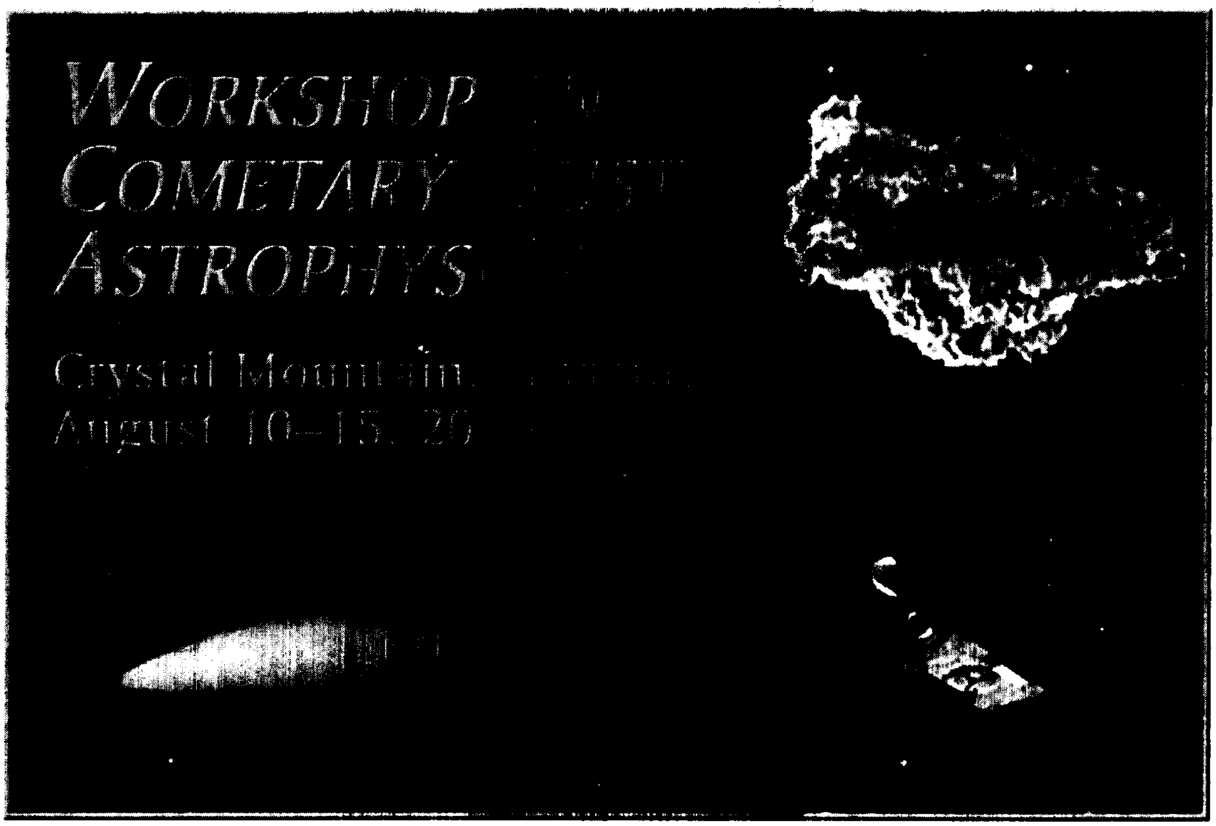

WORKSHOP ON COMETARY DUST IN ASTROPHYSICS

Crystal Mountain, Washington
August 10–15, 2003

PROGRAM AND ABSTRACTS

Workshop on Cometary Dust in Astrophysics

August 10–15, 2003

Crystal Mountain, Washington

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Preface

This volume contains abstracts that have been accepted for presentation at the Workshop on Cometary Dust in Astrophysics, August 10–15, 2003, in Crystal Mountain, Washington.

Administration and publications support for this meeting were provided by the staff of the Publications and Program Services Department at the Lunar and Planetary Institute.

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C. C. Allen

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D. P. Cruikshank

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IN-SITU ANALYSIS OF COMPLEX ORGANIC MATTER IN COMETARY DUST BY ION MICROPROBE.

J. Aléon, CRPG-CNRS, 15 rue Notre-Dame des Pauvres, BP20, 54501 Vandoeuvre-lès-Nancy, France (aleon@crpg.cnrs-nancy.fr).

Introduction: Based on (1) the comparison with interplanetary dust particles (IDPs) [1], (2) the observation of abundant carbonaceous dust grains in the coma of comet Halley [2] and (3) the actual models of interstellar dust composition [3,4], it is believed that carbonaceous matter will be a major component of the Stardust returned samples. Given the importance of carbonaceous compounds in interstellar and nebular chemistry, in the formation of planetary atmospheres and in the potential delivery of prebiotic molecules to planetary surfaces, it is thus necessary to be able to provide a complete and accurate study of the carbonaceous components of cometary dust. Since carbonaceous units in this dust have a small µm to sub-µm size, only in-situ techniques with high lateral resolution will be useful to study these grains, such as synchrotron-based spectroscopies, high resolution transmission electron microscope and ion microprobe. Here I summarize the work done with a IMS 1270 ion microprobe to understand the composition of complex organic matter in IDPs of probable cometary origin and the possible processes responsible for its formation.

Samples and techniques: 5 stratospheric dust particles (K1, E22, R5, A6 and R6), were studied by ion microprobe scanning imaging [5,6]. Hydrogen and nitrogen isotopes were mapped together with carbon, oxygen, aluminum and silicon using a primary Cs^+ beam of ~1.5 µm. The map of carbon was used to compare the distribution of carbonaceous grains in order to ensure that grains of interest were not eroded after the H isotope analysis.

Results and discussion: Hydrogen in these particles was attributed to a mixture of organic and hydrated phases based on the distribution of C/H and D/H ratios [5]. Each of the 5 particles have different components.

H isotopes and Al-oxides grains indicate that R6 is a terrestrial contaminant. H in R5 was attributed to a mixture of chondritic hydroxyls with minor organic H similar to carbonaceous chondrites insoluble organic matter (CC-IOM). A6 showed the presence of chondritic hydroxyls mixed with several D-rich organic compounds. H in K1 was distributed between 2 major phases and 1 minor : chondritic hydroxyls, an organic component similar to the CC-IOM, and a minor organic component with a large D-excess. Only organic H with extreme D-excess was observed in E22 suggesting that the silicates of this particle are anhydrous.

Organic mixing endmembers with D-excesses were labelled OM1, OM2 and OM3, with OM1 the CC-IOM-like component in K1 and OM2 and OM3 the extremely D-rich components in K1 and E22, respectively (Table 1).

The N concentration and isotopic composition was subsequently determined in these 3 phases [6]. All these phases are extremely N-rich and ^{15}N-rich with the $\delta^{15}N$ correlated with the D/H ratios (Table 1). Comparison with carbonaceous chondrites and comets suggests that these phases are similar to cometary CN-bearing complex organic molecules [6,7].

Therefore ion microprobe analysis of organic components in IDPs allows identification of (i) terrestrial contaminants, (ii) asteroidal grains of CC-type, and (iii) cometary grains. In the case of cometary organics it also provides a critical information on their chemistry : they are complex macromolecular material, with variable aliphaticity and aromaticity as shown by the C/H ratios, they have high N concentration and they share ^{15}N and D excesses.

Using the isotopic fractionation between ^{15}N-D-rich organic matter and the average interstellar gas 4.5 Ga ago, exothermicities of the N isotopic fractionation reactions can be calculated, assuming that the gas is identical to the protosolar nebula [8]. Obtained exothermicities are similar to the predictions of ion-molecule chemistry [9]. However ion-molecule chemistry also predicts dilution of the isotopic effects in the gas-phase. This suggests that ^{15}N-D-rich organic matter was formed by condensation of ^{15}N-D-rich gas-phase precursors, subsequently incorporated into complex macromolecular structures [8].

	C/H	D/H (10^{-6})	N (wt%)	$\delta^{15}N$ (‰)
OM1	1.5 ± 0.2	253 ± 18	11 ± 5	208 ± 46
OM2	1.0 ± 0.1	1480 ± 104	12 ± 6	372 ± 54
OM3	2.9 ± 0.3	1880 ± 112	16 ± 8	383 ± 23

Table 1. Chemical and isotopic composition of cometary organics in IDPs (from Table 8 in [6]).

References: [1] Bradley J.P. and Brownlee D.E. (1986) *Science* 231, 1542-1544 [2] Jessberger E.K. et al. (1988) *Nature* 332, 691-695. [3] Greenberg J.M. and Li A. (1996) *in: The cosmic dust connection* (Greenberg J.M. ed.), 43-70. [4] Kimura H. et al. (2003) *ApJ* 583, 314-321. [5] Aléon J. et al. (2001) *GCA* 65, 4399-4412. [6] Aléon J. et al. (2003) *GCA*, in press. [7] Arpigny C. et al. (2003) *Science*, submitted. [8] Aléon J. and Robert F. (2003) *Icarus*, in prep. [9] Terzieva R. and Herbst E. (2000) *MNRAS* 317, 563-568.

PRISTINE PRESOLAR SILICON CARBIDE T. J. Bernatowicz[1], S. Messenger[2], O. Pravdivtseva[1], P. Swan[1] and R. M. Walker[1]. [1]Laboratory for Space Sciences and Department of Physics, Washington University, St. Louis, MO 63130 USA; [2]Mail Code SR, NASA Johnson Space Center, Houston TX 77058 USA

The study of presolar grains found in primitive meteorites has yielded new, often otherwise inaccessible information about stellar nucleosynthesis, stellar evolution, and the formation of solids in stellar ejecta. The principal focus of most presolar grain studies has been the determination of isotopic structures of both major and minor elements. The interpretations of these detailed structures in terms of stellar nuclear physics and dynamics have contributed significantly to our understanding of element synthesis [1-3]. Progress has also been made in understanding the composition and structure of presolar grains in terms of grain condensation and the physico-chemical conditions in stellar environments [4 -11]. However, the potential use of presolar grains as monitors of the environments to which they have been exposed has been virtually unexplored, except for some notable work on their progressive destruction with increasing severity of metamorphism on meteorite parent bodies [12-13], and on their destruction by oxidation reactions in the solar nebula [14]. It is important to consider that because the grains formed in various kinds of circumstellar winds and supernova ejecta, they *necessarily* had to migrate from these environments *via* the interstellar medium (ISM) into the protosolar nebula, and finally become incorporated into cometary and asteroidal parent bodies, samples of which come to us in the form of interplanetary dust particles (IDPs) and meteorites. Any of these environments could have left its mark on the surviving presolar grains, particularly on their *surfaces*, which therefore might serve as monitors of various processes.

Hitherto it has not been possible to study the surfaces of presolar grains as they occur in their parent meteorites—in the parlance used here, in their "pristine" state—because of the typical means by which they are isolated for study. The very effective dissolution methods developed to prepare presolar grain concentrates for isotopic studies [15] can alter grain surface morphologies, as well as entirely destroy petrographic context. An exception is the case of internal crystals sequestered within larger presolar grains, such as the various carbides and other minerals found within presolar graphite [7,11,16]. In this case, the graphite serves as a protective envelope that preserves the original characteristics of the internal crystals as well as their petrographic context.

In this talk we discuss a simple physical disaggregation technique coupled with an X-ray mapping procedure used to locate 81 micrometer-sized presolar SiC grains from the Murchison carbonaceous chondrite, that preserves them in their pristine state. We then describe pristine SiC surface characteristics and overall morphologies determined by high resolution field emission scanning electron microscopy (FESEM), and compare these features to those of presolar SiC grains that have been prepared using chemical dissolution techniques.

Nine-tenths of the pristine SiCs are bounded by one or more planar surfaces consistent with crystal faces based on manifest symmetry elements. In addition, multiple polygonal depressions (generally < 100 nm deep) are observed in more than half of these crystal faces (Fig.1), and these possess symmetries consistent with the structure of the 3C polytype of SiC. By comparison of these features with the surface features present on heavily etched presolar SiC grains from Murchison separate KJG [15], we show that the polygonal depressions on pristine grains are likely primary growth features. The etched SiCs have high densities of surface pits (Fig.2), in addition to polygonal depressions. If these pits are etched linear defects in the SiC, then defect densities are quite high (as much as 10^8 – 10^9/cm^2), at least 10^3 – 10^4 times higher than in typical synthetic SiCs. The polygonal depressions on crystal faces of pristine grains, as well as the high defect densities, indicate rapid formation of presolar SiC.

No other primary minerals are observed to be intergrown with or overgrown on the pristine SiCs, so the presence of overgrowths of other minerals cannot be invoked to account for the survival of presolar SiC in the solar nebula. We take the absence of other primary condensates to indicate that further growth or back-reaction with the gas became kinetically inhibited as the gas phase densities in the expanding AGB stellar atmospheres (in which most of the grains condensed) became too low. However, we did observe an oxygen peak in the X-ray spectra of most pristine grains. Comparison of the O signal strength with those of synthetic coatings of silica implies that silica coatings of as much as several tens of nm thickness may be present on the grains, perhaps due to oxidation of the SiC in the solar nebula.

We see little or no evidence on the pristine grains of the surface sputtering or cratering that are predicted theoretically to occur in the ISM due to supernova shocks. A possible implication is that the grains may have been protected during their residence in the ISM by surface coatings, including simple ices. Residues of such coatings may indeed be present on some pristine SiCs, because many (60%) are coated with an apparently amorphous, possibly organic phase. However, at present we do not have sufficient data on the coatings to draw secure inferences as to their nature or origin.

A few irregular pristine SiCs, either fragments produced by regolith gardening on the Murchison parent body or by grain-grain collisions in the ISM, were also observed.

References: [1] Bernatowicz T. and Zinner E. (1997), eds., *AIP Conference Proceedings* **402**. [2] Bernatowicz T. J. and Walker R. M. (1997) *Physics Today*, **50 No. 12**, 26. [3] Zinner E. (1998) *Annu. Rev. Earth Planet. Sci.* **26**, 147. [4] Lodders K. and Fegley B. Jr. (1995) *Meteoritics* **30**, 661. [5] Lodders K. and Fegley B. Jr. (1997) *Astrophys. J.* **484**, L71. [6] Sharp C. M. and Wasserburg G. J. (1995) *GCA* **59**, 1633. [7] Bernatowicz T. et al. (1996) *Astrophys. J.* **472**, 760. [8] Daulton T. et al. (2002) *Science* **296**, 1852. [9] Daulton T. et al. (2003) *GCA*, in press. [10] Chigai T. et al. (2002) *Meteoritics & Planet. Sci.* **37**, 1937. [11] Croat T. K. et al. (2003) *GCA* in press. [12] Huss G. (1997) in *AIP Conference Proceedings* **402**, 721. [13] Huss G. and Lewis R. (1995) *GCA* **59**, 115. [14] Mendybaev R.et al. (2002) *GCA* **66**, 661. [15] Amari S. et al. (1994) *GCA* **58**, 459. [16] Bernatowicz T.et al. (1991) *Astrophys. J.* **373**, L73.

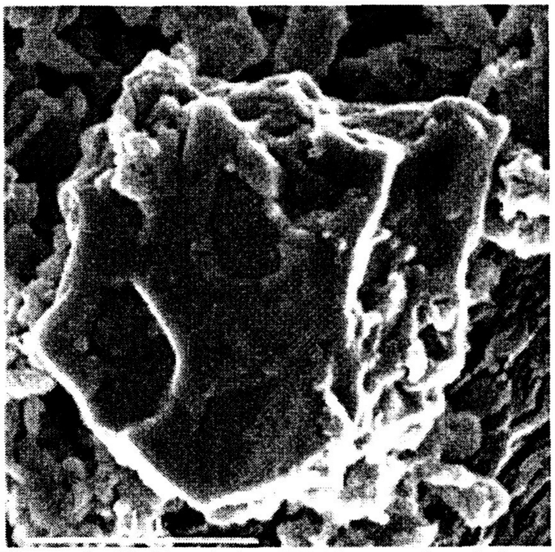

Figure 1: Field emission SEM image of a pristine presolar SiC crystal from Murchison. The angular embayments in the interior are primary growth features probably due to quenching of rapid condensation.

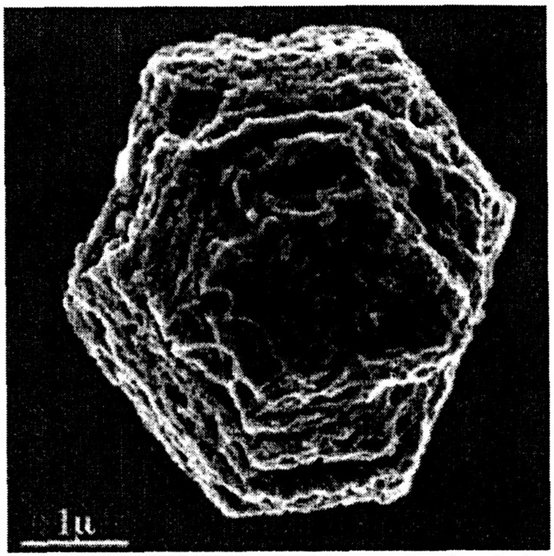

Figure 2: Field emission SEM image of a chemical dissolution presolar SiC crystal from Murchison KJG [15]. Note the stratified appearance as well as the presence of numerous surface etch pits.

THE STARDUST MISSION. D.E. Brownlee[1] and Peter Tsou[2], [1]Department of Astronomy, University of Washington, Seattle, WA, (brownlee@astro.washington.edu), [2] Jet Propulsion Laboratory, Pasadena, CA (ptsou@mail1.jpl.nasa.gov).

The primary goal of the Stardust Mission is to collect >1000 particles >15 micron in diameter from comet Wild2 and return them to Earth in January 2006. The main samples will be captured by 6.1 km s^{-1} impact into low density silica aerogel and additional particles will crater into ~150 cm^2 of 100μm thick pure aluminum foil that covers the aerogel holding grid. It is expected that the impacts into the aerogel will produce tracks that range from deep narrow cones for non-fragmenting particles to shallower more complex tracks for particles that fragment. The impacts into aluminum foil will produce craters but a significant amount of projectile residue is expected to line the crater walls.

The collected samples will be curated at the Johnson Space Center and general sample allocation, (samples that can be requested by all interested parties), will begin ~6 months after return. The first 6 months of analyses will be restricted to preliminary examination done on a small set of simply prepared samples by teams of investigators. The intent is to include as many analysis groups and individuals as is practical in the short duration preliminary examination (PE) effort. The PE effort will focus on basic initial science and it will provide information that will be needed for planning sample investigations for the open and general sample allocation that will follow PE. The PE will be composed of subgroups focused on bulk composition, mineralogy-petrology, organics, rare gases, isotopes and craters.

The Wild2 samples will provide the first opportunity to examine samples from a known comet (or any primitive body). Wild2 is presently in an elliptical orbit that passes from the orbit of Jupiter to the orbit of Mars but prior to its close encounter with Jupiter on September 10, 1974, it was on an orbit that ranged from Jupiter to beyond the orbit of Uranus. Wild2 is a Jupiter family comet and like other comets in this class it is believed to have formed in the Kuiper Belt just beyond Neptune. It is presumed to be an aggregate of solid materials the existed at the outer fringe of the solar nebula accretion disk.

Even thought they formed beyond Neptune, Kuiper Belt objects (KBOs) may well be a complex mix of pre-solar grains, materials transported outwards from the inner solar system and materials modified by KBO parent-body alteration processes. The KBOs formed in a moderately severe collisional environment and some fraction of the initial materials may have been processed by shock and thermal effects related to impacts. In addition, the KBO population contains many large bodies >1000 km in diameter and any Kuiper belt comet could contain components that previously resided inside bodies that were large enough to have moderate internal heating and even aqueous alteration. The Wild2 samples will provide a direct window into the potentially complex mix of materials that accreted to form Kuiper belt comets.

Wild2 samples will provide a fabulous opportunity to compare KBO materials with asteroidal materials that accreted an order of magnitude closer to the Sun. They will provide significant new insight into a wide range of problems related to inner and outer solar system process and materials. Having bona-fide Kuiper Belt materials "in hand" will also provide new insight into the interpretation of astronomical data on comets and circumstellar materials around other stars.

Two examples where simple analyses of the returned sample will provide great synergy between astronomical and meteoritic data are diamonds and "crystalline silicates". If meteoritic diamonds are presolar their abundance in Wild2 should be at least as high as in asteroidal meteorites. If they are not presolar but formed in the solar nebula disk, their abundance in Wild2 would to be lower.

A second astronomical mystery that the Wild2 samples may solve is the odd range of olivine (~forsterite) content in silicates observed by astronomical techniques. Evidence for the presence of olivine in long period comets derived from the Oort cloud is provided by a 11.2 μm fine structure bump on the overall 10 μm infrared "silicate feature" attributed to stretch mode vibrations of the Si-O bond in micron and smaller silicate grains. This "olivine" fine structure is also seen in some circumstellar grains but is not seen for silicate grains in the diffuse interstellar medium nor is it seen for short period comets (derived from the Kuiper Belt). This remarkable situation has been used to suggest that interstellar and KBO silicates are almost entirely amorphous and that the 11.2 olivine (Fo) feature seen elsewhere is the result of thermal annealing of amorphous materials. It has been suggested that Oort cloud cometary materials aggregated interior to the Kuiper belt where temperatures where high enough to form olivine from amorphous precursors. Analysis of the Wild2 samples will clearly reveal the mix of amorphous and crystalline silicates and also provide direct information on their origin and if there is any evidence that crystalline silicate fromed by annealing, direct condensation or some other process.

Detailed study of the expected thousands of returned comet samples will provide a remarkable opportunity to provide links between the sample and astronomical community and a new level of synergy.

LABORATORY ASTROPHYSICS OF SILICATES.

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It is commonly accepted that small objects in the outer part of the Solar System, as comets and Trans Neptunian Objects (TNOs) are a reservoir of partially uncontaminated primordial material from which the Solar System formed about 4.5 billions years ago. Actually, the composition, the physical and structural properties of these objects depend on the formation mechanisms and evolution processes experienced since their accretion. The study of the formation and evolution of comets requires the knowledge of the dynamical evolution of the protosolar nebula where they formed. Infrared (IR) signatures observed both by ground observations and by the Infrared Space Observatory (ISO) have successfully been used for the identification of the types of minerals present in Oort cloud comets and have attracted recently a wide interest of astrophysicists due to the increasing amount and quality of observational data. These observations have posed clear constraints on the chemical composition of silicates, showing that crystalline olivine and pyroxene are abundant. The presence of crystalline grains in Oort comet spectra and the absence or un–observability of crystal signatures in the ISO spectra of dense and diffuse interstellar medium (ISM) raises the question: does the material present in small objects from the external Solar System reflect the physical and chemical properties of the proto–solar nebula? In fact, many competitive processes experienced by the dust affect the physical and chemical evolution of the grains before and after their coagulation in larger objects. In particular, amorphous and crystalline silicates are separated by an energetic gap which has to be overcome by the atoms to move from one structural configurations to the other. Information on possible transformations suffered by the dust may provide evidence for the links between chemical–physical properties of small objects of the Solar System and those of dust in the ISM and around evolved stars.

To understand what the main components of comets are, and what processes affected their nature, dedicated laboratory experiments have been performed. The knowledge of cometary silicate properties is strictly related to the study in the laboratory of the possible formation and transformation mechanisms they experience. The application of production and processing methods, capable to reproduce space conditions, together with the use of analytical techniques to investigate the nature of the material samples, form a subject of a complex laboratory experimental approach directed to the understanding of cosmic matter. The present review is dedicated to the experimental methods applied in various laboratories to simulate and characterise cosmic silicate analogues.

AEROGEL CAPTURE AT THE UNIVERSITY OF KENT.

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Introduction: In order to extract the maximum benefit from space missions using aerogel capture cells, it is necessary to fully understand the capture mechanism and to develop appropriate analysis methods. The capture event in space typically takes place at speeds of many km s^{-1}. This is in what is normally, but misleadingly, called the *H*yper*V*elocity *I*mpact (HVI) regime. HVI typically involves shock pressures that vaporize the projectile. Here of course the whole point of the use of aerogel as the target is to avoid this and capture the projectile relatively intact. However, the tag HVI is often attached to any impact at great than a few km s^{-1} and is thus still used with aerogel capture in space. One recurring feature of HVI studies in general is that models and analytic solutions of the impact event are often insufficient by themselves, and laboratory experimentation is thus crucial in better understanding HVI events. This is particularly true for aerogel capture.

Since the original report [1] of successful capture in aerogel at speeds in excess of a few km s^{-1}, there have been many subsequent reports including work from Kent e.g. [2]. Recently at the University of Kent we switched from examining the mechanical properties of capture (e.g. variation of track length with impact speed [3]) to development of analysis techniques and investigation of physical alteration of samples during capture. These are held to be of more significance as aerogel capture becomes more common and the volume of material collected for analysis increases.

Analysis in-situ: At Kent we initially focussed on in-situ analysis. This offers the captured projectile with minimum contamination (which may arise from extraction). The analysis method must be simple enough to use in a standard, reasonably well equipped laboratory. Previously it was shown elsewhere [4] that X-ray emission stimulated at synchrotron beam lines gave an elemental composition for particles in aerogel, but this is not equipment available in the standard laboratory. Accordingly we selected Raman as the appropriate method and demonstrated that it works with minerals captured in aerogel in HVI conditions [3].The minerals originally used for our Raman studies were olivine and enstatite. Since then other minerals such as pyroxene [5] have also been shown to give recognizable Raman spectra after capture in aerogel. In addition, the organic component of materials can be identified by the broad carbon peaks that can be found at 1350 and 1590 cm^{-1} in Raman spectra. As well as the original minerals (olivine, enstatite and pyroxene) Raman spectra for a wider variety of minerals (e.g. albite, calcite, rhodonite, lizardite) have been obtained and will be shown at the meeting. Current work is looking at capture of organic materials in aerogel. This will also be discussed.

One possible worry about use of Raman is the heating of the sample. Raman works by laser illumination of the sample and collection of the inelastically scattered light. The illumination can involve heating of the particles. Since the particles are small, and embedded in a material famous for its poor heat conduction properties, significant heating may occur. In our work this has found to raise temperatures to 150 to 200 °C. This will be discussed with examples showing that with appropriate caution many types of particles can be successfully studied using Raman techniques.

Extraction: We have also undertaken work on extracting particles from aerogel at Kent. Particles of greater than 100 microns diameter have been extracted and made available for closer study (under SEM for example). Current work is focussing on extraction of particles of less than 100 microns in size. The method involves use of scalpels and drills to cut the aerogel and then extraction using fine needles and tweezers.

Conclusions: Work on capture of particles in aerogel is continuing at the University of Kent using the Kent two stage light gas gun. The emphasis has moved from capture of the particles to their subsequent analysis and characterization. The use of Raman analysis techniques is particularly recommended. This can be combined with subsequent extraction for further study via other methods.

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CAN METEORS BE DIAGNOSTIC OF COMETARY CHONDRULES AND CAIs?

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Studies of the Leonid meteor showers over the past few years have yielded a wealth of results relevant to the structure and composition of cometary solids. One of our goals is to test the existence of chondrules and Ca-Al-rich inclusions (CAIs) in comets based on meteor observations. Chondrule-sized objects would be too faint to study in most meteor showers, but the high velocity (~72 km/sec) of the Leonids (comet Tempel-Tuttle) make these small objects produce meteors in the range of Vmag +3 or +4. There is little consensus about the formation mechanisms for chondrules and CAIs. However, one prominent model (the "X-wind" model [1]) explicitly predicts that chondrules and CAIs will be present in comets. Hence, observational constraints on the presence or absence of chondrules and CAIs in comet Tempel-Tuttle are likely to contribute to a better understanding of their formation process. Evidence could potentially be found in the overall mass distribution of the shower, in chemical analyses of some meteors, or in light curves. There is no evidence for a chondrule abundance in the Leonid meteors similar to that found in chondritic meteorites. There is intriguing evidence for chondrule- or CAI-sized objects in a small fraction of the light curves, but further work is required to generate a definitive test. The STARDUST mission may provide more conclusive results relevant to the presence of chondules and CAIs in comets.

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“DUST BUSTER” -A SINGLE PHOTON IONIZATION TOF MS FOR COMETARY DUSTS.

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It is hard to predict the properties and composition of dust that will be returned by STARDUST from WILD-2. The most interesting but challenging case would be grains, pg to fg in weight, each carrying its own isotopic signature characteristic of its source zones in a variety of stars. How do we extract the maximum amount of science from such grains? Clearly, the best that can be accomplished is to measure every atom in each grain.

All current analytical techniques fall short of this goal but each has a special niche. For instance, the CAMECA Nano-SIMS 50 instrument has very high resolving power plus isotope mapping capabilities. But it can cover only a limited mass range and can detect only six masses during one measurement. In addition, the ionization efficiency for Secondary Ion Mass Spectrometry (SIMS) is below 1% for most elements. Even so, it may be that SIMS is well suited for measuring the major elements in stardust grains while consuming only a very small fraction of the sample prior to completing the analyses of the grain with another technique. On the other hand, resonance ionization in combination with Secondary Neutral Mass Spectrometry (SNMS) has great selectivity and high sensitivity but can only measure a few elements at one time. Laser-ablation ICP-MS can detect all elements at once, but like SIMS also has low instrument efficiency (less than 0.1 %).

Time-of-flight mass spectrometry (TOF MS) is appealing since all masses can be detected simultaneously and single-photon ionization (SPI) is an efficient means of ionizing a large range of elements at once. In SPI, as long as the photon energy is higher than the ionization potential of the elements to be ionized, ionization efficiencies near 100% can be achieved with a reasonable laser flux. Since a typical ionization cross-section is 1Mb, the required laser flux must be near 10^{18} photons/cm^2. In a 0.1 pg sample having a chondritic composition, there is sufficient material so that about two dozen isotope ratios between Li and Cu could be measured without atomic interference at a 3 sigma detection limits of 10%, assuming an instrument efficiency of 30%. At present, the practical limit for SPI is the vacuum ultra-violet (VUV) laser source. The best current option is the 157 nm F_2 laser, which produces photons having an energy of 7.9 eV. This photon energy is insufficient for SPI of many of the major elements of interest to astrophysics, such as C, N, O, Si, S. Another difficulty is molecular interference, especially hydride and hydrocarbon, many of which can be discriminated against with moderate mass resolving power (around 2500) or are small enough to be neglected when detecting large (10%) isotope effect.

Academia Sinica and Argonne National Laboratory (ANL) have entered into a collaboration to develop a SPI TOF MS instrument for analysis of stardust grains. A new instrument will be built at Academia Sinica based on the new TOF mass spectrometer design developed, built and operating at ANL. The instrument is intended for SPI TOF MS analysis of elements from Ca to Cu plus Li after first using SIMS to measure H, C, N, O, Si, and S. There are still technical challenges facing the technique. We will need to improve submicrometer sample handling, avoid the effects of space charge, and increase the dynamic range of the detector. The most difficult obstacle to overcome may be the fact that the flux density of present high repetition rate, VUV lasers is below the level needed to ensure full ionization (saturation) in the source region, which must be several mm in size to achieve the high useful yield needed for analysis of small stardust grains. A potential breakthrough effort is to exploit the novel free electron laser being pioneered at ANL. In principle, this FEL can reach ionization saturation and is tunable up to photon energies of 25 eV, which is higher than the ionization potential of any element. If such high energies can be produced at appropriate energies for SPI, this new FEL will open exciting possibilities such as measuring the isotope ratios of the organic material from comets like the CHONS detected around Halley.

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INFRARED SPECTRA OF MELILITE SOLID SOLUTION. H. Chihara[1,2], A. Tsuchiyama[1] and C. Koike[2], [1]Department of Earth and Space Science, Osaka University, 1-1 Machikaneyama, Toyonaka, Osaka 560-0043, Japan (chi@ess.sci.osaka-u.ac.jp), [2]Laboratory of Physics, Kyoto Pharmaceutical University, Yamashina, Kyoto 607-8412, Japan.

Introduction: We report the infrared optical properties of crystalline melilite solid solution for the first time. Melilite is known as one of a "ring silicate" which have higher equilibrium condensation temperature of 1625 K at a solar nebula pressure of 10^{-3} atm [1]. The general chemical formula for terrestrial sample is represented as $(Ca,Na)_2[(Mg,Fe^{2+},Al,Si)_3O_7]$ [2]. This mineral species commonly occurred in CAIs of primitive chondrite, and in this case, melilite system forms a solid solution between the Al-end member, gehlenite (Ge: $Ca_2Al_2SiO_7$) and the Mg-end member, åkermanite (Åk: $Ca_2MgSi_2O_7$). From an astronomical point of view, melilite is expected to condense in an equilibrium condensation sequence at a slightly higher pressure (~10^{-3} atm) [3]. The optical properties of high temperature condensates give us some important information such as thermal structure or history of circumstellar dust shell, mechanism of nucleation of dust grain and the nature of heterogeneous grain.

In this study, we synthesized the melilite solid solution and measured absorption spectra in the infrared region (6~100 m). In addition, the reflectance spectra for each optical axis were obtained by use of single crystals of the two end members synthesized by the Czochralski (CZ) method [4].

Synthesis of solid solution: Starting materials are reagent grade of $CaCO_3$, Al_2O_3, MgO and SiO_2 powders. Since, the general chemical formula of the solid solution is described as $Ca_2Al_{2(1-x)}Mg_xSi_{1+x}O_7$, ($1\ x\ 0$), the mole ratio of $CaCO_3 : Al_2O_3 : MgO : SiO_2$ follows $2 : 1\text{-}x : x : 1\text{+}x$ for Åk$_X$, where X is the mole percentage of the Åk component (X=100x).

In this study, we synthesized solid solution of Åk$_{100}$, Åk$_{80}$, Åk$_{60}$, Åk$_{50}$, Åk$_{40}$, Åk$_{20}$ and Åk$_{00}$ (Ge$_{100}$). Mixtures of starting materials were heated at subsolidus for each composition for about 90 hours. The products are polycrystalline aggregations of which the grain grown by sintering.

Results: The melilite solid solutions have 15 absorption peaks between 7 and 100 micron wavelength range in a broad way. Absorption peaks located at approximately, 9.8, 10.3, 10.7, 11.4, 11.7, 12.4, 13.1, 14.1, 15.5, 17.0, 20.9, 24.1, 29.5, 36.5 and around 60 m. These absorption features such as peak position, bandwidth and intensity ratio changed systematically depend on the chemical composition. Particularly, the 60 micron features changed drastically; double-structured peaks of Ge united to a single structure at intermediate composition, and again, split to triple structure at the Mg-end member (Åk).

While, reflectance spectra for the two end members were obtained in the wavelength range 1.5~200 m. We can retrive dielectric functions and optical constants (n, k) by applying the Lorentz fit [5] to the reflectance spectra,.

Astrophysical implication and summary: The comparison between the laboratory data and an astronomical spectrum of a planetary nebula (NGC6302) [6] observed by *ISO* (Infrared Space Observatory) was carried out in this study. As a result, we found that the mixture of Åk40~50 and Diopside [7] with 1:1 ratio can reproduce the 60 micron unidentified emission feature of NGC6302. Therefore, we can conclude that crystalline melilite can be considered as another new component of circumstellar dust grain.

And our data sets will supply the spectroscopic basis for the interpretation of astronomical data accumulated by *ISO*, future satellite missions and ground-based observations.

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NEW RESULTS IN PIA ANALYSIS, WITH APPLICATION TO COMETS HALLEY AND WILD 2.

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Introduction: It has long been known, since the Halley flyby missions, that the particles in that cometary coma exhibit not only a great range in physical size, but also span a range of compositions. We report here on new, unpublished results from the continued analysis of data from the Particle Impact Analyzer (PIA) on the Giotto mission which flew through the coma of Halley, less than 600 km from the nucleus, in 1986.

Basis Data: The time-of-flight mass spectrometer (TOF-MS) generated by this instrument during the fast flyby produced approximately 3,600 spectra which could be classified by the sorting tree we have developed.

Of these, over 96% were transmitted at high data compression, using on-board peak identfication and readout, which resulted in fewer minor peaks and also prevented peak centroiding techniques from being used in more detailed analysis on the ground to confirm mass number assignments. Nonetheless, we have shown these data to be representative of the relatively few information-rich spectra that were transmitted.

Approach: A classification scheme adopted here [1] utilizes a key element decision tree, with simple branching. The first major branch in the trunk is for C, with an immediate criterion for Si on both the C and no-C branches. These may be loosely interpreted as mineral and organic branches (although C alone could be graphite or diamond), and the four subsequent branches lead to silicates, non-silicate minerals (e.g., sulfides, oxides), organics, and mixed particles. Subsequent branches result in 23 distinct classifications. Certain classifications can degenerate into other classes if one peak is missing, as can be the case for minor elements. Most of the classes are robust to criteria which provide independent methods of assessing their uniqueness. These data are valuable for relative quantitation of particulate types.

Results: The combination of [Fe, S] occurs only rarely as individual particles, yet it can be shown that S often correlates with Fe at a frequency which exceeds statistical prediction, indicating that FeS grains may be common in the "mixed" particles (the only criterion for which is to contain the four elements C, Mg, Si, and O). Likewise, [Fe,S] accompanies many organic particles, such as in the strict-CHON group, but not those "organics" for which only C and N are present in the spectra (no H, no O).

Similarly, Mg commonly is associated with O-containing "organics", which actually could be consistent with brucite, periclase or magnesite. Comparison of the systemetics of the CHON-classes of particles with those of Clark et al. [2] from PIA and Fomenkova et al. [3] from PUMA data (VEGA missions) confirms general groupings within CHON's but with important quantitative differences.

Numerous "lone" particles are detected, i.e., with just a single element detected. Nonsensical ones, such as H, Ca or O are not interpretable in the context of known or hypothesized constituents of the solar or interstellar neighborhoods. Of greater interest is a preponderance of C lones, which could be inorganic carbon grains which are well known from solar system meteorites and/or their interstellar inclusions.

Several particle types that could have been rationalized but were not detected include NH, FeO, FeC, SiC, and MgS. There are some Fe lones, but at low frequency compared to C.

Applications: Particles from Wild 2 will be analyzed also by TOF-MS, using the CIDA instrument during the Stardust mission flyby. However, the impact velocity will be significantly lower (because of the prograde flyby encounter geometry rather than the energetic retrograde encounter with Halley), with an expectation for a preponderance of molecular fragment ions rather than element ions in the spectra. Nevertheless, the "ground truth" that the analyses of returned samples will provide for CIDA could be helpful in refining the PIA and PUMA results.

Most importantly, the refined analyses of these Halley results will be the *only* method available for ascertaining the similarities and differences in the compositional makeup of the particulate populations of comets Halley and Wild 2. In view of the loss of the CONTOUR comparative cometology mission, these data assume special significance.

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APPROACHES TO ESTABLISHING THE CHEMICAL STRUCTURE OF EXTRATERRESTRIAL ORGANIC SOLIDS.

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The majority of extraterrestrial organic matter in carbonaceous chondrites resides in a chemically complex, insoluble and perhaps macromolecular phase. We have been applying a series of independent solid state NMR experiments that are designed to provide a self consistent chemical characterization of this complex material (see for example Cody et al. 2002).

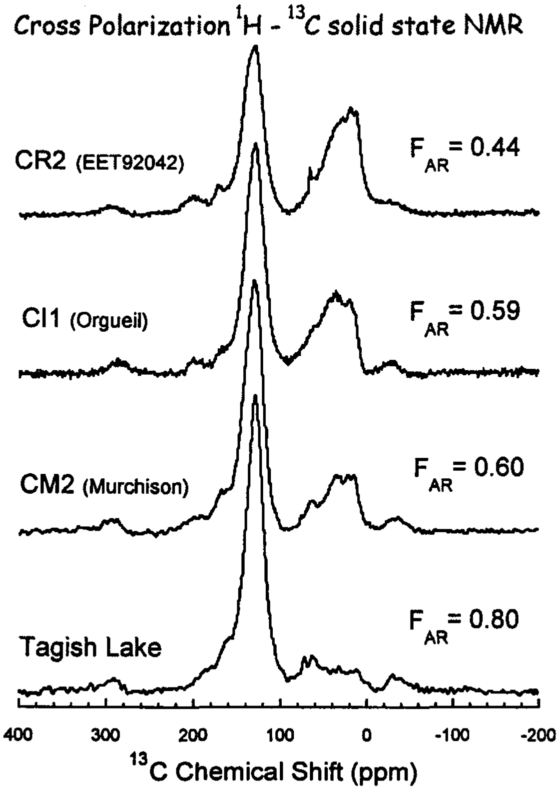

Figure 1: 13C solid state NMR spectra of four organic residues isolated from carbonaceous chondrites

To date we have thoroughly analyzed 8 organic residues from different meteorites, including a CR2 (EET92042), CI1(Orgueil), CM2 (Murchison), Tagish Lake, CM2 (AlH83100), CM2 (Cold Bokkefeld), CM2 (Mighei), CM3 (Y86720). In fig 1. ^{1}H to ^{13}C cross polarization NMR spectra of four of these are shown. Note that there exists an enormous range in chemistry exhibited in organic solid [evident by the breadth of the spectral features both in the aliphatic region (sp^3) and the aromatic region (sp^2)]. There is also considerable differences in the carbon chemistry across the meteorite groups.

As it currently stands the precise origins of such differences in chemistry across the groups and richness in chemistry within the meteorite groups is not well constrained. Scenarios involving either processing prior to parent body accretion or chemical processing within the parent body could be invoked to explain these differences.

As we begin to better understand the chemistry of organic solids in carbonaceous chondrites, the question as to the relationship between these organics and those entrained in inter-planetary dust particles and within comets naturally arises. It is unlikely that we will ever have sufficient mass of organic matter from these sources to apply solid state NMR to solve their chemical structures.

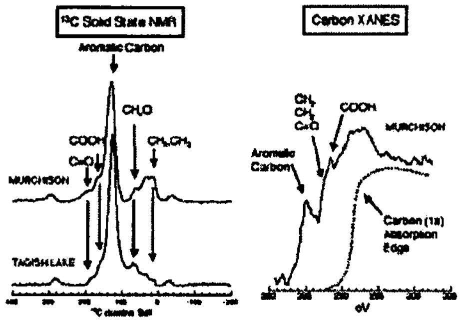

Figure 2: A comparison of ^{13}C solid state NMR spectral information (left) with that derived from Carbon X-ray Absorption Near Spectroscopy (C-XANES). Note that whereas solid state NMR has distinct advantages of C-XANES in that (in principle) signal intensity is directly proportional to the abundance of a given organic functional group a relatively substantial amount of sample is required. Micro C-XANES can be performed on femtogram quantities and is therefore suitable for the analysis of organics in IDP's and cometary samples.

The use of soft X-ray micro-spectroscopy using core to bound state transitions in the pre-edge region of carbon's K edge may provide a means of both comparing the chemical structures of organic solids from meteorites and IDP's (Flynn et al. 2000) as well as with samples obtained from the Star Dust mission. The principle difficulty in extracting information from C-XANES spectra lies in the relatively unknown nature of the types of organic functional groups present as well as the relative oscillator strengths of their characteristic absorption. Note the considerable overlap exhibited in C-XANES spectrum of Murchison, relative to that of its ^{13}C solid state NMR spectrum. Part of this overlap is due to range of oxygen containing functional groups and part may be due to complexity of the aromatic moieties.

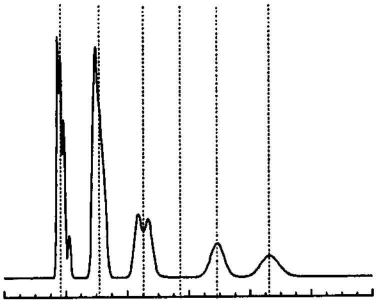

Figure 3: The results of Extended Hückel calculations using the Z+1 approximation for the core level photoexcited state of anthracene. Note of the seven π* states available, the 3π* and 5π* do not exhibit absorption bands. The spectrum is dominated by the 1s to 1, 2, and 4 π* bound states.

The bound states for aromatic molecules include various π* states. Benzene for example has three unoccupied π* states. In the ground state the two lowest energy states are degenerate, however, in the photoexcited state these three states are non-degenarate. The C-XANES spectrum of benzene exhibits two 1s – π* transitions, one very intense transition at ~ 285 eV and an other weaker (~ 25 % as intense) absorption band at ~ 289 eV, the use of extended Hückel calculations employing the Z+1 approximation reveal that for benzene there is no transition intensity corresponding to a 1s-2π* state, rather only the 1s- 1π* and 3π* contribute to the C-XANES spectrum.

An example of such a calculation for anthracene (with seven π* states) is shown in fig. 3. It is clear that these calculations can greatly help deconvolve the C-XANES of organic matter in carbonaceous organic solids. Over the past several years we and others have been developing a large data base of C-XANES spectra of various pure organic compounds. See Fig. 4 for an example of C-XANES spectra of various PAH's. Note that in each case multiple 1s-π* transtions are observed and that the instrinsic line widths of these transitions are relatively narrow when compared with the 285 eV feature of Murchison's C-XANES spectrum shown in Fig. 2.

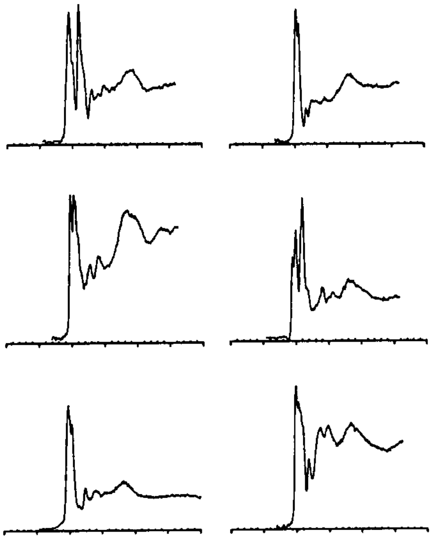

Figure 4: C-XANES spectra of pure PAH's including anthracene, phenanthrene, dimethylnaphthalene, pyrene, crysene, and perylene.

Our goal is to use our detailed chemical information on organic solids from meteorites, derived from solid state NMR, as a basis for quantitative evalution of C-XANES spectra from the same suite of meteorites. We will combine these data with insight and guidance provided from computational approaches, such as extended Hückel calculations. The result will be a data base that will hopefully allow for a quantitative assessment of the chemistry of IDP's as well as future sample return missions, such as Star dust.

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COMET OBSERVATIONS WITH SIRTF.

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Comet observations are included in the programs of the Guaranteed Time Observers (GTO) on the Space Infrared Telescope Facility (SIRTF), scheduled to be in space and operational for five years beginning in late 2003. SIRTF is a cryogenic telescope with three basic instruments for imaging, photometry and spectroscopy from 3.6 m to 160 m. All of these capabilities will be used in studies of comets. The intent is to study the infrared radiation (emission) from comets (and dust tails, where relevant) in all stages of evolution, starting with Kuiper Belt objects and Centaurs (thermal emission at 24, 70, and 160 m to derive dimensions and albedos). Active comets will be observed spectroscopically and in deep thermal images. Several known or suspected extinct comets will be observed spectroscopically (5-37 m) for information on their surface compositions. There are opportunities for Guest Observers (GO) to propose additional comet work.

STARDUST AND Stardust: ISOTOPIC COMPOSITIONS OF TRACE ELEMENTS IN SINGLE CIRCUMSTELLAR GRAINS.

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Introduction: Presolar SiC and graphite grains recovered from primitive meteorites have large isotope anomalies in major, minor and trace elements [1]. The isotopic compositions of heavy trace elements (Kr and heavier) in single grains provide a particularly rich record of nucleosynthesis in red giant stars and supernovae. Most presolar grains are carbon-rich and form around stars with C/O>1. However, most stars (including the Sun) have C/O<1 and their rocks are made of oxides, silicates and sometimes, water. A long-standing question in the presolar grain studies is whether this is simply a selection effect, because SiC and graphite are able to survive the harsh chemical treatment of meteorites needed to extract them, or that oxides and silicates are so highly processed in the solar nebula that their presolar record is obscured. We review the heavy element isotopic compositions of known presolar grains and speculate on the isotopic compositions of the oxides and silicates that must be more abundant among the interstellar grain population.

SiC and Graphite: Based on C, N and Si isotopic compositions, most SiC grains (~90%), the mainstream grains, are believed to come from low-mass (1.5–3 $M_\odot$) asymptotic giant branch (AGB) stars. These stars are the principal sources of heavy elements produced by the *s*-process. The AGB origin of mainstream grains was confirmed first with measurements of *s*-process isotope enhancements in Kr, Sr, Xe, Ba, Nd, Sm and Dy [1] in aggregates of many grains. The development of laser ablation laser resonant ionization mass spectrometry [2,3] led to measurements of Sr, Zr, Mo and Ba in μm-sized single SiC and graphite grains and a much deeper understanding of nucleosynthesis in AGB stars [4,5,6,7,8,9]. The latest element to be measured in presolar SiC grains is Ru, which shows evidence for in situ ^{99}Tc decay after SiC grain condensation [10]. Approximately 2% of presolar SiC, the X-grains, form in Type II supernovae [1]. These grains have quite unusual Zr, Mo and Ba isotopic compositions that indicate that a previously unrecognized mechanism for heavy element nucleosynthesis is at work in supernovae [11]. A neutron burst process due to the explosion shock wave passing through supernova shells rich in ^{22}Ne [12] can produce the large excesses in ^{96}Zr, ^{95}Mo, ^{97}Mo and ^{138}Ba seen in SiC X-grains.

STARDUST Samples: Interplanetary dust particles (IDPs), consisting predominantly of oxides and silicates, are believed to come from comets, and are may be similar to dust from comet Wild 2 to be returned by the STARDUST mission. Although they do contain organic matter and even nanodiamonds [13], no SiC has been reported from an IDP. It is also unclear what the abundance of SiC, graphite and other reduced phases is in genuine interstellar grains, a few of which are expected to be collected by STARDUST. The AGB stars that produce most of the SiC grains appear to form with initially solar isotopic compositions of heavy elements [5,9,10] and likely with approximately solar C/O ratios. AGB stars are normal low mass stars that have finished with the main sequence of stellar evolution. They have a C-O core and alternately burn H at the base of the envelope and He in the helium shell. This causes newly synthesized carbon to be dredged up into envelope. During this stage, AGB stars lose a substantial fraction of their mass (they produce ~90% of the dust returned to the interstellar medium from stars). They begin by condensing oxides and silicates and end by condensing SiC and graphite. Based on models of *s*-process nucleosynthesis in AGB stars [8], oxides and silicates from the earlier stages of AGB star dust production are expected to be enriched in *s*-process isotopes, but not by as large a factor as are observed in SiC grains. Silicate grains from AGB stars have been identified in IDPs, based on oxygen isotopic compositions [14]. Thus, cometary grains collected by STARDUST are likely to contain circumstellar stardust. Isotopic compositions of minor and trace elements in these grains can be measured by sputtering or laser ablation followed by laser resonant ionization mass spectrometry and should be very revealing about sources and interstellar processing of interstellar grains.

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COMPLEX ORGANICS FROM LABORATORY SIMULATED INTERSTELLAR ICES.

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Many of the volatiles in interstellar dense clouds exist in ices surrounding dust grains. The low temperatures of these ices ($T < 50$ K) preclude most chemical reactions, but photolysis can drive reactions that produce a suite of new species, many of which are complex organics. We study the UV and proton radiation processing of interstellar ice analogs to explore links between interstellar chemistry, the organics in comets and meteorites, and the origin of life on Earth. The high D/H ratios in some interstellar species, and the knowledge that many of the organics in primitive meteorites are D-enriched, suggest that such links are plausible [1]. Once identified, these species may serve as markers of interstellar heritage of cometary dust and meteorites.

Of particular interest are our findings that UV photolysis of interstellar ice analogs produce molecules of importance in current living organisms, including quinones, amphiphiles, and amino acids. Quinones are essential in vital metabolic roles such as electron transport. Studies show that quinones should be made wherever polycyclic aromatic hydrocarbons are photolyzed in interstellar ices [2]. In the case of anthracene-containing ices, we have observed the production of 9-anthrone and 9,10 anthraquinone, both of which have been observed in the Murchison meteorite [3]. Amphiphiles are also made when mixed molecular ices are photolyzed. These amphiphiles self-assemble into fluorescent vesicles when placed in liquid water, as do Murchison extracts [4]. Both have the ability to trap an ionic dye. Photolysis of plausible ices can also produce alanine, serine, and glycine as well as a number of small alcohols and amines [5]. Flash heating of the room temperature residue generated by such experiments generates mass spectral distributions similar to those of IDPs [6].

The detection of high D/H ratios in some interstellar molecular species, and the knowledge that many of the organics, such as hydroxy and amino acids, in primitive meteorites are D-enriched provides evidence for a connection between intact organic material in the interstellar medium and in meteorites. Thus, some of the oxidized aromatics, amphiphiles, amino acids, hydroxy acids, and other compounds found in meteorites may have had an interstellar ancestry and not solely a product of parent body aqueous alteration. Such compounds should also be targeted for searches of organics in cometary dust.

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ICES AND CARBON CHEMISTRY IN COMETS.

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Introduction: Our knowledge on the composition of small bodies is mainly determined from remote observations, however, fragments such as meteorites and interplanetary dust particles (IDPs) are frequently transported to Earth and provide the only extraterrestrial material which can be measured directly in laboratories. The cometary composition has been revisited through extensive observations of the very bright comets of the last decade, Hale-Bopp and Hyakutake. Though much has been learned about the coma chemistry our knowledge on the comet nucleus is still rather scarce.

Cometary nuclei, being porous and stratified in various layers of different densities and temperatures are furthermore characterized by different coexisting ice phases, clathrates, and trapped gases. This leads to a rather complicate outgassing pattern. The bulk of cosmic carbon in the interstellar medium, and meteorites seems to be incorporated into complex aromatic networks. This strongly indicates that such networks must also be represented in comets.

We present recent observation, results from interstellar laboratory ice simulations and the analysis of the carbon fraction of meteoritic samples. A combined analysis using astronomical observations, laboratory simulations and analysis of extraterrestrial material allows us to reveal the composition of comets, to establish an inventory of material that could have been transported to the early planets via extraterrestrial delivery and to provide insights into the origin of our solar system.

HIGH TEMPERATURE COMPONENTS IN CARBONACEOUS CHONDRITES AND COMETS: SOME INTERESTING COMPARISONS.

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Introduction: The diverse components in the many different kinds of chondritic meteorites record a long and complex history of events in the early solar system, from high temperature condensation and melting through aqueous alteration on undifferentiated asteroids. All but the most resilient presolar grains were heavily processed to the point of destruction in most chondrites. In contrast, comets are likely to preserve a more pristine record of the solid materials that comprised the nebular cloud that preceded our solar system [1]. For this reason a close comparison of the major components of the most primitive (carbonaceous) chondrites, CCs, with those of comets can be very instructive in terms of understanding the original materials and the processes that affected them.

Components of chondrites: Carbonaceous chondrites are composed of highly variable proportions of chondrules, Ca-Al-rich inclusions (CAIs), amoeboid olivine aggregates (AOAs), accretionary rims, dark inclusions, matrix, presolar grains, and secondary minerals [2]. In addition, hydrous alteration products indicate that ices were present in some chondrite parent bodies [e.g., 3]. Dark inclusions are typically not abundant, but may prove to be significant because, in spite of their great variety, they are usually finer-grained and show more evidence of hydrous alteration than their host chondrites [4], as might be expected for cometary materials. CAIs and AOAs also exhibit great variety, but are characterized by a relatively small number of refractory minerals and most of them have distinct ^{16}O-rich isotopic compositions [5, 6]. The fine-grained accretionary rims that mantle CAIs and other objects have (where unaltered) mineralogy and oxygen isotopic compositions indicative of high temperature condensation from an ^{16}O-rich nebular gas [6].

CAIs, AOAs, and nebular mixing: The refractory mineralogies of CAIs, AOAs, and accretionary rims require petrogenesis in a high-temperature (>~1250K) setting. Their ^{16}O-rich compositions are consistent with formation in a single, probably spatially restricted, ^{16}O-rich oxygen reservoir followed by dispersal to chondrite-forming regions [7, 8]. The recent finding [9] that chondritic CAIs contained the short-lived nuclide ^{10}Be (of non-presolar origin) at the time of their formation suggests that they probably originated close to the sun (see however [10]). These results are consistent with the "X-wind" model [11], in which CAIs formed very close to the protosun and then were ballistically ejected to great radial distances in the nebula by high-angle (to the plane of the nebula) winds emanating from magnetically active areas near the sun. One prediction of this model is that CAIs, AOAs, and accretionary rim grains should have been dispersed throughout the nebular disk, and thus they should be present in cometary material. Therefore the variety, abundance, and isotopic properties of such materials in comets vs. chondrites may serve as a test for the scale of radial mixing in the nebula in general, and for an X-wind origin for CAIs [11]. It is interesting in this regard that CAIs, some with ^{16}O-rich compositions, have been identified in interplanetary dust particles (IDPs). This has been used to argue for a link between IDPs and carbonaceous chondrites or related extraterrestrial materials [12-14].

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IN SITU MEASUREMENTS AND LABORATORY ANALYSES OF INTERPLANETARY DUST PARTICLES.

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Introduction: Analyses performed so far on interplanetary dust particles have been based on in situ measurements or laboratory analyses after retrieval, separately. An important improvement for future missions is represented by the possibility of measuring in situ dynamic properties of single grains to be, subsequently, retrieved from the collecting devices (e.g., aerogel collectors) for laboratory analyses. In the present paper we report about a preliminary study performed on a system based on the use of aerogel collectors and optical detection device. Moreover, particles retrieved from aerogel collectors, exposed on the Mir station, and interplanetary dust particles, obtained from NASA, have been analysed in our laboratory.

In situ measurements: The instrument under study is an in situ dust monitoring and collecting system. It consists of two modules placed in cascade. Module 1 is an active system constituted by an optical sensor; Module 2 is a passive system constituted by an aerogel collector. The sensitive area is 100 cm^2. The configuration has been chosen in order to have a new typology of measurement by which it is possible to univocally associate a measurement of dynamical properties to a collected particle, whose morphological, chemical and physical characteristics will be explored in laboratory once the payload has been returned to Earth. In particular, the instrument allows the determination of velocity and trajectory of dust particles.

Laboratory analyses: The know-how developed by our team in the field of handling/preparation/analysis of macro and micro terrestrial samples, e.g. cometary dust analogues, allowed us to set out the analysis of interplanetary dust particles. In addition, we developed a laboratory procedure for the analysis of particles captured in aerogel.

Laboratory analyses include mineralogy characterisation by means of micro-IR spectroscopy, microanalysis by means of Energy Dispersive X-Ray technique and morphology characterisation by means of high spatial resolution Scanning Electron Microscopy.

We successfully applied our techniques to grains captured in silica aerogel collectors, provided by our laboratory, during the Leonid meteor shower, in Nov. 98 onboard the Mir station. Moreover, ten Interplanetary Dust Particles (IDP's) were allocated by NASA-JSC to our group in Naples, for research purposes. The grains were delivered on special holders designed by our team and have been analysed.

ANALYSIS OF THE ORGANIC MATTER IN INTERPLANETARY DUST PARTICLES: CLUES TO THE ORGANIC MATTER IN COMETS, ASTEROIDS, AND INTERSTELLAR GRAINS.

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Introduction: Reflection spectroscopy suggests the C-, P-, and D-types of asteroids contain abundant carbon, but these Vis-nearIR spectra are featureless, providing no information on the type(s) of carbonaceous matter. Infrared spectroscopy demonstrates that organic carbon is a significant component in comets and as grains or grain coatings in the interstellar medium. Most of the interplanetary dust particles (IDPs) recovered from the Earth's stratosphere are believed to be fragments from asteroids or comets [1], thus characterization of the carbon in IDPs provides the opportunity to determine the type(s) and abundance of organic matter in asteroids and comets. Some IDPs exhibit isotopic excesses of D and ^{15}N, indicating the presence of interstellar material [2]. The characterization of the carbon in these IDPs, and particularly any carbon spatially associated with the isotopic anomalies, provides the opportunity to characterize interstellar organic matter.

Measurement Techniques: We have characterized the carbon in both anhydrous and hydrated IDPs and compared it to the carbon in carbonaceous meteorites using two synchrotron-based instruments that offer both *high sensitivity* and *high spatial resolution*:

1) a Scanning Transmission X-ray Microscope (STXM) to: a) determine the C-abundance by mapping the spatial distribution of carbon in ultramicrotome thin sections of IDPs, and b) identify functional groups in the C-rich spots using C-, N-, and O- X-ray Absorption Near-Edge Structure (XANES) spectroscopy, and,
2) a micro-Fourier Transform InfraRed (μ-FTIR) spectrometer to identify C functional groups.

Results: We have performed C-XANES spectroscopy on 13 IDPs [3], 8 anhydrous and 5 hydrated, O-XANES spectroscopy on 3 IDPs, and N-XANES spectroscopy on 2 IDPs [4]. We performed FTIR spectroscopy on 19 IDPs, 14 anhydrous and 5 hydrated, 6 of which were also analyzed by C-XANES [3].

Carbon Mapping Results. The absorption of C increases strongly at the C K-edge (~290 eV), so we map the C, with a spatial resolution of ~100 nm, by comparing the absorption at the same pixel just below and just above 290 eV. In the IDPs, carbon occurs in highly varying abundances, ranging from a few vol-% up to >90 vol-% [5] and three different morphologies:

1) thin (~100 nm) coatings on individual grains,
2) discrete sub-μm to μm carbonaceous units, and,
3) thick (~1/2 μm) coatings on grain aggregates, apparently "glue" holding subunits together.

XANES Results. We identified C=C bonds (typically found in the C-ring) by C-XANES [5], and carbonyl (C=O) by C- and O-XANES [6] in both hydrated and anhydrous IDPs. The concentrations vary from one IDP to another, but the mean concentrations of both species are ~1 to 2 wt-% [3]. The presence of organic matter in anhydrous IDPs demonstrates that aqueous alteration was not required to produce the bulk of the pre-biotic organic matter in the Solar System [7].

Infrared Results. We identified aliphatic C-H_2 and C-H_3 [5], and carbonyl [8] in both hydrated and anhydrous IDPs by FTIR. The C-H stretching region spectra of both anhydrous and hydrated IDPs differ from the spectrum of Murchison acid residue and literature spectra of the interstellar organic matter [3]. The C-H_2 to C-H_3 ratio of IDPs is higher than either Murchison residue or interstellar organic matter. Since the simplest aliphatic hydrocarbons are chains of C-H_2 terminated at both ends by C-H_3, the aliphatic hydrocarbons in both anhydrous and hydrated IDPs have a significantly longer mean chain length than either the aliphatic organics in Murchison or the interstellar grains.

D-Rich IDPs: We examined ultramicrotome slices of three D-rich IDPs in which Messenger previously located D hot-spots. In each case the D hot spot is spatially correlated with high-C, determined by STXM C-mapping, demonstrating that, at least in the IDPs we examined, the D is concentrated in organic matter, rather than water [9]. C-XANES of these D hot spots demonstrates the presence of C=C and carbonyl, and FTIR demonstrates the presence of aliphatic hydrocarbon. However, the infrared spectra of the organic matter in D-rich IDPs has a much higher C-H_2/C-H_3 ratio than is found in the interstellar medium [9].

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A SYNCHROTRON-BASED FACILITY FOR THE IN-SITU CHEMICAL AND MINERALOGICAL ANALYSIS OF ~10 µm PARTICLES IN AEROGEL.

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Introduction: Aerogel is an effective capture medium for hypervelocity particles. Aerogel particle collectors were employed on the MIR Space Station to collect orbital debris and interplanetary dust particles (IDPs), and are being employed on the NASA Stardust mission to collect dust during a fly-through of the Comet Wild-2 coma. Discovery class sample return missions hold the promise of high scientific return for low cost, so future missions using Stardust-like collection techniques are likely to be proposed. Aerogel collection has been proposed for the "Sample Collection for Investigation of Mars" mission to collect Mars' atmospheric dust in aerogel and return it to Earth.

In-Situ Analysis: Most analysis techniques require extraction of the particle from the aerogel. However, hard x-rays (>a few keV) penetrate centimeters into low-density aerogel, allowing chemical and mineralogical analysis of particles deep inside aerogel blocks. Particle extraction runs the risk of contamination or particle loss, so *in-situ* preliminary characterization, which may identify rare particle types, is desirable.

The X26A microprobe [1] uses x-rays from a bending magnet on the x-ray ring of the National Synchrotron Light Source at Brookhaven National Laboratory, which produces a white-light distribution of x-rays, with a peak in intensity at ~10 keV. These x-rays pass through a Si (111) channel-cut monochromator, tunable from 3 to 20 keV, and are focused, using a pair of Kirkpatrick-Baez mirrors, to a spot as small as 10 µm.

X-Ray Fluorescence Chemical Analysis. X-rays induce electron transitions from the core electronic shell to higher energy electron orbitals or the continuum. The resulting core vacancy is quickly filled by an electron in a higher orbital. We detect the resulting fluorescence x-ray with a Canberra SL30165 Si(Li) detector placed at a 90° angle to the incident x-ray beam, the position that provides maximum signal-to-noise.

We demonstrated, using fragments of the carbonaceous meteorite Allende shot into 20 mg/cm^3 silica aerogel, that we can detect elements as light as: a) Al to a depth of ~0.1 mm, b) Ca to a depth of a few mm, and, c) Fe to a depth of several cm [2]. If there are no interferences from elements in the aerogel, the detection limit for most elements from Cr to Sr is ~5 ppm in an ~10 µm particle. We analyzed an ~4 µm particle captured in silica aerogel exposed on MIR and analyzed the aerogel off the particle. Chromium, Mn, Fe, and Ni are present in this particle in a roughly "chondritic" pattern [3], confirming it is extraterrestrial. However trace amounts of Cu and Zn in the aerogel precluded determination of the abundances of these moderately volatile elements, which can distinguish among types of chondritic material. *Thus it is critical that flight aerogel be remarkably clean of any elements to be analyzed in the captured particles!*

X-Ray Diffraction Mineral Analysis. Aerogel, an amorphous silicate, produces only broad x-ray scattering. We employ a Bruker SMART CCD system to acquire the x-ray diffraction patterns of ~10 µm particles in aerogel. An extraterrestrial particle, 2DO3No.1, captured on MIR produced diffraction at three of the d-spacings of fayalite [4]. Silica aerogel is transparent over much of the mid-infrared, and the types of olivine and pyroxene can be distinguished by infrared absorptions. Keller and Flynn [5] confirmed the dominant silicate in 2DO3No.1 is fayalite by in-situ synchrotron-based infrared analysis.

XANES Bonding State Analysis. Hoffman et al. [6] distinguish the "reduced" CV3 chondrites (e.g., Vigarano) from the "oxidized" CV3 chondrites (e.g., Allende) by Fe-bonding state. We determine the Fe-bonding state using in-situ X-ray Absorption Near-Edge Structure (XANES) analysis, and have performed this analysis on extraterrestrial particles ~10 µm in aerogel. Determination of the oxidation states of other elements, e.g., chromium, should be possible [7].

Characterization of Debris Along Tracks: Weak particles can break up during aerogel capture and volatile elements or compounds may partially vaporize during capture. We are upgrading the X26A facility to perform chemical analysis of particles and vapor and computed microtomography to map the distribution of fragments (>2 µm) along the entry track. Small fragments or vapor deposited along the entry track are likely to be destroyed during extraction of the main particle, making in-situ characterization critical.

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INFRARED SPECTROSCOPY OF THE DUST IN COMETS AND RELATIONSHIPS TO INTERSTELLAR DUST

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Infrared spectroscopy of the dust in comets reveals a complex mix of silicate materials, including both crystalline and non-crystalline components of both olivine (forsterite) and pyroxene composition. These various components do not necessarily share a common origin. Since comets formed in cold regions of the solar nebula, pre-solar grains in the nebula could have been accreted into comets with little alteration. Some of the cometary silicates may be of circumstellar (formed in circumstellar outflows of evolved stars) or interstellar (formed in dense region of the interstellar medium) origin. Spectral similarities to both circumstellar and interstellar silicates are seen in comet spectra.

While some comets, such as Hale-Bopp, display a rich infrared spectrum, others (particularly the short-period Kuiper Belt comets) show weak or no spectral features. The lack of features is generally explained as a particle size effect: the small silicate grains are embedded in larger, optically thick particles. However, compositional differences cannot be ruled out. For example, no unambiguous signature of forsterite has yet been seen in the spectrum of a short-period comet.

Thus, the Stardust sample from short-period comet P/Wild 2 will be extremely valuable. Not only grain by grain composition and isotopic ratios but also grain morphology, irradiation history, and evidence of organic refractory mantles are important for understanding their origin. The relative abundance and distinguishing characteristics of the various crystalline and non-crystalline silicate components needs to be established.

CAN PROCESSES USED TO EXTRACT PRESOLAR GRAINS FROM METEORITES BE USED TO PROCESS GRAINS TRAPPED IN AEROGEL?

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Introduction: Over the years, an extensive set of procedures based on chemical and physical properties of minerals have been developed to separate the known types of presolar materials from chondritic meteorites [e.g., 1-4]. While these procedures can be likened to burning down the haystack to find the needle, some aspects may be useful for handling samples trapped in aerogel. The utility of these methods will depend on the chemical resistance of the particle of interest, which could be determined in advance by non-destructive X-ray analysis or a related technique.

Chemical Dissolution: Depending on the nature of the material trapped in the aerogel, it may be feasible to dissolve away the aerogel and leave the particle behind. HF is particularly effective at breaking silicate bonds, converting SiO_2 to SiF_4, which is a gas at room temperature. In meteorite studies, a relatively large amount of acid is used in many cycles, with the used acid removed by decanting or by pipette. This results in some losses of small particles due to adherence to the walls of the containers or inadvertent removal with used liquids. However, the procedure could be miniaturized, particularly if aerogel is not too complicated chemically. Note that the chemical oxidation originally used in test tubes by [1] to remove the "Q" noble gases in meteorites has been adapted to the vacuum inlet system of a noble-gas mass spectrometer [5].

Possibility #1: A small piece of aerogel containing the sample of interest could be placed on a gold or carbon substrate. HF (or other acids) could be added, drop by drop, and allowed to react and evaporate. Volatile reaction products would evaporate as well, but non-volatile products would precipitate onto the substrate. The procedure could be monitored by optical microscope (with care taken to protect the observer and microscope from the acid fumes). Ideally, the sample could be measured on the gold foil or graphite planchette where the processing took place. However, in some cases the sample might have to be transferred for analysis. Transfer could be accomplished either wet or dry depending on the size and characteristics of the sample.

Possibility #2: The aerogel and sample could be placed into a tiny Teflon container. Chemicals could again be added one or a few drops at a time. The main trick to this procedure will be to get the liquids to wet the sample so reactions can take place. Surface tension is a problem for tiny grains, so surfactants may be necessary. Under ideal conditions, it might be possible to centrifuge the container and remove the liquid with a micropipette, leaving the sample in the Teflon tube. One potential problem is that unless the sample is relatively large (>10 microns?), the processing may have to be done largely "blind". However, if the procedure is carefully developed ahead of time, this need not be an insurmountable problem.

Surface Properties: The surface properties of materials become increasingly important in governing the behavior of particles as grain size decreases. For example, micron-sized grains will stick tenaciously to a substrate via Van der Waals forces. Once, to my horror, I inadvertently dropped one of my carefully mapped grain mounts (a stainless-steel "bullet" with a gold foil pressed into the top to hold the sample) and watched it bounce across the table. The grains had been deposited from a liquid and were not pressed into the foil. I put the mount back in SEM and found that none of the grains had moved from its previous location! Surface properties might be utilized to separate components of a trapped particle or simply to transfer the particle from place to place.

Separating Particles. Grain surfaces can be either hydrophilic or hydrophobic, which operationally means that some wet easily (hydrophilic materials) and others do not. Many carbon-rich compounds are hydrophobic and tend to float on aqueous acid solutions or stick to the container walls. Separating such materials might be as simple as adding a drop of distilled water. Hydrophilic would be swallowed by the drop, while hydrophobic materials would be kept outside.

Sample Transfer. One of the easiest ways to transfer tiny particles is to incorporate them into a drop of liquid and then transfer the liquid with a Teflon pipette. Liquids with low surface tension (e.g., isopropanol) wet the sample more easily, but they also can leave the sample behind as they evaporate. In contrast, water, which has high surface tension, can capture a particle within the droplet and can drag it along as a drop is moved or can pull particles into a pile as a drop evaporates.

Although the chemical and physical manipulations described above may not be required for many types of analysis, in certain cases they may be the only way to prepare a sample for analysis.

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THE NATURE OF INTERSTELLAR DUST. G. R. Huss, Department of Geological Sciences, Arizona State University, Box 871404, Temp, AZ 85287-1404, USA. (gary.huss@asu.edu)

Introduction: The STARDUST mission is designed to collect dust the coma of comet Wild 2 and to collect interstellar dust on a second set of collectors. We have a reasonable idea of what to expect from the comet dust collection because the research community has been studying interplanetary dust particles for many years. It is less clear what we should expect from the interstellar dust. This presentation discusses what we might expect to find on the STARDUST interstellar dust collector.

The list of recognized and suspected types of presolar materials acquired by the solar system from the sun's parent molecular cloud continues to grow. Most, but not all, are circumstellar condensates. The list includes highly refractory and chemically resistant phases (Al_2O_3, hibonite, spinel, diamond, SiC), refractory but chemically reactive phases (graphite, silicon nitride), and thermally and chemically unstable material (D-rich hydrocarbons, GEMS). However, there are two powerful lines of evidence that the currently recognized presolar materials are the "tail wagging the dog" with respect to the inventory of materials that made up the sun's parent molecular cloud.

One line of evidence is astronomical and comes from comparing the dust production rate from dying stars and the dust destruction rate in interstellar space. The dust destruction rate is significantly faster than the production rate [1]. Yet, the condensable elements are strongly depleted from the gas phase compared to cosmic abundances in interstellar space, and the most refractory elements are the most highly depleted [2]. The implication of these observations is that the condensable elements must recondense in interstellar space, most probably in dense molecular clouds where grain temperatures are low enough for any condensable gas atom striking a grain to stick [1]. The resulting condensed material is likely to be highly amorphous and chemically unstable, true interstellar dust rather than circumstellar condensates. This dust is also likely to be isotopically relatively "normal", because it forms from atoms produced in all types of stars. Thus, astronomical considerations predict that much of the condensed material in the sun's parent molecular cloud was amorphous, chemically unstable, isotopically almost normal dust. We have not identified such material in meteorites or IDPs, but this is not surprising considering how easily such material might be altered in the solar system and how crude our methods for extracting and recognizing presolar materials are.

The other line of evidence comes from meteorites. First, the known types of presolar grains do not add up to the solar system bulk composition. The missing elements did come into the solar system, and the temperatures in the sun's parent molecular cloud require that they came in as dust. Thus, we have failed to identify the largest component of presolar material that came into the solar system. Second, the known types of presolar grains occur in different relative abundances in the unmetamorphosed members of different chondrite classes [3]. The assemblage in each chondrite class reflects the thermal and chemical environment present just prior to accretion. The degree of processing indicated by the assemblages of presolar grains correlates with the degree of thermal processing necessary to produce the bulk compositions of the hosts meteorites from bulk solar-system material [3-5]. This implies that the same processing that produced the chondrite classes also modified the presolar grains and further suggests that thermal processing of presolar dust (not evaporation and recondensation) was a dominant process in the early solar system.

Both the astronomical and meteoritic evidence require that a major fraction of the interstellar dust has gone unrecognized to date. However, it is not entirely clear to what extent with the STARDUST mission gives us access to that material. The largest depletions of condensable elements are seen in cold molecular clouds. The sun is currently in an old supernova bubble, so one might expect that much of the least stable molecular cloud dust has been destroyed or annealed. Types that might be expected thus include: 1) currently recognized and new types of circumstellar condensates (relatively low abundance), 2) radiation-processed condensates (GEMS?), 3) various types of annealed interstellar material, including grains with organic coatings. There will also likely be some "noise" of interplanetary dust. Type 1 is the only type that can be expected to be highly isotopically anomalous in at least some elements, although the second type might be anomalous. Type 3 grains, at least the silicate/oxide portion, are likely to be isotopically unremarkable, though perhaps not exactly solar in composition. Organic coatings may retain the isotopic signatures that would confirm an interstellar origin.

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MIGRATION OF DUST PARTICLES FROM COMET 2P ENCKE.

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We investigated the migration of dust particles under the gravitational influence of all planets (except for Pluto), radiation pressure, Poynting–Robertson drag and solar wind drag for β equal to 0.002, 0.004, 0.01, 0.05, 0.1, 0.2, and 0.4. For silicate particles such values of β correspond to diameters equal to about 200, 100, 40, 9, 4, 2, and 1 microns, respectively. We used the Bulirsh–Stoer method of integration, and the relative error per integration step was taken to be less than 10^{-8}. Initial orbits of the particles were close to the orbit of Comet 2P Encke. We considered initial particles near perihelion (runs denoted as $\Delta t_o = 0$), near aphelion ($\Delta t_o = 0.5$), and also studied their initial positions when the comet moved for $P_a/4$ after perihelion passage (such runs are denoted as $\Delta t_o = 0.25$), where P_a is the period of the comet. Variations in time τ when perihelion was passed was varied with a step 0.1 day for series 'S' and with a step 1 day for series 'L'. For each β we considered $N = 101$ particles for "S" runs and 150 particles for "L" runs.

In our runs planets were considered as material points, but, basing on orbital elements obtained with a step 20 yr, similar to [1] we calculated the mean probability P=P_Σ/N (P_Σ is the probability for all N considered particles) of a collision of a particle with a planet and the mean time T=T_Σ/N during which perihelion distance q of a particle was less than a semi-major axis of the planet. For considered cometary dust particles, the values of T were not differed much for Venus, Earth, and Mars, but they differed by a factor of several for asteroidal dust particles [2].

Below $P_r = 10^6 P$ and T_l is the largest lifetime of a particle in series of runs. We studied the motion of particles until the last particle collided with the Sun or reached 2000 AU from the Sun. The results obtained are presented in Table 1.

Table 1: Values of P_r, T and T_l (in Kyr) (Venus=V, Earth=E, Mars=M)

			V	E	E	M	
β	Δt_o		P_r	P_r	T	P_r	T_l
0.002	0	S	470	200	94.6	12	551
0.002	0	L	632	208	93.6	14	370
0.004	0	S	370	148	62.9	8.9	213
0.004	0.25	S	430	160	55.0	9.3	109
0.004	0.5	S	235	140	56.3	8.1	108
0.01	0	S	191	105	25.1	5.4	67
0.01	0	L	386	163	28.5	6.4	80
0.01	0.25	S	238	86	24.2	4.2	59
0.01	0.5	S	123	56	22.6	3.8	49
0.05	0	S	120	59	9.3	5.7	1070
0.05	0	L	142	67	7.8	2.9	86
0.05	0.25	S	37	20	4.6	1.6	5
0.05	0.5	S	96	37	6.4	2.3	21
0.1	0	L	23	9.1	6.1	0.6	229
0.1	0.25	S	22	8.6	2.8	0.6	3
0.1	0.5	S	13	6.6	2.7	0.47	3
0.4	0.25	S	24	4.3	1.3	0.32	2
0.4	0.5	S	13	3.5	1.4	0.22	2

All particles collided with the Sun at $\beta \leq 0.01$ for $\Delta t_o = 0$, and at $\beta \leq 0.2$ for $\Delta t_o \geq 0.25$. Relatively large values of T_l for 'S' runs at $\beta = 0.05$ and $\Delta t_o = 0$ and for 'L' runs at $\beta = 0.1$ and $\Delta t_o = 0$ were due to the particles that reached 2000 AU from the Sun.

The values of P_r, T, and T_l are greater for greater particles (i.e., for smaller β). The values of P_r are greater for Venus by a factor of 2 than those for Earth, and sometimes this difference was even greater. Collision probabilities with Earth were greater by a factor of 10-20 than those with Mars. They were greater for particles starting at perihelion than those starting at aphelion.

For the same values of β, the collision probabilities of dust particles with the terrestrial planets were smaller by a factor of several for considered comet particles than for asteroidal dust particles [2]. This difference is mainly due to greater eccentricities and inclinations of cometary particles.

The ratio of total times spent by cometary particles in inner-Earth ($Q = a(1+e) < 0.983$ AU), Aten ($a < 1$ AU, $Q > 0.983$ AU), and Apollo ($a > 1$ AU, $q = a(1-e) <$ 1.017 AU) orbits was about 1.5 : 1 : 2, but it was different for different runs.

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SHRIMP INSTRUMENTAL DEVELOPMENTS FOR SAMPLE RETURN MISSIONS.

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Introduction: The development of ion microprobes for terrestrial applications has led to compromises in performance in some regimes. In effect, it is difficult to design an instrument that has ideal capabilities for all applications. We are in the process of designing a new instrument for dedicated stable isotope analysis that will have a major initial emphasis on materials from sample return missions and so specific capabilities can be designed from the outset.

SHRIMP: The SHRIMP ion optical geometry is markedly different than that used for Cameca ion microscopes most commonly utilized in extraterrestrial applications. The philosophical background for SHRIMP was the analysis of geologically complex materials where isobaric interferences must be resolved at moderate resolution (5,000 M/ΔM) while maintaining high sensitivity. This was achieved with a physically large double-focusing mass analyzer with low-second order aberrations allowing high resolution to be obtained without energy filtering at the energy focus [1]. The first stage of the secondary extraction system uses a relatively low initial secondary extraction potential (400-700 V) which reduces energy dispersion from the target. In order to maximize transmission, an astigmatic secondary system is utilized. The mass analyzer consists of magnetic and electrostatic sectors, as well as quadrupole lenses for aberration reduction (one quadrupole in the SHRIMP II design, four in SHRIMP RG).

Tuning: An important aspect of SHRIMP tuning is the use of a shallow-depth-of-field Schwarzchild visual optical system to place the sample in focus thereby aligning the primary and secondary ion optical axes very reproducibly. This system allows tightly constrained analytical conditions to be maintained thereby facilitating isotopic mass fractionation and elemental ratio measurements. Early measurements on SHRIMP I indicated reproducibility of better than 0.3 ‰ for Mg isotope measurements from Allende spinels [2]. Pb/U measurements in geochronology routinely achieve ca. 1.0 % reproducibility. A system for automatically tuning the secondary ion beam has recently been demonstrated.

SHRIMP SI: Sample return missions will provide new opportunities for analysis but will require new capabilities. To this end we are designing a dedicated stable isotope instrument (SHRIMP SI) which will primarily operate with a Cs^+ ion source and extract negative secondary ions. The source chamber will be reduced in size and differentially pumped to achieve ultrahigh vacuum ($<10^{-10}$ mbar). With a primary purpose of measuring light elements, the design of the multiple collector can be configured to optimize measurements of widely spaced unit masses and in particular allow the use of large electron multipliers that have superior gain, stability, and lifetime characteristics. Faraday cups will be interchangeable at each collector.

The Schwarzchild visual optics allow the introduction of normally incident laser illumination to the sample surface. Laser-assisted SIMS can therefore be readily employed. At the lowest level, laser illumination can be employed to remove surface contaimination. Higher energies can be used to ablate material, break molecular bonds, or effect resonance ionization mass spectrometry.

GENESIS: The new SHRIMP-SI capabilities will be important for the GENESIS mission in particular. With an expected concentration of oxygen of only 170 ppm, contamination from vacuum contaminants and surface contaminants must be kept to a minimum. SIMS is well suited to surface analysis, and in particular where the element of interest is implanted into the substrate away from the surface. Sputter precleaning and laser ablation should enable extremely clean surfaces to be maintained during analysis.

STARDUST: While identification of presolar material with large isotopic anomalies is a major goal of STARDUST, the documentation of more modest effects from solar nebula products or from molecular clouds will also be important. Achieving analytical precision of the order of 0.3 ‰ for most isotopic systems where the target is a major element requires a volume of material equivalent to a 1 μm diameter spot, 0.1 μm deep. The SHRIMP SI will be designed to allow submicron spots while maintaining the high degree of instrument control necessary for high accuracy stable isotope measurements.

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COMET DUST FROM AIRBORNE LEONID STORM OBSERVATIONS

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For the past five years, rare Leonid meteor storms offered unique access to cometary dust by spectacular manifestations of recently ejected dust grains, which could be observed by exceptional meteor observing techniques. The final storms, those of November 19, 2002, measured the dust distribution in a comet dust trail far from the position of the comet itself. The measured spatial and particle size distribution of dust still reflect the conditions of ejection and the influence of radiation pressures on the grains, and provide unique insight into the dust-to-ice ratio in cometary matter. The meteor observations also provide data on meteoroid composition and morphology for grains of mm-cm size that are larger than studied by Stardust. The meteoroids derive from comet 55P/Tempel-Tuttle and were ejected in 1866 and 1767, respectively, only 4 and 7 orbits ago. Both meteor storms were well observed from two research aircraft operated by NASA and USAF. This final mission in the Leonid Multi-Instrument Aircraft Campaign provided an international team of 38 researchers prime viewing without interference of moonlight and with a radiant position high in the sky. En route from Madrid, Spain, to Omaha, Nebraska, the storms were observed to peak at 04:06 UT and 10:47 UT, respectively. A range of spectroscopic and imaging techniques was used to measure the physical properties and composition of the meteors. Apart from accurate flux profiles, highlights include the first near-IR spectra of meteors, high frame-rate (1000/s) images, mid-IR spectra of persistent trains, as well as spectacular video images with a background of aurora.

ORGANICS SYNTHESIZED USING IRON-GRAIN SILICATES.

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Introduction: We use Fischer-Tropsch type (FTT) synthesis to produce hydrocarbons by hydrogenating carbon monoxide via catalytic reactions. The products of these reactions have been studied using 'natural' catalysts [1] and calculations of the efficiency of FTT synthesis in the Solar Nebula suggest that these types of reactions could make significant contributions to the composition of material near three AU [2]. We coat Fe-silicate grains with organic material using FTT synthesis to simulate the chemistry in the early Solar Nebula [3]. In our experimental setup, we roughly model a nebular environment where grains are successively transported from hot to cold regions of the nebula. In other words, the starting gases and FTT products are continuously circulated through the grains at high temperature with intervals of cooling (see Fig 1). Organics generated in this manner could represent the carbonaceous material incorporated in comets and meteorites. We analyze the resulting organics and present the results.

Experiments: Carbon monoxide, N_2, and H_2 gas are circulated through Fe- silicate grains that are maintained at a constant temperature. The reaction progress is monitored by measuring the gases as they pass through an FTIR spectrometer. Each cycle begins with 75 torr N_2, 75 torr CO, and 550 torr H_2 before the grains are brought to temperature (i.e., 400, 500, 600°C). After the gas has circulated for a predetermined amount of time, the heating element is turned off and the gas is pumped away. We repeat this process from twenty to forty times. Samples are analyzed using FTIR, GCMS (including pyrolysis) and potentially by NMR spectroscopy.

We thermally annealed the 500°C post-catalyzed grains under vacuum at 600°C and 700°C. Thermal annealing of the coated grains (particularly at 700°C) deposited an oily brown residue on the walls in the cooler regions of the reaction vessel. Three separate aliquots of the catalyzed grains at 500°C were hydrated at room temperature (~23°C), ~65°C, and 90°C (at atmospheric pressure) respectively. Extractions of all samples will be analyzed by GCMS and data presented.

Initial results: We examined the abovementioned brown oily residue for organic compounds using pyrolysis GCMS. The resulting chromatogram shown in Fig. 2 indicates an organic content as rich and varied as the Tagish Lake meteorite organics [4]. This residue contains primarily saturated and unsaturated hydrocarbons. The following were also identified: alkyl-benzenes, alkyl-phenols, alkyl-phenyl ethers, alkyl-styrenes, alkyl-naphthalenes, alkyl-quinolines, and traces of poly-cyclic aromatic hydrocarbons. If these results are any indicator, continued analysis of synthesized organics may give clues about the origins of meteoritic organics.

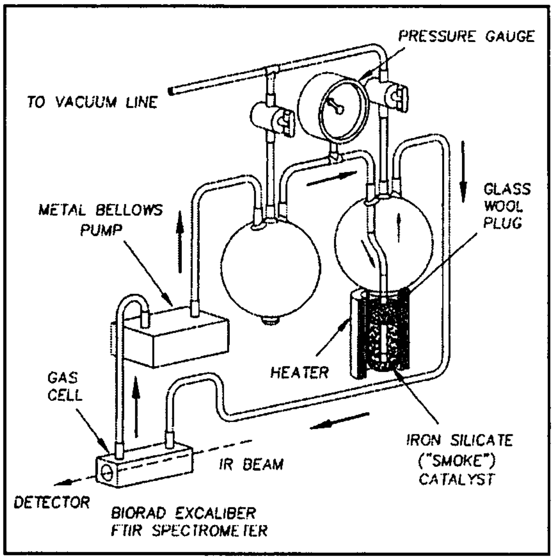

Fig. 1. Diagram of FTT catalyst experimental setup.

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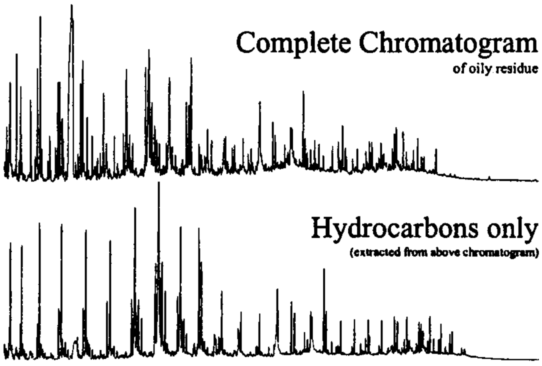

Fig. 2. GCMS chromatogram of residue resulting from annealing.

INFRARED SPECTROSCOPY OF ANHYDROUS INTERPLANETARY DUST PARTICLES.

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Introduction. Infrared (IR) spectroscopy is the primary means of mineralogical analysis of materials outside our solar system. The identity and properties of circumstellar grains are inferred from spectral comparisons between astronomical observations and laboratory data from natural and synthetic materials. These comparisons have been facilitated by the Infrared Space Observatory (ISO), which obtained IR spectra from numerous astrophysical objects over a wide spectral range (out to 50 cm^{-1}) where crystalline silicates and other phases have distinct features. The anhydrous interplanetary dust particles (IDPs) are particularly important comparison materials because some IDPs contain carbonaceous material with non-solar D/H and $^{15}N/^{14}N$ ratios [1,2] and amorphous and crystalline silicates with non-solar O-isotopic ratios [3], demonstrating that these IDPs contain preserved interstellar material. Here, we report on micro-Fourier transform (FT) IR spectrometry of IDPs, focusing on the inorganic components of primitive IDPs (FTIR spectra from the organic/carbonaceous materials in IDPs are described elsewhere [4]).

FTIR spectra from IDPs were first collected from particles pressed into KBr [5], followed later by measurements of IDP thin sections [6]. These efforts were focused largely on the region around 10 µm where silicates have strong absorptions. Synchrotron-based FTIR instruments have greatly expanded the types of measurements that are possible, including measurements of sub-regions within individual IDP thin sections, as well as extending the measurements into the far-IR. The far-IR measurements are particularly important because the long wavelength bands in olivines and pyroxenes are not only diagnostic for the crystalline structure that is present, but can also be used for compositional analysis (e.g. Mg/Fe ratio).

The 10 and 18 µm Silicate Features. IR spectra of the major phases in primitive anhydrous IDPs (crystalline Mg-rich silicates, GEMS [7], Fe-sulfides [8]) match spectral features observed in astronomical observations of comets and young stellar objects. IDP spectra, in the 10 µm Si-O stretching region are dominated by a complex mixture of crystalline (forsterite and enstatite) and amorphous (GEMS) silicates. FTIR spectra from regions of IDPs dominated by GEMS show a broad, asymmetric feature whose absorption maximum varies between 9.3 and 10.2 µm. In bulk IDPs, there are crystalline features at 9.3 µm (enstatite) and 11.2 µm (forsterite) superimposed on the GEMS feature. Figure 1 shows the 10 µm silicate emission from comets Hale-Bopp and Halley taken from Hanner and Bradley (2003) [12]. For comparison, we plot the average spectrum of 12 anhydrous IDPs in Figure 2. Considering the difference in sample size and measurement conditions the average anhydrous IDP spectrum compares favorably with the comet spectra, although the enstatite:forsterite ratio appears higher in the IDP spectrum than in the comet spectra.

The Si-O bending feature occurs at ~18.5 µm in a variety of astrophysical environments where the silicate dust is predominantly amorphous. This feature occurs at longer wavelengths (~18.7-19.4 µm) in all of the IDPs measured to date, including GEMS-rich particles.

The 23 µm Fe-sulfide feature. An emission feature at ~23.5 µm is observed in ISO spectra from two Herbig stars [8] (HD163296 and AB Aur) and in the carbon-rich ejecta of evolved stars [9]. Laboratory IR spectra of Fe sulfide minerals and FeS-rich IDPs show an IR feature that matches well the band shape and position of the ISO feature [8]. Furthermore, the FeS band depth relative to the silicate feature is broadly consistent with abundance constraints.

Far-IR measurements. FTIR spectra for two anhydrous IDPs have been published thus far [10,11]. In both cases, olivine and pyroxene, along with amorphous silicates are observed. The positions of characteristic bands in the IDP spectra indicate that the olivine and pyroxene are both Mg-rich. The spectra of both IDPs show remarkable similiarities to ISO spectra from comet Hale-Bopp and young stellar objects [10,11].

We have identified a number of minor phases (at the % level) in IDPs such as anorthite ($CaAl_2Si_2O_8$), fassaite [$Ca(Mg,Al)(Al,Si)_2O_6$] and gehlenite ($Ca_2Al_2SiO_7$) using transmission electron microscopy (TEM). These minor phases occur with presolar silicates identified in the same particles with combined ion microprobe/TEM measurements. Far-IR measurements on mineral standards show that these phases have characteristic features that should be detectable at low concentration in ISO spectra.

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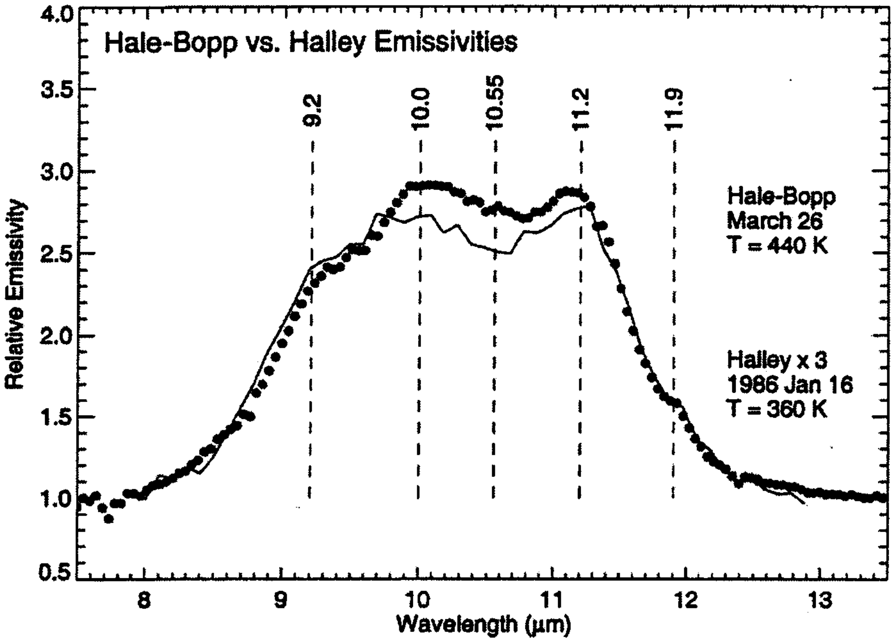

Figure 1. The 10 μm silicate emission from comets Hale-Bopp and Halley. Figure taken directly from Hanner and Bradley (2003) [12].

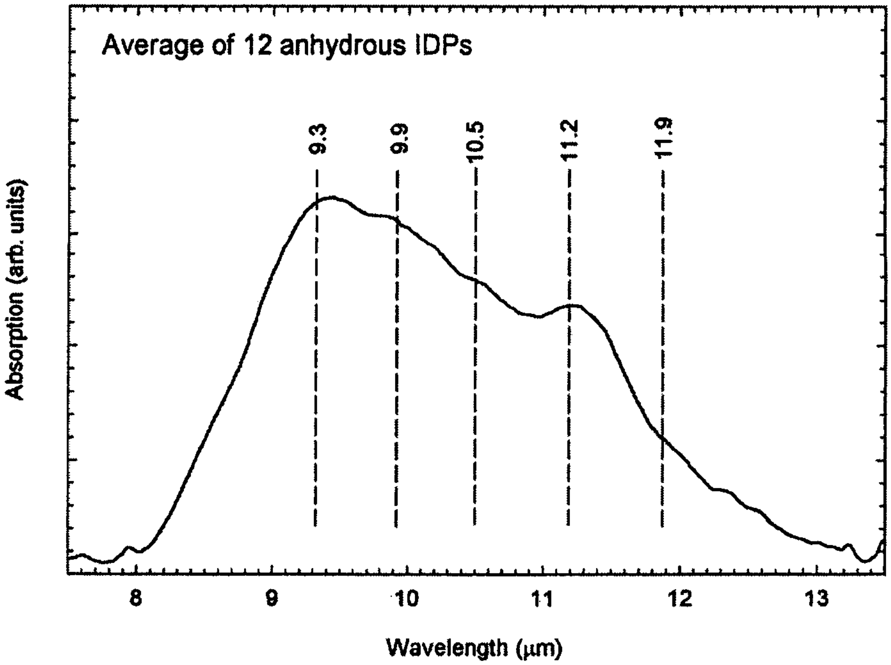

Figure 2. The 10 μm silicate feature obtained by averaging laboratory FTIR data for 12 anhydrous IDPs.

ON THE CRYSTALLINITY OF SILICATES IN THE INTERSTELLAR MEDIUM. F. Kemper, *UCLA, Department of Physics and Astronomy, 405 Hilgard Ave., Los Angeles, CA 90095-1562, USA, (kemper@astro.ucla.edu)*, W.J. Vriend, A.G.G.M. Tielens, *Kapteijn Institute, University of Groningen, P.O. Box 800, 9700 AV Groningen, The Netherlands.*

We present a detailed study on the degree of crystallinity of the silicates in the interstellar medium (ISM), using infrared spectroscopy obtained with the short wavelength spectrometer (SWS) on board of the infrared space observatory (ISO). We focus on the line-of-sight toward the galactic centre (in particular to radio source Sgr A*) which is thought to be representative of the diffuse ISM. Determining the degree of crystallinity of the interstellar silicates is a subject of great astrophyiscal interest. On the one hand, many post- and pre-main-sequence stars exhibit crystalline silicates in their circumstellar dust shells (Waters et al. 1996; Waelkens et al. 1996), while on the other hand, crystalline silicates have not yet been detected in the diffuse ISM. Only one reliable detection of diopside is reported in a star forming region (Onaka & Okada 2003). It is striking that, although during the beginning and the end of the life cycle of dust silicates can be highly crystalline, silicates seem to be completely amorphous during the longest phase in their life time.

The silicate dust in the diffuse interstellar medium causes an absorption feature around 10 μm. The broad shape of this feature, which is due to the Si-O stretching mode within the silica tetrahedras, suggests that the silicate by which it is carried, is mainly amorphous. Crystallinity of the silicates would be revealed by narrow resonances in this wavelength regime, corresponding to placing the Si-O bonds in a regular grid of silica tetrahedras. Typically, these resonances are 0.5–1 μm wide. The crystalline silicates most commonly found in astrophysical environments are forsterite and enstatite. Forsterite has a strong resonance at ~ 11.3 μm and enstatite at ~ 9.2 and ~ 10.4 μm. We searched for those resonances in the absorption spectrum of the line-of-sight toward Sgr A*, and did not significantly detect them. We are able to put the strongest constraints to date on the upper limit to the degree of crystallinity in interstellar silicates.

This indicates that processing occurs when dust enters the ISM upon ejection by evolved stars. We calculate that stellar ejecta contain a significant fraction of crystalline silicates, and from this result we can determine the average life time of a crystalline silicate in the diffuse ISM. Cosmic ray hits and supernova shocks provide the mechanisms to efficiently amorphisize the silicates. Most importantly, the obtained upper limit to the crystallinity provides us with important clues to the processing that occurred in the dense ISM and presolar nebula from which the solar system formed.

Interplanetary dust particles (IDPs) of non-solar isotopic composition are believed to be pristine tracers of interstellar and circumstellar dust (Bradley 1994). Their unusual isotopic composition suggest they have been formed in environments other than the solar nebula, and in fact their formation history can in many cases be traced back to the dust formation zones around either Asymptotic Giant Branch (AGB) stars or supernovae. It is assumed these grains have survived the grain processing and destruction processes in the diffuse ISM.

Recently, Messenger et al. (2003) studied the isotopic composition of silicates in 1031 IDPs. Six of these showed a non-solar isotopic composition, and are believed to be of presolar origin. All six were identified to originate from either Red Supergiants or AGB stars. Of two of these six circumstellar grains the mineralogical composition was determined. One of them was found to be a GEMS grain, which consists of amorphous silicates, while the other one was forsterite, a crystalline silicate. This forsterite grain could of course be the *lucky one* and survived the amorphisation processes in the diffuse ISM. However, we conclude that it is far more likely that this grain has been amorphisized in the diffuse ISM, but again crystallized in the star formation region in which the sun was born, or in the presolar nebula. This forsterite IDP of non-solar isotopic composition, and the detection of crystalline silicates in star forming regions (Onaka & Okada 2003), suggest that significant grain processing can occur in the dense ISM. The preserved anomalous isotopic ratios of this forsterite IDP indicate that this grain was not evaporated during the re-crystallization process. Hence this re-crystallization occurred in a relatively cool environment and radial mixing in the solar nebula can be ruled out for this particular grain.

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THE SYNTHESIS OF INORGANIC AND ORGANIC COMPOUNDS IN AGB AND POST-AGB STARS.

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Introduction: The chemical element carbon is produced by triple-α reactions and dredged up from the helium-burning shell above the core to the surface during the asymptotic giant branch (AGB) phase of stellar evolution. Some time later, the star undergoes large-scale mass loss in the form of a stellar wind. When the entire hydrogen envelope of the star is depleted by this mass loss process, the stellar core is exposed and the surface temperature of the star gradually increases. When the surface temperature exceeds 30,000 K, the ultraviolet photons emitted by the star begin to photoionize the circumstellar material, creating a planetary nebula [1][2].

The material ejected by the stellar wind during the AGB consists primarily of molecular gas and solid-state dust particles. It is now recognized that the short ($\sim 10^3$ yr) evolutionary phase between the AGB and planetary nebulae, called the proto-planetary nebulae or post-AGB phase [3], has active chemistry where new compounds are produced in the circumstellar environment. The ejection of these compounds into the general interstellar medium may play a significant role in the chemical enrichment of the primordial solar system.

From AGB stars to the Solar System: Infrared spectroscopic observations of the circumstellar envelopes of AGB and post-AGB stars have identified a variety of inorganic grains, including amorphous silicates, crystalline silicates, silicon carbide, carbonates, corundum, spinels, and possibly rutiles. Isotopic studies of meteorites have also identified similar species of presolar origin [4][5]. These grains therefore represent an important link between stars and the solar system.

The existence of aromatic and aliphatic features and their associated plateau continuum suggests that organic compounds in solid-state form are also made during the post-AGB phase of stellar evolution [6][7]. These features show similarity with the infrared spectra of kerogen [8], which are also found in meteorites.

The origin of the strong emission feature at 20 microns remains a mystery. Since its initial discovery by the IRAS satellite in 1989 [9], 12 carbon-rich post-AGB stars have been found to show this feature. The broad and smooth nature of this feature suggests that it is due to a solid [10]. Although the 20-micron feature has been suggested to be due to hydrogenated fullerences or titanium carbide nanoclusters, no firm identification has been made.

In this paper, we will summarize the spectroscopic evidence for inorganic and organic grains in the circumstellar environment and discuss possible pathways of their synthesis and transport to the solar system.

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VOLATILE TRACE-ELEMENT ABUNDANCES IN PRIMITIVE METEORITES: APPLICATIONS TO ANALYSIS OF COMETARY PARTICLES.

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Introduction: We are developing new techniques for the analysis of volatile trace elements in very small samples using inductively coupled plasma mass spectrometry (ICP-MS) in preparation for samples returned by the Stardust mission. The instruments that will serve as the bases of our experiments are the ELEMENT2 high-resolution ICP-MS and the Isoprobe multi-collector ICP-MS. The Isoprobe MC-ICP-MS is already installed and available for use. We are in the process of expanding this facility to add the ELEMENT2, making it the ideal place to perform both trace-element and isotopic analyses nearly simultaneously. We are developing techniques for introducing samples to the plasma. We are working on three areas of sample introduction: 1) Thermal heating of small particles under controlled atmospheres; 2) Laser ablation of small particles embedded in aerogel and other matrices; and 3) Direct injection of small particles into the plasma. In addition, we plan to investigate direct analysis of aerogel material with the goal of determining concentrations of volatile elements that may have recondensed on this material after sample collection.

Trace-element Analysis: We are interested in the abundances of volatile elements in Stardust grains and along particle tracks in the aerogel used to collect these grains. The primary goals of this research are (1) to constrain the initial abundances of volatile elements in Stardust grains and use this information to interpret their origin and thermal history and (2) to determine the amount of heating experienced by Stardust grains during collection. The abundances and isotopic compositions of such elements in Stardust grains may reflect low-temperature gas-solid interactions in the outer, early solar system.

The suite of elements of interest includes: Au, As, Ag, Ga, Sb, Ge, Sn, Pb, Bi, Tl, Hg, Zn, Se, Te, In, and Cd. This set of elements includes the most volatile, non-ice-forming elements. All of these trace elements are either chalcophile or siderophile under the conditions expected in the solar nebula. Thus, they were likely incorporated into solid material through gas-solid reactions with metal or sulfide grains. A subset of the volatile trace elements of interest (Au, As, Ag, Ga, Sb, Ge, and Sn) are predicted to condense in the solar nebula by dissolving into the bulk metal phase prior to sulfide formation [1,2]. Another subset are predicted to condense either into the metal (Pb, Bi, Tl, and Hg) or into the sulfide (Zn, Se, Te, In, and Cd) during metal sulfurization in the early solar system [1,3,4]. Elements that previously condensed in the metal may be transferred to the growing sulfide layer. Because of their high volatility and their mobility in aqueous systems, these elements may be excellent indicators of both thermal and hydrological processes experienced by primitive chondritic meteorites and cometary particles.

Results: A thermal analysis (TA-) ICP-MS technique has been applied it to the study of volatile trace-element abundances in primitive meteorites [5,6]. To date meteorites from the CI, CM, CV, CO, LL, L, and H chondrite groups have been analyzed. Of all these meteorites, the CI chondrites are probably the most similar to cometary material [7]. This study has produced some intriguing results. Of the entire suite of elements analyzed, S, As, Se, Sb, Te, Cd, and Hg are released at detectable levels when the meteorites are heated to relatively low temperatures (< 400 °C). There is a correlation between release of As, Se, Sb, and Te and low-temperature S release from a wide variety of primitive meteorites. The relative abundances of As, Se, Sb, and Te in this low-temperature phase is highly variable. There is a strong correlation between As and Se low-temperature release in Vigarano, Kainsaz, Chainpur, and Parnallee. However, in some meteorites (Grosnaja, Murchison, Orgueil) only Se is released and in others (Ornans and Supuhee), only As is released. These results are intriguing because they clearly do not reflect a simple volatility trend. Some other process is controlling the abundances of these elements in low-temperature phases in carbonaceous and ordinary chondrites. We will continue to develop these techniques using CI and CM chondrites as analogs for cometary particles.

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STARDUST GOES TO MARS: THE SCIM MARS SAMPLE RETURN MISSION. L. A. Leshin, Dept. of Geological Sciences and Center for Meteorite Studies, ASU, Tempe, AZ 85287-1404.

The technology developed for low-cost sample return by STARDUST and GENESIS, and the great advancement of laboratory capabilities to perform high precision analyses of very small samples, have resulted in an exciting concept for the first Mars sample return mission. This mission, called Sample Collection for Investigation of Mars (SCIM), is currently in Phase A competition for flight as the first Mars Scout mission.

When SCIM delivers the first martian samples to Earth it will dramatically expand scientific horizons by enabling distinctly new and diverse measurements and engaging a new community of scientists in the exploration of Mars. By returning more than a thousand 10 μm diameter dust particles and a liter of atmospheric gas, SCIM will provide fundamental advances in our understanding of Mars' habitability, geology, and climate. Existing high-precision, cutting-edge terrestrial laboratory instruments will produce high accuracy analyses of SCIM samples, addressing high-priority Mars science, including:

- The abundance of water in the martian near surface environment and the nature of its interaction with rocks; essential for assessing habitability
- The origin and composition of the major rock-types on Mars; key to unraveling martian geologic evolution
- The history of water and other gases in the martian atmosphere; critical for tracing martian climate through time.

Sample return is considered such an important component of the Mars Exploration Program (MEP) that it makes up one third of its implementation strategy of "seek-in situ-sample." SCIM offers a unique early opportunity for embarking on the first Mars sample return as the 2007 Scout mission. SCIM is responsive to 30 years of National Academy and other science community recommendations for sample return. SCIM will enable resolution of conflicting hypotheses generated by prior Mars missions. In addition, SCIM will enhance science return from future missions, pave the way for future sample returns, and allow NASA and the worldwide scientific community to enter the era of Mars returned sample analysis by 2011.

SCIM will be launched in August 2007. A "nodal reencounter" Earth-Mars- Mars-Earth trajectory provides ideal seasonal and latitude conditions for dust collection at the second Mars encounter. SCIM will arrive at Mars in April 2009 at Ls = 245°, 14° S latitude, 70° longitude, at 5 am local time. During an aeropass with periapsis at 37.2 ± 2.5 km, SCIM's Dust Collection Experiment (DuCE) will expose >125 cm^2 of aerogel to collect millions of particles, including >1800 particles with diameters over 10 μm. The Atmosphere Collection Experiment (ACE) will collect at least 1 liter of atmosphere. The mission includes a Light-flash In-situ Dust Counter (LIDC) and a Camera Experiment (CamEx) to document dust and atmospheric conditions, respectively. The locations of these experiments within the flight system are designed to optimize their function and protect them (and the samples) from harsh aero-heating conditions.

Silica aerogel dust collectors are exposed near the aft end of the aeroshell where aeroheating effects are minimized. Analyses demonstrate that the largest, most scientifically valuable particles traverse the bowshock and reach the collectors having experiences only minor heating (> 200°C for <0.03 ms). Because the particles are small compared to the size of the bowshock, they will not break up while traversing this region. Extensive testing demonstrates that particles retain the vast majority of their chemical and mineralogical characteristics after hypervelocity capture in aerogel

The DuCE consists of two sets of aerogel collector modules (CMs), 10 CMs per set, that are launched in position for sample collection. Ablative aeroshell coatings near the CMs ensure that no carbon-carbon ablation products from the aeroshell degrade sample collection. Following the aeropass, each CM set is reeled into the SRC for Earth return.

The ACE consists two, 1 liter collection tanks configured with tubing and valves to conduct atmospheric gases from an inlet at the stagnation point of the aeroshell, which provides high gas pressure with no potential contamination from the aeroshell material. The experiment includes a cryogenic collection system to increase the amount of collected gas.

The SCIM flight system is packaged within a carbon-carbon (C-C) aeroshell that protects from aeroheating and minimizes atmospheric drag losses, and therefore return ΔV. The aeroshell shape is flight heritage from the Radio Attenuation Measurement-C (RAM-C) program, is inherently aerodynamically stable, and requires no active control during the aeropass. The first-principles approach used for the SCIM flight system design focused on the physics of the actual sample collection and yielded a near optimal spacecraft physical configuration—while still allowing the maximum use of heritage subsystems from Stardust, Genesis, and Odyssey.

On Polycyclic Aromatic Hydrocarbon Molecules in Comets

Aigen Li (University of Arizona)

Polycyclic aromatic hydrocarbon (PAH) molecules might have been incorporated into comets if they are formed from relatively unprocessed interstellar material. The presence of PAHs in comets has been suggested by the 3.28μm emission feature detected in some comets. More specifically, a 3-ring PAH molecule – phenanthrene ($C_{14}H_{10}$) – has been proposed as the carrier for the 342–375 nm fluorescence bands seen in comet 1P/Halley. We model the infrared emission process of phenanthrene as well as "generic" PAHs in cometary comae and obtain an upper limit on the coma PAH abundance based on the observed 3.28μm emission feature and the absence of the 6.2, 7.7, 8.6, and 11.3μm PAH emission features in coma spectra.

We find that the 1P/Halley 3.28μm emission feature constrains the neutral phenanthrene production rate to be $< 10^{-3}$ of the total dust mass production rate. It is also found that the mass production rate of "generic" PAHs is only $\lesssim 10^{-3}$ of that of the dust. This is at least ~100 times smaller than the mass fraction of interstellar PAHs relative to the total interstellar dust in the diffuse interstellar medium. In order for the PAH production rate in nucleus surfaces increases to the level in agreement with the interstellar dust model expectation without violating observational constraints, PAHs should be photodissociated rapidly enough in comae (in a few seconds at a heliocentric distance of 1 AU) which is inconsistent with the photodissociation modelling results. Selective sublimation may be the process suppressing the coma PAH abundance.

Modeling the Infrared Emission from Protoplanetary Dust Disks

Aigen Li and J.I. Lunine (University of Arizona)

We model the infrared (IR) emission from protoplanetary dust disks in terms of highly porous cometary-type dust made either of coagulated but otherwise unaltered protostellar interstellar grains, or grains that are highly-processed in protostellar/protoplanetary nebulae with silicate dust annealed and carbon dust oxidized. It is shown that the porous dust model with a vacuum volume fraction of $\sim$ 90% is successful in reproducing the near-IR to submillimeter spectral energy distributions and the mid-IR emission features of amorphous and/or crystalline silicate dust and polycyclic aromatic hydrocarbon (PAH) molecules from four archetypal dust disks: HR 4796A (Li & Lunine 2003a, ApJ, vol. 590, in press), HD 141569A (Li & Lunine 2003b, ApJ, vol. 594, in press), Fomalhaut (Li & Lunine 2003c, in preparation), and β Pictoris (Li & Greenberg 1998, A&A, 331, 291).

PREBIOTIC AND EXTRATERRESTRIAL CHEMISTRY OF HYDROGEN CYANIDE POLYMERS

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Introduction: Hydrogen cyanide polymers- heterogeneous solids ranging in color from yellow to orange to brown to black - could be major components of the dark matter observed on many bodies of the outer solar system and beyond, including asteroids and comets, moons and planets. They are readily hydrolyzed to yield α-amino acids, possibly derived from polyaminomalononitrile, a polyamidine structure built only from hydrogen cyanide. There is some evidence for peptidic substructures. Also, hydrolysis/pyrolysis gives rise to nitrogen heterocycles, including purines and pyrimidines found in nucleic acids today.

Implications for prebiotic chemistry are profound. Through bolide bombardment or by photochemical reactions in a reducing atmosphere, the primitive earth may have been covered by HCN polymers and other organic compounds. Most significant would have been the parallel synthesis of polypeptides and polynucleotides arising from the dehydrating action of polyamidines on nucleotides. On our dynamic planet, this polypeptide-polynucleotide symbiosis mediated by polyamidines may have set the pattern for the evolution of protein-nucleic acid systems controlled by enzymes and ribozymes, the mode characteristic of life on Earth today [1].

Results: Some recent experimental results consistent with this model of HCN polymer chemistry playing an essential role in the origin of life include the detection of:

1. large amounts of HCN in a massive protostar GL2591 [2], suggesting that HCN is produced at starbirth. HCN polymers would be expected to be present in dense interstellar clouds where infrared cyanide signatures have been observed [3] and in planetary nebulae where HCN molecules exist [4];
2. diketopiperazine from the thermochemolysis of HCN polymers [5] pointing to the presence of glycine dimers or oligomer structures in water-treated HCN polymers;
3. increased amounts of glutamic acid and serine when HCN polymer reacts with acrylonitrile and formaldehyde respectively, providing strong evidence for a polyaminomalononitrile structural motif in the polymer [6];
4. substantial amounts of HCN polymer in the solid tholin product from a Titan atmospheric chemistry simulation experiment as determined by TMAH thermochemolysis GC-MS [7];
5. long-lived organic free radicals (C- or N-based) in both HCN polymers and Titan tholin material, identified through ESR studies [8];
5. high molecular weight polymeric heterocycles of H,C,N,O far beyond the orbit of Mars [9] discovered by the Cometary and Interstellar Dust Analyzer of Mission Stardust on its way to rendezvous with Comet Wild in 2004.

As with Comet Halley [10], we predict that samples returned by Stardust in 2006 will contain HCN polymers and related products arising from the dark crust of the comet. These could be subjected to TMAH thermochemolysis GC/MS techniques we have used effectively for the analysis of HCN polymers [11].

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THE MEGASIMS: A NEW INSTRUMENT FOR THE ISOTOPIC ANALYSIS OF CAPTURED SOLAR WIND.

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Introduction: With a few exceptions, the elemental abundances and isotopic compositions of average solar system material are inferred from laboratory analyses of carbonaceous chondrite meteorites because such measurements can usually be made with higher precision and accuracy than spectroscopic observations of the solar photospere [1]. However, this approach is problematic for volatile elements which are known to be fractionated, both elementally and isotopically, in various classes of primitive meteorites. The GENESIS Discovery mission [2] will return captured solar wind for laboratory analyses to determine its elemental and isotopic compositions. Solar compositions would then be based on the analysis of solar materials. Since the Sun contains the bulk composition of the solar nebula, such data will provide an important constraint on the origins and evolution of cometary dust and other planetary materials.

Oxygen is the most abundant element in the rocky planets, yet our understanding of the solar oxygen isotopic composition is poorly constrained and highly model-dependent [3,4]. Oxygen is known to exhibit isotopic anomalies of uncertain origin that are manifest in materials from the inner solar system on all spatial scales, from microns to planets [5]. Knowledge of the bulk solar system oxygen isotope composition would be highly useful in constraining models for evolution of dust and gas in the solar nebula to form planetary materials. For these reasons, the highest priority science goal of Genesis is the determination of the oxygen isotopic compositions with circa permil accuracy in both ^{17}O and ^{18}O.

Analytical Challenge: There is currently no instrument that can perform isotopic analyses of the small amount of implanted solar wind oxygen (total fluence ~ 3 10^{14} cm^{-2}) with the accuracy required for cosmochemistry. Aside from sensitivity requirements, analytical difficulties include contamination by ubiquitous oxygen on collector surfaces and from instrumental background, the large (factor 500) dynamic range, and the presence of molecular ion (hydride) mass interferences. The solution that we have developed at UCLA is combine an ion microscope with improved vacuum and low-energy sputtering capabilities with a tandem accelerator (for molecule destruction) and a high energy multicollector mass spectrometer.

Instrument Description: The "front-end" of the instrument is based on a modified CAMECA ims 6F ion microscope, which maintains good depth resolution (~nm or better) and ion imaging (~1 m resolution). These capabilities allow separation of surface oxygen contamination from the signal which is implanted to a mean depth of ~60 nm. Surface cleaning of a ~150 150 m^2 analytical area is accomplished by very low energy (500 eV) sputtering by Ar^+. A high useful yield is then realized by using Cs+ primary ions and analyzing negative secondary ions; a normal incidence electron gun is available for charge compensation.

The implanted nature of the sample leads to a requirement of true simultaneous detection for the isotope beams. This is accomplished by an isotope separator-recombinator for injection of the extracted 10 keV SIMS beam into the acceleration tube of the tandem. The novel design of the isotope recombinator maintains a first order mass dispersive focal plane at its midpoint and a transmission of the ion image, which is useful for achieving good depth resolution. A range of (isotopic) masses is selected by a slit at the mass dispersive plane, and the beam then is recombined by a second magnetic sector. Phase space overlap for the different mass beams is achieved by some compensating lenses and the recombined beam is stripped of interfering molecular ions by passage through Ar gas at the high-voltage terminal of an NEC Pelletron accelerator. A double-focusing, forward geometry mass spectrometer analyzes the high energy beam, now consisting only of those atomic ions that were passed through the recombinator by simultaneous ion counting at low to moderate mass resolution using moveable collectors.

The ion optics and performance characteristics of the MegaSIMS will be described in detail. The instrument, which is currently under construction, is supported as an *Advanced Analytical Instrumentation Facility* that can address not only the science objectives of GENESIS, but it will advance the state-of-the-art for certain isotopic and elemental analyses that will be appropriate for other sample return missions, including STARDUST.

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SILICATE STARDUST FROM COMETS. S. Messenger and L. P. Keller, NASA Johnson Space Center Code SR Houston TX 77058.

Interplanetary dust particles (IDPs) collected in the Earth's stratosphere are 5–50 μm fragments of asteroids and comets [1-3]. Anhydrous IDPs have escaped significant parent body hydrothermal alteration [2] and are further distinct from meteorites in their greater abundances of volatile elements and C, fine grained (100–500 nm) textures, and unequilibrated mineralogies. Many anhydrous IDPs contain high abundances interstellar organic compounds [4] and grains of silicate stardust [5]. These observations are consistent with properties of comets inferred from remote astronomical observations.

Comets have been thought to be pristine aggregates of interstellar materials. However, spectroscopic observations of crystalline silicates in comets has challenged this notion, given their apparent absence in the interstellar medium.

We measured the isotopic compositions of crystalline and amorphous grains in anhydrous IDPs to establish the relative proportions of solids of presolar and solar system origin in these materials. Stardust grains are distinguished from solar system materials by their exotic isotopic compositions as measured by NanoSIMS ion microprobe. Mineralogical characterization of some of these grains was performed by transmission electron microscopy (TEM) on 70 nm thick IDP microtome sections prior to isotopic analysis.

Roughly 1031 grains were measured for their O isotopic composition with sufficient precision to distinguish solar system material from stardust. Among these, 113 were characterized by TEM prior to analysis by NanoSIMS. We identified 6 grains of silicate stardust, two of which were previously analyzed by TEM where they were identified as an amorphous GEMS [6] grain and a forsterite grain. The remainder of the 1025 grains had O isotopic compositions indistinguishable from solar system materials.

The mineralogy of the isotopically solar grains include enstatite, GEMS, olivine, anorthite, Ca-Al-Mg-rich glass, diopside, and chromite. It has been suggested that interstellar grains may be rendered amorphous and isotopically homogenized by shock sputtering and re-accretion. However, crystalline silicates are very unlikely to form in the ISM. The most probable source of isotopically solar crystalline grains is the solar system itself.

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THE FORMATION AND SURVIVAL OF ORGANIC MOLECULES IN INTERSTELLAR AND CIRCUMSTELLAR ENVIRONMENTS.

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Around 100 of the 120 or so molecules discovered in interstellar and circumstellar regions are organic in nature. In this paper I will discuss the formation of carbon-bearing molecules and the growth of carbonaceous grains, via PAH formation and aggregation, in AGB stars.

I will also discuss the formation of carbon-bearing species in interstellar clouds and discuss the survival of these molecules. In order to become incorporated into the solar-system, it appears necessary for these species to be incorporated into interstellar grain mantles.

The molecular complexity of such mantles may be studied directly, through infrared observations, or indirectly, through millimeter observations of evaporated gas in hot molecular cores around young stars. I shall summarize the observational data and its implications for complex molecule formation and survival.

Finally, I shall present the results of some recent chemical-hydrodynamical models of protostellar disks. As with the interstellar medium, it is clear that the gas-grain interaction is very important in determining the radial distribution of molecules.

RELATIONS BETWEEN CRYSTALLINE SILICATES IN DIFFERENT CIRCUMSTELLAR ENVIRONMENTS?

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Introduction: Amorphous silicates are the most abundant dust species in the Universe. They are present around young stars, evolved stars and even in the medium between the stars. Before the launch of the Infrared Space Observatory (ISO), crystalline silicates were only known in the solar system and around one other (young) star β-Pic. ISO dramatically changed this view. Not only were the crystalline silicates found around other young (mass-accreting) stars, but also around evolved (mass-losing) stars. The presence of crystalline silicates in these environments (but not in the interstellar medium!), has changed our view about (crystalline) silicate formation and evolution.

Crystalline silicates around evolved stars: Although we are not able to study (crystalline) silicates around other stars directly here on earth in a laboratory, we can still determine many of their properties (composition, size and shape) from their infrared spectral properties. The spectral coverage and resolution of ISO were very suitable to study their properties (see e.g. Figure 1) around evolved stars.

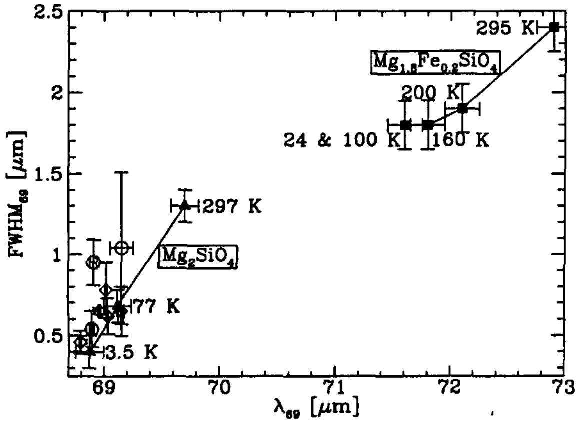

Figure 1: The position of the 69-micron olivine feature found in evolved stars (open symbols) and in the laboratory (solid symbols). The laboratory data points are given for different temperatures and composition. It is clear that the crystalline olivine in mass-losing stars are extremely Fe-poor.

Crystalline silicates around young stars: Early in the ISO mission, the Herbig Ae/Be star HD100546 was observed. Its spectral energy distribution showed clearly the presence of crystalline silicates. However it turned out that its spectrum is not representative for most young stars. A significant fraction does not show evidence for crystalline silicates and most of the others only show it in the 10 micron region. This has implications for our understanding of the formation and evolution of crystalline silicates around young stars.

Crystalline silicates in the solar system: A big advantage of the solar system material is that it can be studies here in the laboratory on earth. Exact mineralogical composition can be determined and often also an indication can be given from where it originates. But one of the questions remains whether or not the material received here on earth is representative for what is present in outer space and how it relates to it.

The combination of information from these different environments: The information retrieved from the crystalline silicates around other stars, can be used to explain the distribution and composition of the crystalline silicates in the solar system. In this talk I will give examples how and where the study of crystalline silicates around other stars have helped us to understand the evolution of crystalline silicates in our own solar system. This in return will help us to understand the formation and evolution of other planetary systems.

A PARTICIPATING SCIENTIST FOR THE STARDUST MISSION.

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Introduction: It is the Policy of NASA's Office of Space Science to emphasize and encourage the addition of Participating Scientist Programs (PSP's) to broaden the scientific impact of missions.

A Participating Scientist Program for the STARDUST Mission: STARDUST is the fourth Discovery mission, and it is the first sample return mission selected within the Discovery Program. The STARDUST Spacecraft will fly through the coma of comet P/Wildt-2 in early January 2004, and return the samples to the Earth in January 2006. The Principal Investigator of the STARDUST mission, Dr. Donald Brownlee, has generously requested the implementation of a PSP for STARDUST in order to provide more community participation in the initial characterization and analysis of the samples from P/Wildt-2. In particular participating scientists will fill out the membership of the Preliminary Examination Team (PET) called for in the original 1994 STARDUST proposal accepted by NASA in 1995. The work of the PET will be organized around major subdiscipline areas such as mineralogy and petrology, isotopic abundances, and elemental composition. There will be leaders for each of these areas, and also a number of team members within each. Support will be commensurate with the level of participation.

Implementation: The OSS will solicit the Participating Scientists for STARDUST through the annual Research Opportunities in Space Science (ROSS) National Research Announcement, and the OSS will select members based on competitive peer review. The solicitation may be for as many as 3 area leads and 40 additional team members depending on a final assessment of the needs of the mission and available support. The program will be administered through NASA Headquarters.

The goal of the STARDUST PET, and also, the STARDUST PSP, will be to provide an initial evaluation of the returned dust samples and a report of their likely significance to the greater scientific community and to the American people. Following the completion of STARDUST PET activities, the curator of Astromaterials located at NASA's Johnson Space Center will make the samples available to the community following established procedures [1]. Support for the analysis of these dust samples will be available through the Discovery Data Analysis Program.

Conclusion: The STARDUST Participating Scientist program will PSP for a mission designed to return samples, and the program make become the archetype for the use of PSPs in future Discovery and New Frontiers missions which return samples.

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FT-IR SPECTROSCOPY OF FINE-GRAINED PLANETARY MATERIALS.

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Introduction: Dust is the basic building block of all larger bodies formed in the Solar System: planets, their satellites, comets and asteroids. Some of these dust grains have survived 4.56 Gyr of processing, and occur as interplanetary dust particles (IDPs), GEMS (Glass with embedded sulphides) within IDPs and presolar grains in meteorites. Primitive meteorites can also be regarded as aggregations of relatively unprocessed dust. Dust particles from these sources are analyzed in laboratories by planetary scientists; most of the presolar grains are carbonaceous (SiC, graphite, diamond), and only few interstellar silicates have been measured [1].

A complementary source of information about dust comes from a different scientific community, and is obtained by astronomical observations from both ground- and space-based observatories of dust in a variety of astrophysical environments. In this case, IR spectra provide information e.g. about mineral composition and structure of the dust particles, which have mainly been identified as silicates.

In order to relate direct and astronomical measurements of dust grains, IR spectra of 'pure' minerals are required. So far, mainly amorphous glasses [e.g. 2] or fine grained smokes [3] have been used as standard materials, rather than natural minerals. These studies also mostly concentrated on pure end members, which are rare in nature. Minerals from meteorites are probably a better comparison for the astronomical analyses, since they formed in a similar environment to the dust grains. The aim of this project is to provide a database of infrared and optical spectra of well characterized minerals from representative meteorites, to assist with more detailed characterization of astrophysical dust.

Techniques: IR spectra will be obtained with a Perkin Elmer Spectrum One FT-IR microscope over a wavelength range of ~ 2.5 to 25 m. The specimens will be characterized by electron beam methods and X-ray diffraction. Unpolished grains hand-picked from meteorites will be analysed, the original morphology taken as a possible approximation for unprocessed dust grains in space. Following this, polished samples will be analysed for high-quality spectra. We intend to apply several FT-IR spectroscopy techniques: specular reflectance, diffuse reflectance, transmission and ATR.

Results: Fig.1 shows a set of diffuse reflectance spectra obtained from powdered olivine grains from terrestrial standards, Fig.2 olivines from terrestrial and meteoritic sources, over a range of forsterite compositions. The terrestrial olivines are pure crystalline mineral standards (not glasses). The meteoritic olivine is from the Admire pallasite, and has a composition of Fo_{88} [4]. In each case, powdered mineral samples were mounted on an abrasive stick and analysed by diffuse reflectance IR spectroscopy.

Similar techniques will be used in the first phase of the project for analyses of randomly oriented meteorite grains in various size fractions. In our preliminary study, we plan to present data on minerals from several type 3 ordinary chondrites (Parnallee LL3.6, Khohar L3.6, Brownfield H3.7).

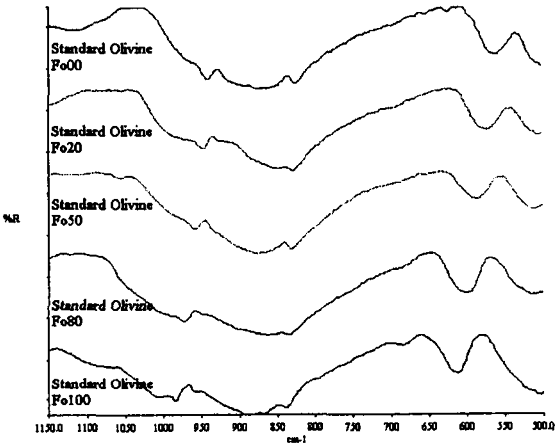

Fig.1: Diffuse reflectance FT-IR spectra of terrestrial standard olivines with a range of composition from Fo_{00} to Fo_{100} (in % reflectance).

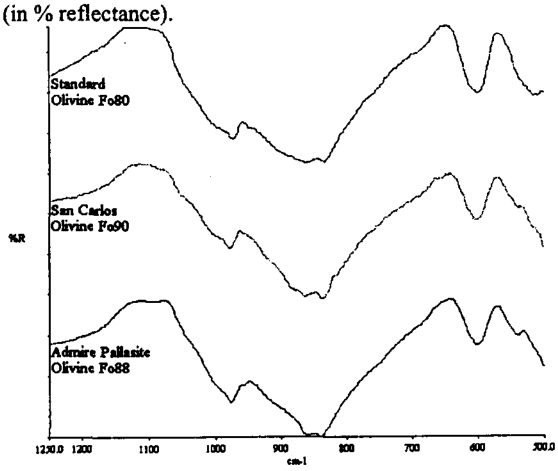

Fig.2: Diffuse reflectance FT-IR spectra of olivines from the Admire pallasite (Fo_{88}) [4], terrestrial San Carlos olivine (Fo_{90}) [5] (in % reflectance)

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COMPREHENSIVE STUDY OF HYDRATED IDPs: X-RAY DIFFRACTION, IR SPECTROSCOPY AND ELECTRON MICROSCOPIC ANALYSIS.

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Introduction: Chondritic hydrated interplanetary dust particles (IDPs) comprise up to 50% of all IDPs collected in the stratosphere[1]. Although much is known about the mineralogy, chemistry and carbon abundance of hydrated IDPs [2-4] controversies still exist regarding their formation, history, and relationship to other primitive solar system materials. Hydrated IDPs are generally believed to be derived from asteroidal sources that have undergone some degree of aqueous alteration. However, the high C contents of hydrated IDPs (by 2 to 6X CI levels [3,4]) indicate that they are probably not derived from the same parent bodies sampled by the known chondritic meteorites.

Methods: We report the comprehensive study of individual hydrated IDPs. The strong depletion in Ca [1] has been used as a diagnostic feature of hydrated IDPs. The particles are embedded in elemental sulfur or low-viscosity epoxy and ultramicrotomed thin sections are observed using a transmission electron microscope (TEM) equipped with an energy-dispersive X-ray detector (EDX) followed by other measurements including: 1) FTIR microspectroscopy to understand the significant constraints on the organic functionality and the nature of the C-bearing phases and 2) powder X-ray diffraction using a synchrotron X-ray source to understand the bulk mineralogy of the particles.

Bulk Composition and Mineralogy: Hydrated IDPs are composed predominantly of smectite and/or serpentine phyllosilicates and usually contain minor anhydrous grains as shown in Figure 1 from IDP L2036E23. L2036E23 exhibits distinctive intergrowth of smectite and serpentine that has been reported from the Orgueil CI chondrite [5], the Tagish Lake CI2 [6] and a hydrated IDP [7]. Mg-Fe carbonates common in CI chondrites [8], Tagish Lake [9] and other hydrated IDPs [8,9] are also abundant in L2036E23. Magnetite is the major Fe-bearing phases in CI chondrites, whereas magnetite in L2036E23 is observed as a prominent rim in response to atmospheric entry heating. Tochilinite which is commonly intergrown with serpentine in CM matrices is observed in IDP L2006A5. Although the majority of hydrated IDPs have chemical compositions that resemble to CI and CM chondrites [1,2,5], there are mineralogical similarities to the fine-grained material in certain altered type-3 carbonaceous and ordinary chondrites [10,11].

Possible Parent Bodies: Reflectance spectra (380-850 nm) of most IDPs are similar to those of P- and D-class outer belt asteroids [12] as well as the Tagish Lake meteorite [13]. Extraterrestrial materials resembling Tagish Lake are rare as meteorites, but appear to be much more common as stratospheric IDPs[14] and micrometeorites [15]. Recent shock experiment results indicate that hydrated asteroids produce dust particles by mutual collisions at much higher rate than anhydrous asteroids[16]. TEM observations of samples recovered from the Murchison CM chondrite shocked at 30 GPa shows marked similarities to the hydrated IDPs[16].

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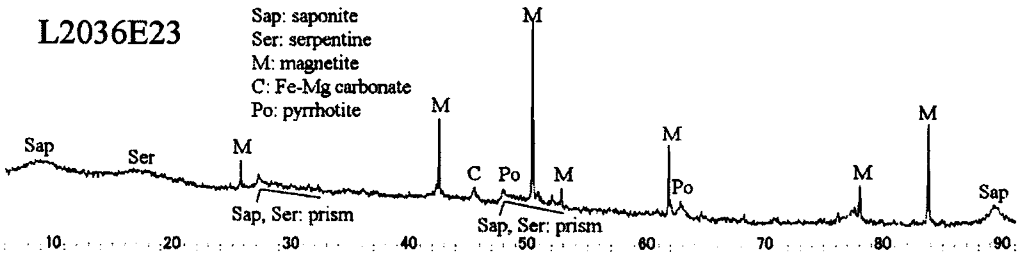

Fig. 1: X-ray diffraction patterns in a range of diffraction angle from 12 to 52° (2θ) of a hydrated IDP L2036E23.

ANALYSIS OF SUBMICRON PRESOLAR OXIDE GRAINS BY SINGLE GRAIN ANALYSIS AND MULTI-DETECTION RASTER IMAGING.

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Introduction: Oxygen isotopic measurements of grains from the spinel-rich Murray residues CF and CG, having average sizes of 0.15μm and 0.45μm, respectively, have been performed with the NanoSIMS. Zinner et al. [1] analyzed individual grains that were well dispersed from one another on a gold foil and found that the smaller grain size fraction CF had a higher abundance of presolar spinel than the fraction CG (15/628 vs. 9/753). For these analyses, the primary ion beam was deflected successively onto single grains. Subsequently we determined the oxygen isotopic compositions of grains from the same residues using multi-detection raster ion imaging of densely packed areas on the grain dispersion mount. Using this technique, we identified 81 presolar spinel and 3 presolar corundum grains out of ~51,700 analyzed CF grains. In addition, we identified 171 presolar spinel and 29 presolar corundum grains among ~21,500 CG grains. While both methods prove to be effective in analyzing very small grains, raster ion imaging is more efficient for locating anomalous grains among many isotopically normal grains.

Experimental: Analyses were made on the NanoSIMS ion microprobe. The same CF and CG grain mounts were used for both single grain analysis and for ion imaging. These sample mounts were prepared by depositing grains from liquid suspensions onto gold foils. In most areas on the mounts, the grains were well dispersed. On the other hand, areas containing tightly packed grains were well suited for ion imaging. For imaging, a Cs^+ primary ion beam of ~100nm diameter was rastered over 15x15 or 20x20μm^2 areas on the sample mount. Negative secondary ions of the three O isotopes, as well as ^{24}MgO and ^{27}AlO ions were counted concurrently in five small electron multipliers. MgO and AlO were measured to distinguish between spinel and corundum grains. Isotopically anomalous grains were identified from oxygen isotopic ratio images (Fig. 1).

Results and Discussion: The analysis of oxide grains larger than 1μm led to the conclusion that presolar spinel grains were much rarer than presolar corundum grains [2]. However, with the NanoSIMS ion microprobe, we now have the capability of measuring submicron grains. Single grain analysis of small spinel grains from the Murray CF and CG residues indicated that the abundance of presolar spinel grains is actually quite large relative to presolar corundum grains, and that the abundance of presolar grains increases with decreasing size (Table 1) [1]. Whereas 26 presolar spinel and 3 presolar corundum grains were identified through single grain analysis, 252 presolar spinel and 32 corundum grains were identified by raster ion imaging in a shorter amount of time. It is apparent that we have two successful NanoSIMS techniques that can be applied to the elemental and isotopic analysis of small grains down to ~0.2μm. Ion imaging is particularly effective in searches for rare presolar grain types, as we can analyze many more grains within a certain amount of time. This method has led to the discovery of presolar silicates in IDPs [3], and can be applied to the search for presolar silicates in meteorites and to the analysis of cometary dust returned from Stardust.

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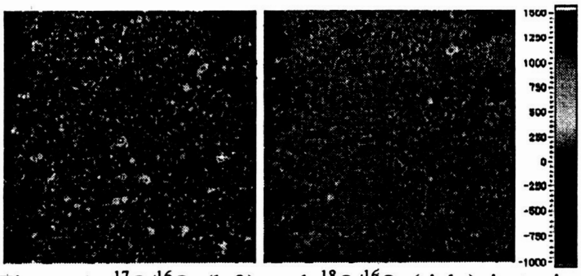

Figure 1. $^{17}O/^{16}O$ (left) and $^{18}O/^{16}O$ (right) isotopic ratio images of a 20x20μm^2 area partly covered with Murray CG grains. Ratios are given as deviations from normal isotopic ratios in permil (‰). Presolar grains can clearly be identified as having large isotopic anomalies.

Meteorite/ Residue	Analysis Technique	Presolar Spinel/ Total	Presolar Corundum/ Total	Abundance Spinel	Abundance Corundum
Murray CF	Ion Imaging	81/51,700	3/51,700	0.2%	0.01%
(0.15μm)	Single Grain*	15/628	3/628	2.4%	0.9%
Murray CG	Ion Imaging	171/21,500	29/21,500	0.8%	0.1%
(0.45μm)	Single Grain*	9/753	0/753	1.2%	<0.2%

*Zinner *et al.* (2003)

FUTURE MISSION PROPOSAL OPPORTUNITIES: DISCOVERY, NEW FRONTIERS, AND PROJECT PROMETHEUS.

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Introduction: The NASA Office of Space Science is expanding opportunities to propose missions to comets, asteroids, and other solar system targets. The Discovery Program continues to be popular, with two sample return missions, Stardust and Genesis, currently in operation. The New Frontiers Program, a new proposal opportunity modeled on the successful Discovery Program, begins this year with the release of its first Announcement of Opportunity. Project Prometheus, a program to develop nuclear electric power and propulsion technology intended to enable a new class of high-power, high-capability investigations, is a third opportunity to propose solar system exploration. All three classes of mission include a commitment to provide data to the Planetary Data System, any samples to the NASA Curatorial Facility at Johnson Space Center, and programs for education and public outreach.

Discovery: NASA's Discovery Program provides regular opportunities to conduct planetary system(s) science investigations that require free-flying missions launched on the space shuttle or expendable launch vehicles. These are complete missions, directed by a single Principal Investigator (PI), with participation from a number of scientific Co-Investigators, Participating Scientists, and Collaborators, as well as the engineering project team and industry partners. Post-mission scientific value is enhanced by the availability of mission data in the Planetary Data System, samples at the Curatorial Facility, and funding available from the Discovery Data Analysis Program, Sample Return Laboratory Instruments and Data Analysis Program, and a number of other programs available through the annual NASA Research Announcement entitled Research Opportunities in Space Science (ROSS NRA). There have been six Discovery missions launched to date: NEAR, Lunar Prospector, Pathfinder, Stardust, Genesis, and Contour. The next opportunity to propose a Discovery mission is planned to occur late in 2003. Discovery missions are cost-capped missions, with a current total NASA Office of Space Science (OSS) cost of up to $350 M. Missions typically launch three years after confirmation.

New Frontiers: The New Frontiers Program has recently been introduced in order to further enable PI-led missions to explore the solar system and/or return samples for study. The National Academy Decadal Survey (*New Frontiers in the Solar System*, National Research Council, 2002) has recommended five medium-class mission investigations as an initial target set: Comet Surface Sample Return, South Pole Aitken Basin Sample Return, Venus In Situ Explorer, Jupiter Polar Orbiter with Probes, and a Kuiper Belt/Pluto mission. The first New Frontiers mission will be New Horizons, a mission to Pluto and the Kuiper Belt. The other four investigations will comprise the possible target set for mission proposals in 2003. The NASA OSS cost for these missions can be up to $650 M. These missions may therefore employ radioactive power sources and Evolved Expendable Launch Vehicles, such as the Atlas V or Delta IV, enabling an expanded opportunity to explore the solar system, including the return of samples. Missions should launch within four years of confirmation.

Project Prometheus: The newly created Project Prometheus Program will develop nuclear electric power and propulsion technology to allow a new era of scientific investigation with capabilities far beyond those available today. These missions will utilize on-board nuclear fission reactors and high power ion engines to provide revolutionary capabilities such as high power levels for instruments (10 – 45 kW), high data rates for acquisition and telecom (10 Mbps), large payload mass, multi-target rendezvous and orbits, and extended observation time. The first Project Prometheus mission is the Jupiter Icy Moons Orbiter, which has recently begun formulation. Since Project Prometheus is planned as a recurring mission line, NASA will soon release a request for studies of future high capability missions. A list of possible future missions includes, but is not limited to, Titan explorer, comet chaser, interstellar probe, and Neptune/Triton missions.

Conclusion: The Discovery, New Frontiers, and Project Prometheus mission lines provide opportunities for small, medium, and high-powered missions to explore the Solar System and return valuable data and extraterrestrial samples. The Office of Space Science welcomes your ideas, proposals, and participation in these three exciting mission lines.

CIRCUMSTELLAR GRAINS IN METEORITES AND IDPS: ISOTOPIC CONNECTIONS BETWEEN STELLAR GENERATIONS.

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Primitive meteorites and interplanetary dust particles (IDPs) contain tiny dust grains that condensed in outflows and explosions of ancient stars prior to the birth of our solar system [1-3]. These *presolar* or *circumstellar* grains are solid samples of stellar matter that trace a diversity of processes including stellar evolution and nucleosynthesis, stellar dust formation, dust processing in the interstellar medium (ISM) and early solar system processes. They are recognized by their highly unusual variations in isotopic compositions, caused in many case by the nuclear reactions which occur at high temperatures in stellar interiors.

This talk will review how isotopic signatures of presolar grains are used to infer their stellar sources and probe the nucleosynthetic and evolutionary processes which led to their compositions. Of particular interest are connections between different types of circumstellar grains and connections between grains found in meteorites and those found in IDPs. Cometary and interstellar samples returned by the STARDUST mission could provide crucial information on these connections.

I will focus on three types of circumstellar grains: SiC, refractory oxides (primarily Al_2O_3 and $MgAl_2O_4$) and silicates (e.g., $MgSiO_3$). The majority of these grain types are all believed to have originated in similar types of stars: low-mass ($<3M_\odot$) red giant branch (RGB) and asymptotic giant branch (AGB) stars. Some tens to hundreds of individual stars probably contributed SiC and/or oxide stardust to the Sun's parent cloud [4, 5]. SiC production is confined to late-stage AGB stars in which convective mixing of freshly synthesized ^{12}C increases the surface C/O ratio greater than unity. In contrast, oxides and silicates can be produced throughout the RGB and early AGB stages and thus can form in the same stars which later condense SiC.

Many isotopic ratios measured in presolar grains are dominated by the effects of nuclear processing within the parent stars themselves. These include C, N, Mg and heavy elements in SiC grains and $^{17}O/^{16}O$ ratios in most oxide grains. These signatures provide constraints on nucleosynthesis and mixing processes in stars. Other isotopic ratios, including Si and Ti isotopes in SiC and $^{18}O/^{16}O$ ratios in O-rich grains, apparently reflect the initial compositions of the parent stars, with little further modification by stellar processing. The initial compositions of stars are determined by the nuclear history of the material from which they form. The theory of Galactic Chemical Evolution (GCE) describes how the composition of the ISM changes with time and location as succeeding generations of stars inject newly-synthesized material [6-7]. Presolar grain data provide new constraints on the GCE of isotope ratios. Comparison of the O-isotope distribution of oxide grains and the Si distribution in SiC indicates that the oxides originated in stars with a wider range of compositions than did the SiC, despite the expectation that they come from similar types of stars.

Although the number of circumstellar silicate grains identified in IDPs is still limited [3], there is a hint that the O-isotopic distribution differs from that observed in the meteoritic oxide grains. This could reflect sampling biases; perhaps different types of stars preferentially produce silicates relative to oxides, though there is little evidence for this from astrophysical considerations. Alternatively, if the IDPs with presolar grains are cometary, this might indicate heterogeneity in the distribution of different presolar grain types in the solar nebula. Clearly STARDUST samples should help shed light on this issue.

It is unknown how large a fraction of present day interstellar dust is comprised of pristine circumstellar grains, but the interstellar dust returned by STARDUST should be extremely useful for presolar grain science. First, direct isotopic measurement of the average isotope composition of present-day interstellar dust will help constrain GCE trends and provide tests of GCE interpretations of the grain data. Second, if circumstellar grains are found, these will have formed much more recently than the presolar grains and thus provide information in how the stardust population has changed in the solar neighborhood in the last 4-5 billion years.

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AN OBSERVATIONAL TEST FOR SHOCK-INDUCED CRYSTALLIZATION OF COMETARY SILICATES.

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Introduction: Crystalline silicates have been observed in comets and in protostellar nebulae[1,2], and there are currently at least two explanations for their formation: thermal annealing in the inner nebula, followed by transport to the regions of cometary formation and in-situ shock processing of amorphous grains at 5 – 10 AU in the Solar Nebula [3,4]. The tests suggested to date to validate these models have not yet been carried out: some of these tests require a long-term commitment to observe both the dust and gas compositions in a large number of comets. Here we suggest a simpler test.

Shock Processing: Harker and Desch [4] presented a fairly comprehensive model of the shock processing of grains in the solar nebula and demonstrated that grain temperatures for moderate-sized dust particles could easily reach the temperatures required for crystallization [5] and maintain these temperatures for a sufficient time to crystallize magnesium silicate grains. We have re-examined the calculations presented in their paper in more detail and present below a simple extrapolation of their results. The ultimate temperatures of the grains heated via single shock events is highly dependent on the individual particle size. It has also been previously demonstrated that magnesium silicate grains anneal to crystallinity within a few seconds at temperatures near 1100K [6] whereas we might expect that iron silicate grains would require temperatures exceeding 1400K to crystallize in this same time scale [7]. If a 'large' silicate grain is heated to near 1100K, a smaller grain can be heated to 1400K. Therefore, if shocks produce large crystalline magnesium silicate minerals, they should also produce a population of smaller crystalline iron silicates. Because smaller grains in a population illuminated by the same source (e.g. the sun) should equilibrate at a higher temperature than larger grains, these small iron silicate grains within the cometary dust population should shine brightly. Detection of a smaller population of crystalline iron silicate grains in cometary comae could therefore demonstrate the viability of the shock processing model for the origin of crystalline silicates in protostellar sources.

Thermal Annealing: It has been proposed that crystalline silicates seen in cometary comae are the product of thermal annealing in the innermost regions of the Solar Nebula followed by transport of some fraction of the processed grains outward to the regions of comet formation [8,9]. No estimate of the residence times for grains at any particular radial distance from the sun is available in the literature. However, timescales of from months to many hours are required to form crystalline silicates at temperatures between 1025K to 1050K [5]. It seems logical to conclude that a grain may spend a minimum of several orbital periods at the temperature (radius) required for crystallization. By this logic, since crystallization of iron silicates could occur within a month or so at temperatures near 1350K, it should also be possible to produce crystalline iron silicates closer to the sun. Should we therefore also see such grains in comets and protostars? No!

The difference between shock processing and straight thermal annealing is one of timescale. Whereas shock processing is complete in from minutes to seconds, thermal annealing in hotter regions of the Solar Nebula may require months to work. On that timescale at 1400K, the grains will evaporate.

CHEMICAL ANALYSIS OF PRIMITIVE OBJECTS USING A SLITLESS ULTRAVIOLET METEOR SPECTROMETER (CAPO-SUMS). J. A. Nuth[1], T. Wdowiak[2], J. Lowrance[3], G. Carruthers[4], P. Jenniskens[5] and P. Gerakines[2], [1]Code 691, NASA-Goddard Space Flight Center, Greenbelt MD 20771 (nuth@gsfc.nasa.gov), [2]Physics Department, University of Alabama, Birmingham, AL, [3]Princeton Scientific Instruments, Fort Monmouth NJ, [4]Naval Research Laboratory, Washington DC, [5]SETI Institute, 2035 Landings Dr., Mountain View, CA 94043.

SUMS Science Objectives: ***Primary Objective:*** Measure the elemental composition in both random meteors and in the bolides forming specific meteor streams (these are traceable to specific small bodies in the solar system). These will yield the average chemical composition and degree of chemical variability in a statistically significant number of planetesimals. CAPO-SUMS is functionally equivalent to a series of multiple, small-body sample analysis missions, but provides much more analytical capability than is possible on any orbital or flyby mission due to the vaporization, ionization and ultraviolet emission from the ablating bolide as it enters the atmosphere. CAPO-SUMS will provide a chemical context from which the detailed analytical studies provided by a cometary or asteroidal lander mission can be interpreted.

Secondary Objectives: 1. Measure the relative abundances of the Biogenic Elements in these same bolides. These measurements will yield the average abundance and degree of variability of the Biogenic Elements in a statistically significant number of planetesimals.

Secondary Objectives: 2. Measure the chemical stratification of primitive bodies by obtaining measurements of the average elemental abundance in their shower meteors over multiple apparitions, thus analyzing materials emitted from the body at different times. These measurements will be used to infer the structural homogeneity of the individual body, thus separating differentiated objects from rubble piles and yielding a better understanding of the formation and evolution of each individual small body.

Secondary Objectives: 3. Compare the atmospheric entry characteristics (deceleration, fragmentation, catastrophic vaporization, etc.) of meteors with their chemistry to search for compositional types that may be under-represented or absent from modern meteorite collections due to atmospheric destruction

SUMS Mission Characteristics: A hyper-spectral imager using seven fast (f/1.5) cameras, each with a 10 degree field of view, looks down into the terrestrial atmosphere. The dispersed spectral images are recorded at 400 frames per second for later transmission to ground control. Each camera contains event-detection software: data is only recorded if a meteor is in the field of view. The payload will be delivered by the Space Shuttle to the International Space Station and accommodated on a truss mounted carrier system to be developed by GSFC's Shuttle Small Payloads Project Office.

Mission Management: The high-frame-rate ultraviolet cameras will be built by Princeton Scientific Instruments as a Phase III Small Business Innovative Research Program Contract. The original instrument concept and demonstration system were constructed using SBIR Phase I and Phase II funding in order to develop and test this innovative camera. Each camera will be integrated into a telescope design that has flown on several successful sounding rocket missions by the Naval Research Laboratory. The cameras will be integrated into the telescopes constructed by NRL, then tested and calibrated at NRL before delivery to GSFC's SSPPO for integration with the truss-mounted carrier system. The SSPPO will manage all interfaces with both the Space Shuttle and the International Space Station (ISS) Offices in order to assure that the payload is fully compliant with all relevant safety standards and to ensure that these offices receive all necessary payload information in a timely manner. The SSPO will manage the launch of the CAPO-SUMS payload to the ISS, the deployment to the attach point and the initial on-orbit testing of the instruments. Ground systems at the University of Alabama, Birmingham and at NASA's Goddard Space Flight Center will operate the CAPO-SUMS Instruments for the next three years through the Marshall Space Flight Center's Payload Operations Center. During this time CAPO-SUMS will acquire the spectra of more than 1000 sporadic meteors as well as the spectra of tens of thousands of meteors originating in specific meteor showers traceable to individual sources such as Comets Halley, Swift-Tuttle, Giacobini-Zinner and Metcalf. This data set will be analyzed to yield measures of the chemical composition and homogeneity of the parent body. A secondary goal will be to extract a measure of the survival probability of incoming meteors as a function of their chemical composition.

Schedule and Cost: The CAPO-SUMS instruments will be constructed and integrated with the truss carrier before January 2008 for launch in July 2009. On orbit operation will extend through July 2012 with return of the CAPO-SUMS payload to GSFC by December 2012. To design, build, test and calibrate the CAPO-SUMS instruments will cost $42M. To acquire and analyze the data will require $30M. Development of the truss carrier, integration and testing of the instruments and carrier system, management of the deployment of the CAPO-SUMS payload to the ISS and its subsequent retrieval will cost $38M. Adding a generous reserve to account for problems caused by changes in the ISS or space shuttle policies or costs of $75M brings the total cost of the mission to $185M.

ASSESSMENT OF ANALOG PARTICLE CAPTURING BY AEROGEL AT THE FLYBY SPEED OF STARDUST. K. Okudaira[1], T. Noguchi[2], T. Nakamura[3], M.J. Burchell[4], M. Cole[4], and H. Yano[1], [1] Institute of Space and Astronautical Science (ISAS) (3-1-1 Yoshinodai, Sagamihara, Kanagawa 229-8510, JAPAN, okudaira@planeta.sci.isas.ac.jp), [2] Ibaraki University (2-1-1 Bunkyo, Mito, Ibaraki 310-8512, JAPAN, tngc@mx.ibaraki.ac.jp), [3] Kyushu University (6-10-1 Hakozaki, Fukuoka 812-8581, JAPAN), [4] University of Kent (Canterbury, Kent, CT2 7NZ, UK).

Introduction: In 2006 the STARDUST spacecraft will return to the Earth with cometary dust and hopefully interstellar dust grains. They are to be collected by silica aerogel, amorphous SiO_2 with extremely low bulk density (0.02 g/cm^3 for STARDUST [1]). Several investigations suggested that aerogel is suitable for hypervelocity particle capturing. But aerogel is an excellent thermal insulator, the heat converted from the kinetic energy of particles would affect the particles themselves. In these few years the authors have evaluated physical alterations of micrometeoroid analog particles captured by aerogel [2]. Here we report on the results of impacts at around 6 km/s, which is the flyby speed of the STARDUST [1].

Hypervelocity Impact Experiment: Hypervelocity impact (HVI) experiments are conducted in order to simulate hypervelocity particle capture. Two-stage light gas guns were used. We conducted the HVI experiments at 2-4 km/s (ISAS) [2] and at 6 km/s (University of Kent) [3].

In this study aerogel with 0.03 g/cm^3 density was used as targets. They were manufactured by the Institute of the High Energy Accelerator Research Organization (KEK), Tsukuba, Japan and they have been proven capable of capture up to 6 km/s [4].

Sample selection and preparation. Serpentine and cronstedtite were selected as projectiles. These phyllosilicate minerals are analog materials of micrometeoroid since they are common in CM/CI and CM chondrites, respectively. As these hydrated minerals are broken down to anhydrous at relatively low temperatures, it is suitable for the evaluation of thermal alteration during the capture process. The powdered samples were packed into a plastic sabot and shot into aerogel separately. The original particle size range was 125 to 167 μm. To verify whether fragmentation occurs at the moment of launch, thin Al film (2 μm) was placed in front of the target in some shots.

Analytical Methods: Both mineralogical and image analyses were applied to the samples.

Image analysis. Before extraction from each aerogel block, several physical parameters such as sizes of the captured particles and diameters of their entrance holes, length and volume of the penetration tracks were measured by an images analysis.

Mineralogical analyses. Some portions of the samples were then extracted for mineralogical analyses, such as SEM/EDS and Synchrotron Radiation-XRD analysis [5].

Results and Discussions: Although there was fragmentation of particles at the moment of launch, we found an apparent mass reduction of each particle in volume during penetration into the aerogel (down to only 1 to 5 % of their original volumes, without Al foil). In the previous study, the same minerals shot at about 4 km/s reduced their volumes down to 10 % [2]. The SR-XRD analysis revealed that a cronstedtite grain shot into aerogel at 6.06 km/s began to break down into maghemite at the surface. The decomposition temperature of cronstedtite is about 470 °C [6] so it can be said that outermost layer of the remained grain has experienced that temperature. On the other hand, a serpentine grain which decomposes at about 600 – 660 °C [7] was unchanged.

Conclusions: Even shot at 6 km/s into 0.03 g/cm^3 aerogel, a serpentine grain and the bulk of the cronstedtite grain remained mineralogically unchanged. Therefore, for the samples of STARDUST, we will be able to see the pristine states of minerals inside each recovered grain, although these grains lose their volumes and the original surface morphologies.

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MID-INFRARED SPECTRUM OF THE ZODIACAL EMISSION: DETECTION OF CRYSTALLINE SILICATES IN INTERPLANETARY DUST.

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Introduction: Within a few astronomical units of the Sun the solar system is filled with interplanetary dust, which is believed to be dust of cometary and asteroidal origin. Spectroscopic observations of the zodiacal emission with moderate resolution provide key information on the composition and size distribution of the dust in the interplanetary space. They can be compared directly to laboratory measurements of candidate materials, meteorites, and dust particles collected in the stratosphere. Recently mid-infrared spectroscopic observations of the zodiacal emission have been made by two instruments on board the Infrared Space Observatory; the camera (ISOCAM) and the spectrophotometer (ISOPHOT-S). A broad excess emission feature in the 9-11 μm range is reported in the ISOCAM spectrum [1], whereas the ISOPHOT-S spectra in 6-12 μm can be well fitted by a blackbody radiation without spectral features [2].

Observation: The spectrum of the zodiacal emission from the dust in the interplanetary space was observed at wavelengths from 4.5 to 11.7 μm with the Mid-Infrared Spectrometer (MIRS) on board the Infrared Telescope in Space (IRTS) [3,4]. The MIRS was one of the four focal plane instruments on board the IRTS and surveyed about 7% of the entire sky. The observations of the IRTS were made from 1995 March 29 to April 24. The mid-infrared spectrum of the zodiacal emission on the ecliptic plane (solar elongation ~ 97 degrees) was used for the analysis.

Results: The MIRS spectrum of the zodiacal emission at the ecliptic plane is compatible with the ISOCAM and the ISOPHOT-S results at a 20% level and the spectral shapes are all quite similar. The MIRS spectrum is well fitted by the three-dimensional DIRBE (Diffuse Infrared Background Experiment) zodiacal dust cloud model spectrum [5] with a possible excess emission feature in 9-11 μm. The excess feature has a broad 10-μm peak and a small peak at 11.2 μm. We found a combination of 75% amorphous and 25% crystalline silicate particles in weight accounts for the "double-peaked" 9-11 μm feature in the MIRS spectrum.

Discussion and Conclusions: Crystalline silicates have been detected in several comets and interplanetary dust particles (IDPs) collected in the stratosphere. The fraction of the crystalline silicate in case of the MIRS spectrum is similar to that of comet Hale-Bopp (~30-38% in weight) [6]. The particles producing the zodiacal emission in the mid-infrared region are composed of silicates similar to those found in the comae of comets and collected IDPs. The MIRS spectrum suggests that the dust particles in the interplanetary space contain crystalline silicates, particularly Mg-rich olivine comes from comets for the first time [7].

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LARGE PARTICLES FROM SHORT-PERIOD COMETS.

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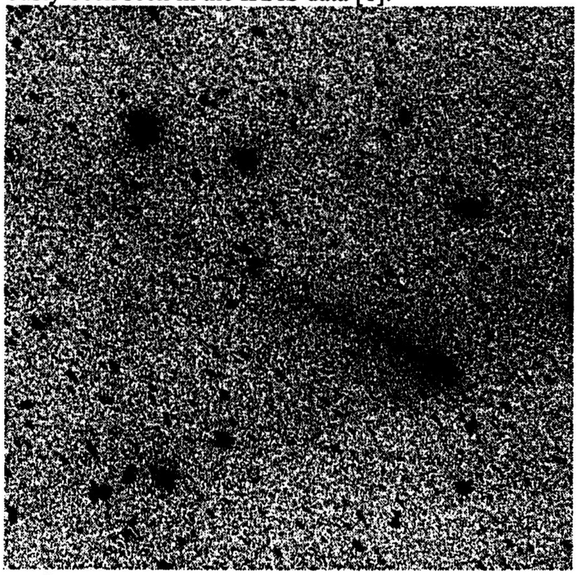
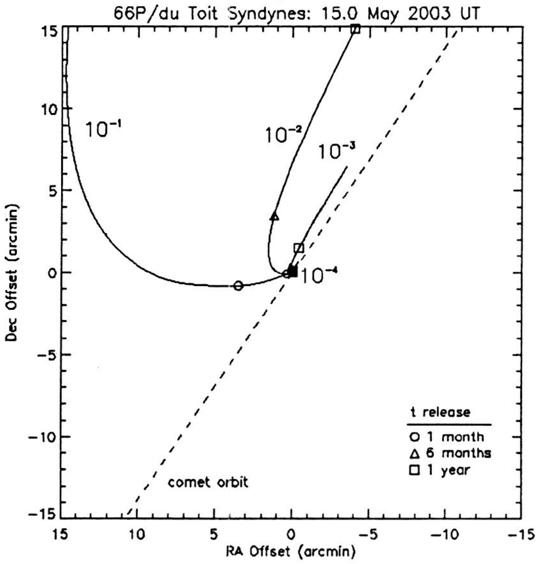
Introduction: Deep optical and mid-infrared images reveal that short-period comets are trailed by large (>mm sized) particles. These particles are the same as those that produce meteor storms in the rare case when a comet's orbit nearly intersects the Earth's. We have begun a campaign of deep observations to determine whether all short-period comets produce large meteoroids. Cometary debris trails were first discovered (serendipitously) by the *Infrared Astronomical Satellite* [1], and they have only recently been detected in visible light [2]. While we ultimately expect to observe nearly all short-period comets, we will initially concentrate on those with favorable apparitions and those that are targets of upcoming spacecraft missions.

Optical Observations: We are using the Palomar Observatory 60-inch and 200-inch telescopes to search for sunlight scattered by large particles with orbits similar to the parent comets. These observations have just begun; so far (May 2003) we have moderately deep observations of Wild 4, duToit, Wirtanen, Tempel 2, Wild 2, Russell 4, Reinmuth 1, Gunn, duToit-Hartley, Churyumov-Gerasimenko, and 2001 RX14. Deep observations of Encke were recently reported [3]. Figure 1 shows a moderately deep observation of Churyumov-Gerasimenko, a potential target for the ESA *ROSETTA* mission, revealing the first optical detection of its dust trail; infrared emission had previously been seen in the IRAS data [1].



Infrared Observations: We used the *Infrared Space Observatory* to observe comets Kopff [4] and Encke[5]. New observations are scheduled for the Space Infrared Telescope Facility (SIRTF). The target list for the SIRTF observations is evolving as the launch is delayed; for an August 2003 launch the target list includes (in time order, from November 2003 to April 2005) Encke, Grigg-Skjellerup, Whipple, Tempel 1, Russell 4, Churyumov-Gerasimenko, Wild 2, Tempel 2, Wilson-Harrington, Neujmin 2, van Biesbroeck, Gunn, Howell, Oljato, Tsuchinsan 2, Hartley-IRAS, Tsuchinsan 1, Elst-Pizarro. For all comets, a 24 micron image will be obtained, and for most comets a 5-40 micron spectrum will be obtained.



Dynamical Modeling: To determine whether large particles are present around the target comets, we predict the trajectories of particles of various size (parameterized by the ratio of radiation pressure to gravity, β, emitted over the current and previous orbit of the comet. Figure 2 shows the syndynes for comet duToit in May 2003. Small particles ($\beta > 10^{-2}$) travel on orbits sufficiently different from the nucleus that they are quickly lost from the nuclear environment and can only be seen if they were produced within months of the observation. Large particles have orbits so similar to the nucleus that they remain close by and only spread gradually, along a trail defining the nucleus' orbit, over years.

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THE ASTROBIOLOGY EXPLORER (ABE) MISSION.

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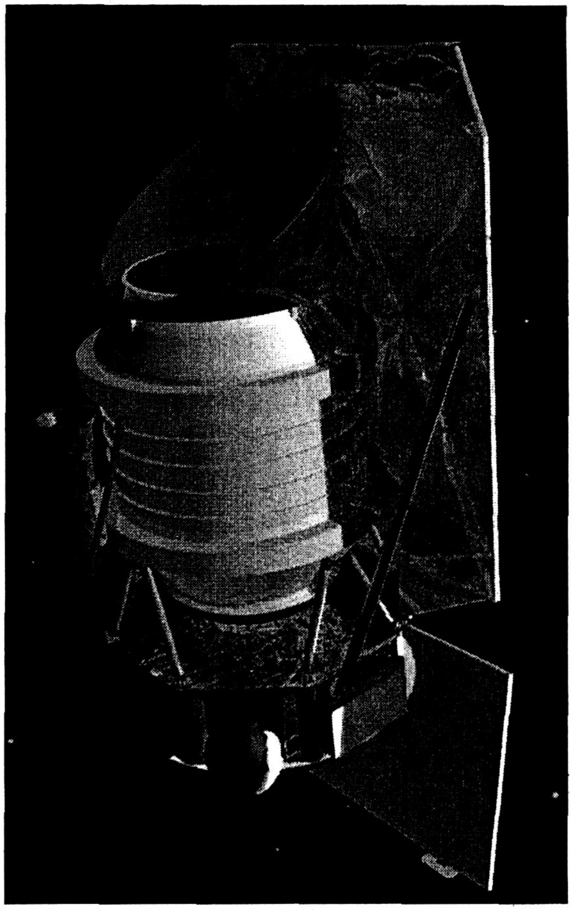
Introduction: Infrared spectroscopy in the 2.5-16 micron range is a principle means by which organic compounds can be detected and identified in space via their vibrational transitions. Ground-based, airborne, and spaceborne IR spectral studies have already demonstrated that a significant fraction of the carbon in the interstellar medium (ISM) resides in the form of complex organic molecular species [1]. Furthermore, the presence of D-enriched organics in meteorites suggests that a portion of these materials survives incorporation into protosolar nebulae [2,3]. Unfortunately, neither the distribution of these materials in space nor their genetic and evolutionary relationships with each other or their environments are currently well understood.

The Astrobiology Explorer (ABE) is a MIDEX mission concept designed to use infrared spectroscopy to address outstanding problems in Astrochemistry which are particularly relevant to Astrobiology and are amenable to astronomical observation. ABE is currently under study at NASA's Ames Research Center in collaboration with Ball Aerospace and Technologies Corporation and the Jet Propulsion Laboratory [4-6]. ABE was selected for Phase A study during the last MIDEX AO round, but has yet to be selected for flight.

ABE's Science Goals: The principal scientific goal of ABE is to detect and identify organic materials in space, ascertain their abundance and distribution, and determine the processes by which they are formed, altered, and destroyed. The core program would make fundamental scientific progress in understanding (1) the chemical evolution of organic molecules in the ISM as they transition from stellar AGB outflows to planetary nebulae to the diffuse ISM to HII regions and dense clouds, (2) the distribution of organics in the diffuse ISM, (3) the evolution of ices and organic matter in dense molecular clouds and forming stellar systems (4) the nature of organics in the Solar System (with an emphasis on comets and asteroids), and (5) the nature and distribution of organics in a wide variety of galaxies. In addition, ABE will attempt to detect and quantify deuterium enrichments in a select set of these materials and environments in order to assist with understanding the chemical processes that occur in these environments and to establish any links that exist between interstellar and meteoritic organics.

Fundamental progress can be made in all of these areas by conducting a coordinated set of infrared spectroscopic observations of approximately 1000 galaxies, stars, planetary nebulae, and young star / planetary systems. These observations require a sensitive observatory above the Earth's atmosphere. There are currently no other existing or planned facilities which have given adequate scientific priority to such observations and which could complete our observing program within their mission lifetimes. A dedicated mission would allow us to optimize mission design to obtain the best data possible for the investigation.



ABE Design: The ABE Observatory consists of a simple spacecraft based on previous Ball designs mounted to a cooled 60 cm diameter space telescope equipped with 3 cross-dispersed spectrometers that share a single common slit. The telescope itself is cooled passively to $T < 55$ K. Each spectrometer measures one spectral octave and together cover the entire 2.5-20 micron region simultaneously. Spectral resolution of the instrument is wavelength dependent but > 2000 at all wavelengths of coverage. The spectrometers use state-of-the-art InSb and Si:As

1024x1024 pixel detectors. Critical optics and the detectors are cooled by solid hydrogen cryogens. ABE would operate in a heliocentric, Earth drift-away orbit and have a core science mission lasting ~1.2 years

ABE at a Glance

Telescope Diameter	60 cm
Orbit	Heliocentric-driftaway
Cryogenic Lifetime	~40 months
Telescope Temperature	< 55 K
Pointing Stability	2.5-3.0" rms
Wavelength Range	2.5-5.1 µm and 4.9-16 µm
Spectral Resolution ( )	2000-3000
Detector Array Size	1024 x 1024 pixels
Detector Array Types	InSb and Si:As

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INTERSTELLAR DEUTERIUM CHEMISTRY.

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Introduction: The presence of isotopic anomalies is the most unequivocal demonstration that meteoritic material contains circumstellar or interstellar components. In the case of organic compounds in meteorites and interplanetary dust particles (IDPs), the most useful isotopic tracer of interstellar components has been deuterium (D) excesses [1]. In some cases these enrichments are seen in bulk meteoritic materials, but D enrichments have also been observed in meteoritic subfractions and even within specific classes of molecular species, such as amino and carboxylic acids [2]. These anomalies are not thought to be the result of nucleosynthetic processes, but are instead ascribed to chemical and physical processes occurring in the interstellar medium (ISM).

The traditional explanation of these D excesses has been to invoke the presence of materials made in the ISM by low temperature gas phase ion-molecule reactions [3]. Indeed, the D/H ratios seen in the simple interstellar gas phase molecules in cold dense clouds amenable to measurement using radio spectral techniques are generally considerably higher than the values seen in enriched Solar System materials [4]. However, the true linkage between the D/H ratios in interstellar and meteoritic materials is obscured by several effects. First, current observations of D enrichment in the ISM have been made of only a few simple molecules, molecules that are not the main carriers of D in Solar System materials. Second, some of the interstellar D enrichment is likely to reside on labile moieties that will have exchanged to some degree with more isotopically normal material during incorporation into the warm protosolar nebula, parent body processing, delivery, recovery, and analysis. Third, ion-molecule reactions represent only one of at least four processes that can produce strong D-H fractionation in the ISM.

Astrochemical Deuterium Enrichment Processes: There are at least four astrochemical processes that are expected to lead to D enrichment in interstellar materials [5]. These enrichment processes are: (i) low temperature gas phase ion-molecule reactions, (ii) low temperature gas-grain reactions, (iii) gas phase unimolecular photodissociation, and (iv) ultraviolet photolysis in D-enriched ice mantles. Each of these processes is expected to yield products with distinct regiochemical signatures (D placement on the product molecules, correlation with specific chemical functionalities or molecules, etc.).

Table 1 and the figure summarize how these different D enrichment processes are manifested in different ways in the chemical class of polycyclic aromatic hydrocarbons (PAHs). PAHs are of particular interest for many reasons. First, PAHs are probably the most abundant and widespread class of organic compounds in the universe [6]. They are observed in the gas phase in a wide variety of interstellar environments, including protoplanetary and planetary nebulae, reflection nebulae, H II regions, the diffuse ISM, ices in dense molecular clouds, and in carbonaceous grains in the diffuse ISM. Second, PAHs are extremely stable molecules and represent one of the few classes of materials that can exist and survive in all the interstellar environments associated with the four chemical processes listed above. Third, PAHs and related aromatic materials are common in carbonaceous chondrites [7] and IDPs [8]. Fourth, the aromatic fractions of meteorites are known to be significant carriers of deuterium [1]. Thus, aromatic molecules represent a known link between the ISM and solar system samples and could potentially serve as probes of the chemical processes associated with interstellar D fractionation.

As can be seen in the table and figure, each of the four different D enrichment processes manifests itself within the overall class of polycyclic aromatic hydrocarbons in different ways. In some processes, for example ion-molecule reactions and unimolecular photodissociation, the placement of D is relatively insensitive to the molecular structure, but is sensitive to overall molecular size. In other cases, for example ice photolysis, molecular size is largely irrelevant and the placement of the D is driven by molecular functionality. As a result, a clear understanding of the placement of the excess D within meteoritic materials should provide important information about the relative different interstellar processes have played in the production of the organic inventory of Solar System materials.

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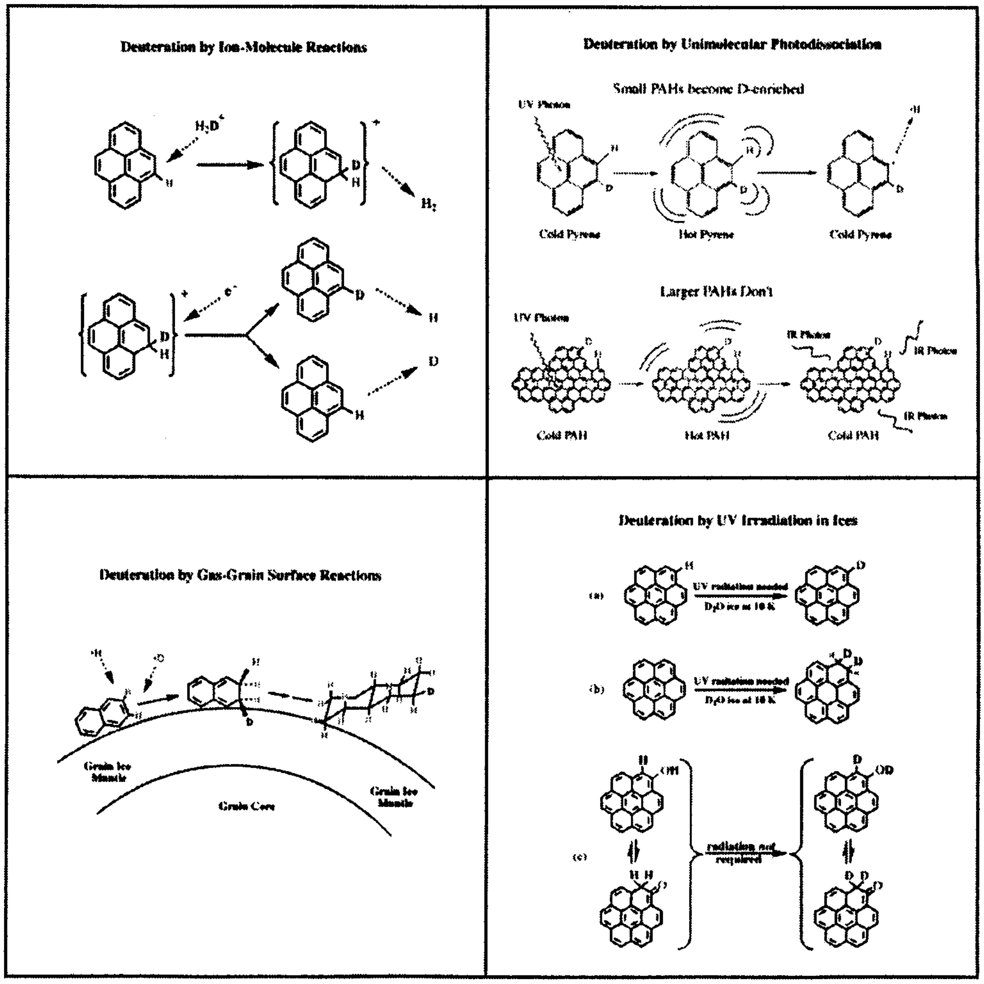
Interstellar Deuterium Chemistry: S. A. Sandford

Table 1: PAH Interstellar D-Enrichment Processes and their Signatures

Process	Low Temperatures Required?	UV Photons Directly Involved?	Deuterium Labile?	Fractionation in other Elements?	Signature
Gas Phase Ion-Molecule Reactions	YES	NO	NO	YES	Favors PAHs with larger numbers of peripheral H atoms (larger PAHs). Probably independent of regiochemistry.
Unimolecular Photo-dissociation Reactions	NO	YES	NO	Probably NO	Favors smaller PAHs (Number of C atoms ≤ 50). Probably independent of regiochemistry.
Gas-Grain Reactions	YES	NO	NO	YES?	May not occur. If it does, the enrichment will reside on the reduced rings of H_n-PAHs.
Ice-PAH Photolysis Reactions	YES	YES	Variable[a]	Possibly	Size independent. Enrichment will correlate with oxidation, reduction, and regiochemistry.

The deuterium associated with oxidized rings on aromatic alcohols and ketones will be labile. Deuterium residing on the reduced rings of H_n-PAHs and on the fully aromatic rings of PAHs will be non-labile.



ISOTOPIC ANALYSIS OF TRACE ELEMENTS IN COMETARY GRAINS

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Introduction: Samples returned from the STARDUST mission will present a strong challenge to the analytical community, particularly to those engaged in trace element isotopic analysis. Questions concerning grain origins can be addressed by looking at the isotopic compositions of heavy element, while fractions among the heavy elements can address issues of residence in the ISM and processing in the protosolar nebula. The very small grain sizes, combined with the low concentrations of heavy elements and finite number of grains available for analysis will require the utmost in sensitivity and multielement capability. Since grains returned by STARDUST will likely be agglomerates of several phases[1], and will at least partially vaporize and leave tracks on the aerogel collector, imaging capability will also be important in the analysis.

Previous Results: We have for several years applied Resonant Ionization Mass Spectrometry (RIMS) on the CHARISMA instrument at Argonne National Laboratory to the isotopic analysis of trace element in individual presolar grains[2, 3]. In brief, material is desorbed from the grain via a pulsed laser beam or focused ion gun, the element of interest is resonantly ionized with tunable lasers, and the ions are analyzed via time-of-flight (TOF) mass spectrometry. RIMS has a unique combination of high sensitivity and high elemental discrimination, which enables the isotopic analysis of trace elements in small (micron-size) grains. In addition, because sample consumption is low, RIMS can be combined with Secondary Ion Mass Spectrometry (SIMS) to perform mixed major/minor multielement analysis on individual grains. RIMS studies have firmly established low-mass AGB stars as the progenitors of mainstream SiC grains[4], and have provided unique information in the quest to identify the astrophysical sites of origin of graphite grains[5]. In some cases, multielement isotopic analysis of metal-rich grains is possible. The isotopic analysis of four heavy elements in a single X-grain is one example[6]. This type of analysis, combined with higher sensitivity and imaging capability, will need to become routine in order to maximize the science gained from STARDUST samples. We are currently implementing significant upgrades to the CHARISMA instrument to meet the special challenges posed by the STARDUST samples[7]. New lasers, a redesigned ion optical system, and a microfocus ion gun will make it possible to perform ultrasensitive multielement isotopic analyses with high lateral resolution.

Future Capabilities: CHARISMA has in the past demonstrated useful yields (atoms detected / atoms consumed) of up to 5%[8], with 1% being typical. The redesigned instrument should boost useful yields for most elements to 30%[9]. Several benefits accrue. The first is that sensitivity will increase by a factor of 30. Apart from the obvious benefit, improving sensitivity while retaining the high discrimination (i.e. low backgrounds) could be crucial to analyzing particle tracks in the aerogel, in which elements present in trace concentrations are further diluted. Second, because the uncertainties scale inversely with the square root of the number of atoms detected, precision will increase by more than 5-fold ($\sqrt{30}$). This is especially important in multielement analyses, which are typically atom-limited. Alternatively, the sample consumption will be reduced at the same measurement precision, enabling measurements to be made on smaller volumes. This will enable grain imaging.

The addition of two new tunable lasers to complement the existing ones will enable the analysis of 2 or 3 elements simultaneously. This will further reduce sample consumption and, combined with the improved useful yield, multiply the number of elements measurable in any single grain. In addition, true multielement imaging will be possible, since elements will be measured simultaneously from the same volume rather than serially from differing volumes.

Finally, the combination of higher useful yield and additional lasers with a microfocus liquid metal ion gun will enable multielement isotopic imaging of trace elements with a lateral resolution as low as 50 nm. Since the particles are expected to be inhomogeneous, and will leave tracks whose composition varies as the particle penetrates the aerogel and vaporizes, this type of imaging could be key in addressing many of issues posed by the STARDUST mission.

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HIGH-TEMPERATURE FRACTIONATIONS IN THE SOLAR NEBULAR PRESERVED IN HIGHLY SIDEROPHILE ELEMENT SYSTEMATICS OF EARTH PRIMITIVE UPPER MANTLE.

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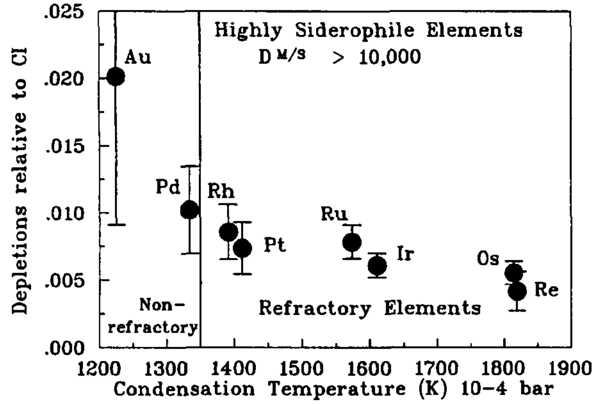
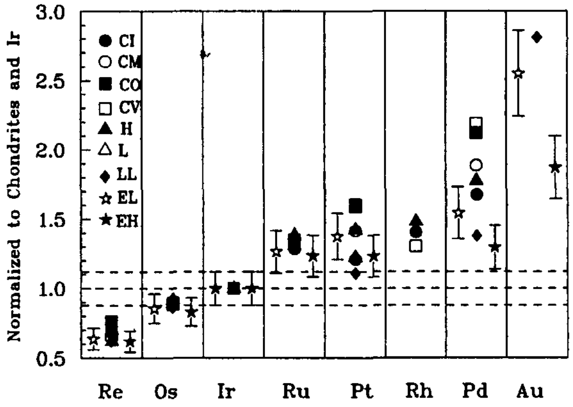
Introduction: Precise abundance data of highly siderophile elements (HSE) in "fertile" mantle rocks will lead to a better understanding of the late accretionary history of the Earth. Primary fractionated HSE in the Earth's mantle would have significant implications for Earth accretion. In this paper, I review high quality data from previous work on HSE abundances in fertile upper mantle samples [1,2] and address cosmochemical constraints for the material of late planetary processes ("late veneer"). I will show the effects of cosmochemical processes in the solar nebular on the abundances of the HSE in Earth upper mantle. The investigations will focus on the evolution of condensed matter in the early solar system to better understand the processes involved in the formation of the Earth and their precursors. It is important to understand the behavior of elements during condensation and later nebular processes that separated elements from one another in the nebula, including separation of dust from gas, and created the components that accreted into asteroids and protoplanets. The results of this work may contribute to our understanding of the origin of the solar system and the processes involved to form planetary bodies and giving the Earth their unique composition.

Mantle abundances related to volatility in a solar gas: The CI-normalized abundances of highly siderophiles in Earth upper mantle are presented in Fig. 1, and shown in order of decreasing volatility in a solar gas. Each point of the HSE represents the mean and one standard deviation of measurements from 13 different samples from Lanzo and the Liguride Units (Italy). The relative abundances of the elements are shown to be nearly CI-chondritic. However, the upper mantle is shown in Fig. 1 to have a systematic enrichment correlated with the volatility of the elements. As can be seen from Fig. 2 the HSE systematics of the late veneer material more closely matching patterns of E- or LL-chondrites than C-chondrites. The HSE pattern of Fremdlinge show systematic enrichments anticorrelated with the volatility of the elements [3].



Conclusions: The abundance distribution of the HSE is remarkably uniform with increasing CI-normalized abundances with decreasing 50% condensation temperatures from Re to Au. The abundances of HSE are related to volatility in a solar gas. The bulk chemical HSE-composition of the late accreted component show that it was formed by high-temperature gas-condensation fractionation processes in the solar nebula. The fractionated HSE show excess of non-refractory elements Pd and Au and depletions in ultra-refractory elements Ir, Os and Re indicating that these elements condensed from a gas in the solar nebular that has suffered an earlier loss of an ultra-refractory component. Qualitatively the pattern of volatility-related fractionations in the HSE show the complementary pattern than observed in ultra-refractory inclusions in carbonaceous chondrites [3]. Contrasting abundance patterns from individual Fremdlinge and the Earth mantle must have been established in the solar nebula. Condensation from a solar gas is the most important process leading to fractionations in primitive objects of our solar system.



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The Ulysses dust detector has identified and measured, recently at GPS and atomic clocks accuracies, stable within one second in thirty two thousands years, the interstellar dust beyond Mars at 1.8 AU.

The Tagish Lake low albedo meteorite, reflect infrared light better than visible light. The pristine carbonaceous chondrite, originated beyond the interstellar dust boundary between Mars and Jupiter, has abundance of atmospheric oxygen isotope feature from its anhydrous precursors (1), high temperature olivine dominant source of CO_2 and low temperature carbonate. The silicate ten micron feature, interpreted as a gap between Aromatic Features in Emission, appeared in warmer meteorite than the interstellar medium (2). Polycyclic aromatic hydrocarbons dominate the spectrum of Kuiper Belt Objects (3), they are frequently produced in the highest concentrations in the meteorite regions rich in carbonates which have high optical density (4).

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CONSTRAINTS ON THE COMPOSITION OF INTERSTELLAR DUST FROM ASTRONOMICAL OBSERVATIONS. Theodore P. Snow[2], [1]CASA – University of Colorado, 389 UCB, Boulder, CO 80309, USA; e-mail tsnow@casa.colorado.edu).

Astronomers infer the composition of interstellar dust by indirect means. Constraints on the composition come from studies of the light-scattering and absorption properties of the dust (i.e., interstellar extinction), and from optical and ultraviolet absorption line measures of the interstellar gas. Further information comes from X-ray spectra of absorption features and from *in situ* measurements of interstellar grains entering the solar system. Extinction data provide constraints on dust particle sizes and also yield some information on grain composition (e.g., the well-known ultraviolet extinction "bump" which is likely created by graphitic carbon). Analyses of optical and ultraviolet atomic absorption lines in the interstellar gas reveal underabundances or "depletions" of certain elements which are therefore thought to reside primarily in the dust. The use of depletions to infer dust grain composition relies on an assumed cosmic abundance pattern, a source of uncertainty that will be discussed. X ray absorption lines and ionization edges (arising from inner-shell electronic transitions) can provide total line-of-sight abundances from which the grain composition can be inferred, while spacecraft detections of incoming interstellar grains can provide unique information on the particle size and mass distribution in the local ISM. This review will provide an overview of these astronomical observational methods and results, and will summarize the current state of knowledge of depletions and the inferred composition of interstellar dust grains. The review will conclude with remarks on the comparison between the inferred composition of interstellar dust and the composition of IDP inclusions such as the GEMS that may be of interstellar origin.

OBSERVATIONAL EVIDENCE FOR PRESOLAR GRAINS AROUND OXYGEN-RICH EVOLVED STARS. Angela K. Speck, *Physics & Astronomy Department, University of Missouri, Columbia, MO 65211, USA (speckan@missouri.edu)*, Anne M. Hofmeister, *Department of Earth & Planetary Science, Washington University, St. Louis, MO 63130, USA*, Melvin Mora, *Physics & Astronomy Department, University of Missouri, Columbia, MO 65211, USA.*

Many presolar grain types have been found in meteorites since the discovery of presolar silicon carbide (SiC) grains in the Murray meteorite [1]. Initially these were mostly limited to carbon-rich grains. However, more recently, oxygen-rich presolar grains have been isolated [e.g. 2, 3]: e.g. corundum (Al_2O_3), spinel ($MgAl_2O_4$), hibonite ($CaAl_{12}O_{19}$) and rutile (TiO_2). The majority of these O-rich grains, like the SiC grains, have isotopic compositions indicative of formation around asymptotic giant branch (AGB) stars [2,3].

Theoretical dust condensation models for O-rich AGB stars include the formation of Al_2O_3 [e.g 4] and TiO_2 [5]. usually as condensation nuclei for the more abundant silicates.

However, there is not much observational evidence for most of these presolar grains around AGB stars, and what little evidence does exist is generally misinterpreted. The dominant minerals observed around AGB stars are the silicates, presolar examples of which are difficult to find in meteorites, although this may be due to the laboratory processing used to extract the grains. There is evidence for presolar silicates in the solar system found in interplanetary dust particles [6,7].

In order to study the mineralogy of dust around AGB stars we observe their infrared (IR) spectra and compare these to laboratory spectra of likely minerals. This technique must be practised with caution, to avoid incorrect attributions of spectral features to certain minerals (e.g. SiC: see discussion in [8]). Until recently a feature in the spectra of some AGB stars at ~12.5-13.0μm was attributed to Al_2O_3 [e.g. 9]. There is some dispute over this attribution [e.g. 10], since for most polytypes the spectral features of Al_2O_3 are both the wrong shape and peak at the wrong wavelength. There is one polytype of Al_2O_3 with a peak in the right range. This feature is accompanied by a feature at 21μm which is not seen in the observed spectra, however the 21μm feature is much weaker than the ~13μm feature, which may explain why it is not seen. A further problem is that the ~13μm feature is not ubiquitous in AGB star spectra, which would be odd if it were due to a mineral as important as Al_2O_3 in the expected dust condensation sequence. We present observational evidence for Al_2O_3 in the mid-IR spectra of O-rich AGB stars and red supergiants, demonstrating that this mineral is indeed present in observable abundance around many evolved stars in an amorphous form.

Another presolar grain has also been suggested as the carrier of the ~13μm feature: spinel [11,12]. This attribution also has problems. Previously published optical data for crystalline spinel [e.g. [13,14] suggests that the spectral feature peaks longward of 13.5μm and is therefore unlikely to be responsible for the observed ~13μm feature. It has been shown that spherical grains on stoichiometric spinel could produce IR spectral features at 13, 17 and 32μm, which they observed in astronomical spectra. However, it has been shown that the 17μm feature is, in fact, due to CO_2, and that there is no correlation between 32 and 13μm features [15]. Furthermore, spinel is expected to be associated with the densest circumstellar shells as it can only form in these environments, whereas the 13μm feature is associated with low density (low mass-loss rate) AGB stars [16,17]. It is possible that the appearance of the 13μm feature is due to the formation of small oxide grains (corundum or spinel), which are seen because they are naked. In the denser circumstellar shells, these grains may simply be coated by the more abundant silicates and thus not seen.

The most recently discovered O-rich presolar is hibonite, which is currently under investigation. Recent work on the laboratory spectra of hibonite is available (e.g. [18,19]) It is possible that the IR features of hibonite appear in some ISO spectra (see e.g. spectrum in [19,20]) which are presented here. Spectral features that are currently attributed to calcite and dolomite [20] may be better explained by hibonite and grossite [19].

The remaining mineral, rutile, has not been investigated observationally. This is due to the low abundance of Ti, which makes it unlikely that an observable amount of TiO_2 is produced.

At present, the only O-rich presolar grain type for which the observational evidence is not (currently) disputed is (amorphous) Al_2O_3. In order to progress further in matching these presolar grains and the grains currently forming around AGBs stars we need to know more details about these grains: e.g. polytypes, the level of crystallinity/amorphousness in the grains, the size distributions, etc. With this information we place more constraints on the IR spectral feature we should be looking for. Further observational constraints are also required, such as spatial correlations between related IR spectral features.

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TOF-SIMS — A POWERFUL TOOL FOR THE ANALYSIS OF STARDUST. T. Stephan, Institut für Planetologie/ICEM, Wilhelm-Klemm-Str. 10, 48149 Münster, Germany (stephan@uni-muenster.de).

Introduction: During the last two and a half decades, the analysis of small samples has become more and more important in cosmochemistry. With the collection of interplanetary dust particles (IDPs) [1] and the isolation of presolar grains from primitive meteorites [2], the necessity for new techniques with high sensitivity and high lateral resolution has increased. For many years now, secondary ion mass spectrometry (SIMS) has played an important role in the analysis of such samples [3]. Two major trends in the development of new SIMS instruments emerged during the last years, NanoSIMS and TOF-SIMS. Both will be instrumental in the analysis of samples from the Stardust mission [4].

NanoSIMS: Improvements of the classical ion microprobe with double focusing magnetic mass spectrometers has led to the development of Cameca's NanoSIMS 50 [5–7]. This instrument is characterized by a high spatial resolution, ~50 nm with a cesium primary ion source, used for negative secondary ions, and ~200 nm with an oxygen ion source for the analysis of positive secondary ions. A multi-detection system allows the simultaneous measurement of up to six masses. High secondary ion yields at high mass resolution ideally meets the requirements for isotope analyses of sub-micrometer-sized samples.

TOF-SIMS: Another concept, time-of-flight (TOF-) SIMS, also reaches ~200 nm lateral resolution by using a fine-focused gallium liquid metal ion source. After its introduction into cosmochemistry in the early 1990s, this technique has grown to a powerful tool for the study of micrometer-sized samples [8]. The advantage of this instrument lies in its capability of simultaneously measuring <u>**all**</u> secondary ions with one polarity. Both polarities can be measured in two consecutive analyses. Secondary ions released during sputtering with the Ga-beam are separated in a drift tube according to their flight time after acceleration in an electric field. Due to the time-of-flight concept, secondary ions are generated in a short (typically ~1 ns) primary ion pulse. With 10 kHz repetition rate and 10–50 primary ions per shot, only monolayers of a sample are consumed even during an eight-hour measurement. Consequently count rates at a specific mass are relatively low and the capability of measuring isotopic ratios is limited by counting statistics.

Nevertheless, for presolar grains, where deviations from solar isotopic ratios are often tremendous, statistical errors of some percent are tolerable. It is noteworthy that with TOF-SIMS for the first time the isotopic heterogeneity within a single 2 µm-sized presolar silicon carbide grain was discovered [9].

The main advantage of TOF-SIMS is the parallel detection of the entire mass range that is in principle unlimited. This allows to measure major, minor, and trace elements, their isotopes, as well as molecular ions, all simultaneously in a single measurement. Simultaneous detection is a prerequisite to discover with SIMS possible correlations between different ion species from small samples, since SIMS is always destructive and samples may change under the ion beam. TOF-SIMS is ideally suited to discover unexpected properties of the investigated samples because no preselection of ion species to be analyzed is necessary.

Combination of different techniques: For a comprehensive study of small samples like IDPs a combination of different techniques is appropriate to yield a maximum of information on single grains and their components. While isotopic anomalies within such grains can easily be detected with NanoSIMS, TOF-SIMS allows a chemical and often mineralogical identification of the respective carrier phases [10–12]. With NanoSIMS alone, this would be impossible in case of very small samples due to sample destruction.

Outlook: Because of its characteristics, TOF-SIMS is a suitable technique for the analysis of samples from the Stardust mission. Grains from comet Wild 2 as well as contemporary interstellar dust are projected samples to be brought back in 2006. For both types of particles it is indispensable to use analytical methods that introduce the least possible bias and that allow subsequent analyses with other techniques. TOF-SIMS with its comprehensive analysis and the little sample destruction meets these requirements.

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FOCUSED ION BEAM MICROSCOPY OF EXTRATERRESTRIAL MATERIALS: ADVANCES AND LIMITATIONS. R.M. Stroud, US Naval Research Laboratory, 4555 Overlook Ave SW, Washington, DC 20375, (stroud@nrl.navy.mil).

Introduction: Coordinated isotopic and structural studies of the same cometary, interstellar or presolar grains provide the best basis for determining the origin, and the formation and processing conditions of the grains. Until recently few of these coordinated studies were possible because of the destructive nature of the isotopic measurements, and the awkward grain size, *i.e.* too thick for direct analysis by transmission electron microscopy (TEM), but too small to microtome. The focused ion beam (FIB) workstation dramatically increases the possibility for conducting these coordinated studies by permitting the site selective preparation of ultrathin slices of dust grains as small as 100 nm. The FIB slices can be extracted from isolated dust grains dispersed on stubs or other supports, grain clusters, or even grains embedded in meteorites, before or after isotopic characterization.

Methods: The basic FIB workstation has a Ga^+ ion source that is focused to a 10 to 100-nm diameter beam at an energy of 30 kV. By rastering the beam the sample can be both imaged and sputtered. At low ion currents, the sputtering is slow, but the secondary electron yield is high enough to image the sample. At high ion currents, the Ga^+ beam sputters a few cubic microns of material per minute. The more advanced (dual or cross beam) FIB workstations also include an electron source, so that imaging and analysis without any sputtering is possible. An important feature of the FIB for preparation of TEM samples is that it also can be used for site-selective deposition of metals, typically Pt and W. The metal deposition serves multiple purposes: it protects the region of interest from Ga implantation; it provides an electrically and thermally conductive path to minimize charging and heating; and it increases the total sample breadth to a reasonable size for imaging and manipulation under an optical microscope.

The basic steps for preparing a FIB ultrathin section are: (1) locate the grain or region of interest (ROI), (2) deposit a Pt mask, typically 1-4 microns thick by 10 microns long, (3) at moderate ion current sputter trenches on either side of the ROI to create a vertical section 500 nm thick, 8 microns long, 1 or 2 microns deeper than the ROI, (4) tilt the sample to 45° and at low beam current cut away the bottom and ¾ up the sides of the section, (5) tilt back to vertical and continue sputtering at low ion current until the desired thinness is reached (70-100nm), (6) make final cuts on sides to detach section and (6) transfer the ultrathin section to a TEM support grid using a micromanipulator. At this point the section is ready both TEM and isotopic characterization.

Applications: The FIB lift-out technique has been successfully adapted to extracting thin sections of: CAI rims and associated matrix material from meteorites [1], metal and graphite inclusions in the lodranite GRA 95209 [2], presolar oxide grains [3], *in situ* and physical separate presolar SiC grains [4], and most recently interstellar dust particles [5]. Sections of meteorites as wide as 20 microns, and of grains as small as ~100 nm have been prepared. TEM analysis of the sections showed them to be ideal for diffraction, microstructural studies, and energy dispersive x-ray analysis, but too thick as-supported on carbon films for lattice imaging and electron energy loss spectroscopy. Thinner sections attached directly to copper grids without support films can be produced using a FIB with an electron source and an *in situ* micromanipulator.

Compared to ultramicrotoming the chief advantages of the FIB technique are that it can be used with smaller samples, on heterogeneous materials with large variations in hardness and porosity, with less chance of sample distortion, and that precisely selected sections can be extracted directly from bulk or thick section materials, without destructive polishing of the host material. The disadvantages of the FIB include the high cost, the relative difficulty of producing serial sections, and the surface amorphization due to ion irradiation.

Potential future applications for the FIB technique include the extraction of isotopically distinct subgrains of dust particles, and extraction of Stardust samples from the aerogel collection material. In addition to preparing TEM sections, the FIB may be very useful for cross-sectioning cosmic dust micrometeorite samples for SEM analysis [6].

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THE LIFECYCLE OF INTERSTELLAR DUST

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Interstellar dust is an important component of the interstellar medium. Dust grains are the dominant opacity source and thus regulate the radiative transfer in the interstellar medium. Besides the spectral characteristics of sources, dust therefore influences directly the molecular composition of clouds through photodissociation and the heating of the gas through the photoelectric effect. Furthermore, dust grains also provide surfaces for active chemistry. This talk will review the lifecycle of interstellar dust from their birthsites to their possible incorporation into budding planetary systems with an emphasis on processes involved and their influence on the physical characteristics.

Interstellar dust is affected by a variety of processes. Stars in the late stages of their evolution form dust grains by chemical nucleation and growth and injected them into the ISM. Grains in the ISM are processed by strong shock waves which ao sputter, vaporize, and shatter them. The physics of interstellar shock waves and of these destruction processes will be reviewed. The ISM is organized in a number of phases: HI and molecular clouds, warm (neutral/ionized) intercloud medium, and coronal gas. Dust destruction is dominated by supernova shock waves in the intercloud medium.Because of rapid exchange of dust and gas between the phases, the effects of this are felt through all phases. Further processing will occur in the protostellar nebulae and these processed materials may be dispersed again through the ISM. This will be briefly discussed.

COMETARY DUST CHARACTERISTICS DERIVED FROM LEONID METEOR SHOWER MULTI-INSTRUMENT OBSERVATIONS.

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Introduction:

Meteor storms are usually produced by long period comets with high inclination orbits that produce violent encounters of the meteoroids with the terrestrial atmosphere. Not all meteor outbursts during the last decades were produced by high-velocity material. For example on 27-28 June 1998 an important 7-hour outburst was produced by meteoroids ejected from comet P/Pons-Winnecke [1]. On 8 October 1998 other interesting outburst is produced by Giacobinni-Zinner meteoroids [2]. Both low velocity encounters can allow this matter to deposit into the atmosphere with minimum degradation compared to high-velocity meteoroids [3].
The study of these outbursts can provide us excellent opportunities to collect stratospheric dust from short-period comets [4].

To study the different range of mass of this cometary material we have analyzed the meteoroid mass distribution of the Leonids, the 1998 Pons-Winneckids and Giacobinids, Perseids and other major cometary meteor showers. In order to derive the particle's mass we use the magnitude of the meteor produced when they enter into the terrestrial atmosphere [5, 6].

Taking into account the mass distribution of several meteor showers we are able to deduce the global mass that reach the Earth from annual showers and meteor storms. For example, during a Leonid storm around 10 kg/hour of Tempel-Tuttle dust enters into the terrestrial atmosphere. By comparison during the 1998 Pons-Winneckid 7-hour outburst more than 150 kg of cometary dust was delivered to the Earth. Annual showers as Perseids or Geminids only bring to the atmosphere among 0.1 and 0.7 kg/hour respectively during their maximum activity periods. In consequence, meteoroid streams with geometry capable to produce low geocentric velocity encounters have important mass contribution to the terrestrial atmosphere. One interesting application would be to search for differences in the mass distribution for different comets in order to deduce the mass cut-off in the distributions. For large particles there is usually is found a clear cut-off because the particle mass should allow escape from the gravitational field of the parent comet during ejection [7]. It is accasionally possible to detect a cut-off for small particles depending on the Poyting-Robertson effect and the planetary perturbations that are more important as function of the material composition and the number of revolutions that this material completed around the Sun [8]. Young meteoroid streams such as the Leonid recent ejecta that we have studied during the last years during multi-instrument campaigns are of extraordinary interest to give us direct evidences on the minimum size of mineral grains [9].

From meteor spectroscopy we have found [10] important chemical differences between the cometary meteoroids from different streams and the in situ collected data by the Giotto spacecraft [11] at 1P/Halley. Among these differences is important to note that the deduced abundances of Si-Mg-Fe are in accordance to the hierarchical dust accretion model [12]. In this context is interesting to study the meteoroid mass and size distributions to compare with the range expected for IDPs. Our meteoroid spectra and mass distribution studies shows that (1) 1P/Halley can not be used as type sample of cometary dust and (2), there are important differences between comets, as was already pointed out by [13]. These substantial chemical differences among comets probably are related with the existence of different families as was proposed previously [14].

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TOMOGRAPHIC STUDIES ON THREE-DIMENSIONAL STRUCTURES OF MICROMETEORITES AND FUTURE APPLICATION TO IDP AND COMETARY DUST.

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Introduction: X-ray computed tomography (CT) is a method to obtain internal structures of objects without damaging the samples using X-ray attenuation and provide 3-D structures by stacking successive sliced images. Synchrotron radiation (SR) source provides monochromatized and collimated X-ray beams useful for X-ray CT technique. An X-ray mictotomographic system using SR at SPring-8 [1] has been applied to micrometeorites to examine their 3-D structures and densities [2,3]. In this abstract, we report the CT system, the results of the previous studies on micrometeorites and development of a new tomographic system with higher spatial resolution available for IDPs and cometary dust.

CT system at SPring-8: The X-ray CT experiments were performed at the beamline BL47XU of SPring-8, Japan. The system (SP-μCT) is composed of a high precision rotation stage for a sample and a beam monitor for X-rays. The projection images were obtained by the beam monitor, where the transmitted X-ray was transformed to visible light by a fluorescent screen, expanded by a relay lens and subsequently detected by a 2-D CCD camera. Projection images are reconstructed to CT images using a convolution back projection algorithm. 3-D structures were reconstructed by stacking slice images. The size of each voxel (pixel in 3-D) in CT images is $0.5 \times 0.5 \times 0.5$ μm^3 with the effective spatial resolution of ~1.5 μm [1].

CT images are digital images showing spatial distribution of CT-values of materials. As we used monochromatic beams, the CT-value is uniquely related to X-ray linear attenuation coefficient (LAC), which is a function of the chemical composition and the density of material and X-ray energy. We have obtained quantitative relation between the CT-value and LAC by imaging standard samples with known chemical compositions and densities. From this relation, we can estimate minerals in CT images.

Tomographic studies on micrometeorites: We have applied this system to twelve Antarctic micrometeorites (AMMs) (~100-300 μm in size) [2,3].

Density measurement. The volumes and porosities were obtained from their 3-D structures. The masses of nine samples were measured by an ultra-microbalance (0.8-5.7 μg) and the bulk and solid densities were obtained. The solid densities of two unmelted AMMs with hydrous minerals are 1.9±0.2 and 2.0±0.0 g/cm^3 (CM- and CI-like, respectively). This suggests the presence of sub micron micropores below the spatial resolution [3].

3-D elemental mapping. The concentrations of an element can be obtained quantitatively in a CT image using the adsorption edge of the element by subtraction method. 3-D distribution of Fe of a sample was determined [2].

3-D plaster models. Enlarged 3-D models of plaster (~5 cm) were made from the 3-D structures using rapid prototyping method. These real models helped us to understand their complex 3-D shapes easily.

A higher resolution CT system and its application: As visual light is expanded in the SP-μCT system, the obtained spatial resolution is limited to the wavelength of 0.4-0.7 μm. To obtain higher resolution, X-ray beams themselves should be expanded such as by a Fresnel zone plate (FZP). A new system using an FZP was developed at SPring-8 [4]. The 3-D images were successfully reconstructed with a pitch pattern of 0.6 μm.

This system has a potential spatial resolution of the order of 10-100 nm. A new system with such high resolution is under development at SPring-8. We are planning to apply this new system to IDPs and cometary dust returned by the Stardust spacecraft. The major objectives are (1) identifying the sliced locations of sections made by a microtome in a 3-D structure, (2) identifying constituent grains: the size distribution and the fractal dimension of the aggregate to discuss aggregation process and the shapes to discuss the effect to the IR spectrum.

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DUST MASS AND FLUX MEASUREMENTS ON CASSINI AND STARDUST MISSIONS WITH PVDF DETECTORS.

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Introduction: The PVDF based High Rate Detector (HRD) and the Dust Flux Monitor Instrument (DFMI) from the University of Chicago are part of the Cassini and STARDUST mission payloads [1], [2]. The prime goal of the DFMI and the HRD is to measure the particle flux, intensity profile, and mass distribution during passage through the coma of comet Wild-2 in January 2004 and after Saturn orbit insersion in July 2004, respectively. Both instruments are capable of measuring dust particle mass of 8 decades, from 10^{-11} to > 10^{-3} g.

The Stardust and Cassini PVDF Dust Instruments: The DFMI instrument consists of two different dust detector systems — a polyvinylidene fluoride (PVDF) dust Sensor Unit (SU), which measures particles with mass < ~ 10^{-4} g, and a Dual Acoustic Sensor System (DASS), which utilizes two quartz piezoelectric accelerometers mounted on the first two layers of the spacecraft Whipple dust shield to measure the flux of particles with mass > 10^{-4}g. The electonics box houses all the necessary circuitry for hadling the signals produced in the SU, the memory counters and the software programs that provide the interface to the spacraft. This is all shown in **Figure 1.** The Cassini HRD instrument which is part of Cosmic Dust Analyser (CDA) is similar to the DFMI instrument but without the acustic counters. The following table list the 4 mass thresholds for each PVDF detector.

Large PVDF Sensor Area = 200 cm² Thickness = 28 µm			**Small PVDF Sensor Area = 20 cm² Thickness = 6 µm**		
Electronic Threshold ✦	**Particle Mass Threshold**	**Particle Diameter ***	**Electronic Threshold**	**Particle Mass Threshold**	**Particle Diameter**
1.76×10^{9} e	8.5×10^{-8} g	55 µm	3.77×10^{6} e	9.8×10^{-12} g	2.7 µm
			7.13×10^{7} e	$1.2\ 10^{-10}$ g	6.1 µm
2.67×10^{10} e	1.7×10^{-6} g	148 µm	1.8×10^{8} e	4.3×10^{-9}	20.2 µm
			6.0×10^{9} e	6.3×10^{-7} g	106 µm
2.67×10^{11} e	1.4×10^{-5} g	299 µm	**Ground Command Electronic Threshold**	**Ground Command Particle Mass Threshold**	**Ground Comman Particle Diamete**
			4.6×10^{7} e	7.0×10^{-11} g	5.1 µm
2.0×10^{12} e	1.5×10^{-4} g	659 µm	8.7×10^{8} e	2.6×10^{-8} g	36.8 µm
			2.2×10^{9} e	1.2×10^{-7} g	61 µm
			7.3×10^{10} e	1.7×10^{-5} g	319 µm

* Assuming impacting particle with density 1.0 g/cm³
● Electronic thresholds in units of number of electron charges (e)

Figure 1.

The DFMI instrument on STARDUST will be usufull during the short period during the comet encounter. Using the Wild-2 dust model provided by Ray Newburn [3] an expected counting rate vs time from the closest approach was calculated and shown in Figure 2. This is similar to the dust flux distribution observed during the VEGA-1 and VEGA-2 missions in 1986. [4]

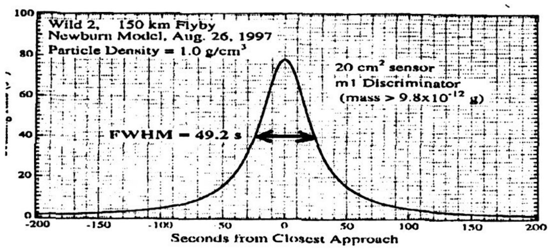

Figure 2

The HRD on Cassini has been obtaining interplanetary data for more than 4 yers now, but the most usuful data will the data from different Saturn rings after July, 2004.

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ROBUST EXTRACTION AND MULTI-TECHNIQUE ANALYSIS OF MICROMETEOROIDS CAPTURED IN LOW EARTH ORBIT.

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Introduction: The use of low-density silica aerogel as the primary capture cell technology for the NASA Discovery mission *Stardust* to Comet Wild-2 [1] is a strong motivation for researchers within the Meteoritics community to develop techniques to handle this material. The unique properties of silica aerogel allow dust particles to be captured at hypervelocity speeds and to remain partially intact. The same unique properties present difficulties in the preparation of particles for analysis. Using tools borrowed from microbiologists, we have developed techniques for robustly extracting captured hypervelocity dust particles and their residues from aerogel collectors[2-3]. It is important not only to refine these extraction techniques but also to develop protocols for analyzing the captured particles. Since *Stardust* does not return material to Earth until 2006, researchers must either analyze particles that are impacted in the laboratory using light-gas-gun facilities [e.g. 4] or examine aerogel collectors that have been exposed in low-Earth orbit (LEO) [5]. While there are certainly benefits in laboratory shots, i.e. accelerating known compositions of projectiles into aerogel, the LEO capture particles offer the opportunity to investigate real particles captured under real conditions

Experimental: The aerogel collectors used in this research are part of the NASA Orbital Debris Collection Experiment that was exposed on the MIR Space Station for 18 months [5]. We have developed the capability at the UCB Space Sciences Laboratory to extract tiny volumes of aerogel that completely contain each impact event, and to mount them on micromachined fixtures so that they can be analyzed with no interfering support (Fig.1). These aerogel "keystones" simultaneously bring the terminal particle and the particle track to within 10 m (15 g cm^{-2}) of the nearest aerogel surface. The extracted aerogel wedges containing both the impact tracks and the captured particles have been characterized using the synchrotron total external reflection X-ray fluorescence (TXRF) microprobe at SSRL, the Nuclear Microprobe at LLNL, synchrotron infrared microscopy at the ALS facility at LBL and the NSLS at BNL, and the Total Reflection X-ray Fluorescence (TXRF) facility at SLAC.

Discussion: Most of the techniques that have been applied on the extracted wedges are essentially non-destructive or have limited detrimental effects on the particles. An exception may be the alteration of hydrogenous material during PIXE, RBS or PESA analysis with the Nuclear Microprobe. While it is important assess the suitability of the various analytical techniques, the particles captured in LEO offer an opportunity to examine material that has not been subjected to selection and modification processes that occur during atmospheric transit by the particles terrestrial repositories of cosmic dust. Of course the captured particle may have undergone alteration during hypervelocity capture. From the X-ray maps acquired using proton induced X-ray emission it is clearly possible to identify fine Fe rich particulate material on the sub-micron scale that has deposited on the walls of impact track (Fig. 2). However the identification of light elements from the data acquired from proton elastic scattering analysis and proton backscattering analysis would suggest that while the particles may fragment during hypervelocity capture the volatile elemental chemistries are not lost. This is clearly important when it comes to the analysis of any organic material.

We are also developing techniques for extracting dust particles from the impact region within keystones, either at the terminus or along the impact track, using both mechanical extraction techniques and focused ion beam (FIB) milling.

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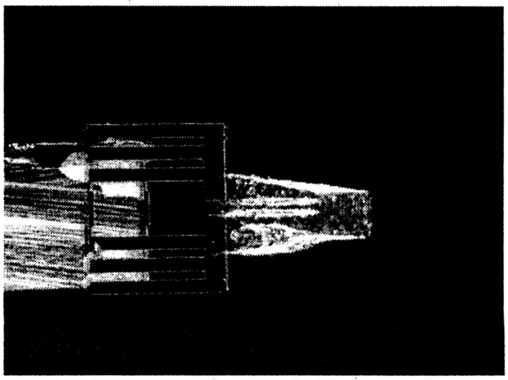

Figure 1: An extracted aerogel "keystone" completely containing a hypervelocity dust impact.

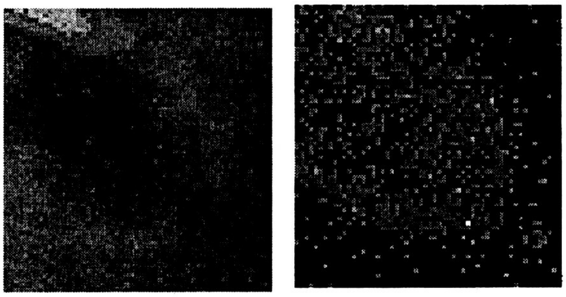

Figure 2: PIXE Si (left) and Fe (right) maps of an impact event from the ODCE collector.

SUCCESSFUL LAUNCH AND SCIENTIFIC PREMISES OF "HAYABUSA" ASTEROID SAMPLE RETURN MISSION

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Introduction: At 13:29:25 on the 9th May 2003 JST, ISAS's engineering test spacecraft "MUSES-C" was successfully launched with the full-stage solid fuel rocket M-V-5, from the ISAS Kagoshima Space Center at Uchinoura. After confirming deployment of its solar array paddles and sampling horn as well as the proper attitude control through the telemetry received by the Deep Space Network, the spacecraft was inserted to interplanetary trajectory and renamed as "Hayabusa", or "Falcon" from its resemblance with the bird that flies fast to its target, hovers to monitor, and catches its prey in "touch & go" sequence. The Hayabusa has become the world's first sample return spacecraft to a near Earth object (NEO) [1] (Fig. 1). The NEO 1998SF36 is its mission target. By previous radar and multi-band optical observations, its orbital and physical characteristics were well understood; the size is (490±100)x (250±55)x(180±50) m with about 12-hour rotation period [2]. It has a red-sloped S(IV)-type spectrum with strong 1- and 2-micron absorption bands, analogous to those measured for ordinary LL chondrites with space weathering effect [3].

Post Launch Sequences: At present, the spacecraft has nearly completed its initial orbital operation and the ion engines have been ignited. Hayabusa is now in a trajectory similar to the earth's orbit around the sun to time the swing-by opportunity in June 2004. Then it changes the course heading to the target asteroid whose perihelion is just inside the earth's orbit. In June 2005, the spacecraft will be inserted to the rendezvous trajectory with 1998SF36, or called "home positioning", which is nearly identical to the orbit of the asteroid itself. Right after inserting the home position, there will be a conjunction period for 2.5 months. It is only after the period that the spacecraft will start global mapping with its on-board instruments in the maximum duration of three months. On-board instruments include the multi-color optical camera (AMICA), the near infrared spectrometer, the X-ray fluorescence spectrometer, and the LIDAR.

After the completion of the global mapping, the first descent for "touch-and-go" sampling will be conducted. Before touching to the surface, one of three "target markers" reflecting 1-second flash light pulses will be dropped and tracked its passage by autonomous navigation. Also a hopping robot called "MINERVA" will be deployed during the last several 10's m of the descent. The rover will carry color stereo cameras and heat probes for studying the asteroid surface conditions.

Sample Return Strategy: We developed a sampling device consisted of projectors, a deployable cylindrical/conical concentrator, in order to receive and deflect ejected fragments, and a catcher with separate rooms for each sampling site of the asteroid surface. As soon as the end of the horn touches on the surface, the laser range finder will detect a few cm retraction of the fabric horn; it triggers to shoot a 5-g Ta projectile onto the asteroid through the interior of the 1-m long horn, at velocity of 300 m/s. The impact produces asteroid ejecta, which are concentrated through the horn toward the catcher. The catcher is transferred into the reentry capsule and sealed. Impact simulation experiment in 1G and micro-gravity environments have proven that each sampling promises several hundred mg to several g of target fragments, regardless regolith or bed rocks [4]. The sampling will be repeated up to three locations before leaving the asteroid in November 2005. In June 2007, the return capsule will be released for the earth re-entry and land on Woomera, Australia.

Sample Curation and Analyses Opportunities: The retrieved samples will be given initial analysis in the ISAS curation facility with the selected "all-Japan" team with American and Australian partners in the maximum period of 1 year. These asteroidal samples will be complement with cometary dust samples collected by STARDUST and peer–reviewed international AO of detailed analysis will be released after the release of the initial results. Combined results of "cosmic dust samples of definitely known origins" by STARDUST and Hayabusa will enable us to give ground truth to a long standing question of meteoritics, "cosmic dust and meteorite origins": comets vs. asteroids and re-classify those collections by origins.

References: [1] J. Kawaguchi, K. Uesugi, and A. Fujiwara (2000) *Prof. 22nd ISTS*, 2000-o-3-06v. [2] M. Kaasulinen, et al. (2002) *Proc. ACM 2002*, ESA SP-500. [3] R. P. Binzel, et al. (2001) *Meteoritics & Planet. Sci.*, 36. [4] H. Yano, S. Hasegawa, M. Abe and A. Fujiwara (2002) *Proc. ACM 2002*, ESA SP-500.

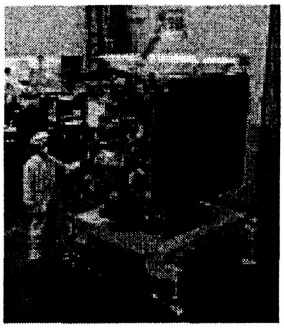

Fig.1: Hayabusa Spacecraft (Courtesy: ISAS)

CURATION AND PRELIMINARY CHARACTERIZATION OF STARDUST SAMPLES.

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Introduction: The Stardust Mission is on the verge of sampling activities at comet Wild-II; this will occur Jan 1, 2004. As this critical date approaches the science team for the mission has begun to make firm plans for the preliminary characterization and analysis of the returned cometary and interstellar dust samples. We expect to return 1000's of 5-20 um sized cometary grains, and on the order of 100 interstellar grains to Earth, all collected in blocks of special silica aerogel.

Curation: The Stardust samples, including the sample return spacecraft itself, will be curated and receive preliminary characterization at the Johnson Space Center. In 2004 we will construct a new dedicated class 100 clean lab, benefiting from three decades of experience with extraterrestrial samples, and fifteen years of experience handling silica aerogel [1,2]. The lab is designed to protect the stardust comet and interstellar grains from terrestrial contamination, as well as protecting the other extraterrestrial collections from contamination from silica aerogel. The lab will be completed a full year before the return of the stardust samples.

Preliminary Characterization: Our plans call for preliminary characterization of the cometary samples first, and the more difficult characterization of the interstellar collectors later. Under normal circumstances we might execute a preliminary analysis program, with very limited sample analysis and interaction with the larger science community. However, given the exceptional value of these returned samples, and obvious desire for release of exciting results to the planetary science community and general public at large, we have decided to run the 9-month long preliminary examination in an accelerated, more inclusive, and, hopefully, more exciting manner. We are proposing that US scientists take advantage of NASA's Participating Scientist Program to obtain NASA support to join the existing Stardust Science Team as leaders of a Preliminary Analysis Team (PAT). In order to participate fully in the PAT effort, such individuals will have to apply for this program in the spring of 2004. Under this plan additional interested and qualified scientists may join the PAT effort at their own expense, if necessary. We plan to organize the PAT team into several sub-teams, each focused on different analytical techniques. These would include at a minimum isotopes, mineralogy, noble gases, organics, and bulk composition.

References: [1] Barrett R. A., Zolensky M. E., Hörz F., Lindstrom D. J., and Gibson E.K. (1992) *Proceedings of the 19th Lunar and Planetary Science Conference*, 203-212. [2] Hörz F., Zolensky M., Bernhard R., See T., and Warren J. (2000) *Icarus,147*, 559-579.