EPSC Abstracts
Vol. 13, EPSC-DPS2019-1246-1, 2019
EPSC-DPS Joint Meeting 2019

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

Shape model of 3200 Phaethon from radar and lightcurve observations

Sean E. Marshall (1), Patrick A. Taylor (2), Edgard G. Rivera-Valentín (2), Flaviane C. F. Venditti (1), Anne K. Virkki (1), Lance A. M. Benner (3), Marina Brozović (3), Shantanu P. Naidu (3), Luisa F. Zambrano-Marin (1), Sriram S. Bhiravarasu (2), Betzaida Aponte-Hernandez (2), and Carolina Rodriguez Sanchez-Vahamonde (4)
(1) Arecibo Observatory, University of Central Florida, Puerto Rico, USA (smarshal@naic.edu), (2) Lunar and Planetary Institute, Universities Space Research Association, Texas, USA, (3) Jet Propulsion Laboratory, California Institute of Technology, California, USA, (4) University of Western Ontario, Ontario, Canada

Abstract

We present the shape and rotation state of near-Earth asteroid 3200 Phaethon, the target of JAXA's upcoming DESTINY$^+$ mission [2]. This shape model was derived using Arecibo and Goldstone radar data from Phaethon's 2007 and 2017 close approaches, and lightcurves from many apparitions. Phaethon is roughly spheroidal with an equatorial ridge. It has an equivalent spherical diameter of about 5.5 kilometers, slightly larger than previously estimated.

1. Introduction

Phaethon (1983 TB) was discovered in 1983 by the Infrared Astronomical Satellite (IRAS). Phaethon has an absolute magnitude of 14.6, and its minimum orbit intersection distance (MOID) with respect to Earth is 0.02 au. Therefore Phaethon is one of the largest potentially hazardous asteroids. It is the parent body of the Geminid meteor stream [11, 4].

Phaethon passed 0.07 au from Earth on December 16, 2017, which was its closest approach to Earth since its discovery and the best chance to observe Phaethon before the DESTINY$^+$ mission. Phaethon will not come closer to Earth until 2093.

2. Observations

2.1. Radar observations

Radar observations provide a means of spatially resolving near-Earth asteroids from the ground. A series of radio waves is transmitted toward the asteroid, and the echoes are received after the two-way light travel time. The measured echoes can be decoded in light travel time (delay) and Doppler-shifted frequency to produce delay-Doppler images of the target.

In December of 2007, Phaethon was observed from Arecibo Observatory on two days. In December of 2017, Phaethon was observed from Arecibo Observatory on five nights and from NASA's Goldstone Deep Space Communications Complex (DSS-14) on eight nights. The Arecibo delay-Doppler images from the 2017 apparition resolve Phaethon's shape, with range resolution as fine as 75 meters [9].

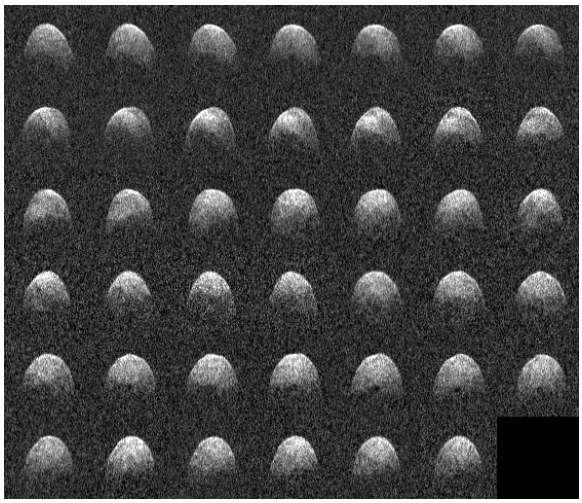

Figure 1: Delay-Doppler images of Phaethon from Arecibo on December 16-18, 2017 [9]. In each frame, Doppler frequency increases to the right, and delay increases downward.

2.2. Lightcurve observations

There are lightcurves of Phaethon from many apparitions, spanning a considerable range of sky positions over nearly twenty years. Several previous publications have found a shape model and rotation state for Phaethon [1, 5, 8, 6], based on lightcurve observations.

Those authors consistently found a rotation period of 3.6 hours, and most found a pole position near ecliptic coordinates $(\lambda, \beta) = (315°, -45°)$.

3. Shape model

We used the SHAPE software [7] to determine Phaethon's shape and other properties from all available radar and lightcurve data. SHAPE iterates through the various model parameters to search for a model that minimizes the objective function, which is the sum of weighted squared residuals and penalty terms (to discourage physically implausible models). The asteroid's shape is represented as a polyhedron with over one thousand triangular facets.

We find Phaethon's pole position to be near ecliptic coordinates $(315°, -45°)$, in agreement with several previous analyses. Our final shape model is approximately spheroidal with an equatorial ridge, resembling the shapes of 101955 Bennu [3] and 162173 Ryugu [10]. Phaethon has a maximum breadth of about 6.6 kilometers and a volumetric mean diameter of about 5.5 kilometers, slightly larger than previous estimates (e.g., effective diameter of 5.1 km in [6]).

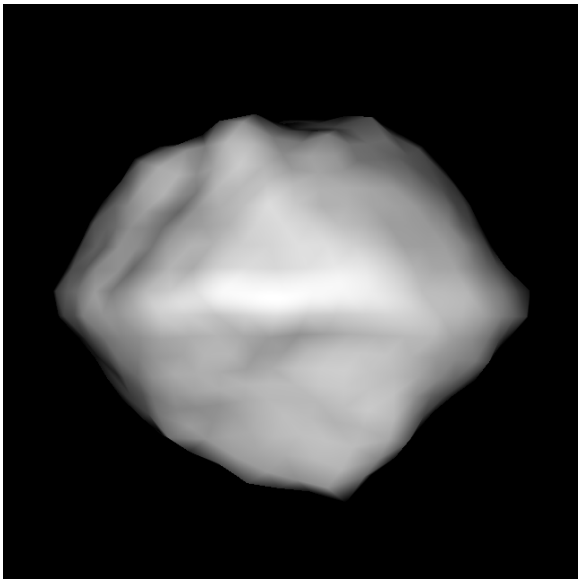

Figure 2: Shape model of 3200 Phaethon

Acknowledgements

This research was supported by NASA's Near-Earth Object Observations Program through grants 80NSSC18K1098 and 80NSSC19K0523 to the University of Central Florida, and through grant NNX13AQ46G to Universities Space Research Association. The Arecibo Observatory is a facility of the National Science Foundation operated under cooperative agreement by University of Central Florida, Yang Enterprises, Inc., and Universidad Ana G. Méndez.

References

[1] Ansdell, M., Meech, K., Hainaut, O., et al.: Refined Rotational Period, Pole Solution, and Shape Model for (3200) Phaethon, The Astrophysical Journal, vol. 793, issue 1, article id. 50, 2014.

[2] Arai, T., Kobayashi, M., Ishibashi, K., et al.: DESTINY+ Mission: Flyby of Geminids Parent Asteroid (3200) Phaethon and In-Situ Analyses of Dust Accreting on the Earth, 49th Lunar and Planetary Science Conference, id. 2570, 2018.

[3] Barnouin, O., Palmer, E., Gaskell, B., et al.: Investigating the Shape of Bennu, 50th Lunar and Planetary Science Conference, id. 1744, 2019.

[4] Gustafson, B.: Geminid meteoroids traced to cometary activity on Phaethon, Astronomy and Astrophysics, vol. 225, no. 2, pp. 533-540, 1989.

[5] Hanuš, J., Delbó, M., Vokrouhlický, D., et al.: Near-Earth asteroid (3200) Phaethon: Characterization of its orbit, spin state, and thermophysical parameters, Astronomy and Astrophysics, vol. 592, id. A34, 2016.

[6] Hanuš, J., Vokrouhlický, D., Delbó, M., et al.: (3200) Phaethon: Bulk density from Yarkovsky drift detection, Astronomy and Astrophysics, vol. 620, id. L8, 2018.

[7] Magri, C., Ostro, S., Scheeres, D., et al.: Radar observations and a physical model of Asteroid 1580 Betulia, Icarus, vol. 186, issue 1, pp. 152-177, 2007.

[8] Kim, M.-J., Lee, H.-J., Lee, S.-M., et al.: Optical observations of NEA 3200 Phaethon (1983 TB) during the 2017 apparition, Astronomy and Astrophysics, vol. 619, id. A123, 2018.

[9] Taylor, P. A., Rivera-Valentín, E. G., Benner, L. A. M., et al.: Arecibo radar observations of near-Earth asteroid (3200) Phaethon during the 2017 apparition, Planetary and Space Science, vol. 167, pp. 1-8, 2019.

[10] Watanabe, S., Hirabayashi, M., Hirata, N., et al.: Hayabusa2 arrives at the carbonaceous asteroid 162173 Ryugu - A spinning top-shaped rubble pile, Science, vol. 364, issue 6437, pp. 268-272, 2019.

[11] Whipple, F.: 1983 TB and the Geminid Meteors, IAU Circ., 3881, 1, 1983.