Signatures of the FFLO phase in modulation spectroscopy and imbalanced gases in highly elongated traps

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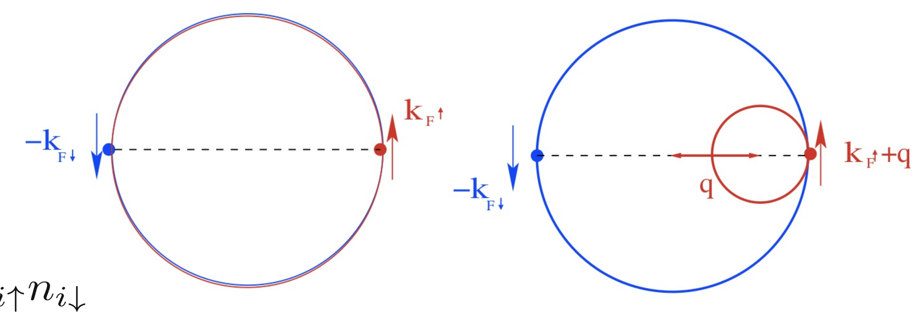
Signatures of FFLO by modulation spectroscopy [1]

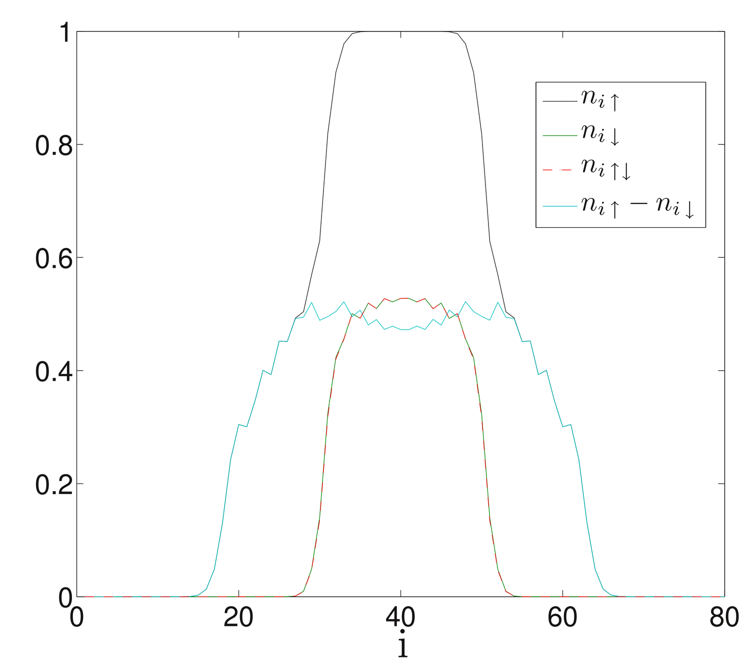
We consider a spin-imbalanced two-component attractive Fermi gas loaded in a **1D** optical lattice in the presence of a harmonic confining potential.

$$H = -J \sum_{i,\sigma}^{L} c_{i\sigma}^{\dagger}(c_{i+1\sigma} + h.c.) + U \sum_{i}^{L} n_{i\uparrow} n_{i\downarrow} + V \sum_{i}^{L} (i - \frac{L}{2})^2 n_{i\uparrow} n_{i\downarrow}$$

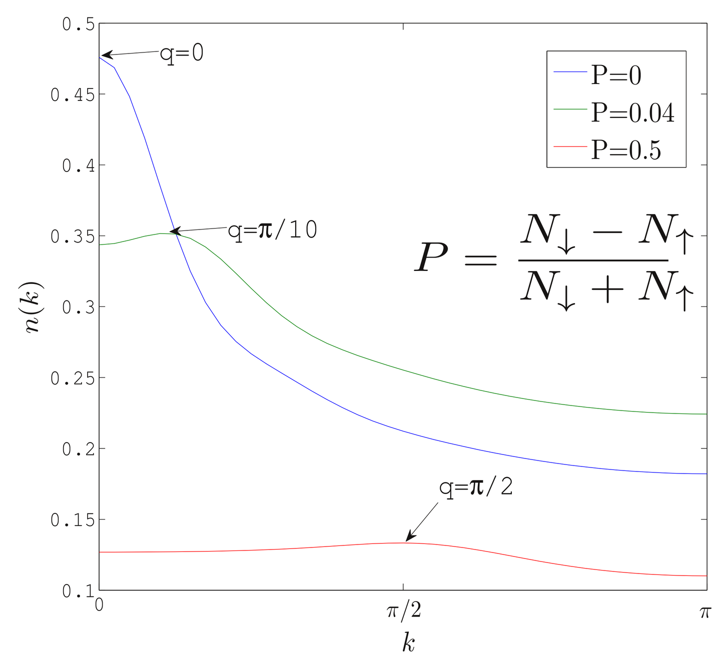


Balanced gas, Cooper pairs — Imbalanced gas, FFLO pairs

Ground States by TEBD



Density profile at P=0.5

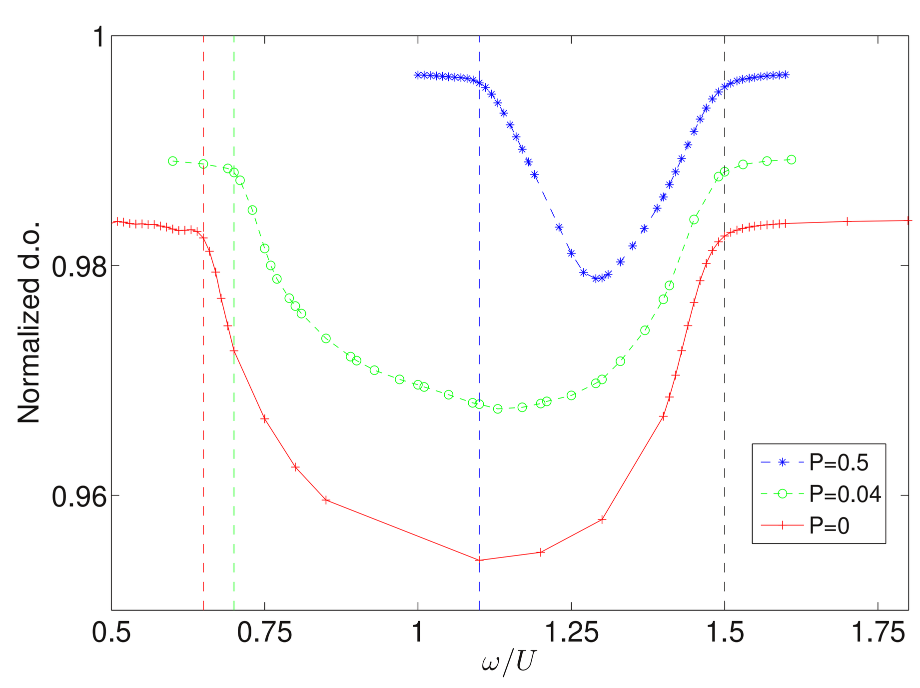


Pair momentum distribution

Peaks determine FFLO vector q for different polarizations.

$$U = -10, J = 1, V = 0.005, L = 80, N_\uparrow + N_\downarrow = 40, N_\uparrow \geqslant N_\downarrow$$

Modulation Spectra by TEBD



Double occupancy for P=0, 0.04, 0.5 at t=10.

Bandwidth:

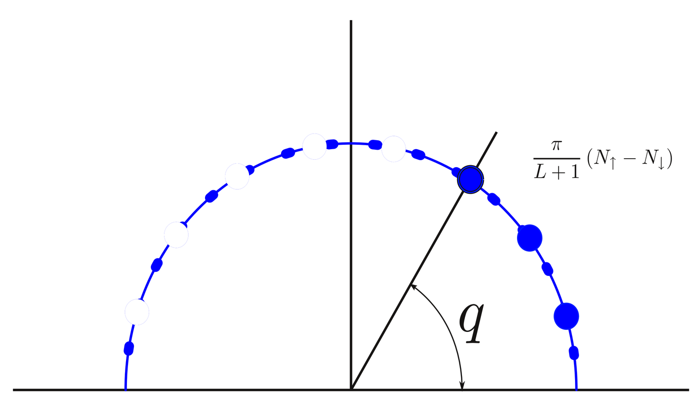
$$\frac{\Delta\omega}{U} = \frac{4J}{U}(1 + \cos q)$$

(see below)

The bandwidth - Bethe Ansatz

Mapping: **attractive** two-component ultracold gas ⟶ **repulsive** two-component ultracold gas ⟶ **spinless fermions**

The energy cost = Pair breaking + Spinless fermion excitation



Spinless fermion excitation:

$$-4J\cos\left(q - \frac{\pi}{L+1}\right) < \Delta E_1 < 4J$$

Pair breaking: $\Delta E_2 \simeq U$

Total width: $U - 4J\cos\left(q - \frac{\pi}{L+1}\right) \leq \omega \leq U + 4J$

We establish a connection between the FFLO vector q and the width of the double occupancy spectrum after modulation. It can provide a direct signature of the FFLO state.

[1] A. Korolyuk, F. Massel, and P. Törmä, PRL 104, 236402 (2010).

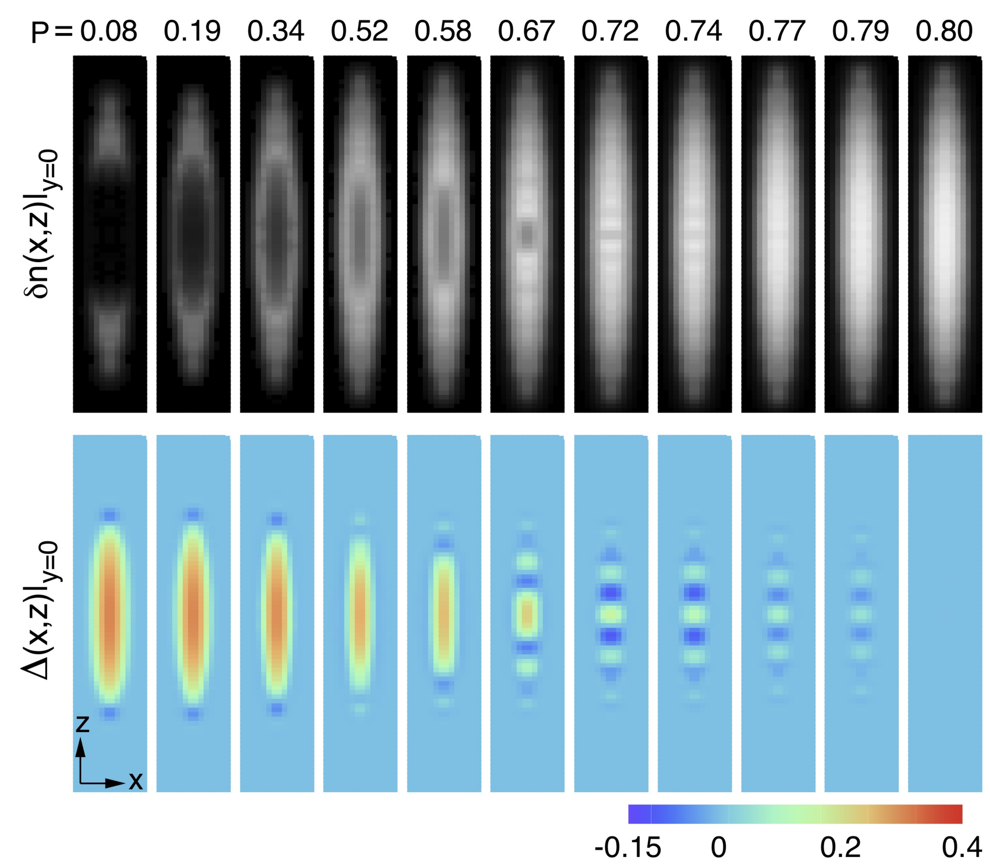
Imbalanced Fermi Gases in Asymmetric Traps

A **real-space dynamical mean-field theory** is used to study the ground states of imbalanced Fermi gases in asymmetric 3D traps.

Examined trap aspect ratio : $\alpha \equiv \frac{\omega_{xy}}{\omega_z} = 1, 2.5, 5, 7.5, 10$

Particle number = ~210 Interaction = -7.9 (corres. to unitary gases)

Density Differences and Pair Potentials at y=0

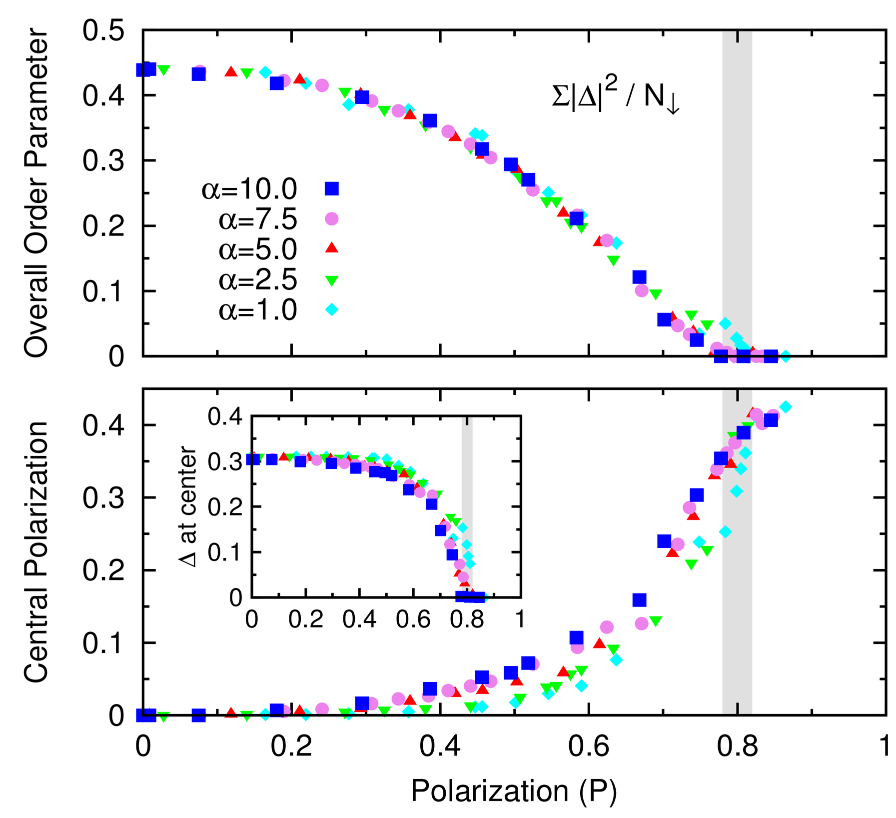


$\alpha = 7.5$

The pair potential is compleletely suppressed above P=0.8.

Oscillations develop in the pair potential and densitiy difference profiles at high polarizations.

Critical Polarization

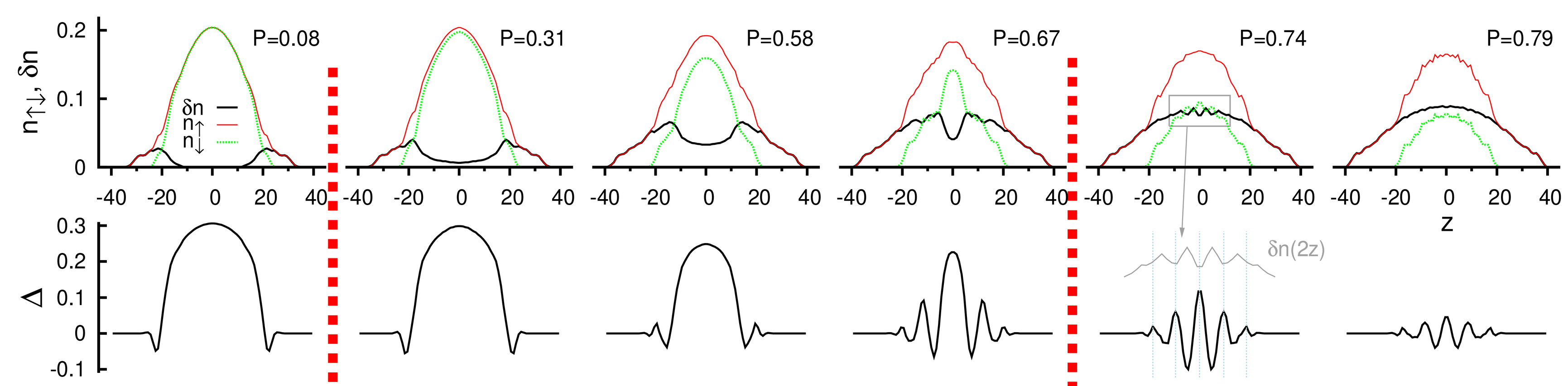


The overall superfluid order parameter goes to 0 near P=0.8 **regardless** of tested trap aspect ratios.

The cloud center is partially polarized in spite of the finite pair potential: a **polarized superfluid** core appears.

Polarized Superfluidity and FFLO-type Oscillations

$\alpha = 7.5$

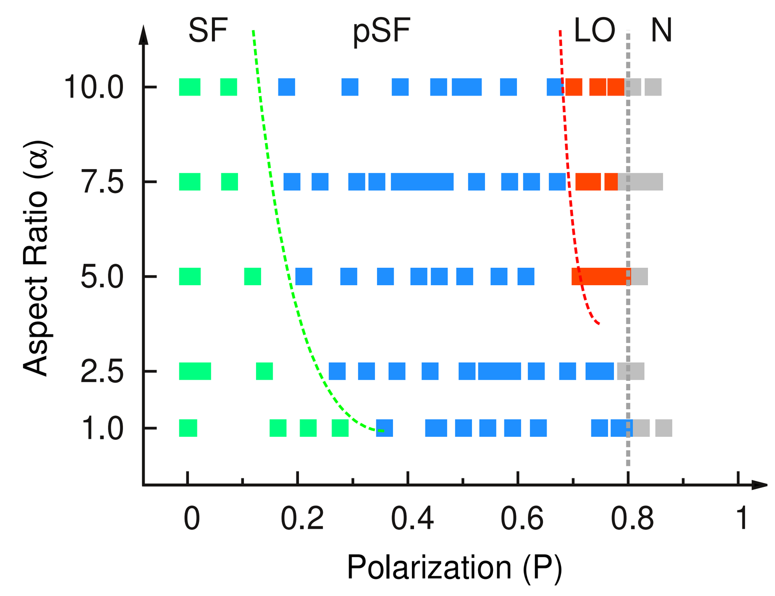


Fully Paired Superfluid core

Partially Polarized Superfluid core

LO type oscillation

Trap Asymmetry Dependence of Core Phases



The polarized superfluid core appears at **lower** polarizations as the **trap** gets **more elongated**.

The LO-type oscillations are found only at **highly elongated traps** with aspect ratios larger than 2.5.