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The opposition effect on Ceres observed by the Dawn Framing Cameras

S. E. Schröder (1), J.-Y. Li (2), M. Rayman (3), S. Joy (4), C. A. Polanskey (3), U. Carsenty (1), J. C. Castillo-Rogez (3), R. Jaumann (1), L. A. McFadden (5), S. Mottola (1), M. Sykes (2), C. A. Raymond (3) and C. T. Russell (4)
(1) Deutsches Zentrum für Luft- und Raumfahrt (DLR), 12489 Berlin, Germany (stefanus.schroeder@dlr.de), (2) Planetary Science Institute (PSI), Tucson, AZ 85719, U.S.A., (3) Jet Propulsion Laboratory (JPL), California Institute of Technology, Pasadena, CA 91109, U.S.A., (4) Institute of Geophysics and Planetary Physics (IGPP), University of California, Los Angeles, CA 90095-1567, U.S.A., (5) Goddard Space Flight Center (GSFC), Greenbelt, MD 20771, U.S.A.

Abstract

Framing cameras on board the Dawn spacecraft have acquired images of dwarf planet Ceres at near-zero phase angles to study its opposition effect. The opposition geometry was reached through an ingenious scheme of orbital navigation. Images were successfully acquired by both the primary and backup camera in different color bands, reaching near zero phase angle on parts of the surface. Coverage includes the well-known bright area in Occator crater known as Cerealia Facula. Analysis of this rich data set and comparisons with results from laboratory experiments will provide insight into the regolith properties of Ceres and its enigmatic bright terrains.

1. Introduction

The reflectance of planetary regoliths is known to increase dramatically towards zero solar phase angle, a phenomenon known as the "opposition effect". The strength of the opposition effect is governed by two mechanisms, shadow hiding and coherent backscatter, which are related to regolith properties like particle size and morphology, composition, packing density, and surface roughness. The first instance of the opposition effect on a minor body was reported for asteroid Massalia [1]. Resolved images of minor body surfaces at near-zero phase angles are rarely acquired by spacecraft because of the resources required and the risks of spacecraft eclipse on the other side of the body. Often, such images are acquired on approach during a flyby, as for asteroids Steins [2, 3] and Lutetia [4, 5, 6] by Rosetta. Sometimes, the small mass of the body allows the spacecraft to slowly move into the opposition geometry, as for asteroid Itokawa by Hayabusa [7] and comet 67P/Churyumov-Gerasimenko by Rosetta [8]. The lowest phase angle at which Ceres had thus far been observed by ground-based telescopes (unresolved) was $1.1°$ [9]. The Dawn cameras have now resolved its surface at phase angles smaller than that.

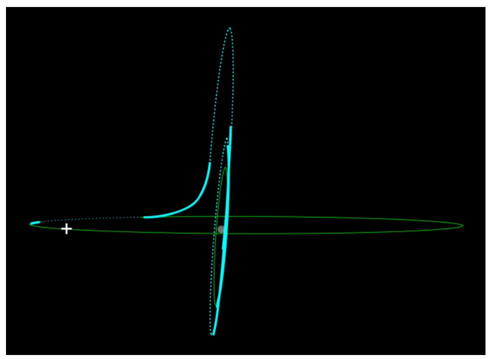

Figure 1: Dawn orbital maneuvers to achieve the opposition geometry (plus sign), with Ceres in the center. Dawn was thrusting in the parts of the orbit drawn in bold.

2. Orbital maneuvers

In a remarkable feat of orbital navigation, Dawn was carefully nudged into the opposition geometry. First, Dawn moved into an elliptical polar orbit, thrusting with its ion engine only in selected parts of the orbit. Then, another thrusting session changed the spacecraft beta angle (the angle between the vector to the Sun and the orbital plane) by almost $90°$, achieving the opposition geometry (Fig. 1). A risky eclipse of the spacecraft behind Ceres was avoided by the natural drift of the beta angle due to Ceres' motion in its orbit around the Sun.

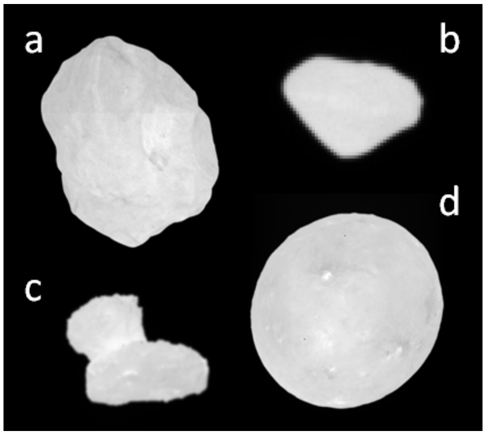

Figure 2: Opposition images of (a) Asteroid Lutetia, (b) asteroid Steins, (c) comet 67P/Churyumov-Gerasimenko, (d) dwarf planet Ceres. Note the absence of any perceptible shadowing, characteristic for images at near-zero phase angle.

3. Data set acquired

Both cameras (FC1 and FC2) were operated during the opposition phase. Images were acquired with four different exposure times every 5 minutes, using the clear filter and five narrow-band filters. We are in the process of validating and calibrating the data. It appears that Dawn reached a geometrical phase angle of zero on the Ceres surface. The effective phase angle of the observations is affected by the finite angular size of the Sun ($0.2°$ at Ceres). For the bright areas inside Occator crater, Cerealia Facula, angles as low as $0.7°$ were reached. The phase function of Ceres has now been sampled over a range of $155°$, the widest available for any minor body. We show a raw image of Ceres in opposition in Fig. 2, together with opposition images of other minor bodies. At first glance, Ceres seems to conform to the relation between strength of the opposition surge and geometric albedo reported by [10], who found that the opposition effect for asteroids of intermediate geometric albedo is stronger than that for asteroids of lower and higher albedo. Special effort will be devoted to analyzing the very bright Faculae, whose photometric properties are very different from Ceres average [11, 12], clues to which we hope to uncover by comparing with the results of photometric experiments.

Acknowledgements

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