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Influence of the internal structure of Europa and of Jupiter on the Doppler signal of a nearly polar and nearly circular Europa orbiter

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Abstract

In an analytical formalism, we compute the effect of the gravity field, the tides and the rotation of Europa on the Doppler effect on a radio link between a Europa orbiter and the Earth. We also study the third body effect of Jupiter on the Doppler signal.

1. Introduction

From the gravity measurements of the Galileo mission, the total thickness of the ice and water layer of Europa is evaluated to be $80 - 170$ km [1]. The thickness of the individual ice and water layers, however, could not be determined from the gravity measurements alone, since their densities are similar. The determination of the ice shell thickness of Europa is one goal of the Europa Jupiter System Mission under study by NASA and ESA. Information on the thickness of the ice shell can be determined by measuring the Doppler effect on the radio link between the Europa orbiter of EJSM and the Earth.

Here, this Doppler effect is modelised by the relative radial velocity between the orbiter and the terrestrial observer and depends on the orbital elements of the orbiter which are computed by integration of Lagrange's equations.

We showed that the geophysical parameters linked to the gravity field (C_{20} and C_{22}), the tides (the Love number k_2 and the quality factor Q) and the rotation of Europa (obliquity, amplitude of libration of the shell and of the interior) have a significant effect on the orbital elements of the Europa orbiter and therefore on the Doppler signal [2]. This strongly suggests that the geophysical parameters can be determined with a radioscience experiment. As these geophysical parameters depend on the internal stucture of Europa, their determination can help to constrain the ice shell thickness and/or the other interior structure parameters, such as the total ice-water thickness that depends on the gravity field coefficient.

Here, we take into account the direct effect of Jupiter on the orbiter (third-body effect), which cannot be neglected because of the high mass of Jupiter. In particular, the third-body effect of Jupiter leads to instability of orbits (collision with Europa after about 15 days) that are initially nearly polar and nearly circular, because it strongly increases the eccentricity of the orbiter.

2. Introduction of Jupiter in the model

We develop an analytical expression of the Doppler signal, with Jupiter considered as a point mass, and compare the individual effects of the geophysical parameters with those in which the effect of Jupiter is neglected.

The classical integration of the Lagrange's equations with the Kaula method is succesful, for example, for an Earth orbiter perturbed by the third-body effect of the Moon, and consists of a successive computation of the dominating secular perturbations and of the minor periodic perturbations of the orbital elements [3]. However, this method fails for the Europa orbiter because of the high mass of Jupiter that causes some periodic perturbations being at least as important as the secular perturbations of the orbital elements. Nevertheless, we have been able to modify Kaula's method, by achieving a correct classification of the perturbations, and to obtain an analytical solution in good agreement with the numerical integration of the Lagrange equations.

As en example, in Fig. 1, we show the result of the numerical integration, the analytical solution obtained with the Kaula method and the new analytical solution

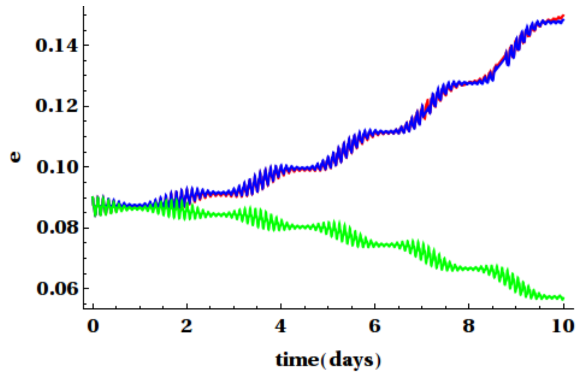

Figure 1: Numerical integration (blue), analytical integration with Kaula method (green) and the new analytical integration (red) of the eccentricity Lagrange's equation for an initial eccentricity of 0.09, on a 10 days time interval begining 01/01/2025 midday, for a nearly polar orbit.

of Lagrange's equation for the eccentricity. The new analytical solution adequatly describes the increase of the eccentricity due to the direct influence of Jupiter, in contrast to the use of Kaula's method.

An analytical expression of the Doppler signal is needed for a preliminary inversion study by the least square method in order to assess the precision on the geophysical parameters that can be reached by using real Doppler data.

We test different sets of initial orbital elements. An interesting set has to

- maximise the effect of the geophysical parameters on the Doppler signal, in order to maximise the constraints the internal stucture of Europa,
- minimise the increase of the eccentricity, in order to minimise the amount of spacecraft manoeuvres needed to avoid a collision with Europa.

References

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[3] Kaula, W. M.: Theory of Satellite Geodesy, Dover Publications, 1966