FM 12: Quantum Sensing: Hardware Platforms

Time: Monday 14:00–16:00 Location: 2006

Invited Talk FM 12.1 Mon 14:00 2006

Quantum sensors with matter waves: geodesy, navigation and general relativity — •Philippe Bouyer — LP2N - CNRS, IOGS, Univ. Bordeaux; Talence

The remarkable success of atom coherent manipulation techniques has motivated competitive research and development in precision metrology. Matter-wave inertial sensors * accelerometers, gyrometers, gravimeters * based on these techniques are all at the forefront of their respective measurement classes. Atom inertial sensors provide nowadays about the best accelerometers and gravimeters and allow, for instance, to make the most precise monitoring of gravity or to device precise tests of the weak equivalence principle (WEP). I present here some recent advances in these fields: The outstanding developments of laser-cooling techniques and related technologies allowed the demonstration of matter-wave interferometers in micro-gravity. Using two atomic species (for instance 39K and 87Rb) allows to verify that two massive bodies will undergo the same gravitational acceleration regardless of their mass or composition, allowing a test of the Weak Equivalence Principle (WEP). New concepts of matter-wave interferometry can be used to study sub Hertz variations of the strain tensor of space-time and gravitation. For instance, the MIGA instrument, which is currently built in France, will allow the monitoring of the evolution of the gravitational field at unprecedented sensitivity, which will be exploited both for geophysical studies and for Gravitational Waves (GWs) detection.

FM 12.2 Mon 14:30 2006

Quantum Technology projects: a main pillar within the German space physical sciences program — •Thomas Driebe — DLR Space Administration, Bonn, Germany

As German Space Agency, the DLR Space Administration manages the German space program. This program integrates the German participation in the ESA programs and the activities in Germany's national program. As part of the space program, the German microgravity program is based on the provision of microgravity platforms, the development of flight hardware, and the preparation, execution, and analysis of both life and physical sciences experiments under space conditions.

The German Physical Sciences Program deals with gravity-dependent effects on physical and chemical processes and covers the research disciplines material sciences, fundamental physics, soft matter, fluid physics and combustion. The main program goal is to gain scientific knowledge by addressing fundamental questions in physics, to foster new technological developments and to reveal new application potentials from both fundamental as well as application-oriented research. Over the last two decades Quantum Physics and Quantum Technology projects have evolved into a main pillar of this programme.

In this talk, highlights of past and on-going Quantum Physics projects will be introduced along with the programmatic framework and priorities. In addition, opportunities and platforms for future research and technology development will be presented.

FM 12.3 Mon 14:45 2006

Fabrication of diamond AFM tips and nanopillars as hardware platforms for quantum sensing and memory — •Alexander Schmidt, Johann P. Reithmaier, and Cyril Popov — Institute of Nanostructure Technologies and Analytics (INA), University of Kassel, Heinrich-Plett-Str. 40, 34132 Kassel, Germany

We report on the fabrication of mono- and nanocrystalline diamond AFM tips and highly dense arrays of nanopillars (200 nm diameter) for implementation in quantum sensing and quantum memories. Both structures are fabricated by electron beam lithography and oxygen plasma reactive-ion etching. They are implemented on nanocrystalline diamond membranes by KOH etching of the silicon substrate for further processing, e.g. mounting the AFM cantilevers or deterministic ion implantation into the pillars. This technique could be transferred to monocrystalline diamond membranes, as demonstrated by preliminary works. Another accessible fabrication method for nanocrystalline AFM tips involving the moulding technique, conventional optical lithography and anisotropic wet etching in KOH of the silicon substrate will also be presented. Upon incorporation of nitrogen-vacancy centers, those structures can be envisioned for quantum sensing of magnetic fields at a nanoscale or implementation as quantum memories.

FM 12.4 Mon 15:00 2006

Quantum sensing with ultracold atomic collisions — •Krzysztof Jachymski[1], Tomasz Wasak[2], Antonio Negretti[3], and Tommaso Calarco[1] — [1]Forschungszentrum Jülich, Institute of Quantum Control (PGI-8), Jülich, Germany — [2]Max Planck Institute for the Physics of Complex Systems, Dresden, Germany — [3]Zentrum für Optische Quantentechnologien, Universität Hamburg, Hamburg, Germany

Feshbach resonances, which allow for tuning the interactions of ultracold atoms with an external magnetic field, have been widely used to control the properties of quantum gases. We propose a scheme for using scattering resonances as a probe for external fields, showing that by carefully tuning the parameters it is possible to reach a 10^-5G (or nT) level of precision with a single pair of atoms. We show that for our collisional setup it is possible to saturate the quantum precision bound with a simple measurement protocol.

FM 12.5 Mon 15:15 2006

Stable optical and vacuum systems for quantum technology applications in space — •Moritz Mihm[1], Sören Boles[1], Jean Pierre Marburger[1], André Wenzlawski[1], Ortwin Hellmig[6], Patrick Windpassinger[1], and the MAIUS Team[1,2,3,4,5,6] — [1]Institut für Physik, JGU Mainz — [2]Institut für Physik, HU Berlin — [3]IQO, LU Hannover — [4]FBH, Berlin — [5]ZARM, Bremen — [6]ILP, UHH Hamburg

Space-based quantum technology applications face harsh stability requirements while making high demands on system size and mass. We have developed a Zerodur based optical bench system for highly robust and miniaturized optical systems that overcomes these hurdles and that we are currently extending to include vacuum systems. I will present the fundamentals of our technology and the optical modules of MAIUS-2 as an example application. MAIUS-2 is a quantum gas experiment performing atom interferometry with Bose-Einstein condensates of potassium and rubidium onboard a sounding rocket.

Furthermore, I will discuss current efforts to build Zerodur based vacuum systems. The miniaturization of the chamber in conjunction with our laser system technology allows the development of highly robust and fully integrated quantum optical systems for space and other field applications.

Our work is supported by JGU Stufe 1 Funding and the German Space Agency DLR with funds provided by the Federal Ministry for Economic Affairs and Energy (BMWi) under grant numbers 50 WP 1433 and 50 WP 1703.

FM 12.6 Mon 15:30 2006

Testing Foundations of Quantum Mechanics with a Waveguide Interferometer — •Sebastian Gstir[1], Robert Keil[1], Thomas Kauten[1], Toni Eichelkraut[2], Alexander Szameit[3], and Gregor Weihs[1] — [1]Institut für Experimentalphysik, Universität Innsbruck, 6020 Innsbruck, Austria — [2]Institute of Applied Physics, Abbe Center of Photonics, Friedrich-Schiller-Universität Jena, Germany — [3]Institut für Physik, Universität Rostock, Germany

In this work we designed and built an integrated three-path waveguide interferometer in fused silica [1] for measuring so-called higher-order interferences [2] and higher-dimensional phases [3]. These hypothetical higher-order interferences and higher-dimensional phases do not occur in ordinary quantum mechanics or classical electrodynamics and thus the experiment tests the foundations of these theories. In our interferometer miniature mechanical shutters switch the individual arms on and off. Our main goal was to avoid cross-talk between the shutter state in a path and the transmissivity or phase in any other path. Using a laser source we were able to bound the occurrence of any higher-order interferences to be less than $8(12) \cdot 10^{-5}$, normalized to the expected two-path interference and the occurrence of any higher-dimensional phases to be less than 2%.

[1] T. Meany et al., Laser Phot. Rev. 9, 363 (2015).
[2] R. D. Sorkin, Mod. Phys. Lett. A 09, 3119 (1994).
[3] A. Peres, Phys. Rev. Lett. 42, 683 (1979).

FM 12.7 Mon 15:45 2006

An optical dipole trap as a source of ultracold atoms in microgravity; the PRIMUS project — •Christian Vogt[1], Mar-

ian Woltmann[1], Sven Herrmann[1], and the PRIMUS Team[1,2] — [1]University of Bremen, Center of Applied Space Technology and Microgravity (ZARM) — [2]LU Hannover, Institute of Quantum Optics

Cold atom based sensor have proven to be effective tools with wide applications in measuring weakest forces and thereby in testing fundamental physics e.g. the weak equivalence principle. As the sensitivity of atom interferometer measurements scales with the square of interrogation time, great effort has been made to bring these techniques to microgravity (μg) environments. For example the first BEC in space was created and effective temperatures down to the pK regime were demonstrated in the drop tower in Bremen. While all of these results in μg were achieved with magnetic traps on atom chips, the PRIMUS-project develops an optical dipole trap for use in weightlessness as an alternative source of cold atom ensembles. Dipole traps have several advantages like a symmetric trap shape and the accessibility of Feshbach resonances. They are well established in ground-based experiments and will most likely play a significant role in space-borne experiments as well. In this manner our project also serves as a pathfinder experiment for future cold atom experiments in weightlessness. With this talk we will present the current staus of the experiment and latest results of evaporative cooling in an optical dipole trap in μg. The PRIMUS-Project is supported by the DLR with funds provided by the BMWi under grant No. DLR 50 WM 1642.