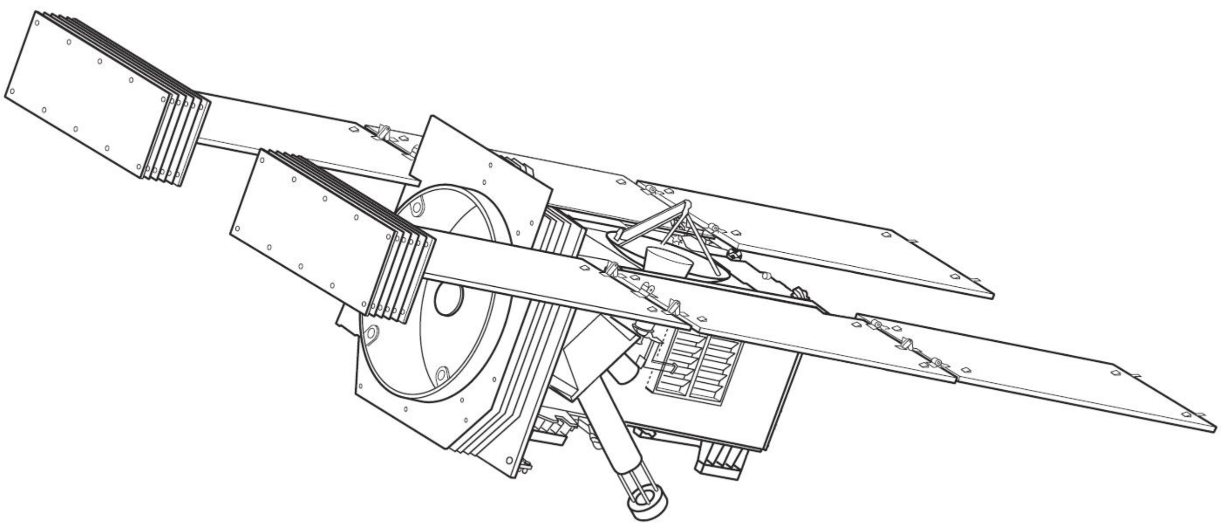
**National Aeronautics and Space Administration**

# Stardust-NExT

## Press Kit
## February 2011

www.nasa.gov



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## Media Services Information

### NASA Television Transmission

All NASA Television Channels *(Public, Education, Media, occasional HD feed and the Live Interactive Media Outlet)* are available on Satellite AMC 3. Cable and satellite service providers, broadcasters, and educational and scientific institutions need to re-tune receiving devices to AMC 3 to continue accessing NASA TV.

"News networks, their reporters, and other broadcast media organizations must tune their satellite receivers to the Media Channel to ensure reception of clean feeds for all mission coverage, news conferences, and other agency distributed news and information. News and other media organizations will no longer be able to rely on content from the Public Channel for clean feeds of mission and other agency activities."

For complete downlink information for Satellite AMC 3 please see "Important Information" at: www.nasa.gov/ntv

In continental North America, Alaska and Hawaii, NASA Television's Public, Education, Media and HD channels are MPEG-2 digital C-band signals carried by QPSK/DVB-S modulation on satellite AMC-3, transponder 15C, at 87 degrees west longitude. Downlink frequency is 4000 MHz, horizontal polarization, with a data rate of 38.86 Mhz, symbol rate of 28.1115 Ms/s, and 3/4 FEC. A Digital Video Broadcast (DVB) compliant Integrated Receiver Decoder (IRD) is needed for reception.

### Media Credentialing

News media representatives who wish to come to JPL to cover the Stardust-NExT's encounter with comet Tempel 1 must contact NASA JPL Media Relations Office in advance at: 818-354-5011.

### Briefings

A post-encounter news briefing is tentatively scheduled be held at NASA JPL at 10 a.m. PST (1 p.m. EST) on Feb. 15, 2011. This confirmed briefing time will be announced in advance and will be televised on NASA TV.

### Internet Information

More information on the Stardust mission, including an electronic copy of this press kit, press releases, status reports, images and videos, can be found at **http://www.stardustnext.jpl.nasa.gov** .

## Quick Facts

### Spacecraft

Dimensions: Main structure 1.7 meters (5.6 feet) high, 0.66 meters (2.16 feet) wide, 0.66 meters (2.16 feet) deep; length of solar arrays 4.8 meters (15.9 feet) tip to tip

Weight: 385 kilograms (848 pounds) total at launch, consisting of 254-kilogram (560-pound) spacecraft and 46-kilogram (101-pound) return capsule, and 85 kilograms (187 pounds) of fuel

Weight total as of Feb. 3, 2011: 256.6 kg (565.7 lbs) total, consisting of 254-kilogram (560-pound) spacecraft and 2.6 kilograms (5.7 pounds) of fuel.

Power: Solar panels providing from 170 to 800 watts, depending on distance from the sun.

### Stardust-NExT mission

Total distance traveled from Earth (since drop off of sample return capsule in 2006) to comet Tempel 1: 1.04 billion kilometers (646 million miles).

Total distance Stardust spacecraft has traveled since 1999 launch (Earth to comet Wild 2 to Earth to comet Tempel 1): about 5.7 billion kilometers (3.5 billion miles).

Spacecraft speed relative to comet Tempel 1 at time of closest approach: 10.9 kilometers per second (6.77 miles per second/24,300 miles per hour).

Distance of spacecraft (and comet) from Earth at time of encounter: 336 million kilometers (209 million miles).

### Program

Stardust-NExT (extended mission) costs: $29 million (FY 2010), for operations from 2007 to end of project at the end of fiscal year 2011.

**Comet Tempel 1**

Official designation: 9P/Tempel. It is a periodic comet discovered by Wilhelm Tempel on April 3, 1867. Tempel 1's orbit lies between the orbits of Mars and Jupiter. The comet orbits the sun every 5.5 years. The comet's orbital period has varied in the past and will do so in the future because of close approaches with the planet Jupiter.

Nucleus shape: Elongated, irregular. Nucleus size: 7.6 and 4.9 kilometers (4.7 and 3 miles) with an equivalent radius of about 3 kilometers.

Nucleus mass: approximately 40 trillion kilograms (88.2 billion tons).
Nucleus rotation period: about 41.9 hours.

Tempel 1 was previously visited by NASA's Deep Impact spacecraft on July 4, 2005.

**Stardust (Prime) Mission 1999 to 2006**

Launch: Feb. 7, 1999, from Cape Canaveral Air Force Station, Fla.
Launch vehicle: Delta II (model 7436) with Star 37 upper stage
Earth-comet Wild 2 distance at time of launch: 820 million kilometers (508 million miles)
Interstellar dust collection: Feb. 22-May 1, 2000; Aug. 5-Dec. 9, 2002
Earth gravity assist flyby: Jan. 15, 2001
Altitude at Earth gravity assist: 6,008 kilometers (3,734 miles)

Asteroid Annefrank flyby: Nov. 2, 2002
Comet Wild 2 encounter: January 2, 2004
Number of pictures of comet nucleus taken during Wild 2 encounter: 72
Earth-comet distance at time of Wild 2 encounter: 389 million kilometers (242 million miles)
Total distance traveled Earth to comet Wild 2: 3.41 billion kilometers (2.12 billion miles)
Spacecraft speed relative to comet Wild 2 at closest approach: 22,023 km/h (13,684 mph)

Earth return: Jan. 15, 2006
Landing site: Utah Test and Training Range, Dugway, Utah
Velocity of sample return capsule entering Earth's atmosphere: 46,440 kilometers per hour (28,860 mph) -- fastest reentry of spacecraft in history
Total distance traveled from comet Wild 2 to Earth: 1.21 billion kilometers (752 million miles)
Total distance traveled during entire Stardust-prime mission (Earth to comet Wild 2 to Earth): 4.63 billion kilometers (2.88 billion miles)

Stardust (prime mission) costs: $300 million (FY 2010) total (including launch vehicle).

## Mission Overview

The Stardust-NExT mission to comet Tempel 1 is an extended mission that makes use of an existing spacecraft to conduct a second mission at a fraction of a typical mission cost.

Launched in 1999, NASA's Stardust spacecraft flew past the nucleus of comet Wild 2 at a distance of 240 kilometers (149 miles) on Jan. 2, 2004. During this close flyby, a special collector captured particles of the comet as the spacecraft flew through the coma, or cloud of dust and debris, surrounding Wild 2. Two years and 13 days after this first-of-its-kind cometary sample mission, the Stardust spacecraft ejected its sample return capsule, which descended into the Department of Defense's Utah Test and Training Range southwest of Salt Lake City, carrying the mission's cosmic booty of cometary and interstellar dust samples.

While the Stardust sample return capsule parachuted to Earth, mission controllers were placing the still-viable spacecraft on a path that would allow NASA the opportunity to re-use the already-proven flight system, if a target of opportunity presented itself. In January 2007, NASA re-christened the mission "Stardust-NExT" (New Exploration of Tempel), and the Stardust spacecraft began the four-and-a-half year journey to comet Tempel 1. The Feb. 14, 2011, flyby will be the second exploration of Tempel 1 by a spacecraft. The first exploration of Tempel 1 was carried out by NASA's Deep Impact mission in July 2005. The Stardust flyby of Tempel 1 will be the first time a comet has been re-visited to look for changes on the comet's surface that occurred as a result of the comet's close flyby of the sun.

Along with high-resolution images of the comet's surface, Stardust-NExT will also measure the composition, size distribution and flux of dust emitted into the coma. The aim is to extend knowledge of the processes that affect comet surfaces and obtain additional information on the internal structure of comet nuclei, and provide important new information on how Jupiter-family comets evolve and how they formed 4.6 billion years ago. A Jupiter-family comet is one whose orbit has been modified by close passages to Jupiter and has an orbital period less than 20 years.

Mission operations will end with spacecraft decommissioning several weeks after the Tempel 1 encounter, and the project will end after data analysis and programmatic closeout.

**Stardust-NExT Mission Highlights**

Oct. 30, 2006 – NASA announced it was studying the possibility of redirecting the Stardust spacecraft on a secondary mission to photograph comet Tempel 1.

July 3, 2007 – NASA approves an extended mission for the Stardust spacecraft under the designation of Stardust-New Exploration of Tempel 1 (NExT).

Aug. 13, 2007 – The Stardust-NExT mission team resumes spacecraft operations.

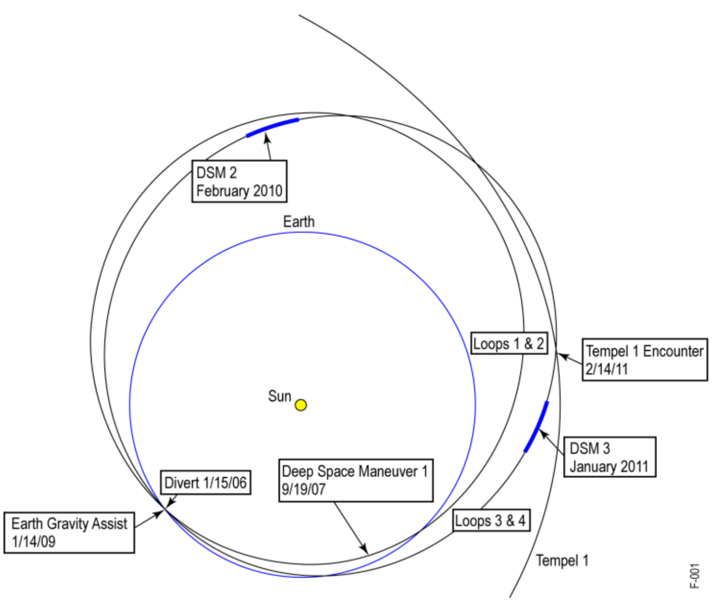
Sept. 19, 2007 – Stardust performs the first trajectory correction maneuver of its new extended mission. The maneuver places the spacecraft on a path for an Earth flyby in January 2009.

Jan. 14, 2009 – Stardust receives a "gravity assist" from Earth.

Feb. 17, 2010 – Stardust spacecraft performs a trajectory correction maneuver to modify its arrival time to the point of closest approach with comet Tempel 1.

Feb. 14, 2011 – Stardust flyby of comet Tempel 1.

**Stardust-NExT Mission Phases**




The trajectory of the Stardust-NExT mission consists of four loops of the sun in two separate orbits. Loops 1 and 2 represent the orbit the spacecraft bus was left in after the sample return on Jan. 15, 2006. The Earth gravity assist on Jan. 14, 2009 placed the spacecraft in the final heliocentric orbit (Loops 3 and 4) intercepting Tempel 1 on Feb. 14, 2011 (39 days after the comet's perihelion).

## Stardust-NExT Mission Phases

### Cruise 1 Phase

This first mission phase for Stardust-NExT began in August 2007. Activity during this stage of the mission was characterized by mission planning on the ground, but minimal interaction with the spacecraft in flight. The Stardust team averaged approximately one short contact with the spacecraft every four weeks to update navigation and spacecraft health.

Also during this phase, two trajectory correction maneuvers were performed. The first of these two maneuvers, on Sept. 19, 2007, placed the spacecraft on a trajectory for an Earth flyby in January 2009.

### Earth Gravity Assist Phase

This phase is the first of only three periods of high activity for the mission (the second and third high-activity phases are approach and encounter). The approximately three-month-long phase was crucial for an efficient and accurate approach to the comet. Two trajectory correction maneuvers were performed during this phase. Stardust made its closest approach to Earth on Jan. 14, 2009. At its closest point to Earth, the spacecraft was about 9,100 kilometers (5,600 miles) over the California/Mexico border south of San Diego and traveling at a speed of approximately 22,400 miles per hour (36,000 kilometer per hour). By performing this Earth flyby (the third and final Earth flyby for the spacecraft), Stardust was placed in a new heliocentric orbit that would result in a flyby of Tempel 1.

### Cruise 2 Phase

Like Cruise 1, Cruise 2 was a maintenance period requiring one contact with the spacecraft every four weeks to update navigation and spacecraft health.

Also during Cruise Phase 2, the Stardust spacecraft executed the largest trajectory correction maneuver of the extended mission. On Feb. 17, 2010, with the spacecraft on the opposite side of the solar system and beyond the orbit of Mars, the rockets fired for 22 minutes and 53 seconds, changing the spacecraft's speed by 24 meters per second (54 miles per hour). The burn adjusted the time of the spacecraft’s encounter with comet Tempel 1 by eight hours and 20 minutes. (The science team requested this delay to maximize the possibility of the spacecraft capturing high-resolution images of desired surface features of the comet.)

### Approach Phase

Beginning at encounter-minus-60 days, this phase is characterized by the beginning of optical navigation of comet Tempel 1 from the spacecraft's onboard camera, NavCam, in addition to frequent spacecraft systems checks and tests, and trajectory correction maneuvers to refine Stardust's trajectory as it approaches the comet.

Several such maneuvers have been scheduled for the approach phase. All of these maneuvers are geared toward the most fuel-efficient refinement of the spacecraft's path toward comet Tempel 1. The final maneuver during this phase (called TCM-33) is scheduled for 48 hours prior to encounter (Feb. 12 at 8:30 p.m. PST, or 11:30 p.m. EST).

Six hours after this trajectory correction maneuver (encounter-minus-42 hours), the spacecraft will take its final set of approach-phase Optical Navigation (OpNav) images and downlink them to Earth. Mission navigators will analyze these images for the latest on the location of the comet and make their final recommendations on whether or not a final maneuver for this phase should be performed to move the spacecraft away from the comet. This would be done if the projected flyby distance is too close.

**Encounter Phase**

The Encounter Phase begins at 24 hours before the time of closest approach and concludes 24 hours after the time of closest approach. The first critical milestone occurs at encounter-minus-24 hours. That is when the Stardust-NExT mission team begins uplinking the set of commands that will carry the spacecraft through its encounter with Tempel 1.

- At encounter-minus-18-hours, engineers will have the last scheduled opportunity for a final trajectory correction maneuver prior to encounter. This maneuver would only be executed if mission navigators indicate the spacecraft could pass closer to the comet's nucleus than planned. The information used in the decision of whether to execute the maneuver or not is based on the data previously taken in the final set of OpNav images. Regardless of whether or not this maneuver is executed, no further maneuvers are scheduled.
- At encounter-minus-16 hours, any final modifications or refinements to the existing flyby commands are uploaded. This is the final scheduled two-way communications with the spacecraft until after encounter.
- At encounter-minus-3 hours, the spacecraft will turn on the Comet and Interstellar Dust Analyzer instrument.
- At encounter-minus-1 hour, the Encounter Phase enters its "critical sequence." This sequence is characterized by the spacecraft carrying out many important milestones. The first milestone of this sequence occurs at encounter-minus-one hour, when the spacecraft turns to place its protective Whipple Shields in the ram direction -- that is the spacecraft puts its shields between it and the anticipated direction cometary particles would approach. This maneuver will place the spacecraft in an attitude that does not allow the high-gain antenna to point at Earth. As a result, there will not be any high-rate communications between the spacecraft and ground during this critical phase.
- At encounter-minus-30 minutes, the spacecraft will initiate its AutoNav program. AutoNav allows the onboard navigation system to assist camera pointing by adjusting the angle of the NavCam's scan mirror. It also provides information to the spacecraft's attitude system on the magnitude of a roll that the spacecraft performs at five minutes before closest approach. The role is designed to correct any out-of-plane error and thus keep the comet's nucleus in the camera's field of view.
- At encounter-minus-20 minutes, the Dust Flux Monitor instrument is turned on.

- At encounter-minus-5 minutes the spacecraft will initiate a "roll-to-comet point." This approximately 40-second long rolling maneuver places the spacecraft in an attitude that optimizes the NavCam's ability to keep Tempel 1's nucleus in its field of view.
- One minute later (encounter-minus-4 minutes), the science imaging begins. The nominal imaging sequence runs from encounter-minus-4 minutes to encounter-plus-4 minutes. The spacecraft's onboard memory is limited to 72 high-resolution images, so the fastest possible NavCam imaging frequency is used around closest approach for best-resolution coverage.

    - From encounter-minus-4 minutes to encounter-minus-2 minutes-and-24 seconds, 12 frames are taken (one every 8 seconds).
    - From encounter-minus-2-minutes-and-24 seconds to encounter-plus-2-minutes-and-30 seconds, 48 frames are taken (one every 6 seconds).
    - From encounter-plus-2-minutes-and-38 seconds to encounter-plus-3-minutes-and-50-seconds, 12 frames are taken (one every 8 seconds).

- At encounter-minus-0 seconds, the spacecraft is expected to be approximately 200 kilometers (124 miles) from the comet's nucleus.
- At encounter-plus-1-minute-and-36-seconds, AutoNav has completed operations and is turned off.
- At encounter-plus-4 minutes, high-resolution science imaging is complete.
- At encounter-plus-20 minutes, the Dust Flux Monitor instrument is turned off.
- At encounter-plus-60 minutes, the spacecraft performs an attitude change to point its high-gain antenna at Earth.
- At encounter-plus-3 hours, the Comet and Interstellar Dust Analyzer instrument is turned off. This completes the collection of science data during the Encounter Phase of the Tempel 1 flyby. A total of 720 megabytes of data, including 72 high-resolution images, are stored for playback.
- At encounter-plus-3-hours-and-38-minutes, the Madrid dish of NASA's Deep Space Network begins to receive the playback of science data collected during encounter. Five selected NavCam images are returned first. Next, data from the two other instruments are downlinked. Finally, the remaining 67 high-resolution images taken during encounter are downlinked. To ensure all images and science instruments data have been collected, the science data from encounter will be downlinked in its entirety up to three times during the next two days.

**Departure Phase**

The Departure Phase for the Stardust-NExT encounter begins at encounter-plus-2-days. The spacecraft will begin imaging the comet as it recedes into the distance. This departure-phase imaging begins at encounter-plus-2-days with one image every 5 minutes. From encounter-plus-4-days to encounter-plus-10-days, a science image of the comet will be taken every 12 minutes.

Mission operations will end with spacecraft decommissioning several weeks after encounter, and the project will end after data analysis and programmatic closeout.

**Stardust (Prime) Mission Highlights, 1999 to 2006**

**Launch**

The Stardust spacecraft began its voyage on Feb. 7, 1999 from Space Launch Complex 17A at Cape Canaveral Air Station, Fla., on a variant of the Delta II launch vehicle known as a Delta 7426.

**Cruise**

Stardust's first two years of flight carried it on the first of its three orbital loops around the sun. In January 2000, when Stardust was between the orbits of Mars and Jupiter -- the most distant point from the sun that it reached during that orbit -- the spacecraft's thrusters fired to place it on course for a later gravity assist by Earth.

Twice, as Stardust traveled through the solar system, it collected interstellar particles flowing through the solar system. One part of the collector mechanism, called its "B side," faced the incoming interstellar dust stream, while the other side, called the "A side," was later used for the spacecraft's dust collection at comet Wild 2.

On Nov. 2, 2002, Stardust flew within 3,100 kilometers (1,927 miles) of asteroid Annefrank. This encounter was used to test spacecraft procedures and operations that would be used during the Wild 2 comet encounter.

**Comet Wild 2 Flyby**

On Jan. 2, 2004, at 11:40 a.m. PST (2:40 p.m. EST), after traveling 3.41 billion kilometers (2.12 billion miles) across the solar system over four years, the Stardust spacecraft made its closest approach of comet Wild 2 at a distance of 240 kilometers (149 miles). During this close encounter, the faster-moving comet actually hurtled past the slower Stardust at a relative speed of 22,023 kilometers per hour (13,684 miles per hour). The spacecraft obtained 72 images of the comet nucleus and captured comet particles in the equivalent of a "cometary catcher's mitt." The particles were stowed within a capsule for the return trip to Earth.

**Sample Return**

After traveling an additional 1.21 billion kilometers (752 million miles) from comet to Earth, the Stardust team prepared to deploy the spacecraft's sample return capsule. On Jan. 14, 2006 at 9:57 PST time (10:57 p.m. MST) -- when the spacecraft was 110,728 kilometers (68,805 miles) from Earth -- Stardust released the capsule. About 15 minutes after separation, the main spacecraft fired its thrusters in a divert maneuver to keep it from hitting Earth. This maneuver put the Stardust spacecraft in an orbit around the sun --making a bonus mission possible.

**Stardust (Prime) Mission Highlights, 1999 to 2006 (cont'd)**

The capsule entered the atmosphere four hours later, at 1:57 a.m. PST (2:57 a.m. MST). The drogue and main parachutes deployed at 2:00 and 2:05 a.m. PST, respectively (3:00 and 3:05 a.m. MST), and the spacecraft touched down at the US Army's Utah Test and Training Range, [location?], soon after that.

**Results**

The comet samples collected by Stardust have gone to scientists worldwide for study by state-of-the-art analytical methods. One of the major scientific findings of the mission is that ice-rich comets, the coldest and most distant solar system bodies, also contain fragments of materials that formed 4.5 billion years ago in the center of the solar system by violent high temperature processes. These remarkable materials formed in the inner solar system, and yet were transported beyond the orbits of the most distant planets by unknown processes.

## Spacecraft

The Stardust spacecraft will have logged more than 5,673,464,575 kilometers (3,525,327,446 miles) and over a dozen years traveling in deep space by the time the Tempel 1 encounter is complete. Back when it launched in 1999, Stardust carried onboard some of the most innovative, state-of-the-art technologies pioneered by other recent missions. It combined this state-of-the-art technology with a combination of off-the-shelf spacecraft components and, in some cases, spare parts and instrumentation left over from previous successful space missions.

The Stardust spacecraft is derived from a rectangular deep-space bus called SpaceProbe developed by Lockheed Martin Space Systems, Denver. The main bus is 1.7 meters (5.6 feet) high, 0.66 meter (2.16 feet) wide and 0.66 meter (2.16 feet) deep, about the size of an average office desk. Panels are made of a core of aluminum honeycomb, with outer layers of graphite fibers and polycyanate face sheets. With its two parallel solar panels deployed, the spacecraft takes on the shape of a letter H. There are three dedicated science packages on Stardust -- the two-sided Dust Collector, the Comet and Interstellar Dust Analyzer, and the Dust Flux Monitor. Science data are also being obtained without dedicated hardware. The navigation camera, for example, provides images of its cometary target for both targeting accuracy and scientific analysis.

## Propulsion System

The Stardust spacecraft needs only a relatively modest propulsion system because of its carefully designed trajectory, which included three loops around the sun with flybys of Earth, comet Wild 2 and an asteroid, plus its return to Earth after the comet flyby.

The spacecraft is equipped with two sets of thrusters that use hydrazine as a monopropellant. Eight larger thrusters, each of which puts out 4.4 newtons (1 pound) of thrust, are used for trajectory correction maneuvers (changing the spacecraft's orbit). Eight smaller thrusters producing 0.9 newton (0.2 pound) of thrust each are used to control the spacecraft’s attitude, or orientation. The thrusters are in four clusters located on the opposite side of the spacecraft from the deployed aerogel. At launch, the spacecraft carried 85 kilograms (187 pounds) of hydrazine propellant.

## Attitude Control

The attitude control system manages the spacecraft’s orientation in space. Like most solar system exploration spacecraft, Stardust is three-axis stabilized, meaning that its orientation is held fixed in relation to space, as opposed to spacecraft that stabilize themselves by spinning.

Stardust determines its orientation at any given time using a star camera or one of two inertial measurement units, each of which consists of three ring-laser gyroscopes and three accelerometers. The spacecraft’s orientation is changed by firing thrusters. The inertial measurement units are needed only during trajectory correction maneuvers and during the fly-through of the cometary coma, when stars may be difficult to detect. Otherwise, the vehicle can be operated in a mode using only stellar guidance for spacecraft positioning. Two sun sensors serve as backup units, coming into play if needed to augment or replace the information provided by the rest of the attitude control system's elements.

**Command and Data Handling**

The spacecraft's computer is embedded in the spacecraft's command and data-handling subsystem, and provides computing capability for all spacecraft subsystems. At its heart is a RAD6000 processor, a radiation-hardened version of the PowerPC chip used on some models of Macintosh computers. It can be switched between clock speeds of 5, 10 or 20 megahertz. The computer includes 128 megabytes of random-access memory (RAM); unlike many previous spacecraft (but common today), Stardust does not have an onboard tape recorder but instead stores data in its RAM for transmission to Earth. The computer also has 3 megabytes of programmable memory that can keep stored data even when the computer is powered off.

The spacecraft uses about 20 percent of the 128 megabytes of data storage for its own internal housekeeping. The rest of the memory is used to store science data and for computer programs that control science observations. Memory allocated to specific instruments includes about 75 megabytes for images taken by the navigation camera, 13 megabytes for data from the comet and interstellar dust analyzer, and 2 megabytes for data from the dust flux monitor.

**Power**

Two solar array panels affixed to the spacecraft were deployed shortly after launch. Together they provide 6.6-square meters (7.9-square yards) of solar collecting area using high-efficiency silicon solar cells. One 16-amp-hour nickel-hydrogen battery provides power when the solar arrays are pointed away from the sun and during peak power operations.

**Thermal Control**

Stardust's thermal control subsystem uses louvers to control the temperature of the inertial measurement units and the telecommunications system's solid-state power amplifiers. Thermal coatings and multilayer insulation blankets and heaters are used to control the temperature of other parts of the spacecraft.

**Telecommunications**

Stardust is equipped with a transponder (radio transmitter/receiver), originally developed for NASA's Cassini mission to Saturn, as well as a 15-watt radio frequency solid-state amplifier. Data rates will range from 40 to 33,000 bits per second.

During cruise, communications are mainly conducted through the spacecraft's medium-gain antenna. Three low-gain antennas are used for initial communications near Earth and to receive commands when the spacecraft is in nearly any orientation.

A 0.6-meter-diameter (2-foot) high-gain dish antenna is used primarily for communication following comet encounter. The antenna is fixed to the “top” of the spacecraft body. Stardust will use the high-gain antenna to transmit images of the comet, as well as data from the Comet and Interstellar Dust Analyzer and the Dust Flux Monitor, at a high data rate to minimize the transmission time and the risk of losing data during the extended time that would be required to transmit the data through the medium-gain antenna. Most data from the spacecraft will be received through the Deep Space Network’s 34-meter-diameter (112-foot) ground antennas, but the network's 70-meter (230-foot) antennas will also be used during some critical telecommunications phases, such as when Stardust transmits science data during and after comet encounter.

**Redundancy**

Virtually all spacecraft components are redundant, with critical items “cross-strapped” or interconnected so that they can be switched in or out most efficiently. The battery includes an extra pair of cells. Fault protection software is designed so that the spacecraft is protected from commonly known faults without unnecessarily putting the spacecraft into a safe mode due to unanticipated but probably benign glitches.

**Whipple Shields**

The shields that protect Stardust from the blast of cometary particles is named for American astronomer Dr. Fred L. Whipple, who in 1950 developed the “dirty snowball” model of the cometary nucleus as a mixture of dark organic material, rocky grains and water ice. Whipple also came up with the idea of shielding spacecraft from high-speed collisions with the bits and pieces from comets and asteroids that are ejected as they circle the sun.

The system includes two bumpers at the front of the spacecraft, which protect the solar panels, and another shield protecting the main spacecraft body. Each of the shields is built around composite panels designed to disperse particles as they impact, augmented by blankets of a ceramic cloth called Nextel that further dissipate and spread particle debris. The Whipple Shield was designed to protect Stardust from impacts of comet fragments as large as 1 centimeter (about 0.4 inch).

**Science Instruments**

**Comet and Interstellar Dust Analyzer**

The instrument is what scientists call a “time-of-flight” mass spectrometer, which separates the masses of ions by comparing differences in their “flight times”. When a dust particle hits the instrument’s target, the impact creates ions, which are extracted from the particle by an electrostatic grid. Depending on the polarity of the target, positive or negative ions can be extracted. As extracted ions move through the instrument, they are reflected and then detected. Heavier ions take more time to travel through the instrument than lighter ones, so these flight times of the ions can be used to calculate their masses. From this information, the ion’s chemical identification can be made. In all, the instrument consists of a particle inlet, a target, an ion extractor, a mass spectrometer and an ion detector. The Co-Investigator in charge of the comet and interstellar dust analyzer is Dr. Jochen Kissel of the Max-Planck-Institut für Extraterrestrische Physik, Garching, Germany. The instrument was developed and fabricated by von Hoerner & Sulger GmbH, Schwetzingen, Germany, under contract to the German Space Agency and the Max-Planck-Institut. Software for the instrument was developed by the Finnish Meteorological Institute, Helsinki, Finland, under subcontract to von Hoerner & Sulger.

**Dust Flux Monitor**

The dust flux monitor measures the size and frequency of dust particles in the comet's coma. The instrument consists of two film sensors and two vibration sensors. The film material responds to particle impacts by generating a small electrical signal when penetrated by dust particles. The mass of the particle is determined by measuring the size of the electrical signal its impact generates. The number of particles is determined by counting the number of signals. By using two film sensors with different diameters and thicknesses, the instrument provides data on what particle sizes were encountered and the overall size distribution of the particles.

The two vibration sensors are designed to provide similar data for larger particles, and are installed on the Whipple shields that protect the spacecraft's main bus. These sensors detect the impact of large comet dust particles that penetrate the outer layers of the shield. This system, essentially a particle impact counter, will give mission engineers information about the potential dust hazard as the spacecraft flies through the coma environment. The Co-Investigator in charge of the dust flux monitor is Dr. Tom Economou of the University of Chicago, where the monitor was developed.

**Navigation Camera**

Stardust's navigation camera is an amalgam of flight-ready hardware left over from other NASA solar system exploration missions. The main camera is a spare wide-angle unit left over from the two Voyager spacecraft missions launched to the outer planets in 1977. The camera uses a single clear filter, thermal housing, and spare optics and mechanisms. For Stardust, designers added a thermal radiator.

Combined with the camera is a modernized sensor head left over from the Galileo mission to Jupiter launched in 1989. The sensor head uses the existing Galileo design updated with a 1024-by-1024-pixel array charge-coupled device (CCD) from the Cassini mission to Saturn, but has been modified to use new miniature electronics. Other components originated for NASA's Deep Space 1 project.

During distant imaging of comet Wild 2's coma in 2003, the camera took pictures through a periscope in order to protect the camera's primary optics as the spacecraft enters the coma. In the periscope, light is reflected off mirrors made of highly polished metals designed to minimize image degradation while withstanding particle impacts. During the Wild 2 encounter in 2004, the comet's nucleus was tracked and 72 images were taken. This imaging process will be repeated at comet Tempel 1.

## Science

### Comet Tempel 1 – A History

Even before the Deep Impact and Stardust-NExT mission, comet Tempel 1 was already one of the most analyzed of the Jupiter-family comets. A Jupiter-family comet is one whose orbit has been modified by close passages to Jupiter and has an orbital period less than 20 years. With the completion of the Stardust-NExT flyby, comet Tempel 1 will be by far the most-scrutinized comet in history.

Tempel 1's orbit lies between the orbits of Mars and Jupiter. The comet orbits the sun every 5.5 years. The comet's orbital period has varied in the past and will do so in the future because of its close approaches with the planet Jupiter.

Tempel 1 is remarkably homogeneous in albedo, or reflectivity, and color. The surface is very dark, reflecting less than five percent of the sunlight that falls on it. Deep Impact identified very few places where water ice is exposed. The comet is oblate and irregular in shape. The nucleus size is 7.6 and 4.9 kilometers (4.7 and 3 miles) with an equivalent radius of about 3 kilometers (1.9 miles). The comet's period of rotation is about 41.85 hours.

Tempel 1 was first seen close up on July 4, 2005, when NASA's Deep Impact mission performed its encounter. The Deep Impact mission consisted of functionally two spacecraft: an impacting spacecraft, and a flyby spacecraft for observing the impact and relaying data from the impactor back to Earth. In reality the mission's impactor was "run over" by the comet at a closing speed of 37,100 kilometers per hour (23,000 miles per hour).

Deep Impact's impactor struck the nucleus obliquely and excavated a crater predicted to be in the range of 100 to 300 meters (328 to 984 feet) across. The crater was not directly observed by Deep Impact due to the large amount of fine dust ejected by the impact. The obscuring ejecta were dominated by particles in the diameter range from 1 to 100 micrometers (a single strand of hair usually has a diameter of 20 to 180 micrometers). The resulting ejecta cone appeared to remain attached to the comet's surface, indicating that formation of the crater was controlled by gravity rather than by material strength.

Deep Impact high-resolution images cover about 30 percent of the nucleus at less than 10 meters per pixel (about 33 feet per pixel). A region about 2 kilometers (1.3 miles) across was imaged at slightly better resolution by the impactor camera shortly before it impacted there.

The nucleus images reveal several regions of distinct morphology, suggesting considerable variation in exposed materials, geologic processes and ages. Two different areas display several dozen apparently circular features, ranging from 40 to 400 meters (131 to 1,312 feet) in diameter. Although the size distribution of these features is consistent with that of an impact crater population, whether these features are indeed impact craters or sublimation pits remains uncertain.

Two regions of smooth surface were revealed by Deep Impact images. Both smooth areas are in gravitational lows. The smoothness is reminiscent of the plateau seen on comet Borrelly, but the surroundings are different. There is circumstantial evidence that the smooth deposits may be associated with either recent or currently active regions on the nucleus.

**Stardust-NExT Science Objectives**

The purpose of the Stardust-NExT mission is to expand the knowledge of comets by flying a spacecraft through the coma of comet Tempel 1 and imaging its nucleus. It is a low-cost mission that will expand the investigation of comet Tempel 1 initiated by Deep Impact in 2005, and, for the first time, assess the changes in the surface of a comet between two successive orbits around the sun. Stardust-NExT will also provide important new information on how Jupiter-family comets evolve and how they were put together.

Stardust-NExT also provides NASA with a unique opportunity to study two entirely different comets with the same instrument. By doing this, scientists will be able to more accurately compare its existing data set.

On February 14, 2011, at a projected distance of 200 kilometers (124 miles), the Stardust-NExT spacecraft will obtain high-resolution images of the coma and nucleus, as well as measurements of the composition, size distribution and density of dust emitted into the coma. Additionally, Stardust-NExT will update the data gathered in 2005 by the Deep Impact mission on the rotational phase of the comet.

**The official primary science objectives of the mission are as follows:**

- To extend our understanding of the processes that affect the surfaces of comet nuclei by documenting the changes that have occurred on comet Tempel 1 between two successive perihelion passages, or orbits around the sun.
- To extend the geologic mapping of the nucleus of Tempel 1 to elucidate the extent and nature of layering, and help refine models of the formation and structure of comet nuclei.
- To extend the study of smooth flow deposits, active areas and known exposure of water ice.

**Other Science Objectives:**

- If possible, to characterize the crater produced by Deep Impact in July 2005, to better understand the structure and mechanical properties of cometary nuclei and elucidate crater formation processes on them.
- Measure the density and mass distribution of dust particles within the coma using the Dust Flux Monitor Instrument instrument.
- Analyze the composition of dust particles within the coma using the Comet and Interstellar Dust Analyzer instrument.

The main objective of the experiment is to obtain high-resolution images to address mission goals. At the nominal flyby distance of 200 kilometers (124 miles), high-resolution imaging of the nucleus at scales as fine as 12 meters (39 feet) per pixel will be obtained. Coma and jet imaging may also be obtained on departure.

Many features of interest seen in the Deep Impact images, such as layers, flows, active areas and exposed ice, have details of interest at spatial scales that are equal to or smaller than 200 meters (660 feet) across.

**Imaging the Deep Impact Generated Crater**

A secondary science objective of the mission is to image, if possible, the Deep Impact crater with sufficient spatial resolution to determine its size, shape, degree of layering and ejecta pattern. Such an achievement would be an added bonus to the huge amount of data that mission scientists expect to obtain. Imaging the crater generated by Deep Impact requires that the comet's face, which includes the crater, be in sunshine and facing the spacecraft during encounter. If this occurs, and the crater is imaged, the observation would be the first ever of a crater created by a human-made impact on a cometary surface.

Imagery obtained of the Deep Impact crater could provide scientists with a better characterization of the surface material that composes comet Tempel 1. The morphology of the crater may provide evidence of surface layering. The form, extent and visibility of the impact ejecta blanket could provide a benchmark for identifying impact craters and ejecta blankets on cometary surfaces, and improve understanding of their material properties. Observations of the crater ejecta would also show what relatively fresh, excavated sub-surface material looks like compared to older surfaces on the comet.

To image the Deep Impact-generated crater requires comet Tempel 1 to put its best face forward during time of closest approach. Conversely, if the imagery from the flyby reveals a different face of Tempel 1 -- the side that does not include the crater generated during the Deep Impact mission -- scientists will be able to further extend the geologic mapping of the comet's nucleus and obtain a better understanding of the formation and structure of comet nuclei surface features.

**Stardust-NExT Science Team**

| Team Member Name | Affiliation | Role and Responsibilities |
|---|---|---|
| Veverka, J. | Cornell | Principal investigator. Imaging science lead. Nucleus geology. Outreach supervisor. |
| Klaasen, K. | JPL | Deputy principal investigator. Camera performance and calibration. |
| A'Hearn, M. | Maryland | Coma modeling, jet and outburst activity. Archiving. Ground-based observing. |
| Belton, M. | Belton Space Exploration Initiatives | Interpretation of nucleus imaging. Jets and other active regions. Determination of nucleus rotation state. Ground based observing. |
| Brownlee, D. | Washington | Interpretation of dust data from DFMI and CIDA. |
| Chesley, S. | JPL | Comet ephemeris and spin state updates. |
| Clark, B. | LMSS | Interpretation of dust counter (DFMI) and dust analyzer (CIDA) data. Assessment of coma dust models. |
| Economou, T. | Chicago | Dust counter lead, responsible for overall implementation of DFMI investigation and for analysis, interpretation, and PDS delivery of DFMI data. |
| Farquhar, R. | Kinetx | Consultant on comet ephemeris and trajectory analysis. |
| Green, S. | Open University, (U.K.) | Interpretation of dust counter data |
| Groussin, O. | LAM (Marseille) | Imaging science, active region studies. Imager calibration. |
| Harris, A. | Space Science Institute | Comet Rotation State and Activity |
| Kissel, J. | Max Planck | CIDA consultant (retired). |
| Mäkinen, T. | Finnish Meteorological Institute | CIDA lead, responsible for the overall implementation of the CIDA investigation and for the analysis, interpretation, and PDS delivery of CIDA data. |
| Meech, K. | Hawaii | Observing Campaign Coordinator. |
| Melosh, J. | Purdue | Cratering mechanics interpretation. |
| Richardson, J. | Purdue | Crater mechanics, ejecta ballistics. |
| Schultz, P. | Brown | Cratering mechanics interpretation. |
| Silén, J. | Finnish Meteorological Institute | CIDA consultant. |
| Sunshine, J. | Maryland | Interpretation of imaging data for the nucleus |
| Thomas, P. | Cornell | Geodesy and shape modeling from imaging. Production of geologic maps. Stereo analysis of images. |

**Comets - an Overview**

Though frequently beautiful, comets historically have stricken terror as often as they have generated wonder as they arc across the sky during their passages around the sun. Astrologers interpreted the sudden appearances of the glowing visitors as ill omens presaging famine, flood or the death of kings. Even as recently as the 1910 appearance of Halley's Comet, entrepreneurs did a brisk business selling gas masks to people who feared Earth's passage through the comet's tail.

In the 4th century B.C., the Greek philosopher Aristotle concluded that comets were some kind of emission from Earth that rose into the sky. The heavens, he maintained, were perfect and orderly; a phenomenon as unexpected and erratic as a comet surely could not be part of the celestial vault. In 1577, Danish astronomer Tycho Brahe carefully examined the positions of a comet and the moon against the star background using observations of the comet made at the same time from two different locations, Tycho noted that both observers saw the comet nearly in the same location with respect to the background stars. If the comet was closer than the moon, this would not have been the case. This so-called parallax effect can be demonstrated if you hold up a finger and look at it while closing one eye and then the other. Tycho concluded that the comet was at least six times farther away than the moon.

A hundred years later, the English physicist Isaac Newton established that a comet appearing in 1680 followed a nearly parabolic orbit. The English astronomer Edmond Halley used Newton's method to study the orbits of two dozen documented cometary visits. The orbits of three comets seen in 1531, 1607 and 1682 were so similar that he concluded they in fact were appearances of a single comet wheeling around the sun in a closed ellipse every 75 years or so. He successfully predicted the next visit in 1758-9, and the comet thereafter bore his name.

Since then, astronomers have concluded that some comets return relatively frequently, in intervals ranging from 3 to 200 years; these are called "short-period" comets. Others have enormous orbits that bring them back only once in hundreds of millennia.

In the mid-1800s, scientists also began to turn their attention to the question of comets' composition. Astronomers noted that several major meteor showers took place when Earth passed through the known orbits of comets, leading them to conclude that the objects are clumps of dust or sand. By the early 20th century, astronomers studied comets using the technique of spectroscopy, breaking down the color spectrum of light given off by an object to reveal the chemical makeup of the object. They concluded that comets also emitted gases and molecular ions in addition to the grains of dust.

In 1950, the American astronomer Fred L. Whipple (1906-2004) authored a major paper proposing what became known as the "dirty snowball" model of the cometary nucleus. This model pictures the nucleus as a mixture of dark organic material, rocky grains and water ice. ("Organic" means that the compound is based on carbon and hydrogen, but is not necessarily biological in origin.) Most nuclei of comets range in size from about 1 to 10 kilometers (1/2 to 6 miles) in diameter.

If comets contain icy material, they must originate and reside somewhere much colder than the relatively warm inner solar system. In 1950, the Dutch astronomer Jan Hendrik Oort (1900-1992) used indirect reasoning from observations to predict the existence of a vast cloud of comets orbiting many billions of miles from the sun -- perhaps 50,000 astronomical units (AU) away (one AU is the distance from Earth to the sun), or nearly halfway to the next nearest star. This region has since become known as the Oort Cloud.

A year later, the Dutch-born American astronomer Gerard Kuiper (1905-1973) pointed out that there should be comet-like objects remaining in the outer planetary region after the solar system formation process was complete. He suggested the existence of a belt of dormant comets lying just outside the orbits of the planets at perhaps 30 to 100 AU from the sun; this has become known as the Kuiper Belt. (Other astronomers such as Frederick Leonard and Kenneth Edgeworth also speculated about the existence of such a belt in the 1930s and 1940s, and so the region is sometimes referred to as the Edgeworth-Kuiper Belt, the Leonard-Edgeworth-Kuiper Belt, and so on.)

The Kuiper Belt is now known to be the source of those comets with relatively short orbital periods about the sun. Close encounters with other dormant comets sometimes change their orbits so that they venture in toward the sun and fall under the influence of the gravities of the giant outer planets -- first Neptune, then Uranus, then Saturn and finally Jupiter.

The Oort Cloud, by contrast, would be the home of long-period comets. They are periodically nudged from their orbits by any one of several influences -- perhaps the gravitational pull of a passing star or giant molecular cloud, or tidal forces of the Milky Way Galaxy.

In addition to the length of time between their visits, another feature distinguishes short- and long-period comets. The orbits of short-period comets are all fairly close to the ecliptic plane, the plane in which Earth and most other planets orbit the sun. Long-period comets, by contrast, dive inwards toward the sun from virtually any part of the sky. This suggests that the Kuiper Belt is a relatively flat belt, whereas the Oort Cloud is a three-dimensional sphere surrounding the solar system.

Where did the Oort Cloud and Kuiper Belt come from? Most astronomers now believe that the vast majority of material that became comets condensed in the outer solar system around the orbits of Uranus and Neptune and beyond. Gravitational effects from those giant planets flung some of the comets outward to the Oort cloud, while the comets in the Kuiper Belt may have remained there.

Residing at the farthest reaches of the sun's influence, comets did not undergo the same heating as the rest of the objects in the solar system, so they retain, largely unchanged, the original composition of solar system materials. As the preserved building blocks of the outer solar system, comets offer clues to the chemical mixture from which the planets formed some 4.6 billion years ago.

The geologic record of the planets shows that, about 3.9 billion years ago, a period of heavy cometary and asteroidal bombardment tapered off. The earliest evidence of life on Earth dates somewhere between 3.5 and 3.9 billion years ago, just after the end of this heavy bombardment. The constant barrage of debris had vaporized any water on Earth, leaving the planet too hot for the survival of the fragile carbon-based molecules upon which life is based.

Scientists therefore wonder: How could life form so quickly when there was so little liquid water or carbon-based molecules on Earth's surface? The answer may be that comets, which are abundant in both water and carbon-based molecules, delivered essential ingredients for life to begin.

Comets are also at least partially responsible for the replenishment of Earth's oceans after the vaporization of an early ocean during the late heavy bombardment. While Earth has long been regarded as the "water planet," it and the other terrestrial planets (Mercury, Venus and Mars) are actually poor in the percentage of water ice and in carbon-based molecules they contain when compared to objects that reside in the outer solar system at Jupiter's orbit or beyond. Comets are about 50 percent water by weight and about 10 to 20 percent carbon by weight. It has long been suspected that what little carbon and water there is on Earth was delivered here by objects such as comets that came from a more water-rich part of the solar system.

While comets are a likely source for life's building blocks, they have also played a devastating role in altering life on our planet. A comet or asteroid is credited as the likely source of the impact that changed Earth's climate, wiped out the dinosaurs and gave rise to the age of mammals 65 million years ago.

Comet dust is not considered to be a threat because it is a natural component of our environment. More than 30,000 tons of comet dust falls to Earth every year. In a single day, the land area of the state of California theoretically collects a billion times as many 10-micron cometary particles as the Stardust mission returned. This flux of outer solar system material has occurred for billions of years and may have even played a role in the evolution of life on our planet by bringing necessary organic compounds to Earth.

## Other Comet Missions

Comets have been studied by several spacecraft, not all of which were originally designed for that purpose. Several new missions to comets are being developed for launch in coming years.

Other past and present cometary missions include:

**Missions to Comets**

| **Encounter Date(s)** | **Mission** | **Agency** | **Comet(s)** |
|---|---|---|---|
| Dec. 15, 1984 | Vega 1 | USSR | Halley |
| Dec. 21, 1984 | Vega 2 | USSR | Halley |
| September 11, 1985<br>March 28, 1986 | International Cometary Explorer | NASA | Giacobini-Zinner (1985)<br>Halley (1986) |
| March 13, 1986 July 10,1992 | Giotto | ESA | Halley (1986) Grigg-Skjellerup (1992) |
| March 11, 1986 | Sakigake | JAXA | Halley |
| March 8, 1986 | Suisei, | JAXA | Halley |
| Sept. 22, 2001 | Deep Space 1 | NASA | Borrelly |
| Jan. 2, 2004 | Stardust | NASA | Wild 2 |
| July 4, 2005 | Deep Impact | NASA | Tempel 1 |
| Nov. 4, 2010 | EPOXI | NASA | Hartley 2 |
| Feb. 14, 2011 | Stardust-NExT | NASA | Tempel 1 |
| Nov. 2014 | Rosetta | ESA | 67P/Churyumov-Gerasimenko |

## Program/Policy Management

Stardust’s principal investigator is Joe Veverka of Cornell University, Ithaca, N.Y.
Ken Klaasen of NASA’s Jet Propulsion Laboratory, Pasadena, Calif., is deputy principal investigator.

The Stardust-NExT mission is managed by the Jet Propulsion Laboratory, Pasadena, Calif., for NASA's Science Mission Directorate, Washington. At NASA Headquarters, Ed Weiler is associate administrator for the Science Mission Directorate. Jim Green is director of the Planetary Science Division, Lindley Johnson is Stardust-NExT program executive, and Michael Kelley is program scientist. Dennon Clardy is the manager of the Discovery/New Frontiers Program office and Brian Key is the program office mission manager.

At JPL, Tim Larson is project manager. Don Sweetnam is deputy program manager, and Al Nakata is mission manager. JPL is a division of the California Institute of Technology in Pasadena.

Lockheed Martin Space Systems in Denver designed, built and operates the Stardust spacecraft. Allan Cheuvront is the company’s Stardust program manager and leads the Stardust flight team.