A 13: Quantum meets gravity and metrology I

Time: Tuesday 11:00–13:00 Location: E 415

Invited Talk A 13.1 Tue 11:00 E 415

Does time exist in quantum gravity? — •Claus Kiefer — Universität zu Köln

Time is absolute in standard quantum theory and dynamical in general relativity. The combination of both theories into a theory of quantum gravity thus leads to a 'problem of time'. In my talk, I shall investigate those consequences for the concept of time that can be drawn without a detailed knowledge of quantum gravity. The only assumptions are the experimentally supported universality of the linear structure of quantum theory and the recovery of general relativity in the classical limit. Among the consequences are the fundamental timelessness of quantum gravity, the approximate nature of a semiclassical time, and the correlation of entropy with the size of the Universe.

Ref.: C. Kiefer, arXiv:0909.3767 [gr-qc].

Invited Talk A 13.2 Tue 11:30 E 415

How Attractive is the Moon for Relativity? — •Jürgen Müller[1,2], Liliane Biskupek[1], Enrico Mai[1], and Franz Hofmann[1] — [1]Institut für Erdmessung (IfE), Leibniz Universität Hannover, Schneiderberg 50, 30167 Hannover, Germany — [2]QUEST – Centre for Quantum Engineering and Space-Time Research, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany

In 1969, a new era for studying relativity has started. With the first returns of laser pulses sent from observatories on Earth to reflector arrays on the Moon, a new space technique – Lunar Laser Ranging (LLR) – has been providing an ongoing time series of highly accurate Earth-Moon distance measurements. To enable data analysis at the mm level of accuracy, all elements of the tracking process have to be modeled at appropriate (relativistic) approximation, i.e. the orbits of the major bodies of the solar system, the rotation of Earth and Moon, the signal propagation, but also the involved reference and time systems.

We will show where relativity enters the LLR analysis and how the whole measurement process is modeled, including the major classical (Newtonian) effects like gravity field of Earth and Moon, tidal effects, ocean loading, lunar tidal acceleration (that causes the increase of the Earth-Moon distance by about 3.8 cm/year), etc.

By analysing the 43-year record of range data, LLR is one of the best tools to test General Relativity in the solar system. It allows for constraining gravitational physics parameters related to the strong equivalence principle, geodetic precession, preferred-frame effects, or the time variability of the gravitational constant. We will present recent results for the various relativistic parameters.

[1] Hofmann, F., Müller, J., Biskupek, L.: Lunar laser ranging test of the Nordtvedt parameter and a possible variation of the gravitational constant. Astronomy and Astrophysics, Vol. 522, No. L5, 2010, doi: 10.1051/0004-6361/201015659.

[2] Müller, J., Hofmann, F., Biskupek, L.: Testing various facets of the equivalence principle using Lunar Laser Ranging. Classical and quantum gravity, Vol. 29, 184006 (9pp), 2012, doi:10.1088/0264-9381/29/18/184006.

[3] Müller, J., Murphy, T., Schreiber, U., Shelus, P., Torre, J., Williams, J., Boggs, D., Bouquillon, S. Francou, G.: Lunar Laser Ranging – A Tool for General Relativity, Lunar Geophysics and Earth Science. ILRS JoG special issue, submitted 2012.

Invited Talk A 13.3 Tue 12:00 E 415

Interferometry with Bose-Einstein condensates in microgravity — •Ernst Rasel — QUEST, Institut für Quantenoptik-Leibniz Universität, Hannover, Germany

A new field in matter wave optics is emerging, which is based on very long baseline atom interferometry (VLBAI). These interferometers strive to increase the sensitivity by coherently spitting and separating wave packets over macroscopic spatial and temporal scales. Bose-Einstein condensates (BECs), representing a textbook example for a macroscopic wave packet, are the ideal source for performing this kind of interferometry and were exploited for the first time in the extended free fall with a chip-based atom laser for Rubidium ^{87}Rb. Combining delta kick cooling with BEC we can produce ensembles with energies equal to temperatures falling below one nK. Employing an asymmetric Mach-Zehnder type interferometer we could study over hundreds of milliseconds the coherent evolution of a wave-packet and analyse delta kick cooling with the help of the observed interference fringes. This experiment can be considered as a gigantic double slit experiment in microgravity. A novel generation of atom chips allows to improve the performance of these flexible devices. We could demonstrate loading of the chip with far more than 10^9 atoms in roughly a second and generate large condensates of more than 100000 atoms, up to now only achievable in room filling devices, in a shoebox sized setup. We discuss as a possible spin-off a chip based quantum gravimeter for ground based applications, recently demonstrated with our device. The design will be employed for a rocket based test of such an interferometer, which will demonstrate the feasibility of satellite based tests of Einsteins principle of equivalence as pursued by the STE-QUEST mission.

The QUANTUS cooperation comprises the group of C. Lämmerzahl (Univ. Bremen), A. Peters (Humboldt Univ. Berlin), T. Hänsch/J.Reichel (MPQ/ENS), K. Sengstock (Univ. Hamburg), R. Walser (TU Darmstadt), and W.P. Schleich (Univ. Ulm).

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Invited Talk A 13.4 Tue 12:30 E 415

Relativistic effects in atom and neutron interferometry — •Wolfgang Schleich — Institut für Quantenphysik, Universität Ulm, Albert-Einstein-Allee 11, D-89081 Ulm

Motivated by the recent debate if the Kasevich-Chu atom interferometer can measure the gravitational redshift, we show [1, 2, 3] that the physical origin of the observed phase shift depends on the representation of quantum mechanics chosen for the calculation. We illustrate this phenomenon using the position and the momentum representations and demonstrate that the decomposition of the total phase shift into three dynamical phases, which emerges in the Feynman path integral approach and is at the very heart of the redshift controversy, does not appear in position space. This feature stands out most clearly in a representation-free analysis of the Kasevich-Chu interferometer where two rather than three phases contribute to the phase shift. We also compare and contrast atom and neutron interferometry.

[1] W.P. Schleich, D.M. Greenberger, and E.M. Rasel, A representation-free description of the Kasevich-Chu interferometer: A resolution of the redshift controversy, New J. Phys. 15, 013007 (2013)

[2] W.P. Schleich, D.M. Greenberger, and E.M. Rasel, The redshift controversy in atom interferometry: Representation dependence of origin of phase shift, Phys. Rev. Lett. 110, 010401 (2013)

[3] D.M. Greenberger, W.P. Schleich, and E.M. Rasel, Relativistic effects in atom and neutron interferometry and the differences between them, Phys. Rev. A 86, 063622 (2012)