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FFLO instability in 2D atomic gases

Talk outline

- Cold atom systems
- The Fulde-Ferrel-Larkin-Ovchinnikov (FFLO) instability
- Analytical approaches followed
- Results for uniform and trapped systems
- Conclusions

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Cold atom gases (I)

- Fermionic alkali atoms e.g. ^{6}Li are trapped by lasers and cooled
- Two contributions to spin: nucleus and valence electron
- A good quantum number is total projected spin
- The electron's interaction with the magnetic field dominates
- In the isolated atom limit get spin-up particles $|a\rangle=|m_{\mathrm{fa}}=1/2\rangle\approx|m_{\mathrm{s}}=-1/2,m_{\mathrm{I}}=1\rangle$, with a bit of $|m_{\mathrm{s}}=1/2,m_{\mathrm{I}}=0\rangle$
- And spin-down particles $|b\rangle=|m_{\mathrm{fb}}=-1/2\rangle\approx|m_{\mathrm{s}}=-1/2,m_{\mathrm{I}}=0\rangle$, with a bit of $|m_{\mathrm{s}}=1/2,m_{\mathrm{I}}=-1\rangle$
- In the dense limit the scattering operator is not diagonal in the states $|a,b\rangle$ and $|c,d\rangle$ so scattering can occur from $|a,b\rangle$ (open channel) into $|c,d\rangle$ (closed channel)

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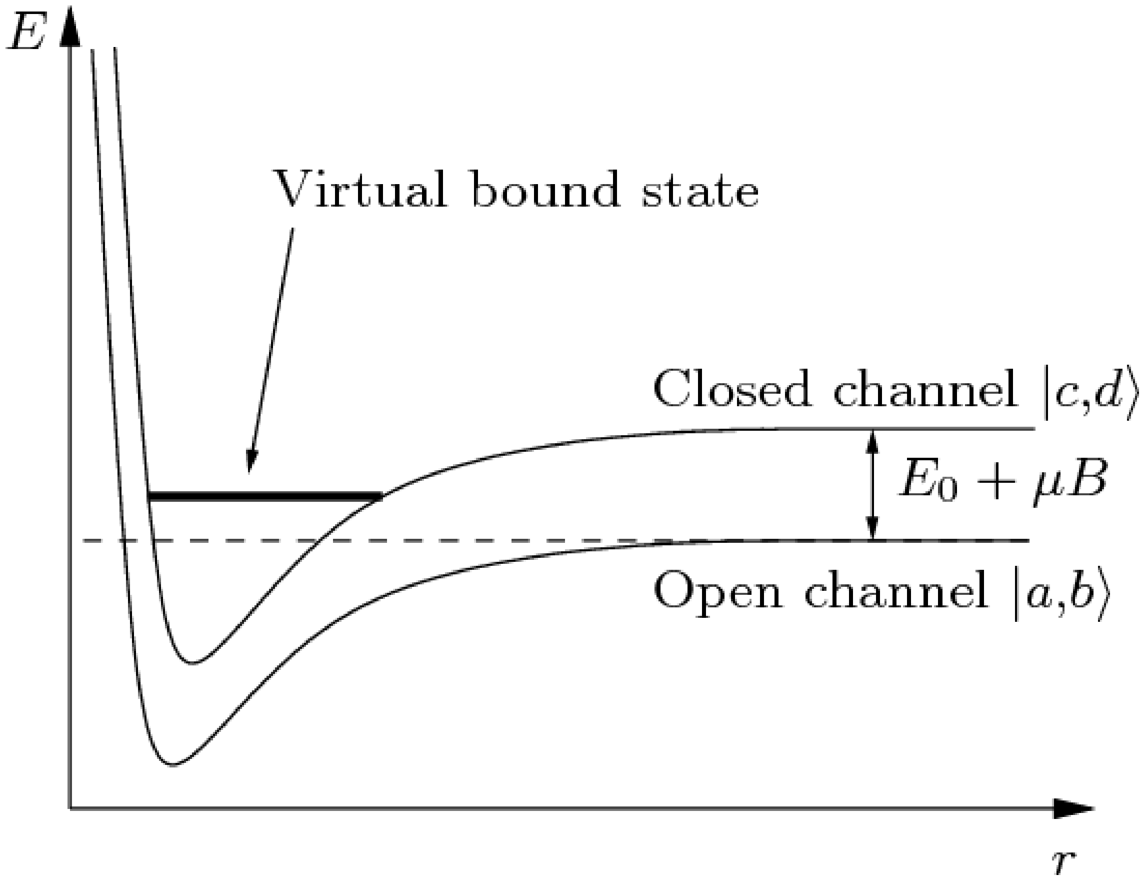
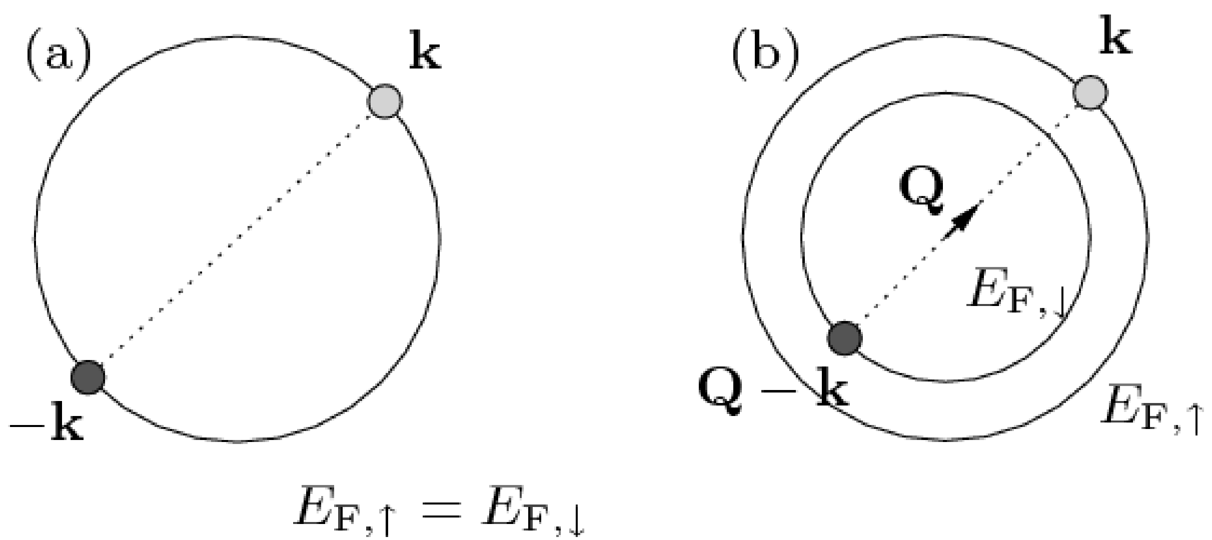
Cold atom gases (II)

- States $|a,b\rangle$ and $|c,d\rangle$ magnetic moments differ by μ so relative energies are shifted by μB
- In a Feshbach resonance a bound state of the closed channel is brought into resonance with the open channel, affecting particle scattering
- Can have atoms with different masses
- Any population imbalance is maintained
- System is in quasiequilibrium, actual equilibrium is a solid



FFLO instability

- In strong binding limit have a Bose condensate, weak binding gives Cooper pairs, in the intermediate regime a modulated phase is possible
- BCS Cooper pairs have no total momentum (a)
- A population imbalance (or a ratio of masses) means Cooper pairs have a non-zero total momentum (b)
- This Fulde-Ferrel-Larkin-Ovchinnikov (FFLO) instability results in a textured state
- Inferred in superconductors with external magnetic field



- Similarities to electron-hole bilayers, where electron/holes are the normal phase and excitons the superfluid

Analytical approach

Ginzburg-Landau approach

- Expand thermodynamic potential Φ in terms of an order parameter $\Delta_{\mathbf{q}}$ to quadratic order over all wave vectors **q**

$$\Phi=\sum_{\mathbf{q}}\alpha_{\mathbf{q}}|\Delta_{\mathbf{q}}|^2$$

- If coefficient $\alpha_{\mathbf{q}}$ is negative, it is favourable for $\Delta_{\mathbf{q}}\neq 0$ -- an FFLO instability
- Get analytical results for phase boundaries but it cannot pick up first order transitions

Single Fourier component approach

- Consider just a single wave vector **Q** and minimise exact thermodynamic potential with respect to that wave vector and the order parameter $\Delta_{\mathbf{Q}}$

$$\Phi(\Delta_{\mathbf{Q}})$$

- Distinguishes between first and second order transitions but results are numerical
- The **Q=0** state can be evaluated analytically

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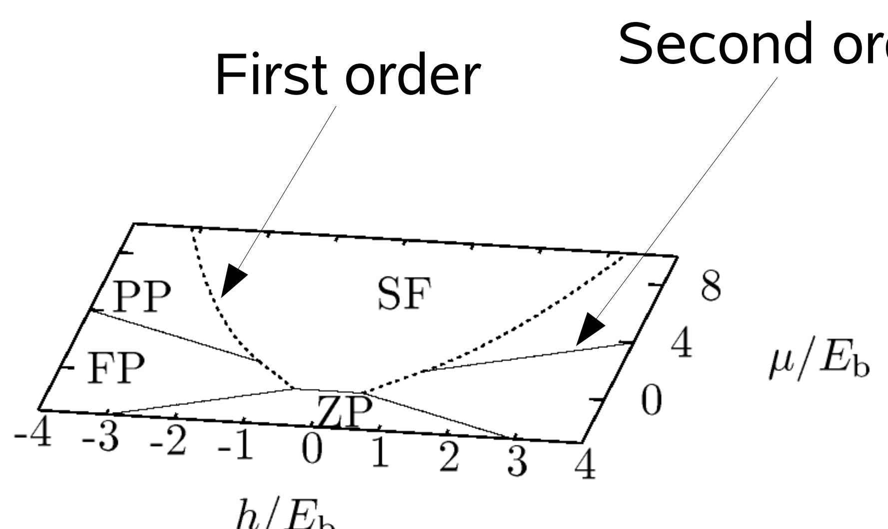
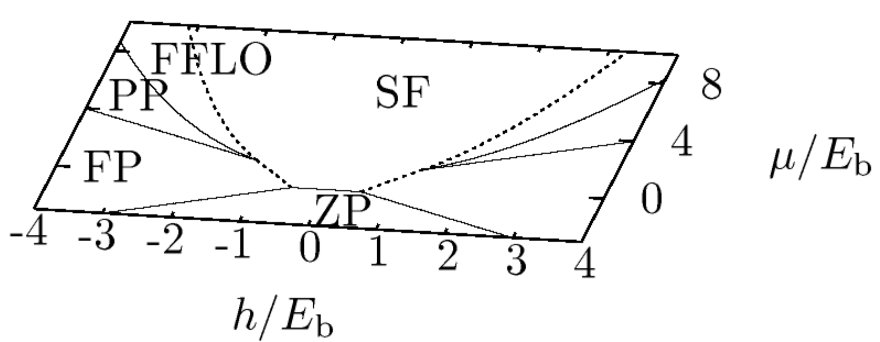
Free system: Q=0

- Equal masses $m_{\uparrow}=m_{\downarrow}$, population imbalanced system with $\mu_{\uparrow}=\mu+h$ and $\mu_{\downarrow}=\mu-h$
- The superfluid (SF), partially polarised normal (PP), fully polarised normal (FP), phases and the system containing no particles (ZP) are shown
- There is a first order phase transition from the normal into the superfluid phase (dotted line)
- The transitions between normal phases are second order and are straight lines (solid) with $\mu=\pm h$
- In constant n system would see phase separated SF and PP normal state



Free system: Q≠0

- The FFLO instabilty encroaches into the partially polarised normal state (PP) but not the superfluid
- Second order transition from partially polarised normal state (PP) into FFLO instability
- First order transition from FFLO instability into superfluid (SF) state
- No FFLO instability in fully polarised state (FP) as there are no minority spin particles
- In constrant *n* system see FFLO rather than a phase separated region



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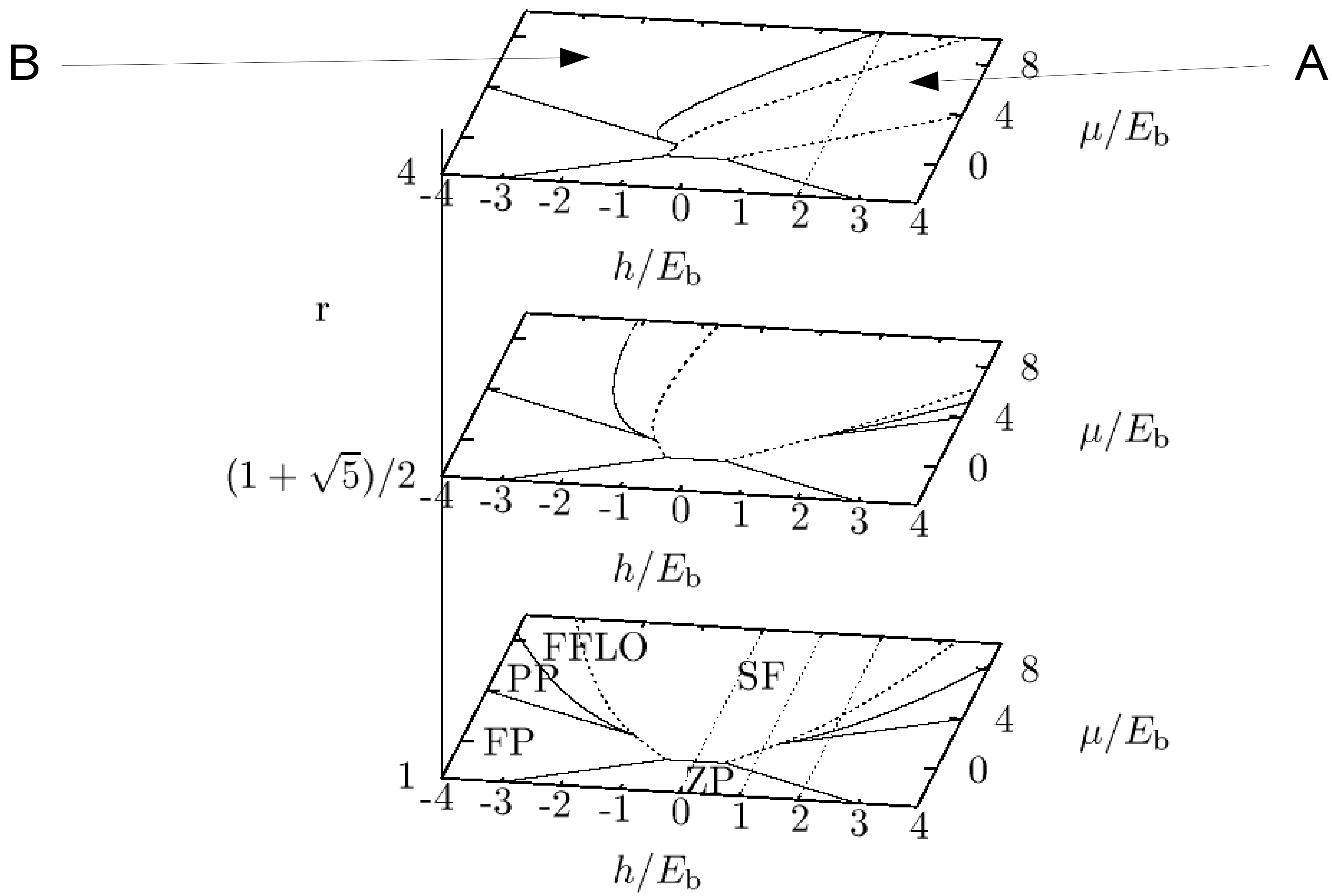
Free system: changing mass ratio r

- Generalise to allow different particle masses where $r = m_{\downarrow}/m_{\uparrow}$ and chemical potentials $\mu_{\uparrow} = \mu + h$ and $\mu_{\downarrow} = \mu - h$
- Superfluidity is favoured if the light species is in excess
- A trap has a varying effective chemical potential $\mu(\boldsymbol{r}) = \mu_0 - V(\boldsymbol{r})$, corresponding to straight line (dotted) trajectories



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Conclusions

- Ginzburg-Landau and single Fourier component approaches were used to derive analytic expressions for phase boundaries in a 2D fermionic atomic gas
- Superfluidity is favoured if the light species is in excess and the FFLO instability was seen
- In a trapped system a superfluid could be bordered on one or both sides by normal phases
- Thanks to Ben Simons and Peter Conlon