Quantum Many-Body Physics | Sheet 9
Lecturer: Prof. Dr. Michael Knap | Winter Term 2023
Tutors: Stefan Birnkammer, Julian Bösl, Gloria Isbrandt, Caterina Zerba | **Deadline: 2024-01-12 (6:00 pm)**

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1 Scientific Essay

For the following week we will depart from the conventional tutorial style. Instead you will have the chance to choose a topic for a scientific essay typically summarizing the content of one theoretical and one experimental paper (see list below). The deadline for the essay will be the after the Christmas break (**Friday 2024-01-12**). To ensure you take away the most from writing the essay the next two open tutorials will give you the chance to ask questions concerning your topic of interest. We will continue with the first conventional sheet again in the week after the Christmas break (**Monday 2024-01-08**) with a deadline at the first tutorial slot of the new year (**Wednesday 2024-01-10**). The grading for the essay will be added to the points you obtain from working on the exercise sheets. To account for the higher workload it will count as two ordinary exercise sheets (4 points equivalent to 4 exercises).

List of Possible Topics

1. *Spinor Condensates* 1. THY: Dan M. Stamper-Kurn, Wolfgang Ketterle, Spinor condensates and light scattering from Bose-Einstein condensates, arXiv:cond-mat/0005001 Chapter 4 2. EXP: J. Stenger, S. Inouye, D.M. Stamper-Kurn, H.-J. Miesner, A.P. Chikkatur, and W. Ketterle, Nature 396, 345 (1998)

2. *Coherent states: collapse and revivals in optical lattices* 1. EXP: M. Greiner, O. Mandel, T. W. Hänsch, I. Bloch, Collapse and revival of the matter wave field of a Bose–Einstein condensate, Nature 419, 51 (2002) 2. THY: D. Jaksch, C. Bruder, J. I. Cirac, C. W. Gardiner, and P. Zoller, Cold Bosonic Atoms in Optical Lattices, Phys. Rev. Lett. 81, 3108 (1998)

3. *Collective excitations in superfluids* 1. EXP: L. A. Sidorenkov, et al. Second sound and the superfluid fraction in a resonantly interacting Fermi gas, Nature 498, 78–81 (2013) . 2. THY: G. Bertaina et al. First and Second Sound in Cylindrically Trapped Gases, Phys. Rev. Lett. 105, 150402 (2010)

4. *Vortices in trapped condensates* 1. THY: A. Fetter, Rev. Mod. Phys. 81, 647 (2009). 2. EXP: M. W. Zwierlein, J. R. Abo-Shaeer, A. Schirotzek, C. H. Schunck, W. Ketterle, Vortices and superfluidity in a strongly interacting Fermi gas, Nature 435 1047 (2005)

5. *Goldstone and Higgs modes in condensed matter* 1. THY: Podolsky, D., Auerbach, A. Arovas, D. P. Visibility of the amplitude (Higgs) mode in condensed matter. Phys. Rev. B 84, 174522 (2011). Sections 1-3 2. EXP: P. Merchant, B. Normand, K.W. Krämer, M. Boehm, D. F. McMorrow and Ch. Rüegg, Quantum and classical criticality in a dimerized quantum antiferromagnet, Nature Physics 10, 373 (2014)

Suggested complementary readings: THY (original): P. W. Anderson, Plasmons, Gauge Invariance, and Mass Phys. Rev. 130, 439 (1963)

6. *BKT Transition in two dimensions* 1. EXP: Rémi Desbuquois, Lauriane Chomaz, Tarik Yefsah, Julian Léonard, Jérôme Beugnon, Christof Weitenberg, Jean Dalibard, Superfluid behaviour of a two-dimensional Bose gas, Nature Physics 8, 645 (2012) 2. THY: J. M. Kosterlitz and D. J. Thouless, J. Phys. C: Solid State Physics 6, 1181 (1973)

7. *Super Tonks-Girardeau gas* 1. EXP: E. Haller, Realization of an Excited, Strongly Correlated Quantum Gas Phase, Science 4 325, 1224, (2009) 2. THY: G. E. Astrakharchik, et al., Beyond the Tonks-Girardeau Gas: Strongly Correlated Regime in Quasi-One-Dimensional Bose Gases, Phys. Rev. Lett. 95, 190407 (2005).

8. *Periodically driven many-body system* 1. THY: Photovoltaic Hall effect in graphene, T Oka, H Aoki Physical Review B 79, 081406 (2009). 2. EXP: Observation of Floquet-Bloch states on the surface of a topological insulator, YH Wang, H Steinberg, P Jarillo-Herrero, N Gedik Science 342, 453 (2013).

9. *Anderson Localization* 1. THY: Anderson, P. W. Absence of diffusion in certain random lattices. Physical Review 109, 1492–1505 (1958). 2. EXP: Billy, J. et al. Direct observation of anderson localization of matter waves in a controlled disorder. Nature 453, 891–894 (2008).

10. *Many-body localization* 1. EXP: Michael Schreiber, et al. Observation of many-body localization of interacting fermions in a quasi-random optical lattice, Science 349, 842 (2015), arXiv:1501.05661 2. THY: Arijeet Pal, David A. Huse, The many-body localization phase transition, Phys. Rev. B 82, 174411 (2010), arXiv:1010.1992 3. THY: Jens Bardarson, et al. Unbounded growth of entanglement in models of many-body localization, Phys. Rev. Lett. 109, 017202 (2012), arXiv:1202.5532

11. *Spin transport in Fermi gases* 1. EXP: A. B. Bardon, Transverse Demagnetization Dynamics of a Unitary Fermi Gas, Science 344, 722 (2014) 2. THY: T. Enss, et al. Shear viscosity and spin diffusion in a 2D Fermi gas. Phys. Rev. A 86, 013617 (2012).

12. *The Fermi polaron* 1. THY: F. Chevy, Universal phase diagram of a strongly interacting Fermi gas with unbalanced spin populations, Phys. Rev. A 74, 063628 (2006) 2. EXP: André Schirotzek, et al, Observation of Fermi Polarons in a Tunable Fermi Liquid of Ultracold Atoms, Phys. Rev. Lett. 102, 230402 (2009)

    Suggested complementary readings: EXP: C. Kohstall, et al, Metastability and coherence of repulsive polarons in a strongly I nteracting Fermi mixture, Nature 485, 615 (2012).

13. *Anderson's Orthogonality Catastrophe* 1. THY: M. Knap, et al, Time dependent impurity in ultracold fermions: orthogonality catastrophe and beyond. Phys. Rev. X 2, 041020 (2012). 2. EXP: M. Cetina, et al, Ultrafast many-body interferometry of impurities coupled to a Fermi sea., Science 07 Oct 2016: Vol. 354, Issue 6308, pp. 96-99 arXiv:1604.07423.

14. *Superfluid to Mott insulator quantum phase transition* 1. THY: Jaksch, D., Bruder, C., Cirac, J. I., Gardiner, C. W. Zoller, P. Cold bosonic atoms in optical lattices. Phys. Rev. Lett.81,3108±3111 (1998). 2. EXP: Greiner et al., Quantum phase transition from a superfluid to a Mott insulator in a gas of ultracold atoms, Nature 415, 39–44 (03 January 2002)

    Suggested complementary readings: THY: Fisher, M. P. A., Weichman, P. B., Grinstein, G. Fisher, D. S., Boson localization and the superfluidinsulator transition.Phys. Rev. B40,546-570 (1989)

15. *Dynamical Quantum Phase Transitions* 1. EXP: Direct Observation of Dynamical Quantum Phase Transitions in an Interacting Many-Body System, P. Jurcevic, et al., Phys. Rev. Lett. 119, 080501 (2017) 2. THY: Zunkovic, et al., Dynamical Quantum Phase Transitions in Spin Chains with Long-Range Interactions: Merging different concepts of non-equilibrium criticality, PRL arxiv: 1609.08482

16. *Emergence of many-body from few-body physics* 1. THY+EXP: Wenz et al., From Few to Many: Observing the Formation of a Fermi Sea One Atom at a Time, Science, Vol. 342, Issue 6157, pp. 457-460 2. EXP: Grebenev, et al. Superfluidity Within a Small Helium-4 Cluster: The Microscopic Andronikashvili Experiment. Science Vol. 279, Issue 5359, pp. 2083-2086 (1998)

17. *Quantum criticality in the Ising chain* 1. EXP: R. Coldea, D.A. Tennant, E.M. Wheeler1, E. Wawrzynska, D. Prabhakaran, M. Telling, K. Habicht, P. Smeibidl, K. Kiefer. Quantum criticality in an Ising chain: experimental evidence for emergent E8 symmetry. Science 08 Jan 2010: Vol. 327, Issue 5962, pp. 177-180 2. THY: (textbook) Subir Sachdev, Quantum phase transitions, Part One: Introduction (online version available in the library)

18. *A simple model for a non-Fermi liquid: The SYK Model* 1. THY: Sumilan Banerjee, Ehud Altman, Solvable model for a dynamical quantum phase transition from fast to slow scrambling, Phys. Rev. B 95, 134302 (2017) 2. EXP: Zhihuang Luo, Yi-Zhuang You, Jun Li, Chao-Ming Jian, Dawei Lu, Cenke Xu, Bei Zeng and Raymond Laflamme. Quantum simulation of the non-fermi-liquid state of Sachdev-Ye-Kitaev model. npj Quantum Information volume 5, Article number: 53 (2019)

    Suggested complementary readings: THY: Joseph Polchinski, Vladimir Rosenhaus, The Spectrum in the Sachdev-Ye-Kitaev Model, 10.1007/JHEP04(2016)001, Chapter 2

19. *Avoided quasiparticle decay from strong quantum interactions*

    1. THY: Verresen, Moessner, Pollmann, Strong quantum interactions prevent quasiparticle decay, Nat. Phys. 15, 750–753 (2019) 2. EXP: Ito, S. et al., Structure of the magnetic excitations in the spin-1/2 triangular-lattice Heisenberg antiferromagnet Ba3CoSb2O9., Nat. Commun. 8, 235 (2017).

20. *Parametric resonances in a driven sine-Gordon model* 1. THY: I. Lovas, R. Citro, E. Demler, T. Giamarchi, M Knap, E. Orignac, Many-body parametric resonances in the driven sine-Gordon model, Phys. Rev. B 106, 075426 (2022) 2. EXP: T. Schweigler, V. Kasper, S. Erne, I. Mazets, B. Rauer, F. Cataldini, T. Langen, T.Gasenzer, J. Berges, J. Schmiedmayer, Experimental characterization of a quantum many-body system via higher-order correlations, Nature 545, 323–326 (2017)

21. *Sine-Gordon dynamics in coupled spin chains* 1. THY: E. Wybo, M. Knap, A. Bastianello, Quantum sine-Gordon dynamics in coupled spin chains, Phys. Rev. B 106, 075102 2. EXP: T. Schweigler, V. Kasper, S. Erne, I. Mazets, B. Rauer, F. Cataldini, T. Langen, T.Gasenzer, J. Berges, J. Schmiedmayer, Experimental characterization of a quantum many-body system via higher-order correlations, Nature 545, 323–326 (2017)

22. *Deconfined Quantum Criticality* 1. THY: T. Senthil et al., Deconfined Quantum Critical Points, Science303,1490-1494 (2004) 2. THY: T. Senthil, Deconfined quantum critical points: a review, arXiv:2306.12638 (2023)

Expectations for the essay

The essay should contain the key ideas discussed in both the experimental and theory papers. This might require the use of certain relevant analytical or numerical results without necessarily repeating full derivations. Despite the fact that you should mention the main message of both theory and experimental work, you are free in laying your main focus. If you are more interested in theory feel free to discuss this paper in more detail and only briefly mention the experimental study or vice versa. Additionally suggested reading material should only serve as a further reference if you have problems with concepts introduced in the main papers and does not need to be discussed in the essay. The length of the essay should be around 2 to 4 pages.