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The gravity field of Enceladus

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Abstract

We report and update on the determination of Enceladus' gravity field (quadrupole and J3) from dedicated gravity flybys of the spacecraft Cassini.

1. Gravity field

Range rate measurements of the spacecraft Cassini, enabled by coherent microwave links, have been successfully used to determine the mass and the low degree gravity field of Saturn's satellites Titan, Rhea and Enceladus. To date, Cassini encountered Enceladus 13 times. Nine additional flybys are scheduled planned before the end of the mission, in 2017. In spite of the large number of flybys, so far only three included gravity observations. Indeed, Cassini lacks an articulated platform for remote sensing instruments, so that pointing instruments on target requires a well-defined spacecraft attitude and a turn of the entire orbiter. Remote sensing observations become therefore incompatible with tracking from ground, as the large high gain antenna cannot be pointed to Earth.

Out of the three gravity flybys (E0, E9 and E12 in the labelling system of the Cassini project), only E9 (Apr. 28, 2010) and E12 (Nov. 30, 2010) provided range rate data around closest approach. For E0 (Feb. 16, 2005, 1460 km altitude at closest approach), tracking from ground was only available before and after closest approach, so that only a determination of the satellite's mass was possible. An additional flyby devoted to gravity is planned for May 2012. All other Cassini flybys were of little value for gravity investigations.

Altitude is a crucial parameter for gravity flybys, especially for a small body like Enceladus. In E9 and E12 Cassini flew above Enceladus respectively at altitudes of 100 and 50 km. In E9, closest approach was over the south polar regions (89 deg latitude), making it particularly sensitive to gravity anomalies associated with the presence of liquid water at depth. The second flyby (E12, Nov. 30, 2010) occurred in the northern hemisphere at a latitude of 62 deg and an altitude of 50 km. Range rate data acquired at X- and Ka-band at NASA's Deep Space Network antennas located in Spain and California showed a post-fit standard deviation of 0.03 mm/s (E9) and 0.07 mm/s (E12) at 60 s integration times. Residuals do not show any signature and appear consistent with white noise.

Although range rate data from each flyby can be fitted separately, stronger and more accurate results are obtained by combining all observables in a single global solution, which includes the state vectors of Cassini and Enceladus and the gravity field coefficients. Although a purely quadrupolar gravity field provides an adequate fit to all available data, we have obtained also a solution including the degree-3 zonal harmonic, associated with a gravitational asymmetry between the hemispheres. Such a choice is strongly suggested by optical imaging, which shows large scale topographic features in Enceladus' south polar regions.

We find that the estimated gravity field is dominated by a large quadrupole contribution roughly consistent with the expectations for a tidally-locked body. However, the values of J2 and C22 do not appear compatible with hydrostatic equilibrium and a fully relaxed shape, although the deviations are not large. The moment of inertia factor C/MR2 can therefore be inferred with some approximation from the Radau-Darwin equation, although the estimates are certainly not as reliable as for a relaxed body such as Titan. Although the range of variation of C/MR2, associated with the formal uncertainties of J2 and C22, is still rather large (about 0.02), one can already infer that Enceladus is a differentiated body. All gravity solutions including the degree 3 zonal harmonic result in a small, negative J3. Such finding is consistent with the presence of a small, negative gravity anomaly in the south polar region. As expected, the values of C21, S21 and S22 are small compared with J2 and C22, an indication that tidal and rotational forces dominate and that the adopted rotational model is substantially correct. However a perturbation analysis has indicated a significant sensitivity of our results to the Enceladus' rotational parameters. Data from E19 in May 2012 are expected to reduce substantially the current uncertainties and provide additional evidence for a North-South asymmetry of the gravity field

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