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Dawn Discovery mission to Vesta and Ceres: Present status

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Abstract

Dawn, the ninth Discovery mission, is a journey to the main belt asteroids Vesta and Ceres to attempt to understand the building blocks of the solar system and the processes occurring at the solar system's earliest epoch. It does this with a spacecraft that utilizes ion propulsion to reach its targets and to maneuver into orbit about these bodies. It carries a framing camera, a visible and infrared mapping spectrometer, and a gamma ray and neutron detector. The mission has passed its critical design review and is scheduled to be launched in June 2006 with arrival at Vesta in 2011 and Ceres in 2015.

Keywords: Vesta; Ceres; Discovery mission; Asteroid

1. Introduction

Our modern understanding of the solar system is that it began in a cold cloud of gas and dust under conditions much like those in the Trifid nebula today, where bright stars, strong UV emitters are evaporating the gas and dust and shutting down the continued growth of planetesimals. Even when the gas and dust have been dissipated, the nebula continues to evolve as the plaesimals or embryos collide and form even larger bodies. These larger bodies are heated by the energy of collision, by

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released gravitational energy and by radioactive decay. It is of much interest to determine the evolutionary state of these small embryos as this state will affect the evolution of the resultant larger bodies. It is also of interest to determine the variation of the composition of these embryos with heliocentric distance as this compositional gradient also affects the resultant nature of the planets formed. Vesta and Ceres as, illustrated in Fig. 1, are the two most massive asteroids in the main belt. They are particularly interesting because they span the region of space between the rocky inner solar system and the wetter bodies of the outer solar system. They are also particularly interesting because they have survived intact from the earliest days of the solar system and hence provide the potential for acting as windows to the conditions present in the first few million years of the solar system's existence. This depends of course on the time at which the bodies stopped evolving or at least stopped forming new crust. We believe that the crust of Vesta dates back to the first few million years of the age of the solar system. However, this may not be true for Ceres.

The Howardite, Eucrite and Diogenites meteorite (HEDs), thought to be derived from Vesta reveal Vesta to be a quite dry body although, evidence of some slight amount of water is now beginning to be found. In contrast, even though no meteorites are known to come from Ceres, it is clear that Ceres must contain much water because of its low density, $\sim$2100 kg/m^3. Despite their very different present compositions, both bodies probably underwent significant thermal evolution, but to quite different maximum internal temperatures, and over quite different epochs.

Our present paradigm on the evolution of Vesta follows the magma ocean model for the evolution of the lunar crust. This is illustrated in Fig. 2 that presents a timeline of a cooling magma ocean formed by collisional and radioactive heating. Light minerals float to the top of this magma ocean, while heavier minerals such as olivine sink to the bottom. When the magma ocean solidifies completely it is layered, with some components formed from remelted layers. Fortunately Vesta, as illustrated in Fig. 1, has a very large southern crater that will permit the probing of this layered crust. We believe this thermal evolution happened rapidly, perhaps in a few million years.

The equivalent evolutionary model of a wet body, as we believe Ceres to be, is illustrated in Fig. 3 (McCord and Sotin, 2005). Depending on the exact initial conditions, Ceres could be now completely frozen as on the left or partially liquid as on the right. In either case it should have a solid ice crust overlying a convecting ice mantle. Ceres has a density similar to Jupiter's moon Ganymede and we might expect a similar surface, albeit with craters formed at lower impact velocities as Ceres does not reside deep inside a large gravitational potential well as do the Galilean moons. A non-convecting icy crust would form early but could be disrupted by impacts if the mantle remained liquid and could be subject to resurfacing as long as water could reach the surface. Thus, we do not have an estimate for the age of Ceres' surface in the face of the McCord–Sotin model.

We have published elsewhere a detailed description of the mission objectives, our present understanding of Vesta and Ceres and the mission plan and instrumentation (Russell et al., 2004). Herein, we wish to update the status of the program and describe recent changes in it.

2. Mission status

Dawn was selected for further study from a pool of approximately 30 proposals in January, 2001. After

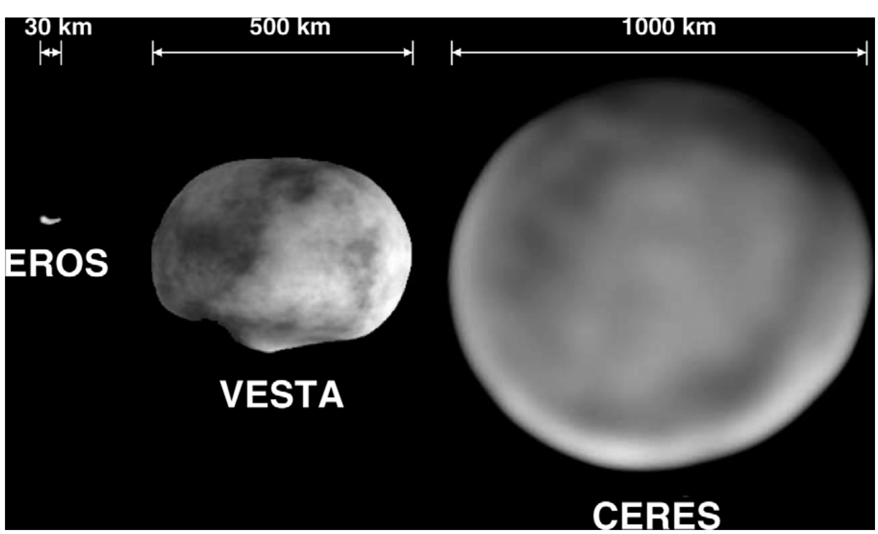

Fig. 1. Images of Vesta and Ceres to scale to compare with Eros the only asteroid previously orbited. Vesta image is a computer reconstruction (Zellner and Thomas, 1997) and the Ceres image is an adaptive optics photograph obtained by C. Dumas (Personal communication, 2002).

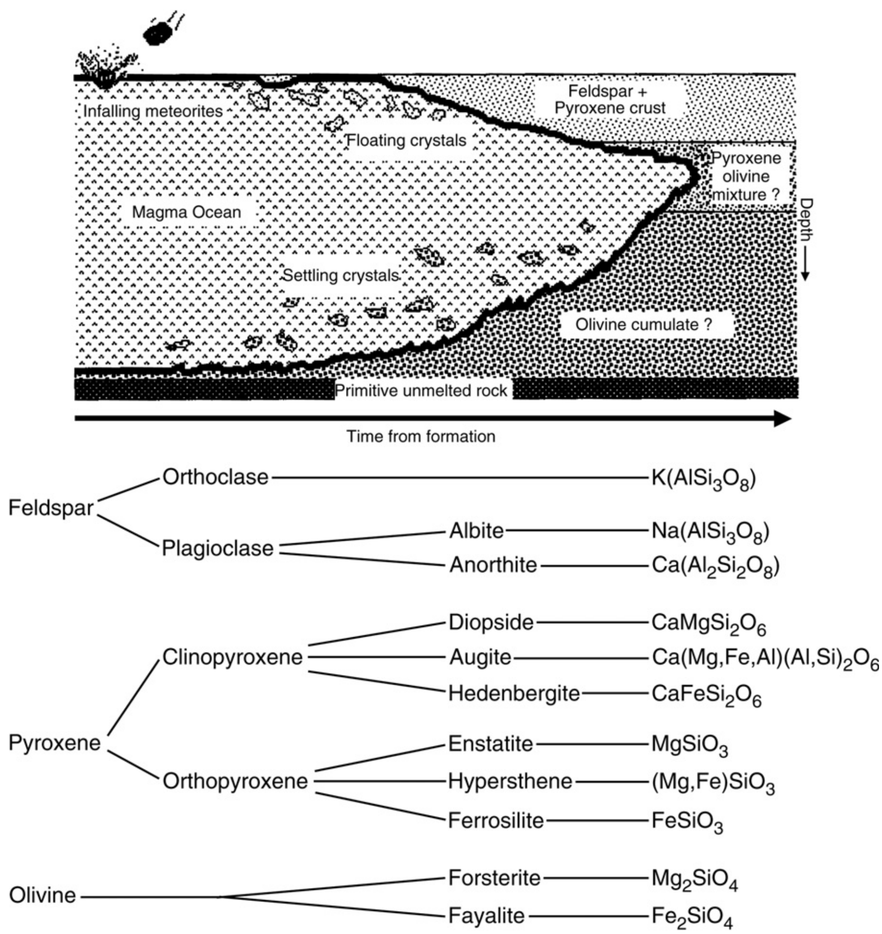

Fig. 2. Model for the evolution of the Vesta crust-based on the magma ocean concept developed for the Earth's moon. As the molten outer layer cools, the heavier minerals sink to the bottom of the magma ocean and the lighter elements float to the top.

the preparation of a Concept Study Report (Phase A) it was selected for formulation in December 2001 (Phase B). A delay in the availability of funds delayed the initiation of formulation until late in 2002. The preliminary design review in October 2003 did not lead to confirmation and a second review was necessary in February 2004 at which time the project was given conditional approval for implementation (Phase C/D). At this writing the project has passed its critical design review and has been given unconditional approval to proceed to assembly, test, and a launch scheduled for June 2006.

3. Mission timeline

In order to increase financial reserves at the behest of the NASA Office of Space Science, changes had to be made in the structure of the mission. A proposal to concentrate the prime mission on Vesta and defer Ceres to an extended mission was denied so the stay time at each body was lessened. Other savings accrued when the spacecraft contractor agreed to forego its fee and when the financing plan for the laser altimeter was not approved by NASA because of rules associated with the conversion to full cost accounting. An unexplained failure to approve the magnetic field investigation added but slightly to the reserves, as this was the lowest cost investigation. Fig. 4 shows the present mission timeline used for planning. As the implementation proceeds and smaller reserves have to be carried, these resources can be allocated to enhancing the mission. Thus, it should be possible to arrive at Vesta somewhat prior to October 2011 and obtain Ceres data after January 2016.

The present baseline mission obtains data in three orbits at each body. In Vesta science orbit 1, measurements are obtained at 2700 km planetocentric. In this orbit a preliminary shape model is obtained and a complete spectral mapping is performed. In Vesta science orbit 2, the prime orbit for the high spatial resolution imaging topography and spectrometry, measurements are obtained at 950 km planetocentric. In Vesta science orbit 3, the prime orbit for the gamma ray and neutron detector, observations are obtained at a radius of 460 km, about 200 km from the surface. If additional time is available for observations it will be spent at the lowest altitude.

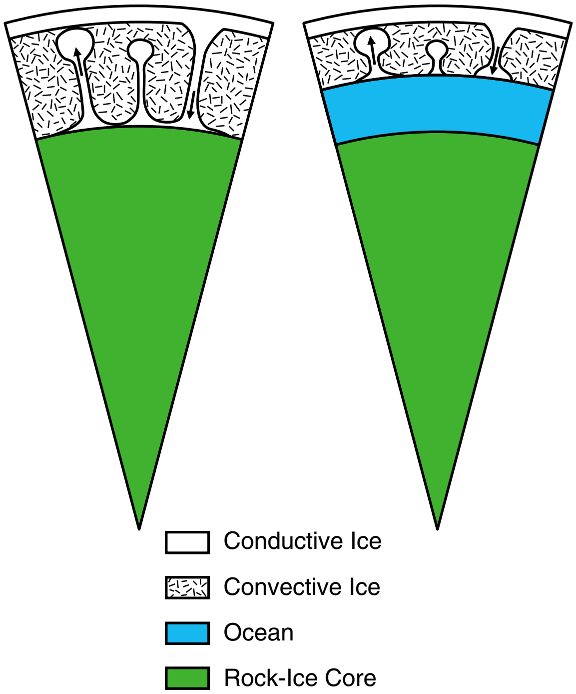

Fig. 3. Evolutionary model of Ceres (adapted from McCord and Sotin, 2005). For a body of the size and at the distance of Ceres, the water accumulated during accretion does not become warm enough to evaporate and forms a water and ice shell above a rocky core.

A similar observing sequence will be undertaken at Ceres. In Ceres science orbit 1 data are obtained at 6400 km planetocentric; in science orbit 2 data are obtained at 1800 km planetocentric and in science orbit 3 at 1180 km, about 700 km above the surface. Table 1 lists the dimension of a pixel in meters at each altitude for visible and infrared mapping spectrometer (VIR) and the framing camera (FC) as well as the data storage capacity.

4. Payload

The scientific payload consists of three instruments, a redundant FC, a VIR, and a gamma ray and neutron detector (GRaND). These measurements are accompanied by gravity science obtained by tracking the spacecraft's motion via Doppler shifts in the radio transmissions. Fig. 5 shows sketches of these instruments. The framing camera supports imaging of the surface, optical navigation of the spacecraft, and determination of the topography of the body. It has a filter wheel with seven color filters and one clear filter. An image consists of a frame of 1024×1024 pixels and one pixel has a field of view (FOV) of 93 μrad. The VIR mapping spectrometer is a compact spectrometer with both visible and infrared ranges: 0.25–1.0 and 0.95–5.0 μm. Its spatial resolution is 0.250 mrad with spectral resolution varying from 30 to 170. The GRaND instrument features neutron spectroscopy using Li-loaded glass and boron-loaded plastic phoswich. The gamma ray detection uses bismuth germanate and cadmium zinc telluride. The design of the instrument enables suppression of background from the space environment.

5. Science data products

The three instruments and gravity science contribute mission datasets whose joint analysis will lead to a deeper understanding of Vesta and Ceres. The framing camera provides nearly global coverage in three color filters as well as three clear maps at different view angles for topography. VIR provides high spectral resolution with nearly global coverage and coverage of selected re-

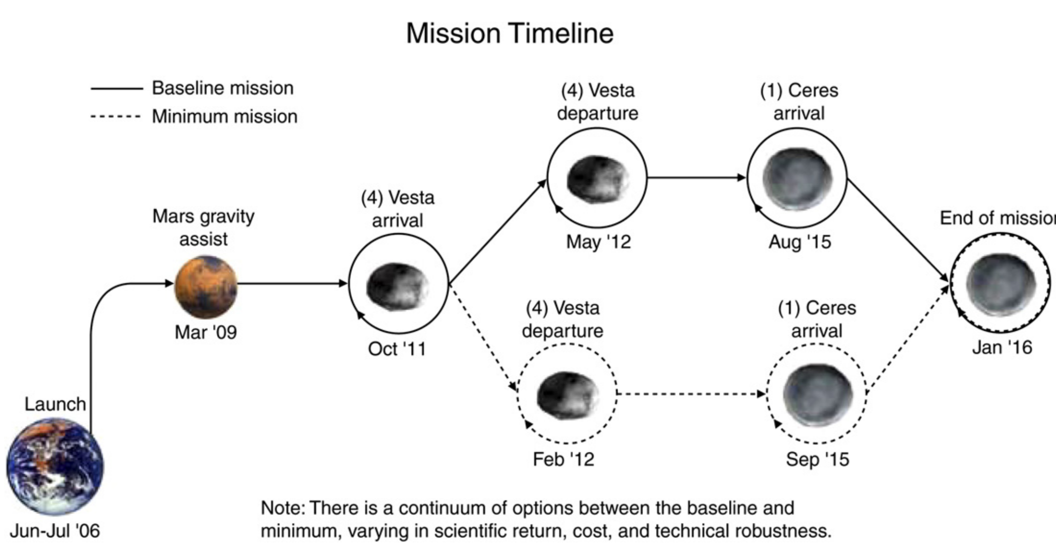

Fig. 4. Mission timeline. Top timeline shows the baseline mission. Bottom timeline shows the minimum mission that the Dawn project guarantees to provide. Expectations are that greater stay times will be available at both Vesta and Ceres than shown here.

Table 1
Sampling/coverage

Orbit	Planetocentric radius (km)	Duration (Days)	Spatial sampling		Data volume
			VIR (m)	FC (m)	Storage Gb
Vesta					
VS01	2700	5	615	–	12
VS02	950	21	170	70	28
VS03	460	60	–	–	53
Ceres					
CS01	6400	8	1530	–	11
CS02	1800	21	340	125	27
CS03	1180	30	–	–	18

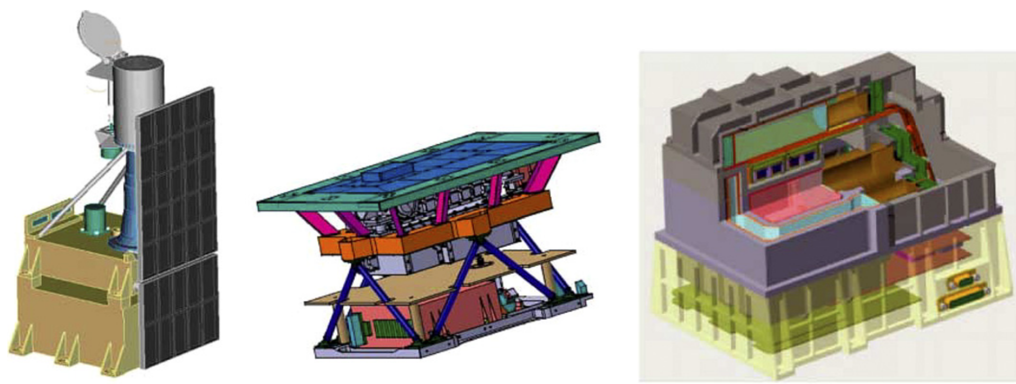

Fig. 5. Dawn payload, consisting of a framing camera, visible and infrared mapping spectrometer and gamma ray and neutron detector.

gions with both high spectral and high spatial resolution. GRaND provides maps of major selected minor elemental abundance divided into 36 separate regions on Vesta and at least 10 on Ceres. Hydrogen abundance maps will be made for Ceres and possibly Vesta. Gravity will be measured to harmonic degree 9 or greater for Vesta and 5 or greater for Ceres.

From the integrated data base a topographic shape model will be constructed upon a body-centered reference frame. This will allow the registration of image mosaics, mineral composition maps with the images and deconvolved elemental composition maps with the images. A internal density model will be developed as well as an integrated geologic map of the surface of each asteroid.

6. Concluding remarks

The Dawn mission has been developed during a very difficult period for space exploration. Disruption of the schedule has occurred because of the response to terrorist attacks, new restrictions on international collaboration, and demands on government budgets. Weak economies and conflicting priorities have caused stretch-outs in programs that, in turn, allowed other events to interfere with the schedule, and brought in new administrators and new agendas. Perhaps the most harmful historical context for Dawn was the failure of the sixth Discovery mission as it was injected into its interplanetary trajectory and a series of technical and resulting financial difficulties with Discovery missions seven and eight. Fortunately, but with much difficulty and great effort on the part of all Dawn team members, development of the mission has continued, and the mission is proceeding well. Dawn remains on schedule for a June 2006 launch, but schedule remains the top concern of the project. To increase project reserves yet remain within budget, the stay times at Vesta and Ceres have been reduced. The data returned during this reduced stay time will satisfy the mission's scientific objectives but we intend to restore some additional stay time by expending additional technical and/or financial reserves at the appropriate moment.

The Dawn team intends to operate as openly and inclusively as possible in the present environment. It is currently working with the telescopic community, both ground-based and space-based to learn as much about Vesta and Ceres as we can prior to arrival, to allow the optimum science return from the orbital measurements. Further, Dawn is planning to add participating scientists to the mission prior to the encounters and to have a data analysis program post encounters that will bring new talent to bear on the problem and to widen the participation by the community.

Acknowledgments

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