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Missions to the outer solar system and beyond

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NASA'S DISCOVERY PROGRAM: MOVING TOWARD THE EDGE (OF THE SOLAR SYSTEM)

Les Johnson and Paul Gilbert

NASA George C. Marshall Space Flight Center

Huntsville, Alabama 35812

c.les.johnson@nasa.gov

ABSTRACT

NASA's Planetary Science Division sponsors a competitive program of small spacecraft missions with the goal of performing focused science investigations that complement NASA's larger planetary science explorations at relatively low cost. The goal of the Discovery program is to launch many smaller missions with fast development times to increase our understanding of the solar system by exploring the planets, dwarf planets, their moons, and small bodies such as comets and asteroids. Discovery missions are solicited from the broad planetary science community approximately every 2 years.

Active missions within the Discovery program include several with direct scientific or engineering connections to potential future missions to the edge of the solar system and beyond. In addition to those in the Discovery program are the missions of the New Frontiers program. The first New Frontiers mission is the New Horizons mission to Pluto, which will explore this 38-AU distant dwarf planet and potentially some Kuiper Belt objects beyond.

The Discovery program's Dawn mission, when launched in mid-2007, will use ion drive as its primary propulsion system. Ion propulsion is one of only two technologies that appear feasible for early interstellar precursor missions with practical flight times.

The Kepler mission will explore the structure and diversity of extrasolar planetary systems, with an emphasis on the detection of Earth-size planets around other stars. Kepler will survey nearby solar systems searching for planets that may fall within the 'habitable zone,' a region surrounding a star within which liquid water may exist on a planet's surface – an essential ingredient for life as we know it.

With its open and competitive approach to mission selections, the Discovery program affords scientists the opportunity to propose missions to virtually any solar system destination. With its emphasis on science and proven openness to the use of new technologies such as ion propulsion, missions flown as part of the program will test out technologies needed for future very deep-space exploration and potentially take us to these difficult and distant destinations.

Keywords: Dawn mission, Kepler mission, Discovery program, extraterrestrial life

INTRODUCTION

The Discovery program was initiated in 1992 as a way to ensure frequent access to space for planetary system(s) science investigations. The program's prime objective is to enhance our understanding of the solar system as it is today and of solar system formation and evolution. The program consists of frequent, small spacecraft missions that perform high-quality, focused scientific investigations. It consists of a long-term series of space science missions that are independent, but share a common program funding, management structure, and set of goals. The program emphasizes missions that can be accomplished under the leadership of the scientific research community.

In order to maintain launch frequency, the program must seek to contain total mission cost and development time, and improve performance through the use of validated new technology and through commitment to, and control of, design, development, and operations costs.

The Discovery program solicits only those investigations which lead to flight projects that investigate planetary science. The term 'planetary science' encompasses the scientific objectives in the NASA Science Mission Directorate Strategic Plan that address the Solar System Exploration theme and the search for extrasolar planetary systems elements of the Astronomical Search for Origins theme.

The Discovery program provides the following two classes of projects:

- Discovery missions – complete science investigations launched on an expendable launch vehicle as a primary payload. Each mission includes definition, development, launch service, mission operations, archiving, data analysis, education, and public outreach, and is performed typically at a program cost cap of $425 million (in fiscal year 2005 dollars) total cost to NASA.
- Missions of opportunity – investigations flown as part of a non-Space Science mission of any size, and having a NASA cost under $35 million (in fiscal year 2005 dollars) total cost to NASA. These missions are conducted on a no-exchange-of-funds basis with the organization sponsoring the mission.

The Principal Investigator (PI) for each Discovery project is responsible for the overall success of the project, and is accountable to the Associate Administrator of the Science Mission Directorate for the scientific success and to the Discovery Program Manager for the programmatic success.

Key Discovery program goals include the launch, on average, of one mission per 18 to 24 months, and for each mission, the primary planned launch date shall be within the time period specified by the associated Announcement of Opportunity, typically 35 months from the start of project implementation.

Many current and near-future Discovery missions will take our explorations to the very edge of the solar system, and, in one case, indirectly beyond our solar system and into those of our stellar neighbors.

1. THE DAWN MISSION

The Dawn mission is managed for NASA by the Jet Propulsion Laboratory, Pasadena, CA. The PI is Dr. Christopher Russell, UCLA. The Dawn mission will be the ninth Discovery mission to be launched.

Planned for launch in the summer of 2007, Dawn will be the first spacecraft to rendezvous with two solar system bodies, the main belt asteroids Vesta and Ceres (Figure 1). This is made possible by utilizing ion propulsion to reach its targets and to maneuver into (and depart) orbits about these bodies. Vesta and Ceres are two terrestrial protoplanets that have survived since the earliest epoch of the solar system and will provide important insights into planet building processes and their evolution under very different circumstances, with and without water. Dawn carries a double framing camera, a visible and infrared mapping spectrometer, and a gamma ray and neutron detector. At Vesta, studies will include the volcanic emplacement of basalts, its differentiation, and the possible exposure of its interior near the South Pole. At Ceres, studies will include the role of water in its evolution, hydration processes on its surface, and the possible existence of a subsurface ocean.[1]

The central scientific drivers for the mission are first that it captures the earliest moments in the origin of the solar system, enabling an understanding of the conditions under which these objects formed. Second, determine the nature of the building blocks from which the terrestrial planets formed, improving the understanding of this formation. Finally, it contrasts the formation and evolution of two small planets that followed very different evolutionary paths so that we understand what controls that evolution:

- Internal structure, density, and homogeneity of two complementary protoplanets – 1 Ceres and 4 Vesta – one wet and one dry.
- Determine shape, size, composition, and mass.
- Surface morphology, cratering.
- Determine thermal history and size of core.
- Understand role of water in controlling asteroid evolution.
- Test the current paradigm of Vesta as the howardite, eucrite, and diogenite (HED) parent body and determine which, if any, meteorites come from Ceres.
- Provide a geologic context for HEDs.

The Dawn mission summary information is shown in Table 1.

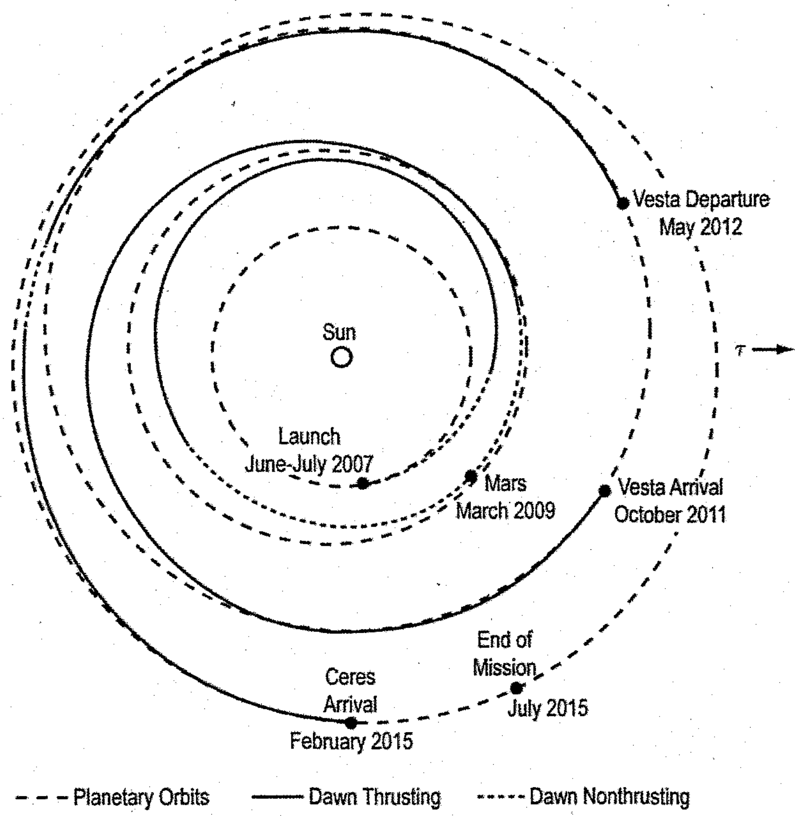

Fig. 1. Dawn's interplanetary trajectory takes it to asteroids Ceres and Vesta[1]

Table 1. Dawn mission summary information

Instrument suite	Framing camera Visible and infrared mapping spectrometer Gamma ray and neutron detector
Spacecraft mass	1210 kg (at launch) 740 kg (dry weight)
Propulsion	Solar electric propulsion using three gimbaled ion propulsion engines. Ion propulsion makes efficient use of the onboard fuel by accelerating it to a velocity ten times that of chemical rockets. Dawn's engines have a specific impulse of 3100 s and a thrust of 90 mN.[2] The ion thruster is powered by Dawn's large solar panels.
Reaction control system	Hydrazine with twelve 0.9 N engines
Power	10-kW, triple-junction solar arrays
Communications	Deep Space Network (41–128 kbps)
Orbital altitude at target asteroids	As high as 4500 km and as low as 25 km
Mission life	10 years
Launch vehicle	Delta 2925H
Planned launch date	Summer 2007

While not actually going into deep space, the Dawn mission will be NASA's first to use solar electric propulsion (SEP) for primary propulsion. This is significant because the extreme propulsive requirements of missions to the outer solar system make them very difficult to achieve with conventional chemical propulsion. Only high specific impulse systems like SEP, or perhaps solar sails, will allow the overall spacecraft to be of a size that is both affordable and launchable with one of today's launch vehicles. With the demonstration of SEP on Dawn, other missions will almost certainly begin using this very important propulsion technology in order to go to these very distant and difficult to reach destinations. Figure 2 shows an artist's concept of the Dawn mission approaching an asteroid.

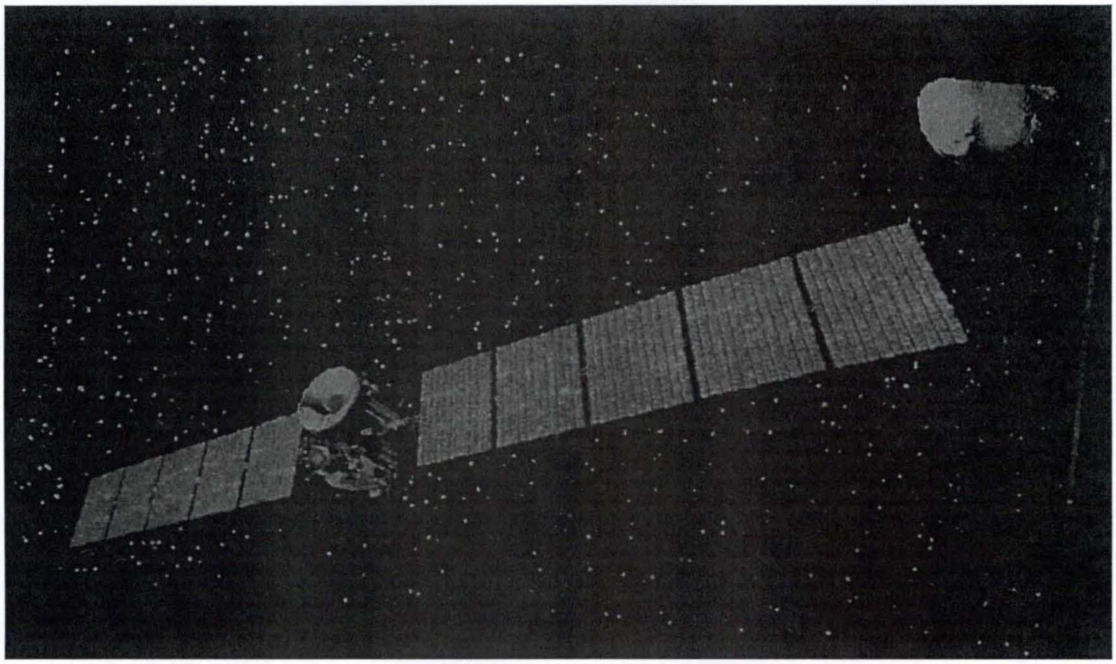

Fig. 2. Artist's concept of the Dawn spacecraft approaching an asteroid

2. THE KEPLER MISSION

The Kepler mission is managed for NASA by the Jet Propulsion Laboratory, Pasadena, CA. The PI is William Borucki, NASA Ames Research Center.

Planned for launch in 2008, the Kepler mission will monitor 100,000 stars similar to our Sun for 4 years. The Kepler mission will use a method known as the transit method of planet finding. Monitoring the planet transients will allow Kepler to determine the size of a planet, the size of the planet's orbit, and estimate the planet's temperature. These qualities determine possibilities for life on the target planet.

All of the extrasolar planets detected so far by other projects are giant planets. Kepler is poised to find planets 30 to 600 times less massive than Jupiter.[1] If Kepler detects many habitable, Earth-size planets, it could mean the universe is full of life. Kepler would then serve as a stepping stone to the next extensive search for habitable planets and life.

"The Kepler Mission will, for the first time, enable humans to search our galaxy for Earth-size or even smaller planets," said PI William Borucki of NASA Ames. "With this cutting-edge capability, Kepler may help us answer one of the most enduring questions humans have asked throughout history: are there others like us in the universe?"

The scientific objective of the Kepler mission is to explore the structure and diversity of planetary systems. This is achieved by surveying a large sample of stars to:

- Determine the percentage of terrestrial and larger planets there are in or near the habitable zone of a wide variety of stars.
- Determine the distribution of sizes and shapes of the orbits of these planets.

- Estimate how many planets there are in multiple-star systems.
- Determine the variety of orbit sizes and planet reflectivities, sizes, masses, and densities of short-period giant planets.
- Identify additional members of each discovered planetary system using other techniques.
- Determine the properties of those stars that harbor planetary systems.[3]

The Kepler mission summary information is shown in Table 2.

Table 2. Kepler mission summary information

Instrument	Photometer: 0.95-m aperture
Primary mirror	1.4-m diameter
Dynamic range of the detectors	9th to 15th magnitude stars
Fine guidance sensors	Four CCDs located on the focal plane
Attitude stability requirement	<9 milliarcseconds over 15 min
Communications	Deep Space Network (3.4 mbps)
Spacecraft mass	1039 kg
Power requirement	651 W
Mission lifetime	4–6 years
Launch vehicle	Delta 2925-10L (Delta II)
Orbit	Earth-trailing heliocentric orbit
Planned launch date	2008

The Kepler instrument is a specially designed 0.95-m-diameter telescope called a photometer. It is basically a Schmidt telescope design. The photometer is composed of just one 'instrument,' which is an array of 42 charge coupled devices (CCDs). Each 50×25 mm CCD has 2200×1024 pixels. It has a very large field of view for an astronomical telescope — 105 square degrees. It stares at the same star field for the entire mission and continuously and simultaneously monitors the brightnesses of more than 100,000 stars for the 4-year life of the mission.

The photometer must be space based to obtain the photometric precision needed to reliably see Earth-like transits. The spacecraft provides the power, pointing, and telemetry for the photometer. Pointing at a single group of stars for the entire mission greatly increases the photometric stability and simplifies the spacecraft design. Figure 3 shows an artist's concept of the Kepler mission searching for planets around other stars.

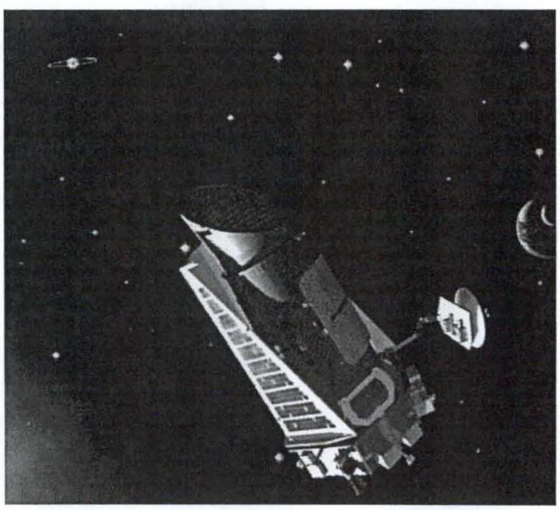

Fig. 3. Artist's concept of the Kepler spacecraft searching for planets around other stars

Kepler will never physically leave the inner solar system. However, once it is in operation, it will tell us a great deal about nearby interstellar planetary systems. Knowing which stellar systems have planets and, among those, which have planets that are Earth-like in mass and orbital distance, will guide future interstellar explorations.

3. NEW HORIZONS: THE FIRST NEW FRONTIERS MISSION

Considered the 'big sister' of the Discovery program, due to its larger scope and budget, the New Frontiers program will explore the solar system with frequent, medium-class spacecraft missions. The destinations of interest to New Frontiers will typically be more distant than those in Discovery and the science to be performed more comprehensive.

New Horizons, managed by Johns Hopkins University's Applied Physics Laboratory, will be humanity's first mission to Pluto, its moon Charon, and perhaps Kuiper Belt objects beyond. Launched in 2006, New Horizons recently completed its gravity-assist maneuver at Jupiter, enabling it to attain the speeds necessary to reach Pluto in 2015. New Horizons will pass just 9600 km miles from Pluto as it speeds past toward the outermost edges of the solar system.

The objectives of New Horizons are to:

- Map the surface composition of Pluto and Charon.
- Characterize the geology and morphology of Pluto and Charon.
- Characterize the neutral atmosphere of Pluto and its escape rate.
- Search for an atmosphere around Charon.
- Map surface temperatures on Pluto and Charon.
- Search for rings and additional satellites around Pluto.
- Conduct similar investigations of one or more Kuiper Belt objects.[4]

CONCLUSIONS

The robust exploration of the outer solar system that so many have dreamt of since the dawn of the space age is now taking place, albeit at a slower pace than originally hoped and envisioned. With a 9-year travel time, New Horizons is en route to fly by the most famous of the Kuiper Belt objects, Pluto and its moon Charon. Dawn will soon be launched to rendezvous with two main asteroids, Ceres and Vesta, using a state-of-the-art SEP system — showing the way for future missions using SEP to reach yet more difficult destinations throughout the solar system. Kepler, when launched in 2008, will provide us unprecedented information about our interstellar neighborhood and possible planetary systems located therein.

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