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A possible determination of Jupiter's frequency-dependent tides at the end of the Juno mission

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Abstract

Juno has currently completed 12 orbits around Jupiter, of which 5 have been dedicated to the gravity science experiment. The gravity experiment consists in the measurement of the Doppler shift of X- and Ka- band signals transmitted from NASA's DSS 25 antenna to the spacecraft and retransmittend back coherently to the same station (two-way link). The Doppler data are used to accurately reconstruct the trajectory of the spacecraft, whilst determining several geophysical parameters (such as the harmonic coefficients of Jupiter's gravity field) to characterize the gas giant's interior mass distribution [1].

The analysis of Doppler data from the Juno spacecraft allowed to determine Jupiter's gravity field with unprecedented accuracy, as well as to reveal the depth of its atmospheric zonal winds [2, 3].

Until the end of the nominal mission in July 2021, Juno will complete 20 additional gravity orbits. The full dataset will be fundamental to uncover features of Jupiter's gravity not currently observable, such as the planet's response to the frequency-dependent tides raised by the satellites as they orbit around the planet with different periods.

[4] computed Jupiter's static Love numbers (the geophysical parameters that characterize a planet's response to a tidal perturbation) for Io, Europa and Ganymede, the main tide-raising bodies for the gas giant. In addition, resonances between the frequencies of the tidal perturbation and Jupiter's natural oscillation eigenfrequencies, not considered in their paper, could amplify the dynamical response of the planet to the satellite-dependent perturbation.

Nevertheless, no theory can currently predict the dynamical tidal response of Jupiter to tides raised by its moons. [5] developed an incomplete dynamical theory by computing the frequency-dependent Love numbers as a function of the satellite mean motion and of Jupiter's oscillation eigenfrequencies. However, they did not consider the fast rotation of the gas giant, which increases its tidal response [6].

We report on simulations performed over the nominal science mission to determine whether Juno is sensitive to frequency-dependent tides on Jupiter. In fact, Doppler measurements from the Juno spacecraft can be used to sample the tidal bulge raised on Jupiter by its moons. We first simulated Doppler data from Juno considering a 6-hour two-way link from NASA's DSS 25 antenna at X- and Ka-band, covering the pericenter, along with an additional 3-hour X-band two-way tracking window from NASA DSS 43. We assumed a realistic noise level on the Doppler observables (1.4 mHz for Ka-band and 0.6 mHz for X-band at 60-s integration time), coherently with the results from data analysis [2].

For the parameter estimation, we used a multi-arc least-square batch filter that provides an estimate of the solve-for parameters by minimizing the difference between the simulated measurements and the ones computed with a dynamical model of the spacecraft. The solve-for vector is divided into local parameters, which pertain to each gravity pass (such as the spacecraft's state), and global parameters. The tidal model currently used for gravity data analysis assumes that the Jovian satellites contribute equally to the total tidal perturbation, and thus only one Love number is estimated. We implemented a frequency-dependent tidal model within the orbit determination software, defining one Love number for each of the Galilean satellites.

We defined as global parameters Jupiter's GM and its gravity field up to zonal degree 30 and tesseral order 4, as well as the frequency-dependent Love numbers for Io, Europa, Ganymede and Callisto up to degree and order 4. We also included the motion of Jupiter's spin-axis (pole position and rate), and we considered the uncertainty on the GM of the Galilean

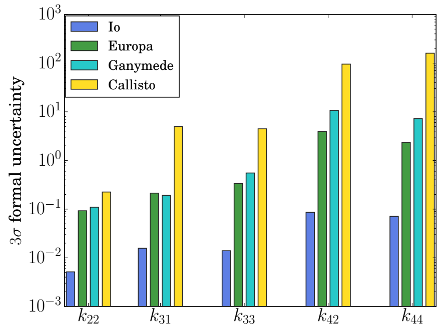

Figure 1: 3σ formal uncertainty on the Love numbers up to degree and order 4 for Io (blue), Europa (green), Ganymede (cyan) and Callisto (yellow).

satellites to account for errors in their trajectories.

The formal uncertainty obtained on the satellite-dependent Love numbers after the nominal 25 gravity-dedicated orbits is shown in Figure 1. Juno shows good sensitivity to tides raised by Io, Europa and Ganymede, the main sources of the tidal perturbation. The uncertainty on the Love numbers for a given degree and order increases with the distance from the planet, and grows also with increasing degree of the perturbation.

The results of our simulations show that Juno is indeed sensitive to frequency-dependent tides on Jupiter. However, a future determination of this effect, and thus a separation of the different contributions, depends on the actual values of the satellite-dependent Love numbers, which cannot be currently predicted in the framework of the dynamical tidal response. The determination of frequency-dependent tides with Juno would shed further light on Jupiter's interior mass distribution and stratification, and would contribute to the development of a new theory for dynamical tides on fast-rotating giant planets.

Acknowledgements

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