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The interior structure of Enceladus from Cassini gravity measurements

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The Cassini spacecraft flew by the small Saturnian moon Enceladus in three close flybys (April 28, 2010, November 30, 2010 and May 2, 2012, to carry out measurements of the satellite's gravity field [1]. One of the main motivations was the search for a hemispherical asymmetry in the gravity field, the gravitational counterpart of the striking North-South asymmetry shown by optical imaging and other Cassini instruments in the geological features of the moon.

The estimation of Enceladus' gravity field by Cassini was especially complex because of the small surface gravity (0.11 m/s^2), the short duration of the gravitational interaction (only a few minutes) and the small, nearly impulsive, neutral particles drag occurring when the spacecraft crossed the south polar plume during the first and the third flyby. Including the non-gravitational acceleration due to the plume in the dynamical model was crucial to obtain a reliable solution for the gravity field. In order to maximize the sensitivity to the hemispherical asymmetry, controlled by the spherical harmonic coefficient J3, the closest approaches occurred at the low altitudes (respectively 100, 48 and 70 km), and at high latitudes in both hemispheres (89°S, 62°N, and 72°S).

Enceladus' gravity field is dominated by large quadrupole terms not far from those expected for a body in a relaxed shape. Although the deviations from the hydrostaticity are weak (J2/C22=3.55±0.05), the straightforward application of the Radau-Darwin approximation yields a value of the moment of inertia factor (MOIF=C/MR^2) that is incompatible (0.34) with the differentiated interior structure suggested by cryovolcanism and the large heat flow. The other remarkable feature of the gravity field is the small but still statistically significant value of J3 (10^6 x J3 = -115.3±22.9). A differentiated interior structure (corresponding to a smaller MOIF) may be reconciled with the gravity measurement by assuming that the rocky core has retained some memory of a faster rotation rate (about 10% above current). J3, whose value is uncontaminated by tides and rotation, provides a way to separate the non-hydrostatic contribution to J2 and C22, from which we infer a MOIF of about 0.336, now compatible with a differentiated structure. Similar conclusions are obtained from the analysis of the admittance.

The interpretation of J3 and the associated, negative gravity anomaly (about 2.5 mGal) is non-unique. In a proposed explanation, the anomaly originates in the core and is not directly related to the presence of liquid masses beneath the surface. Our interpretation seeks the source of the anomaly in the observed 1 km depression in the southern polar region. This mass deficiency generates indeed a negative anomaly, but its magnitude is far smaller (about 20%) than expected from an uncompensated topography. An obvious source of compensation is a reservoir of liquid water at depth, in contact with the rocky core. This interpretation is consistent with the observed cryovolcanism and the presence of silicate grains in the plumes. The estimated gravity field is more consistent with a reservoir that extends in latitude about halfway to the equator, but our data cannot rule out a thin, global ocean.