Optical clocks and cavity stabilised lasers for future space deployment

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We discuss work at the UK National Physical Laboratory (NPL) targeting the development of optical cavities for laser frequency stabilisation in space. These cavities have applications in upcoming Earth Observation gravity missions, science missions (e.g. LISA) and as sub-systems of next generation optical clocks for navigation. We will present results from our recent work across these areas.

NPL has been working over the last decade with the European Space Agency, the UK Space Agency and European industrial partners towards a high technology readiness level (TRL) version of its patented cubic cavity [1], most recently as part of a consortium demonstrating the requirements for TRL6 [2]. This project targeted future global navigation satellite systems (GNSS), the Next Generation Gravity Mission (NGGM), and we have also developed two cavities to support a European contribution to the LISA mission [3]. We review the frequency noise specifications for these missions and present data for the cavities built to date.

In parallel with the development of an NPL single axis cubic cavity for gravity missions, we are progressing a dual-axis design under ESA's Navigation Innovation Support Programme (NAVISP) to be integrated within a future spaced-based optical clock. Optical clocks require a sub-Hz linewidth laser, a physics package for confining and cooling atoms or a single ion and a frequency comb for dividing down the optical frequency to provide a microwave output. To date, we have demonstrated a dual axis cubic cavity [4] for stabilising all the lasers for a neutral strontium lattice clock. This cavity was also capable of stabilising the frequency of some of the lasers for a strontium ion ($^{88}Sr^+$) optical clock. A new dual axis cavity is under development, including digital servo electronics to replace our earlier frequency control system [4]. This new cavity targets use with a space deployable version of a $^{88}Sr^+$ ion trap physics package [5] which is a modification of [6]. We have used finite element analysis (FEA) to show that this new trap can withstand the mechanical loads expected during launch. Four auxiliary lasers requiring frequency stabilisation are needed for photoionisation, cooling, metastable state repumping and clear-out. These are frequency stabilised via one bore of the dual-axis cavity. The cooling and photoionisation wavelengths are generated by frequency doubling, so that cavity broadband mirrors are required for 1092 nm, 1033 nm, 922 nm and 844 nm. Light at 922 nm is frequency doubled to 461 nm light for photoionisation and 844 nm is frequency doubled to 422 nm for cooling. The orthogonal cavity axis will stabilise the 674-nm optical clock laser. However, the frequency stability requirement for an optical clock is more stringent than for gravity missions. Whereas ~30 Hz frequency instability at ~1 s is typically required for gravity missions, optical clocks require sub-Hz laser linewidths. For a $^{88}Sr^+$ optical clock, a fractional frequency instability of a few parts in 10^{16} at ~100 s is required to demonstrate a quantum projection noise instability limit of $\sim 3 \times 10^{-15}/\sqrt{\tau}$. We will discuss progress and the long-term outlook for a space deployable strontium ion optical clock.

References

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