A new avenue to nuclear fragmentation in a dissipative quantum mean field

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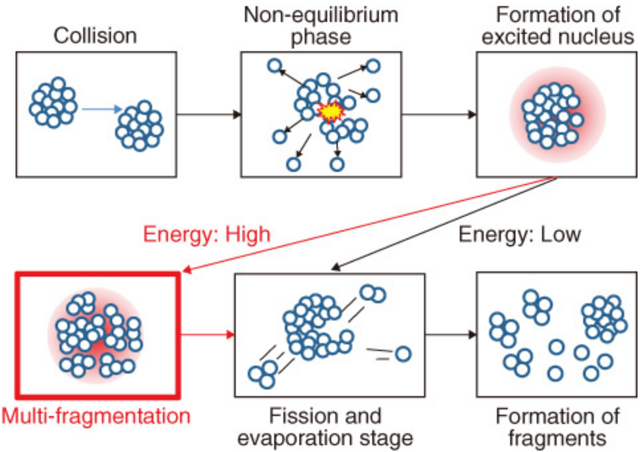
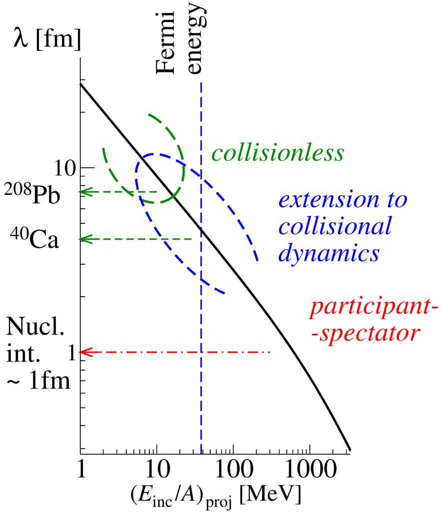
Introduction



[Ogawa, T. et al., JAEA R&D Review 2013,85]

Overview



- Collective behaviour at low energy (TDHF)
- Two body nucleonic interaction at intermediate to high energy (MD)
- Interplay between collective and dissapative effects at Fermi energy (Boltzmann)

- Search for theory that can cover Fermi to low energy to study fragmentation formation!

Theoretical Background

Connections of microscopic models

N-Body Schroedinger Equation

$$i\hbar\partial_t|\Psi\rangle = \mathcal{H}|\Psi\rangle$$

general solution

$$|\Psi\rangle = \sum_I c_I \mathcal{A}\left(\prod_I |\phi_i\rangle\right)$$

Single-Slater approximation

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keeping non-local orthogonal states

TDHF

$$\hat{\rho} = \sum^N |\phi_i\rangle\langle\phi_i|$$

LCAO approximation

$$|\phi_i\rangle = \sum^M c_{ij}|g_j\rangle$$

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F/AMD

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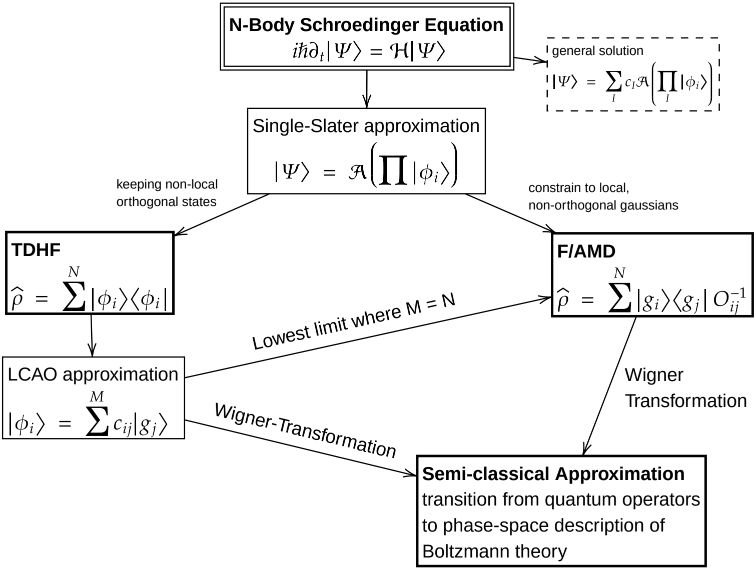
Lowest limit where M = N

Connections of microscopic models



One-Body Dynamics

Stochastic-Collisional-TDHF

$$i\hbar\partial_t\rho_1 \approx [h_1, \rho_1] + \bar{I}_{\text{coll}} + \delta I_{\text{coll}}$$

- Approximation of BBGKY
- $\bar{I}_{\text{coll}}$ average collision term
- δI_{coll} fluctuating collision term

Boltzmann-Langevin

$$\partial_t f = \{h, f\} + I_{\text{UU}} + \delta I_{\text{UU}}$$

- Wigner-transform of SC-TDHF
- $\bar{I}_{\text{coll}}$ and δI_{coll} contribution replaced by UU analog

Boltzmann-Langevin One-Body (BLOB)

$$\partial_t f - \{h, f\} = I_{\text{UU}} + \delta I_{\text{UU}} = g \int \frac{\mathrm{d}\mathbf{p}}{h^3} \int W(AB \leftrightarrow CD) F(AB \rightarrow CD) \mathrm{d}\Omega$$

- A,B,C,D: extended equal-isospin phase-space portions

Model

Implementation

Decoherence approximation

[V. de la Mota, Il Nuovo Cimento 41 C, 2018, 189]

$$\rho = \sum_i \omega_i \left| g_i \right\rangle \left\langle g_i \right|$$

Coherent state parametrization

$$g_x(x) = \mathcal{N} \exp\{-a(\chi,\varphi)(x-x_0)^2 + i k_0 (x - x_0)\}$$

$$g(\vec{r}) = g_x(x) g_y(y) g_z(z)$$

Mean-field evolution

$$i\hbar \partial_t g_i = \left(\frac{\hbar^2 \vec{k}^2}{2m} + V^{\mathrm{HF}}(\rho) \right) g_i$$

Equation of Motion

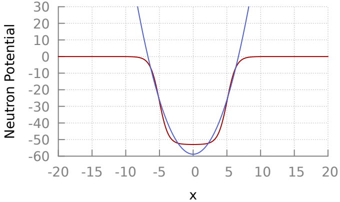
$$\begin{aligned}
\dot{x} &= \frac{\hbar k_x}{m} \\
\dot{k} &= -\frac{1}{\hbar}\partial_x \left\langle V^{\mathrm{HF}} \right\rangle \\
\dot{\chi} &= \frac{4\hbar}{m}\gamma\chi \\
\dot{\gamma} &= \frac{\hbar}{8m} - \frac{2\hbar\gamma^2}{m} - \frac{1}{\hbar}\partial_\chi \left\langle V^{\mathrm{HF}} \right\rangle
\end{aligned}$$

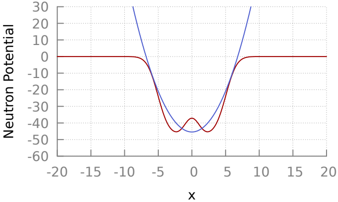
V^{HF}: Hartee-Fock potential, Skyrme-type effective force, density and isospin dependent and with surface term (Skt5)

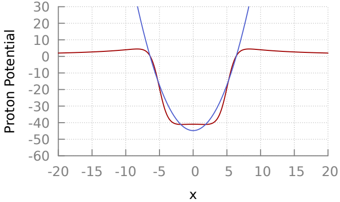
Initialization

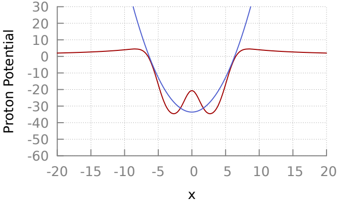
Self-consistency iteration routine of $[h_1, \rho_1] = 0$

Demonstration on 58-Ni

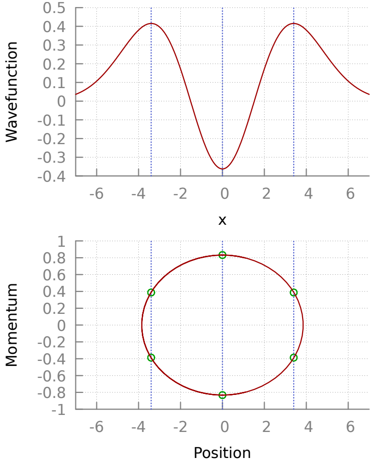








Decomposition of the coherent states

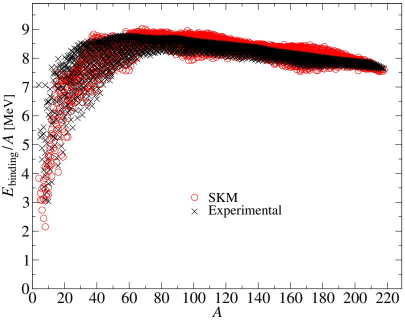


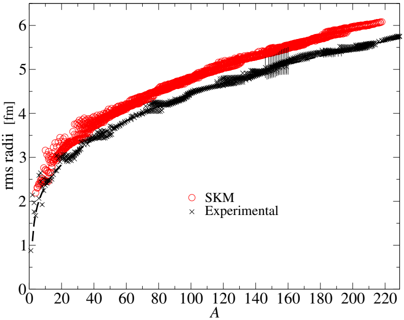
1. Find the peaks of reference wavefunction
2. Wigner-transform the wavefunction and fit with the Wigner-transform of the coherent states at the corresponding positions

$$\omega_i = \frac{1}{N_{CS,i}}$$

Remark: The Wigner-transform of the coherent states take the form of a rotated gaussian in phasespace

Binding Energy

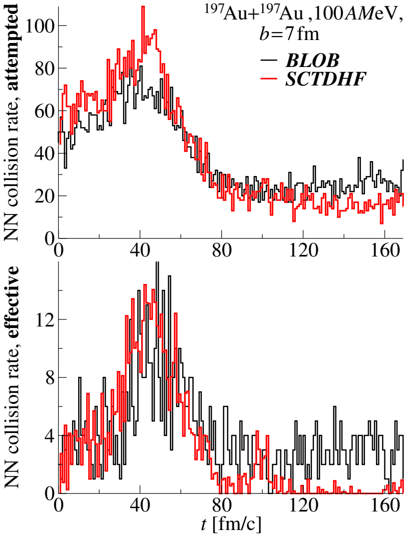




- slight deviation of the binding energy due to the initialization with the harmonic oscillator states
- Systematic deviation to the experimental size of the nuclei
- Work in progress: cooling procedure

Collision-Fluctuation effects

- scalarproduct provides naturally a phasespace metric
- Follow a BLOB prescription for the fluctuating collision term
  1. Sample a nucleonic representation
  2. define nucleonic wavepacket through scalarproduct
  3. check for possible collision to attempt
  4. perform nucleonic collision considering the overlap in the final state
  5. work in progress: cluster recognition



Conclusion

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- Range of different mechanism in the final state of heavy-ion collisions are difficult to model
- Current model achieves low energy, due to the stability of TDHF
- Improvements would give TDHF-like model which can give fragments
- Work in progress: Due to the setting we can assign more consistent properties to the residues
- Goal: Nuclear features emerge dynamically without extrapolation in the fragments