EPSC
EPSC-DPS Joint Meeting 2019
15–20 September 2019 | Geneva, Switzerland

Gravity, equilibrium, and height system of Phobos and Deimos: an updated geodetic analysis

Xuanyu Hu (1), Jürgen Oberst (1,2) and Konrad Willner (2)
(1) Institute of Geodesy and Geoinformation Science, Technical University Berlin, Berlin, Germany (hu@tu-berlin.de),
(2) Institute of Planetary Research, German Aerospace Center, Berlin-Adlershof, Germany

Abstract

We evaluate the gravity equilibrium forms of the irregular-shaped Martian moons, Phobos and Deimos. We derive their normal ellipsoids and propose the ellipsoidal height system to characterize the surface topography. We study the height distributions on Phobos and Deimos and compare their statistics with those of nearly spherical terrestrial planets. We identify a new criterion for determining surface equilibrium of the Martian moons and discuss its generality to other small bodies.

1. Introduction

The Martian moons display distinctly tri-axial shapes [1, 2]. At least for the inner moon Phobos, it is plausible that the shape resulted from tidal accretion close to Mars, with the tri-axiality reminiscent of the shape of the equipotential Roche lobe defining the region of accretion [3]. This scenario has yet to be explored in detail. Here, we propose a method to characterize the shapes of the irregular moons in terms of surface heights referred unambiguously to their respective figures of equilibria. It is then a straightforward task to measure the state (or deviation) of surface equilibrium. Consequently, we may quantify the equilibrium state as a function of distance from Mars, which sheds light on the origins of the Martian moons.

2. Method

Previous studies adopted *dynamic height* as a measure of surface undulation [1], namely,

$$H_{\mathrm{D}}(\mathbf{r}) = -\frac{W(\mathbf{r}) - W_0}{g_0} \qquad (1)$$

where $W(\mathbf{r})$ is the gravity potential at a given position $\mathbf{r}$ on the surface. W_0 indicates a reference potential number, e.g., the average potential over the surface.

Another constant, g_0, is a reference value for the magnitude of surface gravity acceleration, $\mathbf{g}(\mathbf{r})$. Thus, the potential difference is scaled directly and *uniformly* into a height number. The geometric meaning of H_{D} becomes questionable on a highly non-spherical object. The reasons are twofold: firstly, $|\mathbf{g}(\mathbf{r})|$ likely exhibits strong global variations that cannot be accommodated by g_0; secondly, the local gravity (or plumb line) on an arbitrary-shaped object can be notably deflected from the radial direction (along the center of mass of the body) in which case the reference level for height definition and measurement is obscure.

The difficulties mentioned above can be mitigated if the equipotential surface of the body can be determined. We apply the method proposed in [4] to derive the normal ellipsoids of Phobos and Deimos. The normal ellipsoid is an equipotential surface in the gravity field of the body, whose surface potential is given by W_0. It serves as a reference level from which height can be unambiguously defined and easily measured. Specifically, we introduce the system of *ellipsoidal height* measured from the normal ellipsoid along orthogonal directions.

3. Data Analysis

We present the normal ellipsoids of the Martian moons. We demonstrate that the dynamical environment around the normal ellipsoid is a valid approximation of the true environment around the (more) irregular body. We will measure ellipsoidal heights on Phobos and Deimos using the respective shape models [1, 2]. We will derive the distributions of ellipsoidal heights and perform a statistical analysis. One of the objectives here is to characterize the deviation of the body from surface equilibrium. In the case of Phobos, whose orbit has been steadily decaying due to tidal dissipation, we will analyze the evolution of height distribution in different orbits.

4. Discussion

We compare the height distributions of the Martian moons to those observed for terrestrial planets, such as Mercury [5], and explore the underlying physical mechanisms that could shape planets and small bodies alike. We will develop a statistical criterion for identifying surface equilibria of Phobos and Deimos and discuss the robustness and applicability of the criterion to other objects. Last, but not least, we attempt to infer the accretion distances of Phobos and Deimos based on the height analysis as an independent form of evidence, and discuss its agreement with the state-of-the-art formation models [6, 7].

Acknowledgements

References

[1] Thomas, P. C.: Gravity, tides, and topography on small satellites and asteroids: application to surface features of the Martian satellites, *Icarus*, 105, pp. 326-344, 1993.

[2] Willner, K., Shi, X., and Oberst, J.: Phobos' shape and topography models, *Planetary & Space Science* 102, pp. 51-59, 2014

[3] Rosenblatt, P., and Charnoz, S.: On the formation of the martian moons from a circum-martian accretion disk, *Icarus*, 221, pp. 806-815, 2012.

[4] Hu, X.: Normal gravity fields and equipotential ellipsoids of small objects in the solar system: a closed-form solution in ellipsoidal harmonics up to the second degree, *The Astrophysical Journal*, 850:107, 2017

[5] Zuber, M. T., et al.: Topography of the northern hemisphere of Mercury from MESSENGER laser altimetry, *Science*, 336, pp. 217-220, 2012

[6] Rosenblatt, P., Charnoz, S., Dunseath, K. M., et al.: Accretion of Phobos and Deimos in an extended debris disc stirred by transient moons, *Nature Geoscience*, 9, pp. 581-583, 2016

[7] Hesselbrock A. J., and Minton, D. A.: An ongoing satellite-ring cycle of Mars and the origins of Phobos and Deimos, *Nature Geoscience*, 10, pp. 266-269, 2017