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The low-degree gravity field of Phobos from two Mars Express flybys

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Abstract

Several close spacecraft flybys of Phobos have been performed over the past 40 years in order to determine the gravity field of this tiny Martian moon. In this work, the gravity field of Phobos is derived from the radio tracking data of two combined MEX flybys (2010 and 2013) applying a least squares inverse technique, by using as a first guess the gravity field modelled from the shape model and a constant density hypothesis. A GM estimate of $(7.077 \pm 0.0075) \times 10^5$ m^3s^{-2} and second order gravity coefficients C_{20} = -0.137 ± 0.035 and C_{22}= 0.017 ± 0.015 (3σ) are derived. These values suggest a decrease of the density of Phobos from the surface towards its center.

1. Introduction

The Mars Express spacecraft (MEX) flew by Phobos in the years 2010 and 2013 conducting radio science experiments at minimum distances of 77 km, and 59 km. Several estimates of the gravitational mass GM and second order gravity field coefficients from the analysis of the two-way Doppler recordings acquired during these flybys were published with increasing precision. The latest estimate of the GM is GM = $(7.072 \pm 0.013) \times 10^5$ m^3s^{-2} (Pätzold et al., 2014). The estimates of the second degree and order gravity field coefficients, however, carry large error bars.

We estimated the Phobos GM and the C_{20} coefficients from the MEX 2010 and 2013 flybys. The first guesses for the gravity field values are from the shape model assuming constant bulk density as observed from the past flybys. We also implement a priori information computed from the shape model for the least squares fit. The result shows a good agreement with previous publications and the precision of GM as well as C_{20} increased by two to three times.

2. Methods and Data

During the flyby of March 2010, the Deep Space Network (DSN) tracked the MEX spacecraft by recording X-band and S-band carrier frequencies at its 70-m antenna near Madrid, Spain. The available tracking data consists of four hours, starting one hour before the closest approach until three hours after the closest approach. During the flyby of December 2013, coherent two-way Doppler data were recorded at the 70-m antenna in Spain, at the 70-m antenna in California, and at the ESA 35-m antenna in Australia. About 30 hours of Doppler tracking were recorded during this flyby, from 13 hours before closest approach to 17 hours after closest approach covering almost four full orbit periods of MEX about Mars. Our predicted Doppler velocity is based on a highly precise force model. All calculations were performed with the software package MAGREAS developed at our Laboratory in Wuhan, China.

3. Results and discussion

Figure 1 shows the Doppler velocity residuals (observed minus predicted Doppler velocities without Phobos perturbation) during the MEX flybys of 2010 and 2013, respectively. Figure 2 and Figure 3 show the best estimate of the Phobos gravity field, taking into account the modelled gravity field of Phobos from the shape model as a first guess and the two-way Doppler velocity observations from the 2010 and 2013 Mars Express flybys. Three sets of a priori error-bars (50%, 100%, and 200%) are given for the second degree and order gravity coefficients. The mass M of Phobos is computed as $(1.0604 \pm 0.0011) \times 10^{16}$ kg (for G = $(6.67408 \pm 0.00031) \times 10^{-11}$ m^3kg^-

$^{1}s^{-2}$). As already stated by Andert et al. (2010) and Pätzold et al. (2014), this low bulk density implies that the interior of Phobos must be porous.

The C_{20} value from the shape model with constant density (designated as $C_{20,\ shape}$) shall be used as a reference value to interpret the Phobos internal mass distribution (Pätzold et al., 2014). From Figure 4, it is evident that our measured value is mostly lower than $C_{20,shape}$. This is not consistent with a core denser than the average bulk density of Phobos, but indicates a rubble pile structure by increasing porosity, voids, or the presence of lighter material as water ice (Le Maistre et al., 2018).

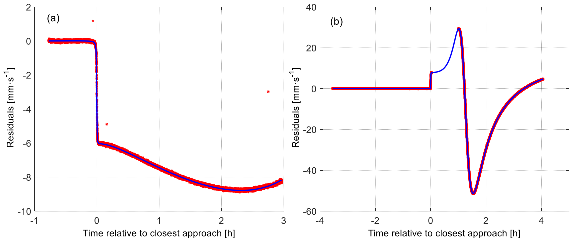

Figure 1: MEX Doppler velocity residuals (observed minus predicted without Phobos perturbation) from the (a) 2010 flyby and (b) 2013 flyby.

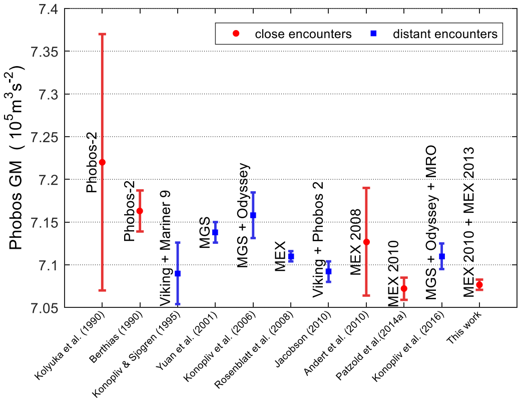

Figure 2: Phobos GM solutions from close and distant encounters.

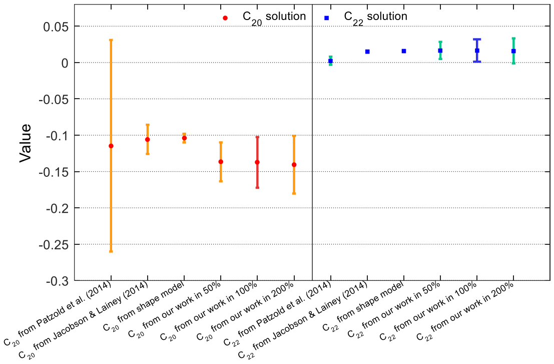

Figure 3: Comparison of the Phobos C_{20} and C_{22} gravity coefficients estimates from different authors.

4. Summary and Conclusions

We estimated the Phobos gravitational parameter GM, and the C20, and C22 coefficients from the MEX 2010 and 2013 Phobos flybys by introducing first guesses and a priori information for the least squares fit computed from the shape model assuming constant density. The best estimate for GM is $(7.077 \pm 0.008) \times 10^5$ $m^3s^{-2}(3\sigma)$, and for the second degree coefficients are $C_{20} = -0.137 \pm 0.035$ (3σ) and $C_{22} = 0.017 \pm 0.015$ (3σ).

Acknowledgements

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