STE-QUEST: MISSION DESIGN WITH EVOLVING SCIENCE CONSTRAINTS

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Keywords: *mission design, three-body-problem, STE-Quest, Highly Eccentric Orbit*

This paper will introduce the science goals of the Space-Time Explorer and Quantum Equivalence Space Test (STE-QUEST) mission. The science requirements to a achieve these goals were regularly updated during the design phase and caused significant changes in the orbit design. The different orbit designs are presented together with the rational for their selection. The impact of space debris mitigation on the orbit design will be discussed.

The STE-Quest science objectives are to test Einstein's theory of relativity to a high degree of precision exploiting the predictions for the relativistic red-shift in the gravitational field of the Sun, the Earth, and the Moon, as well as for the propagation of matter waves. For this purpose high-precision clocks on board are linked to clocks on the ground via a coherent microwave link using microwave terminals (MWTs). Large variations of the Earth's gravitational potential along the orbit are important to maximize the relative accuracy of the red-shift measurement. To test the weak equivalence principle for quantum objects the S/C carries atom interferometers.

The locations of the three high precision clocks on the ground are all assumed to be at science centres in the northern Hemisphere, roughly separated by 120 Deg in longitude and thus spread around the globe.

The science objectives require that an orbit with repeated measurements from all three. This fact calls for an orbit in resonance with the Earth's rotation to allow repeated passes in the visibility of the terminals. An orbit with a semi-major axis resulting in an orbital period of about 16 hours is in a 3:2 resonance and has three perigee locations with respect to the surface of the Earth.

The original science requirements demanded visibility of the perigee and the apogee from the science ground stations. Such a visibility can only be provided with the ground stations located near the equator, since only then the ground track location of the perigee and apogee are at similar latitude. With the science ground stations located in the northern hemisphere a fixed orbit geometry fulfilling the constraints is infeasible.

Thus, the constraint on only using science ground stations in the northern hemisphere was given up and an orbit at the frozen inclination was selected. Six ground stations were envisioned with the locations optimized such that three ground stations could observe the perigee pass in the southern hemisphere and three ground stations would provide for long common visibility of the S/C from two science terminals during the apogee pass. However, due to the unavailability of precise clocks in the southern hemisphere this option was later discarded.

To achieve visibility of perigee and apogee passes from the northern hemisphere science stations a drifting orbit geometry was then proposed with an inclination above the critical one such that the argument of perigee is rotated by the J2-effect. The launch is in an initial orbit with perigee visibility. Over the years the argument of perigee is rotated such that the apogee will be visible from the science ground stations, while the perigee visibility is lost. The measurements are thus not taken alternating, but in subsequent phases.

Further investigation of the simulated science data from this orbit showed that the perigee measurement could be replaced by a continuous measurement along a major part of the orbit. It was thus decided to return to fixed orbit geometry at the frozen inclination in order to minimize mission risk, since with drifting orbit geometry a return to the initial conditions would have been impossible. In addition the science data of both measurements is available right from the start of the mission and one doesn't have to wait for years for the first apogee measurement.

A HEO is subject to third body perturbations constantly changing the eccentricity of the orbit. This change in the eccentricity is problematic with respect to the lifetime of the orbit. With a proper choice of the initial right ascension of ascending node the lifetime of the orbit can be controlled and the S/C can be setup for a cheap re-entry at the end of the mission in order to comply with space debris mitigation standards.

In the full paper the iterative process of mission design and requirements analysis is presented in detail for this special case of STE/Quest, for which a deep understanding of the science requirements for the mission analyst is as important as the deep understanding of the operational, geometrical, and dynamical constraints on orbit for the scientist.