Scuola di Dottorato di Ricerca in Fisica, XVIII ciclo

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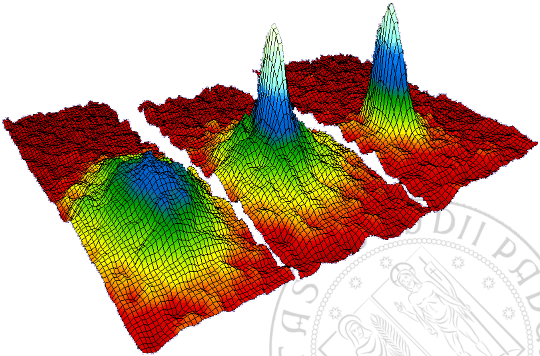
Ultracold Fermi gases (1/4)

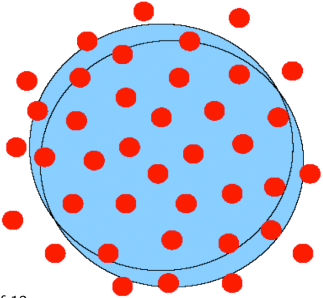
- My main research topic (supervisor: Prof. Luca Salasnich)
- Ultracold gases: experimental observation of quantum properties of matter. Vortices in a superfluid, BEC.
- Bose-Einstein condensation (1995), degenerate Fermi gas (2003)



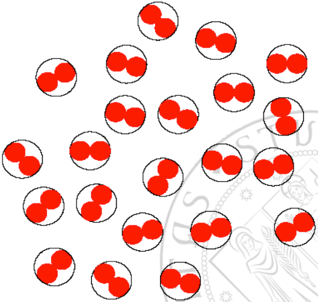
Ultracold Fermi gases (2/4)

Why are ultracold Fermi gases interesting? The fermion-fermion attractive interaction can be tuned (using a Feshbach resonance), from weakly to strongly interacting: the **BCS-BEC crossover**.

BCS regime: coherence in momentum space.

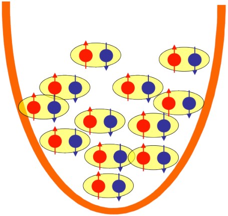


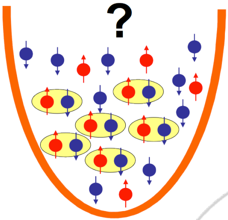
BEC regime: coherence in coordinate space.



Ultracold Fermi gases (3/4)

Polarized Fermi gases

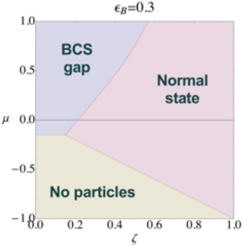


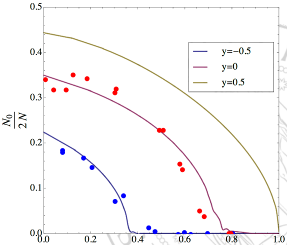


Ultracold Fermi gases (4/4)

My work on ultracold Fermi gases:

- Starting point: BCS-Leggett theory. The BCS trial wavefunction is valid throughout the crossover up to the strong-coupling regime at $T = 0$.
- Extension to the unbalanced case.
- Phase diagram: QPT.
- Condensate fraction, preliminary results, as a function of $y = \frac{1}{k_F a_s}$ and $P = \frac{N_\uparrow - N_\downarrow}{N_\uparrow + N_\downarrow}$





Condensate fraction for an unbalanced 3D Fermi gas

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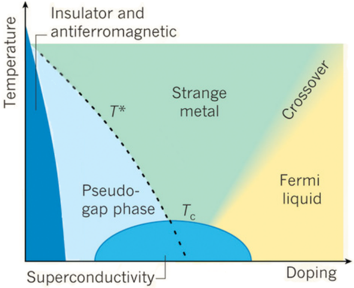
Dipartimento di Fisica e Astronomia "Galileo Galilei" and CNISM, Università di Padova, Via Marzolo 8, 35131 Padova, Italy

(Dated: November 18, 2013)

High-T_c superconducting cuprates (1/3)



- Very complicated phenomenology; superconducting up to 135 °K; no widely-accepted microscopical theoretical model.
- Discovered in 1985 (Bednorz, Müller), very active research field, over 100k scientific papers in $\sim$ 25 years.
- I am continuing the work I began with my Master's thesis, supervisor: Prof. P.A. Marchetti.

High-T_c superconducting cuprates (2/3)

In the formalism I am working with the electron has a **composite structure**: spinon + holon.

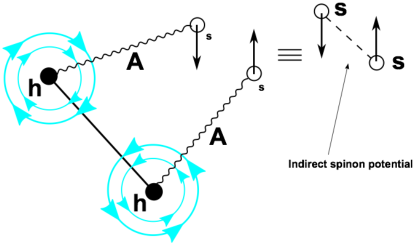


Figure : The attractive potential between the spinons, essential for the SC, is mediated by a gauge field “binding” holon and spinons, and by the holon attraction.

As a consequence, the superconductivity is achieved in **three steps**: holon pairing (T_{ph}), spinon pairing (T_{ps}), phase coherence (T_c):

$$\Delta_c \sim \frac{|\Delta^s|}{|\Delta^h|} e^{\mathrm{i}(\overbrace{\phi_s - \phi_h}^{\equiv\phi})}$$

$$SC \iff \langle \Delta_c \rangle \neq 0$$

High-T_c superconducting cuprates (3/3)

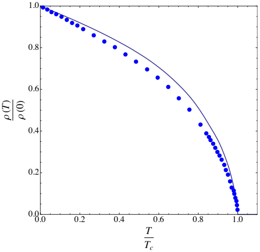


Figure : Superfluid density as a function of the temperature: our model (solid line) vs. experimental data (blue points).

- My focus: superfluid density (ρ_s).
  $S_{\mathsf{EFF}} = \frac{\rho_s}{2} \int \mathrm{d}\tau \mathrm{d}^d r \, (\nabla\theta)^2 + \cdots$
- Importance: lot of experimental data, $\rho_s \propto \lambda^{-2}$, very different from BCS.
- Summation formula ($\sim$ Ioffe-Larkin)

$$\rho_s = \frac{\rho_s^s \rho_s^h}{\rho_s^s + \rho_s^h}$$

- Our results are in fairly good agreement with experimental data. The critical exponent is exactly reproduced:
  $\rho_s \sim \left| \frac{T - T_c}{T} \right|^{\frac{2}{3}} \quad \text{for } T \longrightarrow T_c$

Summer school: Quantum Matter — Foundations and Applications

- Granada (Spain), September 15th-19th, 2013
- I presented a poster there: *"Condensate fraction for an unbalanced Fermi gas"*.

Exams

- Fisica statistica dei fenomeni emergenti: dalla geometria delle reti fluviali alla biogeografia. (A. Maritan) ✓ 28/10/2013
- Risposta dei Sistemi Complessi: Teoria ed Esperimenti (F. Baldovin, M. Pierno) ✓ 12/11/2013
- Standard Model (M. Passera, E. Torassa) due on 16/12/2013
- Processi stocastici e dinamica dei mercati (A. Stella, F. Baldovin) attending now, exam due in late December or January.

Future work and plans

- Ultracold Fermi gases: role of fluctuations at finite temperature in 3D.
- Ultracold Fermi gases: two-dimensional case.
  - Phase (as opposed to modulus) fluctuations should play a key role in the finite-temperature behavior.
  - Vortices in 2D.
  - Finite temperature effects.
- The theoretical methods used for cuprates can also be applied in describing the dynamics of ultracold gases. The pseudogap region.
- Collaboration with Prof. Jacques Tempère, Universiteit Antwerpen, Belgium

Thanks for your attention.