CORRELATIONS IN QUENCHED SPINOR CONDENSATES

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Intro

Ultra cold atomic gases offer a highly tunable platform to study the dynamics of thermalization in closed quantum systems, a topic of central importance to many areas of physics.

Recent experiments [1,2] observed a separation of timescales between integrable and ergodic dynamics, leading to a steady state corresponding to a universal non-thermal fixed point.

We study the equilibration of a spinor gas after a sudden quench into its ferromagnetic phase, leading to a growth of fluctuations and magnetization. Thermalization and its temporal regimes are described by developing a hierarchy of higher order correlation functions [3].

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System and Hamiltonian

Spinor wave function: $\hat{\Psi} = \left(\hat{\psi}_{+1} \quad \hat{\psi}_0 \quad \hat{\psi}_{-1}\right)^T$

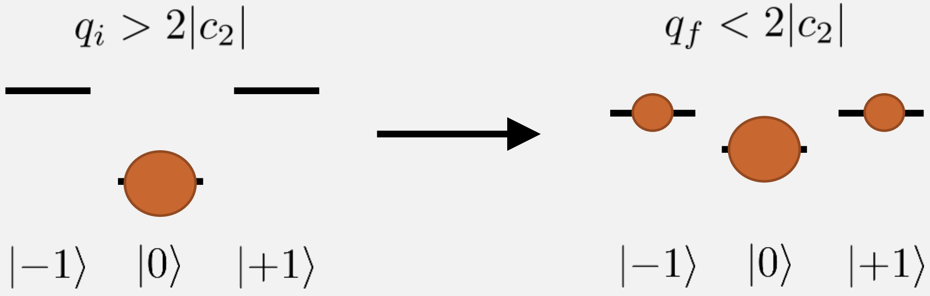
$$\hat{H} = \int \mathrm{d}\mathbf{r} \left\{ \hat{\Psi}^\dagger \left[\frac{-\hbar^2}{2M} \boldsymbol{\nabla}^2 + p f_z + q f_z^2 \right] \hat{\Psi} + \frac{c_0}{2} \hat{n}^2 + \frac{c_2}{2} \hat{\mathbf{F}}^2 \right\}$$

Zeeman splitting ($p f_z + q f_z^2$)

$\hat{\mathbf{F}} = \hat{\Psi}^\dagger \mathbf{f} \hat{\Psi}$

$\hat{n} = \hat{\Psi}^\dagger \hat{\Psi}$

Quantum phase transition



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Methods

Condensate/fluctuations:
$$\begin{cases} \hat{\psi}_{+1} \to \delta\hat{\psi}_{+1} \\ \hat{\psi}_{0} \to \phi_0 + \delta\hat{\psi}_{0} \\ \hat{\psi}_{-1} \to \delta\hat{\psi}_{-1} \end{cases}$$

Momentum space:
$$\delta\hat{\psi}_m = \frac{1}{\sqrt{\Omega}} \sum_{\mathbf{k}} \hat{a}_{\mathbf{k},m} e^{i\mathbf{k}\cdot\mathbf{r}}$$

Hamiltonian expansion:
$$\hat{H} = E_0 + \hat{H}^{(2)} + \hat{H}^{(3)} + \hat{H}^{(4)}$$

$\hat{H}^{(2)} \to \hat{a}\hat{a}$, $\hat{H}^{(3)} \to \hat{a}\hat{a}\hat{a}$, $\hat{H}^{(4)} \to \hat{a}\hat{a}\hat{a}\hat{a}$

$\hat{a} \sim \hat{a}^{(\dagger)}_{\mathbf{k},m}$

Observables: occupation numbers
$$n_{\mathbf{k},m} = \left\langle \hat{a}^{\dagger}_{\mathbf{k},m} \hat{a}_{\mathbf{k},m} \right\rangle$$

Dynamics

Approximation schemes:

$$i\hbar \frac{\mathrm{d}n_{\mathbf{k},m}}{\mathrm{d}t} = \left\langle [\hat{n}_{\mathbf{k},m}, \hat{H}^{(2)}] \right\rangle + \left\langle [\hat{n}_{\mathbf{k},m}, \hat{H}^{(4)}] \right\rangle + \left\langle [\hat{n}_{\mathbf{k},m}, \hat{H}^{(3)}] \right\rangle$$

Hartree-Fock-Bogoliubov

$\langle \hat{a}\hat{a}\hat{a}\hat{a} \rangle$ → Wick → $\langle \hat{a}\hat{a} \rangle \langle \hat{a}\hat{a} \rangle$

Renormalized HFB → Full quadratic description $\langle \hat{a}\hat{a}\hat{a} \rangle$

Truncated hierarchy of correlations

$$i\hbar \frac{\mathrm{d}\langle \hat{a}\hat{a} \rangle}{\mathrm{d}t} \sim \langle \hat{a}\hat{a}\hat{a} \rangle$$
$$i\hbar \frac{\mathrm{d}\langle \hat{a}\hat{a}\hat{a} \rangle}{\mathrm{d}t} \sim \langle \hat{a}\hat{a}\hat{a}\hat{a} \rangle \dashrightarrow \langle \hat{a}\hat{a} \rangle \langle \hat{a}\hat{a} \rangle$$

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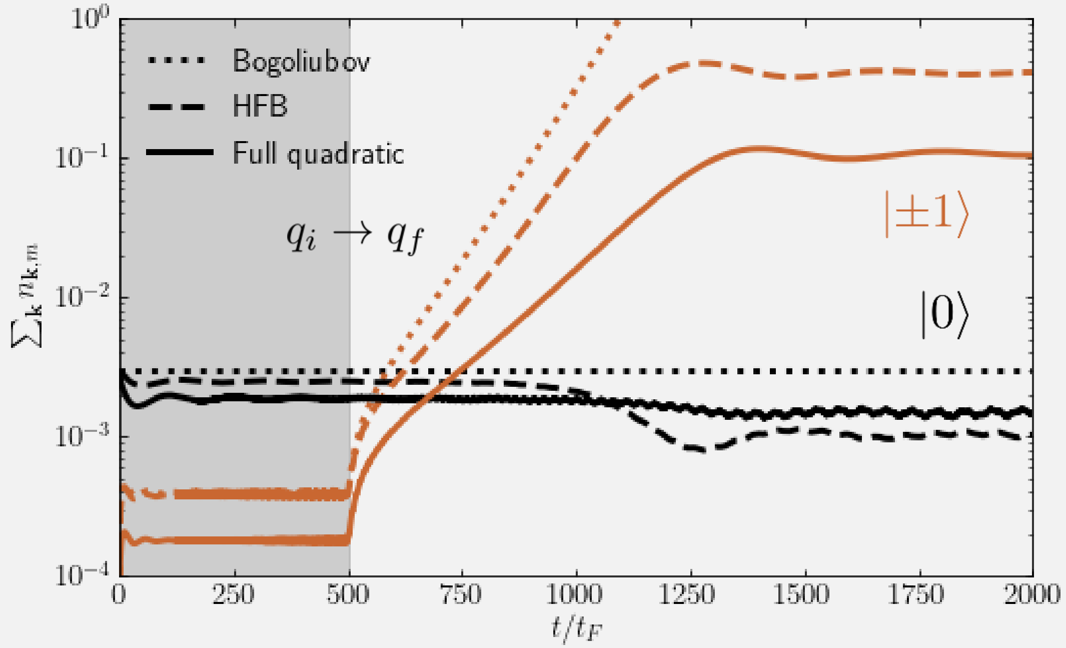
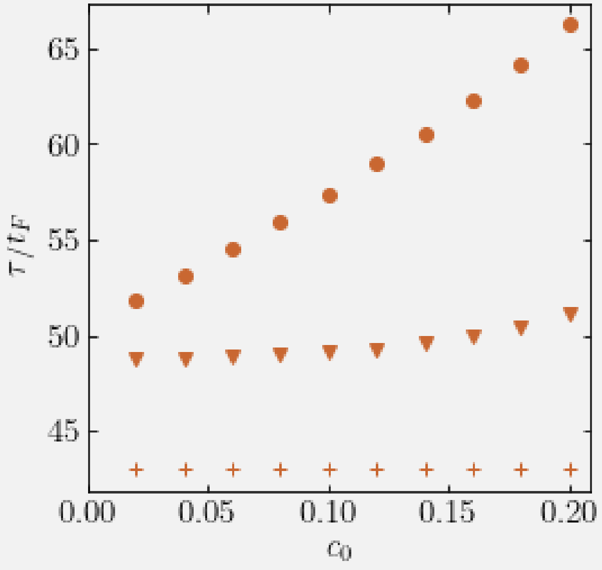
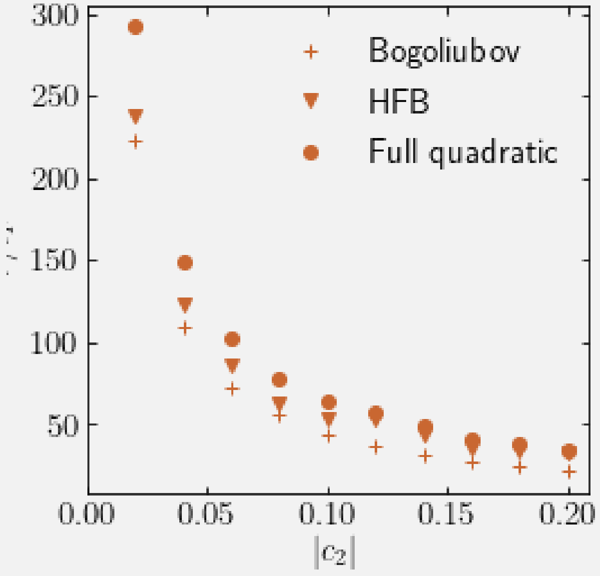
Results: growth of excitations



Longer time scale τ and lower final depletion in full quadratic theory due to fluctuation-fluctuation interactions.

Results: time scale and interaction strengths





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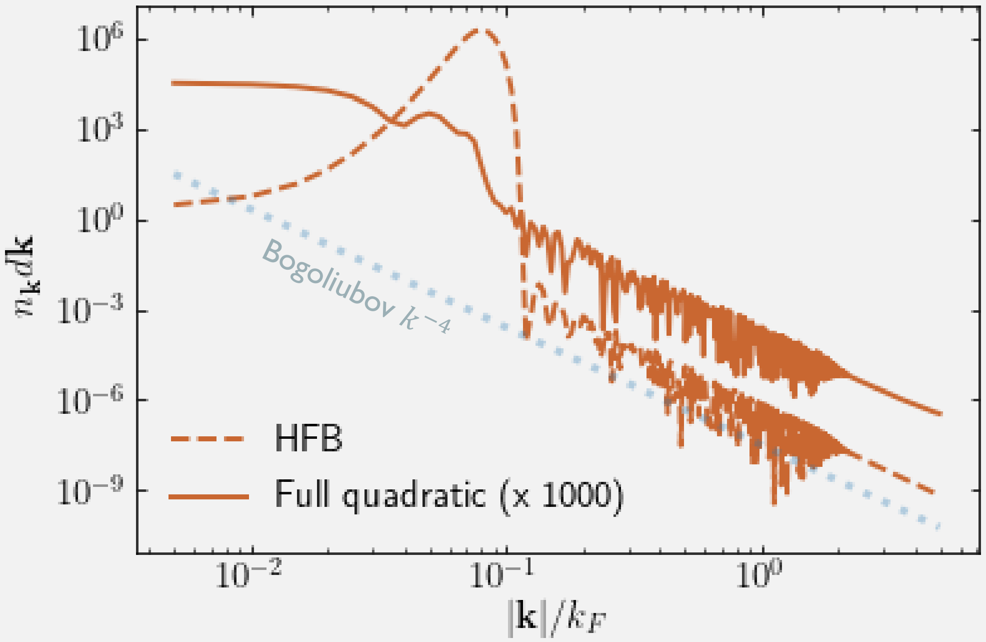
Results: momentum distribution



Signature of $|\pm 1\rangle$ condensate, weaker in full quadratic description.

Outlook

- Triple condensate expansion
- Numerical integration of 3rd order system
- Kinetic picture (Boltzmann equations)
- Separation of time scales

Bibliography

[1] M. Prüfer *et al.*, Nature **563** (2018)

[2] C. Eigen *et al.*, Nature **563** (2018)

[3] M.Van Regemortel *et al.*, Phys. Rev. A **98** (2018)

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