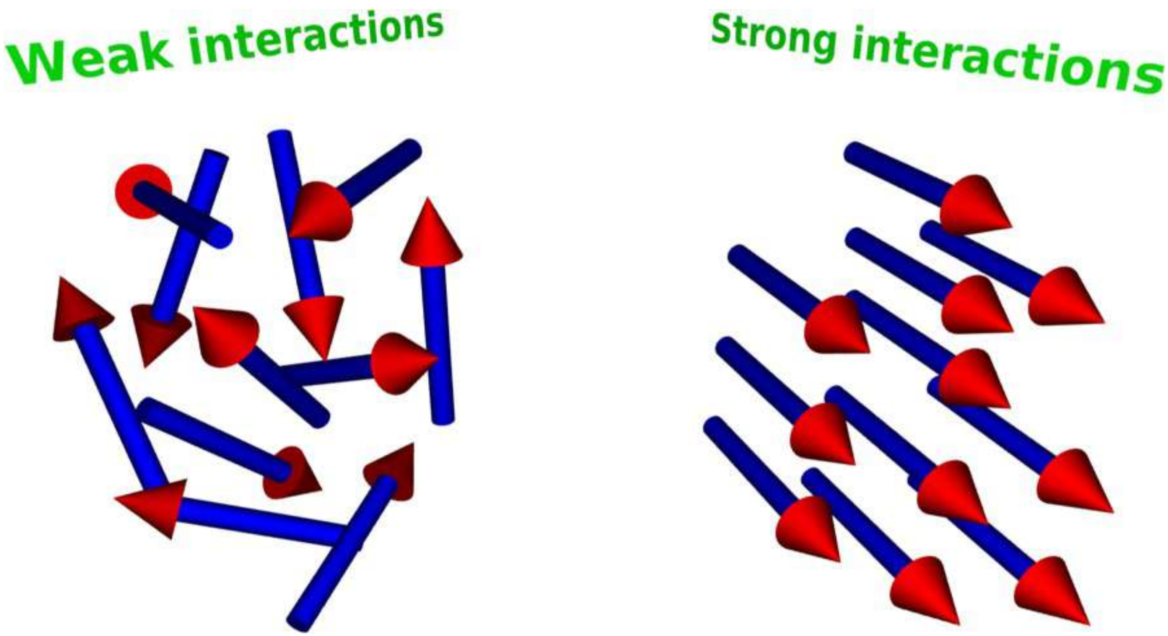
# New experimental protocols to probe the Stoner transition in a Fermi gas




**Gareth Conduit**[1], Ehud Altman[2] & Curt von Keyserlingk[3]

1. University of Cambridge 2. Weizmann Institute of Science 3. University of Oxford

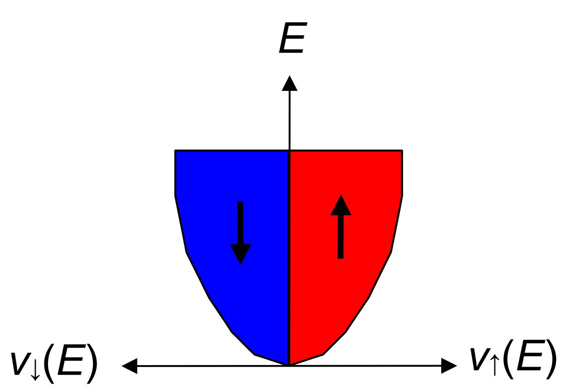
# Stoner instability with repulsive interactions

$$\hat{H} = \sum_{\mathbf{k},\sigma} \epsilon_{\mathbf{k}} c^{\dagger}_{\mathbf{k}\sigma} c_{\mathbf{k}\sigma} + g \sum_{\mathbf{k}\mathbf{k}'\mathbf{q}} c^{\dagger}_{\mathbf{k}\uparrow} c^{\dagger}_{\mathbf{k}'+\mathbf{q}\downarrow} c_{\mathbf{k}'+\mathbf{q}\downarrow} c_{\mathbf{k}'\uparrow}$$

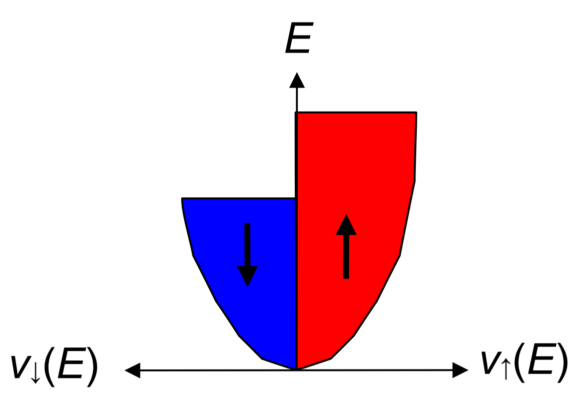
- Mean-field energy

$$E = \sum_{\mathbf{k},\sigma} \epsilon_{\mathbf{k}} n_{\sigma}(\epsilon_{\mathbf{k}}) + g N_{\uparrow} N_{\downarrow}$$

**Not magnetised**

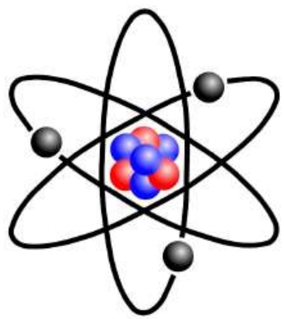



**Partially magnetised**



# Atomic gases: a new forum for ferromagnetism

- A gas of atoms simulates electrons in a solid



$^{6}$Li atom

$$|F = 1/2, m_F = 1/2\rangle$$

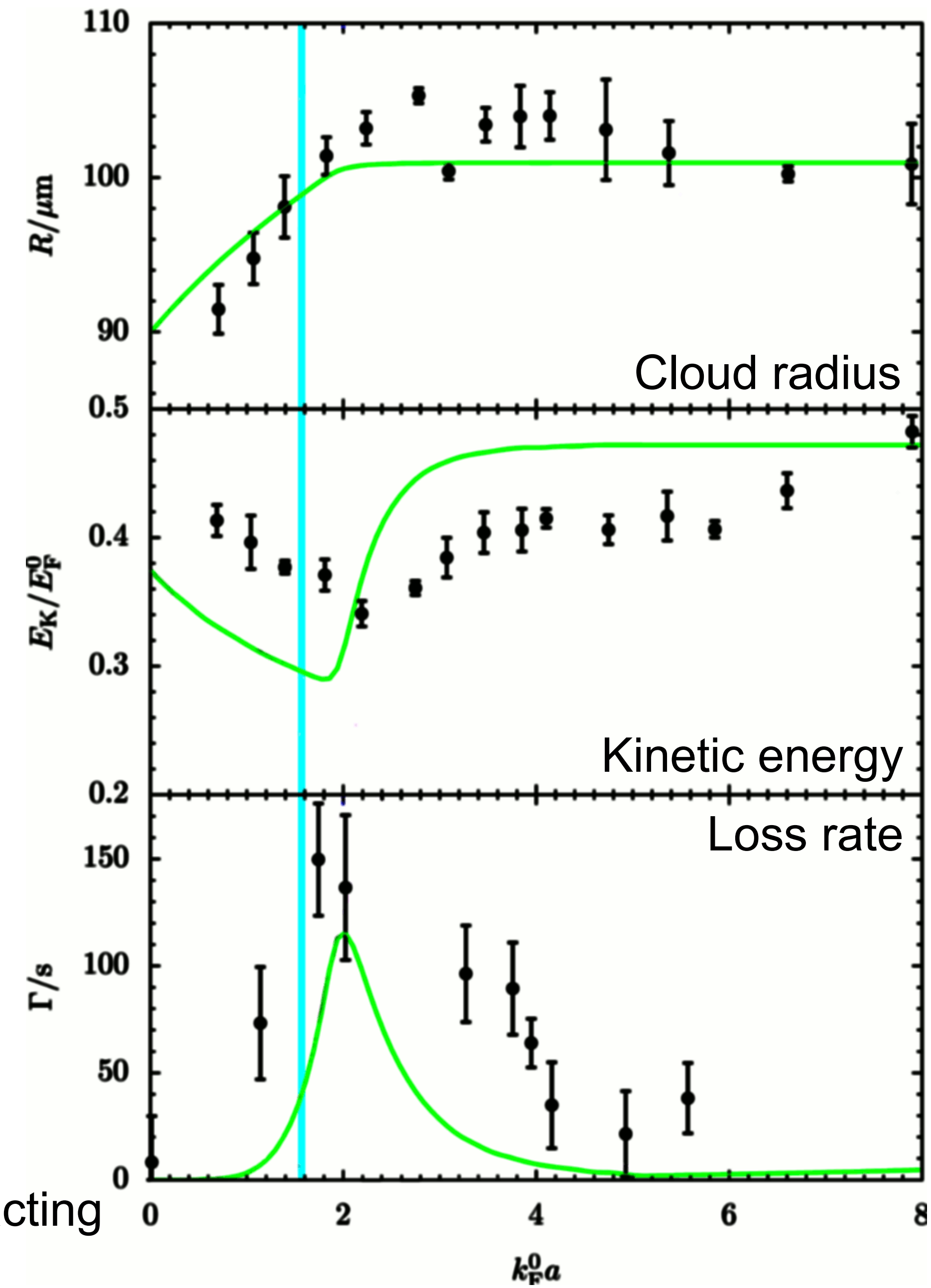
Up spin electron

$$|F = 1/2, m_F = -1/2\rangle$$

Down spin electron

- Key experimental advantages:
  - Magnetic field controls interaction strength
  - Contact interaction
  - Clean system

# Ketterle experiment

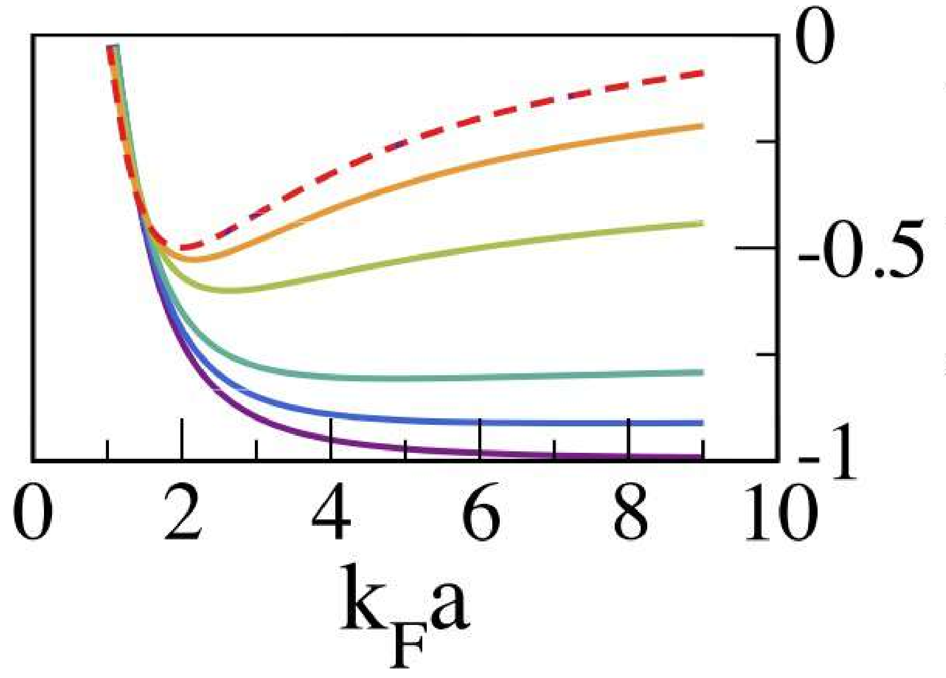


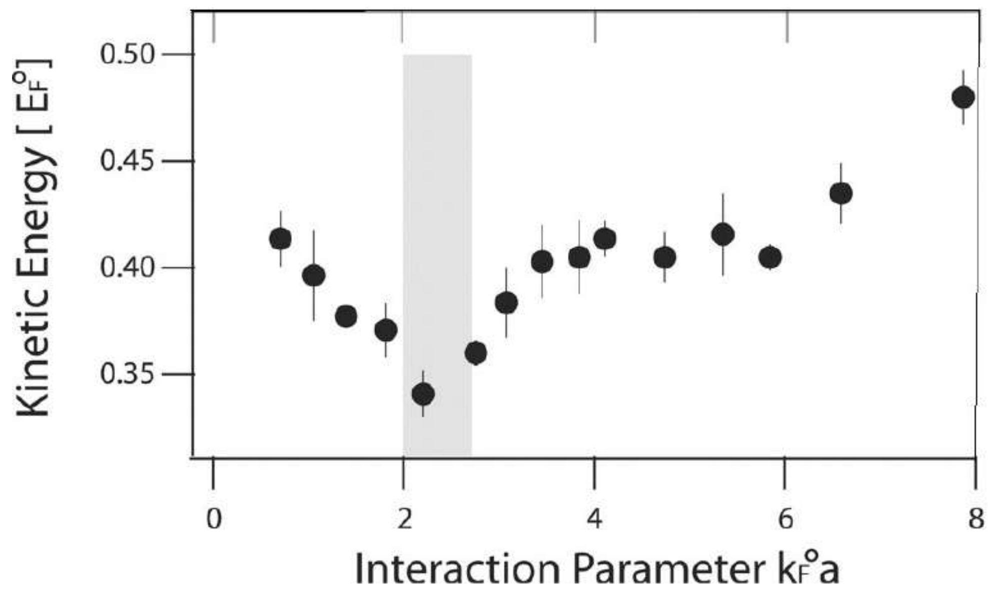

Non-interacting

Strongly repulsive

Jo *et al*, Science **325**, 1521 (2009)
GJC & Simons, PRL **103**, 200403 (2009)

# Two-body loss

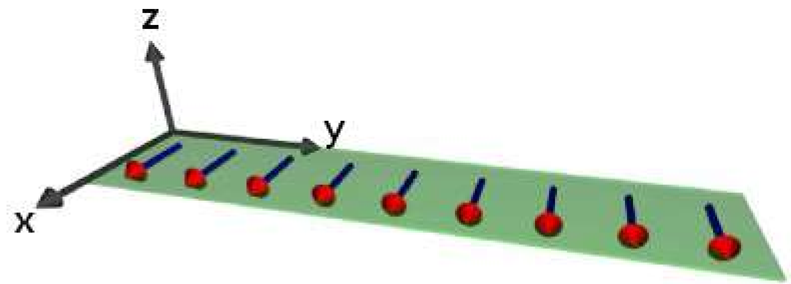


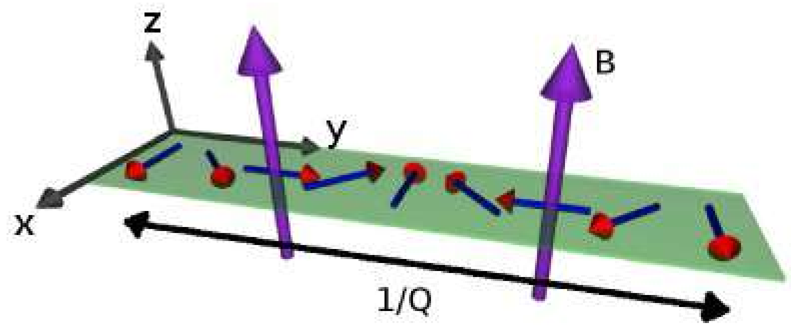

Pekker *et al*, PRL **106**, 050402 (2011)

# Alternative strategy: spin spiral

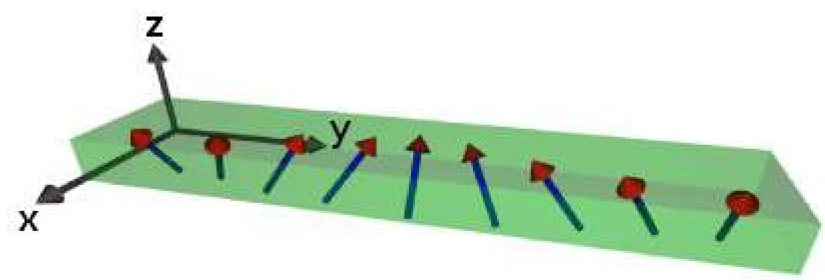
(a) Fully polarized state




(b) Magnetic field gradient forms spin spiral



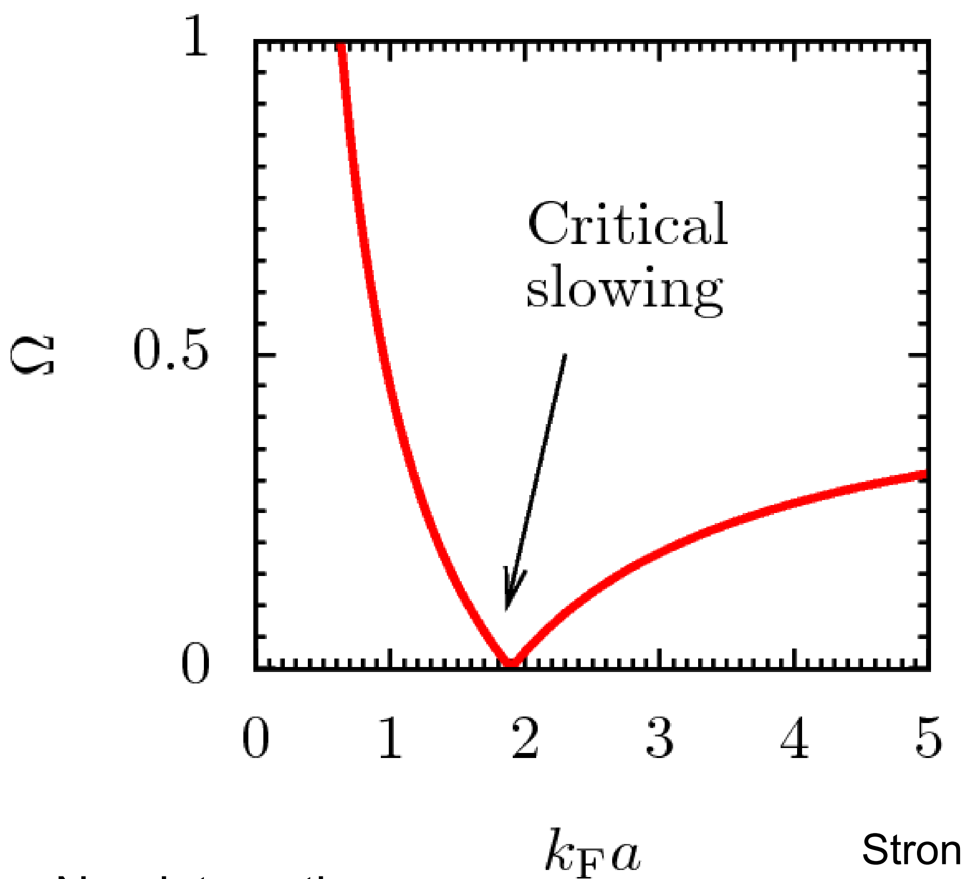

(c) Interactions cant the spiral



# Spin spiral collective modes

- Exponentially growing collective modes if $k<Q$ [GJC & Altman, PRA **82**, 043603 (2010)]

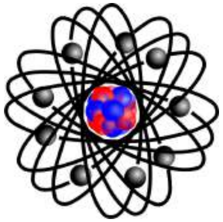
$$\Omega = \pm \left( \frac{1}{2} - \frac{2^{2/3}3}{5 k_F a} \right) k \sqrt{Q^2 - k^2}$$




Non-interacting

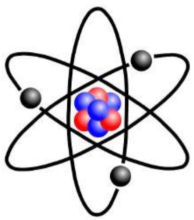
Strongly repulsive

# Mass imbalance ferromagnetism



$^{40}$K atom, $m$=40$m_0$

Up spin electron



$^{6}$Li atom, $m$=6$m_0$

Down spin electron

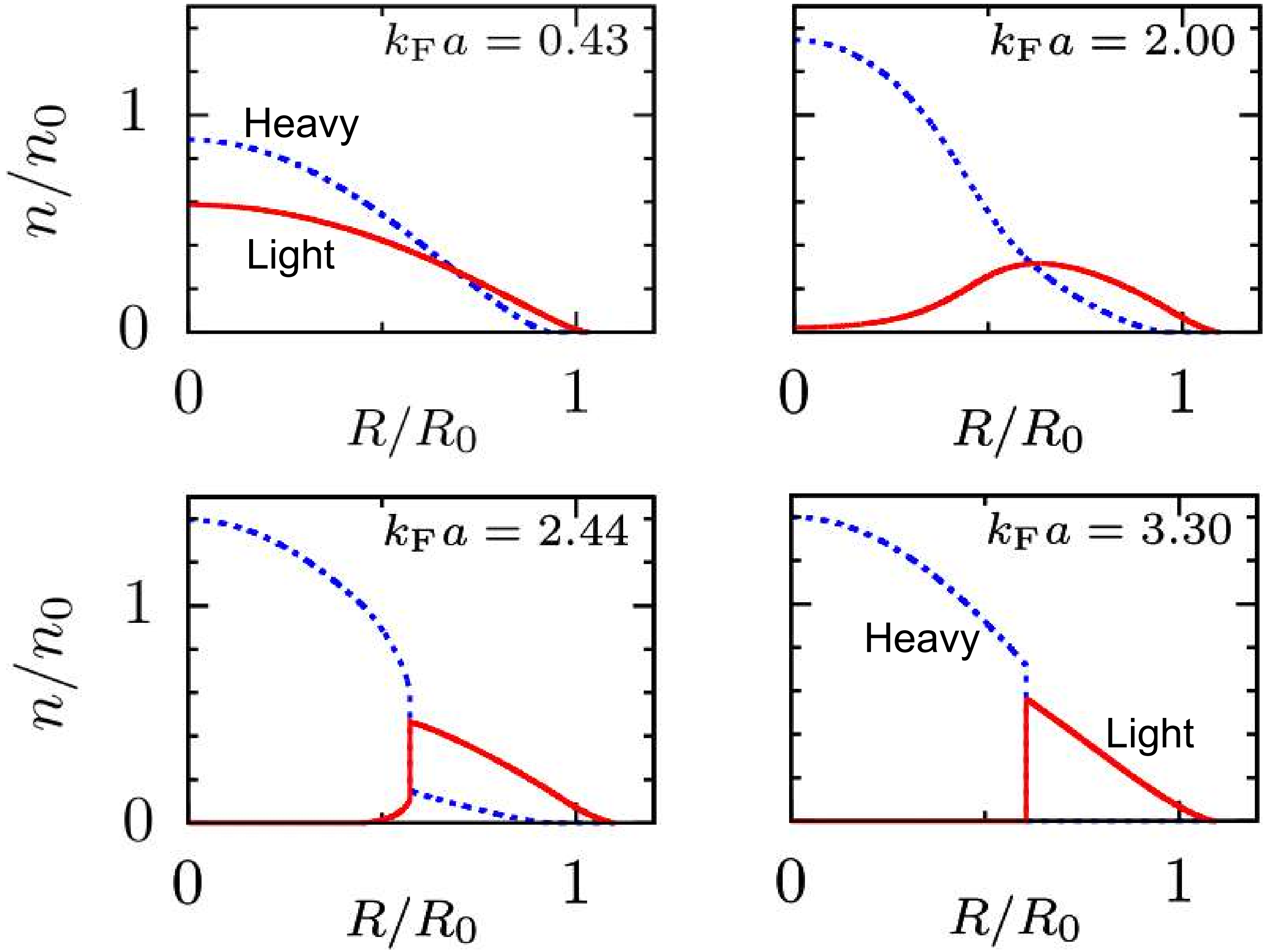
$$\hat{H} = \sum_{k} \frac{k^2}{2\mathrm{m}_{\uparrow}} c^{\dagger}_{k\uparrow} c_{k\uparrow} + \sum_{k} \frac{k^2}{2\mathrm{m}_{\downarrow}} c^{\dagger}_{k\downarrow} c_{k\downarrow} + g \sum_{kk'q} c^{\dagger}_{k\uparrow} c^{\dagger}_{k'+q\downarrow} c_{k'+q\downarrow} c_{k'\uparrow}$$

- Magnetic moment formed along quantization axis

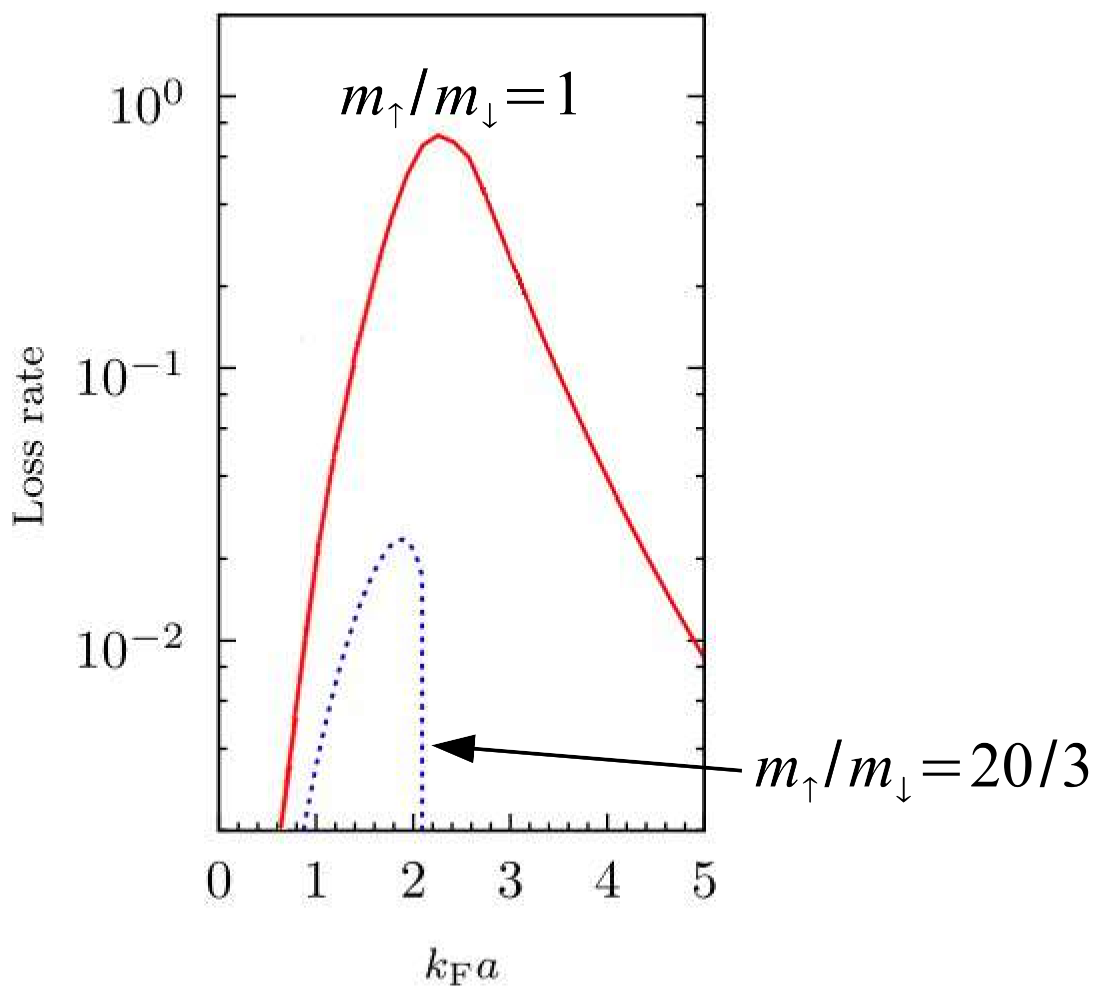
Keyserlingk & GJC, PRA **83**, 053625 (2011)

# Behavior in a trap

- At zero interaction strength atoms spread all over trap, at high interaction strength light atoms forced to outside



# Reduced many-body losses



# Summary

- Ketterle's experiment is consistent with the formation of a ferromagnetic ground state
- Competing many-body instabilities provide alternative explanation
- Circumvent loss by studying the evolution of a spin spiral or mass imbalance
- Answer long-standing questions about solid state ferromagnetism and motivate new research arenas