LOCAL TESTS OF GENERAL RELATIVITY WITH GAIA AND SOLAR SYSTEM OBJECTS

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ABSTRACT. The Gaia mission has been launched by ESA on 2013 December, 19. It aims to survey, in addition to stars, a large number of solar system objects (SSO). Hence, Gaia will provide during its 5 years mission high precision astrometry in an absolute reference frame of about 300 000 asteroids, including many Near-Earth Objects. The very precise orbits Gaia will provide, will enable to determine simultaneously the solar J_2 and the PPN parameter beta and other parameters for testing the GR. Improvement from combining Gaia and radar data are also expected.

1. INTRODUCTION

The Gaia space mission is an ESA astrometric mission of the Horizon 2000+ programme provides Europe with a successor to Hipparcos/Tycho, with many huge improvements. The number of stars observed and catalogued, in addition to the precision of the measures – astrometric, photometric, and spectroscopic – complemented by some imaging capabilities, make it more than a Hipparcos-II. In this respect, the Gaia satellite and telescope will observe a large number of Solar System Objects (SSO) during the 5 years mission duration, down to magnitude $V \approx G \leq 20.5$, as presented in e.g. Hestroffer & Tanga (2014) and Mignard et al. (2007). Given the astrometric precision involved—at the sub-mas level—relativistic effects have to be taken into account in the data reduction and analysis. This was already the case in the Hipparcos mission, also for the Solar System objects (Hestroffer & Morando 1995, Hestroffer 1997), and is now also mandatory at all stages of the reduction pipeline within the Gaia mission. A group, REMAT, within the Gaia DPAC Data Processing and Analysis Consortium, is providing RElativity Models And Testings. In this framework tests of Genaral Relativity (GR) can be performed by measuring the Parameterised Post-Newtonian (PPN) parameters, and more exactly their possible deviation from the canonical value of the GR theory. This is done for instance from the astrometry of stars and a measure of the light deflection through parameter γ (e.g. Mignard & Klioner 2010; Raison et al. 2010), but also by a test of the quadrupole effect around Jupiter and the GAREX experiment (Crosta & Mignard 2006; Le Poncin-Lafitte & Teyssandier 2008), and last, from the orbit of solar system objects. We will present in the following some aspects of the scientific outcome of Gaia within the Solar System for deriving the PPN β, together with the Solar quadrupole J_2 and other parameters, and prospective for testing GR or other alternative theory.

2. MISSION AND EXPECTED RESULTS

There are some obvious advantages to use astrometry from space, of high precision and accuracy, with a single instrument and data reduction performed directly in a fundamental stellar catalogue. All these are provided by the Gaia satellite, telescope and mission. On the other hand the programmatic of the Gaia observations is not adapted to SSO, but imposed by the scanning law of the satellite. Since most of Gaia asteroids are well known objects, we will be able to derive orbit improvements from ordinary least squares techniques involving only Gaia observations within the DPAC consortium. We can then perform a variance analysis of the system of equations' inversion and get the formal precisions of all unknown parameters estimation.

The astrometric precision is—depending on the target's magnitude—of the order of 1 mas and better. Given such unprecedented astrometric precision available for the observations of Solar System, big improvements are expected in orbit refinement, so that small effects and perturbations on the orbits can be detected, dynamical or physical parameters estimated such as mass of asteroids (Mouret et al. 2007), and models tested. In particular, small additional acceleration due to GR is affecting all orbits of SSOs, and mostly this of eccentric orbits close to the Sun. Thus Near Earth Objects (asteroids and comets) are particularly good test particles for the purpose of testing the General Relativity in the Solar System. It is well known that both the Sun quadrupole J_2 and GR imply an advance of the perihelion of the orbit that can hardly be separated from the observation of one single target, such as Mercury, alone. Gaia will provide observations of bout 2000 NEOs and will yield a simultaneous determination of both J_2 and PPN β. The order of precision obtained 10^{-4} for β, 10^{-8} for J_2, are not much better than current estimates but completely independent of other modelling (Nordvedt, Sun interior, . . .) or assumption on one of the parameters. Besides of these test of GR combined with the measure of Sun dynamical flattening, one will be able to test a possible variation of the gravitational constant. Moreover, since all SSO positions will be derived directly in the optical ICRF realised by the Gaia QSOs, a direct link between the dynamical and kinematical non-rotating frames will be established. This will put the ecliptic and equinox within the ICRF, and also test a possible rotation rate at the μas/year level (Hestroffer 2010).

3. PROSPECTIVE

The influence of the Lense-Thirring drag is tested. It mimics precession from Solar J_2 and can account to 7% of the value so determined (Folkner et al. 2014); the perihelion precession can reach 2.8 mas/cy in the case of NEA 2000 BD_{19} (a = 0.876 AU; e = 0.895), similar to the one from PPN β. Besides, other framework can be considered such as post-Einsteinian gravity, MOND, SME (Hees et al. 2014, and references therein). Some improvements can hence be expected in several ways:

- observing more objects down to magnitude $V \leq 21$. This is considered because the limitation in magnitude is not imposed by the telescope and instruments sensitivity, but by the data downlink to Earth. Going to fainter magnitude has his cost of operations but shows some benefits particularly for testing the GR.
- one year mission extension. Such extension can be decided by ESA at later stages of the mission. Increasing the time span has obvious advantages for deriving orbits' precession and their secular effects, making angles and longitudes on the orbit vary quadratically with time. Combined with the push in limiting magnitude, a gain of factor 2 can be expected.
- complementary ground-based observations for a few targets. Only measures of high precision and with high accuracy can be considered here, these are already obtained by radar techniques at Arecibo (Margot & Giorgini 2010) and will span about two decades.

4. REFERENCES

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