Artemis Science White Paper

Ultrahigh accuracy time synchronization technique operation on the Moon

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Abstract. *Ultrahigh accuracy time synchronization technique based on the GHZ radiofrequency spiral scanning deflector is suggested to install on the Moon during the ARTEMIS mission. The comparison with the parameters of an analogous device operated in the Earth's gravity will enable the testing to unattained accuracy variety of fundamental physical principles.*

The installation of retroreflectors on the Moon by Apollo 11 and by subsequent missions and Lunar laser ranging opened entire new paths for research, from testing of fundamental physics, General Relativity, Nordtvedt effect[1], up to a bunch of issues of the structure and evolution of the Moon. The present proposal aims the operation on the Moon during the ARTEMIS mission of to date the highest accuracy synchronization technique.

Present proposal is based on authors' experience on to date the highest accuracy test of light speed invariance (Kennedy–Thorndike test) at the GRAAL experiment at European Synchrotron Radiation Facility (ESRF, Grenoble) [1], General Relativity's Lense-Thirring effect testing via LARES satellite laser ranging measurements [2],[3].

Femtosecond optical frequency combs are revolutionizing precision measurements of time and frequency [4]. The simplicity, robustness and improved precision femtosecond lasers have now led to their prominence in the field of optical frequency metrology. In addition, their use is developing significant new time domain applications based on the precise control of the carrier-envelope phase. Narrow linewidth lasers referenced to optical transitions in atoms and ions are the best electromagnetic references, with projected fractional frequency instability and uncertainties well below $10^{-15}\tau^{-1/2}$ and 10^{-18}, respectively. When used in conjunction with such ultraprecise frequency standards, the femtosecond laser serves as a broadband synthesizer that phase-coherently converts the input optical frequency to microwave frequencies. The excess fractional frequency noise introduced in the synthesis process can approach the level 10^{-19} [5].

Combination of femtosecond optical frequency combs with a radio frequency timing technique of visible photons [6, 7] results in a new tool for precision time or frequency measurements [8]. The principal idea is in the comparative operation of the optical and radio frequency techniques. Namely, a GHz radiofrequency spiral scanning deflector is used, which is capable of real-time conversion of a sequence of electrons into two-dimensional spatial images, synchronously with the optical frequency comb. This ultrafast timing processor creates a sequence of keV energy electrons directly encoded onto the spatial locus, producing a two-dimensional spatial image of

[1] Ken Nordtvedt had told to one of the authors (VG), how he approached Robert Dicke, the then NASA official, during a joint air flight, suggesting to include a retroreflector in Apollo 11 mission.

the electrons arrival time. This produces a THz bandwidth and a dead-time free device for electron detection which is capable of achieving 1 Tbit/s sampling rate and 1 *ps* time resolution in a few hundred *ns* time range.

The use of radiofrequency technique will provide precisions of 1 *ps* or less with fast readouts and essentially no dead-time. Although the idea is based on the same principles as streak cameras that can respond in the *ps* or sub-*ps* regimes, those cameras have limited dynamic range and there is no device that can read it out fast enough. The suggested technique solves both challenges, so that the dynamic range is expanded and the fast readout makes it useable in the described context.

The GHz radiofrequency timing technique with such ultrahigh level of precision in time measurements operated in the Moon gravity, then compared with the analogous device operation in the Earth's gravity, will enable the testing to unattained accuracy variety of fundamental physical principles, not even easy for mentioning exhaustively now.

Various technical realization options and solutions can be considered to reach the possibly lightest, spatially smallest transportable device.

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