Itinerant ferromagnetism in an ultracold atomic gas

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INTRODUCTION

1. OVERALL AIM

The Ketterle group at MIT have presented the first evidence for ferromagnetic phenomena in a cold atom gas [1]. To critically analyze their experimental results we:

- Compare experiment to mean-field and fluctuation corrected theory
- Understand how three-body losses renormalize the interaction strength
- Study the collective modes in a spin spiral to reduce three-body losses

2. EXPERIMENT & THEORY

The results in Fig. 1 show that with increasing repulsive interactions atoms are forced apart so their density drops and therefore their kinetic energy falls. At the ferromagnetic transition ($k_F a$~2) the atoms enter the same Fermi surface so kinetic energy increases. Atom loss $(k_F a)^6 n_\uparrow n_\downarrow (n_\uparrow + n_\downarrow)$ rises before the transition as $(k_F a)^6$, and in the ferromagnetic state falls as $n_\downarrow \rightarrow 0$.

There is qualitative agreement with mean-field and fluctuation corrected theory [2,3]. However, there is a discrepancy in the critical interaction strength.

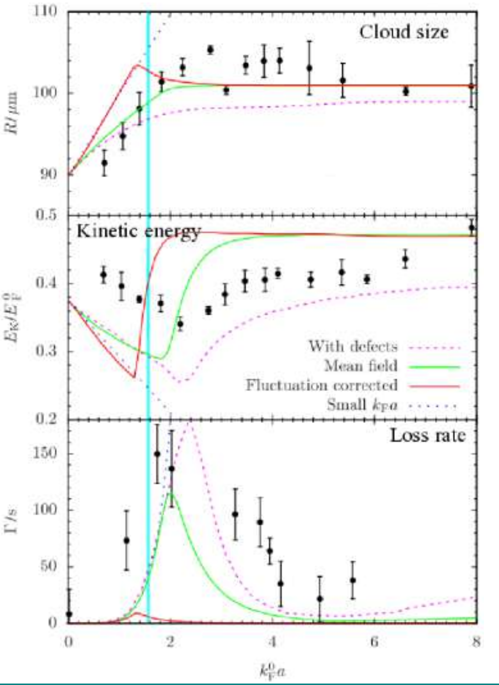

Fig. 1. Experimental points for the cloud size, kinetic energy and atom loss rate. The theoretical results for mean-field theory are shown in green, fluctuation corrected theory in red, and the out-of-equilibrium theory with defect annihilation in dashed magenta.

THREE-BODY LOSS

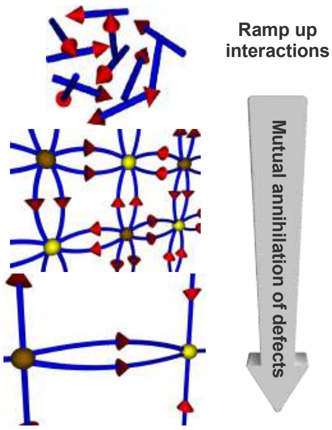

Fig. 2. Topological defects freeze out of the paramagnetic gas and undergo mutual annihilation.

3. MEAN-FIELD DENSITY DROP

To minimize losses the experiment was performed rapidly. The topological defects in Fig. 2 condense out of the gas. They mutually annihilate but inhibit the formation of the ferromagnetic phase [2], which Fig. 1 shows raises the critical interaction strength to $k_F a$~2.

4. DAMPING OF FLUCTUATIONS

Three-body loss also damps quantum fluctuations [4]. Fig. 3 shows how the loss rate renormalizes the effective interaction strength downwards. We therefore require a raised bare interaction strength $k_F a$~2 to realize ferromagnetism.

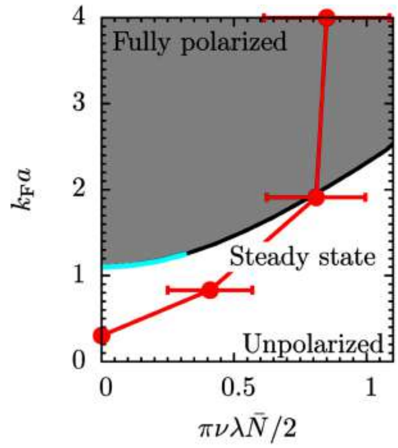

Fig. 3. The phase diagram with interaction strength (kFa) and loss rate (λ). Blue represents a first order, and black a second order transition. The experimental variation of loss rate is shown in red.

5. COLLECTIVE MODES

To circumvent three-body loss the system could be started in a spin spiral (Fig. 4). This relaxes through collective modes growing normal to the spin spiral. By considering the feedback of the growing modes we recover the collective mode growth rates in Fig. 5.

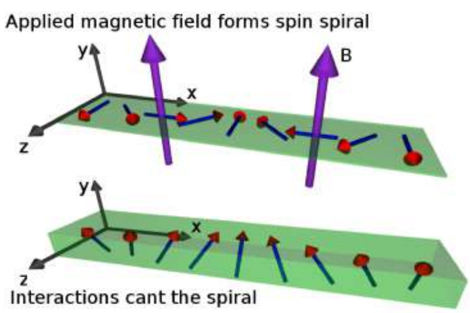

Fig. 4. Evolution of the spin spiral state.

SPIN SPIRAL

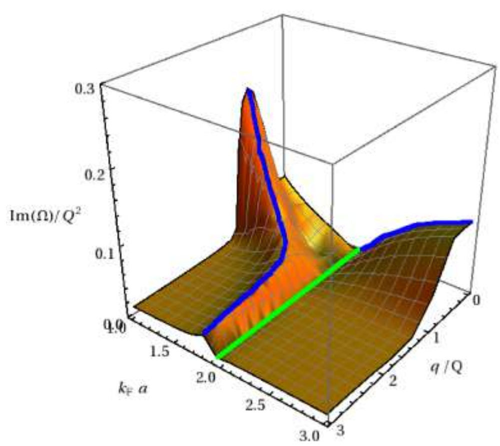

Fig. 5. Growth rate of modes from a spiral state.

CONCLUSIONS

- Mean-field and fluctuation corrected theory are in qualitative agreement with experiment
- Topological defects inhibit the ferromagnetic transition
- Atom loss damps fluctuations so renormalizes the interaction strength
- A spin spiral circumvents atom loss and exhibits distinctive collective modes

REFERENCES

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