MSU Year 4 Status Report

I) Density Matrix Expansions

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II) In-medium SRG

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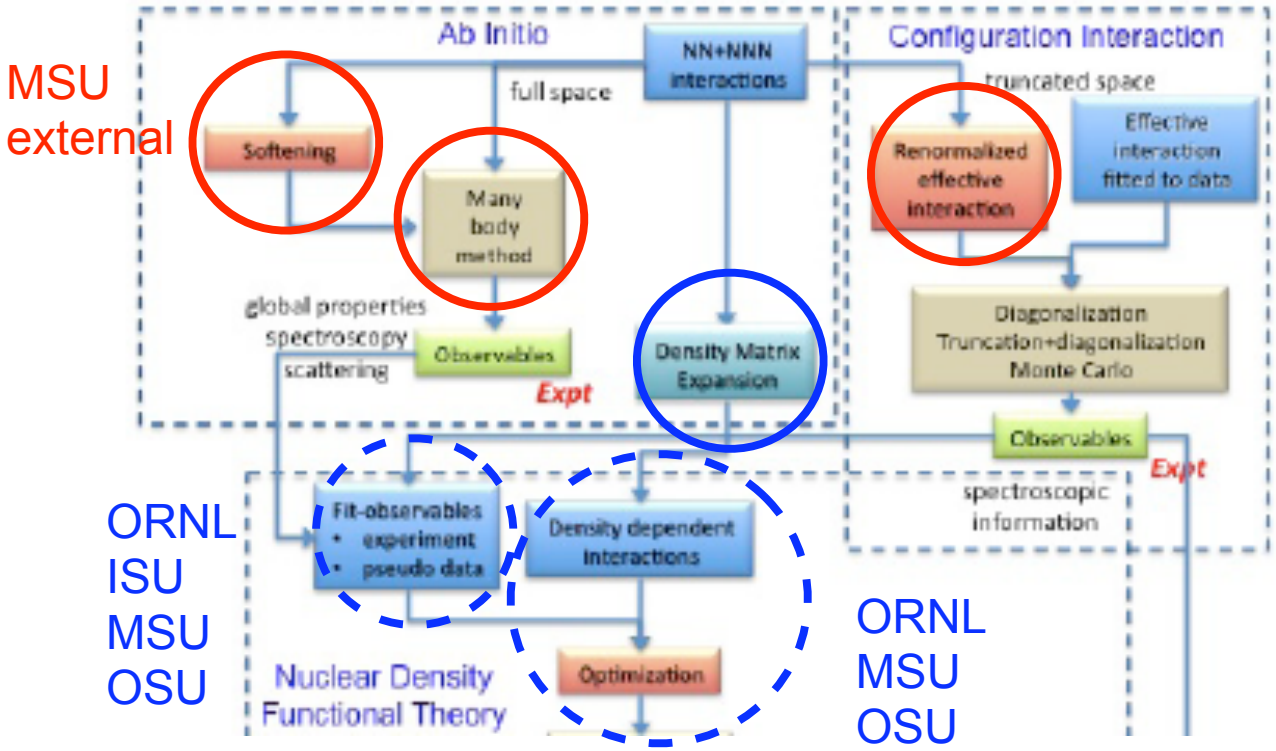
Achim Schwenk**

**External



Microscopically-guided functionals

- $V_{NN} + V_{NNN}$ + MBPT + DME to guide next-generation EDFs

In-medium similarity renormalization group (IM-SRG)

- new ab-initio method
- effective interactions

DME Year 4 Deliverables

- DME $E_x[\rho]$ from chiral EFT NN + NNN thru NNLO delivered to ORNL EDF group
  - Mathematica package + Python scripts available to public
  - Original NV-DME or PSA-DME options (others easy to implement)
  - Implemented in HFTHO and HFBRAD and 1st optimizations begun by ORNL group (Stoitsov, Kortelainen)
- Use improved DME to validate against ab-initio
  - 1st results obtained for neutron droplets w/Minnesota NN potential
  - Beyond HF and more realistic NN + NNN rest of Year 4 and 5
- Year 5 roadmap
  - revisit comparison to ab initio for nuclei w/realistic NN + NNN (DME improvements + exact Hartree)
  - microscopic constraints on short-range non-analytic density dependencies ($\rho^{2+\gamma}$ etc.)
  - comparison to OEP for E_x

DME-related papers completed in Year 4

1. "Microscopically-constrained Fock energy density functionals from chiral effective field theory. I. Two-nucleon interactions"
   B. Gebremariam, S. K. Bogner and T. Duguet
   arXiv:1003.5210 [nucl-th] SPIRES entry

2. "Symbolic Integration Of A Product Of Two Spherical Bessel Functions With An Additional Exponential And Polynomial Factor"
   B. Gebremariam, T. Duguet and S. K. Bogner
   Comput. Phys. Commun. **181**, 1136 (2010) SPIRES entry

3. "Symbolic computation of the Hartree-Fock energy from a chiral EFT three-nucleon interaction at N^2LO"
   B. Gebremariam, S. K. Bogner and T. Duguet
   Comput. Phys. Commun. **181**, 1167 (2010) [arXiv:0912.3086 [physics.comp-ph]] SPIRES entry

4. "An improved density matrix expansion for spin-unsaturated nuclei,"
   B. Gebremariam, T. Duguet and S. K. Bogner,
   arXiv:0910.4979 [nucl-th] SPIRES entry

and 1 Ph.D. thesis (Biruk Gebremariam)

What could be missing in phenomenological EDFs ?

- **Density dependencies too simplistic**
- **Isovector components not well constrained**
- **What's the connection to many-body forces?**

Turn to microscopic many body theory for guidance, aided by the simplifications enabled by soft RG-evolved interactions

Simplest idea: Map non-local exchange energy into local EDF (non-trivial density-dependence)

Density Matrix Expansion Revisited (Negele and Vautherin)

Expand of DM in local operators w/factorized non-locality

$$\langle \Phi | \psi^\dagger \left(\mathbf{R} - \frac{1}{2}\mathbf{r} \right) \psi \left(\mathbf{R} + \frac{1}{2}\mathbf{r} | \Phi \right\rangle = \sum_n \Pi_n(k_F r) \langle \mathcal{O}_n(\mathbf{R}) \rangle$$

$$\langle \mathcal{O}_n(\mathbf{R}) \rangle = \left[\rho(\mathbf{R}), \nabla^2 \rho(\mathbf{R}), \tau(\mathbf{R}), \mathbf{J}(\mathbf{R}), \ldots \right]$$

NV, PSA, ...

Dependence on local densities/currents now manifest

$$\langle V_2 \rangle \sim \sum_{n,m} \int d\mathbf{R}\, \mathcal{O}_n(\mathbf{R}) \mathcal{O}_m(\mathbf{R}) \int d\mathbf{r}\, \Pi_n(k_F r) \Pi_m(k_F r) V_2(r)$$

$$\sim \sum_t \int d\mathbf{R} \left\{ C_t^{\rho\rho} \rho_t^2 + C_t^{\rho\tau} \rho_t \tau_t + C_t^{\rho\Delta\rho} \rho_t \Delta\rho_t + C_t^{JJ} \mathbf{J}_t^2 + C_t^{J\nabla\rho} \mathbf{J}_t \nabla\rho_t \cdots \right\}$$

$$C^{ij}[u] \xi_i \xi_j \ , \quad u \equiv \frac{k_F(R)}{m_\pi}$$

$$C^{ij}[u] = C_1^{ij}[u] + C_2^{ij}[u] \ln(1+4u^2) + C_3^{ij}[u] \arctan(2u),$$

$$C^{ij}[u] \ = \ \text{rational polynomial}$$

Similarly for $\langle V_{NNN} \rangle$ (but trilinear and many more terms...)

$$
\begin{aligned}
\mathcal{E}^{CR4,2x} \;=\; \int d\vec{r} \Big\{ & \mathcal{C}_7^{\rho_0^3}\, \rho_0^3(\vec{r}) \;+\; \mathcal{C}_7^{\rho_0\rho_1^2}\, \rho_0(\vec{r})\, \rho_1^2(\vec{r}) \;+\; \mathcal{C}_7^{\rho_0\rho_1\varsigma_1^1}\, \rho_0(\vec{r})\, \rho_1(\vec{r})\, \varsigma_1^1(\vec{r}) \\
& + \mathcal{C}_7^{\rho_0^2\Delta\rho_0}\, \rho_0^2(\vec{r})\, \Delta\rho_0(\vec{r}) \;+\; \mathcal{C}_7^{\rho_0\rho_1\Delta\rho_1}\, \rho_0(\vec{r})\, \rho_1(\vec{r})\, \Delta\rho_1(\vec{r}) \;+\; \mathcal{C}_7^{\rho_0^2\varsigma_0^2}\, \rho_0^2(\vec{r})\, \varsigma_0^2(\vec{r}) \\
& + \mathcal{C}_7^{\rho_1^2\varsigma_0^2}\, \rho_1^2(\vec{r})\, \varsigma_0^2(\vec{r}) \;+\; \mathcal{C}_7^{\rho_0\rho_1\varsigma_1^2}\, \rho_0(\vec{r})\, \rho_1(\vec{r})\, \varsigma_1^2(\vec{r}) \;+\; \mathcal{C}_7^{\rho_0^2\varsigma_0^1}\, \rho_0^2(\vec{r})\, \varsigma_0^1(\vec{r}) \\
& + \mathcal{C}_7^{\rho_0 J_0^2}\, \rho_0(\vec{r})\, \vec{J}_0(\vec{r})\cdot\vec{J}_0(\vec{r}) \;+\; \mathcal{C}_7^{\rho_1 J_0 J_1}\, \rho_1(\vec{r})\, \vec{J}_0(\vec{r})\cdot\vec{J}_1(\vec{r}) \;+\; \mathcal{C}_7^{\rho_0 J_1^2}\, \rho_0(\vec{r})\, \vec{J}_1(\vec{r})\cdot\vec{J}_1(\vec{r}) \\
& + \mathcal{C}_7^{J_0^2\nabla J_0}\, \vec{J}_0(\vec{r})\cdot\vec{J}_0(\vec{r})\,\vec{\nabla}\cdot\vec{J}_0(\vec{r}) \;+\; \mathcal{C}_7^{J_1^2\nabla J_0}\, \vec{J}_1(\vec{r})\cdot\vec{J}_1(\vec{r})\,\vec{\nabla}\cdot\vec{J}_0(\vec{r}) \;+\; \mathcal{C}_7^{J_0 J_1\nabla J_1}\, \vec{J}_0(\vec{r})\,\vec{J}_1(\vec{r})\,\vec{\nabla}\cdot\vec{J}_1(\vec{r}) \\
& + \mathcal{C}_7^{\Delta\rho_0 J_0^2}\, \Delta\rho_0(\vec{r})\, \vec{J}_0(\vec{r})\cdot\vec{J}_0(\vec{r}) \;+\; \mathcal{C}_7^{\varsigma_0^2 J_0^2}\, \varsigma_0^2(\vec{r})\, \vec{J}_0(\vec{r})\cdot\vec{J}_0(\vec{r}) \;+\; \mathcal{C}_7^{\varsigma_0^1 J_0^2}\, \varsigma_0^1(\vec{r})\, \vec{J}_0(\vec{r})\cdot\vec{J}_0(\vec{r}) \\
& + \mathcal{C}_7^{\nabla\rho_0 J_0\nabla J_0}\, \vec{\nabla}\rho_0(\vec{r})\, \vec{J}_0(\vec{r})\,\vec{\nabla}\cdot\vec{J}_0(\vec{r}) \;+\; \mathcal{C}_7^{\rho_0\nabla J_0\nabla J_0}\, \rho_0(\vec{r})\, \big[\vec{\nabla}\cdot\vec{J}_0(\vec{r})\big]^2 \;+\; \mathcal{C}_7^{\rho_0 J_0\Delta J_0}\, \rho_0(\vec{r})\, \vec{J}_0(\vec{r})\cdot\Delta\vec{J}_0(\vec{r}) \\
& + \mathcal{C}_7^{\varsigma_1^1 J_0 J_1}\, \varsigma_1^1(\vec{r})\, \vec{J}_0(\vec{r})\cdot\vec{J}_1(\vec{r}) \;+\; \mathcal{C}_7^{\Delta\rho_1 J_0 J_1}\, \Delta\rho_1(\vec{r})\, \vec{J}_0(\vec{r})\cdot\vec{J}_1(\vec{r}) \;+\; \mathcal{C}_7^{\varsigma_1^2 J_0 J_1}\, \varsigma_1^2(\vec{r})\, \vec{J}_0(\vec{r})\cdot\vec{J}_1(\vec{r}) \\
& + \mathcal{C}_7^{\nabla\rho_1 J_1\nabla J_0}\, \vec{\nabla}\rho_1(\vec{r})\cdot\vec{J}_1(\vec{r})\,\vec{\nabla}\cdot\vec{J}_0(\vec{r}) \;+\; \mathcal{C}_7^{\rho_1 J_1\Delta J_0}\, \rho_1(\vec{r})\, \vec{J}_1(\vec{r})\cdot\Delta\vec{J}_0(\vec{r}) \;+\; \mathcal{C}_7^{\varsigma_0^2 J_1^2}\, \varsigma_0^2(\vec{r})\, \vec{J}_1(\vec{r})\cdot\vec{J}_1(\vec{r}) \\
& + \mathcal{C}_7^{\nabla\rho_1 J_0\nabla J_1}\, \vec{\nabla}\rho_1(\vec{r})\cdot\vec{J}_0(\vec{r})\,\vec{\nabla}\cdot\vec{J}_1(\vec{r}) \;+\; \mathcal{C}_7^{\rho_1\nabla J_0\nabla J_1}\, \rho_1(\vec{r})\,\vec{\nabla}\cdot\vec{J}_0(\vec{r})\,\vec{\nabla}\cdot\vec{J}_1(\vec{r}) \;+\; \mathcal{C}_7^{\rho_0\nabla J_1\nabla J_1}\, \rho_0(\vec{r})\, \big[\vec{\nabla}\cdot\vec{J}_1(\vec{r})\big]^2 \\
& + \mathcal{C}_7^{\rho_1 J_0\Delta J_1}\, \rho_1(\vec{r})\, \vec{J}_0(\vec{r})\cdot\Delta\vec{J}_1(\vec{r}) \;+\; \mathcal{C}_7^{\rho_0 J_1\Delta J_1}\, \rho_0(\vec{r})\, \vec{J}_1(\vec{r})\cdot\Delta\vec{J}_1(\vec{r}) \Big\}. \qquad (91)
\end{aligned}
$$

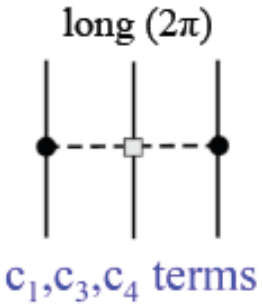
$$C^{ijk}[u]\xi_i\xi_j\xi_k \;, \quad u \equiv \frac{k_F(R)}{m_\pi}$$ (note: u is NOT small)

$$C^{ijk}[u] = C_1^{ijk}[u] + C_2^{ijk}[u]\,\ln(1+4u^2) + C_3^{ijk}[u]\arctan(2u),$$

$$C_\alpha^{ijk}[u] = \text{rational polynomial}$$

New development: DME for chiral NNN force (N2LO)

- Expect interesting spin-orbit/tensor couplings from TPE



$$V_c(\mathbf{q}_1,\mathbf{q}_2,\mathbf{q}_3) \sim \frac{\sigma_1\cdot\mathbf{q_1}\sigma_2\cdot\mathbf{q_2}}{(q_1^2+m_\pi^2)(q_2^2+m_\pi^2)}F_{123}^{\alpha\beta}\tau_1^\alpha\tau_2^\beta + perms$$

$$F_{123}^{\alpha\beta} \equiv \delta_{\alpha\beta}\left[-4\frac{c_1 m_\pi^2}{f_\pi^2}+2\frac{c_3}{f_\pi^2}\mathbf{q}_1\cdot\mathbf{q}_2\right] + \frac{c_4}{f_\pi^2}\epsilon^{\alpha\beta\gamma}\tau_3^\gamma\sigma_3\cdot(\mathbf{q}_1\times\mathbf{q}_2)$$

Empirical EDFs (Skyrme, Gogny,...) spin-orbit coupling is density independent => appropriate for NN spin-orbit forces (short range)

This is a mismatch since microscopic NNN interactions are long-range (DME ==> density dependent J·∇ρ couplings)

Prescriptions for Π_n-functions

Phase space averaging (PSA-DME) (Gebremariam et al. arXiv:0910.4979)

$$\rho(\vec{r}_1,\vec{r}_2) \;=\; e^{i\vec{r}\cdot\vec{k}}\, e^{\frac{\vec{r}}{2}\cdot(\nabla_1-\nabla_2)-i\vec{r}\cdot\vec{k}}\rho(\vec{r}_1,\vec{r}_2)\Big|_{\vec{r}_1=\vec{r}_2=\vec{R}}$$

Average the non-locality operator over local momentum distribution g(**R,k**) and expand exponentiated gradients

$$\rho(\vec{r}_1,\vec{r}_2) \;\approx\; \int d^3\vec{k}\; g(\vec{R},\vec{k})\, e^{i\vec{k}\cdot\vec{r}} \sum_{n=0}^{2}\frac{1}{n!}\left\{\vec{r}\cdot\left(\frac{\nabla_1-\nabla_2}{2}-i\vec{k}\right)\right\}^n \rho(\vec{r}_1,\vec{r}_2)\Big|_{\vec{r}_1=\vec{r}_2=\vec{R}}$$

Easy to build in physics associated with surface effects in finite fermi systems (non-isotropic g(R,k))

Crucial to accurately describe spin-vector part of OBDM

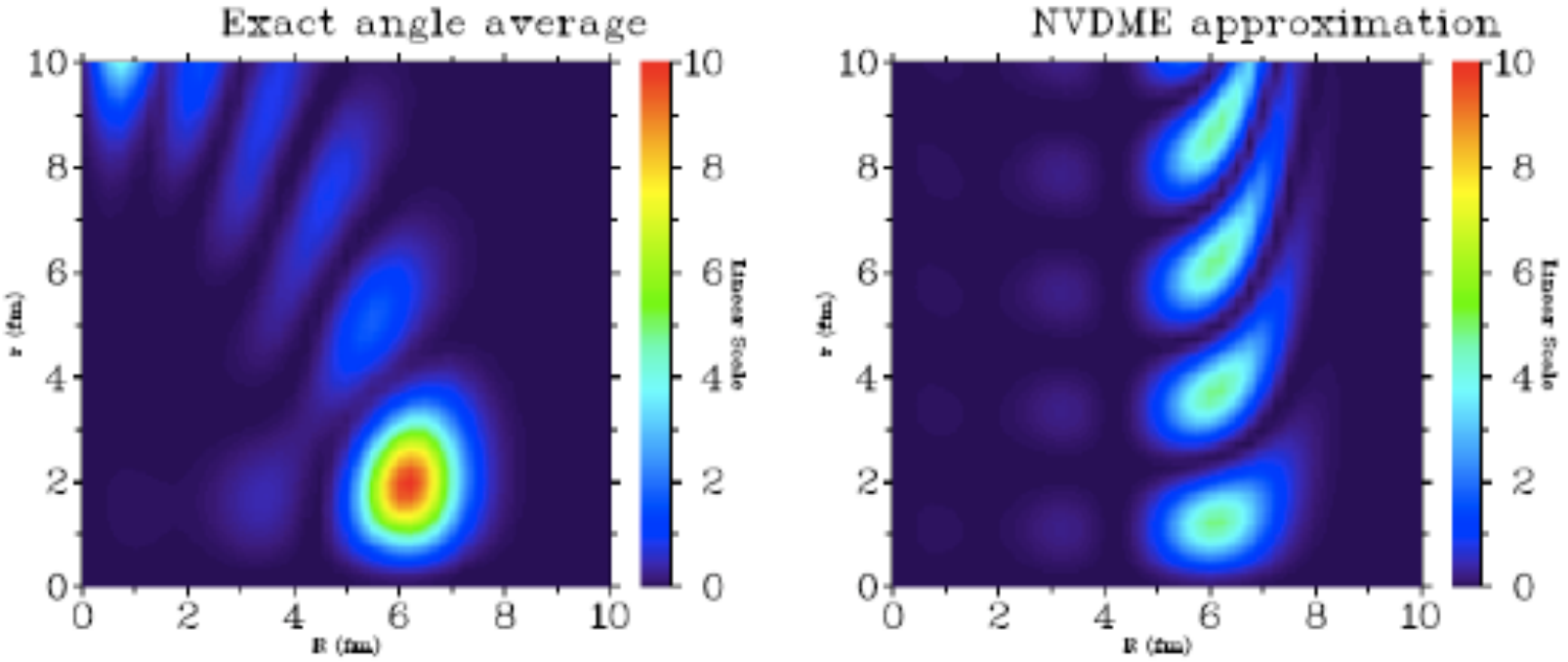
Prescriptions for Π_n-functions

Negele and Vautherin (NV-DME)

Truncated Bessel expansion of non-locality operator

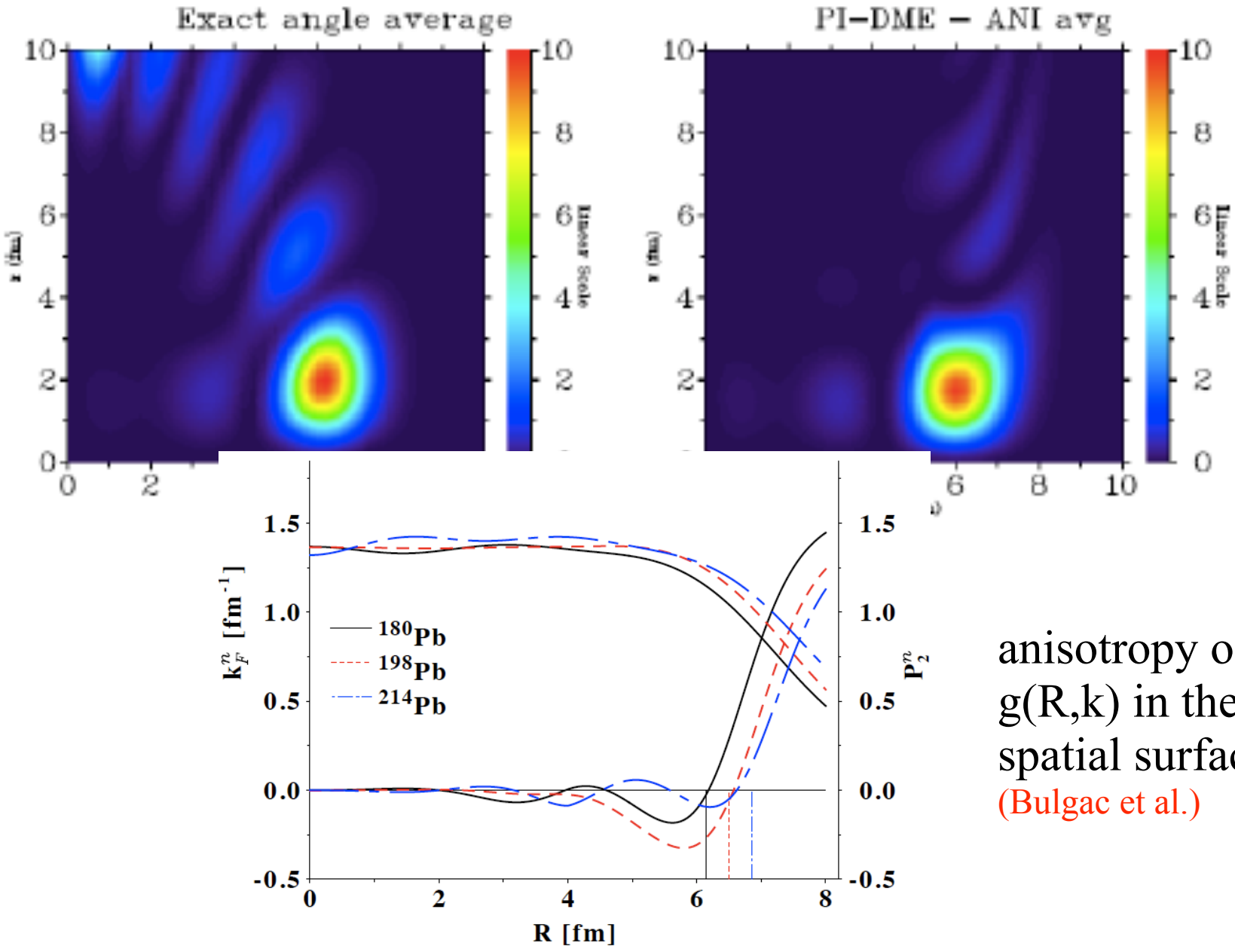
Sufficient for spin-unsaturated nuclei only

$$\int d\Omega_r \, \mathbf{s}_n(\mathbf{r}_1, \mathbf{r}_2) \cdot \mathbf{s}_n(\mathbf{r}_2, \mathbf{r}_1)$$



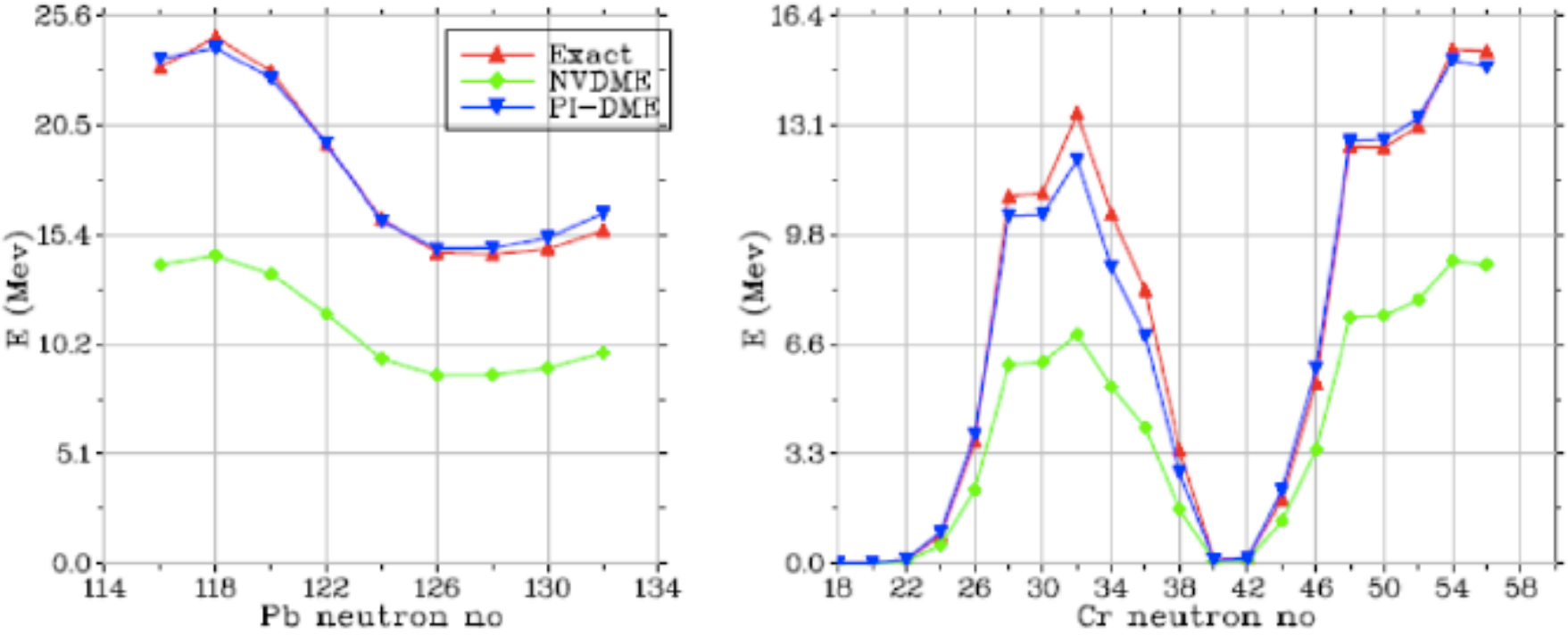
Why it fails: no phase space averaging (not even over INM) done for spin-vector part

Improved Vector PSA-DME



anisotropy of g(R,k) in the spatial surface (Bulgac et al.)

Look at $\int d\mathbf{r}\, d\mathbf{R}\, V_{1\pi}(r)\, \mathbf{s}_n(\mathbf{r}_1, \mathbf{r}_2) \cdot \mathbf{s}_n(\mathbf{r}_2, \mathbf{r}_1)$:



- Inclusion of finite fermi phase space effects crucial for **quantitative** agreement
- completely parameter-free

Can now apply modified DME with confidence to spin-unsaturated systems

Including Long Range Chiral EFT in Skyrme-like EDFs

$$V_{EFT} = V_{ct}(\Lambda) + V_{1\pi} + V_{2\pi} + \cdots$$

Each HF DME coupling function splits into 2 terms

1) Skyrme-like coupling **constants (contact terms)**
2) Nontrivial coupling **functions** from "universal" pion physics

$$C_t^{\rho\tau} \Rightarrow C_t^{\rho\tau}(\Lambda; V_{ct}) + C_t^{\rho\tau}[k_F(\mathbf{R}); V_\pi]$$

Etc…

From contact terms in EFT/RG V's

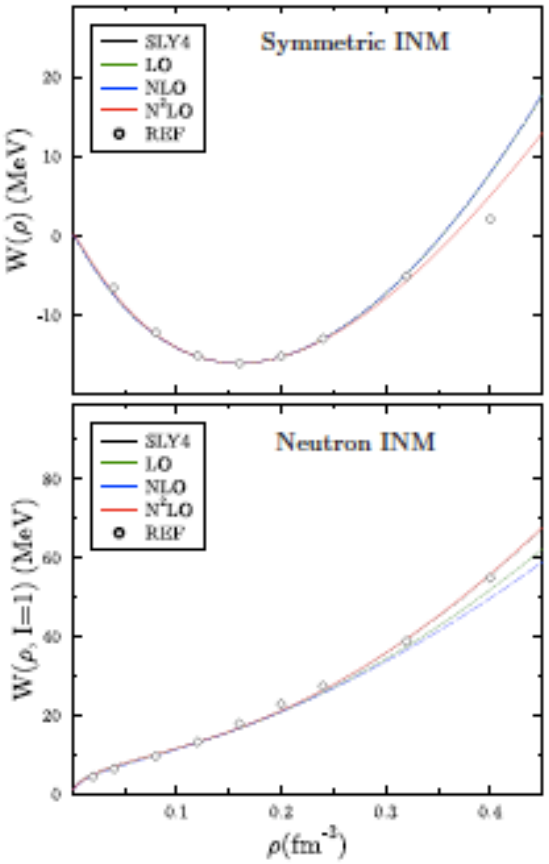
From pion exchanges

Suggests a microscopically-improved Skyrme phenomenology

Add pion-exchange couplings to existing Skyrme EDF and refit Skyrme constants (mimics higher-order ladder contributions)

Analogous to separation of long- and short-distance Coulomb (J. Drut's talk)

Including DME pion couplings in Skyrme



SVD Optimization Results

χ^2	12.5002	2.1235	1.837	1.7662	1.7884
$RMSD(E)$	7.008	2.6931	2.5539	2.5143	2.590
$RMSD(\Delta_n)$	0.1297	0.0828	0.0587	0.0554	0.0476
$RMSD(\Delta_p)$	0.094	0.0988	0.0902	0.0866	0.0706

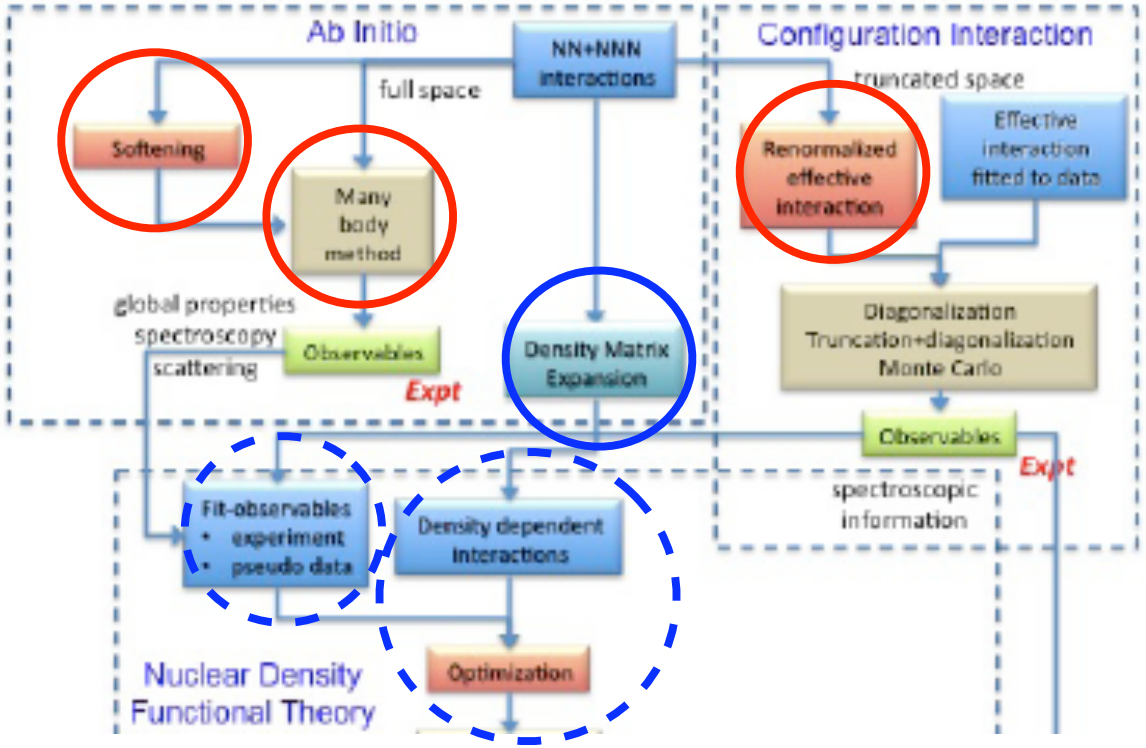
See Mario/Markus's talk for details of the implementation and restricted "pre-optimization" fits.

1) Implemented into HFTHO and HFBRAD
2) Stable enough for optimization
3) Bulk properties ok (as expected)
4) Small but stable improvement over Skyrme

No show stoppers yet!

* 1st paper by ORNL group + MSU & OSU coming soon

Part 2: In-medium SRG



In-medium similarity renormalization group (IM-SRG)

- new ab-initio method
- effective interactions

See arXiv:1006.3639

The Similarity Renormalization Group

Wegner, Glazek and Wilson

Unitary transformation via flow equations:

$$\frac{dH_\lambda}{d\lambda} = [\eta(\lambda), H_\lambda] \qquad \text{with} \qquad \eta(\lambda) \equiv \frac{dU(\lambda)}{d\lambda} U^\dagger(\lambda)$$

Engineer η to do different things as λ => 0

$$\lambda \equiv s^{-1/4}$$

$$\eta(\lambda) = [\mathcal{G}_\lambda, H_\lambda]$$

$$\mathcal{G}_\lambda = T \;\Rightarrow\; H_\lambda \text{ driven towards diagonal in k} - \text{space}$$

$$\mathcal{G}_\lambda = PH_\lambda P + QH_\lambda Q \;\Rightarrow\; H_\lambda \text{ driven to block}-\text{diagonal}$$

increases “perturbativeness”, accelerates basis expansions, ...

need to evolve NNN (at least) to keep λ independent
A > 2 observables (E. Jurgenson’s talk)

Normal Ordered Hamiltonians

$$H = \sum t_i a_i^\dagger a_i + \frac{1}{4}\sum V^{(2)}_{ijkl} a_i^\dagger a_j^\dagger a_l a_k + \frac{1}{36}\sum V^{(3)}_{ijklmn} a_i^\dagger a_j^\dagger a_k^\dagger a_n a_m a_l$$

Normal-order w.r.t. some reference state Φ (e.g., HF) :

$$H = E_{vac} + \sum f_i N(a_i^\dagger a_i) + \frac{1}{4}\sum \Gamma_{ijkl} N(a_i^\dagger a_j^\dagger a_l a_k) + \frac{1}{36}\sum W_{ijklmn} N(a_i^\dagger a_j^\dagger a_k^\dagger a_n a_m a_l)$$

$$\begin{aligned}
E_{vac} &= \langle\Phi|H|\Phi\rangle \\
f_i &= t_{ii} + \sum_h \langle ih|V_2|ih\rangle\, n_h + \frac{1}{2}\sum_{hh'} \langle ihh'|V_3|ihh'\rangle\, n_h n_{h'} \\
\Gamma_{ijkl} &= \langle ij|V_2|kl\rangle + \sum_h \langle ijh|V_3|klh\rangle\, n_h \\
W_{ijklmn} &= \langle ijk|V_3|lmn\rangle
\end{aligned}$$

$$\langle\Phi|N(\cdots)|\Phi\rangle = 0$$

0-, 1-, 2-body terms contain some 3NF effects thru density dependence => Efficient truncation scheme for evolution of 3N?

In-medium SRG for Nuclear matter

- Normal order H w.r.t. non-int. fermi sea
- Choose SRG generator to eliminate "off-diagonal" pieces

$$\frac{dH(s)}{ds} = [\eta(s), H(s)] \qquad \eta = [\hat{f}, \hat{\Gamma}]$$

$$\lim_{s\to\infty} \Gamma_{od}(s) = 0 \qquad \langle 12|\Gamma_{od}|34\rangle = 0 \ \text{ if } \ \mathrm{f}_{12} = \mathrm{f}_{34}$$

$\lambda \equiv s^{-1/4}$

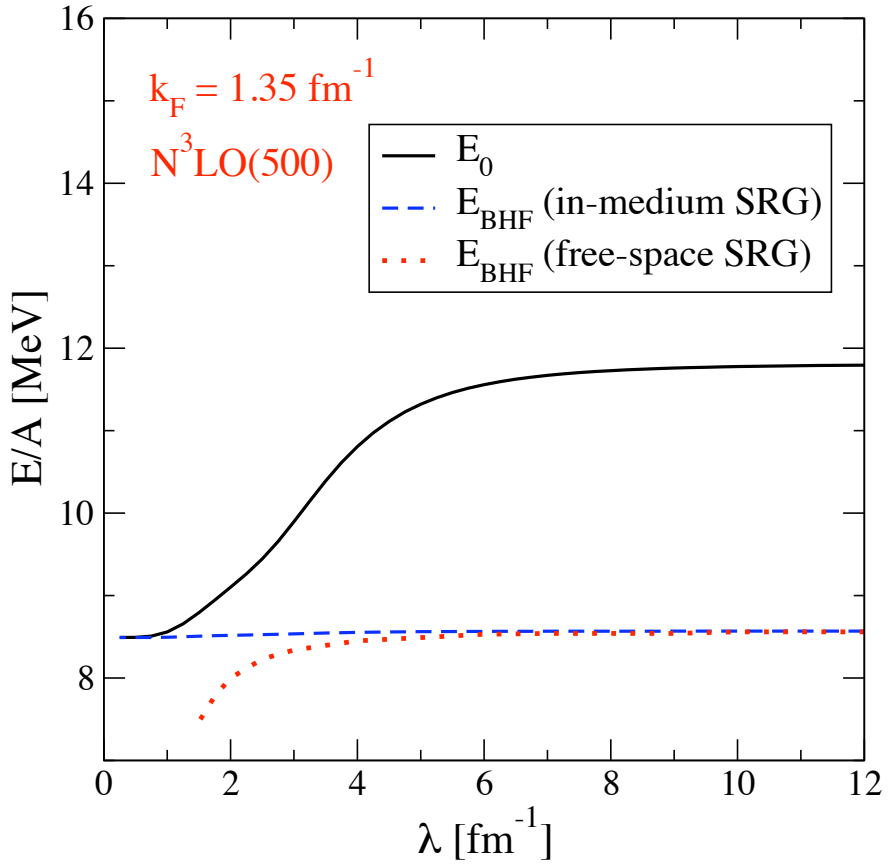
- Truncate to 2-body normal-ordered operators "IM-SRG(2)"
  - dominant parts of induced many-body forces included implicitly

$$H(\infty) = E_{vac}(\infty) + \sum f_i(\infty) N(a_i^\dagger a_i) + \frac{1}{4}\sum [\Gamma_d(\infty)]_{ijkl} N(a_i^\dagger a_j^\dagger a_l a_k)$$

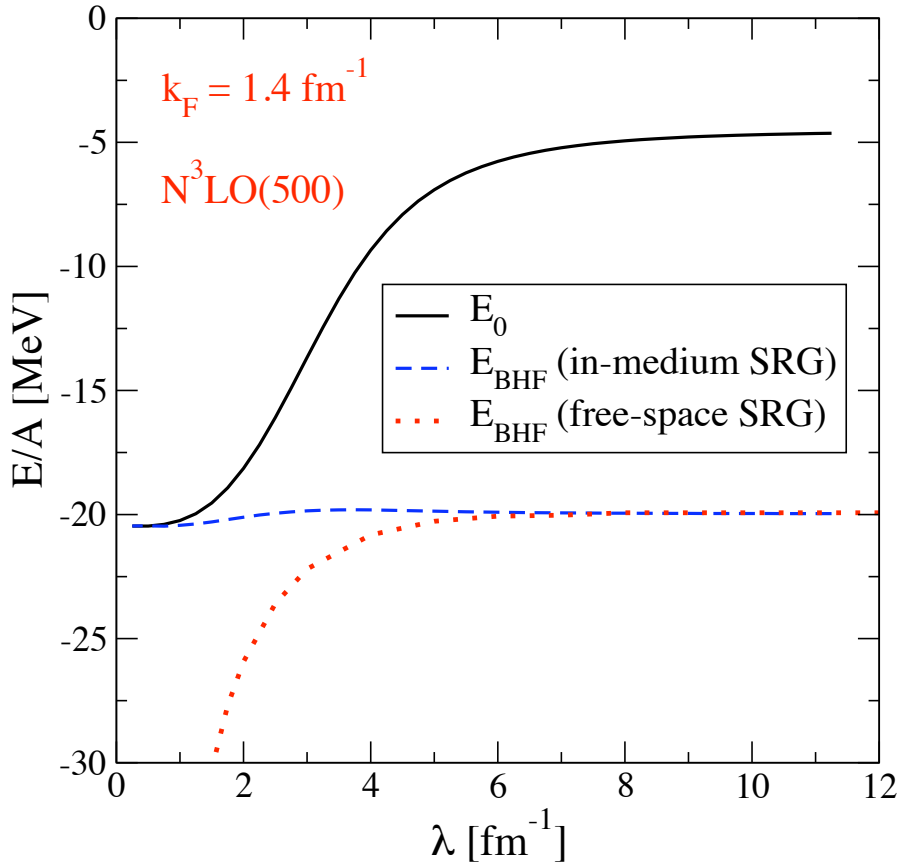
$$\begin{aligned} E_{vac}(\infty) &\rightarrow E_{gs} \\ f_k(\infty) &\rightarrow \epsilon_k \ \text{(fully dressed s.p.e.)} \\ \Gamma_d(\infty) &\rightarrow f(k',k) \ \text{(Landau q.p. interaction)} \end{aligned}$$

Microscopic realization of SM ideas: dominant MF + weak A-dependent $\mathrm{NN_{eff}}$

Correlations "adiabatically" summed into H(λ)



PNM*



SNM*

Weak cutoff dependence over large range => dominant 3,4,...-body terms evolved implicitly

*Neglects ph-channel. See Heiko Hergert's talk.

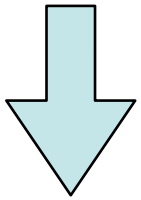
In-medium SRG to diagonalize closed-shell nuclei

Define "offdiagonal" as terms that don't annihilate the reference HF state

$$\Gamma^{od}(s) = \sum_{pp'hh'} \Gamma_{pp'hh'}(s)\{a_p^\dagger a_{p'}^\dagger a_h a_{h'}\} + h.c.$$

$$f^{od}(s) = \sum_{ph} f_{ph}(s)\{a_p^\dagger a_h\} + h.c.\,,$$

$$\eta(s) = [H(s), H \quad (s)]$$



HF reference state decouples from higher npnh states

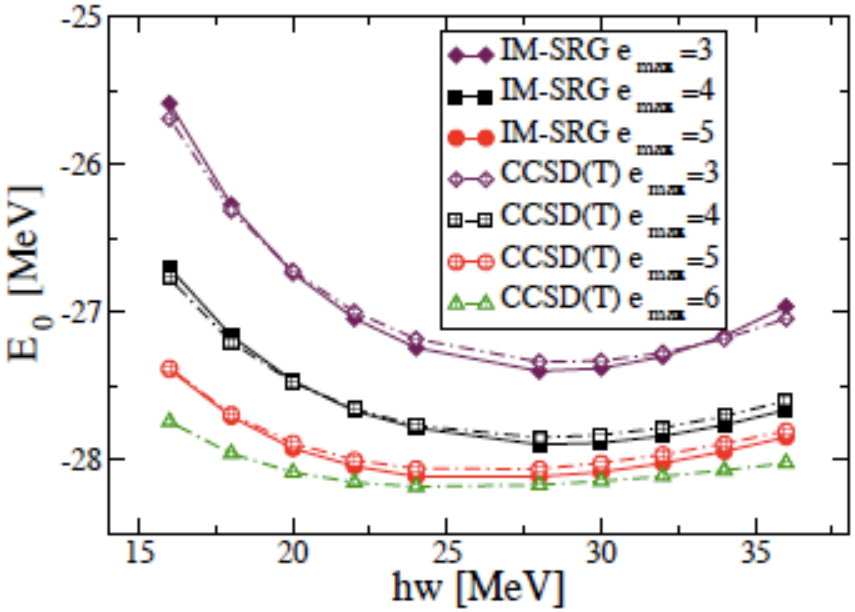
$$\lim_{s\to\infty} \langle\phi|H(s)|\phi\rangle = E_{gs}$$

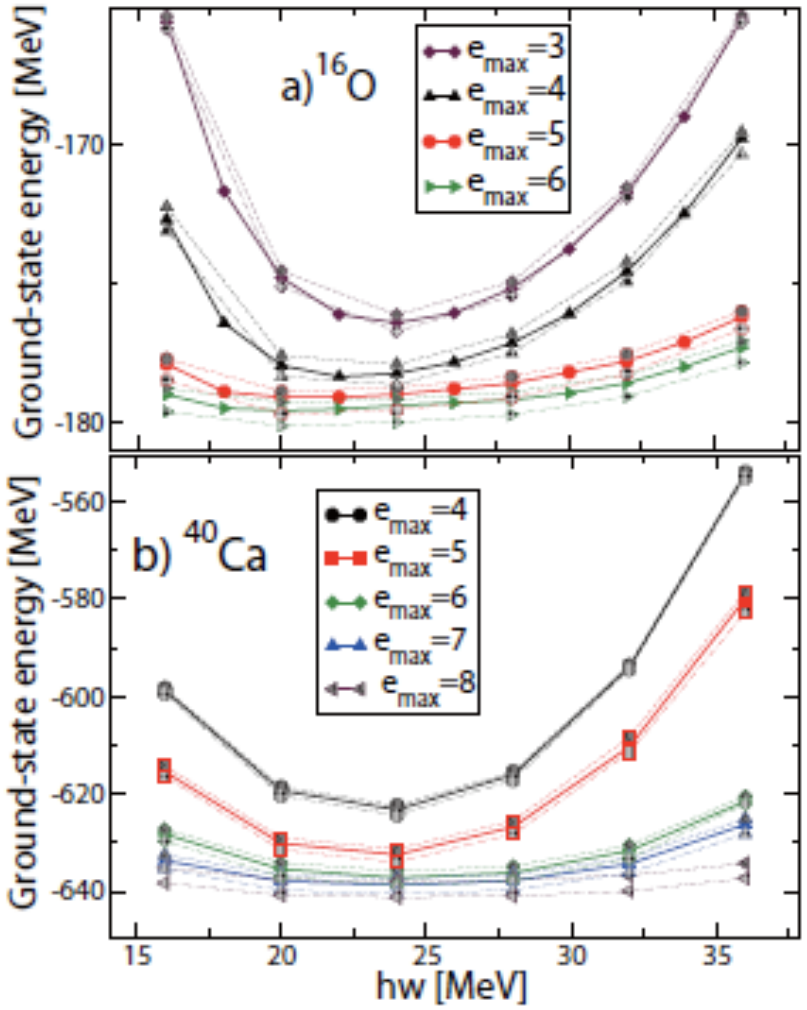
$$\lambda \equiv s^{-1/4}$$

$$QH(\infty)P = 0, \quad PH(\infty)Q = 0,$$

where $P = |\Phi\rangle\langle\Phi|$ and $Q = 1 - P$.

IM-SRG(2) diagonalization of closed-shell systems



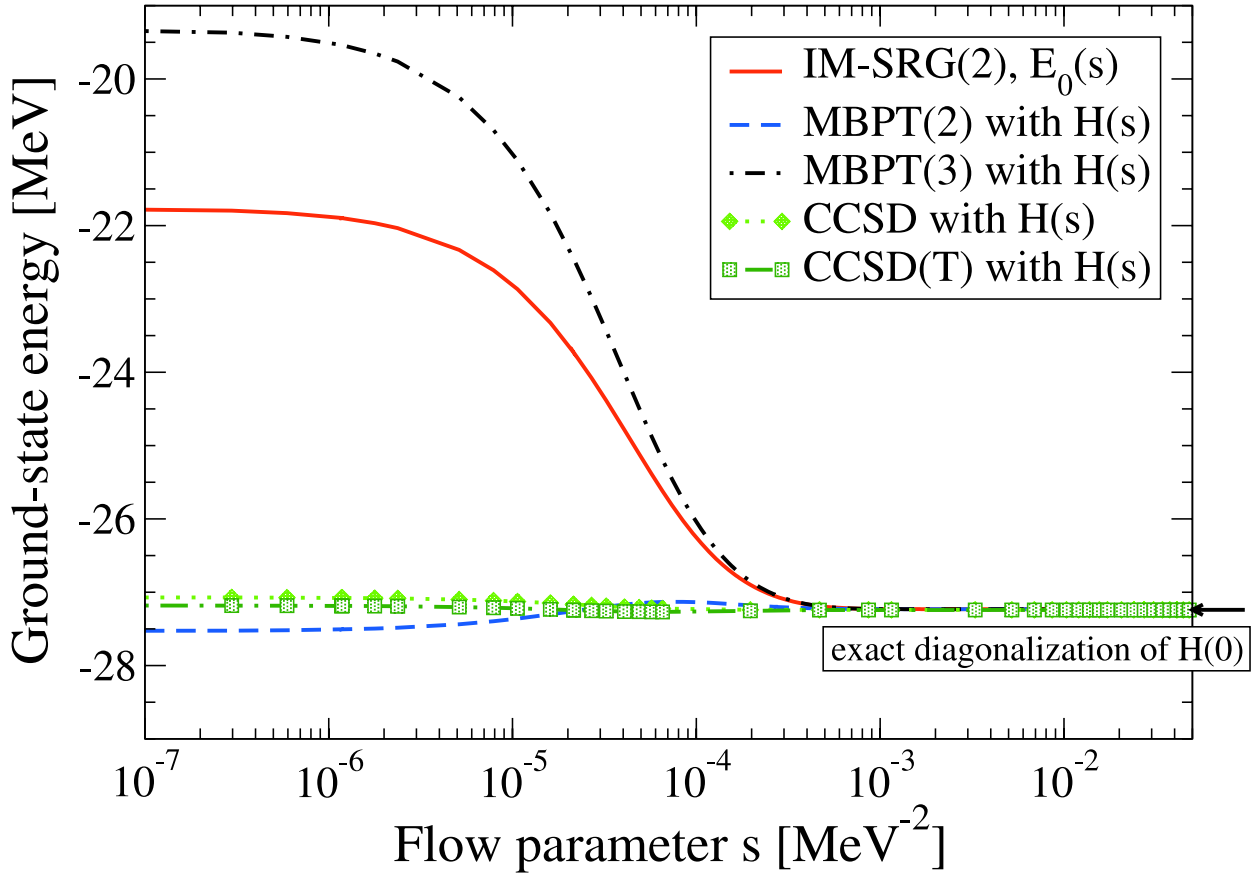


Comparable to coupled-cluster in closed shell nuclei.

Similar scaling with number of orbitals ~ N^6

Neutron droplet comparisons in rest of year 4

Can also use IM-SRG(2) to "soften" convergence of MBPT well before total decoupling achieved



Note the ~ cutoff-independent CC results using H(s). Further indication that our N-ordered truncation is robust.

Some observations

1) pp channel + 2 ph channels treated on equal footing (like Parquet theory but without the technical problems of energy-dependence, poles, etc.)

2) Intrinsically non-perturbative, and issues of small energy denominators, poles, etc. bypassed.

3) no unlinked diagrams (size extensive, etc.)

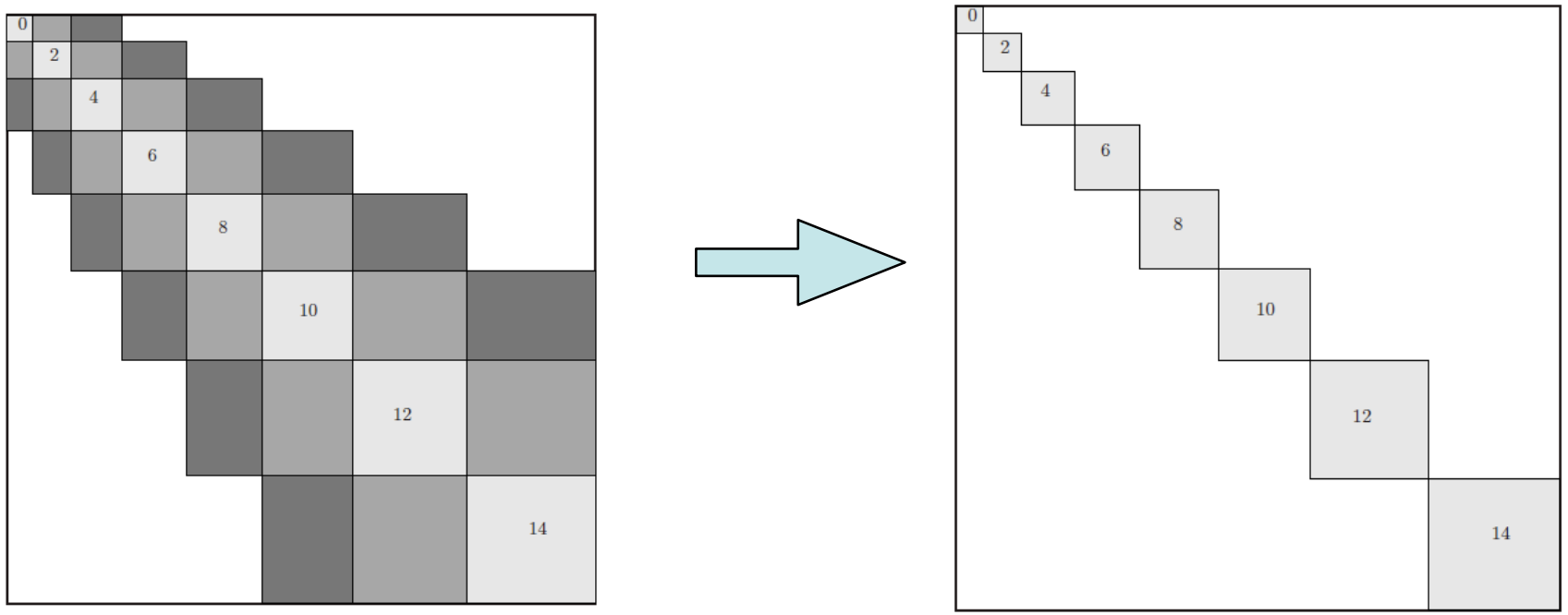
4) "3rd-order exact" and similar scaling to coupled cluster (deeper connection?)

5) Extensions to open shell possible (derive valence Heff)

Year 4 and 5 roadmap for IM-SRG

1) Eliminate quasi-particle number changing interactions

$$\eta = [Q, H(s)] \ , Q = \sum_i sgn(\epsilon_i - \epsilon_F) \{a_i^\dagger a_i\}$$

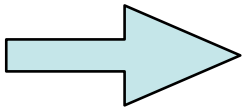


non-perturbatively derive valence shell-model Heff/Oeff

Year 4 and 5 roadmap for IM-SRG

2) Decouple highly-virtual s.p. orbitals

$$\eta = [Q, H(s)] \ , Q = \sum_i \theta(\epsilon_i - (\epsilon_F + \Lambda) \{a_i^\dagger a_i\}$$



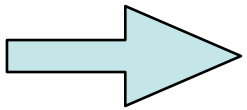
Evolved H(∞) doesn't mix many-body states that differ in the number of s.p. orbits above the chosen cutoff

use to truncate # of basis states for ab-initio calculation of low-lying states

Year 4 and 5 roadmap for IM-SRG

3) Decouple highly-virtual and deeply bound s.p. orbitals

$$\eta = [Q, H(s)] \ , Q = \sum_i \theta(|\epsilon_i - \epsilon_F| - \Lambda) \{a_i^\dagger a_i\}$$



Evolved H(∞) doesn't mix many-body states that differ in the # of s.p. orbits lying within the cutoff centered on the fermi level

reduce d.o.f. to just a few active orbitals close to the fermi level (i.e., shell model)

Year 4 and 5 roadmap for IM-SRG

4) IM-SRG for infinite matter (See Heiko's talk)

- include particle-hole channel (hard!!)
  - is it worth the effort? Folklore about ph-contributions to bulk...

- Use HFB groundstate to N-order w.r.t.
  - bypass technical problems of Nambu-Gorkov Green's functions?