Countdown to Encounter

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stardust

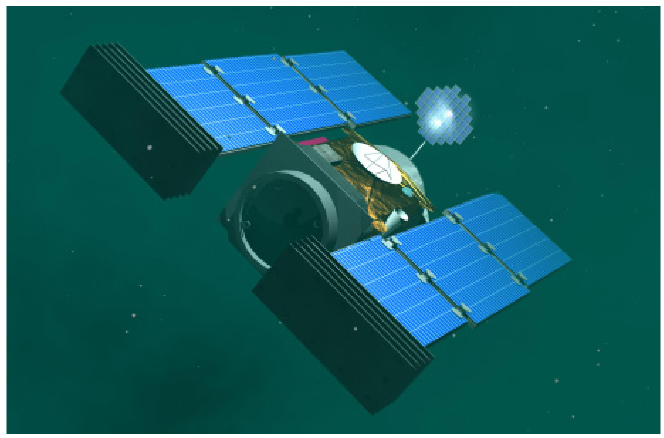
NASA's First Comet Mission
Stardust on the Internet — http://stardust.jpl.nasa.gov

Stardust Teams Prepare for Encounter

SHYAM BHASKARAN, JET PROPULSION LABORATORY

Stardust is the first U.S. mission dedicated solely to a comet. Stardust's main objective is to capture and return to Earth samples from comet Wild 2. The encounter with Wild 2 is January 2, 2004, and samples will be returned on January 15, 2006.

As the encounter with comet Wild 2 nears, the Stardust flight team becomes correspondingly busier with preparation activities. Between critical events, the flight team has only limited contact with the spacecraft, but as the encounter nears, contact will increase. The trajectory of the spacecraft will be more closely watched to ensure we are in the correct path of comet Wild 2. The camera will start imaging the comet so that the navigation team will have accurate information with which to aim the flyby.



Operational Readiness Tests

In addition to monitoring the spacecraft, the most important activity involves a multitude of tests. Foremost among these are Operational Readiness Tests, or ORTs for short. ORTs are exercises that simulate various operations and procedures during critical events close to the encounter.

Similar to what an airline pilot does during training, realistic data and situations are simulated by a test director and fed to the teams. The data are generated based on a "truth" model of the universe, which only the director knows. The teams execute their respective processes just as they would in a real flight situation. For example, the navigation team receives tracking data and uses the information to compute maneuvers that would guide the spacecraft to its flyby target. The navigation team sends the information to the spacecraft flight team at Lockheed Martin Space Systems in Denver, Colorado; that team builds the appropriate sequences and products that would be sent to the spacecraft to execute the maneuver. Because only the test director knows the "truth" trajectory of the spacecraft, he or she can apply the commanded maneuvers to the truth model and determine where the spacecraft flew by the comet. When the test is over, the director provides feedback to the teams on how closely the truth matched what the team thought was happening. The test procedures are timed and evaluated on whether interfaces between the teams were handled properly. Thus many critical events can be tested beforehand so the teams are prepared for them when they happen in real life.

Despite the very intense schedule that accompanies important events, this is an exciting time. This is where years of preparation finally pay off, and the rewards of a successful encounter invariably make the huge effort needed to carry out such a complex series of events very much worth it!

Origins of the Stardust Mission

PETER TSOU, JET PROPULSION LABORATORY

Why Stardust? Stardust is the first U.S. mission dedicated to traveling to a comet and returning samples from the coma — the cloud of dust and gas surrounding the comet's nucleus — for study. For the last three decades, analyses of interplanetary dust particles and meteoritic samples have demonstrated that key information about the solar system is retained at the submicron level of these samples. This "space paleontology" is not possible with astronomical or remote-sensing instruments. Stardust will act as a space paleontologist and will help to

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STARDUST Mission

unlock the detailed records of cosmic history. Interplanetary dust particles are believed to contain the elemental, chemical, isotopic and mineralogical composition of tiny components from comet Wild 2. Stardust will provide context with samples from newly discovered contemporary interstellar grains.

The Stardust spacecraft was launched on February 7, 1999, from Cape Canaveral, Florida.

Our Pursuit of a Comet Mission

Comets offer a unique opportunity for combining an initial flyby mission with a sample return, since their comas comprise fresh material ejected from their nuclei.

The first comet coma sample return proposal evolved into a Halley Earth Return mission carrying only a sample collector and a camera. However, the U.S. ultimately decided against participating in the international armada of spacecraft launched to study comet Halley on the comet's swing past the Sun in 1986.

In the early 1990s, NASA developed the Comet Rendezvous and Asteroid Flyby Mission (CRAF), a nine-year journey by a spacecraft that would fly alongside a comet and encounter an asteroid. When CRAF was cancelled in 1992, the European Space Agency, which was developing the Rosetta mission, altered Rosetta's objectives from comet nucleus sample return to CRAF-like goals. At the same time, Japan's ISAS moved from their Sample of Comet Coma for Earth Return (SOCCER) mission to one that would study an asteroid, called Muses-C and later renamed Hayabusa ("falcon"). These and other pivotal programmatic developments moved the pursuit of a comet coma sample return mission back to NASA. Stardust's objectives changed in 1994 from an interstellar-focused NASA Discovery sample return proposal to a mission targeting comet coma sample return.

A Comet Mission Is Born

Extensive laboratory experimentation, Earth orbital flights of the intact capture experiments and the introduction of silica aerogel as the dust-capture medium generated both excitement and acceptance in the planetary science community for a comet coma sample return mission. These factors enabled the selection of Stardust as the first openly competed, fourth NASA Discovery mission — it was our thirteenth flight mission proposal.

The development of the seven-year trajectory to comet Wild 2 is another enabling factor for Stardust. Back in 1984, a systematic all-sky search of comet coma sample return opportunities yielded few attractive comets with encounter speeds low enough (less than 15 kilometers, or about 9 miles, per second) to permit intact capture of the particles. For Stardust, all science and program imperatives were met in one remarkable trajectory: a dusty "fresh" comet with centuries of history, a suitably low comet encounter speed (as low as 5.4 kilometers, or 3.4 miles, per second), only small velocity changes needed (reducing the amount of fuel the spacecraft had to carry and thus lowering the payload mass) and a spacecraft of appropriate size and mass capable of being launched by a medium-sized rocket, the Boeing Delta II. The Stardust trajectory also incorporated an asteroid encounter (asteroid Annefrank), plus three interstellar dust collection opportunities.

Pictures from Space

RAY NEWBURN & KEN WILLIAMS,
JET PROPULSION LABORATORY

Stardust is carrying an imaging camera that is used primarily for approach navigation but will also provide secondary science about the size and shape of Wild 2's nucleus. During an engineering readiness test, the Stardust flight team took an opportunity to perform an engineering test on asteroid 5535, also known as Annefrank. The camera provided useful scientific data about the asteroid that will add to our growing knowledge of small bodies.

Following the "better, faster, cheaper" paradigm that guides Discovery-class missions, the camera is a hybrid of new and old. The lens, filter wheel and shutter are spare components from the Voyager spacecraft, and the charge-coupled device (CCD) is a Cassini spacecraft spare. Additional components are new but have inherited designs, such as the compressor (Cassini), the scan mirror motor and electronics (Mars Pathfinder) and the CCD drivers.

The Approach to Wild 2

As Stardust begins its approach toward comet Wild 2, a series of images, or snapshots, of the comet will be taken at intervals of about half a week, then daily within 30 days of arrival, then three times daily within 10 days, then hourly for the last three days.

Based on these collective images, the targeting of the spacecraft will be adjusted to arrive at a distance of 300 kilometers (186 miles) from the center of the comet body on January 2, 2004, at the time of closest approach. This targeting will be accomplished by using the spacecraft's 16 thrusters to perform a series of course corrections known as trajectory correction maneuvers, or TCMs.

The "Croquet" Gambit

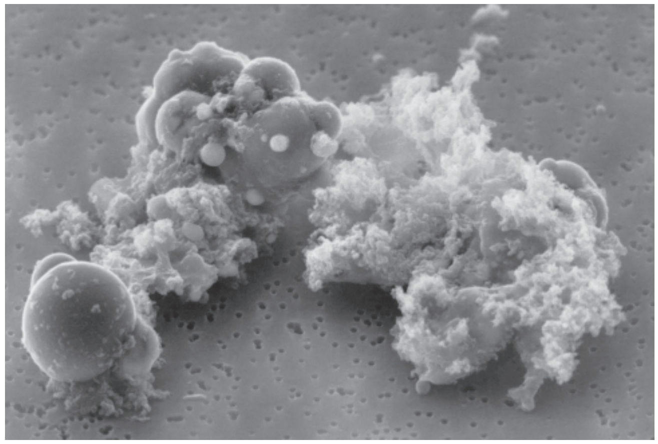
The approach strategy, with TCMs performed at 30 days, 10 days, two days and then 18 hours before the time of closest approach, is analogous to a game of croquet. The goal in croquet is to hit the ball through the wicket with a mallet and ultimately reach an end stake. The player lines up a series of shots by viewing the location of the wicket and hits the ball in the direction of this target. The first hit from relatively far away is used to set up the next hit, which is closer to the goal, and so on, until a final hit easily knocks the ball through the wicket.

A similar approach is used during Stardust's approach to the comet. With each successive TCM, the uncertainty in targeting is reduced from several hundred kilometers to fall within a circular area of 15–20 kilometers (about 9–12 miles) radius about the final target point, based on an evaluation of the accumulated images using a process known as optical navigation.

In this way, Stardust passes close enough to the comet to collect sufficient dust samples, as well as take close-up images of the comet nucleus. This is Stardust's way of "passing through the wicket" with the goal of ultimately returning the samples to the "end stake" (Earth) in January 2006.

The Dust Flux Monitoring Instrument

TOM ECONOMOU, UNIVERSITY OF CHICAGO



Microscopic comet and interstellar dust particles collected by Stardust will be returned to Earth in January 2006. The samples will be taken to the planetary material curatorial facility at NASA's Johnson Space Center in Houston for analysis.

Flying a spacecraft through the coma of a comet is a very scary thing. It is something like driving a car during a severe hailstorm, but several hundreds times worse — particles of many different sizes will fly out from the nucleus and hit the spacecraft at very high velocity. In the case of the Stardust encounter with comet Wild 2, this velocity is over 20,000 kilometers per hour (more than 13,000 miles per hour), which is a relatively low encounter speed.

Flying Through the Coma

The Stardust spacecraft is designed to fly through the coma of comet Wild 2 at a distance between 150 and 300 kilometers (between 93 and 186 miles), make scientific measurements and collect cometary and extrasolar dust particles and return them safely to Earth.

The Dust Flux Monitoring Instrument (DFMI) is designed to achieve several objectives and was provided to the Stardust project by the Laboratory of Astrophysics and Space Research of the University of Chicago, under the direction of Dr. Anthony Tuzzolino. The prime scientific objective of the DFMI is to carry out quantitative measurements of dust particle flux and particle mass distribution throughout the flyby of comet Wild 2. This information is fundamental for determining the physical processes of dust emission from the nucleus, the propagation of dust to form a coma and the formation of dust jets. The second objective of the DFMI is to use these data to assess spacecraft risk and health, and for correlation and interpretation of the laboratory analyses of dust captured by the aerogel dust collectors and returned to Earth.

Instrument Technical Details

The DFMI consists of two different dust-detector systems: a sensor unit consisting of two thin polyvinylidene fluoride (PVDF) foils, which measure dust particles with mass between 10^{-4} grams and 10^{-11} grams, and a dual acoustic sensor system (DASS), in collaboration with Open University, which utilizes two quartz piezoelectric accelerometers to measure the flux of dust particles with mass greater than 10^{-4} grams.

The DFMI instrument weighs only 1.7 kilograms (3.7 pounds), needs only 1.8 watts to operate, and imposes very few requirements on the spacecraft.

Mission Update

Allan Cheuvront, Spacecraft Engineer, Stardust Mission

From the Spacecraft Engineer

Have you ever wondered what it would be like to go to space? Maybe even dreamed of commanding your own spacecraft like Captain Kirk? Well, Stardust spacecraft engineer Allan Cheuvront did, as he takes a moment to reflect on his role working as a member of the Stardust mission team. "I remember, as a kid," Cheuvront said, "watching Echo as it orbited the Earth and wishing I could be there with it." Allan has worked at Lockheed Martin Space Systems in Denver, Colorado, for 23 years, working on the Magellan and Mars Global Surveyor missions. Still working for Lockheed, Cheuvront now plays another important role on the Stardust mission team.

My job description has the appearance of most people's grocery lists, but my role, with support from the operations team, is to test all encounter commands that will be sent to the spacecraft, perform necessary readiness training exercises and carry out a variety of other tasks related to "flying" the spacecraft.

One of the most exciting experiences for me is simply coming to work every day. I say this because I love what I'm doing and consider myself to have the best job in the company. Where else would I get to work with a group of very talented, smart engineers and fly a spacecraft that will encounter a comet and bring back dust and comet particles?

There have been several nerve-wracking times, like launch, recovering from safe mode, and the successful Annefrank flyby, but just flying the spacecraft is exciting in itself. When flying a spacecraft, the saying is that "boring is good." That's because when outsiders see the same routine being performed over and over, some might consider it boring. But to those of us who fly the spacecraft, routine operations are exactly what we want to see. By following the procedures and checklists, we help prevent the nerve-wracking times of a safe-mode event.

Needless to say, getting ready for encounter is an extremely busy time. It is my job to ensure that the activities are accomplished successfully. These activities include testing the Wild 2 encounter commands, performing readiness training exercises, providing status to management, implementing the approach optical navigation commands and trajectory correction maneuvers and demonstrating our readiness to a review board. The most time-consuming process is testing the Wild 2 encounter commands in the Spacecraft Test Laboratory (STL). The STL simulates the extreme conditions that can occur while inside the comet's coma and demonstrates the spacecraft's ability to survive and collect the science data.

I'm confident the Wild 2 encounter will be successful and the science data obtained will raise many more questions than it will answer. After the encounter, I will start focusing on returning the spacecraft and the sample return capsule to Earth. Once the encounter is performed successfully, we will have two years to prepare for the safe return of the dust particles.

STARDUST Mission Partners

- University of Washington — Dr. Don Brownlee, Principal Investigator
- Jet Propulsion Laboratory, California Institute of Technology — Thomas Duxbury, Project Manager
- Lockheed Martin Astronautics of Denver, Colorado — Joe Vellinga, Program Manager
- Boeing — Delta II Launch Vehicle
- Max-Planck-Institut, Germany, and the firm of von Hoerner & Sulger
- University of Chicago
- NASA Johnson Space Center

STARDUST Education Outreach Team

- Jet Propulsion Laboratory: Aimee Whalen, Ron Baalke, and Derek Blackway
- JPL Ambassadors Program
- JPL Solar System Educators Program

Outreach Programs

- Challenger Center for Space Science Education
- NASA's Space Place

National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

JPL 410-56-4 12/03

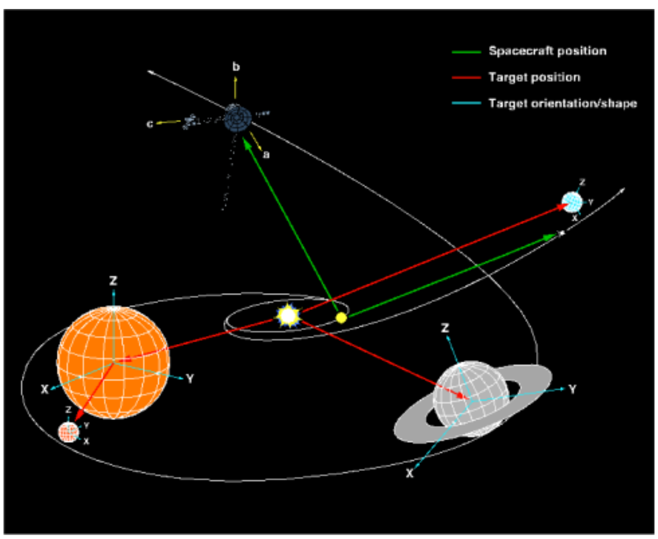
Getting Science Data to the Scientists

CHUCK ACTON, JET PROPULSION LABORATORY

The collection and return to Earth of particles from comet Wild 2 is the primary scientific goal of the Stardust mission. But the Stardust spacecraft also has some science instruments on board that will make important measurements about the comet. The digital data obtained from these instruments will be provided to scientists for analysis. In order to fully and correctly interpret these measurements, the scientists also need to know the observing geometry at the time the measurements were taken — engineering quantities such as the location of the spacecraft relative to the comet's nucleus and tail, and the direction to the Sun. It is the job of the Stardust Data Management and Archive (DM&A) team to accomplish these tasks.

The DM&A team writes and operates computer programs that gather the science and engineering data at the JPL mission control center, make sure that no data are missing, organize and package the data into electronic packages called computer files, and deliver them to the scientists for their analysis work.

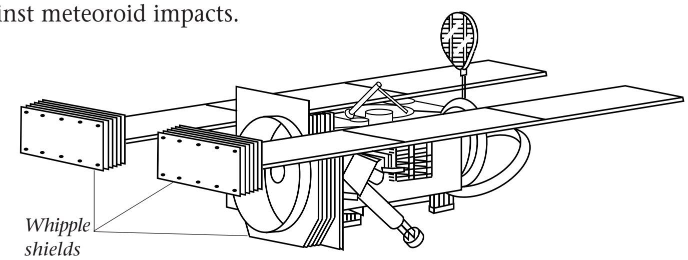
Another important job for the DM&A team is to carefully document and archive these data in NASA's Planetary Data System so that all scientists, as well as the public, can access and examine the data in the future.



To correctly interpret measurements made by a spacecraft's instruments, scientists need to know the observing geometry at the time the measurements were taken.

Whipple Shields: Stardust's Bullet-Proof Vest

In 1946, not many Americans were thinking about traveling through deep space — and even fewer were pondering the concerns of satellite safety. Enter Dr. Fred Whipple, an astronomer who was one of the few who not only thought about spaceflight, but also helped prepare the world for safety in space during the past decades. His designs of the Whipple shield helped revolutionize the way spacecraft travel through deep space as the shields help protect against meteoroid impacts.



A Meteor Bumper

Inventing what he called a "meteor bumper," which is popularly known as the "Whipple shield," for the military in 1946, the shield was designed so that a thin outer skin on a spacecraft explodes a striking meteoroid, allowing only gas to hit the real skin of the spacecraft without puncturing it. When Stardust — a mission designed specifically for capturing comet particles — was introduced, it seemed only fitting when two Whipple shields were incorporated into the design. "I was not surprised, because it's essential for space travel," said Dr. Whipple. Protecting spacecraft from crippling meteoroids was only a part of Dr. Whipple's career repertoire. He also headed the Harvard College Observatory observing program, invented an enemy radar-jamming device during World War II and discovered six comets as well.

The Dirty Snowball Model

Fred Whipple not only discovered comets, he helped define them. He believed that comets were made of ice and dust during a time when many other astronomers believed that comets were, "interplanetary gravel banks and not discrete bodies," Whipple said. His "dirty snowball" theory was validated, and comets are now known to be composed of ice and dust. Dr. Whipple has said he is "delighted that the Whipple shield is being used for Stardust. I am delighted with the idea of getting close to comets and learning about their detailed composition and detailed structural characteristics. Comets are the most primitive material of the solar system, and are vital to study the evolution of the solar system." With the help of Stardust, Whipple is "just waiting to find out more details about comets," and wants to learn more about the deuterium to hydrogen ratios of comets, as do many other scientists who share his enthusiasm about these bodies. "Knowing that so many other scientists are interested in comets too is a warm feeling for a guy who's 97 years old."

Dr. Fred Whipple is currently Professor of Astronomy Emeritus at Harvard University.