STARDUST Curation Team

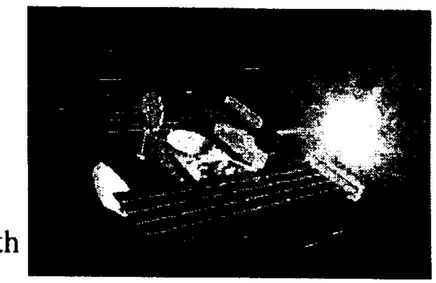
The Mission

Sample Collection

Contamination Control

Curation and Sample Analysis

Contact Us



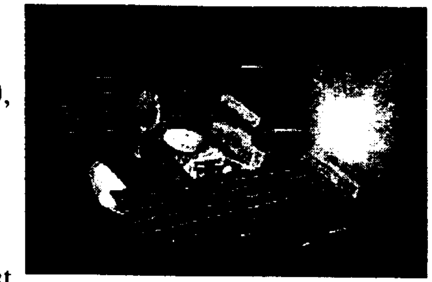
STARDUST, a NASA Discovery-class mission, is the first to return samples from a comet. Grains from comet Wild 2's coma—the gas and dust envelope that surrounds the nucleus—will be collected as well as interstellar dust. The mission which launched on February 7, 1999 will encounter the comet on January 10, 2004. As the spacecraft passes through the coma, a tray of silica aerogel will be exposed, and coma grains will impact there and become captured. Following the collection, the aerogel tray is closed for return to Earth in 2006.

A dust impact mass spectrometer on board the *STARDUST* spacecraft will be used to gather spectra of dust during the entire mission, including the coma passage. This instrument will be the best chance to obtain data on volatile grains, which will not be well-collected in the aerogel. The dust impact mass spectrometer will also be used to study the composition of interstellar grains.

In the past 5 years, analysis of data from dust detectors aboard the *Ulysses* and *Galileo* spacecraft have revealed that there is a stream of interstellar dust flowing through our solar system. These grains will be captured during the cruise phase of the *STARDUST* mission, as the spacecraft travels toward the comet.

The sample return capsule will parachute to Earth in February 2006, and will land in western Utah. Once on the ground, the sample return capsule will be placed into a dry nitrogen environment and flown to the curation lab at JSC.

Approximately six months of preliminary investigation by a dedicated team will precede release of the sample



STARDUST, a NASA Discovery-class mission, is the first to return samples from a comet. Grains from comet Wild 2's coma—the gas and dust envelope that surrounds the nucleus—will be collected as well as interstellar dust. The mission which launched on February 7, 1999 will encounter the comet on January 10, 2004. As the spacecraft passes through the coma, a tray of silica aerogel will be exposed, and coma grains will impact there and become captured. Following the collection, the aerogel tray is closed for return to Earth in 2006.

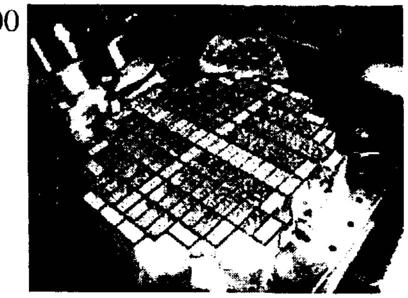
A dust impact mass spectrometer on board the *STARDUST* spacecraft will be used to gather spectra of dust during the entire mission, including the coma passage. This instrument will be the best chance to obtain data on volatile grains, which will not be well-collected in the aerogel. The dust impact mass spectrometer will also be used to study the composition of interstellar grains.

In the past 5 years, analysis of data from dust detectors aboard the *Ulysses* and *Galileo* spacecraft have revealed that there is a stream of interstellar dust flowing through our solar system. These grains will be captured during the cruise phase of the *STARDUST* mission, as the spacecraft travels toward the comet.

The sample return capsule will parachute to Earth in February 2006, and will land in western Utah. Once on the ground, the sample return capsule will be placed into a dry nitrogen environment and flown to the curation lab at JSC.

Approximately six months of preliminary investigation by a dedicated team will precede release of the sample to the general analysis community. This preliminary investigation period has the goal of documenting the initial state of the collected sample, identifying the range of samples present, and assessing the best way to proceed with general sample distribution and analysis.

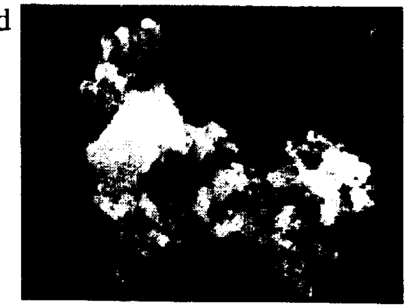
Sample Collection on Stardust Mission



The sample harvest from *STARDUST* will consist of ~1000 **cometary dust particles** measuring less than 100 μm each, and ~100 **interstellar dust grains** of mostly sub-micron size. The total mass of returned sample will be on approximately 1 mg. The comet samples will be collected during a 6.1 km/s flyby of Comet Wild 2. The **collector module** consists of blocks of 1 and 3 cm thick underdense, microporous silica **aerogel** mounted in modular aluminum cells. One side of the collector will be used to collect samples during the comet encounter, and the opposite side will be used for interstellar collection.

Particle collection at this speed has been extensively demonstrated in laboratory simulations, Shuttle flights and on the MIR Space Station, and we have shown that the comet dust collection can be done with acceptable levels of sample alteration. On this mission, both comet coma samples and the contemporary interstellar grains must be captured at high velocity with minimal heating and other effects of physical alteration. We are certain that solid materials from the comet flyby can be recovered in excellent condition because experiments at this speed and with this particle type have been successfully simulated in the laboratory, both at JSC and at NASA Ames Research Center. The state of captured interstellar dust is less secure because of the small particle size, higher impact velocity, and unknown material properties.

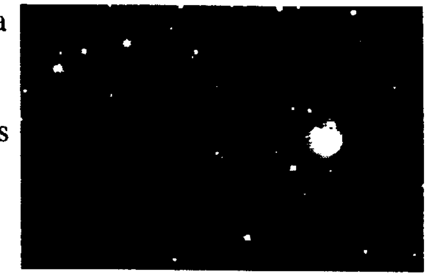
Cometary Dust Particles



When comets struck the Earth millions of years ago they created changes in our atmosphere and climate, and brought with them carbon-based molecules, a fundamental element of life on this planet. By studying comet particles, scientists may be able to solve some of the mysteries surrounding the birth and evolution of life in the solar system.

The *STARDUST* mission will capture cometary particles similar to the stratospheric dust shown here. Currently, stratospheric dust is collected in Earth's stratosphere using U2 aircraft. This particle is similar in elemental composition to primitive meteorites but differs in having higher carbon and volatile element abundance. The particle is composed of glass, carbon and many types of silicate mineral grains. It is a sample of either an asteroid or a comet. The porosity and unusual mineralogical composition suggests that it may be of cometary origin.

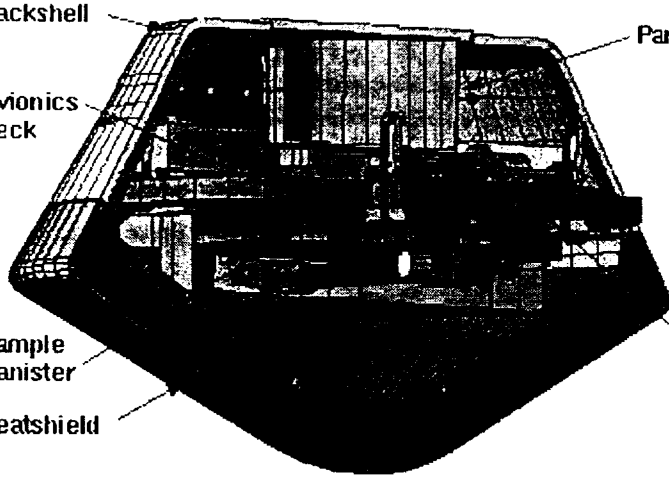
Interstellar Dust Grains



Analysis of data from dust detectors aboard the *Ulysses* and *Galileo* spacecraft have revealed that there is a stream of interstellar dust flowing through our solar system. These grains, of unkown mineralogy, generallly measure less than 1μm, and so are impossible to collect at Earth by current techniques. Approximately 100 of these grains will be collected on the *STARDUST* mission. Analysis of these particles will represent the most difficult challenge of the post-flight operations.

Scientists hope that these samples will provide a window into the distant past, unlocking secrects surrounding the birth and evolution of the solar system and the emergence of life.

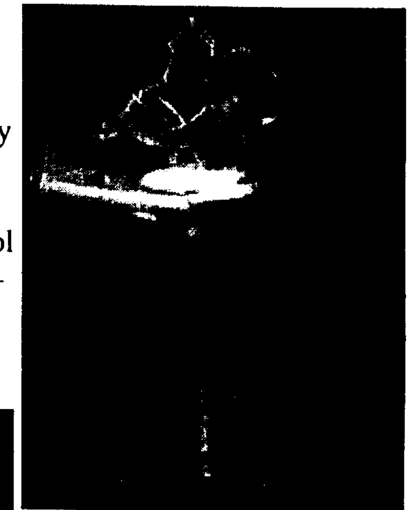
Collector Module



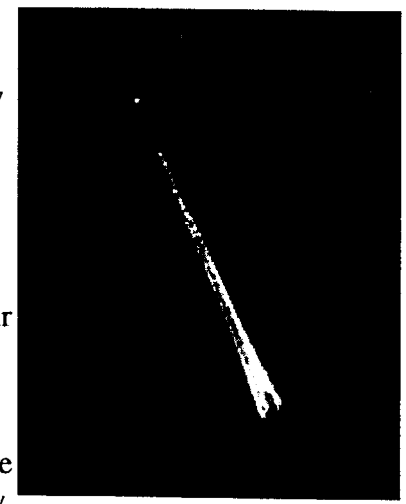
The collector module, a two-sided, grid-shaped array, will deploy from the Sample Return Capsule (SRC). After exposure, the cells assembly will fold up to a compact configuration for stowage into the Earth return capsule. The SRC is about a meter in diameter, and is shown here open like a clamshell with the dust collector gid deployed into the dust stream.

The SRC consists of the sample canister, the aeroshield/basecover, navigation recovery aids, and event sequencer, and a small parachute system. The *STARDUST* spacecraft sets up the proper flight trajectory and entry angle, then releases the sample return canister. Upon entering the Earth's atmosphere the SRC will free-fall until approximately 3 km, at which point the parachute deployment sequence will initiate. The planned landing site is the Utah Test and Training Range.

Aerogel



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 air. Aerogel is 1,000 times less dense than glass, another silicon-based solid. This exotic material has many unusual properties, such as uniquely low thermal conductivity, refractive index, and sound speed, in addition to its exceptional ability to capture hypervelocity dust. Aerogel is made by high temperature and pressure critical point drying of a gel composed of colloidal silica structural units filled with solvents. Over the past three years, aerogel has been made and flight qualified at the Jet Propulsion Laboratory. We used the JPL facility because it allowed us to have full control over the media properties and purity. Silica aerogel produced at JPL is a water clear, high purity silica glass-like material that can be made with bulk density approaching the density of air. We have repeatedly demonstrated it's strength during launch and space environments.

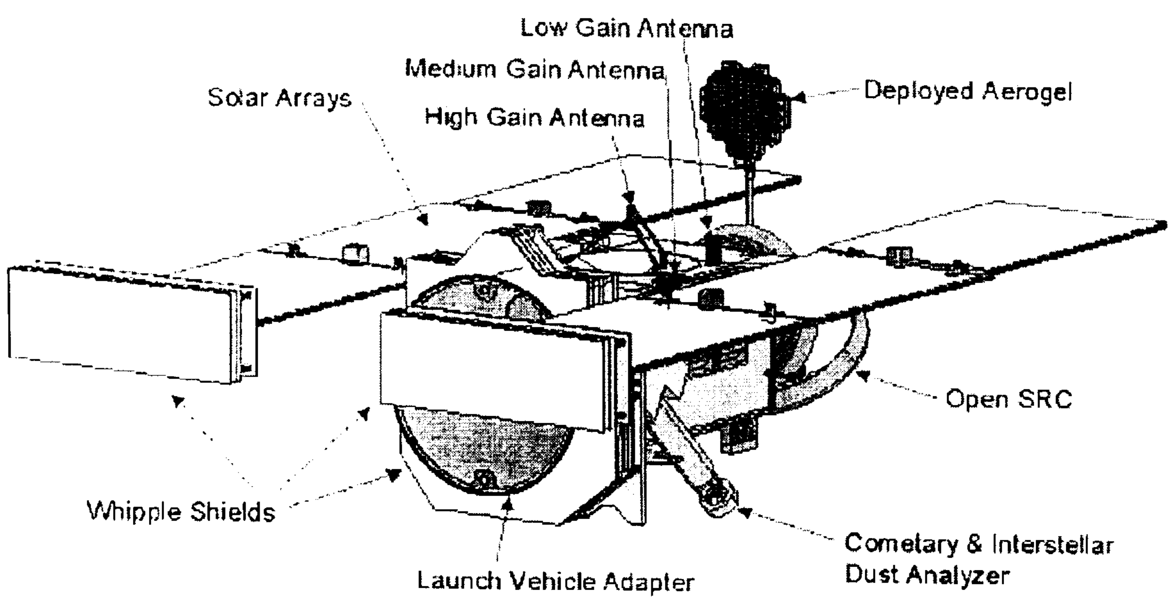


When a hypervelocity particle hits the aerogel, it will bury itself in the material, creating a narrow cone-shaped track, as is slows down and comes to a stop. Since aerogel is mostly transparent and the tracks can easily be seen by using a stereo microscope. The cone is largest at the point of entry, and the particle is collected at the point of the cone. This provides a directionality detector and is the basis of our approach of using single slabs of aerogel to collect both cometary and interstellar dust, and being able to differentiate between them because the one side of the collector is exposed in the comet dust impact direction and the opposite side is positioned toward the interstellar dust stream. The captured particle is seen optically just beyond the tip of the cone, and it can be recovered by a variety of techniques, ranging from extraction with a needle, to microtoming, and focused ion beam etching. Recovered samples are then treated by sequential analysis techniques that have been developed for the analysis of small meteoritic samples and interplanetary dust particles (IDPs). We have already developed techniques for the removal and analysis of captured grains from silica aerogel, but we will be developing these techniques further between now and when the comet samples return in 2006.

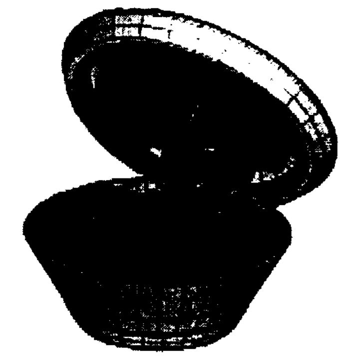
Contamintation Control

JSC scientist Mike Zolensky has taken the lead in formulating and implementing the Contamination Control Plan for the *STARDUST* Mission (Zolensky and Girard, 1997). This plan is the blueprint for ensuring that the returned sample remains as pristine as possible, so that the maximum may be learned from its study. It has been almost 30 years since we had to write the last such plan (for Apollo and Luna Missions to the Moon), and so for *STARDUST* we had to learn all over again how to make and operate a clean spacecraft. The experience we have gained is now being applied to succeeding sample return missions like ***Genesis*** and *MUSES-C*.

A significant constraint on any sample return is the absolute requirement for a contamination-free sample container. Calculations indicate that for a chondritic composition sample weighing 1 µg, the total permitted contamination levels for inorganic elements on the walls of the sample container vary from 10-9 to 10-16 g for instrumental and radiochemical neutron activation analyses (INAA and RNAA). For nanogram-sized grains the requirements are significantly more stringent. Accordingly, smaller-scale techniques such as ion probery, proton induced X-ray emission analysis (PIXE), and resonance ionization mass spectrometry (RIMS) require even more care in contamination control. For organic compounds, contamination control requirements are not only hard to achieve, but currently often difficult to usefully define.



STARDUST differs from a 'typical' spacecraft in two distinct ways. One is that the primary payload is housed in a canister that is returned to earth via direct reentry of the Sample Return Canister (SRC). Secondly, the spacecraft is protected from high velocity particles anticipated during encounters by 'bumper shields' located at one end of the solar panels and spacecraft bus.



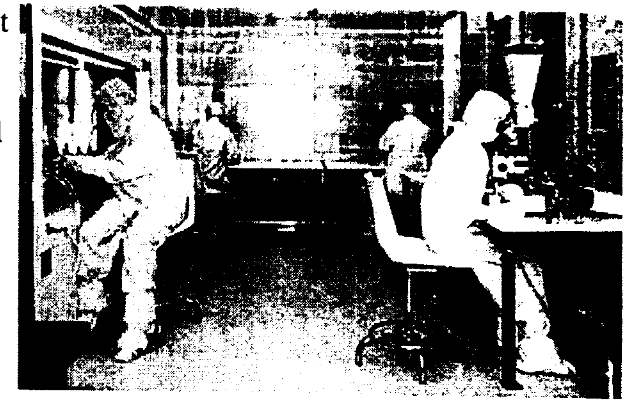
The interstellar and comet coma collection medium is aerogel. The aerogel is contained in a tray and is located in the canister. The canister is an integral part of the SRC which opens in a 'clam shell' fashion. Once opened the aerogel tray is deployed on an arm, exposing the aerogel to the environment. After the final exposure period the arm is contracted and the SRC closed. The canister is designed to limit ingestion of materials that may obfuscate analysis of the returned samples. Filtered vents are used to limit the potential of contaminating the return sample during reentry.

The Comet and Interplanetary Dust Analyzer (CIDA) instrument is also flown on STARDUST. This mass spectrometer type device that identifies the mass number of species observed from a dust particle impact and its vaporization contains only two parts which are considered contamination sensitive - the detector and target surfaces. Accordingly, these surfaces required a separate nitrogen purge until lift-off.

Aluminum and sapphire witness plates were used to monitor facility contamination fallout levels during ground processing the STARDUST spacecraft. The particulate contamination levels were strictly set and adhered to. Witness plates are required to assist the Science Team in distinguishing cometary matter from matter accumulated from contamination sources. Four types of control coupons were used. These include 5/8" diameter, 0.04" thick sapphire and polished aluminum coupons, 4cmx2cmx1cm aerogel coupons, and larger aluminum plates. Ten sets of controls were used to distinguish canister processing, aerogel processing and flight sources of contamination. Three witness plates are flying on the spacecraft, so that in-flight contamination can be assessed in 2006.

Right now JSC is curating the hundreds of spare aerogel pieces that were manufactured but not flown. These critical samples will permit scientists to develop the techniques they will use to remove comet dust from the aerogel, and study it in 2006.

Sample Curation



In 2006, the *STARDUST* sample return canister (SRC) will return to Earth (at the Utah Test and Training Range), and be immediately flown to the **Curation Laboratory** at the Johnson Space Center. Once safely at JSC, the canister can be opened and the aerogel and its comet harvest will be inspected. The SRC contents, including the aerogel and contained sample, must be maintained at a class 10 clean room environment or better during this deintegration. Particulate and non-volatile residue (NVR) witness plates will be used to monitor the environment during all times aerogel is open to the laboratory air, and will be monitored daily for visible particulate contamination.

The remaining portions of the SRC will remain in another lab for the inevitable characterization of the effects of exposure to contamination and the space environment, including surveys of the micrometeorite impact record. The details of these latter efforts are to be determined.

Sample analysis will be carried out in three major sequential phases. The first phase involves nondestructive preliminary examination of the aerogel cells and included samples, and will be performed in the **Curatorial Facility**. This task will be accomplished using mainly light optical techniques, and will have as the primary goal the documentation of the state of the samples and aerogel cells, location and identification of the most critical samples to be analyzed, and selection of the samples to be preserved for distant, future analyses (posterity samples). The aerogel cells will be transferred into a stainless steel gloved cabinet with a constant flow of dry nitrogen. The various cells will be deintegrated in this cabinet, and long term storage of posterity samples will also occur in this or a similar cabinet. The constant flow of dry nitrogen is essential to prevent mineralogical and physical alteration of the samples. Samples can be removed from the cabinet for brief periods into the class 100 clean room environment permitting dissection and photography.

The second phase will be an intensive preliminary investigation of the state and principal characteristics of the comet dust, and will be performed over a 6 month operiod by the *STARDUST* Science Team.

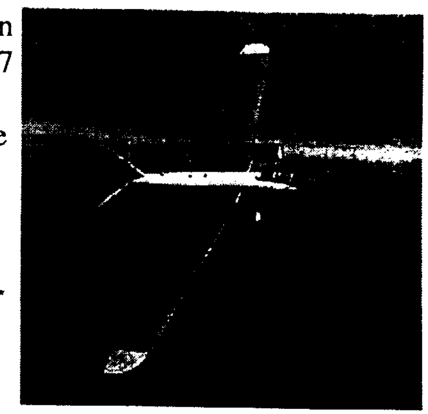
The third phase includes all sample analyses, both non-destructive and destructive, to be performed by scientists worldwide. Individual samples will be dissected (if required), containerized, and allocated. Samples will be allocated in several different ways: as entire aerogel cells, as smaller pieces of aerogel containing one or more sample grains, as completely excavated sample grains, and as ultramicrotomed grains. All tools coming in contact with the aerogel will have been previously cleaned as per JSC-03243. The same holds for all bags and containers used in curatorial operations.

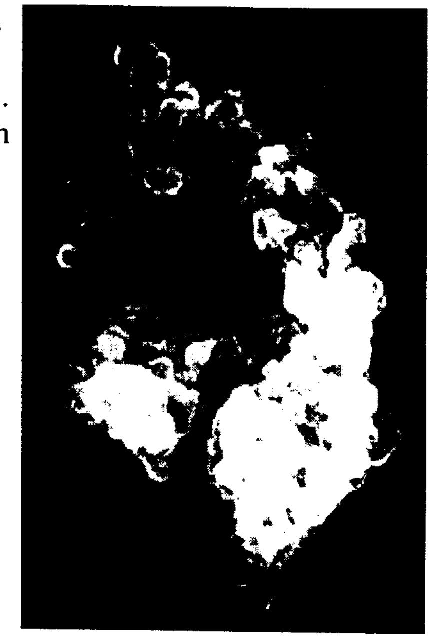
All samples not immediately consumed by analysis or distributed to other laboratories will be archived within a dedicated stainless steel cabinet under a GN2 Purge to prevent alteration. These samples will be preserved so that future scientists can have access to the comet samples, when new techniques and questions arise. This archived sample represents the greatest product of the *STARDUST* Mission - a resource for the future.

Sample Analysis:
What Can Be Done With Such Tiny Particles?

We are entering a new and golden age of sample return missions. In the coming decade we will harvest samples from Comet P/Wild 2 and interstellar dust courtesy of the *STARDUST* Mission, an asteroid (probably 4660 Nereus or 1989ML) by the ISAS *MUSES-C* Mission, and solar wind by the *Genesis* Mission. A sample return from Mars is also envisioned as early as 2008. It is, however, sobering to realize that *MUSES-C* aims to return 3-10 g of sample, *STARDUST* will provide micrograms of comet and interstellar dust, and *Genesis* will harvest only few micrograms of atoms. The diminutive size of the returning samples may be a source of concern for petrologists used only to looking at hefty lunar rocks and meteorites.

Since 1981, NASA has supported asteroid and comet science by collecting dust grains from these bodies in the stratosphere, and making them available for analysis in laboratories worldwide. Over the succeeding 17 years, many new techniques have been developed for these painstaking analyses, by at least 24 different laboratories across the globe. Despite the fact that the particle supply has always exceeded the demand, the painstaking efforts required for most of the nano-scale analyses have resulted in only 1520 grains having been analyzed, with a total mass of only 0.52 micrograms.

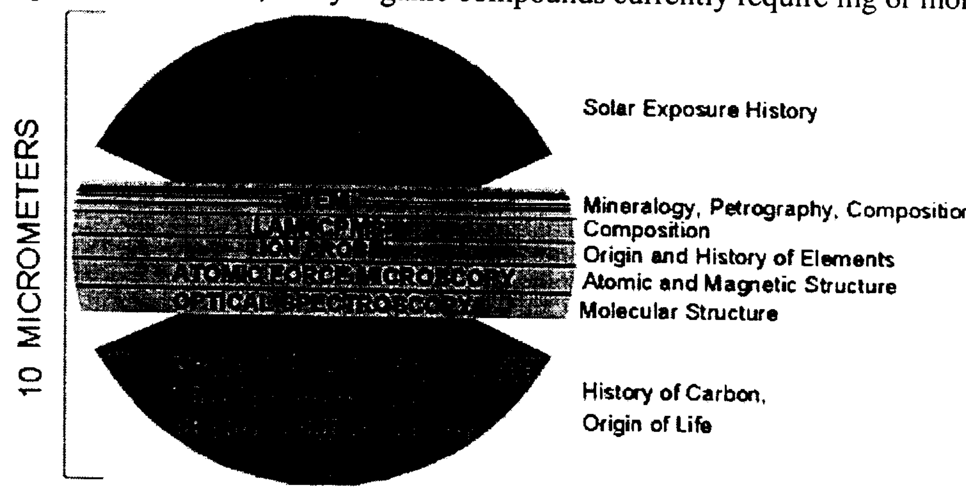




How much sample is really needed to achieve prime science objectives, while maintaining a cost effective mission? The range of geological processes that we will want to address with these samples is staggering, encompassing not merely the entire history of the Solar system, but the history of the elements themselves. The interstellar processes include element formation, production and interactions with radiation, formation of organics, grain condensation and evolution, and interactions with magnetic fields. In the pre-accretionary (nebular) environment we wish to understand grain condensation, evaporation and recondensation, shock, radiation processing, solar energetic particle implantation, gas composition, the magnetic environment, and the evolution of organics. Finally, for solid bodies we wish to examine accretion history, shock, brecciation, impact gardening, metamorphism, aqueous alteration, weathering, exposure history, volcanism, fumarolic activity, differentiation, the magnetic environment, atmosphere evolution, and the evolution of organics.

With advanced technology, small is beautiful. The capability of modern methods to characterize ultra-small samples is well established from analysis of interplanetary dust particles (IDPs), interstellar grains recovered from meteorites, and other materials requiring ultra-sensitive analytical capabilities. Powerful analytical techniques are available that require, under favorable circumstances, only nanogram- to microgram-sized single particles for entire suites of fairly comprehensive characterizations. Oxygen isotope analyses, for example, can be applied to any oxygen-bearing grain. Thus, a returned sample mass of just a few micrograms (~1000 10μm particles) permits comprehensive quantitative geochemical measurements that are impossible to carry out in situ with flight instruments.

On the other hand, for complex differentiated bodies, carefully-selected gram-sized quantities (and perhaps more) will clearly be required for the array of primary science issues related to the evolution of the body. Age dating requires recovery of specific, often trace mineral phases which are unlikely to be present at the μg scale. Petrographic relations between components (e.g., cooling sequence, matrix-inclusion relations, etc.) cannot generally be directly addressed with individual particles, and many bulk physical properties (bulk density, porosity, etc.) are difficult to characterize with particulate samples. Furthermore, many organic compounds currently require mg or more for analysis (although advanced techniques are improving).



The principal value of a returned sample (as opposed to remote sensing or robotic analysis) is that state of the art instruments need not be flight qualified and flown. Instead, sample analyses can be performed in ground-based laboratories, checked by complementary techniques and labs, and questionable analyses be repeated.

First-time visitors to the Cosmic Dust Lab at the Johnson Space Center are frequently surprised at the ease with which particles measuring only a few microns are manipulated, catalogued, stored, retrieved and studied. Of course nanotechnology is at the heart of our industrial civilization, although these skills are not particular to scientists. In fact the manipulation of submicron interstellar grains is the current state of the art for planetary scientists.

In the Table below we summarize the techniques that can be applied now to nanogram-sized particles. We also identify such factors as ease of analyses (in-situ vs. sample preparation required) and destructive vs. partially or non-destructive. We term many of the analyses as partially destructive because of complicated sample preparation. These samples are considered by us to be degraded, but still remain in a state permitting significant subsequent analyses. We fully expect that even more techniques will be available for these tiny particles by the time the Wild II sample returns to Earth in 2006.

Summary of Analytical Techniques

Technique	Required Sample Mass	Destructiveness
Imaging		
Light-Optical Techniques	ng	non-destructive
Scanning Electron Microscopy/ Energy Dispersive Spectrometry	ng	non-destructive
Transmission/Analytical Electron Microscopy	ng	partially
Atomic Force Microscopy	ng	partially
Force Spectroscopy	ng	partially
Holographic Low-Energy Electron Diffraction	ng	partially
SIMS Ion Imaging	ng	destructive
Bulk and Mineral Compositional Analyses		
Microparticle Instrumental Neutron Activation Analysis	ng	non-destructive
Synchrotron X-ray Fluorescence	ng	non-destructive
XRF Tomography	ng	non-destructive
Electron Microprobe Analysis	ng-mg	partially
Protron Induced X-ray Emission	ng	partially
X-ray Spectroscopy	ng	partially
Secondary Ion Mass Spectrometry	ng	destructive
Time-of-Flight Secondary Ion Mass Spectrometry	ng	destructive
Laser Ablation Microprobe- Inductively Coupled Plasma-Mass Spectrometry	ng	destructive
Double Focusing Secondary Ion Mass Spectrometry	ng-mg	destructive

Spectrometry		
Resonance Ion Mass Spectrometry	ng	destructive
Thermal Ionization Mass Spectrometry	ng-mg	destructive
Organic Analyses		
Micro Raman Spectroscopy	ng-mg	non-destructive
Fluorescence	ng	non-destructive
Transmission and Reflectance IR-Vis Spectroscopy	ng	partially
Optically- and Acoustically-Excited Phonon Spectroscopy	ng	partially
Two-Stage Laser Desorption/Laser Multiphoton Ionization Mass Spectrometry	ng	destructive
Noble Gas and Exposure History		
Solar Flare Track Analysis	ng	partially
Double-Focusing Mass Spectrometer	ng-mg	destructive
Age Dating		
Laser Ablation Mass Spectrometry	ng-mg	destructive
Mineralogy and Atomic Structure		
Synchrotron X-ray Diffraction	ng	non-destructive
X-ray Absorption Spectroscopy	ng	non-destructive
Transmission IR-Vis Spectroscopy	ng	non-destructive
Transmission Electron Microscopy	ng	partially
Electron Energy-Loss Near Edge Structure	ng	partially
Atomic Force Microscopy	ng	partially
Electron Energy Loss Spectroscopy	ng	partially
Extended X-ray Absorption Fine Structure	ng	partially
X-ray Absorption Near-edge Structure	ng	partially
IR-Vis Reflectance Spectroscopy	ng	partially
Cathodoluminescence Microscopy and Spectroscopy	ng	partially
Physical Properties		
Magnetic Force Microscopy	ng-mg	partially
Force Spectroscopy	ng	partially
Density Measurements	ng	non-destructive to partially

JSC STARDUST Curation Team

Fred Hörz
Design and Testing Aerogel Capture Media

Mike Zolensky
Design and Implementation of the Spacecraft Contamination Control Plan
Curation of Returned Samples

Responsible NASA Official: Mike Zolensky
Web Curator: Anita Dodson (anita.dodson1@jsc.nasa.gov)
Last Updated: June 25, 1999

JSC Approval of External Presentations/Papers, Journal Articles, and NASA Scientific and Technical Reports Series
(see page 2 for instructions)

1a. Principal JSC Author/Speaker: Michael E. Zolensky | **Org. Code:** SN2 | **Phone No.:** 483-5128

1b. Coauthor(s) / Affiliations (List also on abstract page)

2. Title of Paper or Presentation (List also on abstract page)
JSC Stardust Curation Team

3. Type of Release (attach 2 copies of abstract and paper)
Attached: [X] Final [ ] Draft

[ ] **a. Presentation or meeting paper:**
- Meeting name
- Meeting location and date
- Sponsoring society name and location

[ ] **b. Journal article or other external release:**
- Title of journal or other publication
- Projected release date

[ ] **c. Electronic release:**
-URL or access point
Website

[ ] **d. NASA-numbered scientific and technical report series:**
(Check appropriate prefix - GS4 will assign number.)

[ ] **NASA Technical Memoradum (TM):** Scientific and technical findings that are preliminary or of narrow interest: e.g., quick release reports, working papers, and preliminary results. Do not contain extensive analysis.

[ ] **NASA Technical Publication (TP):** Report of completed research or a major signficant phase of research. NASA counterpart to peer-reviewed formal professional papers, but having fewer limitations on manuscript length and extent of graphics. Also can be reference works of long-term value.

[ ] **NASA Conference Publication (CP):** Collected papers from scientific and technical conferences, symposia, seminars, or other meetings sponsored or cosponsored by NASA.

[ ] **NASA Special Publication (SP):** Scientific, technical, or historical information from NASA programs, projects, and missions, often concerned with subjects having substantial public interest.

4. Technology Development
- Does this technology have commercial potential? [ ] Yes [X] No
- If yes, has it been disclosed to the JSC Technology Transfer and Commercialization Office? [ ] Yes [ ] No

5. JSC Funding Information: Give RTOP, project, contract number, or other funding source: 624-08-01-01

6. External Billing Cost *(May be estimated. Requires Budget Approval signature in block 9 by financial personnel in originating JSC organization.)* 0

7. Security Classification: [X] Unclass. [ ] Confid. [ ] Secret

8. NASA Form 1676
[ ] Attached
[X] Waived by blanket release for 624-08

9. Availability Category *(check one block only)*
[X] Publicly Available *(may be distributed worldwide)*
[ ] Restricted *(check applicable category on attached NASA Form 1676.)*

10. Signatures	Date
Author/Speaker Michael E. Zolensky	06/30/99
Technical Reviewer XXXXXXXXX C. Meyer, Jr.	8/16/99
Division Office Gordon A. McKay, Acting Chief ES&SSD	
Budget Approval *(if necessary)*	
Directorate/Program Office	
Technology Transfer & Commercialization Office (HA)	
Publications Review (GS4)	
Associate Director, Management (AC)	

For GS4 use only: NASA Number ______
S Number ____ Camera-ready pages ____ Copies ____
Sent to Print: Date ______ Place ______

JSC Form 548 (Rev Apr 98) (MS Word Jun 97)

Distribution: Original - Return to GS4 (for center record)
GS4 sends copy to originator