universität innsbruck

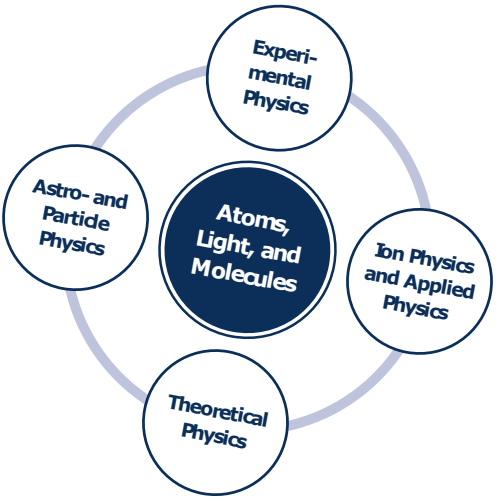
FWF Doctoral Programme
Atoms, Light, and Molecules

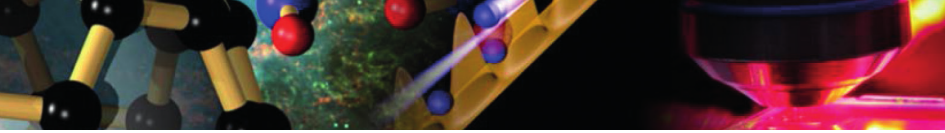
International Master course 2025

AMO physics

April 9th – 11th 2025

University of Innsbruck,
Technikerstraße 21a
6020 Innsbruck, Austria





Katrin Erath-Dulitz
Cold and Controlled
Collision Dynamics

Francesca Ferlaino
Dipolar Quantum Gases

Gerhard Kirchmair
Superconducting
Quantum Circuits

Hanns-Christoph Nägerl
Quantum Gases

Helmut Ritsch
Cavity Quantum
Electrodynamics

Christian Roos
Quantum Simulation and
Spectroscopy

Philipp Schindler
Molecular Quantum
Technologies

Roland Wester
Molecular Systems

Programme

Wednesday April 9th

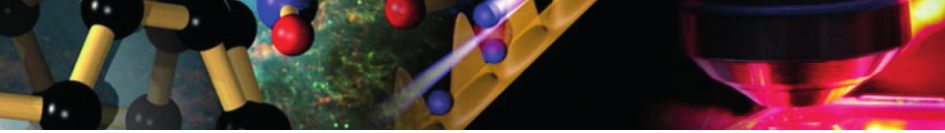
08:00 - 08:45	Registration
08:45 - 09:00	Welcome
09:00 - 10:30	Lecture: Roland Wester, Lecture Hall 1
10:30 - 11:00	Coffee Break
11:00 - 12:30	Lecture: Francesca Ferlaino, Lecture Hall 1
12:30 - 14:00	Lunch break
14:00 - 18:05	Labtours
18:30	Meet the DK Alumnis & PhD students

Thursday April 10th

09:00 - 10:30	Lecture: Helmut Ritsch, Lecture Hall 1
10:30 - 11:00	Coffee Break
11:00 - 12:30	Lecture: Philipp Schindler, Lecture Hall 1
12:30 - 14:00	Lunch break
14:00 - 18:05	Labtours
18:30	Course Dinner

Friday April 11th

09:00 - 10:30	Parallel lectures: Hanns-Christoph Nägerl, Lecture Hall 1 Gerhard Kirchmair, Lecture Hall 2
10:30 - 11:00	Coffee Break
11:00 - 12:30	Parallel lectures: Katrin Erath-Dulitz, Lecture Hall 1 Christian Roos, Lecture Hall 2
12:30 - 14:00	Lunch break and Departure



Introduction to Cold and Controlled Chemistry

Katrin Erath-Dulitz
Cold and Controlled
Collision Dynamics

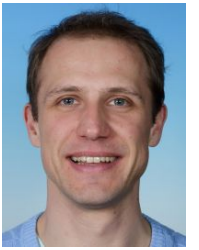
Our research in the field of cold and controlled chemistry aims to unravel the fundamental nature of chemical reactions by carrying out experiments at low collision energies and by manipulating the quantum states of reactants. This work advances our fundamental understanding of the dynamics of chemical interactions, because it provides a clearer picture of reaction pathways that are otherwise obscured at higher energies. It also sheds light on chemical processes in the interstellar medium, where low-temperature and low-pressure conditions prevail. In this presentation, I will provide an introduction to some fundamental concepts which help us understand how reactions occur under these unique conditions. This includes a detailed description of classical capture theory and the role of quantum tunneling through reaction barriers.

Ultacold Quantum Gases

Francesca Ferlaino
Dipolar Quantum Gases

Dipolar quantum gases represent a fascinating and rapidly evolving field at the forefront of many-body quantum physics and quantum simulation. These gases, composed of ultracold atoms with strong magnetic, exhibit unique and tunable long-range interactions, distinct from the short-range interactions in traditional atomic gases. This talk provides an overview of recent developments and key insights in the study of dipolar quantum gases and their implications in various experimental setups, such as optical lattices and bulk systems. Moreover, we highlight recent experimental and theoretical advancements in understanding quantum phases, dynamics, and collective phenomena in dipolar gases, ranging from the discover of a supersolid state of matter to the realization of ‘extended’ quantum simulators. Overall, the study of dipolar quantum gases continues to inspire innovative research directions and offers promising avenues for exploring new frontiers in quantum science and technology

Quantum Information Processing with Superconducting Circuits



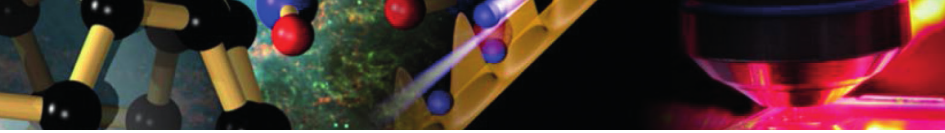
Gerhard Kirchmair
Superconducting Quantum Circuits

Since the initial demonstration that superconducting circuits based on Josephson junctions can be considered as qubits, there has been remarkable progress in the field. Superconducting quantum circuits have proven to be a prime candidate for the implementation of complex quantum systems, to realize quantum computers and quantum simulations. These systems have increased their capabilities tremendously over the last couple of years, demonstrated by the hugely increased coherence times of qubits, the creation of multi qubit entangled states, the implementation of quantum algorithms and even error correction. Many state of the art experiments employ the concept of a "quantum bus," where qubits couple via a superconducting cavity which is also suited for quantum optics experiments and quantum information protocols. In this lecture I will give an overview of some of the key concepts of the circuit QED architecture. Furthermore, I want to show how to measure the state of a superconducting qubit and realize single and two qubit gate operations to implement quantum information protocols.

Quantum Gases

Hanns-Christoph Nägerl
Quantum Gases

Ultracold quantum gases with atoms in the nano-Kelvin temperature range have evolved into a fascinating platform for the investigation and the (quantum) simulation of strongly correlated quantum matter. I will give a broad introduction to how we prepare our source of cold atoms by forming a Bose-Einstein condensate (BEC), and outline the various "control knobs" that the atoms give us. I will then present selected recent highlights from my group, for example on how one cools a system by compression (quite counter-intuitively), on the observation of dynamical quantum localization of an interacting many-body quantum system (also not obvious from any point of view), and on the observation of "anyon-ization" of bosons, i.e. how bosons can start to behave as particles in between bosons and fermions, so called "anyons" (also quite counter-intuitive).



Quantum Optics - Basics & Applications

Helmut Ritsch
Cavity Quantum
Electrodynamics

In Quantum Optics we focus on the quantum mechanical properties of light and its interactions with matter. As central approximation to full relativistic QED atoms are described nonrelativistic in a chosen rest frame. It explores phenomena such as entanglement, superposition, and quantum coherence, which are fundamental to understanding the behaviour of coupled light-matter dynamics at the quantum level. This field has led to significant advancements in technologies like lasers and more recently quantum computing, quantum cryptography, and precision measurement techniques. Research in quantum optics often involves the manipulation of individual photons and atoms to study the foundational principles of quantum mechanics.

Entanglement in Trapped-Ion Experiments

Christian Roos
Quantum Simulation
and Spectroscopy

The long coherence times of atomic superposition states demonstrated in trapped-ion clock experiments makes ions also interesting for processing quantum information. However, in trapped-ion crystals, the only relevant force between particles is the Coulomb force, which does not depend on the internal state of the ions. Therefore, any entangling interaction between trapped ions needs to be engineered. I will discuss entanglement, methods for generating entanglement between laser-cooled ions, detecting entangled states, as well as possible applications of entanglement in quantum computation, simulation and sensing.

Useful Quantum Technologies: From Quantum Computing to Precision Measurements

Quantum technologies promise to exploit genuine quantum effects for computing, sensing, and communication. Currently, multiple physical systems that can host such devices are investigated. This lecture will focus one architecture, based on trapped atomic and molecular ions. We will cover the physical foundations of these systems as well as their experimental realization. Finally, we will explore how the quantum engineering effort can help us to learn more about the structure of molecular ions and to test fundamental physical theories.

Philipp Schindler
Molecular Quantum Technologies

Molecular Ions

Atomic and molecular ions are omnipresent in many gaseous environments as well as in aqueous solution. This lecture will review the importance of ionic species and their interaction with other particles in these environments. Because of their relevance, ions and ionic processes are actively investigated with a range of techniques. Several examples from current research will be discussed, such as quantum state-selective formation, cooling and trapping, state-resolved collision dynamics, reactive scattering, and cluster formation. Special emphasis will be put on the role of ions in the cold interstellar medium.

Roland Wester
Molecular Systems

International Master course 2025

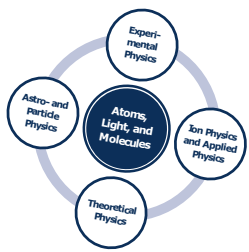
AMO physics

April 9th – 11th 2025

University of Innsbruck,
Technikerstraße 21a
6020 Innsbruck, Austria

universität innsbruck

FWF Doctoral Programme
Atoms, Light, and Molecules



Accommodation

Youth Hostel Innsbruck
Reichenauerstraße 147
6020 Innsbruck

Day program venues

Lecture Hall 1:
Seminarroom 1
ICT-Building
Ground floor
Technikerstraße 21a
6020 Innsbruck

Lecture Hall 2:
Seminarroom 2
ICT-Building
Ground floor
Technikerstr 21a
6020 Innsbruck

Lunch:
13:00 @ TechCafe
ICT-Building
Ground floor
Technikerstraße 21a
6020 Innsbruck

Evening program venues

Master Course Dinner
Thursday April 10th
Pippilotta
Heiliggeiststraße 7-9
6020 Innsbruck

Meet the DK Alumnis & PhD students:
Wednesday 9th
Das Brett – boardgames & bar
Mariahilfstraße 12
6020 Innsbruck

*To make a contribution to climate protection, all dishes on offer are vegetarian and/or vegan.

Contact:

DK Atoms, Light, and Molecules
Dr. Heide Streicher / Dr. Eric Endres
Tel.: +43 512 507-52760
E-Mail: dk-alm@uibk.ac.at
www.uibk.ac.at/dk-alm

FWF Österreichischer Wissenschaftsfonds

LAND TIROL