

DAWN: A JOURNEY TO THE BEGINNING OF THE SOLAR SYSTEM

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ABSTRACT/RESUME

Dawn, NASA's ninth Discovery mission, is scheduled to launch on May 27, 2006 on a journey that will take it into orbit about the two most massive asteroids 4 Vesta and 1 Ceres. Dawn's goal is to understand the conditions and processes present at the solar system's earliest epoch, and the role of water content and size in planetary evolution. To this end Dawn carries a framing camera, a mapping spectrometer, a laser altimeter, a gamma-ray/neutron spectrometer, a magnetometer and a gravity investigation. Dawn uses solar arrays to power its xenon ion engine that provides thrust at an efficiency that is ten times greater than chemical rockets provide. Dawn is a partnership between UCLA, JPL, and the American, German and Italian space agencies.

1. INTRODUCTION

Over 4.6 billion years ago a cold gas cloud, containing the material now found in the solar system, began to collapse. In that cloud two competing processes took place: a chemical process, in which solid material formed out of the gases, making rocks and small planetesimals; and a physical process, in which stars formed by a gravitational instability. Hot stars, once formed, dispersed the gas cloud and stopped the formation of rocky planetary materials. In the region that we now call the asteroid belt, the accretion process was stopped in yet another competition between physics and chemistry.

Once Jupiter formed, by gravitational collapse, its orbital motion relative to the asteroids provided a periodic gravitational pulse that accelerated them so they would no longer accrete. Thus the formation of Jupiter stopped much of the geochemical evolution of this region. By exploring the two most massive planetesimals, Dawn studies some of the earliest processes in the solar system, those occurring during its first 5-10 million years.

2. THE MISSION

Figure 1 introduces the Dawn mission. The backdrop is a painting by W.K. Hartmann of a nebula as the central star begins to shine. Visible are the dust and rocks that are coming together to form the terrestrial or rocky planets. Also shown are the protoplanets, 4 Vesta and 1 Ceres as we see them today with Hubble Space Telescope. Vesta is about 520 km across and Ceres almost 1000 km. Vesta has a very bright surface and is 2.34 AU from the sun. Ceres at 2.77 AU is much darker, consistent with the general darkening of material with distance from the sun in this region of space.

The spacecraft has rather large solar panels roughly 21 m tip-to-tip, a 5 m magnetometer boom and three ion thrusters, one of which is shown in operation. The communication dish is aimed at the Earth by pointing the entire spacecraft. When the instrument panel on the top of the spacecraft has to face the body, the spacecraft is oriented in this direction (nadir

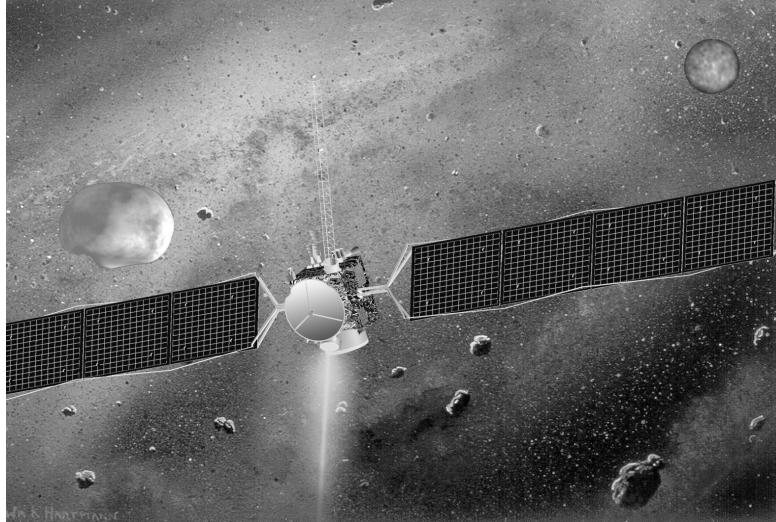


Fig. 1. Artist's conception of Dawn spacecraft thrusting its ion engines on the way to Vesta and Ceres.

pointing). To undertake such a mission is difficult and expensive. In order both to employ relevant and recent heritage and to afford to be able to visit each of Vesta and Ceres, a partnership was formed between the American, German and Italian space agencies. The German space agency, DLR, is represented by the Institute of Space Sensor Technology and Planetary Exploration in Berlin and the Italian space agency, ASI, by CNR/IFSI in Rome. The project is managed by the Jet Propulsion Laboratory for NASA and the spacecraft is built by Orbital Sciences Corporation. The overall direction of the project is provided by the UCLA principal investigator, C. T. Russell, with the advice of the science team, the co-authors of this report.

3. TARGETS

Late in the 18th century it was realized that the Titius-Bode's law predicted a planet near 2.8 AU where none had been seen. Thus a search was initiated by Baron Von Zach, the court astronomer at Gotha. His consortium was scooped, however, on the first day of the nineteenth century when Giuseppe Piazzi of Palermo discovered Ceres. Later other asteroids

were found by the Von Zach search team, including Vesta discovered by H. Olbers on March 29, 1807.

We now know much about Ceres and Vesta. They are two of three remaining large asteroids, the other being Pallas, which is much more difficult to reach. Tables 1 and 2 give some of the physical parameters of these bodies. Pallas is dark, resides in the same region of the asteroid belt as Ceres and has relatively low density approaching that of Ceres. Although measurements at Pallas are highly desirable, exploring Vesta and Ceres may be sufficient to bracket the properties of large "minor" planets.

The reflectance spectrum of Vesta, contrasted to that of the other asteroids in Figure 2, is similar to that of the Howardite-Eucrite-Diogenite meteorites and to terrestrial basalts. The existence of basalts on the surface of Vesta indicates that it melted at least partially. This belief was later reinforced by geochemical analyses of the HED meteorites that indicate that a core formed. It appears that Vesta melted and resolidified creating a layered structure with lighter crust on the outside, then pyroxene and olivine, and iron in successively deeper layers.

Table 1. Physical properties of the three largest asteroids

| Body | Mass [10 ¹⁹ kg] | Principal Radii [km] | Density [kg/m ³] | Period [hr] | G [m/s ²] | IRAS Albedo |
|----------|-------------------------------|-------------------------|---------------------------------|----------------|--------------------------|----------------|
| 1 Ceres | 94.8 ± 0.3 | 480x480x454 | 2200 ± 50 | 9.08 | 0.23 | 0.11 |
| 2 Pallas | 21.4 ± 0.8 | 287x263x251 | 2700 ± 150 | 7.81 | 0.30 | 0.16 |
| 4 Vesta | 26.7 ± 0.3 | 280x272x227 | 3700 ± 100 | 5.34 | 0.32 | 0.42 |

Table 2. Orbital parameters of the largest asteroids

| Body | SMA | Eccentricity | Inclination | Period |
|----------|---------|--------------|-------------|----------|
| 1 Ceres | 2.77 AU | 0.077 | 10.6 | 4.61 yrs |
| 2 Pallas | 2.77 AU | 0.232 | 34.8 | 4.61 yrs |
| 4 Vesta | 2.36 AU | 0.090 | 7.1 | 3.63 yrs |

Ceres is very different than Vesta. It has not been linked to any specific meteorites because in part it has a very bland spectrum. It is much darker than Vesta and much less dense. It is believed to contain much water: on cosmological grounds, based on its average density, and from evidence for the alteration of surface materials by water in the spectrum shown in Figure 3. If Ceres could retain a lot of water then it might have remained cool and unmelted with very little thermal alteration since formation.

4. MISSION DESIGN

Dawn's launch is scheduled to take place on May 27, 2006 on a Delta 2925H launch vehicle. Figure 4 shows the interplanetary trajectory, including thrusting and non-thrusting periods. Dawn arrives at Vesta four years after launch in July 2010 and spends 11 months in orbit there. In June 2011 it spirals outward from Vesta and heads to Ceres arriving three years later in August 2014. Again it spends 11 months mapping. All interplanetary and most planetary

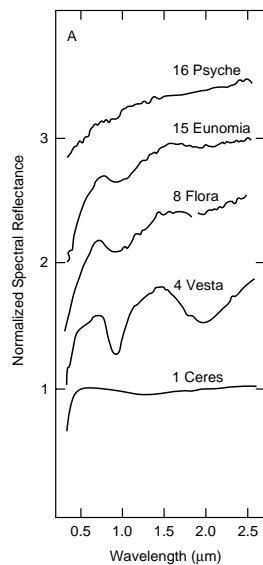


Fig. 2 Visible and near IR reflectance spectrum of Vesta, Ceres and several other major asteroids[1]

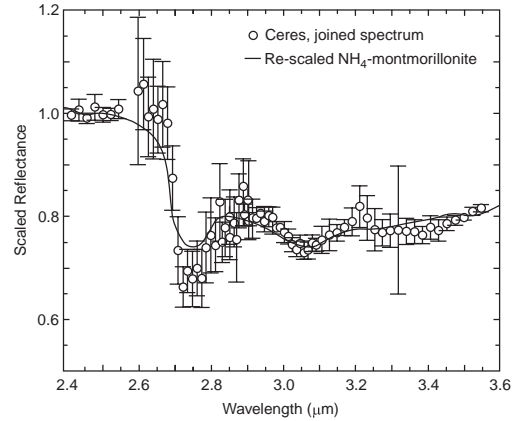


Fig. 3. IR reflectance of Ceres showing a spectral feature possibly associated with the effects aqueous alteration [2]

propulsion is performed using the ion thrusters and 400 kg of xenon fuel. The ion thrusters accelerate the xenon to a speed ten times that of chemical engines, enabling the mission to be carried out with a small launch vehicle, keeping costs within the Discovery guidelines. When the spacecraft arrives at each object it is moving very slowly because it fires its ion engines to decelerate for many months prior to performing a search of the sky around the body for moons and dust. When this survey is complete, the orbit is lowered to an approximately 700 km altitude orbit and the surface completely mapped with the framing camera.

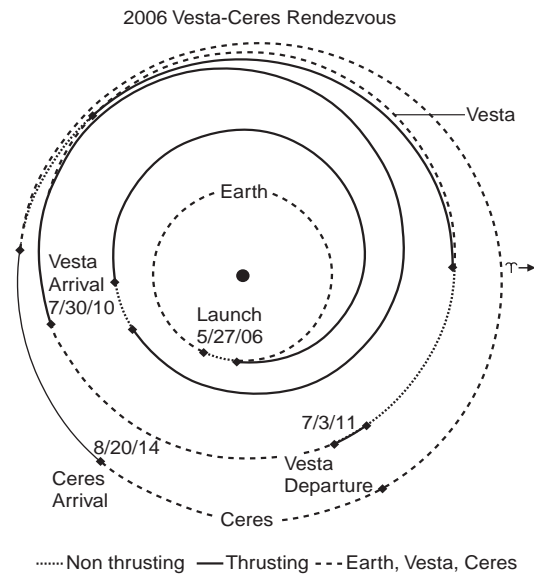


Fig. 4. The planned Dawn interplanetary trajectory

Table 3. Orbital parameters of the Dawn spacecraft at Vesta and Ceres

| Body | Period [hr] | Dist. [km] | Altitude [km] | FOV ¹ [km] | Pixel ¹ [m] | Pointing Optimized for |
|-------|-------------|------------|---------------|-----------------------|------------------------|------------------------------|
| Vesta | 12.1 | 950 | 661-721 | 69 | 69 | Optical mapping* |
| | 3.0 | 375 | 86-146 | 12 | 12 | Laser altimetry [#] |
| | 2.2 | 304 | 15-75 | 5 | 5 | High-res.images ⁺ |
| Ceres | 11.0 | 1360 | 880-906 | 89 | 89 | Optical mapping* |
| | 3.3 | 610 | 130-156 | 14 | 14 | Laser altimetry [#] |
| | 2.7 | 529 | 49-75 | 6 | 6 | High-res.images ⁺ |

*Visible and IR; [#]Including gamma ray, magnetic and gravity data; ⁺Shared control but generally nadir pointing; ¹ framing camera

An equal amount of data is taken with the mapping spectrometer. After two weeks the spacecraft is lowered to a laser altimetry and gamma ray optimized orbit with an altitude of about 120 km, where magnetic and gravity data are also obtained. After about 6 months, if safe, the orbit is lowered further and high resolution imagery and spectra are taken. Orbital parameters from these orbits are given in Table 3 for both Ceres and Vesta.

5. INSTRUMENTATION AND SCIENCE OBJECTIVES

The top level objectives of the Dawn mission are to understand the conditions and processes occurring at the earliest moments in the solar system and to determine the role of water in controlling planetary evolution. To do this Dawn investigates the internal structure, density, and homogeneity of two complementary bodies, Ceres and Vesta, that have remained intact from the time of their formation, by measuring their mass, shape, volume and spin state with imagery, laser altimetry and gravity. Dawn records the protoplanet's remanent magnetization, elemental and mineral composition to determine their history and evolution. It provides context for the meteorites associated with Vesta and looks for evidence of processes that might explain the origin of primitive, but aqueously altered, meteorites. Dawn images Ceres' and Vesta's surfaces to determine their bombardment and tectonic history; uses gravity, spin state, and magnetic data to limit the size of any metallic core; and uses infrared and gamma ray spectrometry to search for water bearing minerals. The framing camera covers the spectral range from 400 nm to 1000 nm with 7 color filter bands and one clear filter. The mapping spectrometer covers the visible range to 5 microns in the infrared. The laser altimeter is a

copy of that designed for the MESSENGER Mercury orbiter. The gamma ray and neutron spectrometer has much heritage from the spectrometer carried on Lunar Prospector. The magnetometer is a copy of that built for the ST5 mission configured as a dual-sensor gradiometer along the 5 m boom. A third new technology sensor is carried to provide redundancy and to test a new method of measuring the magnetic field.

6. CONCLUDING REMARKS

The Dawn mission completes the first-order exploration of the inner solar system. It also promises to surprise us. While our telescopes and meteorite studies have told us much about Vesta and something about Ceres, today we know very little compared to what we hope to achieve with Dawn.

7. ACKNOWLEDGEMENTS

We would like to thank W.K. Hartmann for permission to use his painting, "A cocoon nebula, perhaps the primordial solar nebula" in association with the Dawn mission. We also wish to thank the many people who helped with the Dawn proposals, in particular M. Shirobacheh, C. Henry, G. Vane and A. McGlynn. The preparation of this paper was supported by a grant from the Discovery project office.

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