TRIUMF

Two-major-shell effective Hamiltonian from in-medium similarity renormalization group

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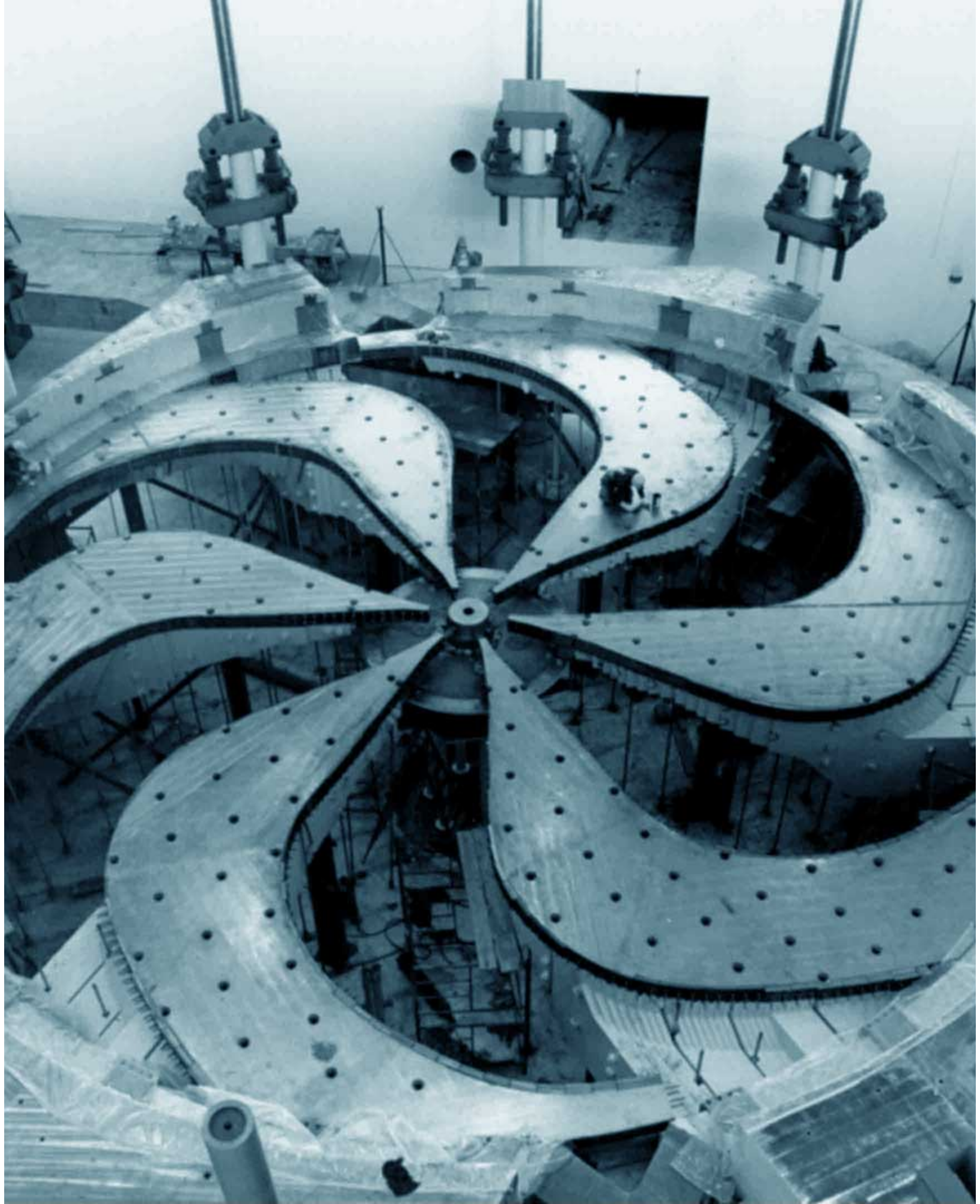
CAP Congress June, 2019 @ SFU

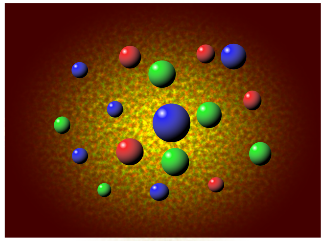


Discovery, accelerated

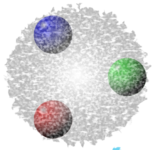
Motivation

Ideal path

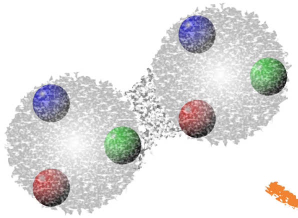
Quarks & gluons



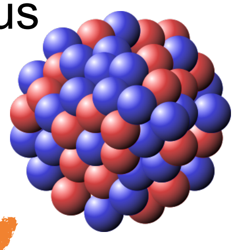
Nucleon



NN int

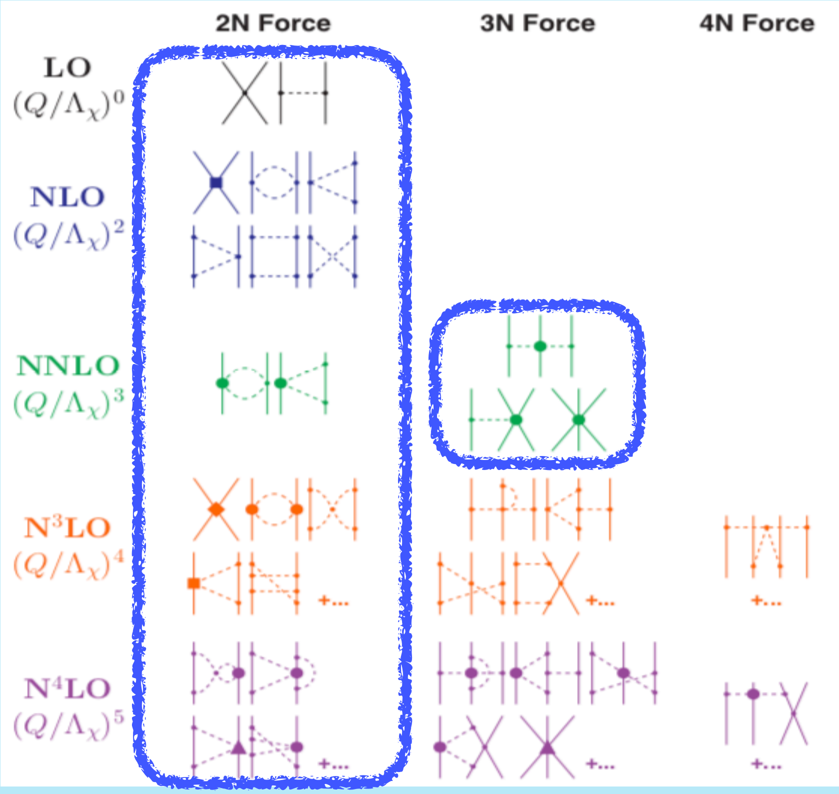


Nucleus



Practical path

Chiral effective-field theory



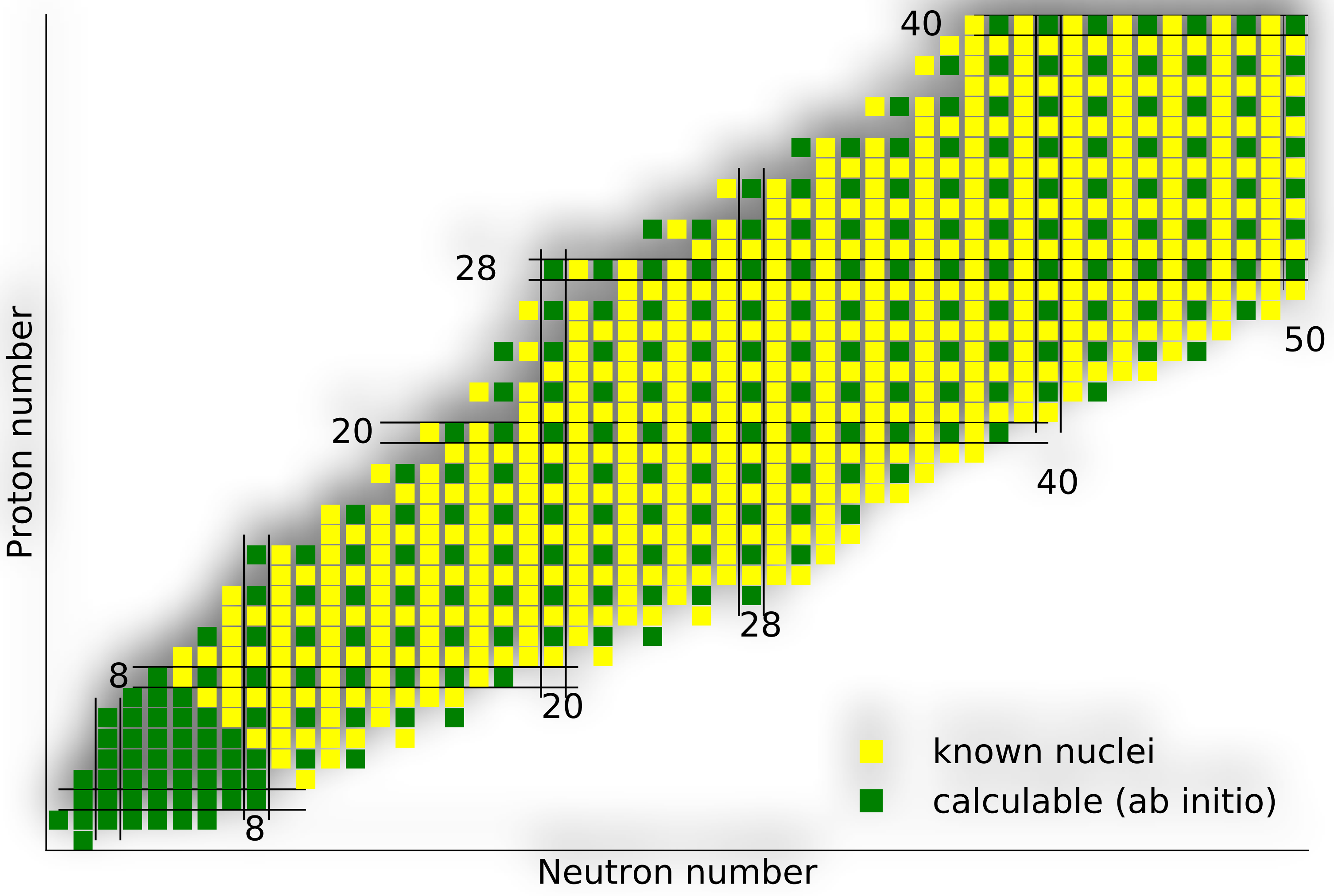
Weinberg, van Kolck, Kaiser, Epelbaum, Glöckle, Meißner, Entem, Machleidt, …

Nuclear many-body problem

- ✦ Green’s function Monte Carlo
- ✦ No-core shell model
- ✦ Nuclear lattice effective field theory
- ✦ Coupled-cluster
- ✦ Self-consistent Green’s function method
- ✦ In-medium similarity renormalization group
- ✦ …

Motivation

- Limitations:
  - ✦ Light-mass region
  - ✦ Ground state of even-even nuclei



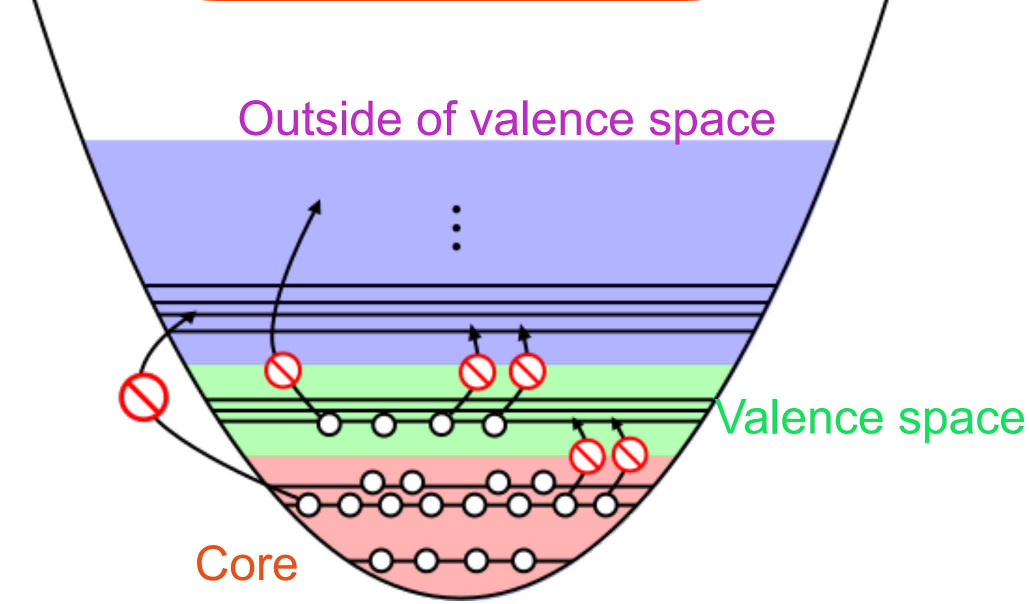
Motivation

- Combination with the shell-model calculations

In-medium similarity renormalization group
Coupled cluster method
…

Shell-model calc.

Construct the effective Hamiltonian for the valence space

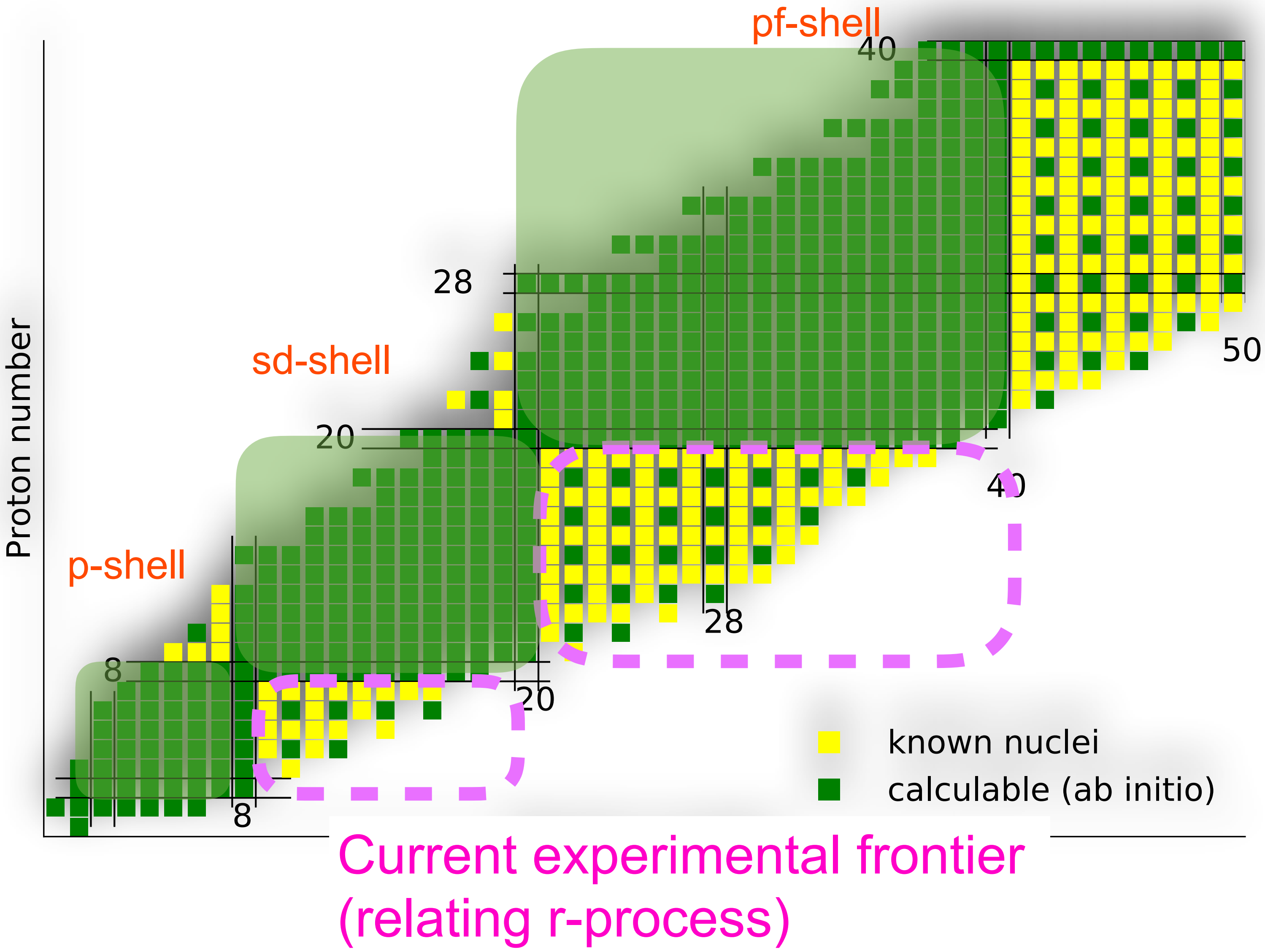


G. R. Jansen, M. D. Schuster, A. Signoracci, G. Hagen, and P. Navrátil, Phys. Rev. C **94**, 011301 (2016).

S. R. Stroberg, H. Hergert, J. D. Holt, S. K. Bogner, and A. Schwenk, Phys. Rev. C **93**, 051301 (2016).

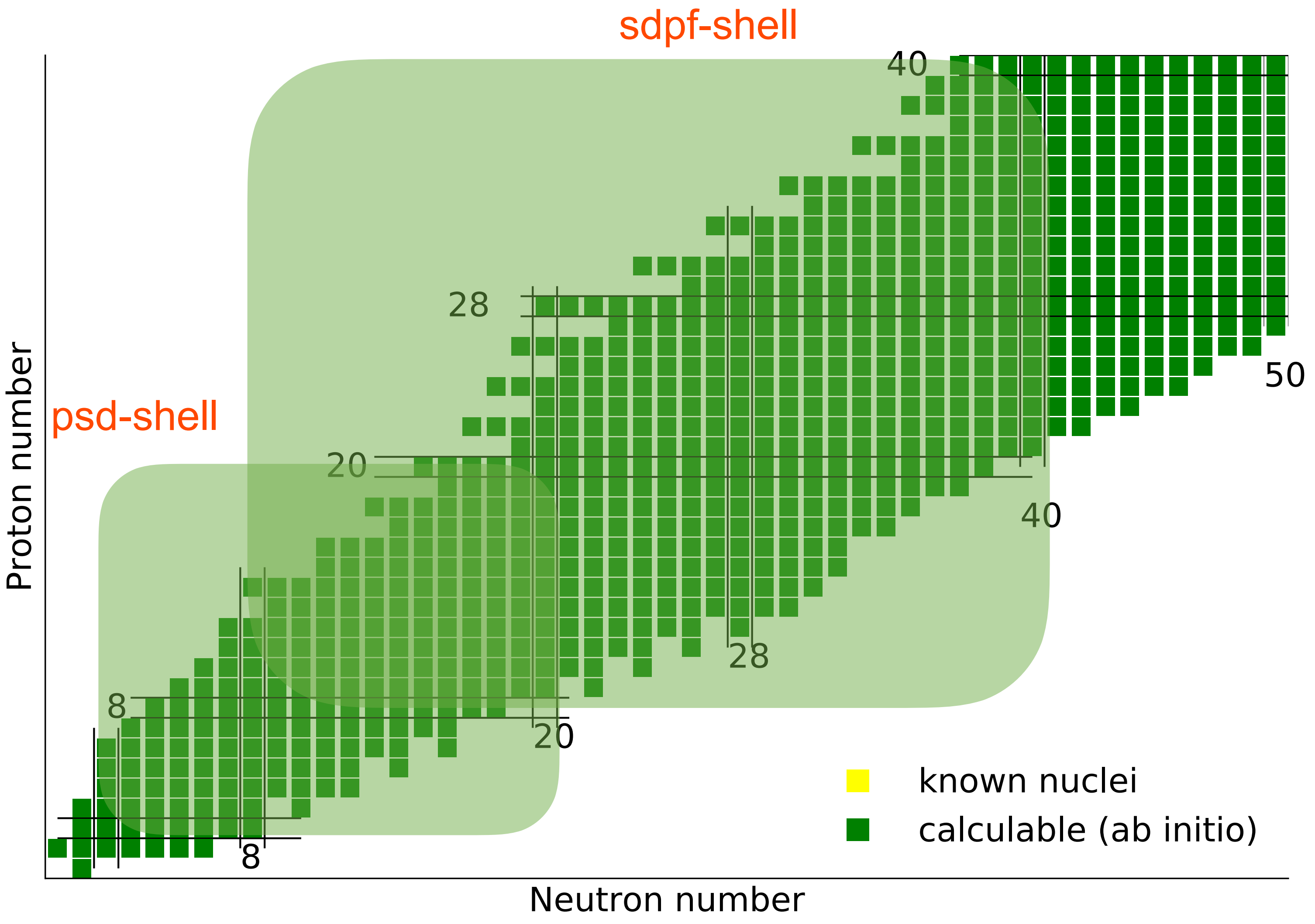
Motivation

- Combination with shell-model calculations



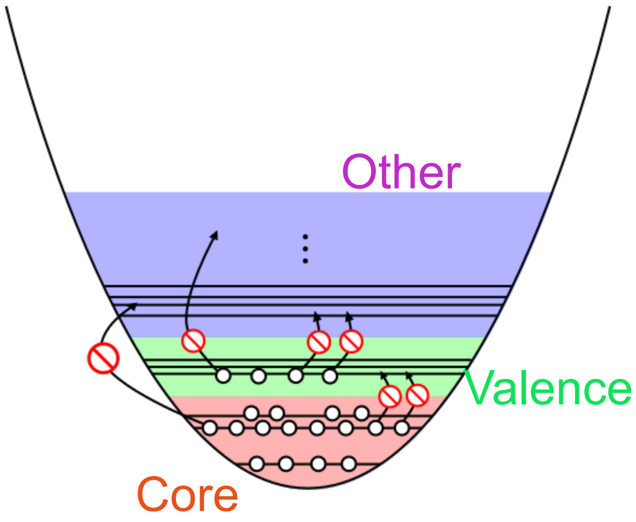
Motivation

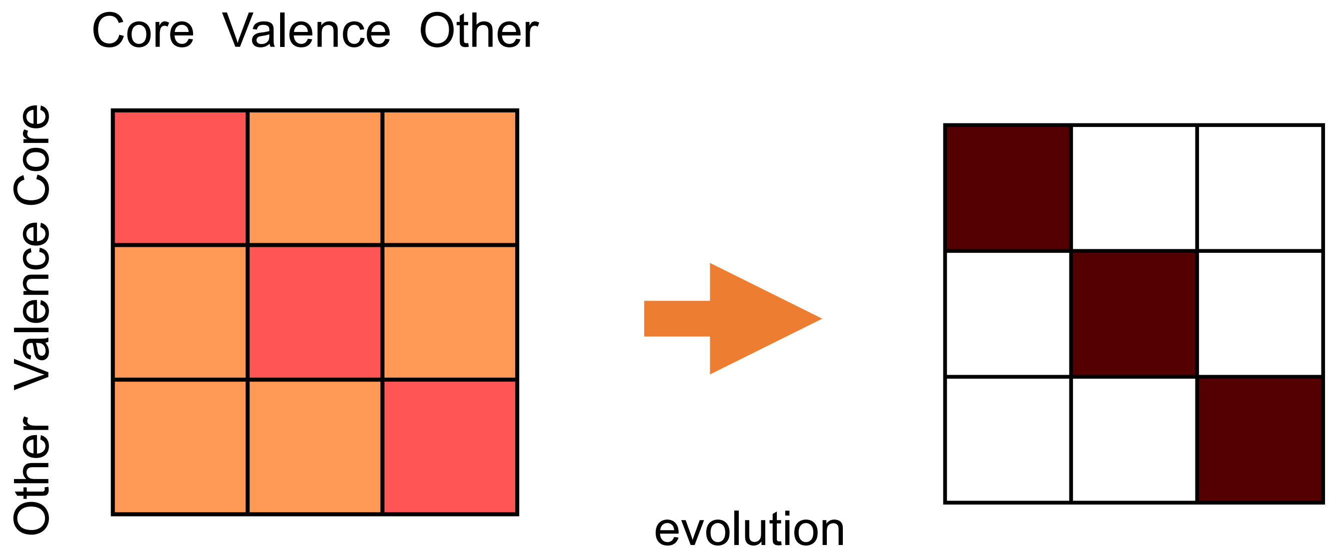
- Larger valence-space calculations are needed to access the neutron rich region.



H. Hergert, S. K. Bogner, T. D. Morris, A. Schwenk, and K. Tsukiyama, Phys. Rep. **621**, 165 (2016).
S. R. Stroberg, A. Calci, H. Hergert, J. D. Holt, S. K. Bogner, R. Roth, and A. Schwenk, Phys. Rev. Lett. **118**, 032502 (2017).

In-medium similarity renormalization group





$$H \longrightarrow H(s) \approx E(s) + \sum_{12} f_{12}(s) a_1^\dagger a_2 + \frac{1}{4}\sum_{1234} \Gamma_{1234}(s) a_1^\dagger a_2^\dagger a_4 a_3$$

s: flow parameter

$$\frac{dE}{ds} = \sum_{ab}(n_a - n_b)\eta_{ab} f_{ba} + \frac{1}{2}\sum_{abcd} \eta_{abcd}\Gamma_{cdab} n_a n_b \overline{n}_c \overline{n}_d$$

$$\frac{df_{12}}{ds} = \sum_{a}(1+P_{12})\eta_{1a} f_{a2} + \frac{1}{2}\sum_{ab}(n_a - n_b)(\eta_{ab}\Gamma_{b1a2} - f_{ab}\eta_{b1a2}) + \cdots$$

$$\frac{d\Gamma_{1234}}{ds} = \sum_{a}[(1-P_{12})(\eta_{1a}\Gamma_{a234} - f_{1a}\eta_{a234}) - (1-P_{34})(\eta_{a3}\Gamma_{12a4} - f_{a3}\eta_{12a3})] + \cdots$$

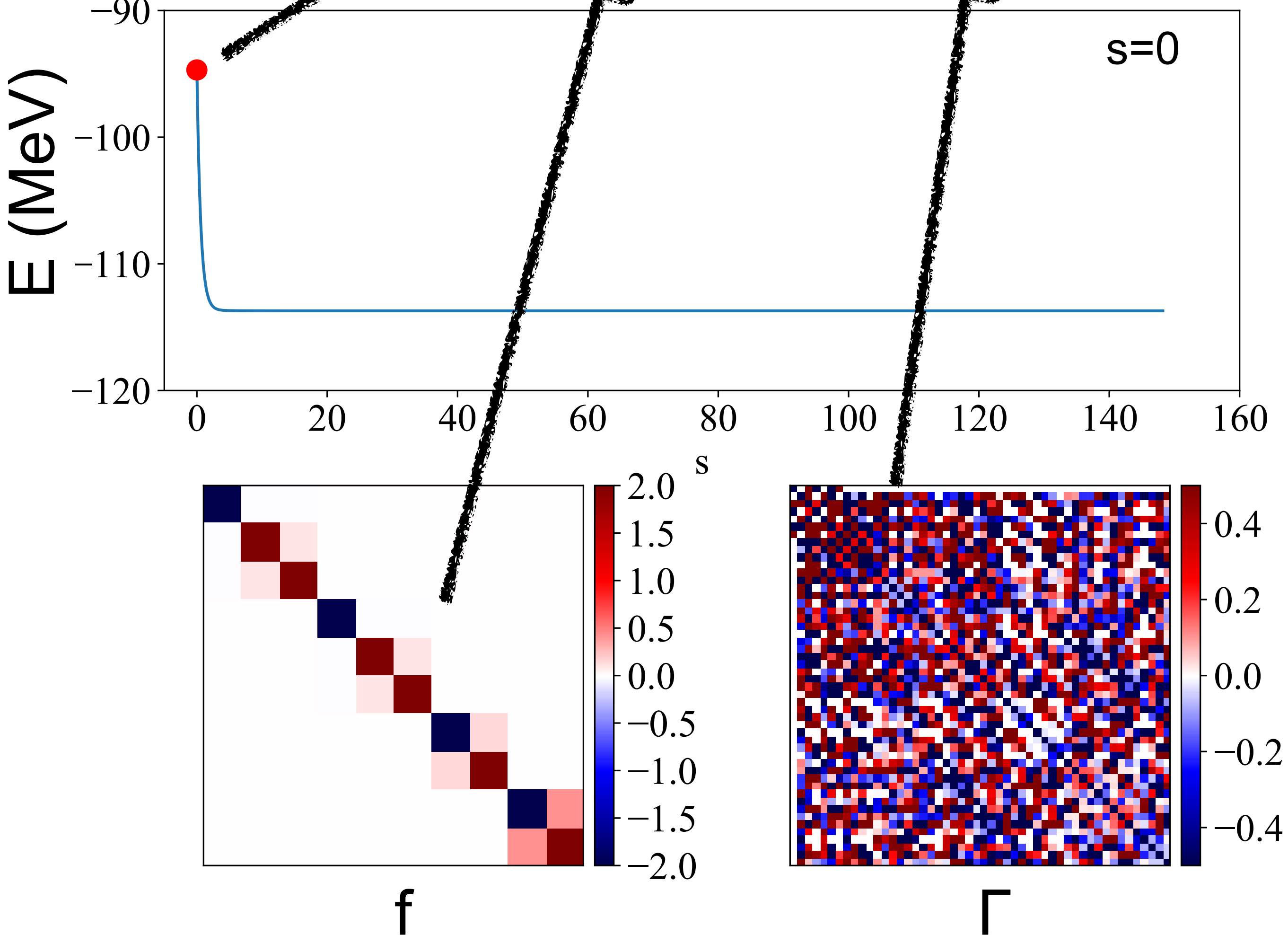
n_a : occupation number

$\overline{n}_a = 1 - n_a$

Hamiltonian evolution

Evolution (^{14}C [^{4}He core] case)

$$H \longrightarrow H(s) \approx E(s) + \sum_{12} f_{12}(s) a_1^\dagger a_2 + \frac{1}{4} \sum_{1234} \Gamma_{1234}(s) a_1^\dagger a_2^\dagger a_4 a_3$$



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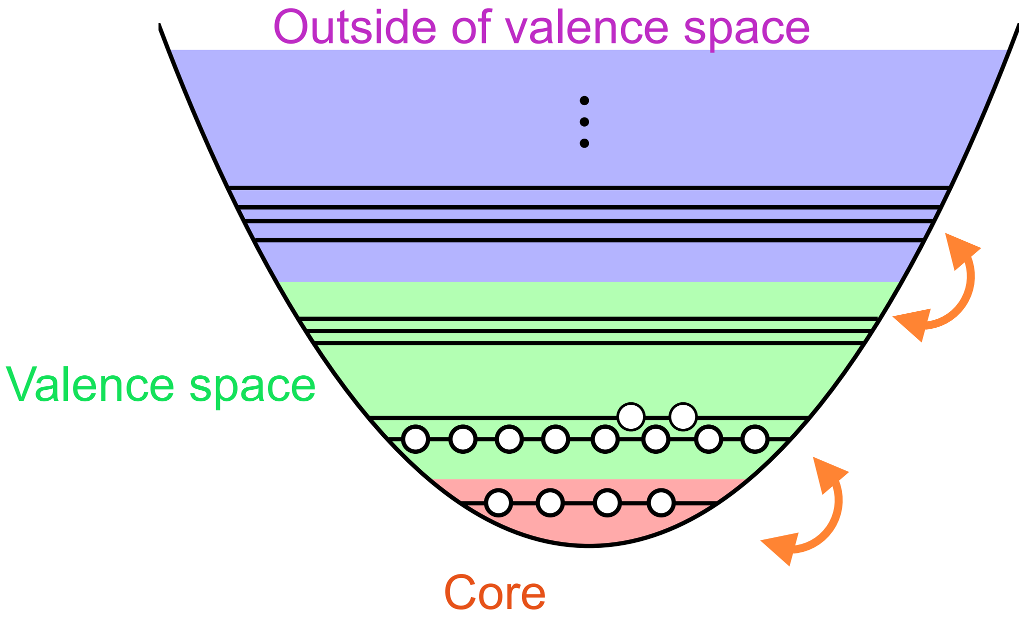

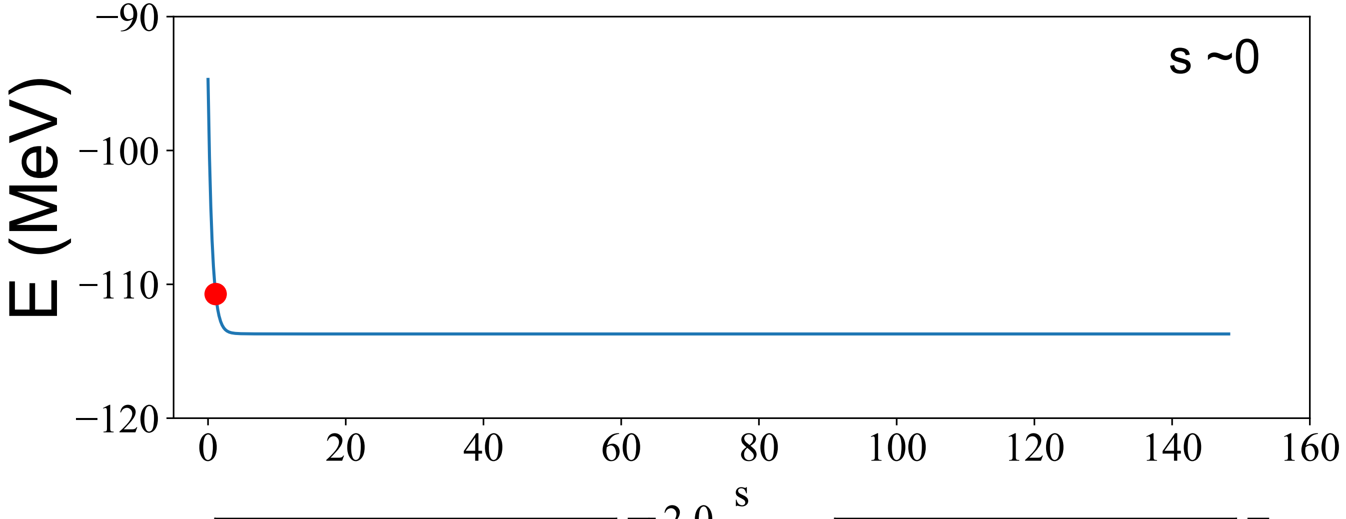

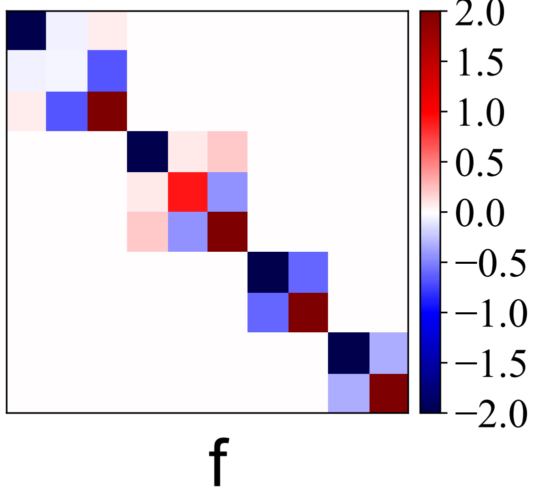

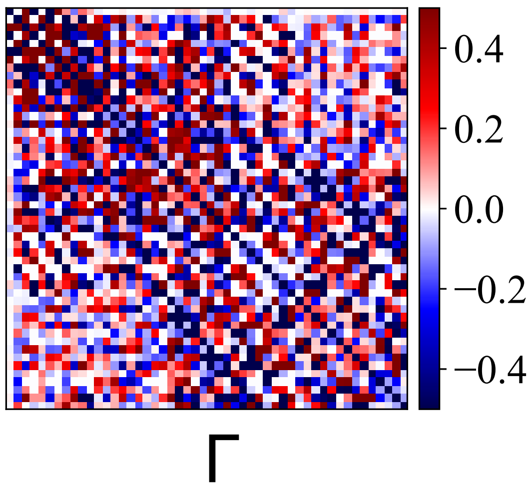

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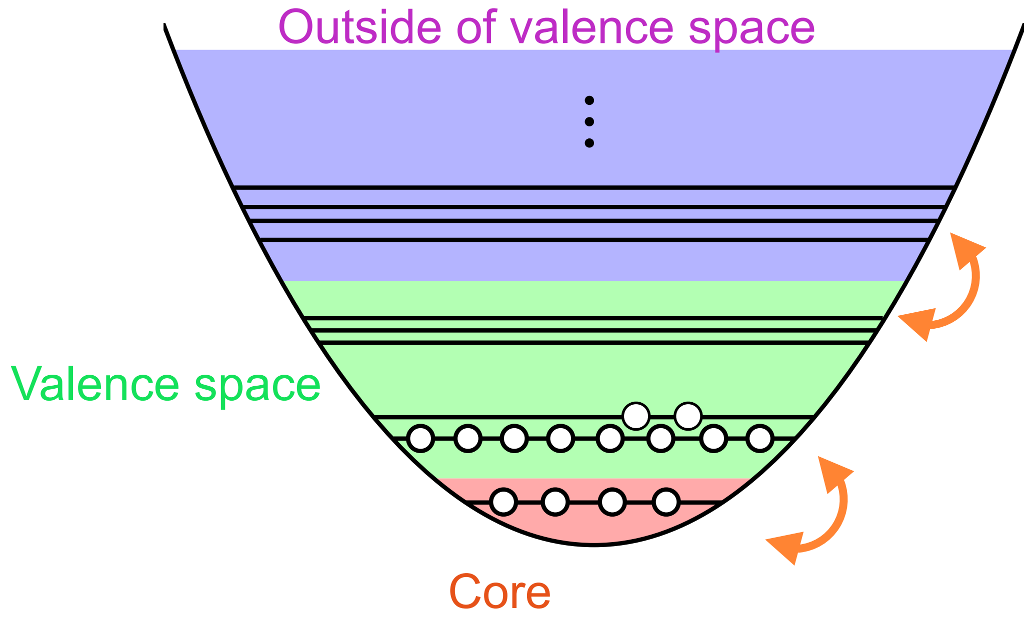

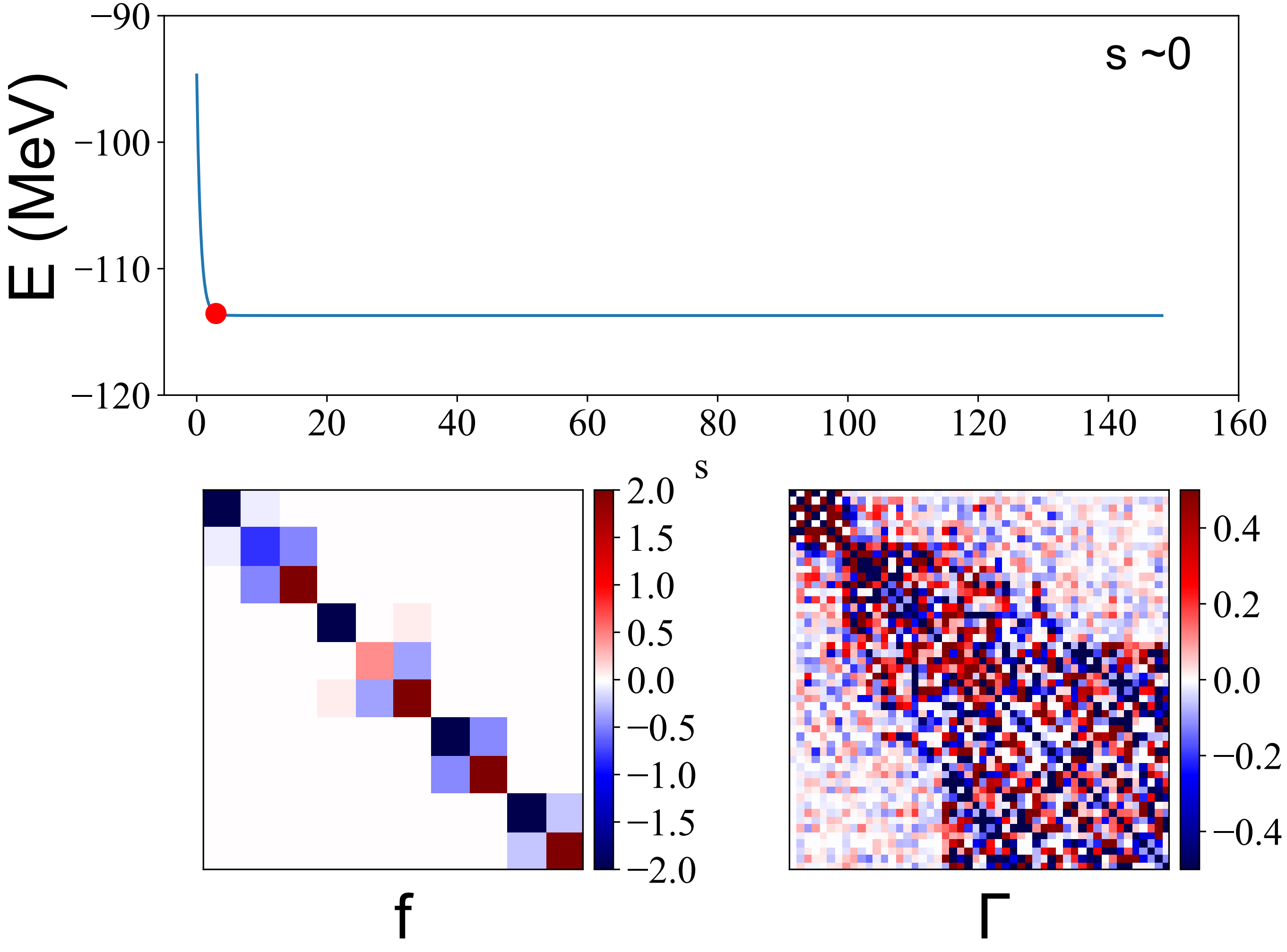

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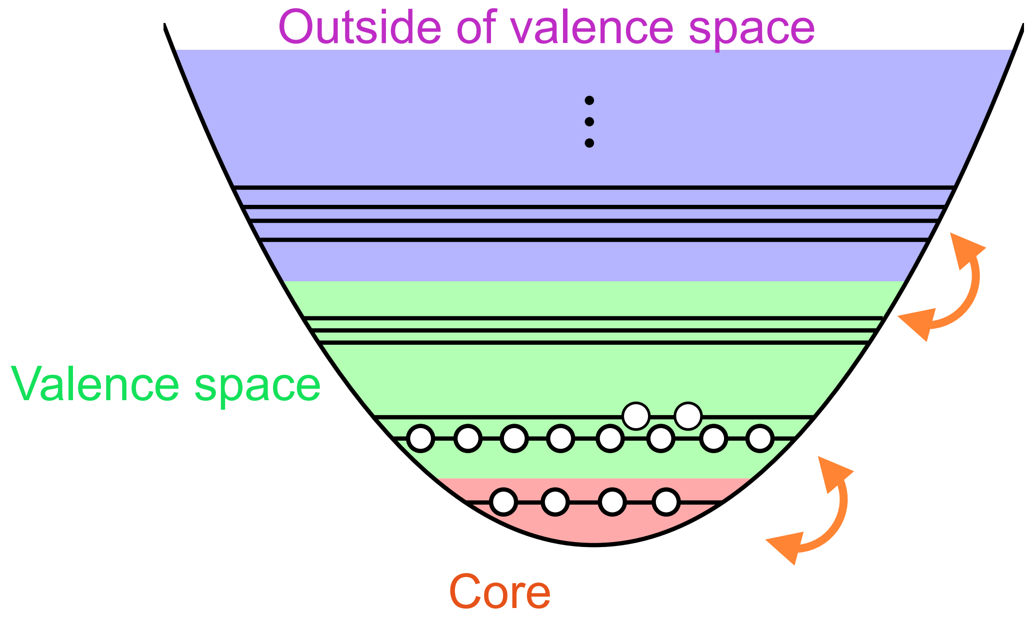

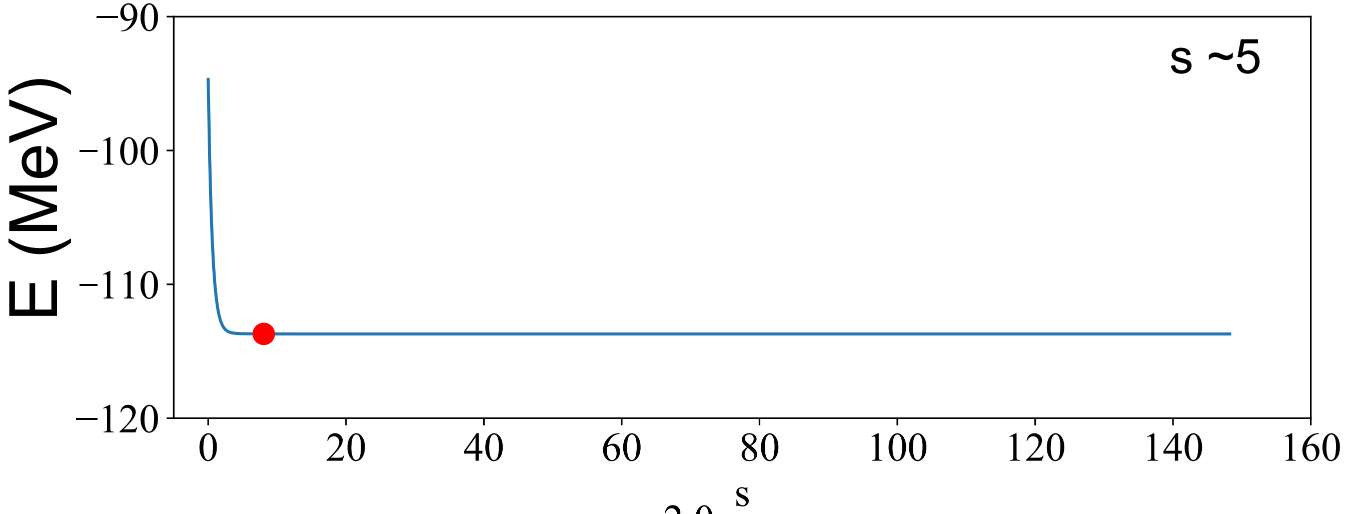

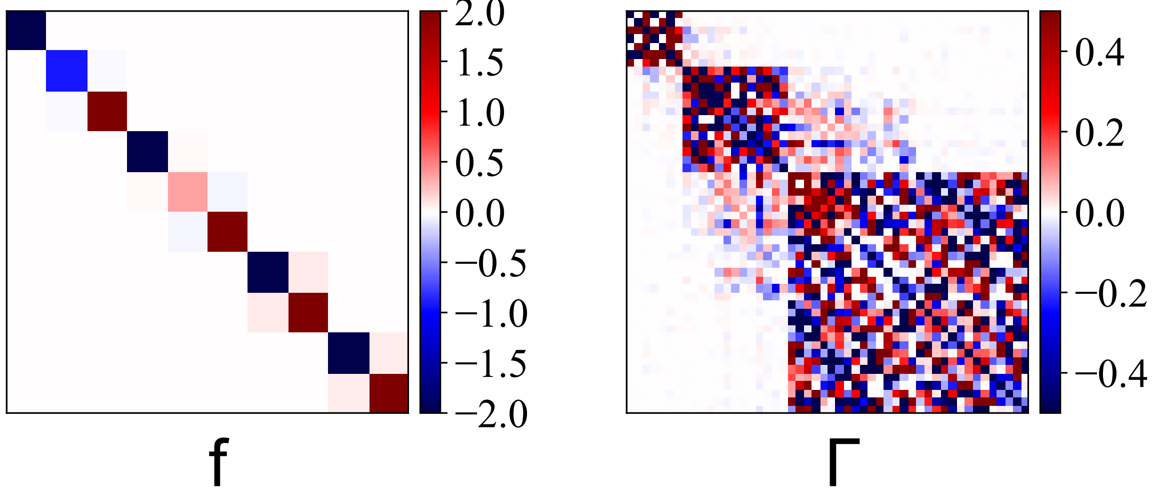

Hamiltonian evolution

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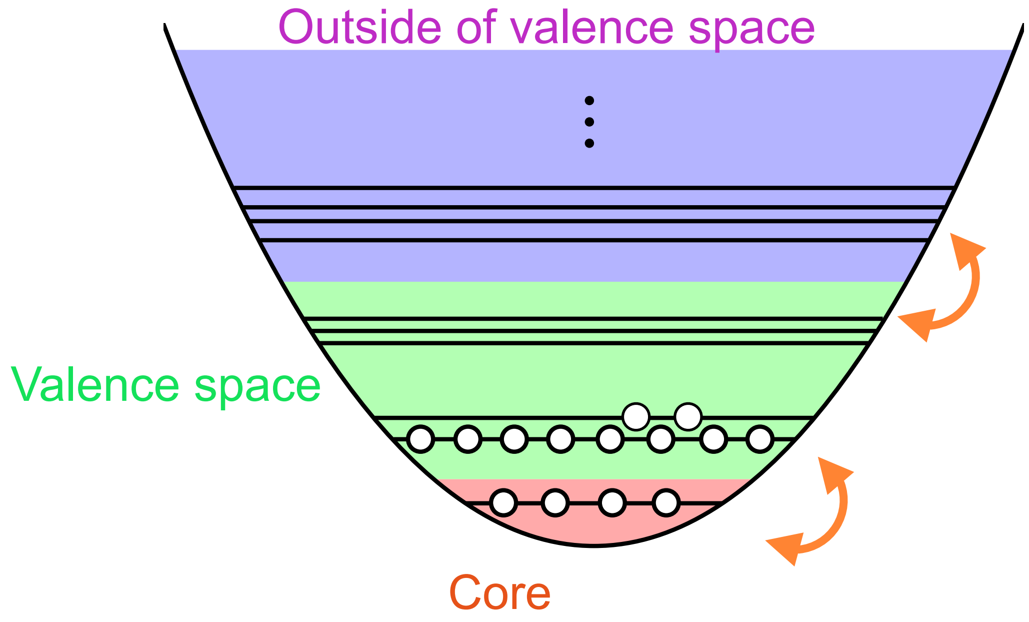

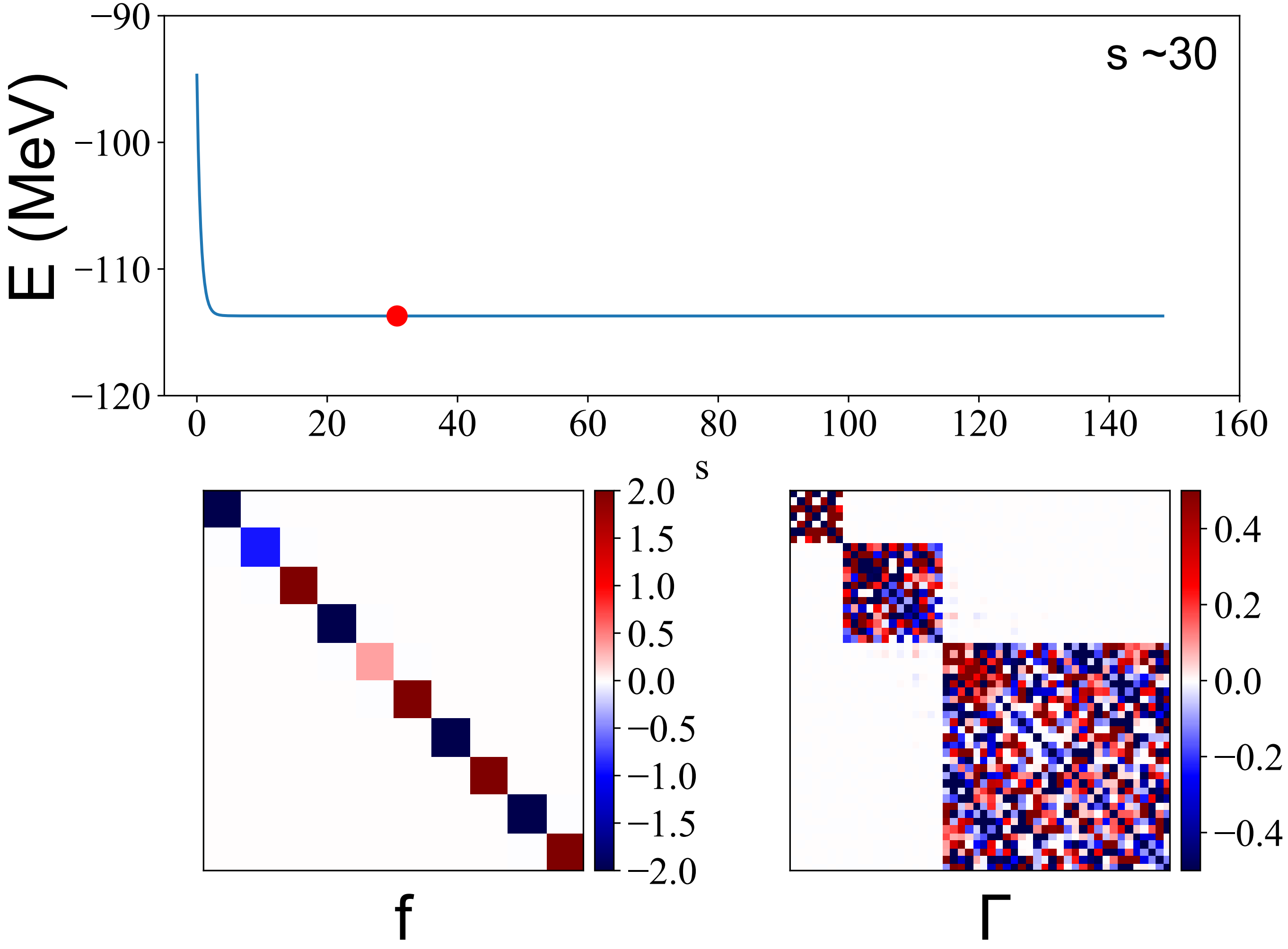

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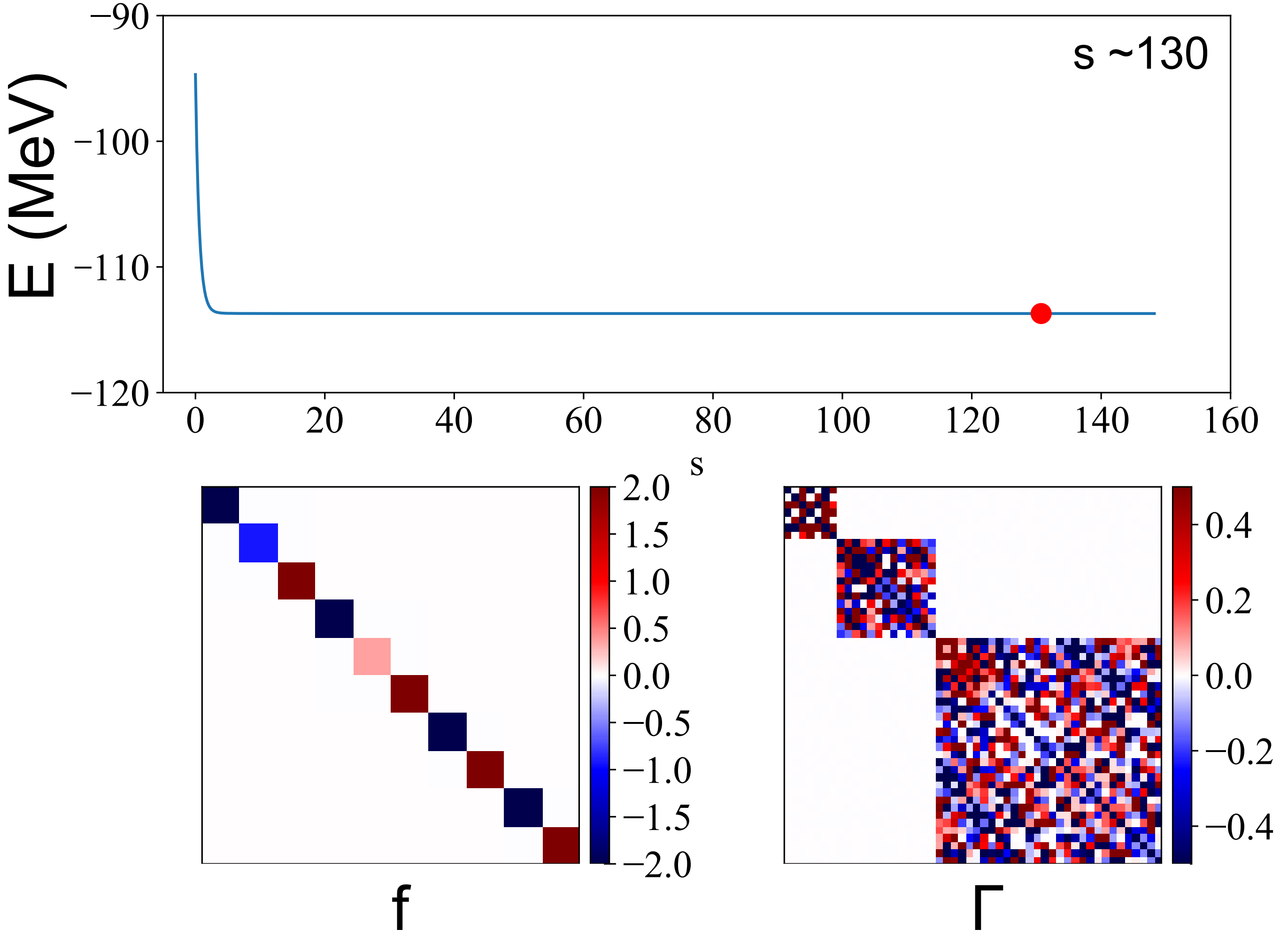
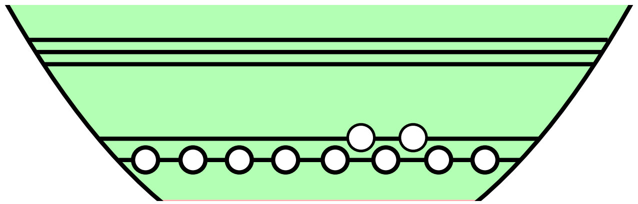
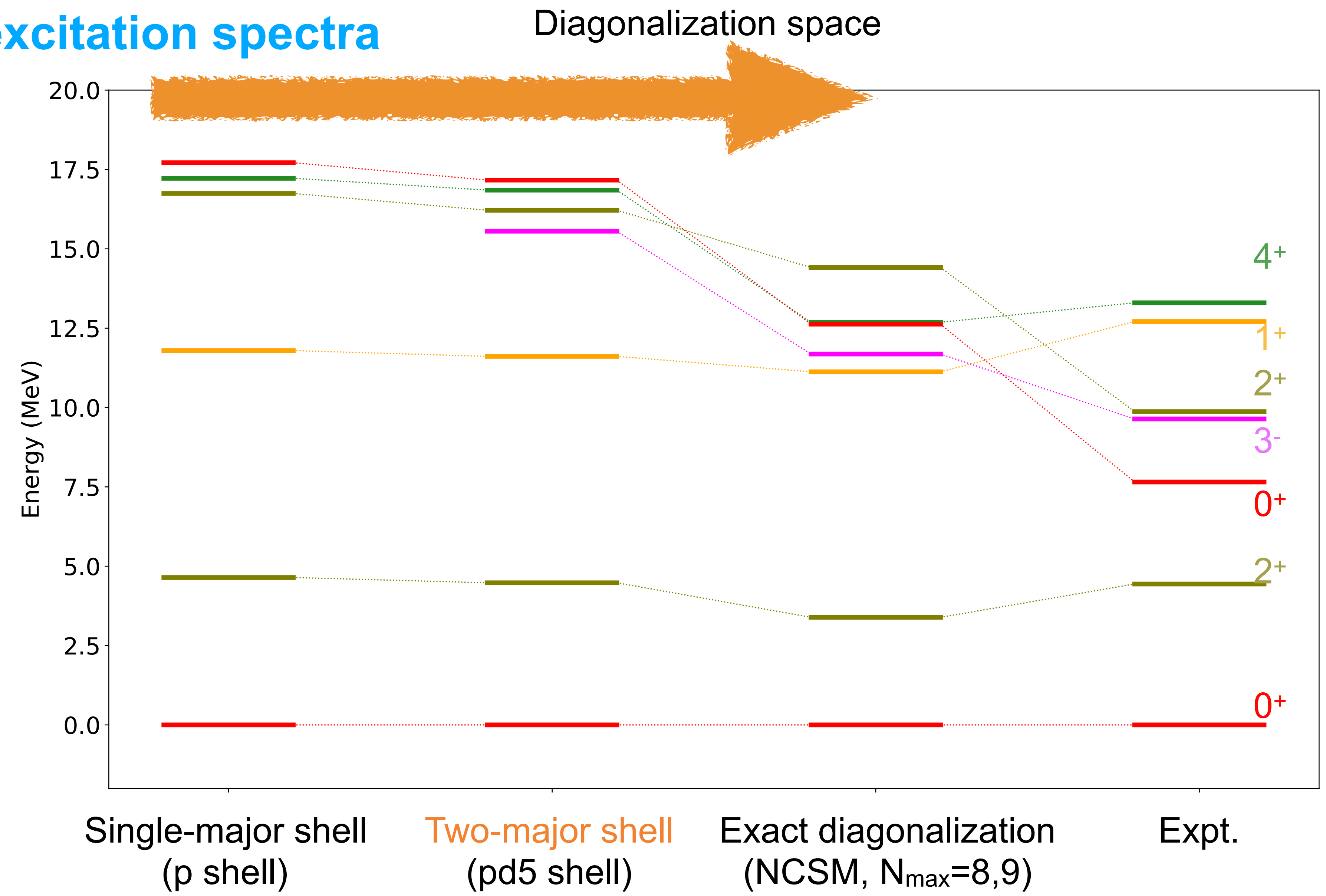


Configuration mixing



^{12}C excitation spectra



Summary & Future work

- Through in-medium similarity renormalization group, the two-major shell-model effective Hamiltonian can be obtained.
- Obtained results are promising

- Application to neutron rich region

H. Hergert, S. K. Bogner, T. D. Morris, A. Schwenk, and K. Tsukiyama, Phys. Rep. **621**, 165 (2016).
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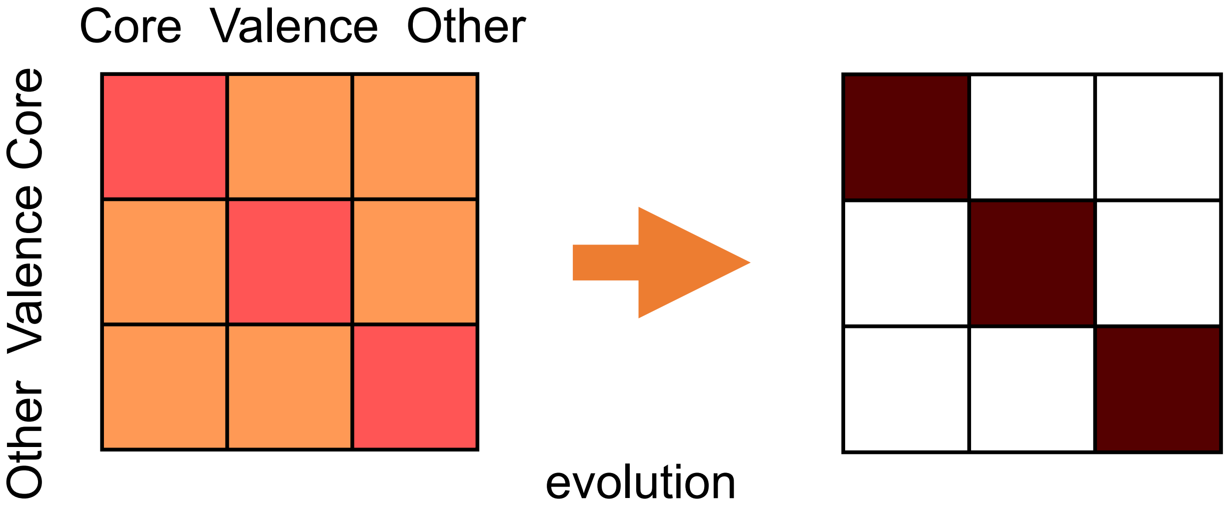
In-medium similarity renormalization group



$$\frac{dE}{ds} = \sum_{ab}(n_a - n_b)\eta_{ab}f_{ba} + \frac{1}{2}\sum_{abcd}\eta_{abcd}\Gamma_{cdab}n_a n_b \overline{n}_c \overline{n}_d$$

$$\frac{df_{12}}{ds} = \sum_{a}(1+P_{12})\eta_{1a}f_{a2} + \frac{1}{2}\sum_{ab}(n_a - n_b)(\eta_{ab}\Gamma_{b1a2} - f_{ab}\eta_{b1a2}) + \frac{1}{2}\sum_{abc}(n_a n_b \overline{n}_c + \overline{n}_a \overline{n}_b n_c)(1+P_{12})\eta_{c1ab}\Gamma_{abc2}$$

$$\frac{d\Gamma_{1234}}{ds} = \sum_{a}[(1-P_{12})(\eta_{1a}\Gamma_{a234} - f_{1a}\eta_{a234}) - (1-P_{34})(\eta_{a3}\Gamma_{12a4} - f_{a3}\eta_{12a3})] + \frac{1}{2}\sum_{ab}(1-n_a-n_b)(\eta_{12ab}\Gamma_{ab34} - \Gamma_{12ab}\eta_{ab34}) - \sum_{ab}(n_a - n_b)(1-P_{12})(1-P_{34})\eta_{b2a4}\Gamma_{a1b3}$$

$$H \longrightarrow H(s) \approx E(s) + \sum_{12} f_{12}(s)a_1^\dagger a_2 + \frac{1}{4}\sum_{1234}\Gamma_{1234}(s)a_1^\dagger a_2^\dagger a_4 a_3$$

s: flow parameter

n_a : occupation number

$\overline{n}_a = 1 - n_a$

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In-medium similarity renormalization group

Generator is chosen to suppress the off diagonal component:

$$\eta_{12} = \frac{1}{2}\arctan\left(\frac{2f_{12}}{f_{11} - f_{22} + \Gamma_{1212} + \Delta}\right)$$

$$\eta_{1234} = \frac{1}{2}\arctan\left(\frac{2\Gamma_{1234}}{f_{11} + f_{22} - f_{33} - f_{44} + A_{1234} + \Delta}\right)$$

$$A_{1234} = \Gamma_{1212} + \Gamma_{3434} - \Gamma_{1313} - \Gamma_{2424} - \Gamma_{1414} - \Gamma_{2323}$$

f_{12}, Γ_{1234} : matrix element we want to suppress

Δ : newly introduced parameter

$$\frac{dE}{ds} = \sum_{ab}(n_a - n_b)\eta_{ab} f_{ba} + \frac{1}{2}\sum_{abcd}\eta_{abcd}\Gamma_{cdab} n_a n_b \overline{n}_c \overline{n}_d$$

$$\frac{df_{12}}{ds} = \sum_{a}(1 + P_{12})\eta_{1a} f_{a2} + \frac{1}{2}\sum_{ab}(n_a - n_b)(\eta_{ab}\Gamma_{b1a2} - f_{ab}\eta_{b1a2}) + \frac{1}{2}\sum_{abc}(n_a n_b \overline{n}_c + \overline{n}_a \overline{n}_b n_c)(1 + P_{12})\eta_{c1ab}\Gamma_{abc2}$$

$$\frac{d\Gamma_{1234}}{ds} = \sum_{a}[(1 - P_{12})(\eta_{1a}\Gamma_{a234} - f_{1a}\eta_{a234}) - (1 - P_{34})(\eta_{a3}\Gamma_{12a4} - f_{a3}\eta_{12a3})] + \frac{1}{2}\sum_{ab}(1 - n_a - n_b)(\eta_{12ab}\Gamma_{ab34} - \Gamma_{12ab}\eta_{ab34}) - \sum_{ab}(n_a - n_b)(1 - P_{12})(1 - P_{34})\eta_{b2a4}\Gamma_{a1b3}$$

n_a : occupation number

$\overline{n}_a = 1 - n_a$