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STARDUST: Comet and Interstellar Dust Sample Return Mission

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Abstract. STARDUST, a Discovery-class mission, will return intact samples of cometary dust and volatiles from comet P/Wild 2, as well as samples of the interstellar dust moving through the solar system. Dust capture utilizes aerogel, a microporous silica that is capable of intact capture of hypervelocity particles. A navigation camera, an *in situ* dust analyzer, and a dust flux monitor complete the payload. The Wild 2 flyby takes place in January 2004, with Earth return in January 2006.

1. Introduction

The STARDUST comet sample return mission, selected by NASA as the 4th Discovery mission, will capture an intact sample of cometary dust particles, in the 1 to 200 µm size range, and return them to Earth for elemental, isotopic, chemical, and mineralogical analysis. This is the primary objective of the mission. *In situ* measurements of the dust composition will also be obtained with CIDA, a dust mass spectrometer provided by Germany, and images of the nucleus at a resolution of ~10 meters will be acquired.

STARDUST capitalizes upon a 1974 Jupiter deflection which reduced the perihelion distance of comet P/Wild 2 from 5 AU to 1.49 AU. Thus, Wild 2 is a relatively "fresh" comet and can be expected to produce ample dust and volatiles for collection. The trajectory allows a relatively slow flyby speed of 6.1 km/s.

A stream of interstellar (IS) dust moving through the solar system parallel to the flow of interstellar gas has been discovered by the dust detectors on Ulysses and Galileo (Grün et al. 1993,1994). A second set of aerogel collectors will capture samples of this IS dust during the interplanetary cruise, and CIDA will also be used for *in situ* analysis. Thus, in a single mission, 5 billion year old IS dust retained in a comet and modern IS dust can be acquired for analysis.

The cometary and IS dust samples will be curated at the JSC Lunar Curatorial Facility and will be made available to the scientific community for analysis.

2. Instrument Payload

The sample collection medium will be low density aerogel (Tsou 1995), a material proven effective for intact capture of particles at speeds up to 10 km/s in the laboratory (Tsou 1990) and in Earth orbit (Tsou et al. 1993; Brownlee et al. 1994). Because the aerogel is transparent, the characteristic carrot-shaped tracks of the captured particles can be readily located. The aerogel will be mounted in capture cells in two panels mounted back-to-back, each with a total surface area of 0.1 m^2. The front panel will be exposed to the comet flux while the back panel will be exposed to the IS dust stream.

A cometary and IS dust analyzer, CIDA, to be provided by Germany's DARA, will measure the elemental composition of the dust during the flyby. This time of flight mass spectrometer is a modified version of the PUMA and PIA instruments successfully flown on the Vega and Giotto Halley missions (Kissel et al. 1986). It will sample the micron and submicron sized particles in the coma. Comparison of the data from CIDA with the returned samples will allow full definition of the dust composition from a few x 10^{-16} g to 10^{-5} g and a comparison with the PUMA/PIA Halley data. The lower impact speed at Wild 2 will favor the survival of molecular fragments that were not preserved during the Halley encounters.

Optical navigation is required for accurate targeting of the S/C relative to the comet nucleus. The navigation camera is a 1024 x 1024 CCD array with an instantaneous field of view of 0.08 milliradian per pixel. The camera will be used to acquire images of the nucleus with a resolution an order of magnitude better than the Giotto images of P/Halley. The camera remains fixed and a scan mirror tracks the nucleus during the flyby. A flyby at 100 km will allow best resolution < 10 m. During the approach to Wild 2, images of the inner coma will be obtained to monitor the dust and gas production rates.

3. Spacecraft Design

The S/C design is depicted in Fig.1. STARDUST utilizes the SpaceProbe deep-space bus under development at Lockheed Martin Astronautics. The sample return capsule is derived from the Viking capsule and studies that have been performed over the past several years under Mars Sample Return contracts. The aerogel capture cells are mounted in a sample tray that can be raised and lowered from the sample return capsule. The front surface of the aerogel will be perpendicular to the velocity vector during the comet flyby, while the rear surface samples will face the interstellar dust flux during the inbound leg of each orbit.

4. Mission Design

The spacecraft will be launched in February 1999 on board a Delta launch vehicle. An Earth gravity assist in January 2001 targets the S/C for the slow flyby of P/Wild 2 on January 1, 2004 at R=1.86 AU, 97 days after perihelion (Fig. 2). The nominal flyby distance of 100 km on the sunward side can be adjusted in-flight based

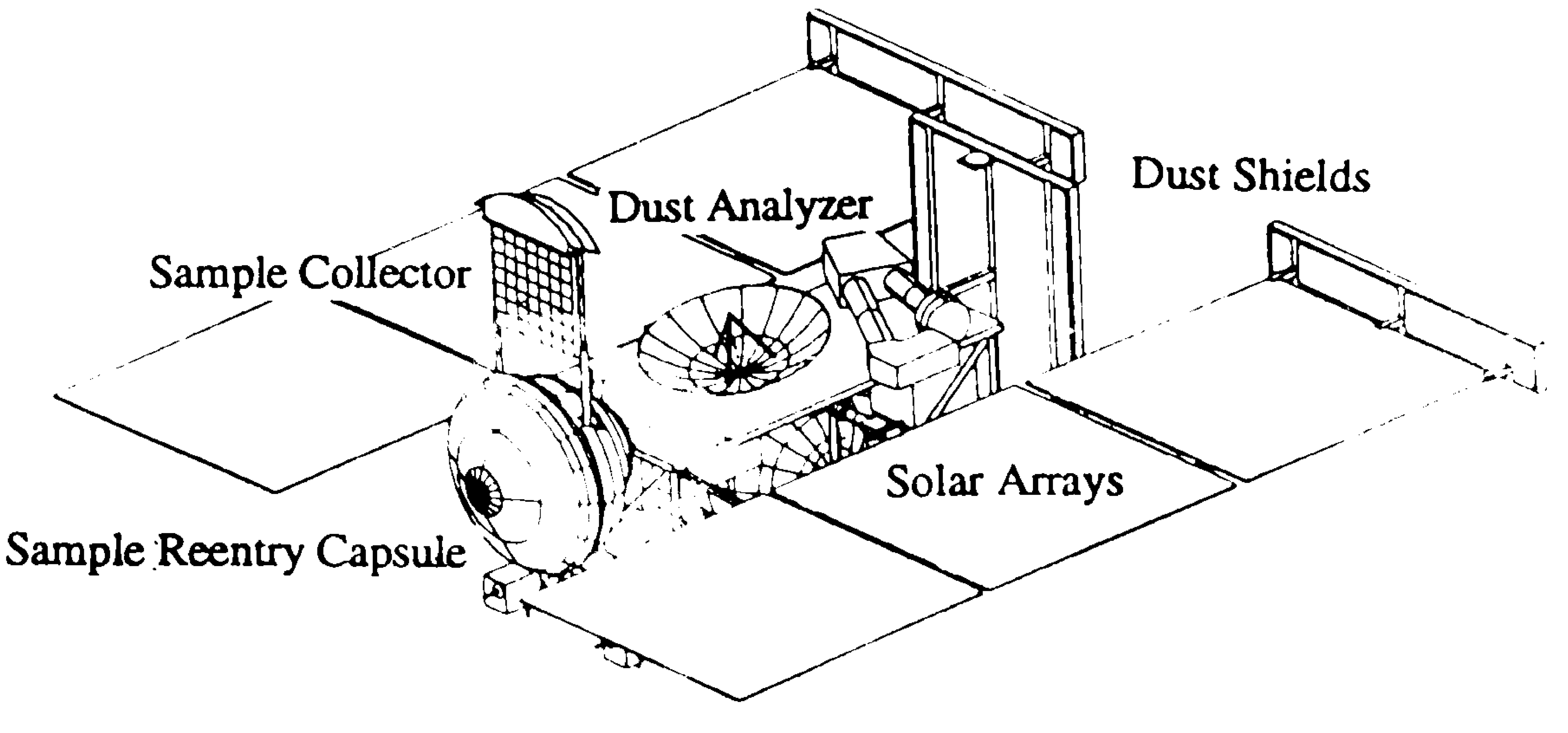


Fig. 1: STARDUST Spacecraft

on the anticipated dust flux and fluence. The final Earth encounter takes place in January 2006, at which time the Sample Reentry Capsule separates from the main S/C and performs a direct entry.

The direction of the IS dust stream is shown in Fig. 2. During the inbound leg of each orbit the S/C will be moving roughly parallel to the IS stream, enabling capture of IS dust particles at velocities well below 20 km/s. On the outbound leg of each orbit, when the S/C is moving into the dust stream, CIDA will measure the composition of the IS dust. The combined velocities of the S/C and the dust will be on the order of 50 km/s, a velocity domain similar to that experienced by the PIA and PUMA instruments during their Halley encounters.

5. Science Return

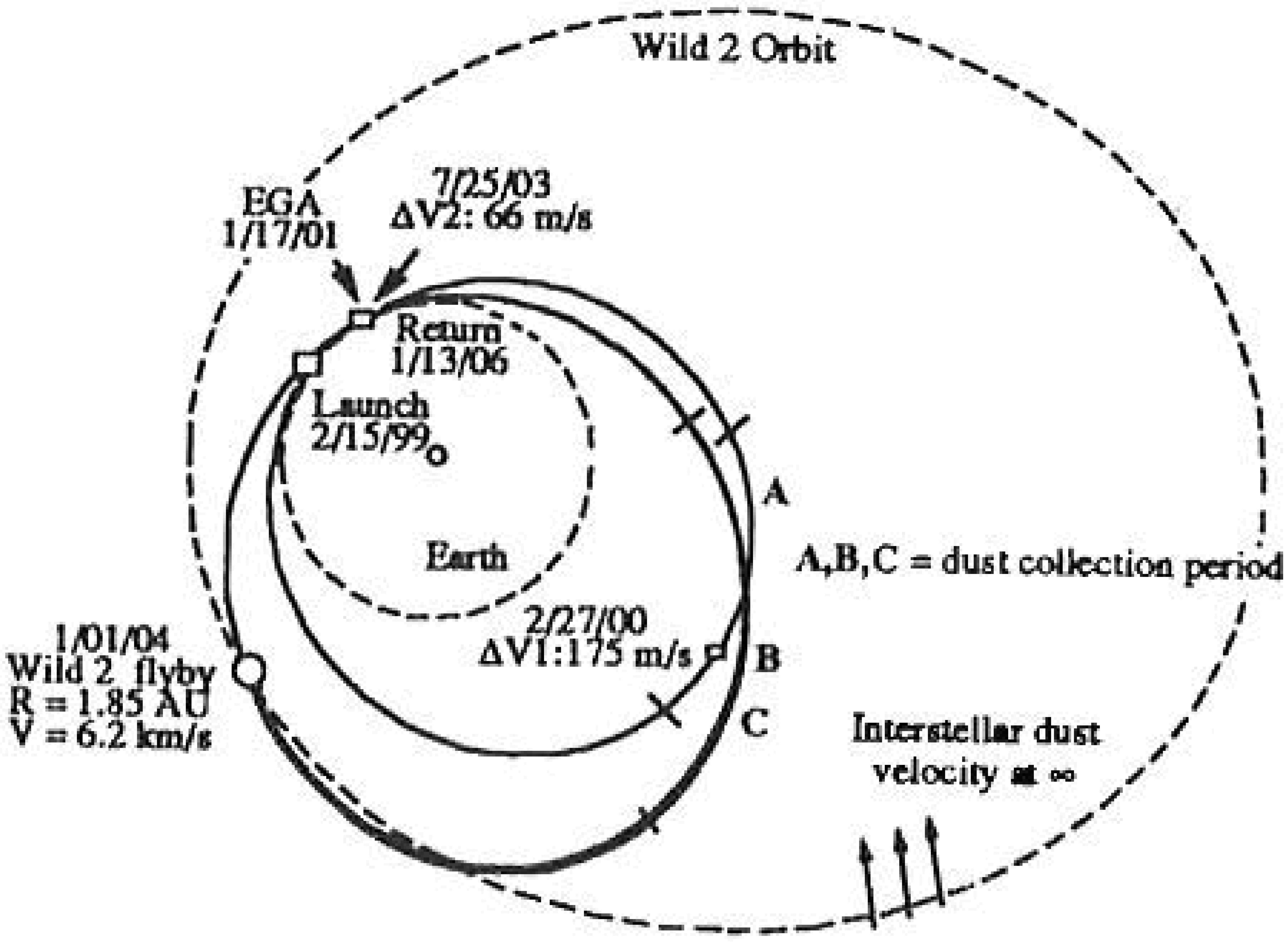
The primary goal of STARDUST is to return at least 1,000 cometary particles > 15 μm diameter. These will be analyzed by a variety of sophisticated techniques perfected for IDPs as well as techniques that will be developed in the next decade. Experience with IDPs and meteorite samples has amply demonstrated that the key information is retained at the submicron level. From the STARDUST sample we can study the elemental, chemical, and mineralogical composition at the submicron level; look for isotopic anomalies; learn the nature of the carbonaceous material; see if hydrated minerals are present; and compare with IDPs and primitive meteorites.

Biogenic elements and organic molecules captured on the surface of the collectors or embedded within solid particles are of special interest. The collected dust samples can be analyzed for the presence of a wide variety of organic compounds, such as PAHs, compounds similar to polyoxymethylene, and aliphatic rich kerogens, as well as complex organic molecules physisorbed on the aerogel surface.

Analysis of even a few captured IS dust particles will greatly improve our understanding of the IS medium and aid the interpretation of remote sensing data. Although the capture velocities will exceed 10 km/s, the more refractory components of the grains should survive sufficiently to give some mineralogical information. CIDA will also provide data on the elemental composition of individual particles. It should be possible to determine the elemental composition; the isotopic composition of H,C, O, Mg, Si; the prevalence of graphite grains; the presence of SiC grains; and the extent of physical mixing among mineral phases.

The flyby of P/Wild 2 at a range of 100 km will allow the navigation camera to

Fig. 2:
Mission Trajectory



obtain images over a range of phase angles with resolution down to < 10 meters. With these data we can determine the size and shape of the nucleus, the fraction of the surface that is active, the structure and texture of the nucleus surface, and variations of albedo and color across the surface.

The S/C dust shield will have more than a square meter of surface area. Acoustic dust sensors will be mounted on the front and rear dust shield panels to monitor the flux, mass distribution, and spatial distribution of impacting particles > 10^{-9} g. The results can be compared with impact data from Giotto and Vega.

In summary, the STARDUST mission will provide critical links between several areas of study of interplanetary dust. This mission should provide important insight into the nature and amount of dust released by comets and the links between meteoritic samples (meteorites and IDPs collected at Earth) and a known cometary body. The measured properties of cometary dust should provide important clues to the importance of comets in producing dust in our zodiacal cloud as well as circumstellar dust around other stars. STARDUST is a focused mission and the information that it provides is complementary to that to be returned by the more comprehensive Rosetta mission. Together the Rosetta and STARDUST missions will provide fundamental insights into the comets and their past and present roles in planetary systems.

7. References

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