Harvard University Physics 284 Spring 2018

Strongly correlated systems in atomic and condensed matter physics

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Course Meetings Mon and Wed, 10-11:30 in Jeff 453

Course Grade Grading will be based on homeworks (60%) and final projects (40%).

Office hours to be arranged

This course will focus on recent progress in realizing strongly correlated many-body systems with ultracold atoms. Both theoretical ideas and experimental results will be reviewed. Connection between many-body systems of ultracold atoms and strongly correlated electron systems will be emphasized throughout the class. We will discuss unique features of ultracold atomic systems such as dynamical control of band structures and interaction strength, availability of local probes with single atom resolution, interferometric probes, use of quantum noise to analyze many-body systems, the possibility to study nonequilibrium quantum dynamics. Developments at the interface of quantum optics and atomic physics, such as superradiance in optical cavities and spin models realized with Rydberg excitations will be reviewed.

Lecture notes from previous years are available at
http://cmt.harvard.edu/demler/TEACHING/Physics284/physics284.html

Tentative Outline of Lectures

1. Introduction. Many-body physics with ultracold atoms.

2. Atoms in external field. Magnetic and optical trapping of atoms.

3. Bose-Einstein condensation of weakly interacting atomic gases. Bogoliubov equations. Analogue gravity with BEC.

4. Superradiance. Dicke quantum phase transition with a superfluid gas in an optical cavity.

5. Spinor condensates. Two component mixtures. F=1 spinor condensates.

6. Noninteracting atoms in optical lattices. State dependent lattices.

7. Synthetic gauge fields. Topological Bloch bands. Experimental probes of topological bands. Floquet Hamiltonians. Topological characterization of Floquet systems

8. Bose Hubbard model. Phase diagram. Collective modes: Bogoliubov sound mode and Higgs amplitude mode. Nonequilibrium dynamics. Extended Hubbard models.

9. Quantum magnetism with ultracold atoms in optical lattices.

10. Quantum noise measurements as a probe of many-body states.

11. Feshbach resonances. Basics of scattering theory. Simple model for interatomic interactions. Multichannel model. Geometrical resonances in one and two dimensional systems.

12. Fermion pairing close to Feshbach resonance. The BCS-BEC crossover. RF spectroscopy and photoemission. Pairing with spin imbalance and FFLO phases.

13. Polarons in systems of bosonic and fermionic ultracold atoms. Orthogonality catastrophe and RF spectroscopy.

14. Fermionic Hubbard model. Antiferromagnetism in the Hubbard model at half-filling. Competing phases away from half-filling. Symmetry between the repulsive and attractive Hubbard models. Quantum gas microscopes.

15. Realizing and probing topological states with ultracold atoms. Fractional quantum Hall states and beyond.

16. Non-perturbative effects of interactions in one dimensional systems. Luttinger liquids.

17. Many-body physics with alkaline-earth atoms. Kondo effect. Fermi systems with SU(N) symmetry.
18. Systems with dipolar interactions. Polar molecules. Atoms with large magnetic moments. Long range interactions of Rydbeg atoms.
19. Interplay of disorder and interactions. Many-body localization.

Useful books

- *Bose-Einstein Condensation in dilute gases*, C.J. Pethick and H. Smith, Cambridge University Press, Cambridge (2002)
- *Bose-Einstein condensation*, L. Pitaevskii and S. Stringari, Oxford science publishing, Clarendon press, Oxford (2003)
- *Quantum physics in one dimension*, T. Giamarchi, Oxford science publishing, Clarendon press, Oxford (2004)
- *Ultracold quantum fields*, H. Stoof, K. Gubbels, D. Dickerscheid, Springer Science+Business Media (2009)
- *Fundamentals and frontiers of Bose-Einstein Condensation*, M. Ueda, World Scientific Publishing, Singapore, (2010)

Useful review articles

- *Theory of Bose-Einstein condensation in trapped gases.* Dalfovo, Giorgini, Pitaevskii, Stringari. Rev. Mod. Phys. 71:463 (1999).
- *Spinor condensates and light scattering from Bose-Einstein condensates.* Ketterle, Stamper-Kurn. Les Houches lecture notes. cond-mat/0005001.
- *Low dimensional trapped gases.* Petrov, Gangardt, Shlyapnikov. J. Phys IV France 1 (2008). cond-mat/0409230.
- *Strong correlations in low dimensional systems.* Giamarchi. Lecture notes for the Salerno Training course. cond-mat/0605472.
- *Ultracold atomic gases in optical lattices: mimicing condensed matter physics and beyond.* Lewenstein, Sanpera, Ahufinger, Damaski, Sen, Sen. Advances in Physics 56:243 (2007).
- *Making, probing and understanding ultracold Fermi gases.* Ketterle, Zwierlein. Varenna lecture notes. arXiv0801:2500
- *Many-body physics with ultracold gases.* Bloch, Dalibard, Zwerger. Rev. Mod. Phys. 80:885 (2008)
- *Theory of ultracold atomic Fermi gases.* Giorgini, Pitaevskii, Stringari. Rev. Mod. Phys. 80:1215 (2008).
- *Rapidly rotating atomic gases.* Cooper. Advances in Physics 57:539 (2008)
- *Theoretical progress in many-body physics with ultracold dipolar gases.* Baranov. Physics Reports 464:71 (2008).
- *Rotating trapped Bose-Einstein condensates.* Fetter. Rev. Mod. Phys. 81:647 (2009).
- *The physics of dipolar bosonic quantum gases.* Lahaye, Menotti, Santos, Lewenstein, Pfau. Rep. Prog. Phys. 72:126401 (2009).
- *Feshbach resonances in ultracold gases.* Chin, Grimm, Julienne, Tiesinga. Rev. Mod. Phys. 82:1225 (2010).

- *One dimensional bosons: from condensed matter systems to ultracold gases.* Cazalilla, Citro, Giamarchi, Orignac, Rigol. arXiv1101.5337.

- *Colloquium: Artificial gauge potentials for neutral atoms.* Dalibard, Gerbier, Juzelinas, Öhberg, Rev. Mod. Phys. 83:1523 (2011).

- *Spinor Bose gases: Symmetries, magnetism, and quantum dynamics*, Stamper-Kurn, Ueda. Rev. Mod. Phys. 85:1192 (2013).