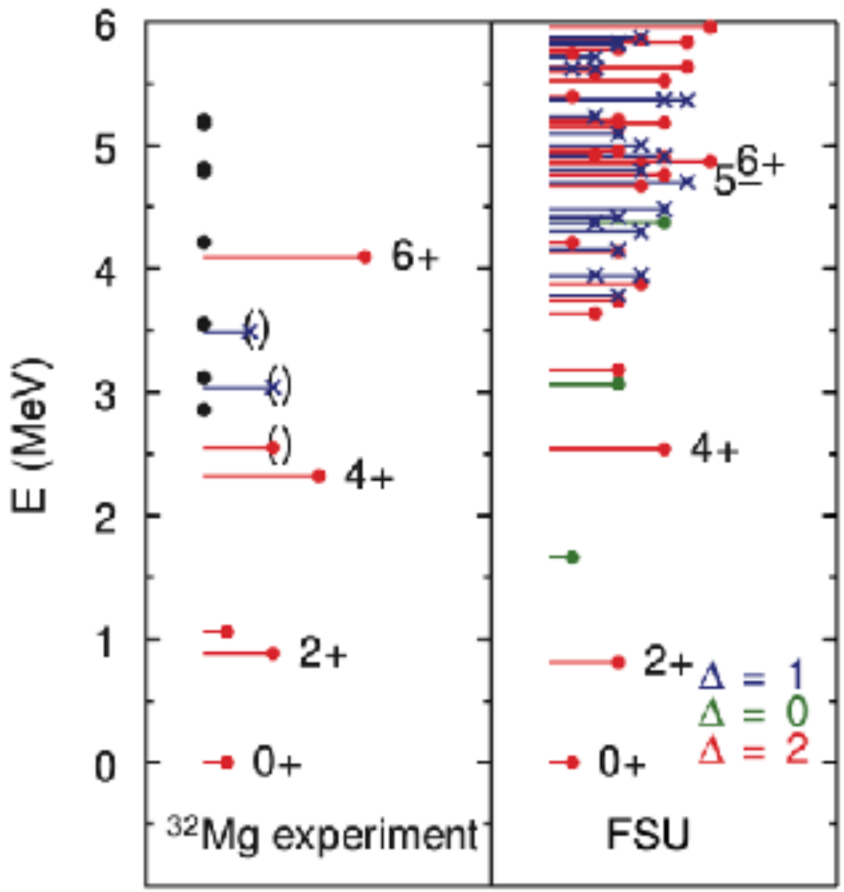
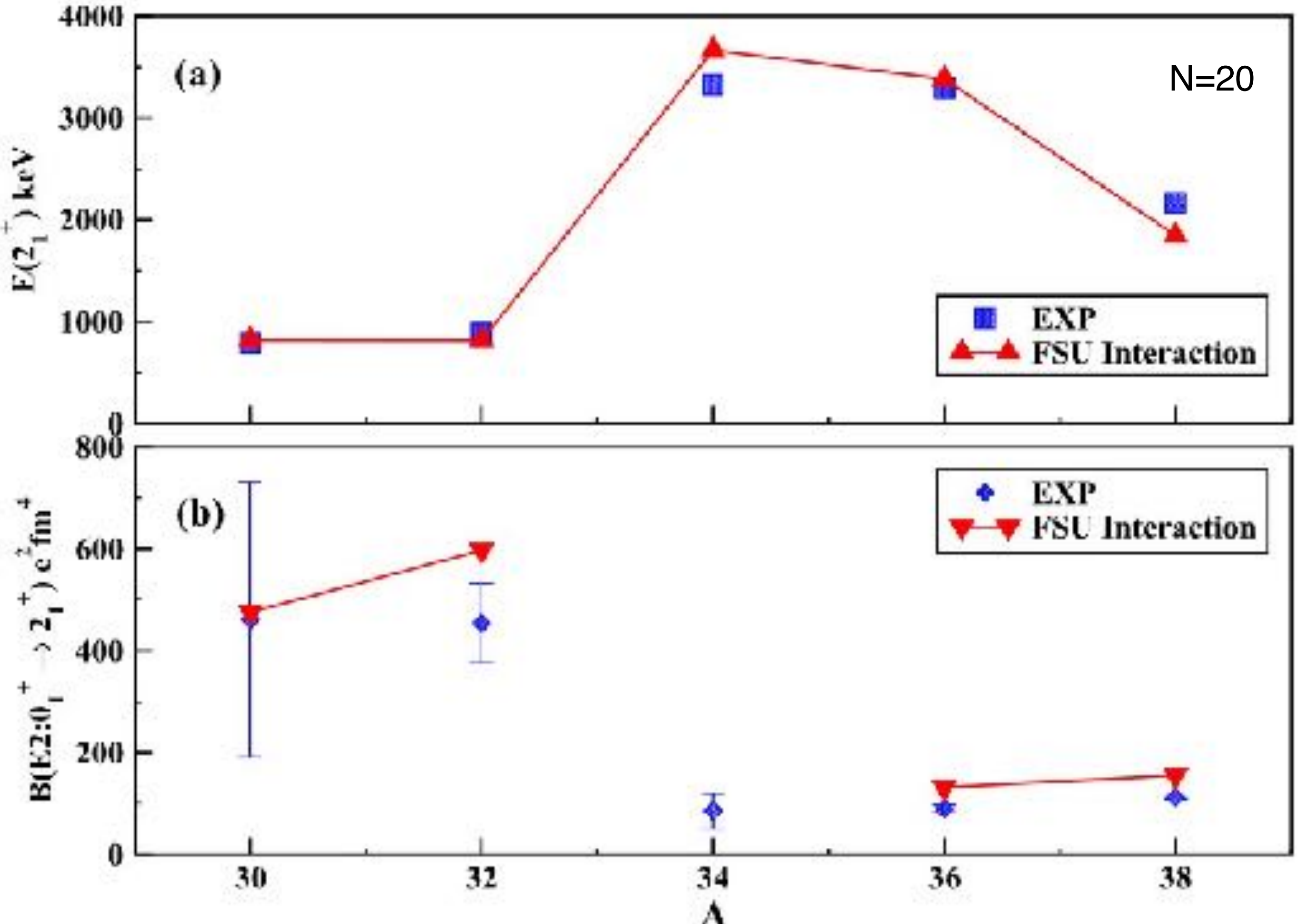


Figure from review paper
B. A. Brown, The Nuclear Shell Model Towards The Drip Lines, Physics 4, 525--547 (2022).

Phenomenological Shell Model



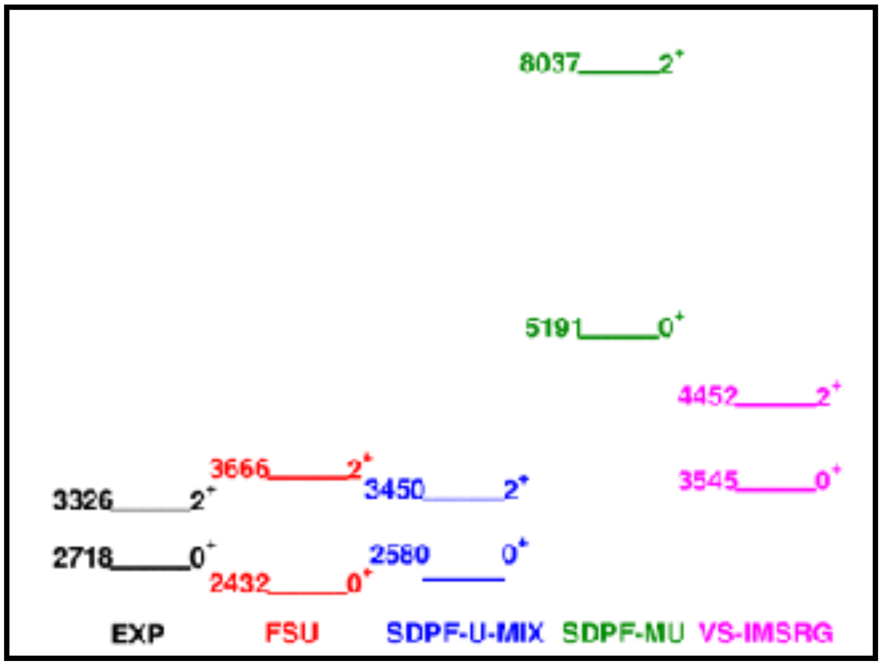
- Reproduce N = 20 IoI phenomena successfully.
- Satisfactory predictions of spectroscopic factors.

1. Phys. Rev. Research 2, 043342 (2020)
2. Phys. Rev. C 46, 923 (1992).
3. Phys. Rev. C 74, 034315 (2006).
4. Eur. Phys. J A 25, 499 (2005).

Phenomenological Shell Model

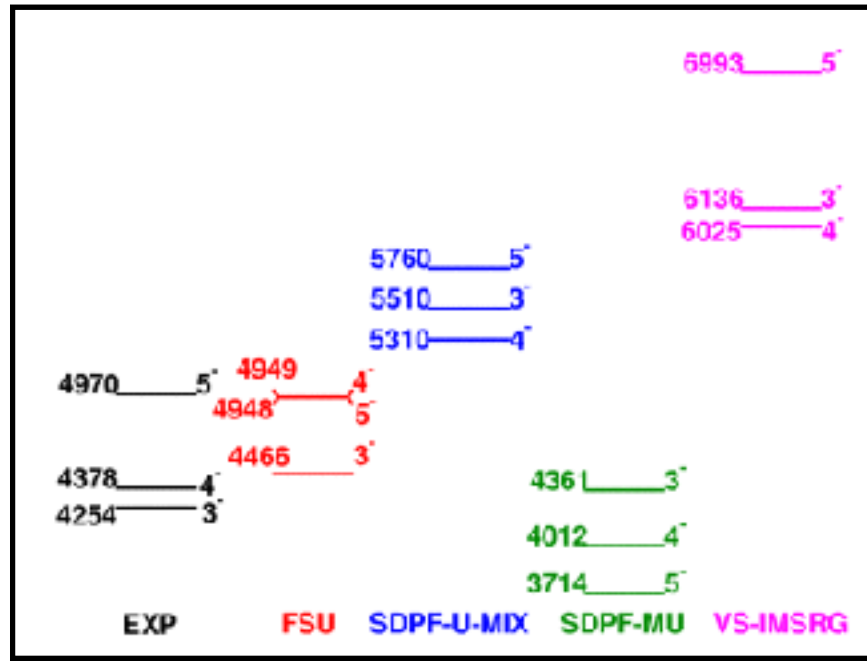
34Si positive parity states

$2\hbar\omega$



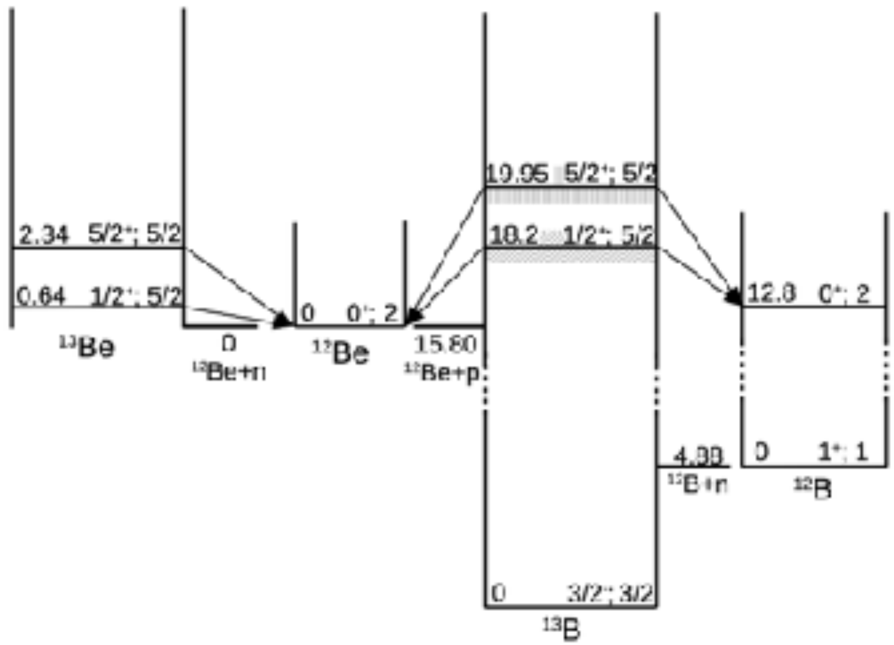
34Si negative parity states parity states

$1\hbar\omega$



1. *Phys. Rev. Research 2, 043342 (2020)*
2. *Phys. Rev. C 46, 923 (1992).*
3. *Phys. Rev. C 74, 034315 (2006).*
4. *Eur. Phys. J A 25, 499 (2005).*

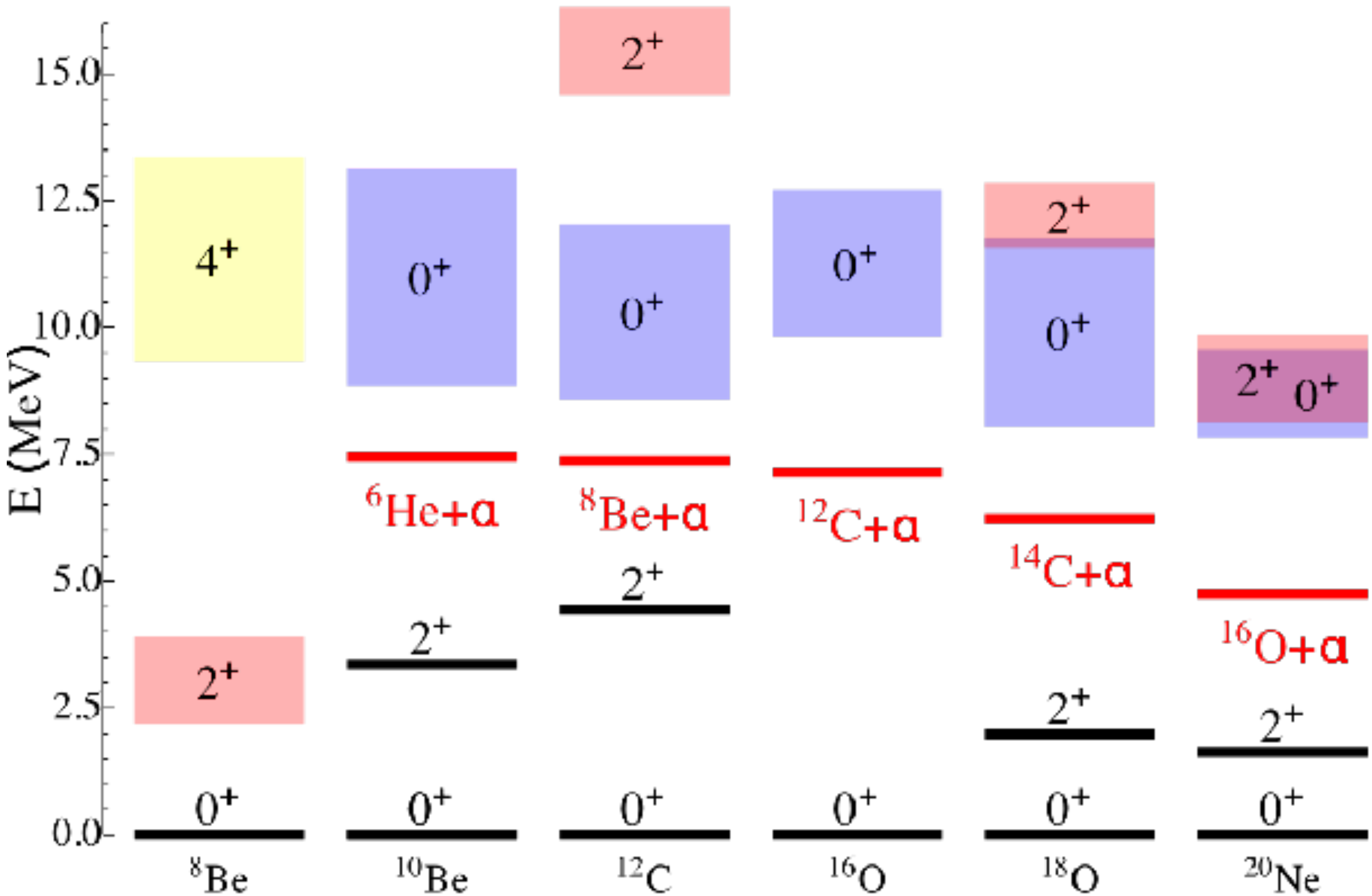
Mixing in ^{13}Be



J^π	E_{cm}	S_{unmix}	S_{mix}	S_{exp}
$1/2^+$	2.45 ± 0.1	0.91	0.23	$0.16^{+0.09}_{-0.06}$
$5/2^+$	4.15 ± 0.06	0	0.69	0.49 ± 0.08

C. Hunt et. al Spectroscopy of ^{13}Be through isobaric analogue states in ^{13}B (2023)

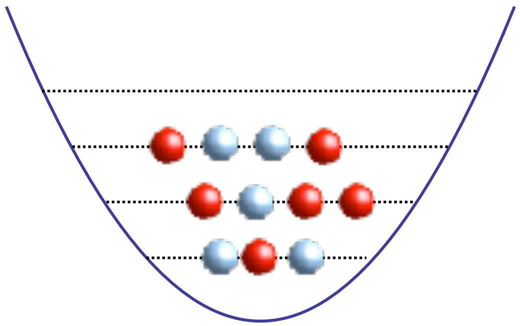
Alpha clustering



Configuration interaction approach and clustering

Traditional shell model configuration
m-scheme

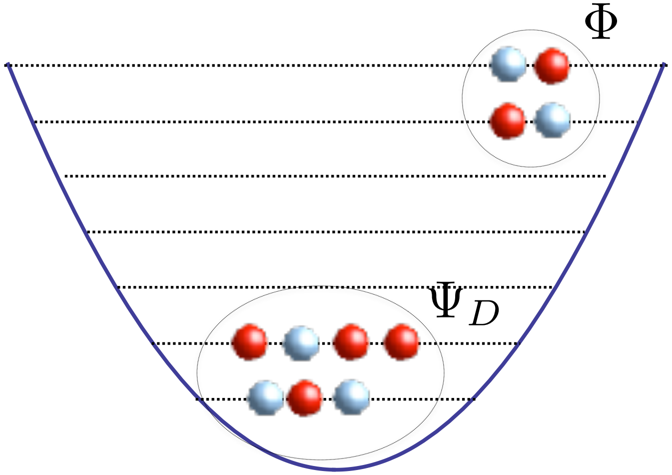
$$|\Psi\rangle = \Psi^\dagger|0\rangle \sim a_1^\dagger a_2^\dagger \ldots a_A^\dagger|0\rangle$$



+

Cluster configuration

$$|\text{channel}\rangle \sim |\Phi\Psi_D\rangle \equiv \Phi^\dagger\Psi_D^\dagger|0\rangle$$



$$|\Psi\rangle \quad + \quad \Phi^\dagger|\Psi_D\rangle$$

Translational invariance and Center of Mass (CM)

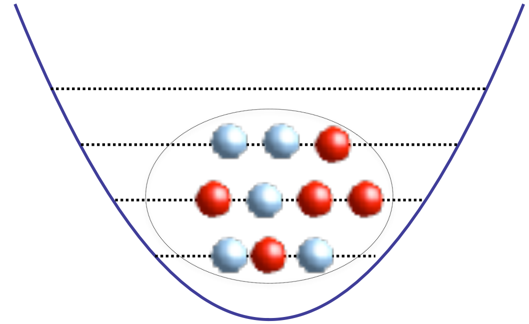
Shell model, Glockner-Lawson procedure

$$\Psi_D = \phi_{000}(\mathbf{R}_D)\,\Psi'_D$$

SM state

Center-of-mass vibration

Intrinsic state



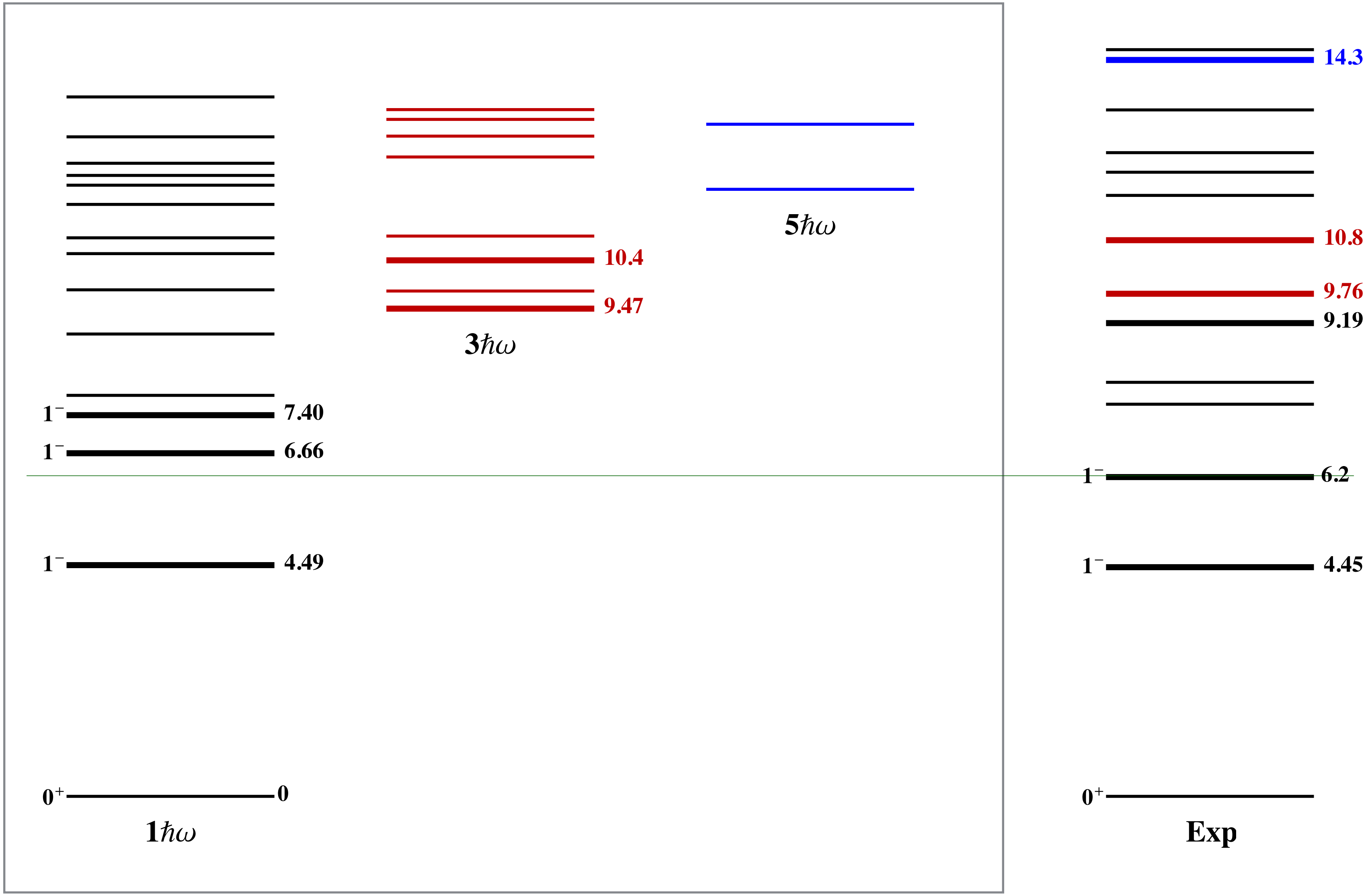
Controlling CM with operator $\mathbf{R}$

Control only CM quanta

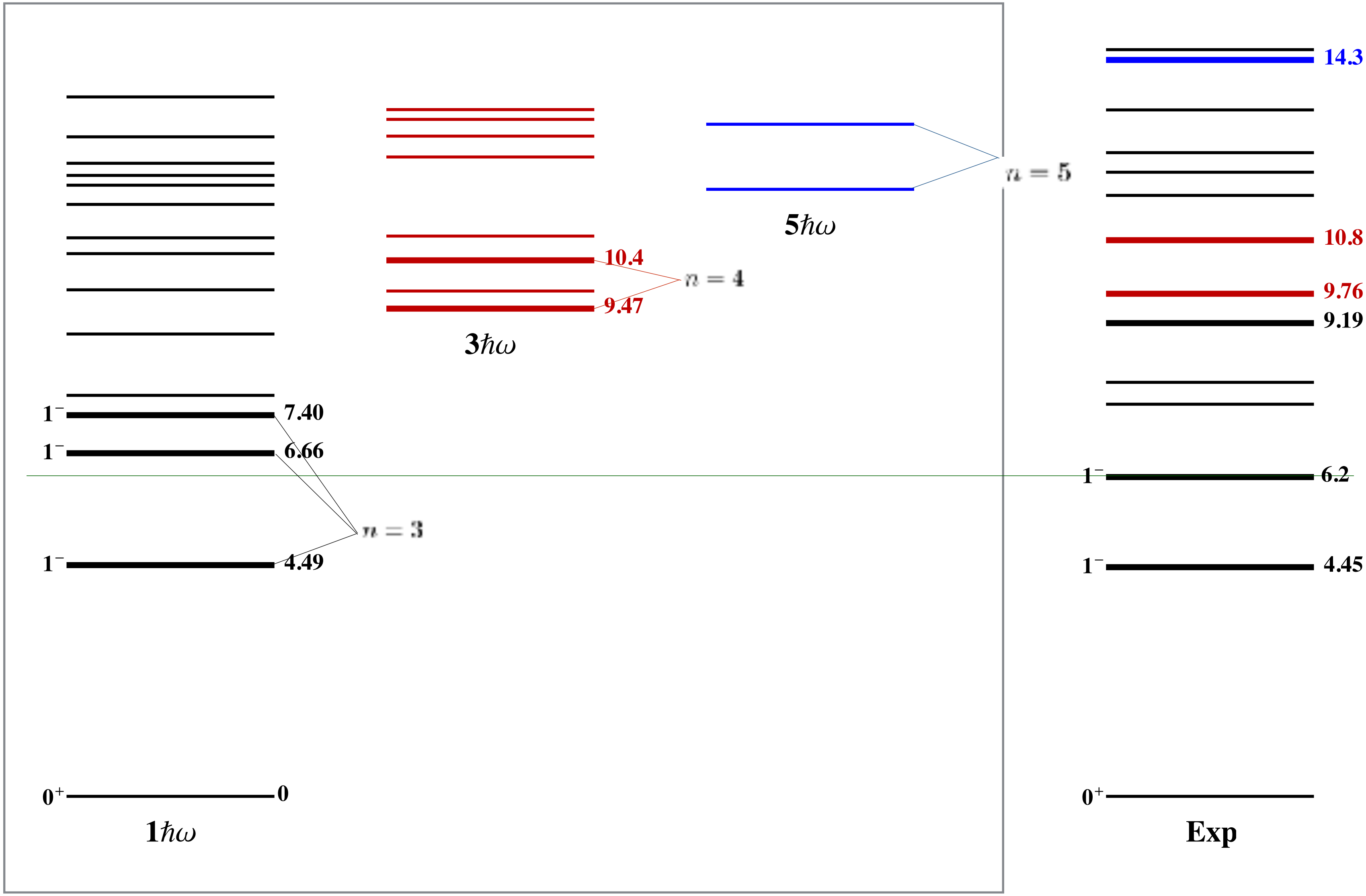
$$D_\mu = \sqrt{\frac{4\pi}{3}}R_\mu \qquad R_\mu = \sqrt{\frac{\hbar}{2Am\omega}}(\mathcal{B}^\dagger_\mu + \mathcal{B}_\mu)$$

K. Kravvaris and A. Volya, “Study of nuclear clustering from an ab initio perspective,” *Phys. Rev. Lett.*, vol. 119, no. 6, p. 062501, 2017.
K. Kravvaris and A. Volya, “Clustering in structure and reactions using configuration interaction techniques,” *Phys. Rev. C*, vol. 100, no. 3, p. 034321, Sep. 2019, doi: 10.1103/PhysRevC.100.034321.

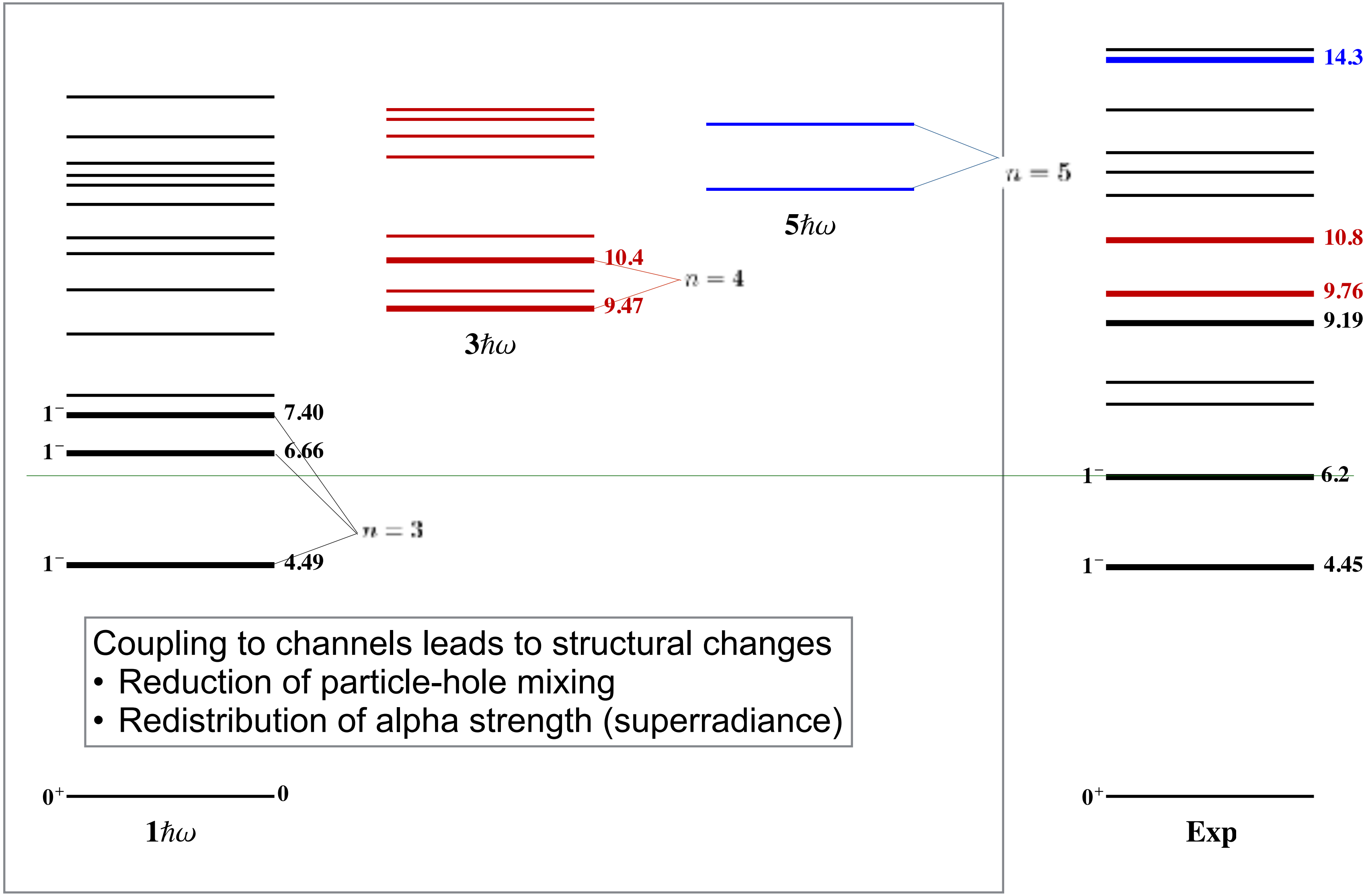
Clustering studies in ^{18}O
l=1 channel



Channel coupling in ^{18}O
l=1 channel

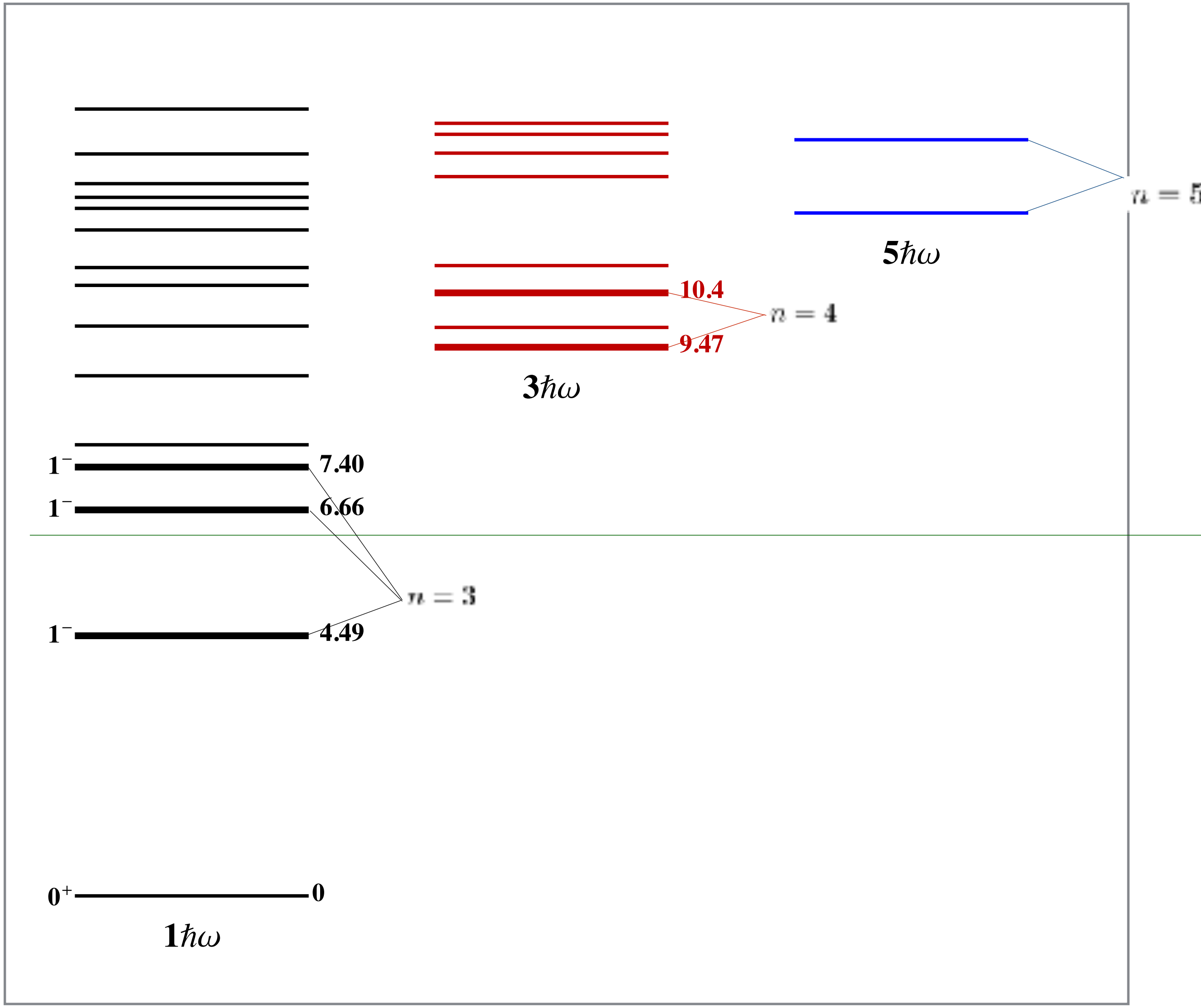


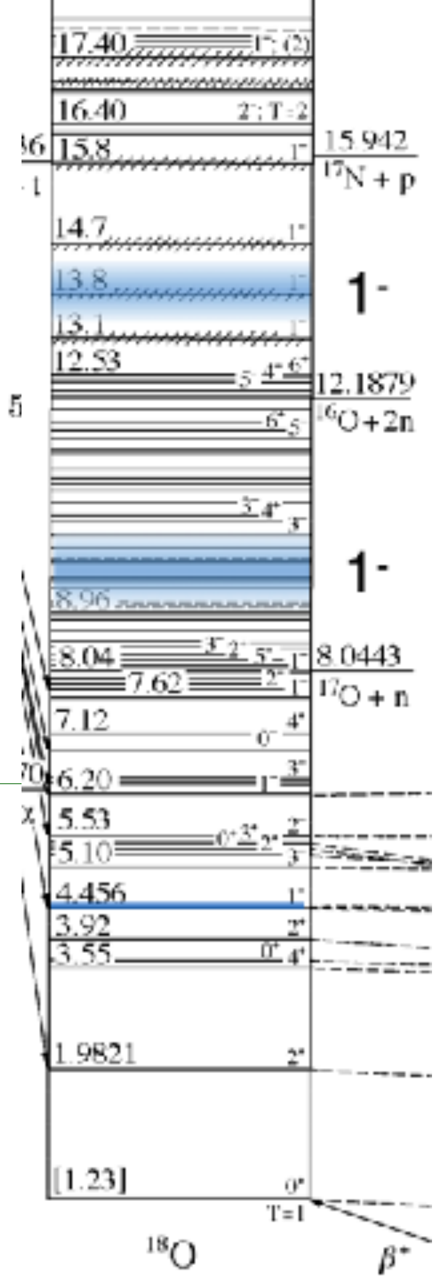
Channel coupling in ^{18}O
l=1 channel



Coupling to channels leads to structural changes
- Reduction of particle-hole mixing
- Redistribution of alpha strength (superradiance)

Channel coupling in 18O
l=1 channel





Availability: (CC-BY-NC)

- Description and tables: R. S. Lubna, Ph.D. thesis, Florida State University
- Part of shell model packages (NushellX, cosmo, etc)
- Upon request

References:

[1] R. S. Lubna, K. Kravvaris, S. L. Tabor, V. Tripathi, E. Rubino, and A. Volya, Evolution Of The $N=20$ And 28 Shell Gaps And Two-Particle-Two-Hole States In The Fsu Interaction, Phys. Rev. Research **2**, 043342 (2020).

[2] E. Rubino, S. L. Tabor, V. Tripathi, R. S. Lubna, B. Abromeit, J. M. Allmond, L. T. Baby, D. D. Caussyn, K. Kravvaris, and A. Volya, *Multiparticle-Hole Excitations In Nuclei Near N = Z = 20: 41K*, The European Physical Journal A **58**, 107 (2022).

[3] R. S. Lubna, K. Kravvaris, S. L. Tabor, V. Tripathi, A. Volya, E. Rubino, J. M. Allmond, B. Abromeit, L. T. Baby, and T. C. Hensley, *Structure Of 38Cl And The Quest For A Comprehensive Shell Model Interaction*, Phys. Rev. C **100**, 034308 (2019).

[4]M. Barbui, A. Volya, E. Aboud, S. Ahn, J. Bishop, V. Z. Goldberg, J. Hooker, C. H. Hunt, H. Jayatissa, T. Kokalova, E. Koshchiy, S. Pirrie, E. Pollacco, B. T. Roeder, A. Saastamoinen, S. Upadhyayula, C. Wheldon, and G. V. Rogachev, alpha-*Cluster Structure Of 18Ne*, Phys. Rev. C **106**, 054310 (2022).

[5] V. Z. Goldberg, A. K. Nurmukhanbetova, A. Volya, D. K. Nauruzbayev, G. E. Serikbayeva, and G. V. Rogachev, alpha-*Cluster Structure In 19F and 19Ne In Resonant Scattering*, Phys. Rev. C **105**, 014615 (2022).

[6]A. Volya, V. Z. Goldberg, A. K. Nurmukhanbetova, D. K. Nauruzbayev, and G. V. Rogachev, *Lowest-Energy Broad alpha-Cluster Resonances In 19F*, Phys. Rev. C **105**, 014614 (2022).

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