The Exploration of comet P/Wild 2 by STARDUST

T. Duxbury (Jet Propulsion Laboratory)

The NASA Discovery STARDUST Mission will fly by comet P/Wild 2 in January 2004 and return cometary dust particles to earth in January 2006. This is the first planetary sample return mission launched since the Apollo days. The STARDUST spacecraft is over half way on its voyage to P/Wild 2 and is carrying JPL Aerogel Dust Collector, the Max Planck Institute Cometary and Interstellar Dust Analyzer (CIDA), the University of Chicago Dust Flux Monitor Instrument (DFMI) and the JPL camera. Additionally, radio science and high rate attitude data will be taken within the comet coma. The aerogel collector has been deployed already to collect interstellar dust particles and will open again this summer for its second collection of interstellar dust particles. The camera had been contaminated with an unknown coating after launch that has since been successfully removed by heating the optics and CCD. The DFMI has a power problem that only allows the instrument to operate less than 1 hour before needing to be reset. However both CIDA and DFMI have made observations of interstellar dust during cruise and the camera has imaged the moon during an earth gravity assist flyby. Details of the remaining mission will be given.
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Solar System Planetary Missions

Exploration of Comet P/Wild 2
by STARDUST

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Technical University of Berlin
29 July 2002
• 4th NASA Discovery Project
  – Mars Pathfinder, NEAR, Lunar Explorer prior Missions
• 1st NASA Unmanned Planetary Sample Return Mission
• NASA, Univ of WA, JPL and LMA Partnership
• Prof. Donald Brownlee, University of Washington, PI
  – Co-I’s
    • Drs. Martha Hanner, JPL, Fred Horz, JSC,
    • Tony McDonald, UK, Scott Sandford, ARC,
    • Zdenek Sekanina, JPL, and Mike Zolensky, JSC
  – Co-I’s with Payload Instruments
    • Aerogel Collector - Dr. Peter Tsou, Deputy PI, JPL
    • CIDA - Dr. Jochen Kissel, MPI fur Kernphysik,
    • DFMI - Dr. Anthony J. Tuzzolino, U of Chicago
    • NavCam - Dr. Ray Newburn, JPL
    • Radio Science - Dr. John Anderson, JPL
    • High Rate Attitude - Dr. Benton Clark, LMA
Primary Requirement: Collect 1000 Comet particles >15 μm at encounter velocity < 6.5 km/sec and return to Earth

Secondary Requirements: Collect 100 Interstellar particles >0.1 μm and return to Earth.
Provide ≥ 65 images of P/Wild 2, having a resolution of at least 67 μrad per pixel, taken within 2000 km of the comet nucleus through selected filters;
Provide in situ particle analysis for comet coma flythrough capable of resolving abundant elements in cometary solids

Tertiary Requirements: Provide in situ particle analysis for interstellar and interplanetary dust;
Measure dust mass fluence, large particles and comet mass upper limit
Provide dust flux measurement of $10^{-9}$ g to $10^{-4}$ g particles
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Trajectory Overview

Comet Wild-2 Orbit

Earth Orbit

Launch 02/07/99

Earth Gravity Assist 01/15/01

Earth Return 01/15/06

Loop 1

Loops 2 & 3

Wild-2 Encounter 01/02/04

V_{inf} = 6.1 km/s
R_{sun} = 1.9 AU
R_{Earth} = 2.6 AU

Interstellar Particle Stream

Heliocentric Loops 1, 2, and 3
Feb 99-Jan 01-Jul 03-Jan 06

Interstellar Particle Collection
A-B: Feb-May 00, Jul-Dec 01

Deep Space Maneuvers
1: Jan 2000, 2: Mar 2002
3: Jul 2003, 4: Feb 2004

* second day of launch period
Loop 1: As Flown v. Plans

- **Planned Events**: Inner circle
- **Actual Events**: Outer circle

- TCM-4, NavCam Htg, L+667d, 12/5
- EGA, L+706d, 1/15
- Moon Images, L+709d, 1/16
- *Launch, L+0d, 2/7/99*
- DFM1 On, L+12d, 2/19
- CIDA On, L+15d, 2/22
- *Allstellar Safing, L+26d, 3/7*
- CIDA/DFM1 On, L+32d, 3/11
- NavCam Safing, L+40d, 3/19
- DFM1 On, L+44d, 3/23
- CIDA Operational, L+54d, 4/2
- SSPA Anomaly, L+65d, 4/13
- DFM1 Read Errs, L+71d, 4/19
- *Start CIDA-1, L+82d, 4/30*
- DFM1 Test/Off, L+88d, 5/6
- SRC Unlatched, L+95d, 5/13
- CIDA Reset, L+104-111d, 5/22-29
- *Start SSPA Cycling, L+134d, 6/21*
- HGA Checkout, L+137d, 6/24
- PACI Safing, End CIDA-1, L+160d, 7/17
- *PACI Safing, L+178d, 8/4*
- DFM1 Test/Off, CIDA On, L+218d, 9/13
- NavCam Images, L+143d, 6/30
- NavCam Images, L+150d, 7/7
- End CIDA-1, L+174d, 8/29
- NavCam Images, L+200d, 8/28
- NavCam Images, L+256d, 9/21
- PACI FSW Patch, L+278d, 11/12
- DFM1 Test/Off, CIDA On, L+304d, 10/1
- NavCam Images, L+336d, 10/12
- Alastellar Test, LGA Calibration, L+247d, 10/12
- DFM1 Test CIDA Off, C&DH-1GHz (for PACI)
- *NavCam Images, L+362d, 10/16-30*
- NavCam Images, L+544d, 8/16-22
- NavCam C&DH Hr On, L+556-562d, 8/16-22
- SSPA Anomaly, L+55d, 9/10
- *NavCam Images (solar flare), L+548d, 8/18*
- CIDA-1, L+56d, 9/26
- NavCam Images, L+607d, 1/15
- TCM-5, L+607d, 1/15
- *EGA, L+607d, 1/15*
- Moon Images, L+709d, 1/16
- EGA, E&M Images, L+706d, 1/15
- Imaging Mirror
- Imaging Mirror
- *Launch, L+0d, 2/7/99*
- DFM1 On, L+12d, 2/19
- CIDA On, L+15d, 2/22
- *Allstellar Safing, L+26d, 3/7*
- CIDA/DFM1 On, L+32d, 3/11
- NavCam Safing, L+40d, 3/19
- DFM1 On, L+44d, 3/23
- CIDA Operational, L+54d, 4/2
- SSPA Anomaly, L+65d, 4/13
- DFM1 Read Errs, L+71d, 4/19
- *Start CIDA-1, L+82d, 4/30*
- DFM1 Test/Off, L+88d, 5/6
- SRC Unlatched, L+95d, 5/13
- CIDA Reset, L+104-111d, 5/22-29
- *Start SSPA Cycling, L+134d, 6/21*
- HGA Checkout, L+137d, 6/24
- PACI Safing, End CIDA-1, L+160d, 7/17
- *PACI Safing, L+178d, 8/4*
- DFM1 Test/Off, CIDA On, L+218d, 9/13
- NavCam Images, L+256d, 10/21
LMA Spacecraft w/ SRC

CIDA not shown. Mounted on +y deck.
LGAs: 1 on +z deck, 2 on -z deck.
To collect the particles without damaging them, STARDUST will use an extraordinary substance called aerogel - a silicon-based solid with a porous, sponge-like structure in which 99 percent of the volume is empty space. Aerogel is 1,000 times less dense than glass, another silicon-based solid. When a particle hits the aerogel, it will bury itself in the material, creating a carrot-shaped track up to 200 times its own length, as it slows down and comes to a stop - like an airplane setting down on a runway and braking to reduce its speed gradually. Since aerogel is mostly transparent - sometimes called blue smoke - scientists will use these tracks to find the tiny particles.

Dr. Peter Tsou, Deputy PI
Dr. Jochen Kissel with CIDA

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DFM1 ACOUSTIC SENSORS LOCATION
SEE FIGURE 3.3.1.2-2

ACOUSTIC PLATE
SEE FIG. 3.3.1.2-2

DFM ELECTRONICS BOX LOCATION
SEE FIGURE 3.3.1.2-1C

DFM ELECTRONICS BOX LOCATION ELECTRONICS
SEE FIGURE 3.3.1.2-1C

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JPL CAMERA

CHARACTERISTICS
- 200 mm VGR WA Optics
- 1024 x 1024 Cassini CCD
- 60 μrad / pixel
- 1 Deg-of-freedom Mirror (200 deg)
- 8 Filters
  - 5140 ± 60 C₂ (Blue)
  - 5800 ± 20 Yellow Continuum
  - 5900 ± 1000 Hi Res (Nucleus)
  - 6340 ± 60 O[H]
  - 6650 ± 75 NH₂
  - 7000 ± 2000 Navigation
  - 7130 ± 30 Red Continuum
  - 8700 ± 150 Near IR
- Periscope - protect optics during approach

DURING FLYBY
- WILD 2 MIRROR TRACKING
- PERISCOPE
- MIRROR
- WHIPPLE SHIELD

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Nav Cam Cleanup

- Completed Nav Cam Heating Sequence #2
  - Removed 60% of Contamination
  - Additional Heating Under Study

PRE-LAUNCH

PRE-HEATING

POST-HEATING
STARDUST EARTH GRAVITY ASSIST

Flyby Attitude:
-41° off-sun
time tics: 10 min
to Moon
\[ 380,000 \text{ km}, 230,000 \text{ mi} \]

EGA Significant Events
TCM-4 Dec. 05, 2000 CIA-41 days
TCM-5 Jan. 05, 2001 CIA-10 days
Earth Flyby* Jan. 15, 2001 11:14:28 UTC
N Speed = 10.3 km/s [37,000 kph, 23,000 mph]
Altitude = 6007.6 km [3733.8 mi]
Long = 18.1° E

Moon Flyby* Jan. 16, 2001 02:02:20 UTC
C/A-30 days
Range = 97,797 km [60,781 mi]
Feb. 14, 2001 C/A+30 days

TRAJECTORY POLE VIEW

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EGA Close Flyby (Actual)

To Sun
To Ecliptic X-axis

Earth Gravity Assist

EGA ON 15 Jan 2001 03:15 am PST
Post EGA Lunar Images

- 21 Lunar & 4 Dark Current Images
  - Perfectly Exposed & Pointed
• ESA Mars Express Orbiter and Beagle 2 Lander
• Japanese Nozomi Mars Orbiter
• MGS and MS’01 Odyssey Orbital Operations at Mars
• STARDUST Wild 2 Encounter
• MER-A and MER-B Landings at Mars
• Deep Impact & Messenger Launches
• Cassini Gravity Wave / Solar Occultation Experiment
• Etc., etc.

• New Radiometric Data Type Delta DOR - reduces Nav Tracking
• 20 Kw transmitters at all 34 m BWG’s
• New 34 m Station at Madrid
Wild-2 Encounter Geometry

Closest approach: 01/02/2004 19:20:00 ET

- Radius: 2 km
- Approach Phase Angle: 73 deg
- 150 km Flyby on Sunside
- S/C Attitude: +x // Vinf, +z to Earth, +y out of page
- V_∞ = 6.12 km/s
- SPE angle: 17 deg
- Sun: 1.86 AU
- Earth: 2.60 AU
- XS

Earth is 16.7 degrees from XS and 1.9 degrees above the flyby plane. Vinf points 2.8 degrees below the ecliptic.

Wild-2 heliocentric speed is 26.4 km, s/c is 21.7 km/s.

Flyby plane coordinates (xₛ, yₛ, zₛ) defined by Vinf and Sun Vector.
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RELEASE OF PROJECT DATA to the PLANETARY DATA SYSTEM

Launch

Cruise 1

Earth Gravity Assist

Cruise 2

Wild 2 Encounter

Cruise 3

JPL NAIF-lead Data Management and Archive

PDS Delivery

#1 #2 #3 #4 #5 #6 #7 #8

1999 2000 2001 2002 2003 2004 2005 2006

Particles to be Delivered to JSC Office of Curation International Analysis Program will Follow

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Stardust will fly by Comet Wild 2 and, for the first time, return pristine samples of cometary materials to Earth for analysis by scientists worldwide.

**Education and Public Outreach Approach**
Stardust has established partnerships with numerous educational organizations and programs, museums, and science centers to provide opportunities for students, educators, and the general public to learn about small bodies and the mission.

- Challenger Center
- Virginia Space Grant Consortium
- NASA/JPL Ambassadors Program
- JASON Project
- Space Place for Kids
- From the Sun to the Star Nations: Native American Initiative
- Space Explorers, Inc.
- Parents and Children As Co-Travelers
- Omniplex at the Kirkpatrick Planetarium
- Young Astronaut Council
- United States Space Foundation

**“Think SMALL In A BIG Way”**
A comprehensive Educator’s Activity Guide for grades 5–8 focusing on asteroids, comets, and meteorites, the guide contains a dozen fun activities that are tied to mission events and correlated to national science education standards.

**“Be a Spacecraft Engineer”**
An educational program designed to excite and engage students in science and technology, this activity introduces students to elements of spacecraft design using the Stardust spacecraft and the International Space Station as examples.