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

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

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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 10\textsuperscript{E}-6 level, a relative frequency stability (Allan deviation) equal to 10\textsuperscript{E}-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 10\textsuperscript{E}-6 level, and tests of local Lorentz invariance at the 10\textsuperscript{E}-10 level, ground-to-ground clock comparisons will enable a search of the time variation of fundamental constants with uncertainty at the 10\textsuperscript{E}-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.

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

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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.
Quantum engineering of SU(3) hyper-clocks

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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}.


*Speaker
