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Report on JUICE 3GM gravity experiment performance

P. Cappuccio, M. Di Benedetto, G. Cascioli and L.Iess
University La Sapienza of Rome, Department of Mechanical and Aerospace Engineering, Italy, Rome, Via Eudossiana 18 (paolo.cappuccio@uniroma1.it)

Abstract

The ESA's JUICE mission will provide a multi-disciplinary investigation of Jupiter and its Galilean moons through a suite of eleven different experiments. JUICE will perform 2 Europa flybys, more than 10 Callisto flybys, and will orbit about Ganymede in the last 9 months of the mission. The 3GM (Geodesy and Geophysics of Jupiter and the Galilean Moons) experiment will use accurate Doppler and range measurements to infer the moons' internal structure by measuring their gravity field and, for Ganymede and Callisto, their tidal Love number k_2. This work presents the attainable 3GM gravity experiment performances with the latest trajectory kernels and the High Accuracy Accelerometer (HAA) to remove the dynamical noise induced by propellant sloshing.

1. Introduction

JUICE -JUpiter ICy moons Explorer- is an ESA L-class mission devoted to study the Jovian system. The nominal launch date is in September 2022, with arrival at Jupiter foreseen in July 2029.

After the JOI maneuver, JUICE will use multiple gravity assists of the Galilean satellites to shape a comprehensive orbital tour over 3.5 years. The mission includes Europa, Callisto and Ganymede flybys and it will culminate in a dedicated, nine-month orbital phase around Ganymede. It consists of a 5 months elliptic phase, with a periapsis at about 1000 km and an apoapsis at about 10000 km, and a final circular orbit phase at an altitude of 500 km (named Ganymede Circular Orbit - GCO500). This will be the first time that a moon beyond our own will be orbited by a spacecraft [1].

The 3GM experiment is one of the eleven investigations that JUICE will perform (one has no HW onboard as it will rely on ground-based observations). The 3GM gravity experiment performances are addressed in this work. In particular, we investigate one of the 3GM main scientific goals, namely the determination of Galilean moons' gravity fields and the spacecraft orbital accuracy relative to those moons. The latter goal is important to provide a precise reference to the onboard laser altimeter.

2. 3GM instruments

The KaT is the core of the gravity experiment, providing a two-way coherent Ka/Ka link supporting range and range-rate data as accurate as 20 cm (two-way) and 3 μm/s @ 1000s integration time. Radio metric measurements will enable a precise orbit determination of the JUICE spacecraft and the estimation of Europa, Ganymede and Callisto's gravity fields. Such accuracies are attainable thanks to the simultaneous use of the KaT and the onboard DST (Deep Space Transponder) providing the two additional X/X and X/Ka links. Such multi-frequency scheme will allow a nearly complete calibration of the dispersive plasma noise, while the use of advanced Microwave Radiometers (MWRs) on ground will allow the calibration of the non-dispersive tropospheric noise. This corresponds to an expected end-to-end link frequency stability at an Allan Deviation of $\sim 10^{-14}$. The high accuracy radio link will permit also an improvement of the solar system ephemerides thanks to the 24 Mcps PN ranging system. It will guarantee a 20 cm two-way accuracy after 10 s integration time.

All the three ESTRACK stations (New Norcia, Cebreros, Malargüe) are considered capable of Ka-band uplink at the time of the experiment; thus, radio tracking data are simulated from all of them, without permitting overlapping in time.

In addition to that, 3GM will make use also of data from the onboard HAA to calibrate out the non-gravitational disturbances, mainly due the propellant sloshing. The HAA selected for JUICE is identical in design to the Italian Spring Accelerometer (ISA) already mounted onboard the ESA's BepiColombo mission.

3GM science package comprises another instrument, the Ultra Stable Oscillator (USO), which will be used to carry out an occultation experiment.

3. 3GM gravity experiment

JUICE will perform only 2 Europa flybys that will allow the independent estimation of the J_2 and C_{22} gravity parameters, which are sufficient to test the hydrostatic equilibrium hypothesis ($J_2/C_{22} = 10/3$). The 12 Callisto flybys will provide enough data to infer its gravity field at least up to degree and order 3. Concerning Ganymede only the circular phase at 500 km altitude will be considered for the gravity experiment. It will allow the estimation of the 10x10 (or higher) gravity field and rotation parameters. Measurements of Callisto and Ganymede gravity fields at different moons mean anomalies will allow also the estimation of the tidal Love number k_2, this parameter will let us to infer the presence or absence of a liquid ocean under the superficial icy shell. The estimation of the complex k_2 will allow not only to prove (or disprove) the presence of an internal ocean, but also to measure the tidal phase lag and ice viscosity.

Preliminary simulations carried out by 3GM team with the initial baseline trajectory envisioned in the JUICE Announcement of Opportunity (AO) showed an attainable accuracy of 0.06 for Callisto k_2 Love number, and for Ganymede an accuracy of about 10^{-3} for the complex k_2 [2]. However, because of some stringent mass constrains reducing the available propellant onboard the spacecraft, the number of Callisto flybys has decreased from 20 to 12 while the old GCO200 phase is no more baselined, turning out into an extended GCO500. Therefore, this work does not consider a GCO200 phase, also if there are good chances to recover it in the future. The accuracy at which it is possible to compute Callisto's k_2 is the main concern because of the reduced amount of data available. An additional concern comes from the dynamical stability of the platform, which is subject to unpredictable accelerations due to propellant sloshing during flybys.

4. Conclusions

The estimation of the accuracies at which is possible to recover the gravity fields of Europa, Callisto and Ganymede, and the orbit of the spacecraft relative to those moons are investigated in this work. The estimation of these parameters is obtained from refined simulations of 3GM gravity experiment, taking into account the latest available JUICE baseline trajectory (141a of the CReMA 3.2) and the inclusion of the HAA data into the orbit determination software.

Acknowledgements

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References

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