Mem. S.A.It. Suppl. Vol. 20, 132

Memorie della
Supplementi

The effect of Tirawa impact basin on the determination of Rhea's gravity field

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Abstract. On 26^{th} November 2005 Cassini spacecraft encountered Saturn satellite Rhea. Several analyses of radiometric data obtained during this flyby have been published. Their aim was to obtain the best estimate of the mass and the quadrupole gravity filed of Rhea. Here we present a new analysis to evaluate the effects of the gravity anomaly produced by Tirawa impact basin on the gravity field estimate. Moreover we evaluated the amount of the reorientation of the inertia ellipsoid caused by the mass redistribution occurred after the impact. Results show that the estimate is strongly influenced by Tirawa basin. The quadrupole gravity field is affected and the solution moves towards the hydrostatic equilibrium even if it is not reached. Furthermore the reorientation of the inertia ellipsoid is of about 1°-2°.

Key words. Gravity – Hydrostatic equilibrium – Moment of Inertia – Reorientation

1. Introduction

Cassini spacecraft encountered Saturn's satellite Rhea on 26^{th} November 2005 for the first and only flyby devoted to gravity science. This flyby provided the first precise determination of Rhea's mass and quadrupole gravity field. For a synchronously rotating body in hydrostatic equilibrium, the relation between gravity coefficients J_2 and C_{22} fulfills the relation $3J_2=10C_{22}$ (Zharkov et al. 1985). Therefore the estimation of quadrupole gravity coefficients can be used to infer whether a body is in a relaxed shape or not. If this is the case, the moment of inertia (MoI) of the satellite, a very important quantity for the construction of geophysical models of the interior structure, can be derived from the Radau-Darwin equation. Several analyses of the radiometric data obtained during the flyby have been published, all of them aiming to determine the mass and the quadrupole gravity field of the satellite. Mackenzie et al. (2007) for the Cassini Navigation Team (NAV) and Iess et al. (2007) for the Cassini Radio Science Team (RS) have obtained independent and compatible results, without any a priori assumption about the hydrostatic equilibrium. However Anderson & Schubert (2007) used a hydrostatically constrained solution for geophysical interpretation. A new analysis, which combines the Radio Science and NAV approaches (Mackenzie et al. 2008) confirmed that a reliable gravity field estimate is obtained without using any constraint about hy-

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drostatic equilibrium. According to this analysis, Rhea's quadrupole field is partly non-hydrostatic. However the authors suggested that a mechanism that can produce a non-hydrostatic gravity field is the formation of impact basins after the completion of the satellite's thermal evolution. The analysis we present here aims to evaluate the effect of a gravity anomaly produced by a large impact basin, called Tirawa, on the estimate of the gravity field. The determination has been carried out using range and range-rate X/X and X/Ka band data acquired by the stations of the DSN (Deep Space Network). By comparing the gravity field of the pure quadrupole with the one derived by fitting the quadrupole and the gravity anomaly produced by Tirawa, we attempt an estimate of the reorientation of the inertia ellipsoid caused by the post-impact mass redistribution.

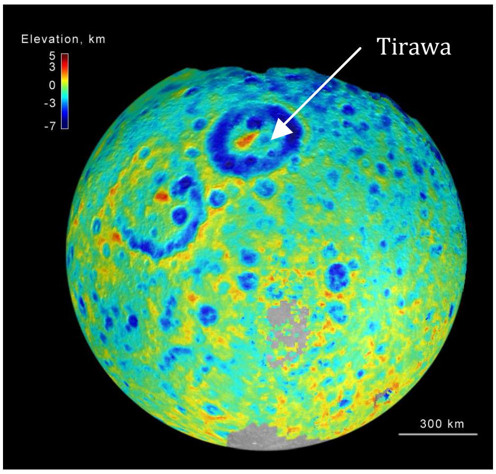

Fig. 1. Topography of Rhea derived from Cassini images. The stacked profiles reveal a mass deficiency. The complex morphology of the basin (in particular the rim which overlaps with that of the closely located big basin) and the unknown near surface density structure make the determination of the missing mass somewhat uncertain.

2. Tirawa impact basin

Mackenzie et al. (2008) suggested that a non-hydrostatic J_2/C_{22} can be produced by the formation of impact basins occurred after the completion of the thermal evolution of the satellite. The mass redistribution resulting from a large impact would change the orientation of the principal axes of inertia. After an appropriate time, internal dissipation will force a reorientation of the principal axes. In order to reach a state, which represents a minimum of the rotational energy, this reorientation will occur around the axis normal to the orbital plane in the direction of the focus of the orbit almost coinciding with Saturn. Therefore the permanent tidal bulge is no longer orientated toward Saturn. The orbit determination software uses a body-fixed reference frame, which is almost coinciding with the orbital reference frame. Therefore the reorientation will affect the estimates of J_2 and C_{22} leading to a non-hydrostatic value of the ratio J_2/C_{22}. In order to evaluate the influence of the impact basin of Tirawa on the estimate of the quadrupole gravity field we insert the presence of a negative mascon, represented as a point mass, in the dynamical model used in the orbit determination software. Its location coincides with the center of Tirawa. Assuming to have a rigid crust, we are essentially estimating the pre-impact quadrupole field. We must underline that we did not account for a possible isostatic rebound which would reduce, of course, the effect of Tirawa on the gravity field estimation. Determination of the pre-impact quadrupole requires indeed the knowledge of the topography of Rhea and especially the characteristics of Tirawa. The Cam team determined many possible profiles of the Tirawa basin from which they inferred different values of the missing mass. However, as Fig. 1 shows, the complex morphology of the basin and especially the unknown density of the rim and central material make the determination of the missing mass somewhat uncertain. Therefore we used three different values of the missing mass. A minimum value of 1.0E17 kg , a mean value of 1.3E17 kg, which is considered the best estimate of the missing mass and a maximum value of 2.0E17 kg which was mainly used to underline a possible trend of the solution.

3. Reorientation

Determination of inertia axes reorientation angle is carried out using MacCullagh formula:

$$\mathbf{Q} = \frac{1}{3}\mathbf{1}Tr(\boldsymbol{I})\text{-}\boldsymbol{I} \quad (1)$$

This formula relates the moments of inertia to the second degree gravity coefficients. Quadrupole tensor **Q** and inertia tensor **I** have the same eigenvectors. Thereby the orientation of inertia principal axes can be easily determined by a diagonalization of the quadrupole tensor. The orientation of the pre-impact principal axes is given by the eigenvectors of the quadrupole tensor, whose elements are the estimated pre-impact gravity field coefficients. The complete quadrupole tensor determined with estimated J_2, C_{22}, S_{22} and Tirawa's negative mascon provides the new, post-impact principal axes. Supposing that the effect of the impact is a rotation of inertia axes only in the orbital plane, the reorientation angle is simply determined by the difference between the two set of inertia axes previously found.

4. Conclusions

Results clearly show that the estimate of the quadrupole field is strongly influenced by the presence of Tirawa. Increasing the missing mass associated to the Tirawa basin, the estimated quadrupole field shifts towards more hydrostatic values. However equilibrium is never reached, even for the maximum value of the missing mass compatible with the images of the Cassini's camera. Regarding the reorientation process the effect of the impact that generated Tirawa is clear. Our results confirm the hypothesis that after that event Rhea underwent a reorientation. The amount of the reorientation angle depends on Tirawa missing mass in an almost proportional way and is about 1°-2°. Further refinements of this solution are possible. A complete topography model of Rhea would allow a more accurate determination of its gravity field. Moreover other craters located near flyby's ground track could be inserted in the dynamical model as missing masses allowing a better estimation of Rhea's gravity field.

References

Anderson, J. D., & Schubert, G. 2007, Geophys. Res. Lett. 34, L02202

Ekelund, J. E., Esposito, P. B., & Benson, R. 1996, *DPTRAJ-ODP User's Refrence Manual, Vol. 1*, Navigation Software Group: NASA JPL.

Iess, L., et al. 2007, Icarus, 190, 585

Mackenzie, R. A. et al. 2007, *A determination of RheaÕs gravity field from Cassini navigation analysis*, paper presented at 17th Space Flight Mechanics Meeting, Am. Astronaut. Soc., Sedona, Ariz.

Mackenzie, R. A., et al. 2008, Geophys. Res. Lett., 35, L05204

Nimmo, F., & Matsuyama, I. 2007, Geophys. Res. Lett., 34, L19203

Zharkov, V. N., Leontjev, V. V., & Kozenko, A. V. 1985, Icarus, 61, 92