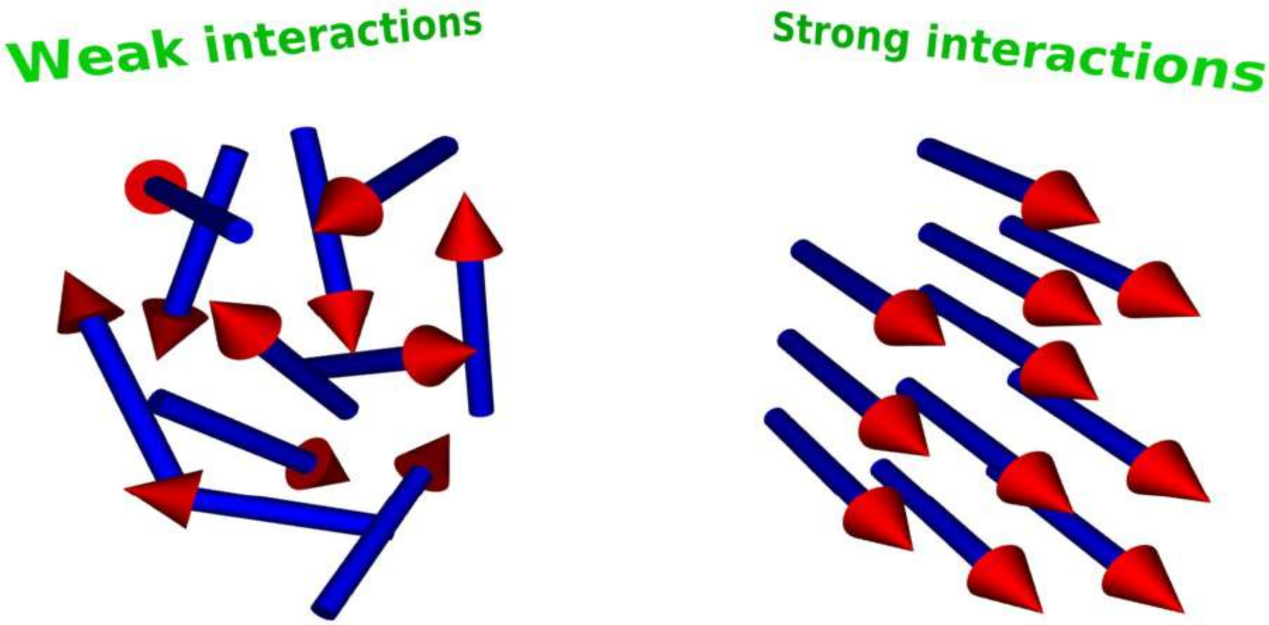
The realization of itinerant ferromagnetism in an atomic Fermi gas



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G.J. Conduit & B.D. Simons, Phys. Rev. A **79**, 053606 (2009)

G.J. Conduit, A.G. Green & B.D. Simons, Phys. Rev. Lett. **103**, 207201 (2009)

G.J. Conduit & B.D. Simons, Phys. Rev. Lett. **103**, 200403 (2009)

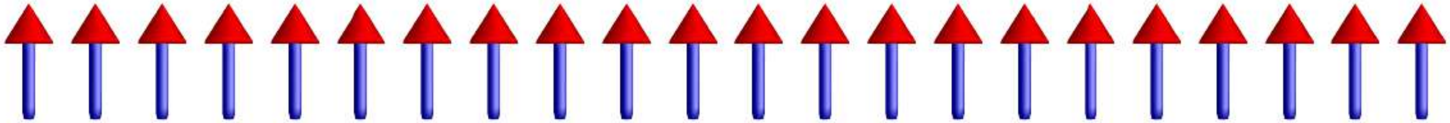
G.J Conduit & E. Altman, Phys. Rev. A **82**, 043603 (2010)

G.J. Conduit, Phys. Rev. A **82**, 043604 (2010)

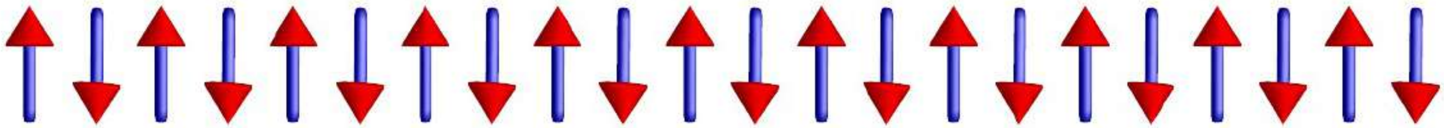
What is itinerant ferromagnetism?

- **Localized ferromagnetism**: moments confined in real space

Ferromagnet:

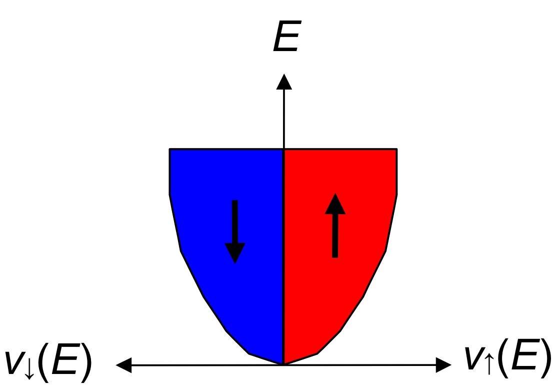


Antiferromagnet:

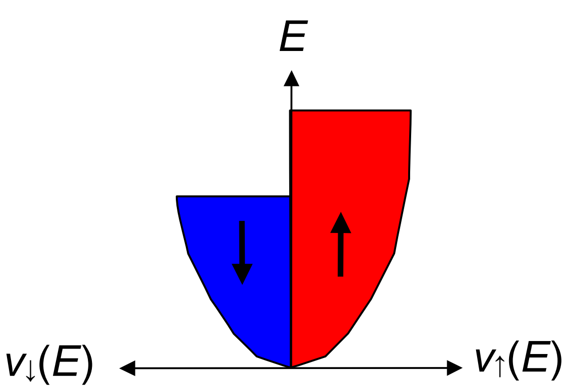


- **Itinerant ferromagnetism**: electrons in Bloch wave states

Not magnetised



Partially magnetised



Stoner instability with repulsive interactions

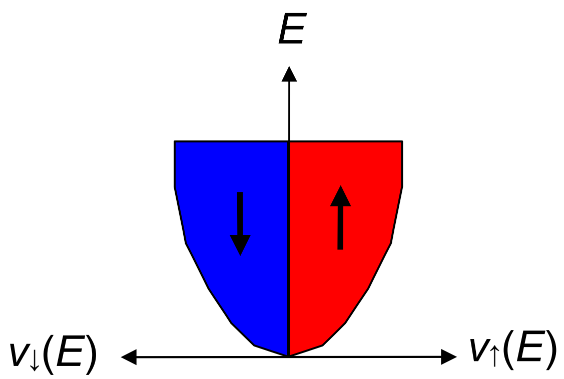
$$\hat{H}=\sum_{k\sigma}\epsilon_k c^\dagger_{k\sigma}c_{k\sigma}+g\sum_{kk'q}c^\dagger_{k\uparrow}c^\dagger_{k'+q\downarrow}c_{k'+q\downarrow}c_{k'\uparrow}$$

- Following a mean-field approximation

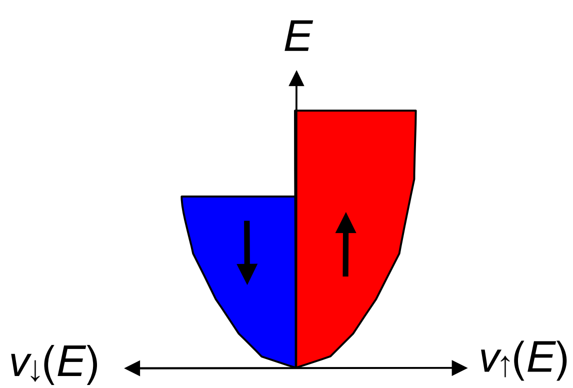
$$E=\sum_{\mathbf{k},\sigma}\epsilon_{\mathbf{k}}n_\sigma(\epsilon_{\mathbf{k}})+gN_\uparrow N_\downarrow$$

- A Fermi surface shift increases the kinetic energy and potential energy falls
- Ferromagnetic transition occurs if $g\nu>1$

Not magnetised



Partially magnetised

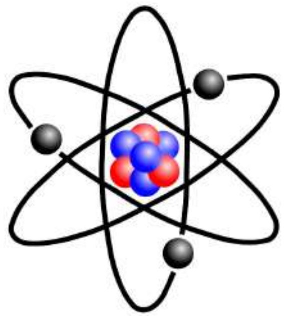


Conduit & Simons, Phys. Rev. A **79**, 053606 (2009)

Jo, Lee, Choi, Christensen, Kim, Thywissen, Pritchard & Ketterle, Science **325**, 1521 (2009)

Atomic gases: a new forum for many-body physics

- A gas of atoms simulates electrons in a solid

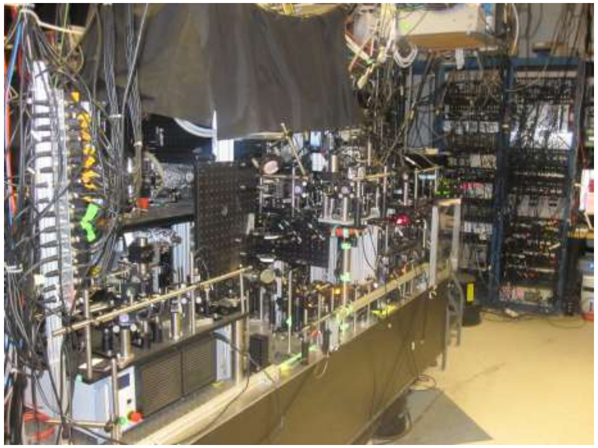


^{6}Li atom

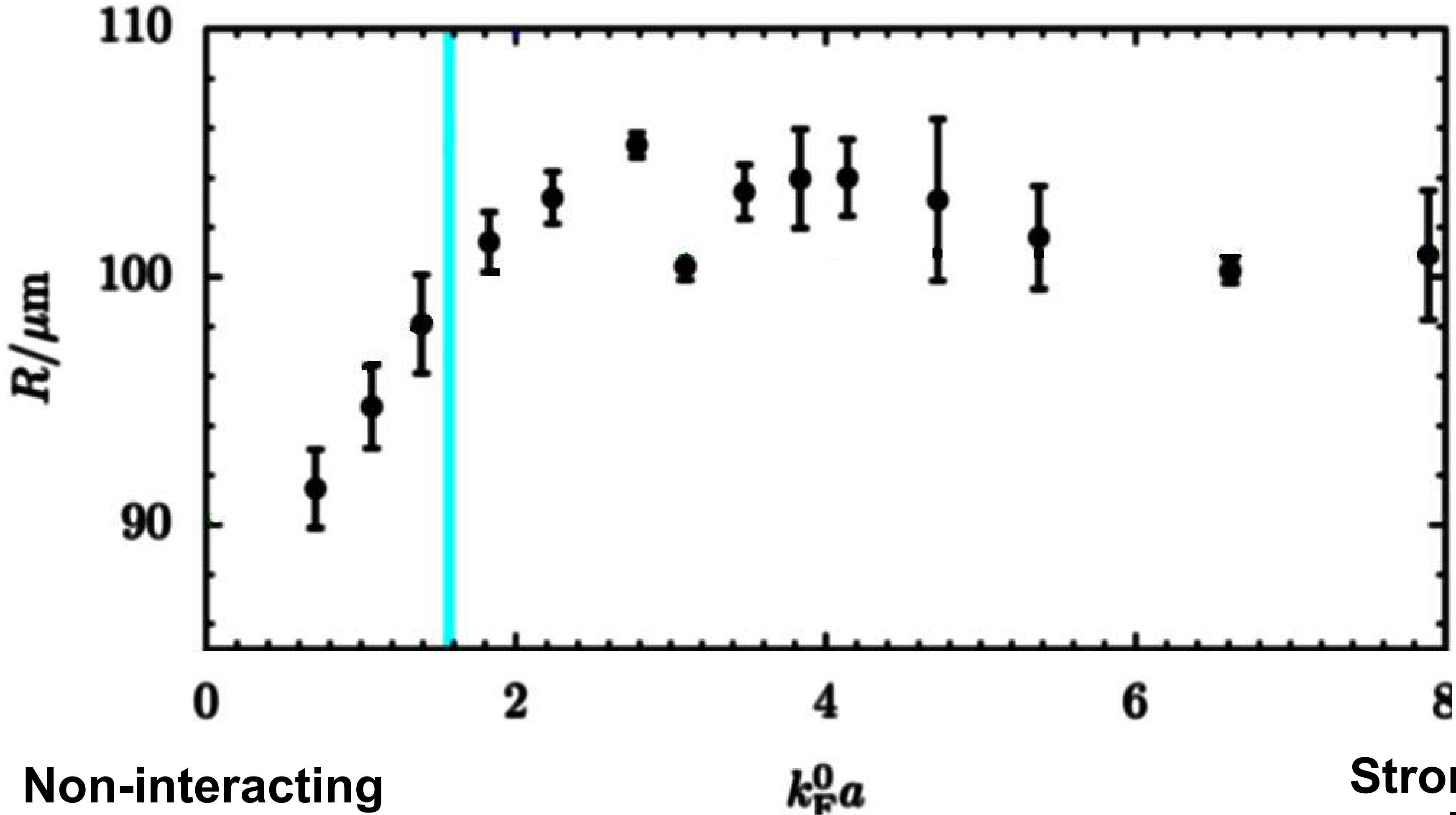
$$|F = 1/2, m_F = 1/2\rangle$$ →  Up spin electron

$$|F = 1/2, m_F = -1/2\rangle$$ →  Down spin electron

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



Experimental evidence for ferromagnetism

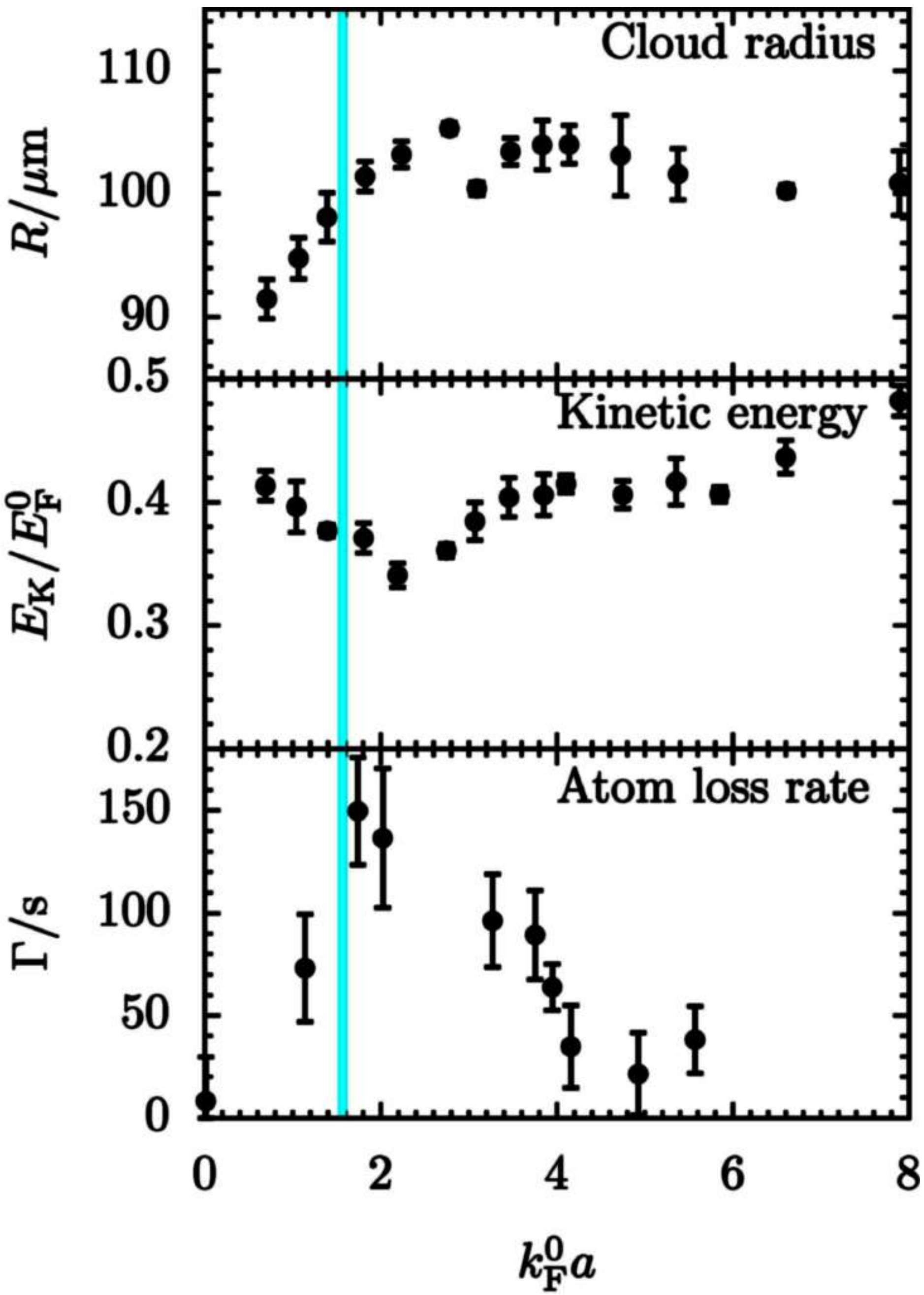


Non-interacting

Strongly repulsive

Jo, Lee, Choi, Christensen, Kim, Thywissen, Pritchard & Ketterle, Science **325**, 1521 (2009)

Further key experimental signatures



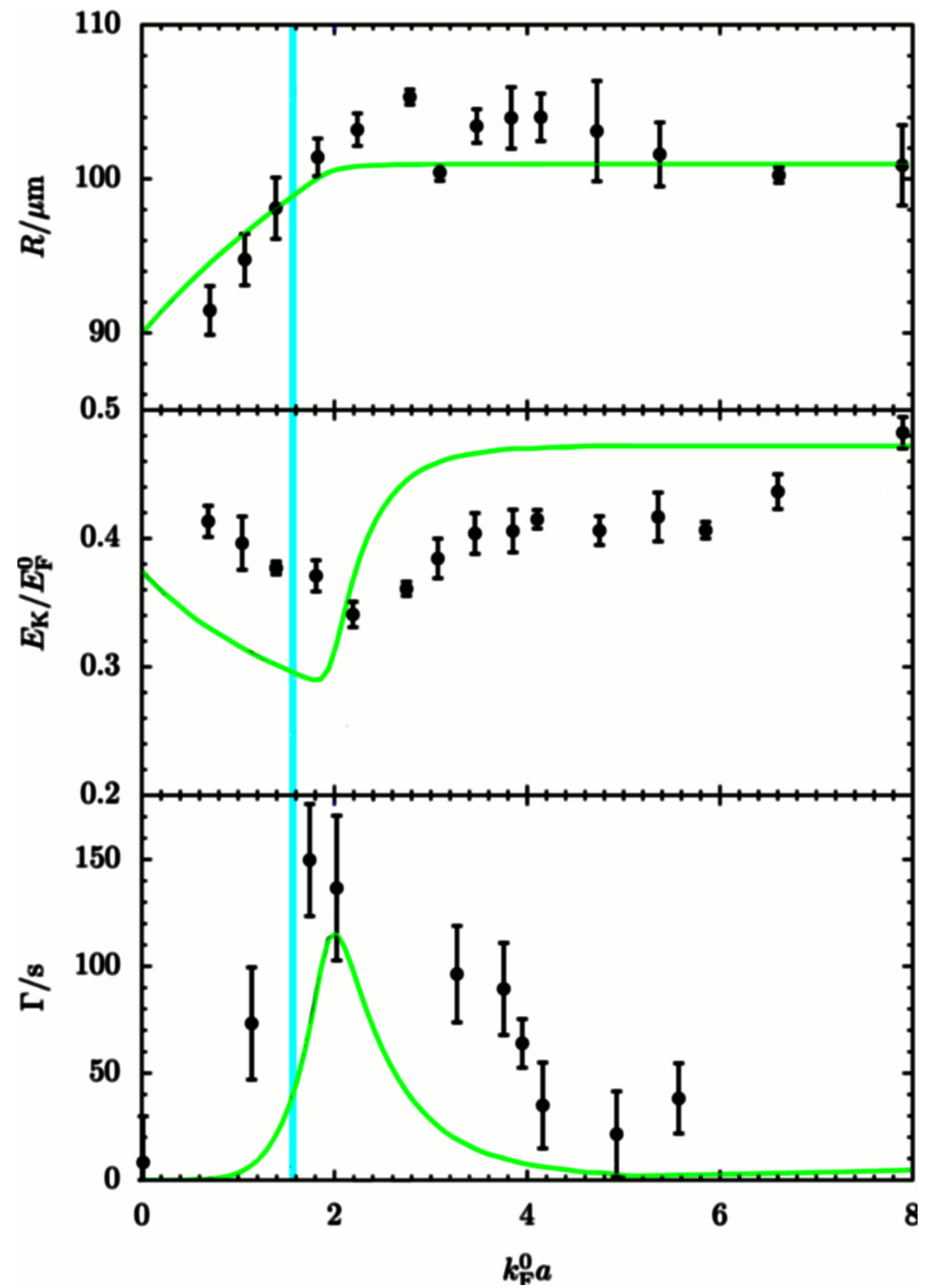
$$E_K \propto n^{5/3}$$

$$\Gamma \propto (k_F a)^6 n_\uparrow n_\downarrow (n_\uparrow + n_\downarrow)$$

Jo, Lee, Choi, Christensen, Kim, Thywissen, Pritchard & Ketterle, Science **325**, 1521 (2009)

Mean-field analysis & consequences of trap

- Recovers qualitative behavior[1] but transition at $k_F a$=1.8 instead of $k_F a$=2.2
- Fluctuation corrections: $k_F a$=1.1
- QMC calculations: $k_F a$=0.8

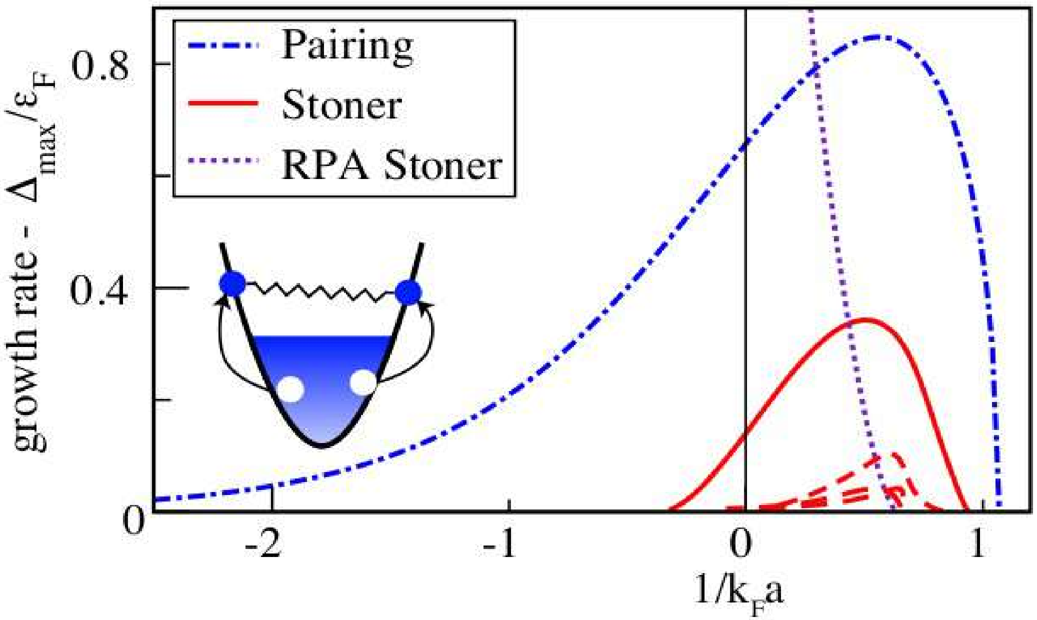


[1]LeBlanc, Thywissen, Burkov & Paramekanti, Phys. Rev. A **80**, 013607 (2009) & GJC & Simons, Phys. Rev. Lett. **103**, 200403 (2009)

Consequences of atom loss

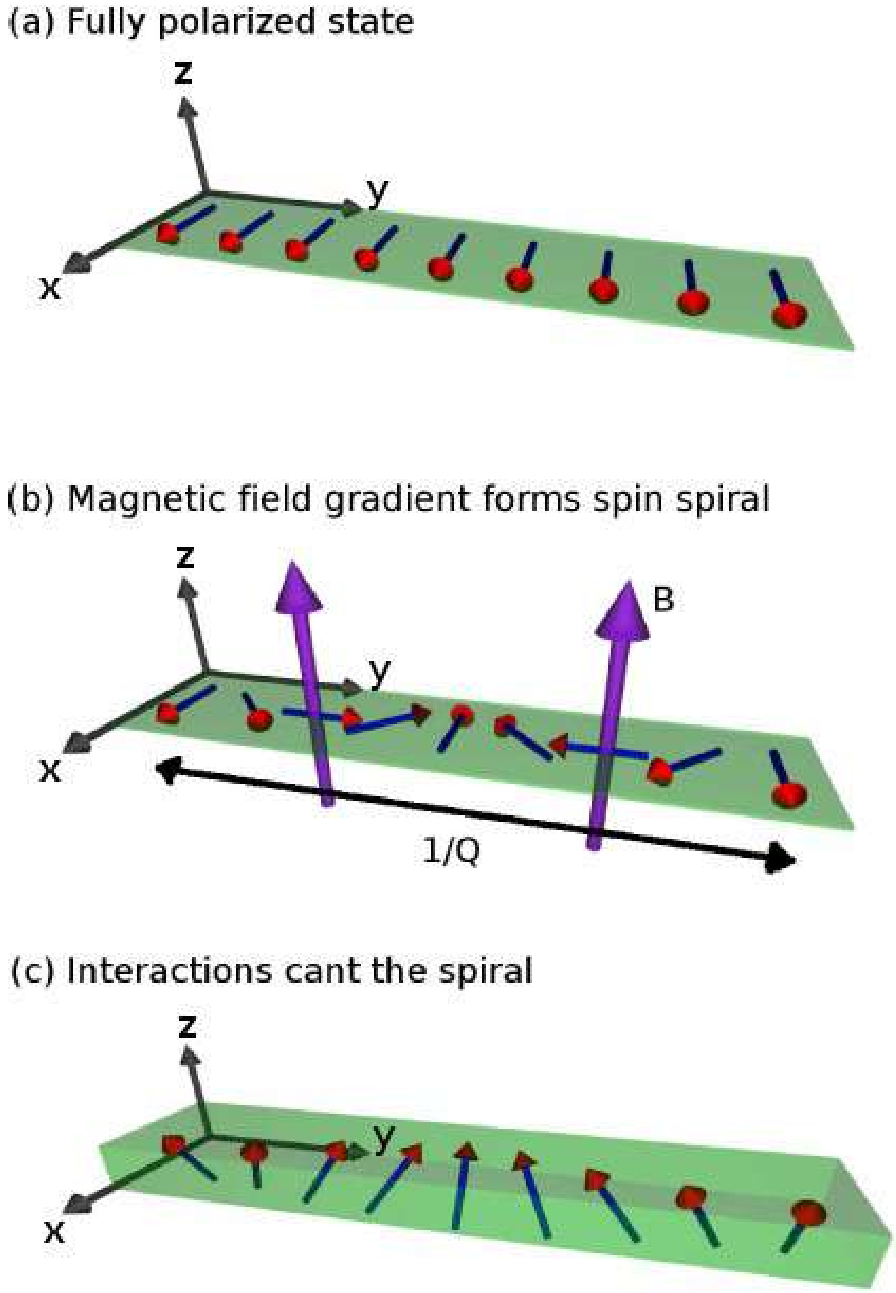
- Three-body loss can damp fluctuations inhibiting ferromagnetism [GJC & Altman, arXiv:0911.2839]

- Pairing instability supported by Fermi surface [Pekker *et al*., arXiv:1005.2366]



- Defects freeze out from paramagnetic state and undergo mutual annihilation [GJC & Simons, Phys. Rev. Lett. **103**, 200403 (2009)]

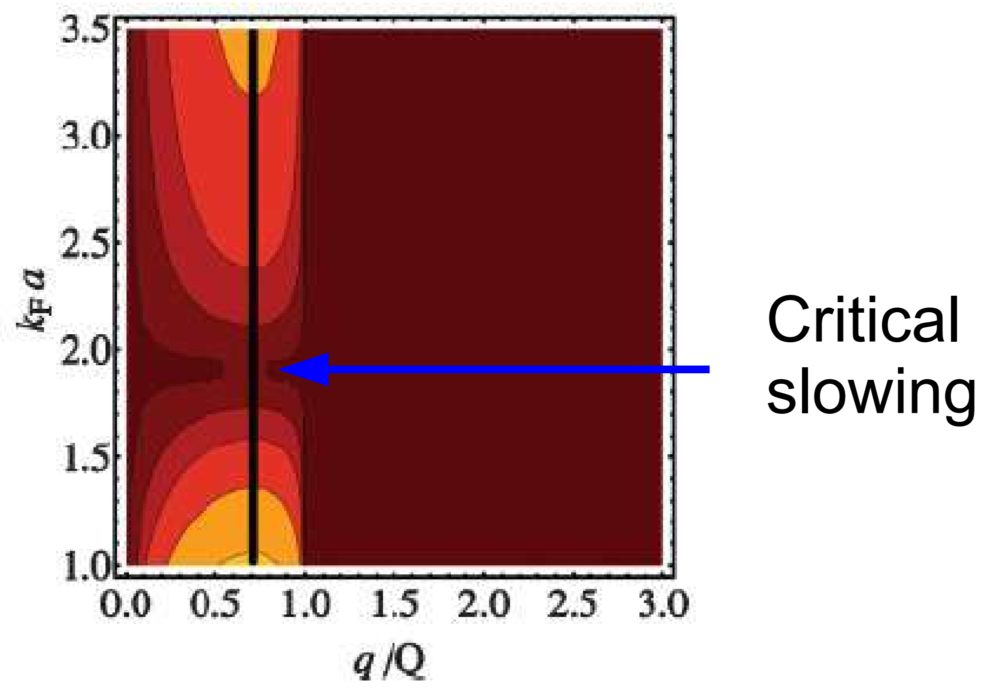
Alternative strategy: spin spiral



Spin spiral collective modes

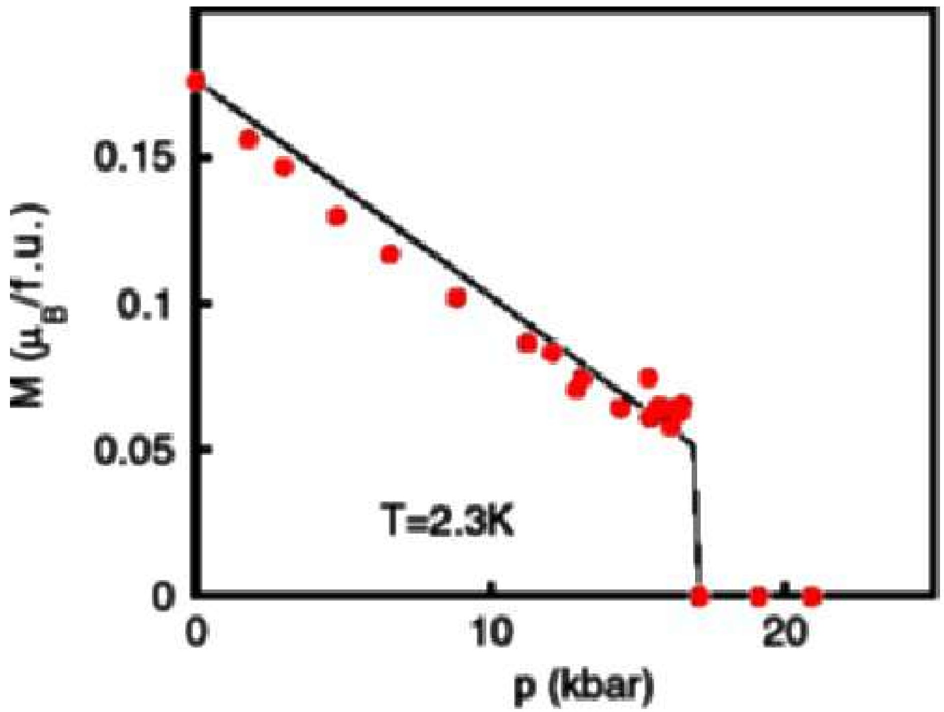
- Exponentially growing collective modes if *p*<*Q*
  [GJC & Altman, PRA **82**, 043603 (2010)]

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



Outlook

- First order transition
- Textured phase
- Mass imbalance
- SU(N) spins
- Two-dimensional itinerant ferromagnetism



Summary

- Equilibrium theory provides a reasonable qualitative description of the transition
- Dynamical effects can provide a better description of ferromagnetism but also disrupt the ferromagnetic phase
- Circumvent three-body loss by studying the evolution of a spin spiral
- Answer long-standing questions about solid state ferromagnetism and motivate new research arenas