Reconstruction of matter-wave diffraction experiments - A potential concept for sensing and lithography applications

Johannes Fiedler*[1] and Bodil Holst[1]

[1]University of Bergen – Norway

Abstract

The diffraction of matter waves is an established experiment that verifies the wave-particle duality. This fundamental principle relates the corresponding matter wave's wavelength to the particle's momentum leading to sub-nanometre wavelengths typically. In contrast to standard interferometers with light, matter-wave interferometers provide the potential for much higher resolutions by simultaneously dramatical decreasing the amount of transferred energy. To this end, matter-wave diffraction has a wide range of potential applications, such as lithography (1), inelastic surface scattering (2), or quantum sensing of physical properties (3). Beyond the drastic reduction of the wavelength, matter waves typically carry more information about the physical objects and the conditions they are prepared in due to the matter-matter interactions leading to a more complex wave structure that needs to be reconstructed to extract the wanted information.

In this presentation, we will introduce the involved matter-matter interactions that need to be considered in matter-wave diffraction experiments and demonstrate their impact on interference patterns. We will discuss the difficulties concerning their reconstruction with standard methods developed for light interference and provide an alternative approach via machine learning. We successfully applied this method to estimate masks for matter-wave lithography (4), which will be demonstrated.

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*Speaker

ACES/PHARAO: high performance space-to-ground and ground-to-ground clock comparison for fundamental physics

Marie-Christine Angonin[1], Pacôme Delva[1], Christine Guerlin[2], Christophe Le Poncin-Lafitte[1], Marc Lilley*[1], Frédéric Meynadier[3], Etienne Savalle[4], and Peter Wolf[1]

[1]Systèmes de Référence Temps Espace – Sorbonne Universite, Centre National de la Recherche Scientifique : UMR8630, Observatoire de Paris, Institut national des sciences de lÚnivers, Institut national des sciences de lÚnivers, Institut national des sciences de lÚnivers, Institut national des sciences de lÚnivers, Institut national des sciences de lÚnivers, Institut National des Sciences de l'Univers – France

[2]Laboratoire Kastler Brossel – Fédération de recherche du Département de physique de lÉcole Normale Supérieure - ENS Paris, Centre National de la Recherche Scientifique : UMR8552, Sorbonne Universite – France

[3]BIPM – Bureau International des Poids et Mesures – France

[4]CEA- Saclay – Commissariat à l'énergie atomique et aux énergies alternatives – France

Abstract

The Atomic Clocks Ensemble in Space (ACES) mission (Salomon, 2007), is a fundamental physics mission of the European Space Agency (ESA) to be launched in 2025. It relies on a high performance clock onboard the International Space Station (ISS), a network of high-performance clocks on ground, a dedicated two-way microwave link (MWL) enabling space-to-ground and ground-to-ground clock comparisons, as well as an optical link (ELT). PHARAO/SHM (Projet d'Horloge Atomique par Refroidissement d'Atomes en Orbite/Space Hydrogen Maser), the clock onboard the ISS, has a relative frequency accuracy at the 10E-6 level, a relative frequency stability (Allan deviation) equal to 10E-13/Sqrt(t) (t being the integration time in seconds) and a time deviation of 12 picoseconds after one day of integration. The MWL is designed to reach a time deviation below 7 ps after one day of integration. While space-to-ground clock comparisons will enable precise tests of the gravitational redshift, tests of deviations from General Relativity (GR) at the 10E-6 level, and tests of local Lorentz invariance at the 10E-10 level, ground-to-ground clock comparisons will enable a search of the time variation of fundamental constants with uncertainty at the 10E-17 level after one year. In this contribution, we review the mission set up with a particular emphasis on the MWL, discuss the simulation and data analysis software developed to investigate mission performance, focusing on its primary scientific objective: the test of the gravitational redshift.

*Speaker

Towards a GEodesy and Time Reference In Space (GETRIS): A simulation study

Stefan Marz*[1], Anja Schlicht[1], and Urs Hugentobler[1]

[1]Forschungseinrichtung Satellitengeodäsie, Technical University of Munich – Germany

Abstract

The progress for satellite Precise Orbit Determination (POD) and navigation depends on the future ranging and time transfer capabilities. This leads to the need for high-precision links as well as high-precision clocks. The GETRIS (GEodesy and Time Reference In Space) concept is based on the idea to have high-precision clocks carried by geosynchronous orbit (GSO) satellites. With high-precision optical links, the connection to Medium Earth Orbit (MEO) and Low Earth Orbit (LEO) satellites, but also to far Earth satellites shall be established. The goal is to achieve a GSO satellite-based reference in space with orbit accuracies at the same level as the ground stations accuracy – a few millimeters. In a simulation study, we performed scenarios using the synergy between L-band observations as well as high-precision dual one-way Optical Inter-Satellite Links (OISL) and ground-space based dual one-way links, called Optical Two-Way Links (OTWL). Having the observation technique combinations, we show the POD capabilities within a MEO+GSO constellation not only for the GSO satellites, but also for the MEO satellites. While first using Passive Hydrogen Masers (PHM) on all satellites in the constellation, we compare the solutions regarding clock estimation and prediction with solutions using the ACES (Atomic Clock Ensemble in Space) clock as a high-precision clock example.

*Speaker

Quantum engineering of SU(3) hyper-clocks

Thomas Zanon*[1,2], David Wilkowski[3], and Caroline Champenois[4]

[1]Laboratoire d'Etude du Rayonnement et de la Matière en Astrophysique (LERMA) – Université Pierre et Marie Curie [UPMC] - Paris VI, Observatoire de Paris, Université de Cergy Pontoise, Université Pierre et Marie Curie (UPMC) - Paris VI, INSU, CNRS : UMR8112, École normale supérieure [ENS] - Paris – 61, avenue de l'Observatoire - 75014 PARIS, France

[2]Université Pierre et Marie Curie - Paris 6 (UPMC) – Université Pierre et Marie Curie [UPMC] - Paris VI, Université Pierre et Marie Curie (UPMC) - Paris VI – 4 place Jussieu - 75005 Paris, France

[3]MajuLab, International Research Laboratory IRL 3654, Université Côte d'Azur, Sorbonne Université, NUS, NTU, CQT, 117543 Singapore, SPMS NTU, 637371 Singapore – Singapore

[4]PIIM – Université d'Aix-Marseille, CNRS, PIIM, UMR7345 Centre de St Jérôme, Case C21, 13397 Marseille Cedex 20, France – France

Abstract

SU(2) hyper-clocks based on qubits are using composite pulses in a Ramsey interferometer to provide better robustness against technical defects synchronized with laser pulses {1,2}. The rapid evolution of ultra-stable high finesse cavities, femto-combs and ultra-cold atomic sources are pushing quantum technologies to a new level of accuracy offering tools for optimal control of a new generation of atomic sensors. We have derived for the first time a quantum hyper-clock with SU(3) Gell-Mann symmetry dynamics, incorporating one, two and three-photon coherent excitations {3,4,5}. The atomic flavor associated to various dynamics of atom-light interaction based on arbitrary sequences of multiple laser pulses is presented. A three-level three-photon optical clock in a closed-contour interaction is proposed extending a recent proposal to test quantum mechanics with three connected narrow atomic transitions {6}. The hyper qutrit-clock exhibits robustness to environmental fluctuation inducing decoherence and chiral symmetry-breaking of population dynamics {7}.
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