

# PhD-Symposium – Many-body Physics in Ultracold Quantum Systems (SYPD)

jointly organised by the Working Group "Young DPG" (AKJDPG)  
supported by all divisions of the section AMOP

Mareike Hetzel  
Institut für Quantenoptik  
Leibniz Universität Hannover  
Welfengarten 1  
30167 Hannover  
hetzel@iqo.uni-hannover.de

Bernd Meyer-Hoppe  
Institut für Quantenoptik  
Leibniz Universität Hannover  
Welfengarten 1  
30167 Hannover  
b.meyer@iqo.uni-hannover.de

Exploring the fascinating properties of many-body quantum systems demands a well-controlled experimental platform. Because of their low temperature and good isolation from the environment, ultracold neutral atom systems excellently fulfill these requirements. In this session, we will explore a wide range of intriguing effects in these systems. We will look into supersolidity caused by long-range dipolar interactions and non-equilibrium phenomena. We will learn about quantum entanglement and how it can be employed for quantum simulation, where atoms can be used to model complex systems and simulate their behavior. Furthermore, we will discuss applications of ultracold quantum systems where atoms are collectively manipulated to measure real-world properties.

## Overview of Invited Talks and Sessions

(Lecture hall E415)

### Invited Talks

SYPD 1.1	Thu	14:30–15:00	E415	<b>Entanglement and quantum metrology with microcavities</b> — ●JAKOB REICHEL
SYPD 1.2	Thu	15:00–15:30	E415	<b>Many-body physics in dipolar quantum gases</b> — ●FRANCESCA FERLAINO
SYPD 1.3	Thu	15:30–16:00	E415	<b>Quantum Simulation: from Dipolar Quantum Gases to Frustrated Quantum Magnets</b> — ●MARKUS GREINER
SYPD 1.4	Thu	16:00–16:30	E415	<b>Quantum gas in a box</b> — ●ZORAN HADZIBABIC

### Sessions

SYPD 1.1–1.4	Thu	14:30–16:30	E415	<b>Many-body Physics in Ultracold Quantum Systems</b>
--------------	-----	-------------	------	---

## SYPD 1: Many-body Physics in Ultracold Quantum Systems

Time: Thursday 14:30–16:30

Location: E415

**Invited Talk** SYPD 1.1 Thu 14:30 E415  
**Entanglement and quantum metrology with microcavities** — ●JAKOB REICHEL — Laboratoire Kastler Brossel (ENS-PSL, SU, CRNS, CdF) Paris

Entanglement is at the heart of quantum science and technology, and is a key resource for quantum-enhanced precision measurement. In cold-atom systems, photon-mediated interactions in optical cavities are a particularly attractive platform for generating high-fidelity entangled states in a scalable way. This relatively new approach is rapidly gaining importance, with important advances being achieved in the last few years. I will try to give an overview of the different ways in which cavities can be used to create and detect entanglement, and discuss some recent advances, showing where we are on the way to entanglement-enhanced metrology-grade clocks and sensors. One of the factors driving the progress in this field is the advancement of optical cavity technology, and I will also highlight the progress of the fiber Fabry-Perot microcavities used in the work in our group.

**Invited Talk** SYPD 1.2 Thu 15:00 E415  
**Many-body physics in dipolar quantum gases** — ●FRANCESCA FERLAINO — Institute for Experimental Physics, University of Innsbruck, Austria — Institute for Quantum Optics and Quantum Information (IQOQI), Austrian Academy of Sciences, Innsbruck, Austria

Brought to quantum degeneracy, ultracold gases enable the study of many-body quantum phenomena, in which the interaction between atoms can be so carefully mastered as to determine the very state of matter. Typically, this interaction has a short-range and isotropic nature, the latter meaning that the atoms globally attract or repel each other. However, there is another possibility that naturally emerges for some specific atomic species, such as erbium and dysprosium, featuring an extraordinarily large magnetic dipole moment. Magnetic properties give rise to dipolar many-body interactions, qualitatively very different from others in that they are long-range and anisotropic, thus adding connectivity and directionality at the quantum level.

In the present talk, we will retrace the fundamental steps in the study of dipolar gases, with emphasis on the Innsbruck results, from their creation to the new phenomena unveiled such as the emergence of rotonic excitations, so named by Landau, to the observation of a new

and paradoxical state of matter with multiple spontaneous symmetry breaking, known as supersolid.

**Invited Talk** SYPD 1.3 Thu 15:30 E415  
**Quantum Simulation: from Dipolar Quantum Gases to Frustrated Quantum Magnets** — ●MARKUS GREINER — Harvard University, Cambridge, Massachusetts, USA

Ultracold atoms in our quantum gas microscope offer a fascinating view of the quantum world. With quantum simulations we can experimentally realize and study quantum-mechanical model systems that are otherwise extremely difficult to compute on classical computers, but relevant to understanding real world quantum materials. I will present recent work on frustrated quantum magnets, fractional quantum Hall physics, and on dipolar physics.

**Invited Talk** SYPD 1.4 Thu 16:00 E415  
**Quantum gas in a box** — ●ZORAN HADZIBABIC — University of Cambridge

Ultracold atomic gases are used with great success to study fundamental many-body phenomena. While traditionally they were produced in harmonic traps and had inhomogeneous densities, one can now also create homogeneous samples using optical box traps [1,2]. This simplifies the interpretation of experiments, provides more direct connections with theory, and sometimes allows qualitatively new studies [2]. I will give an overview of our recent experiments with box-trapped Bose gases, focusing on non-equilibrium phenomena such as turbulence and evolution of far-from-equilibrium closed quantum systems [3-5].

[1] Bose-Einstein condensation of atoms in a uniform potential, A. L. Gaunt et al., *Phys. Rev. Lett.* 110, 200406 (2013).

[2] Review: Quantum gases in optical boxes, N. Navon, R. P. Smith, and Z. Hadzibabic, *Nat. Phys.* 17, 1334 (2021).

[3] Emergence of a turbulent cascade in a quantum gas, N. Navon, A. L. Gaunt, R. P. Smith, and Z. Hadzibabic, *Nature* 539, 72 (2016).

[4] Bidirectional dynamic scaling in an isolated Bose gas far from equilibrium, J. A. P. Glidden et al., *Nat. Phys.* 17, 457 (2021).

[5] Universal equation of state for wave turbulence in a quantum gas, L. H. Dogra et al., arXiv:2212.08652.