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The gravity field and interior structure of Dione inferred from Cassini radio-tracking data

M. Ducci (1), S. W. Asmar (2), J. W. Armstrong (2), L. Iess (1), R. A. Jacobson (2), N. Rappaport(2), P. Tortora (3)
(1) Dipartimento di Ingegneria Meccanica e Aerospaziale, Università La Sapienza, via Eudossiana 18, 00184 Rome, Italy (marco.ducci@uniroma1.it)
(2) Jet Propulsion Laboratory, 4800 Oak Grove Drive, Pasadena, CA 91109, USA
(3) DIEM-II Facoltà di Ingegneria, Università di Bologna, I-47121 Forli, Italy

Abstract

On December 12, 2011 a close flyby, with a closest approach altitude of 99 km allowed a good measurement of Dione's quadrupole with a relative accuracy up to 1.5% for J_2 and 1.0% for C_{22}. Here we report our results and a description of the analysis method. We present solutions for the quadrupole coefficients both when the body is assumed in a relaxed shape (hydrostatic constraint) and for a generic, unconstrained field.

1. Introduction

Cassini spacecraft visited Dione for the first time on October 11, 2005, allowing the determination of its mass [1]. Thomas et al. [3] determined Dione's shape using Cassini Imaging Science Subsystem (ISS) data and inferred its mean radius (561.7 ± 0.9 km) and density (1476 ± 7 kg/m^3). It turned out that Dione is the third in size and second in density among Saturn's icy satellites (excluding Titan). Since the largest mass fraction can be attributed to water ice it must have a rocky core to justify the high density. However, to infer more detailed information about its internal structure, such as core dimensions and composition, a more complete knowledge of the gravity field is required. In particular, the interior mass distribution requires at least the knowledge of the quadrupole harmonic coefficients. This determination was possible thanks to Cassini's advanced telecommunication system, which provides range-rate-measurements accurate up to 10 micron/s at 1000 s integration time under favorable flyby geometry conditions. To date, Cassini encountered Dione three times and two more flybys are scheduled before the end of the mission in 2017. To infer the quadrupole gravity field coefficients of small bodies like Dione it is necessary to have tracking throughout closest approach and low altitude flybys (under 150 km). Of the three flybys completed so far only the last one, named D3, possessed these characteristics. The other two had tracking before and after CA thus allowing only the determination of Dione's mass. The D3 flyby provided data significantly affected by plasma noise (41 μm/s RMS for the post fit residuals around CA) due to the low Sun-Earth-Probe angle but, given its low altitude, gravity field parameters could be estimated with good sensitivity.

2. Data analysis

The X and Ka band Doppler tracking data acquired by NASA's Deep Space Network were calibrated for the path delay due to the wet troposphere using the Advanced Media Calibration system (AMC). The dynamical model used for the fit included all the gravitational perturbations and the main non-gravitational accelerations (solar radiation pressure, Cassini RTG's anisotropic thermal emission). We estimated the quadrupole coefficients J2, C22 and S22. In addition a correction to the orbit of the spacecraft and Dione was also estimated along with the satellite's mass. Two different solutions were produced: in the first one J2 and C22 were constrained to the hydrostatic equilibrium while in the second one no constraint was applied. Range rate residuals from both solutions do not show any signature and are consistent with the expected noise level.

3. Conclusions

Voyager spacecraft took Dione's first close image in 1980. On the basis of the shape determined by Smith et al. [2] a first interior model was proposed by Zharkov et al., [4]. In this model Dione was partially differentiated with a Moment of Inertia factor of about 0.32. For the hydrostatically constrained solution we were able to apply Radau-Darwin equation to infer Dione's MOI. Our result confirms that Dione is a differentiated body, with a MOI close to the one predicted by Zharkov. This preliminary conclusion needs to be confirmed by data provided by next Dione flyby in 2015.

Acknowledgements

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References

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