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Enceladus' Gravity Field inferred from Range Rate Measurements of the Cassini Spacecraft

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On Apr. 28 and Nov. 30, 2010, the Cassini spacecraft encountered Enceladus in two close flybys aimed at the determination of the main features of the satellite's gravity field. Previous Cassini flybys were either too high or did not have tracking from ground at closest approach, and therefore were of little value for gravity investigations. The April 28 flyby (labelled as E9 by the Cassini project) occurred at an altitude of 100 km above the south polar region and was especially designed to provide a good sensitivity to gravity anomalies associated with the presence of liquid water beneath the surface. The second flyby (Nov. 30, labelled as E12) occurred at high latitudes in the northern hemisphere, at an altitude of 50 km. Continuous tracking of the spacecraft at X- and Ka-band across closest approach was provided by NASA's Deep Space Network antennas located in Spain and California. The standard deviation of post-fit range rate residuals (one-way) was 0.03 mm/s (E9) and 0.07 mm/s (E12) at 60 s integration time.

Doppler data from E9, E12 and other Cassini flybys were combined in gravity field solutions limited to quadrupole harmonic coefficients and J3. Although a pure quadrupole provides an adequate fit to the data, a solution that includes a north-south asymmetry is strongly suggested by optical imaging, showing large scale topographic features in Enceladus' south polar regions. In addition to the six Stokes coefficients J2, C21, S21, S22, C22 and J3, all solutions include a correction to the orbit of the spacecraft and Enceladus, and the estimation of the satellite's mass. The range rate residuals do not show any signature and are roughly consistent with white noise.

The estimated gravity field is dominated by large quadrupole terms as expected for a tidally-locked body. However the values of J2 and C22 are not consistent with those of a relaxed body in hydrostatic equilibrium. Moreover, the deviations from hydrostaticity are not so large to rule out the applicability of Radau-Darwin equation, although the inferred moment of inertia factor C/MR2 is certainly not as reliable as for a relaxed body. The value of C/MR2 derived both from C22 and J2 show that Enceladus is a differentiated body. All gravity solutions including the degree 3 zonal harmonic entail a negative J3, consistent with a negative mass and gravity anomaly in the south polar region. If such mass anomaly is due to a liquid water pocket, a negative J3 ensures its stability at the south pole.