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Cold atoms in a spin

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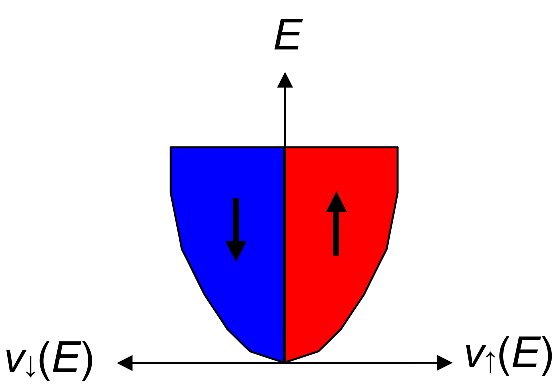
Stoner instability

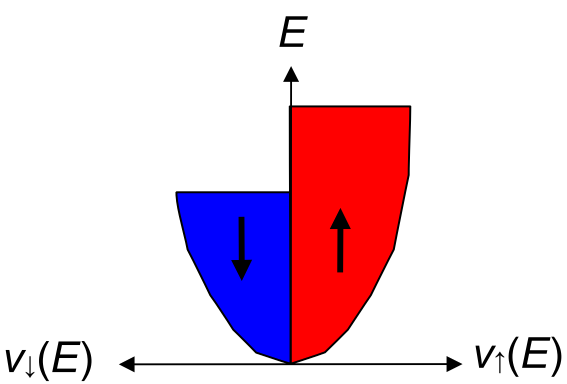
$$\hat{H} = \sum_{k\sigma} \epsilon_k c^{\dagger}_{k\sigma} c_{k\sigma} + g \sum_{kk'q} c^{\dagger}_{k\uparrow} c^{\dagger}_{k'+q\downarrow} c_{k'+q\downarrow} c_{k'\uparrow}$$

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

Not magnetized

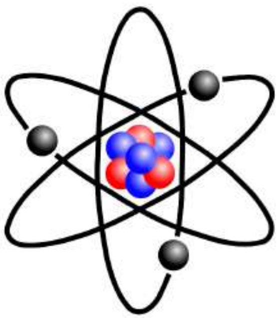


Partially magnetized



Magnetism with cold atoms

- A gas of atoms simulates electrons in a solid



^{6}Li atom

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

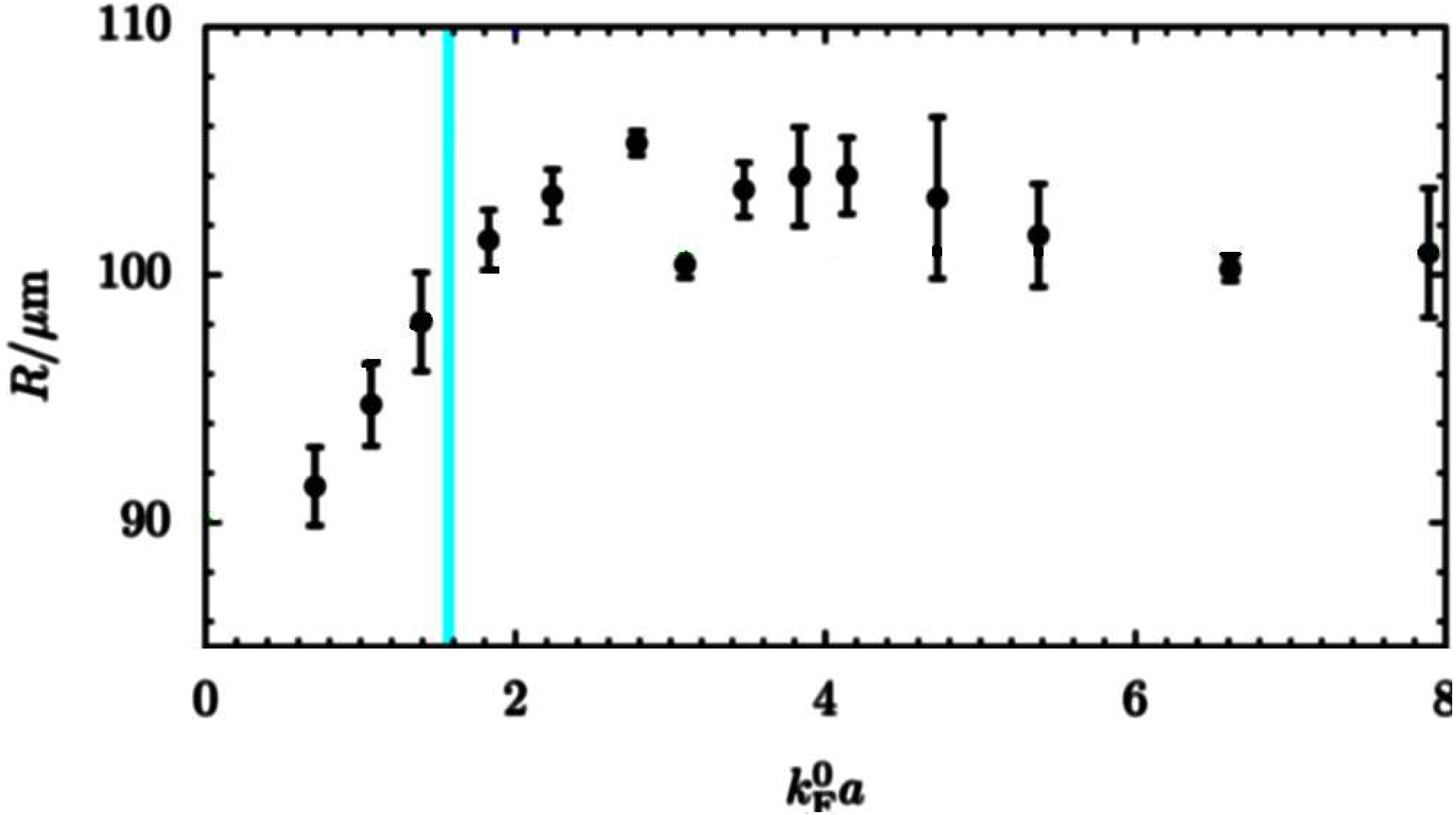
Up spin electron

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

Down spin electron

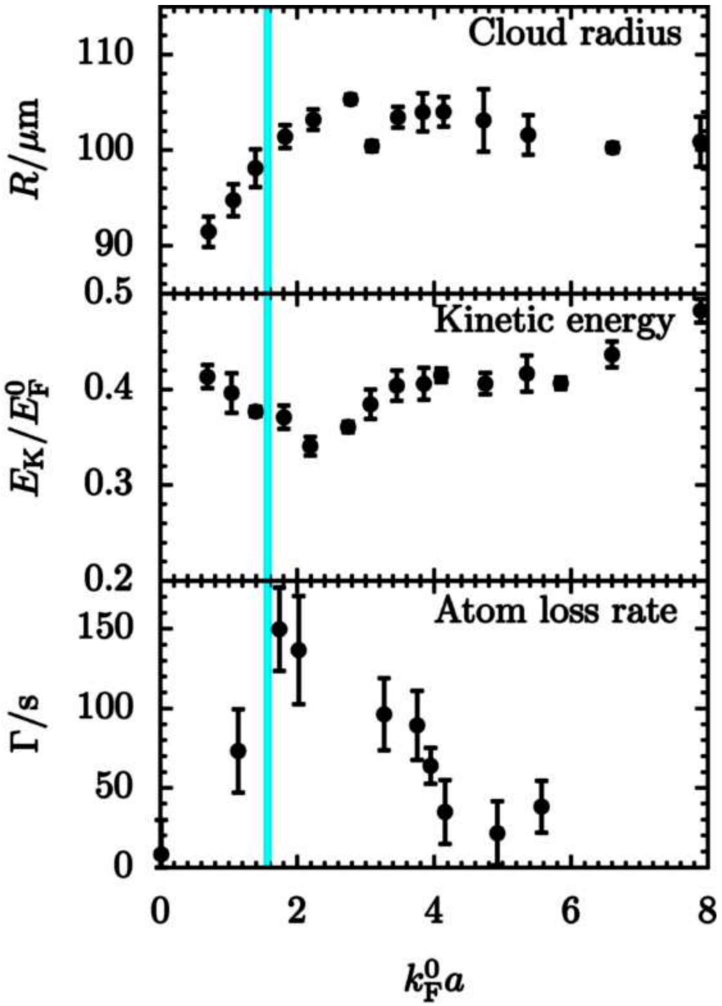
- Magnetic field controls interaction strength
- Contact interaction
- Clean system

Experimental evidence for ferromagnetism



Jo *et al*, Science **325**, 1521 (2009)

Further experimental signatures

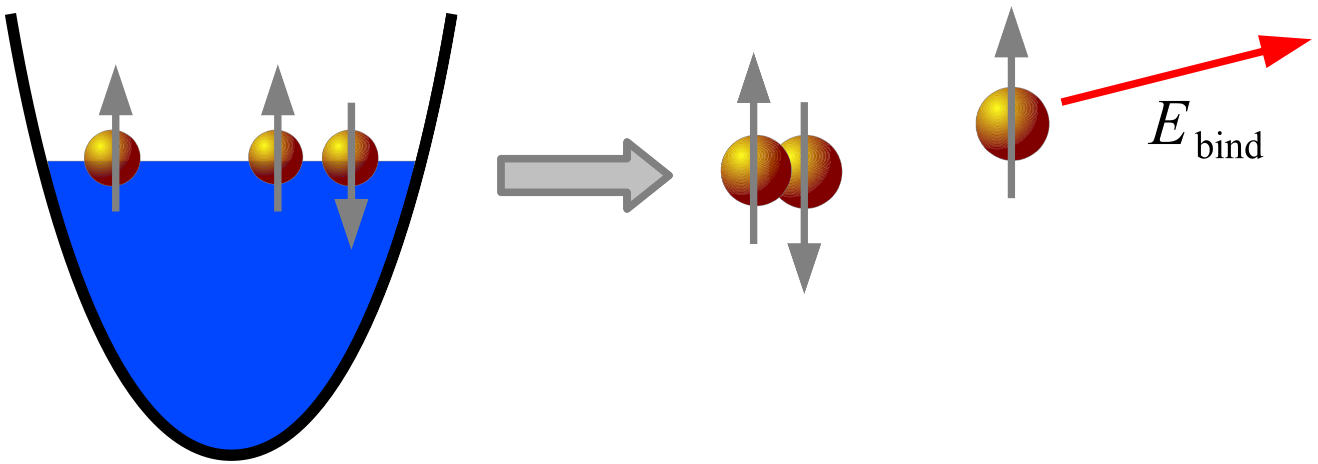


$$E_K \propto n^{5/3}$$

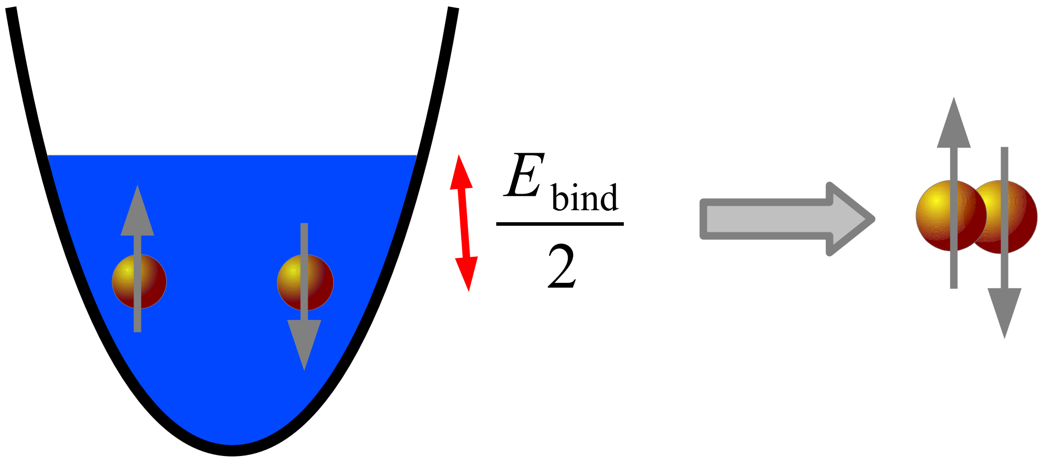
$$\Gamma \propto (k_F a)^6 n_\uparrow n_\downarrow (n_\uparrow + n_\downarrow)$$

Two vs three-body loss

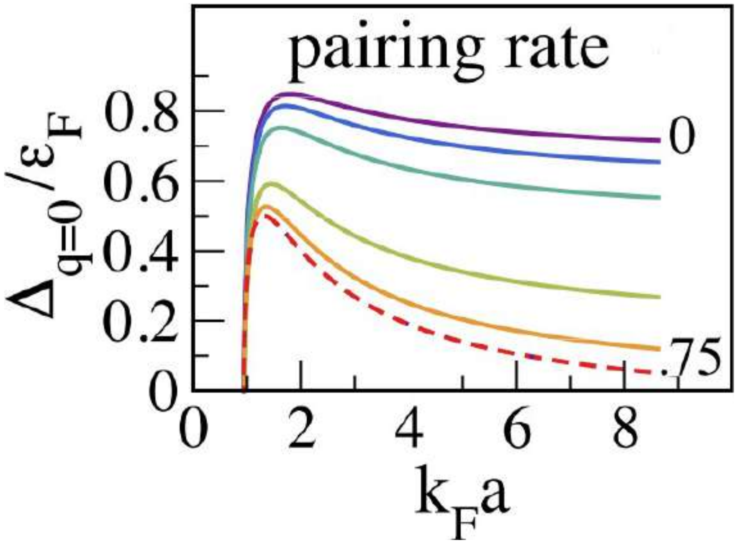
Three-body mechanism

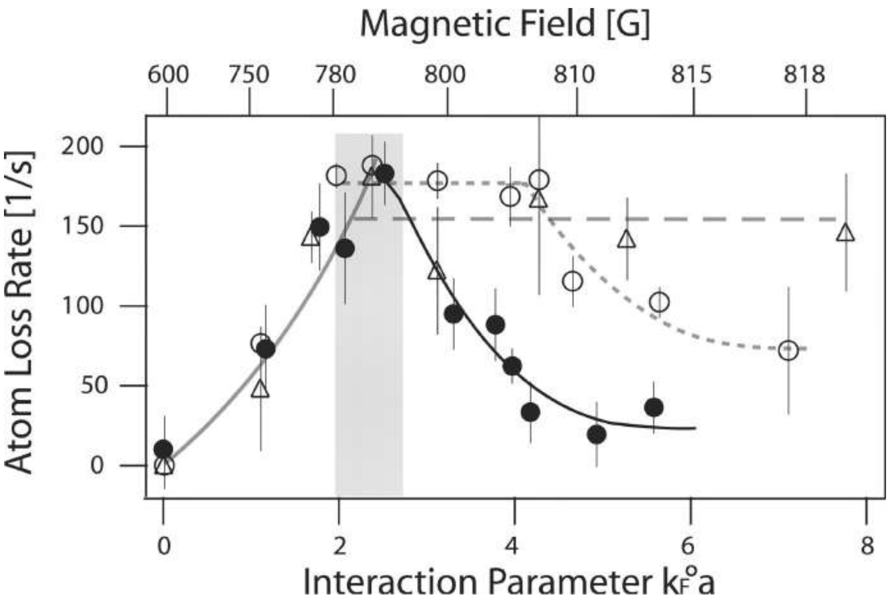


Two-body mechanism

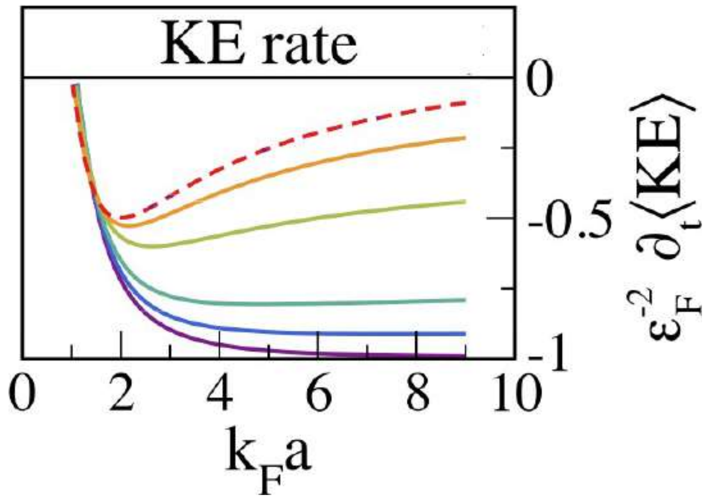


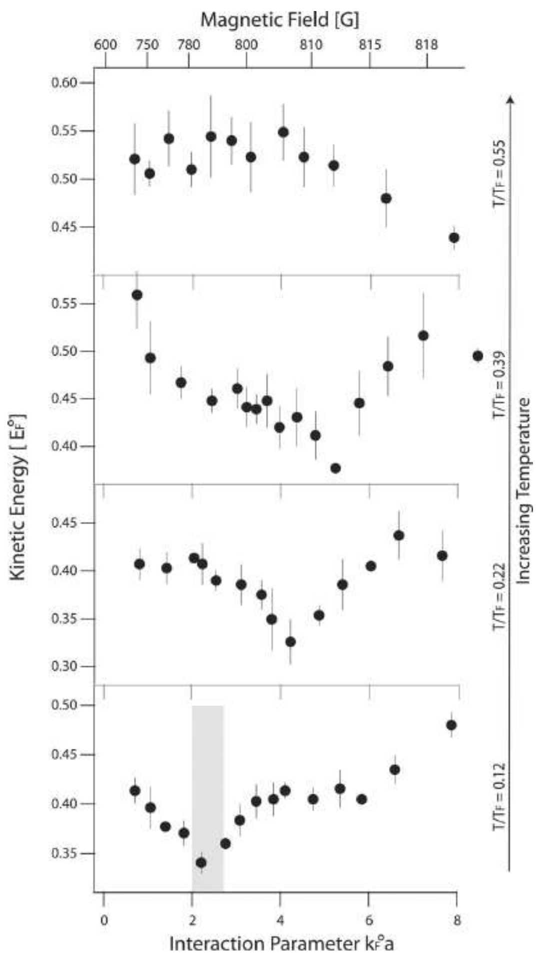
Pairing loss rate



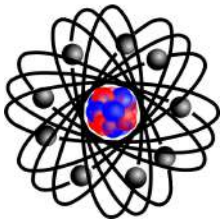


Pairing losses: kinetic energy

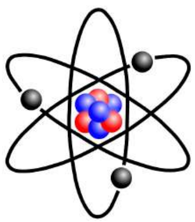


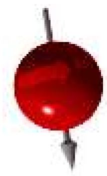


Mass imbalance ferromagnetism



^{40}K atom, m=40m_0 →  Up spin electron



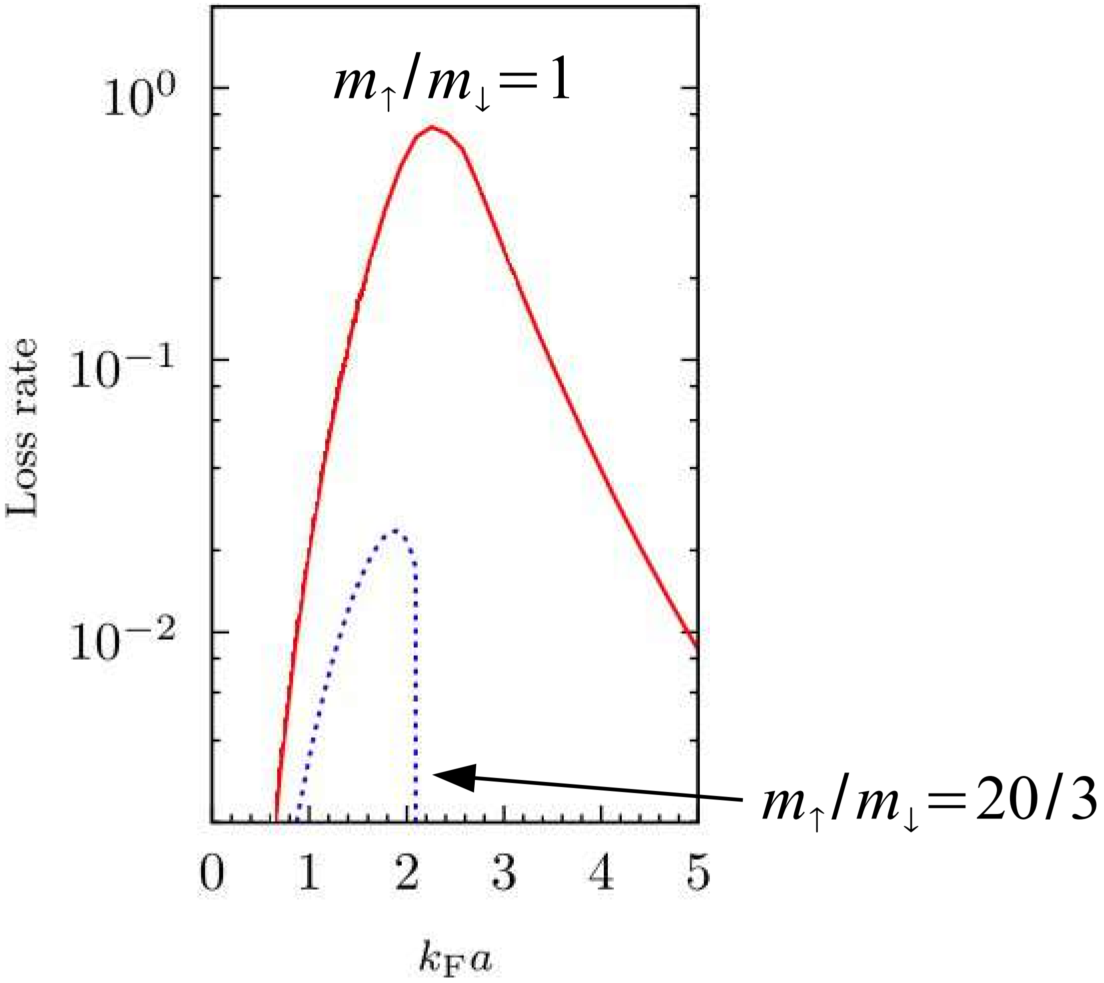
^{6}Li atom, m=6m_0 →  Down spin electron

$$\hat{H} = \sum_k \frac{k^2}{2m_\uparrow} c^\dagger_{k\uparrow} c_{k\uparrow} + \sum_k \frac{k^2}{2m_\downarrow} c^\dagger_{k\downarrow} c_{k\downarrow} + g \sum_{k k' q} c^\dagger_{k\uparrow} c^\dagger_{k'+q\downarrow} c_{k'+q\downarrow} c_{k'\uparrow}$$

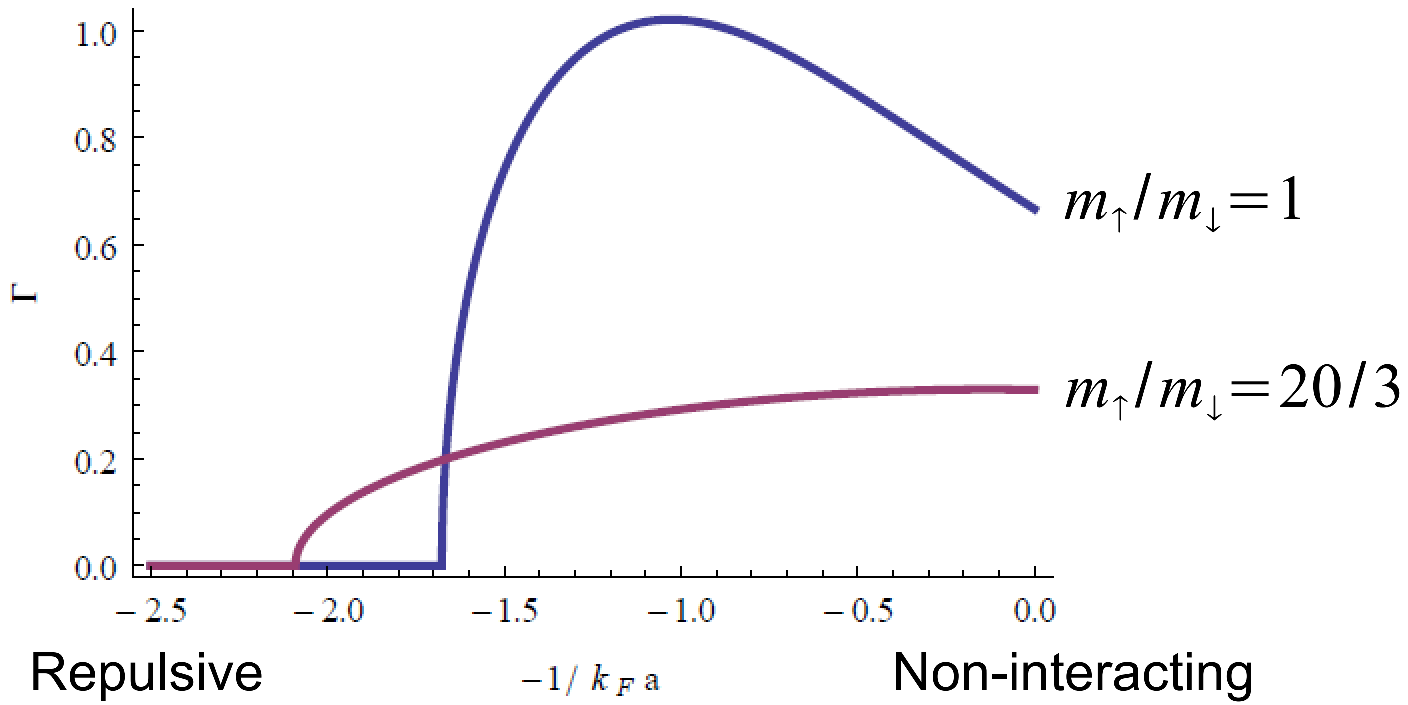
- Magnetic moment formed along quantization axis

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

Reduced three-body losses

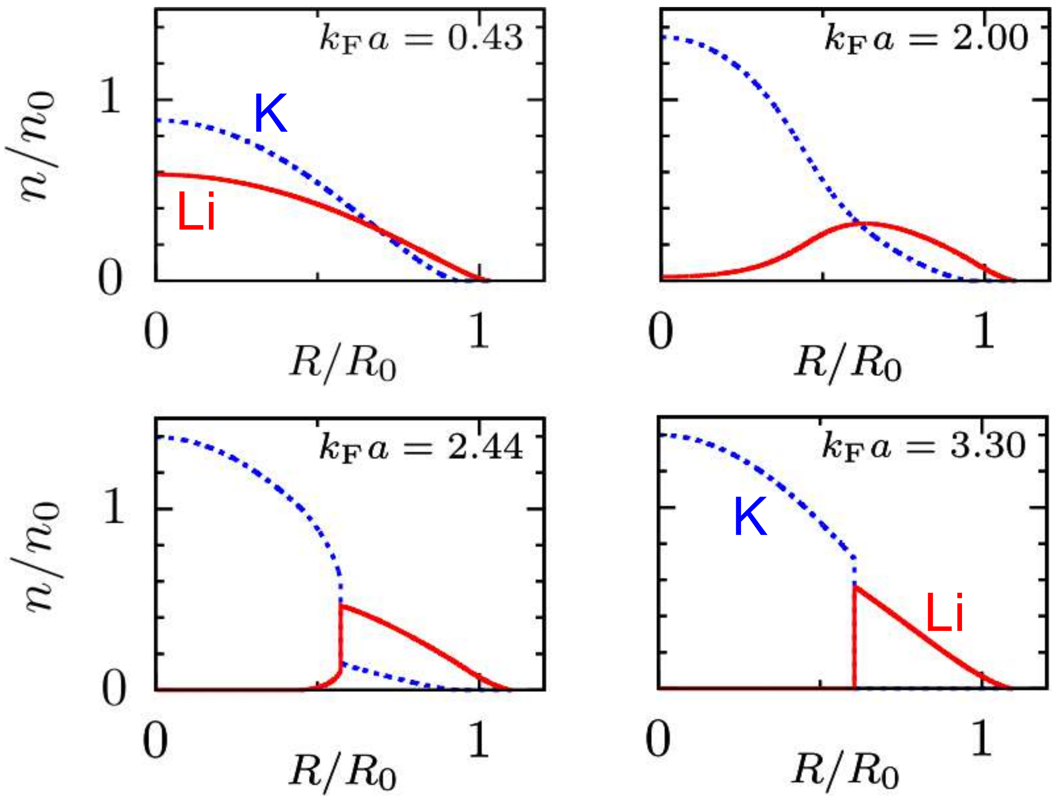


Reduced two-body losses

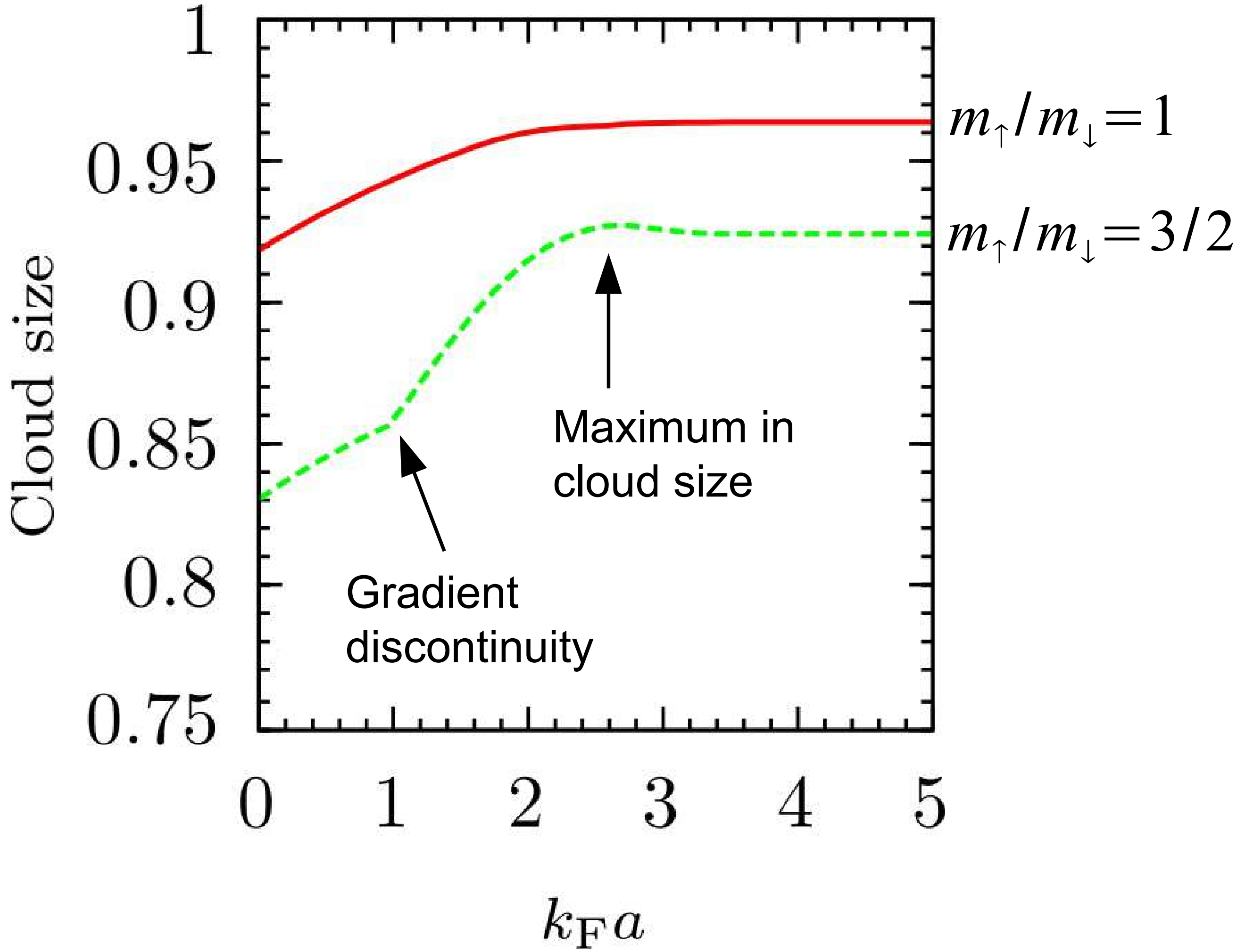


Trapped behavior

- At high interaction strength light atoms forced to outside



Unique signatures of ferromagnetism

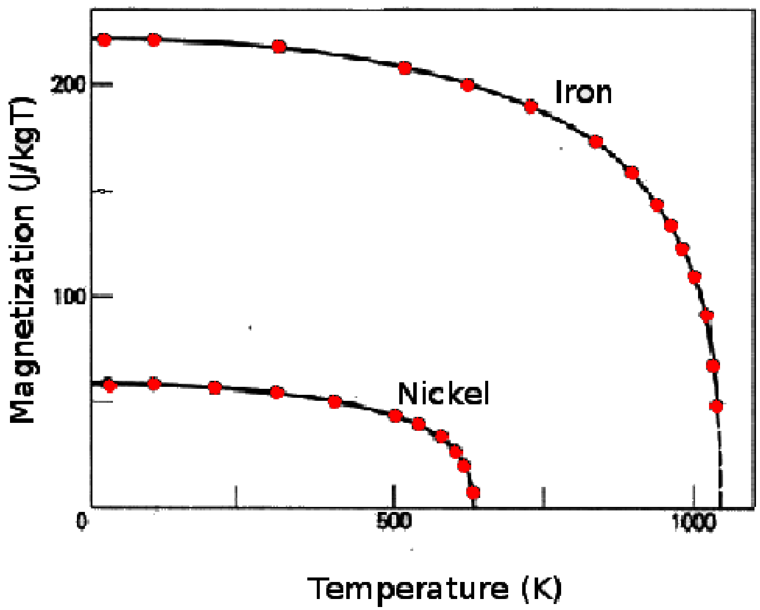


Conclusions

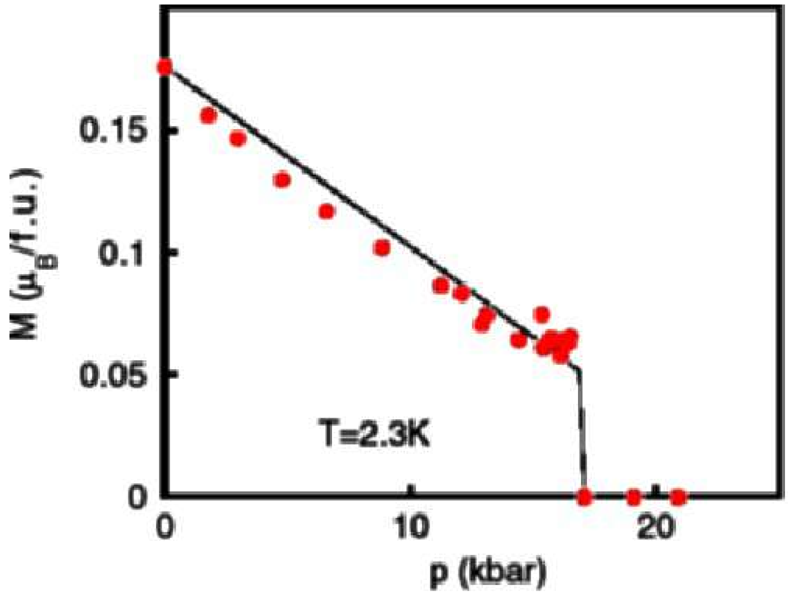
- Equilibrium theory provides a reasonable qualitative description of the transition
- Competing many-body instabilities provide alternative explanation
- Suppress losses and give stronger signatures of ferromagnetism by studying mass imbalance
- Answer long-standing questions about solid state ferromagnetism and motivate new research arenas

Solid state ferromagnetism

Second order in Fe & Ni

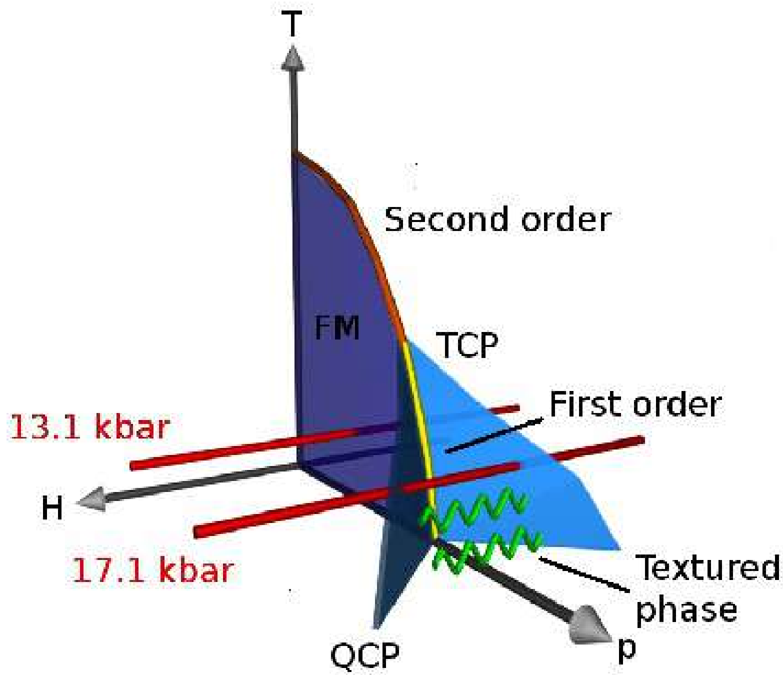


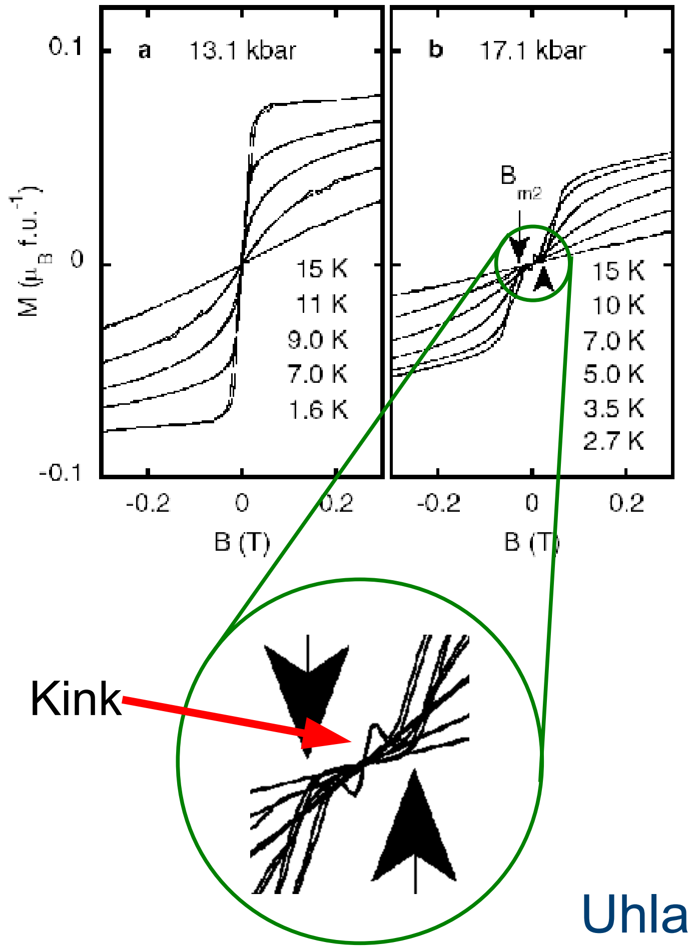
First order in $ZrZn_2$



Uhlarz *et al*, PRL (2004)

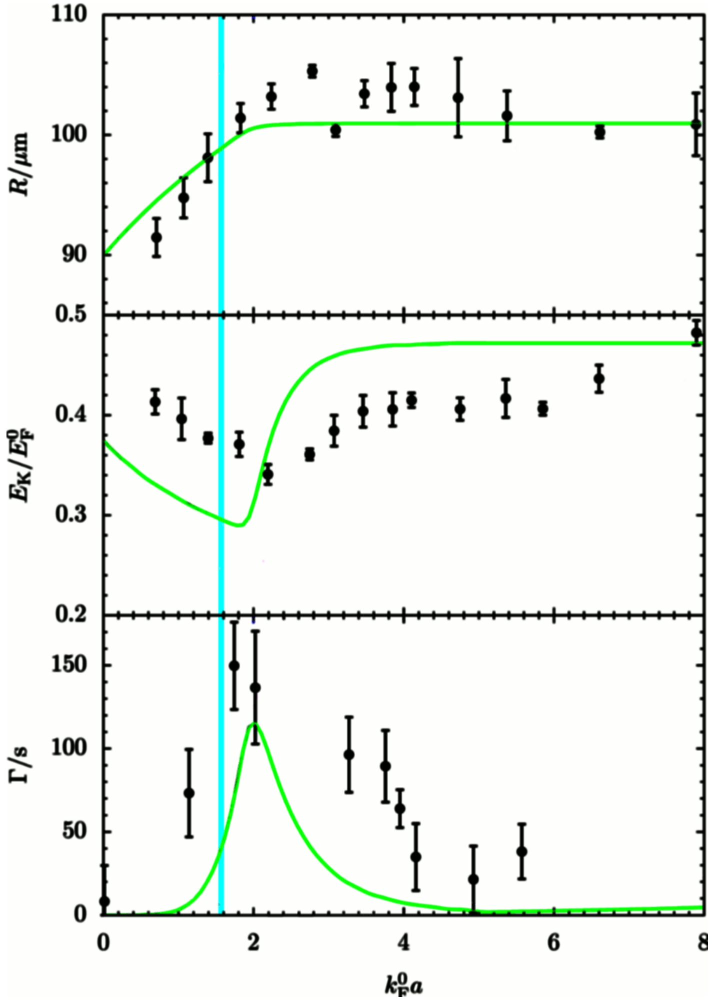
Magnetism mysteries





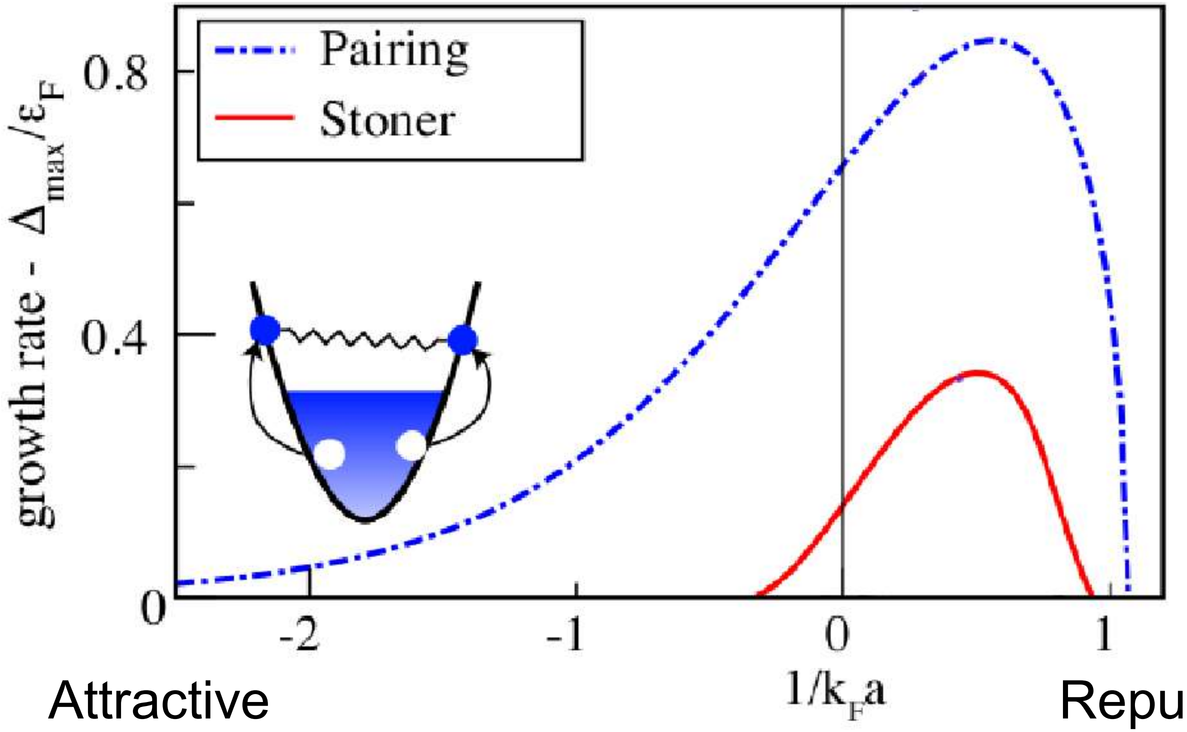
Uhlarz *et al*, PRL (2004)

Mean-field theory



GJC & Simons, PRL **103**, 200403 (2009)

Pairing loss rate



Attractive

Repulsive

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