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Dawn's operations in cruise from Vesta to Ceres ☆

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ABSTRACT

On 5 September 2012, Dawn concluded its successful exploration of Vesta, the second most massive object in the main asteroid belt. The spacecraft departed after 14 months in orbit and is now using its ion propulsion system to travel to dwarf planet Ceres, the most massive main-belt asteroid. The principal activity now is thrusting with the ion propulsion system to provide the 3.5 km/s required to rendezvous with Ceres early in 2015. Because two of the four reaction wheels have experienced faults and are likely unrecoverable, a substantial effort has been invested in preparing for Ceres operations with alternate attitude control methods. The project has engaged in an intensive campaign to reduce hydrazine expenditures, which has resulted in a significant increase in the hydrazine expected to be available for Ceres. Based on this work, studies provide good confidence that the required activities at Ceres can be completed. This paper describes post-Vesta operations, including measures taken to conserve hydrazine as well as other preparations for Ceres.

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1. Introduction

The Dawn mission is designed to investigate the two most massive objects in the main asteroid belt, Vesta and Ceres. These protoplanets are believed to be remnants from the epoch of planet formation, and Dawn's exploration is intended to help reveal important physical and chemical processes and conditions present at that time and during the subsequent evolution of the solar system.

Dawn is the ninth project in the National Aeronautics and Space Administration's (NASA's) Discovery Program. NASA's Jet Propulsion Laboratory (JPL) manages the project and conducts the mission operations. Scientific leadership is the responsibility of the principal investigator, from the University of California, Los Angeles.

The mission to orbit both Vesta and Ceres is enabled by the use of solar electric propulsion, implemented on Dawn as an ion propulsion system (IPS). Without it, even a mission to only one of these bodies would not have been affordable within the Discovery Program. A mission to both would have been impossible. The IPS design is inherited directly from the one flown on Deep Space 1 [1].

The Dawn spacecraft was designed, built, and tested by Orbital Sciences Corporation. JPL delivered the IPS and components of other subsystems to Orbital.

Dawn's scientific measurements at both destinations include panchromatic (in stereo) and multispectral imagery; neutron, near ultraviolet, visible, infrared, and γ-ray spectra; and gravimetry. To acquire these data, Dawn's instrument payload comprises a γ-ray and neutron detector (GRaND), a visible and infrared mapping spectrometer (VIR), and a pair of identical imaging cameras. Gravimetry is accomplished with the telecommunications subsystem, and does not require dedicated flight hardware.

GRaND was delivered by the Los Alamos National Laboratory and is now operated by the Planetary Science Institute. VIR was contributed to NASA by the Agenzia Spaziale Italiana (Italian Space Agency, or ASI). ASI funds

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the Istituto Nazionale di Astrofisica (National Institute for Astrophysics) to operate VIR, which was designed, built, and tested at Galileo Avionica. The cameras were contributed to NASA by the Max-Planck-Institut für Sonnensystemforschung (Max Planck Institute for Solar System Research, or MPS) with cooperation by the Institut für Planetenforschung (Institute for Planetary Research) of the Deutsches Zentrum für Luft- und Raumfahrt (German Aerospace Center, or DLR) and the Institut für Datentechnik und Kommunikationsnetze (Institute for Computer and Communication Network Engineering, or IDA) of the Technischen Universität Braunschweig (Technical University of Braunschweig).

The design of the spacecraft and payload and of the mission as well as the scientific objectives have been presented in detail elsewhere [2,3].

Dawn launched on 27 September 2007. Mission operations from launch through the end of 2008 were described by Rayman and Patel [4], and the progress through 2009 was discussed by Rayman and Mase [5]. The remainder of the cruise to Vesta and Vesta operations, including the three-month approach phase as well as activities from orbit insertion on 16 July 2011 through escape on 5 September 2012, were reported by Rayman and Mase [6] and by Polanskey et al. [7].

Many authors have presented findings from Vesta [8]. We will present an overview of some of the results before addressing the interplanetary cruise to Ceres.

2. Vesta

Dawn returned nearly 31,000 images, 20 million visible and infrared spectra, and thousands of hours of neutron spectra, γ-ray spectra, and gravity measurements of Vesta. Figs. 1 and 2 show two views of Vesta. The IPS allowed Dawn to tune the circular, near-polar orbits for its six science phases to optimize the investigations. The longest duration science phase was 141 days at a mean altitude of 210 km, the lowest of the six science orbits, with a period of 4.3 h.

Collectively the data yield a picture of the second most massive object in the main asteroid belt that shows it to be

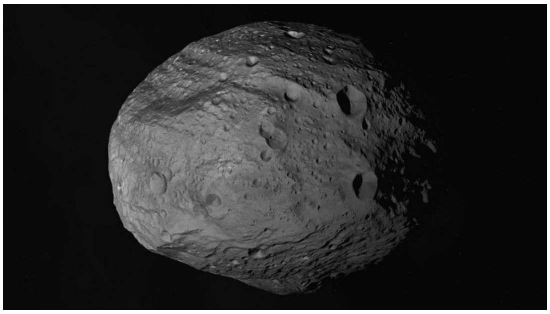

Fig. 1. Global, near-equatorial view of Vesta from shape model. The central peak of the Rheasilvia impact basin is at the bottom. The difference in crater density between northern and southern hemispheres can be seen. Vesta's mean equatorial diameter is 562 km. This image was developed through a collaboration of JPL, UCLA, DLR, MPS, and IDA.

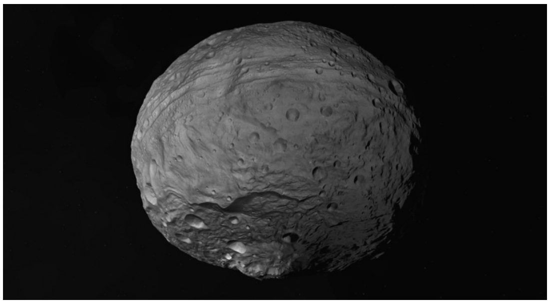

Fig. 2. Global, southern hemisphere view of Vesta from shape model. The extensive network of chasms near the equator is evident in the top of the image. Part of the surviving wall of the Rheasilvia impact basin is prominent one-third of the way up from the bottom, and the central peak is clear at the bottom. This image was developed through a collaboration of JPL, UCLA, DLR, MPS, and IDA.

quite complex. With principal radii of 285 × 277 × 226 km, and GM = 17.3 km^3/s^2, this body is unlike typical smaller asteroids. It appears to have experienced many of the geological processes that characterize the rocky terrestrial planets.

One of the major distinctions from most asteroids is that Vesta differentiated into layers. Modeling of the gravimetry suggests Vesta has a dense solid core (composed principally of iron and nickel) 100–125 km in radius, a mantle, and a crust ~20 km thick.

One of the most prominent surface features is the Rheasilvia impact basin, with a diameter of 500 km, or about 96% of the mean body diameter. This is the largest impact feature relative to body size yet observed anywhere in the solar system. The central peak in this basin is about 180 km across at the base and rises 20–25 km above the variable elevation of Rheasilvia's floor.

Centered at 72° S latitude, the impact that excavated Rheasilvia 1–2 Ga ago deposited so much ejecta that the southern hemisphere was virtually resurfaced. As a result, Vesta now displays a pronounced hemispherical dichotomy, with the north much more heavily cratered than the south.

Rheasilvia lies on top of an older basin centered at 52° S. The 400-km-diameter Veneneia is the second largest impact feature observed on Vesta.

Near the equator is a system of almost 100 chasms that were formed as a result of these two impacts. They are believed to be graben produced from the propagation of energy through Vesta's interior, and models suggest that their formation depends on an interior consistent with a differentiated body.

Dawn has greatly strengthened the case for Vesta being the parent body of the large class of meteorites composed principally of howardites, eucrites, and diogenites (HEDs). Well in excess of 1000 named meteorites are HEDs, far more than the number of meteorites identified as having originated on Mars or the Moon.

Dawn met or exceeded all of its objectives at Vesta, and the wealth of data it yielded will continue to be analyzed for years. This is the only main belt asteroid that a spacecraft has orbited so far.

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