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DAWN DISCOVERY MISSION: STATUS REPORT

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ABSTRACT

The Dawn mission is the ninth spacecraft in the Discovery series, selected for study in January 2001 and approved for development in December 2001. It is now being readied for launch in late June 2006 to rendezvous with and orbit the two largest minor planets 4 Vesta and 1 Ceres. Dawn is the first purely science mission to use ion propulsion as an enabling technology and the first to orbit two planetary bodies other than Earth. This mission is well into its assembly test and launch operations phase. This paper gives an overview of the science objectives and payload, reports on the status of the mission, and provides pointers to the literature describing the Dawn mission in greater detail.

1. INTRODUCTION

Planetary systems arise in cold clouds of dust and gas, called nebulae. The dust forms from minerals that precipitate as the gas cools. The dust then accretes into ever larger bodies, or planetary embryos, eventually forming protoplanets, and then planets. Hot stars may also form in the nebula through gravitational instabilities, shine brightly, dissipate the gas, and leave only the orbiting bodies. The history of this process is largely hidden from view by the distance of these planet-forming regions, and in the case of our own solar system, the thermal and dynamical evolution of the system.

The solar system consists of several distinct classes of bodies: the terrestrial planets that are largely silicate mantles surrounding iron cores; the gas giants that are hydrogen-helium balls around rocky cores, some with thick water mantles between these two layers. There are several belts of smaller bodies, the main asteroid belt between Mars and Jupiter, the Kuiper belt beyond Neptune, closely related to Pluto, and the Oort cloud beyond that. It is difficult to learn much about the early solar nebula from the present-day planets. The planets are well separated. The composition of each planet is expected to be an average over the material originally in a broad region of the solar nebula in the approximate neighborhood of the planet. The

temperature in the interior of planets is sufficiently high that they evolve thermally and differentiate over the age of the solar system. In order to understand the planet-forming process we wish to be able to resolve the heliocentric gradient in the solar nebula. The asteroid belt is the best region in which to explore this gradient, because shortly after the formation of the belt, Jupiter condensed and began to stir the asteroids gravitationally. This stirring was sufficient to stop accretion and to begin the collisional disruption of the protoplanets in the belt. The resultant, rather small sizes of the asteroids kept their thermal evolution to a minimum. The largest of these bodies, especially 1 Ceres and 4 Vesta, survived the collisions and seem not to have moved greatly from their point of formation. Dawn's objective is to place constraints on the nature of the early solar nebulae by learning as much as we can about the two very different bodies.

Vesta, the closer to the Sun, lies at 2.34 Astronomical Units (AU). Telescopic observations show it to be roughly a triaxial ellipsoid of dimensions 289 x 280 x 229 km, with a large southern crater. Its surface has the reflectance spectrum of basalt. This spectrum is very similar to the reflected spectrum of light from the Howardite-Eucrite-Diogenite class of meteorite (HEDs). Most asteroid researchers believe that the HED meteorites derive from the disruption of larger bodies or vestoids, ejected from Vesta during the southern cratering event. Some of this material now resides near orbital resonances with Jupiter at which point they can be perturbed onto impact trajectories with Earth, producing 5% of observed meteorite falls. These HED meteorites, in turn, allow us to paint a picture of Vesta that is very consistent with the inferences from the reflectance spectra. Vesta is a dry, rocky body with an iron core. It has extensively melted, recrystallized, and formed a differentiated body [1].

Ceres, the larger body, lies at 2.77 AU. Recent Hubble observations show that Ceres is rotationally symmetric and oblate with dimensions 487 x 487 x 455 km [2]. The shape is not consistent with a homogeneous density but rather with a two-layer structure, a rocky core covered with a 100-km ice mantle. Because ice is



Fig. 1 Two assembled framing cameras, covered by thermal blankets, after successfully completing environmental testing

not visible on the surface it must be covered by a thick layer of dust. This surface is dark but has discernible features. Some of these features are circular but at this time we cannot be certain as to the source of these features [3]. These observations are consistent with the earlier modeling predictions [4].

Improvement in our understanding of Vesta and Ceres has paralleled the development of the flight system. This evolution has proceeded not just through the efforts of the Dawn science team, but as a concerted effort of the members of the science community, both inside and outside the Dawn family. It occurs both in collaborations with Dawn team members and in independent studies. The existence of a mission to targets such as Vesta and Ceres does much to focus attention, and provide direction to the efforts of the scientific community [5].

2. SCIENTIFIC PAYLOAD

The spacecraft carries three scientific instruments: a framing camera, a visible and infrared spectrometer, and a gamma ray and neutron spectrometer. In addition gravity measurements will be obtained through analysis of the radio transmissions and other navigational measurements. The camera, illustrated in Figure 1, has two identical (and redundant) units and obtains images on a frame transfer CCD with 1024 x 1024 sensitive pixels. The camera samples the surface of the bodies with a resolution of 18.6 m/pixel a distance of 200 km. The camera serves to provide optical navigation data as well as scientific data. The camera includes a filter wheel with one clear filter and 7 spectral filters. The heritage of the camera is based on several previous missions, including a data processing unit from the Venus Monitoring Camera on the Venus Express Mission, with an operating system developed for the science imager (OSIRIS) from the



Fig. 2 The visible and infrared spectrometer (VIR) mounted to the vibration test table with GSE fixturing

Rosetta mission. The detector and readout electronics are copies of the units implemented in the downward-looking imager (ROLIS) from Rosetta. The camera is provided by the Max-Planck-Institut für Sonnensystemforschung (MPS) in Lindau Germany under the leadership of H. Uwe Keller with assistance from the Institut für Planetenforschung of the Deutsches Zentrum für Luft-und Raumfahrt (DLR) in Berlin. The DPU is fabricated by the Institut für Datentechnik und Kommunikationsnetze of the Technische Universität Braunschweig. The two redundant framing cameras have been delivered to the spacecraft.

The mapping spectrometer, illustrated in Figure 2, combines two data channels in one compact instrument with a visible channel from 0.25 to 1.0 microns and an infrared channel from 1 to 5 microns. The instantaneous field of view is 500 m/pixel at 200 km with a full field of view of 64 mrad. The spectrometer is a modification of the Rosetta mapping spectrometer (VIRTIS) that in turn derives much heritage from the Cassini VIMS spectrometer. The spectrometer is provided to Dawn by the Agenzia Spaziale Italiana (ASI) under the direction of Angioletta Coradini of the Istituto Nazionale Di Astrofisica (INAF). The spectrometer was designed, built and tested at Galileo Avionica. At this writing the main electronics has been delivered to Orbital and returned to Galileo Avionica for refurbishment. It is expected to be returned to Orbital and installed by the end of the ICLCPM conference.

The gamma ray and neutron spectrometer (GRaND), illustrated in Figure 3, maps the abundance of rock forming elements (O, Si, Fe, Ti, Mg, Al, and Ca) as well as radioactive elements (K, U, Th) and elements such as H, C and N that are major constituents of ices. The instrument draws on decades of experience in

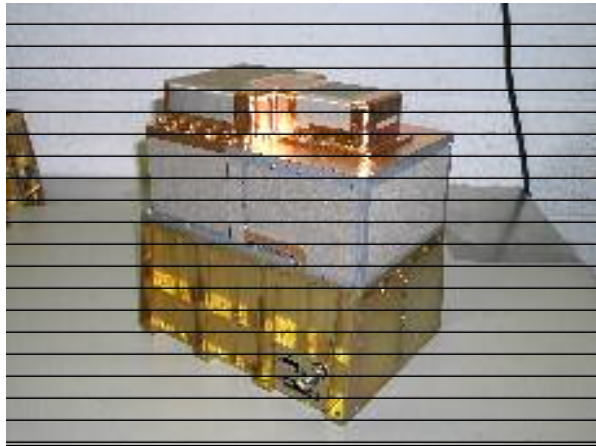


Fig. 3 The gamma ray neutron spectrometer prior to thermal blanket installation

measuring neutrons and energetic photons. It includes improved detectors deriving heritage from Lunar Prospector and Mars Odyssey as well as a new set of detectors employing cadmium-zinc telluride. GRaND has been built at the Los Alamos National Laboratory with funds provided by Dawn under the leadership of Tom Prettyman. At this writing the unit is undergoing final test and integration and will be delivered to Orbital Sciences Corporation, just after the completion of the conference.

3. SPACECRAFT

Figure 4 shows an artist's conception of the Dawn spacecraft in flight with one of its xenon thrusters firing. Three ion thrusters are carried, in order to process sufficient xenon fuel to execute the mission. The thruster grids are ablated by the accelerated xenon, and have a limited expected life based on xenon fuel throughput. The thrusters are used one at a time, as depicted here in order to simplify the design.

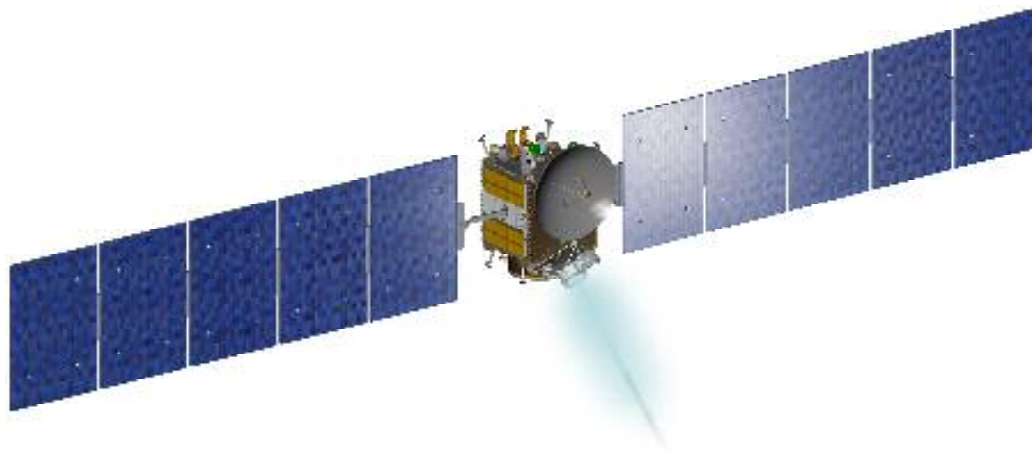


Fig. 4 Artist's conception of the Dawn spacecraft firing one of its side thrusters

The solar array is 19.7 m tip-to-tip and provides approximately 10 kW of power at 1 AU. During launch the two five-paneled solar array wings are folded against the sides of the spacecraft, and are deployed after successful injection into the launch trajectory. The solar array is Dawn's only deployable appendage. Figure 5 shows one wing of Dawn's solar array, deployed at the manufacturer's facility. Other mechanical systems include gimbals for the thrusters and covers for the optical instruments.

The core of the spacecraft is a central thrust tube inside of which are the two fuel tanks, one for hydrazine used by the reaction control system and one for the ion propulsion system's xenon. The external panels are mounted to the thrust tube forming the bus structure. The thrust tube also supports the solar array that rotates around its longitudinal axis so that the solar panels can be maintained perpendicular to the solar direction at all times. In order to maintain thrusting through the spacecraft center of gravity, all three thrusters can gimbal, the side thrusters are canted and mounted to plates with sliding axial struts. Figure 6 shows photos of several ion thruster components.

The instruments are mounted to view in the direction opposite the thrusters. In orbit the top or +Z deck is generally pointed to the center of the body, i.e., nadir pointed. Because the high gain antenna, shown in Figure 7, is not articulated, communication to Earth requires reorienting the spacecraft. Orientation is maintained by reaction wheels which are desaturated with a hydrazine reaction control system. Attitude is determined by a star tracker, gyros, and Sun sensors. All spacecraft subsystems have been delivered at this point and are now installed or ready to be installed.



Fig. 5 One wing of Dawn's solar array extended on the deployment rig

Dawn has not been immune from the difficulties generally encountered by spaceflight projects that have fixed, tight schedules. Manufacturers have fluctuations in their workloads when unexpected orders arrive. Small changes in process may be made without much concern or documentation, until the subsystem fails inspection or test. Advanced planning may be inadequate so that needed parts are not on hand on assembly day, etc. These lapses all lead to delays which must be overcome with the expenditure of schedule or cost reserves. Thus far Dawn has delayed its launch date only by three weeks, principally due to an early lapse in support for the project, rather than any of the many technical issues experienced in system development. It is the Dawn project's self-assessment at the present time that it can continue to move on schedule to launch, barring a major technical problem outside the control of the project, such as the perennial problem of the possibility of a launch vehicle standdown. A potential issue of this nature does exist with the processes used to fabricate Dawn's xenon tank. However, we expect that Dawn will not be affected by the questions associated with the processes used to build the tank for the reasons outlined below.

4. XENON TANK

Because the xenon and hydrazine tanks are mounted inside the thrust tube they were some of the earliest hardware to be installed on the spacecraft which has been largely built around them. Figure 8 shows schematically where these tanks lie. The xenon tank has a titanium liner covered with a composite overwrap. The two halves of the liner are welded together around the belly of the tank. Many tanks have been built, tested and compared against theoretical expectations. The flight tank installed in Dawn has been tested to well above the pressures needed for ground and flight operations and it has been taken to these high pressures repeatedly. However, when tanks similar to the flight tank have been ruptured by increasing the pressure on them until they cracked, the tanks ruptured at pressures above that needed by Dawn but below the theoretical estimates, necessitating a review of the construction processes, assumptions and the actualities of the as-built tanks. The root causes for the reduced pressure at rupture are now known and how to build stronger tanks understood. Thus there should not be problems with future tanks, but what to do with Dawn's tank now in the spacecraft?



Fig. 6 Ion thruster components; clockwise from top left neutralizer, plasma shield views from top and bottom, and the iron grid



Fig. 7 Dawn's high gain antenna (without sunshield)

Fortunately Dawn has robust technical margins, designed from the start of the program. One of these was in the amount of fuel the tank could hold compared to that needed for the execution of the mission. Dawn does not need the full capacity of the tank. Thus we will not fill the tank to its capacity. Second, when designing the tanks we assumed the tank would be much warmer than it could physically achieve without heater power being applied. Thus we can control the maximum pressure further by simply keeping the tank at a cooler temperature without any cost to spacecraft operations. The only temperature constraint is to keep the xenon in its gaseous state, a condition that occurs near room temperature. By taking these two actions Dawn has close to a factor of 2 safety margin in its xenon tank.

5. TRAJECTORY

Now that we know the mass of the spacecraft and the amount of fuel to be carried with much more certainty, we can refine and improve the trajectory. Thus, we can complete the mission in the summer of 2015 as originally planned [5], even with the Mars gravity assist, as illustrated in Figure 9.

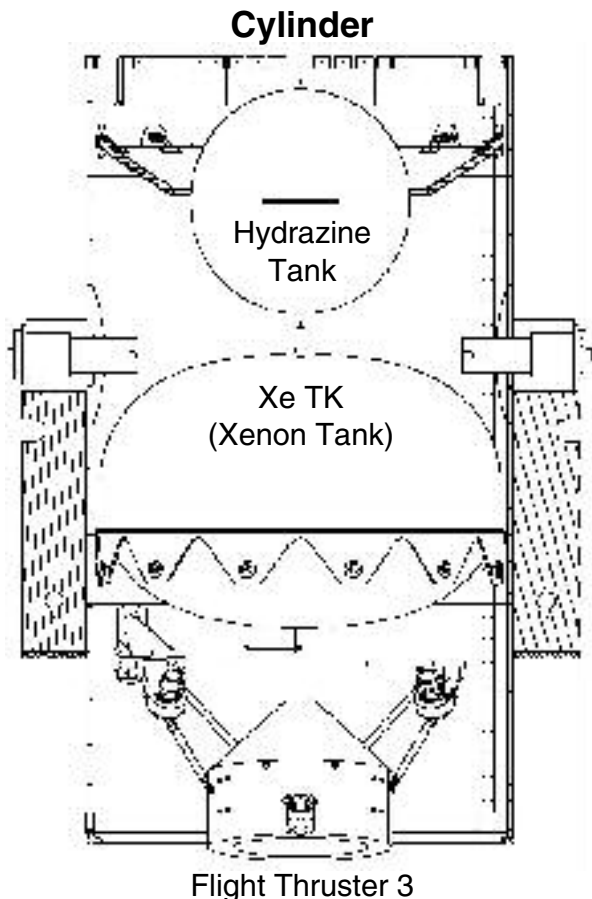


Fig. 8 Dawn's hydrazine (top) and xenon (bottom) tanks in the thrust tube

However, the use of the Mars Gravity Assist does come at a price. The stay time at Vesta is now 8 months and not 11, and at Ceres, 7 months. Mitigating these shorter stay times is the absence of the magnetic and laser altimeter measurements on the present mission. Nevertheless longer stay times are desirable to increase the resolution and sensitivity of the gamma ray and neutron measurements. An increase in stay time is possible by skipping the Mars flyby. This is dynamically possible but whether this course can be followed depends on the final technical margins for the option on the expected launch day.

6. FURTHER INFORMATION ON DAWN

This status report on Dawn has been necessarily brief. Several longer papers have been written describing different aspects of the mission. Herein we briefly note the unique contents of each paper, for those seeking further information. The first paper published after selection is in the Proceedings of the Asteroids, Comets and Meteors meeting in August 2002 [5]. This paper, written during phase B, describes the mission prior to any descopes. The second paper [6] was also written in 2002 during phase B but after the demanifesting of the laser altimeter when, because of a change in rules on cost accounting, the instrument could not be built for the funds available. After this second paper was in review, the magnetometer was demanifested by NASA's selecting official for reasons that still are unclear but plainly invalid. This latter paper contains a detailed description of the mission objectives, the mission plan and the instrumentation as they appeared in the Step 1 and Step 2 proposals.

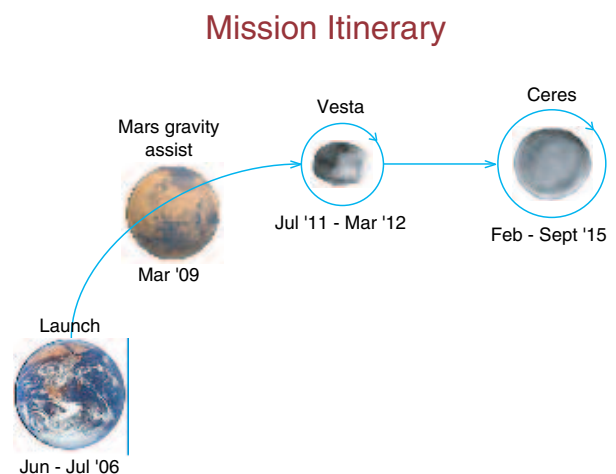


Fig. 9 Schematic of Dawn's trajectory to Vesta and Ceres using a Mars Gravity Assist

Updates to these articles have been written recently. The first contains a detailed description of the flight system and mission trajectory [7]. The second, written in late 2004, but still in the publication process, describes in detail the early history of the Dawn project, updates our understanding of Vesta and Ceres based on the symbiotic efforts of the remote sensing and theoretical modeling communities, provides a more accurate description of the as-built instrument status (as of Phase C) and briefly describes the operations plan [1].

Most recently a paper has been submitted to the 2005 Asteroid, Comets and Meteors conference proceedings that updates our scientific understanding particularly of Ceres and adds much greater detail on the planned science operations [8]. At this conference an accompanying paper describes some of the lessons learned by the Dawn project in the course of the flight system development [9]. Finally a paper to be presented at the IAF/IAA conference describes the inter-relationship of technical resources on an ion propulsion mission and how the margins can be managed and used to increase the scientific potential of the mission [10]. Another source of information on the mission is Dawn's education and public outreach website that can be reached at <http://dawn.jpl.nasa.gov>.

7. CONCLUDING REMARKS

At the risk of sounding over-confident, we believe that Dawn is in much better shape than many other recent missions this close to launch. We believe Dawn has faced as many technical and programmatic obstacles as similar projects, not significantly more, nor significantly less. To date we have been able to address all the technical issues successfully. The programmatic demanifesting of the two instruments, for a cost savings of less than 4% of the total cost of the mission has reduced the expected science return from the mission, but still the expected scientific rewards of the mission are many. With but 9 months to go we anticipate a very successful launch and bountiful scientific return at Vesta and Ceres.

8. ACKNOWLEDGEMENTS

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