# ARES

## Astromaterials Research & Exploration Science

## BI-ANNUAL REPORT 2005 - 2006

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# *Office of Astromaterials Research and Exploration Science*

***Steven A. Hawley, Ph.D. Director, ARES***
***http://ares.jsc.nasa.gov/***

The Astromaterials Research and Exploration Science Directorate (ARES) at NASA's Johnson Space Center (JSC) conducts research in basic and applied space and planetary science. ARES scientific staff represents a broad diversity of expertise in the physical sciences (physics, chemistry, geology, astronomy) as well as mathematics and engineering. This capability at JSC originated during the Apollo program with scientists who were responsible for the science planning and training of the astronauts for the lunar surface activities. With the return of the first lunar samples, ARES has been assigned curatorial responsibility for all NASA-held extraterrestrial materials.

The curation function consists not only of the long term care of the samples, but also the development of new curatorial techniques and associated laboratories, support to sample return mission planning, and the basic research that allows ARES scientists to provide a service to the external research community who rely on access to the samples. The Lunar Sample Facility and other curation cleanrooms, laboratories, and associated instrumentation are unique NASA resources. Along with approximately 382 kg of lunar rocks and soil returned to Earth during the Apollo program, the astromaterials collection now includes meteorites, cosmic dust, particles of solar wind, comet material, and space exposed hardware. Some of the meteorites in the collection have been confirmed to have originated on the Moon and on Mars. The curation efforts are greatly enhanced by a strong group of planetary scientists who conduct peer-reviewed astromaterials research. ARES scientists conduct peer-reviewed research in planetary science and participate as Principle or Co-Investigators in many of NASA's robotic planetary missions.

ARES is organized into three offices (see Figure 1), Astromaterials Research (KR), Astromaterials Acquisition and Curation (KT), and Human Exploration Science (KX). Each office has multiple research goals and functions. KR staff conducts basic research in astromaterials and astrobiology and shares the results through publications, conference presentations, and education and outreach activities. KT staff manages curation of the current astromaterials collections, plans for future collections, and conducts basic research. KX staff conducts research in Earth and image sciences, the space debris environment and mitigations for improving the tolerance of human and robotic spacecraft to the threat of space debris, supports Shuttle and ISS missions, and supports the planning for future human missions to the Moon and eventually to Mars.

Since the last report, ARES has achieved several noteworthy milestones, some of which are documented in detail in the sections that follow. For the first time since Apollo 17, extraterrestrial samples were returned to NASA from two different robotic missions. Genesis returned samples of solar wind in 2004, although the spacecraft crashed upon return. ARES personnel and expertise were critical to the task of recovering the science represented in the sample collectors. In 2006, Stardust returned from a mission to Comet Wild-2 with a collection of cometary particles as well as interstellar dust. During this period ARES acquired two new state-of-the-art instruments -- a NanoSIMS and a new TEM. These instruments provide ARES with a unique ability to perform precision, high resolution analyses of astromaterials. ARES regularly participates in expeditions to the Antarctic to search for meteorites and the last two years of finds have added extensively to the collection of meteorites. Significantly, the new additions include meteorites of both lunar and martian origin. ARES scientists are participants in the on-going robotic exploration of Mars including the Mars Exploration Rover missions, the Mars Reconnaissance Orbiter mission, and several other missions that are in planning. In 2006, NASA marked the 10th anniversary of the announcement of potential indicators of primitive life found in ALH84001 by a team of ARES scientists. Although the issue remains unresolved and controversial, that research essentially originated the field of Astrobiology. New research provides more evidence suggestive of the possible existence of past biology on Mars and this continues to be an active and exciting area of research. ARES scientists also have unique expertise in "ground truth" relevant to the kind of rocks expected to be studied on Mars, making ARES a unique contributor to instrument development and calibration.

ARES is a world leader in orbital debris research, including modeling and monitoring the debris environment, designing debris shielding, and policy development to control and mitigate the orbital debris population. ARES has aggressively pursued refinements in the knowledge of the debris environment and hazards that it represents to spacecraft. ARES researchers led the impact testing on the foam on the Orbiter thermal protection surfaces that resulted in the conclusive demonstration of the cause of the Columbia accident in 2003. Additionally, the ARES Image Science and Analysis Group (ISAG) has been recognized as world class as a result of their contribution to the Columbia mishap investigation. The ISAG continues to provide real time analysis of debris shedding and any associated potential damage during space shuttle missions. ARES earth scientists manage the database of astronaut photography that is predominantly from Shuttle and ISS missions, but includes the results of 40 years of human space flight. In 2006, ARES received the 200,000th image downloaded from ISS crews. The Crew Earth Observations web site (http://eol.jsc.nasa.gov/Education/ESS/crew.htm) continues to receive between 10 and 20 million hits per month. ARES scientists are also active in the planning of future human exploration of the Moon and Mars through the study of analog activities in collaboration with Engineering and Flight Operations disciplines at JSC.

ARES serves as host to numerous students and visiting scientists as part of the services provided to the research community and ARES conducts a robust education and outreach program. ARES scientists are recognized nationally and internationally by virtue of their success in publishing in peer-reviewed journals and winning competitive research proposals. ARES scientists have won every major award presented by the Meteoritical Society, including the Leonard Medal, the most prestigious award in planetary science and cosmochemistry, and the Nier Prize for outstanding research by a young scientist. ARES has established numerous partnerships with other NASA Centers, universities, and national laboratories. ARES scientists serve as society officers, journal editors, and members of advisory panels and review committees.

This Bi-Annual Report summarizes accomplishments made by each of the ARES offices and highlights participation in the development of new missions to be launched later this decade and in planning for the eventual return of humans to the Moon and on to Mars starting in the next decade.

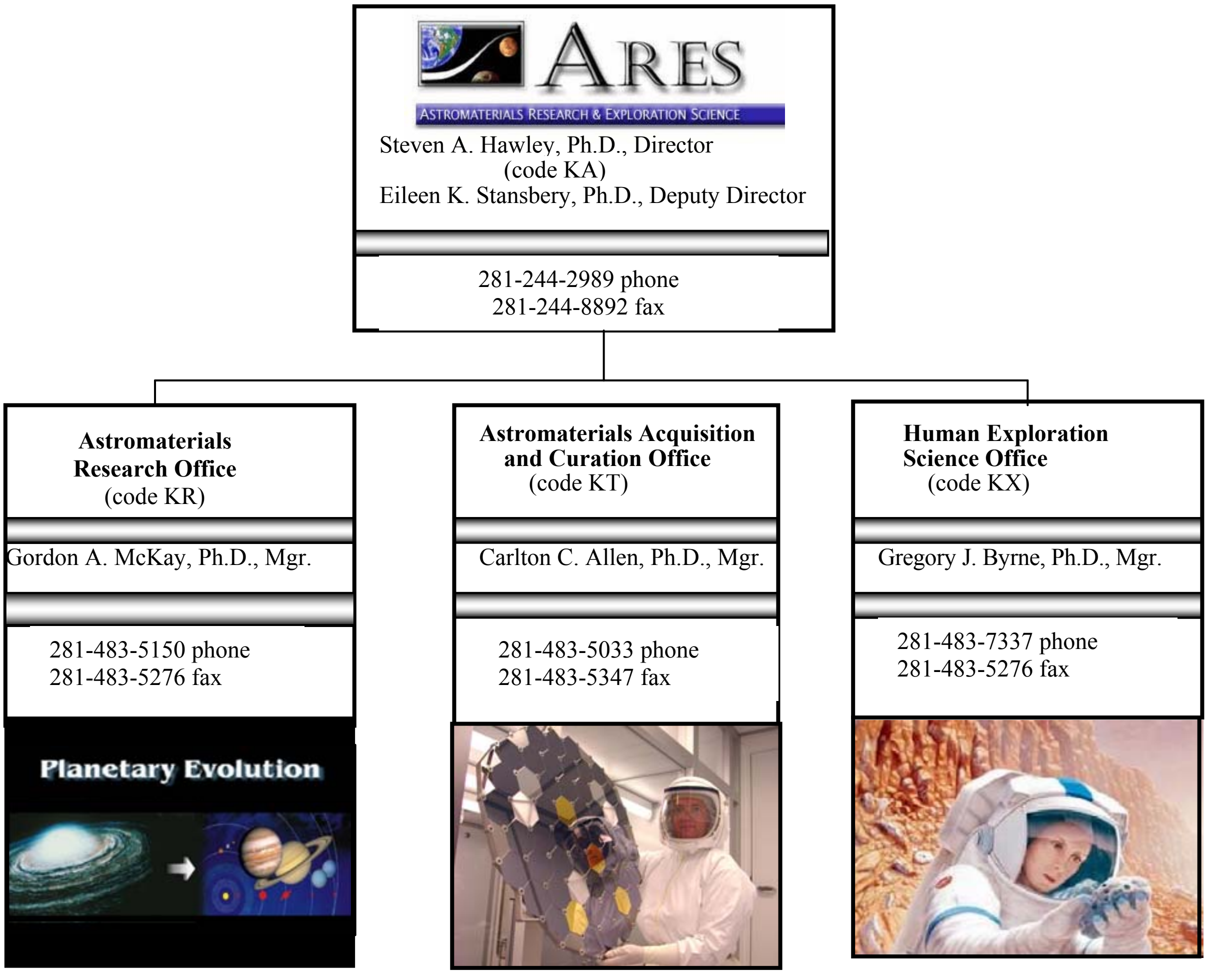
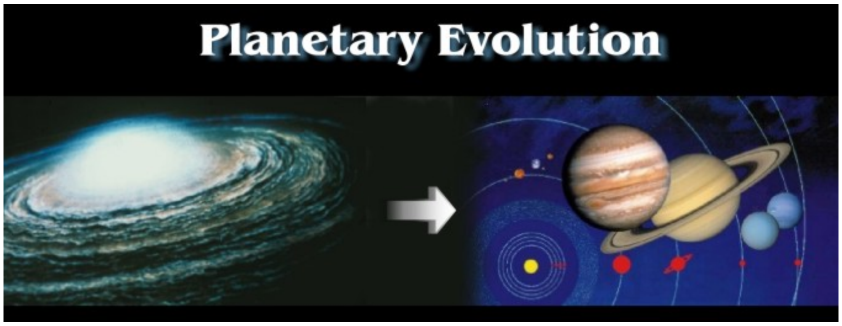


*Figure 1. Astromaterials Research and Exploration Science Organization Chart*



## *Astromaterials Research Office (KR)*

***Gordon A. McKay, Ph.D., Manager***
***http://ares.jsc.nasa.gov/AstroResearch/intro.html***

The staff of the Astromaterials Research Office conducts peer-reviewed research in astromaterials and astrobiology. Scientists are funded through basic science disciplines of the NASA ROSS NRA (http://research.hq.nasa.gov/code_s/nra/current/), particularly Cosmochemistry, but also Origins, Exobiology, Planetary Geology, and Planetary Astronomy. Further funding comes from planetary missions, instrument development, and data analysis programs.

The fundamental goals of our research are to understand the origin and evolution of the solar system and the nature and distribution of life in the solar system. Our research involves analysis of, and experiments on, astromaterials in order to understand their nature, sources, and processes of formation. Our state-of-the-art analytical laboratories include four electron microbeam labs for mineral analysis, four spectroscopy labs for chemical and mineralogical analysis, and three mass spectrometry labs for isotopic analysis. Other facilities include the experimental impact laboratory and both one-atmosphere gas mixing and high-pressure experimental petrology labs. Recent research has emphasized a diverse range of topics, including

- study of the solar system's primitive materials such as carbonaceous chondrites and interplanetary dust
- study of early solar system chronology using short-lived radioisotopes
- study of large-scale planetary differentiation and evolution through study of siderophile element partitioning and isotopic systematics
- study of the petrogenesis of martian meteorites through petrographic, isotopic, chemical, and experimental melting studies
- interpretation of remote sensing data, especially from current robotic Mars missions, through study of terrestrial analog materials
- study of the role of biological systems in evolution of astromaterials

***The following reports give examples of astromaterials research done by members of this and other ARES offices.***

# *Interstellar Materials in Interplanetary Dust*

***Scott Messenger***

Largely unnoticed, the Earth accretes about 40,000 tons of interplanetary dust each year. These interplanetary dust particles (IDPs) originate from the disintegration of comets as they pass through the inner Solar System and by collisions among asteroids. This dust is so abundant in the inner Solar System that it is easily visible to the naked eye just above the horizon shortly after sunset in the west and before sunrise in the east, known as the Zodiacal light. NASA collects IDPs in the stratosphere with high altitude aircraft, including the ER-2, and WB-57.

Most IDPs are clearly different from meteorites, in both their physical properties and their chemical and mineralogical compositions. Typical IDPs are about 20 μm in size, and they are extremely fine grained and highly porous, with their building blocks ranging in size from ~0.1 to 1 μm. In comparison to meteorites, IDPs are rich in volatile elements, carbon and nitrogen, and have peculiar mineral assemblages. Many IDPs have never interacted with liquid water, and are full of microscopic glassy silicate grains. These properties point to their most likely sources: comets.

IDPs are of great interest because they have preserved the original building blocks of the solar system, including grains that formed in the solar nebula, and still older dust grains from other stars and organic matter from cold interstellar dust clouds. Although incredibly tiny (about 1 um) these materials are direct samples of diverse astrophysical environments that are far beyond the reach of spacecraft and have hitherto been only studied with telescopes. By having these samples in hand, we gain valuable insight into the lifecycle of matter in the galaxy and the origin of the solar system.

Our research on IDPs is focused on two topics: the nature and histories of ancient stardust and the origin and evolution of interstellar molecular cloud organic matter. These interstellar materials are rare, microscopic, and hidden within a sea of materials that formed in the solar system. They are also far too small for age dating, so we must use a different way to distinguish them from solar system material.

During the formation of the solar system, virtually all preexisting materials were obliterated and homogenized. Consequently, the relative abundances of the isotopes of all elements are very uniform throughout the Solar System on scales ranging from micrometers to astronomical units. Thus, materials from beyond the solar system can easily be recognized since their isotopic compositions stand out among the uniformity of solar system materials. We are then faced with the challenge of measuring isotopic compositions on scales far smaller than a single cell. ARES space scientist Scott Messenger recently installed a revolutionary new instrument, the NanoSIMS 50L, that is one of the few instruments capable of making these isotopic measurements at sub-micrometer scales. For the past decade, Scott has coordinated his isotopic measurements with colleague Lindsay Keller's transmission electron microscopy (TEM) studies of the same materials. Lindsay's TEM analyses provide the essential chemical and mineralogical information necessary to understand the histories and formation conditions of the target materials. The coordination of these two instruments on the same samples can yield a compelling story, if we find the right sample.

One recent success story involves the discovery of a grain (found in an IDP) whose isotopic abundances are so exotic that it is so far unique. Measurements from the NanoSIMS showed the 500 nanometer grain to have thirteen times more $^{18}O$ and one third the $^{17}O$, relative to $^{16}O$, compared with solar system materials. This strange oxygen isotopic composition leaves no doubt that it was a true grain of stardust. By comparing the isotopic ratios with models of stellar nucleosynthesis, the origin was clear: this was a grain from a type II supernova. Fortunately, in this case we had several slices of the supernova grain to work with since we had sliced the parent IDP into 70 nanometer-thick sections. Lindsay's analysis of other slices of the supernova grain showed that it was an olivine mineral grain containing a fair amount of iron.

This result was exciting, because this was the first silicate mineral ever found from a supernova. But it was also surprising, because under normal circumstances silicates that form from high-temperature gases contain very little iron. Of course, we realized that an exploding star is not a normal circumstance. We turned to our colleague Dante Lauretta at the University of Arizona, who models the formation of minerals. By combining our knowledge of our grain's elemental abundances, mineralogy, and isotopic compositions, and comparing this with supernova models, Dante was able to show that our novel olivine grain could form by invoking particular mixtures of material within the supernova explosion. Amazingly, from the analysis of one sub-micrometer grain, we had shown that complex, large scale turbulence and mixing must occur in supernova explosions.

Lindsay took the analysis of our supernova grain one step further, and showed that it had no signs of the extensive radiation damage that we'd expect for a typical interstellar grain. Our conclusion is that this grain spent much less than the average time roaming the Galaxy, perhaps less than 10 million years. This is rather a cosmic blink of the eye, and is such a short lifetime that we speculate that the parent star exploded within the stellar nursery from which our solar system formed.

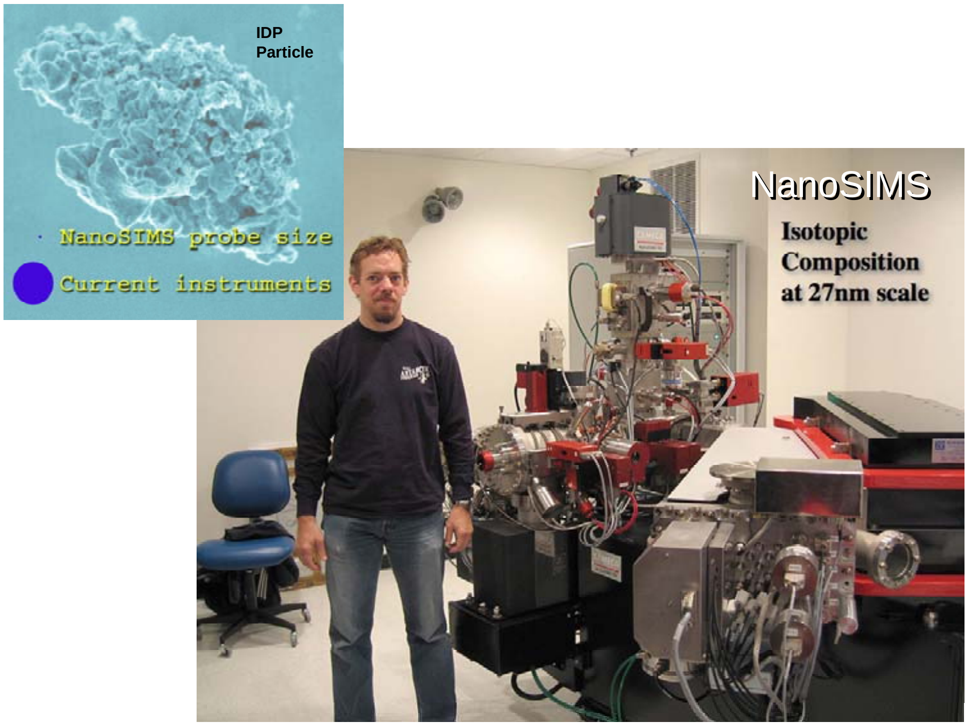


Figure 1. ARES Scientist Scott Messenger with newly-installed NanoSIMS instrument. Inset shows scanning electron microscope image if Interplanetary Dust Particle. Ths particle is about 20 micrometers across. Note that it is made up of thousands of sub-micrometer grains. Large blue dot shows probe size for previous generation if ion probes. Such a large probe size is not capable of analyzing individual grains within IDPs. Tiny blue dot shows NanoSIMS probe size. This probe is small enough to analyze several spots across individual sub-micron grains.

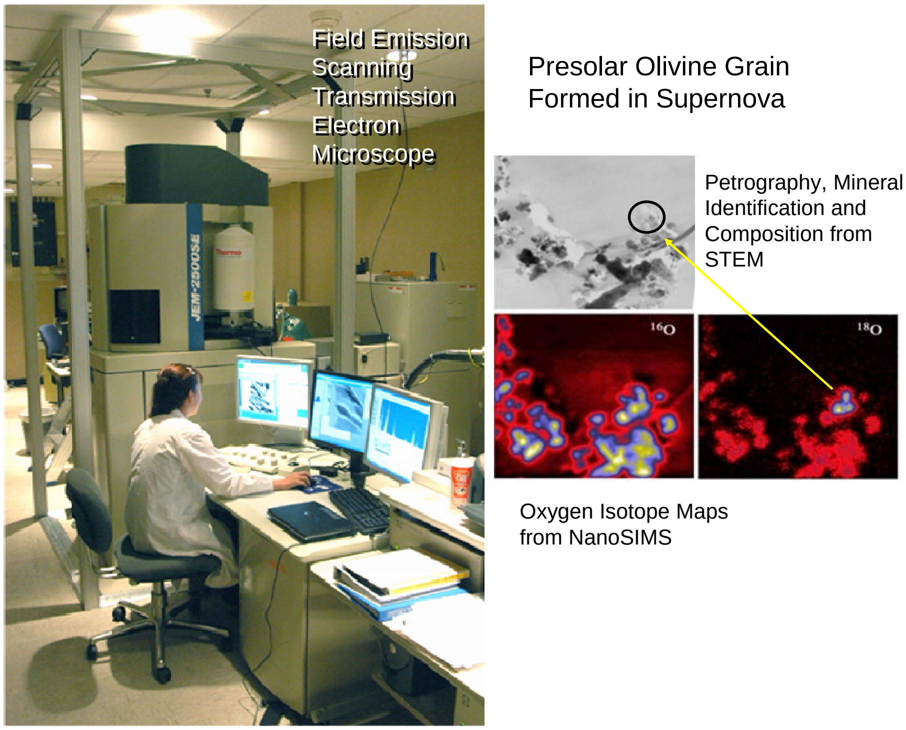


Figure 2. Left: ARES scientist Keiko Nakamura-Messenger using newly installed Field Emission Scanning Transmission Electron Microscope. This instrument is used to determine the size, shape, chemical composition, and mineralogy of grains in thin slices of material. Top Right: Transmission Electron Microscope image of IDP. Bottom Right: NanoSIMS maps of the same IDP, showing abundances of two isotopes of Oxygen. The map on the left shows the common isotope, $^{16}$O, while the map on the right shows an isotope, $^{18}$O, that is very rare in material formed in our solar system, but that is formed in abundance during supernova explosions. Note that most of the grains are red, indicating low abundance of $^{18}$O except for one small “hot spot”. Correlation with the STEM image shows that this grain is olivine.

## *TWO YEARS OF MARS EXPLORATION ROVER SCIENCE*

***David Mittlefehldt***

The *Spirit* rover (MER-A) landed in Gusev crater on 4 January 2004. Three weeks later, the *Opportunity* rover (MER-B) landed on Meridiani Planum on the opposite side of Mars (Fig. 1). Full mission success criteria included surface operations at each site for at least 90 sols (Mars days) and total traverse of 600 meters for at least one rover. In fact, the rovers have greatly exceeded these requirements. As of 31 January 2007, *Spirit* is conducting science activities on sol 1094 and has 6915 meters on the odometer, while *Opportunity* is doing sol 1073 activities with 9927 meters under its belt.. Three ARES scientists are members of the MER Athena Science Team, working principally with the Mössbauer Spectrometer and Alpha Particle X-ray

Spectrometer (APXS) instruments; Doug Ming, Dick Morris and Dave Mittlefehldt. (Despite rumors to the contrary, having the initials "DM" is not a requirement for JSC scientists to join the MER science team.)

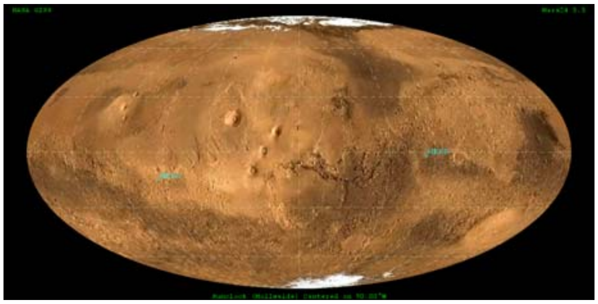


Figure 1. Mollweide projection of Mars centered on longitude 90ºW showing the locations of the rovers.

***Spirit* in Gusev crater:** Gusev crater was chosen as one of the landing sites in part because of morphologic evidence that suggested the crater was partially filled by water-born sediments brought in via Ma'adim Valles from the south. This was in keeping with the NASA Mars Mantra "Follow the Water." Reality was quite different. Upon first look, *Spirit* saw a dusty plain littered with angular, dark rocks. Upon examination by the full panoply of instruments, these rocks proved to be volcanic, olivine-basalts similar in composition to known martian meteorites. These rocks are little altered by aqueous fluids. Clearly, water was not important in forming the plains rocks in Gusev crater. But early on the mission team decided to take full advantage of the rover's capabilities and strike out for the Columbia Hills rising above the plain 3-4 km away. As any field geologist would do, *Spirit* ascended one of the highest peaks, Husband Hill, looked around, and descended the other side. Along the way, *Spirit* encountered a wide range of rock types and some unusual soils.

Many of the rocks on Husband Hill are highly altered. One measure of alteration is the ratio of trivalent iron to total iron ($Fe^{3+}/Fe_T$) measured by the Mössbauer instrument. For the plains olivine-basalts, this ratio is about 0.12. For martian meteorites, it is <0.06. Contrast this with two distinct rock classes from Husband Hill with ratios of approximately 0.73. This was an early indication for the role of water in the formation of rocks in Gusev crater. Curiously, although we know water was important in the history of these rocks, we are unsure how the rocks were formed. Based on the outcrop attitudes and textures observed with the panoramic camera and microscopic imager, we infer that the rocks are clastic; that is, they are made up of rock and mineral fragments. They could represent volcanic rocks formed as air-fall deposits from an eruption, or ejecta deposited from some near-by impact event.

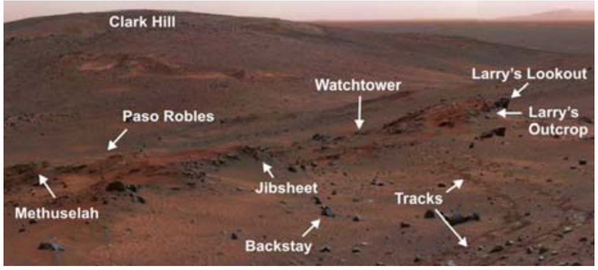


Figure 2. Outcrop of Watchtower class rocks on Husband Hill. These rocks are highly altered and demonstrate that aqueous solutions were present during their formation. Backstay is a fresh basalt, while Paso Robles is an unusual light-toned soil. Figure from Arvidson et al. (2006) *Journal of Geophysical Research–Planets*, **111**: doi:10.1029/2005JE002499

We also uncovered a strange soil that was exposed by the rover wheels. This light-toned soil, named Paso Robles, lay below the surface of normal dark soil (Fig. 3). It (and its kin) contains the highest sulfur content of any materials yet analyzed on Mars, the thermal emission spectrometer found a spectral signature for water bound in mineral structures, and Mössbauer spectra show that it's iron mineralogy is dominated by ferric sulfate and has a $Fe^{3+}/Fe_T$ of approximately 0.83. We have subsequently found patches of similar light-toned, S-rich soils during the descent from Husband Hill, always discovered serendipitously when the rover wheels dig deeply into normal looking soil. At present, we don't know how these soils were formed. They could represent portions of old hydrothermal systems, or sedimentary deposits of highly altered materials, or something else. They do, however, demonstrate that water was an important ingredient in their formation.

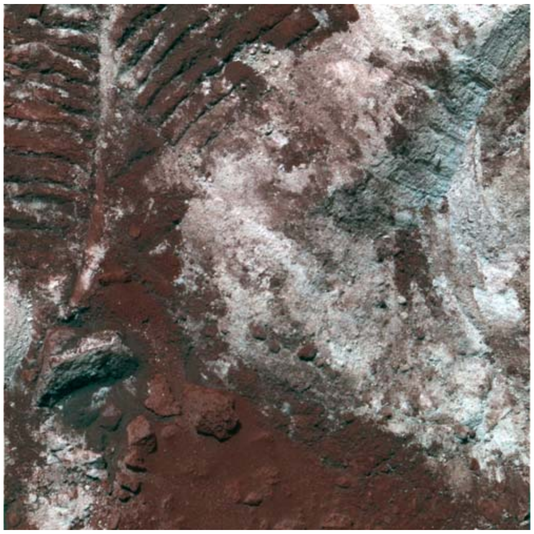


Figure 3. False color Pancam image (sol 400, P2551, filters L2, L5, L7) of light-toned soil Paso Robles. The image is 40 cm across. The leaf-like impression in the upper left is NOT a fossil; it is the rover track.

On our descent from the summit of Husband Hill we again encountered magmatic rocks. We passed a series of very olivine-rich rocks with very high nickel contents. The odd thing about these rocks is that they do not conform to elemental fractionation trends observed for martian meteorites. Possibly, this indicates they tapped a region of the martian interior not sampled by the meteorite suite. We crossed terrain covered with vesicular basalts indicating gas-rich magmas, and next examined in detail the feature informally named Home Plate. This feature is visible from orbital images as a bright ring roughly 80 m in diameter. Home Plate is composed of laminated rocks fining upward with microscopic and macroscopic textures that suggest an origin as air-fall volcanics (Fig. 4). The attitudes of the beds suggest that the vent may be in the interior of Home Plate. Compositionally, the rocks are unusual in being rich in some of the more volatile elements chlorine, bromine, zinc and germanium. (Germanium has not been detected in any other rock or soil studied by either rover.) Similar volcanic structures on Earth are often formed when magma erupts through water-saturated rock. A leading hypothesis for the origin of Home Plate is that magma ascended through rock saturated with brine – salt-rich water. The high volatile element contents of Home Plate rocks then are due to interaction with the salty water.

Figure 4. The rocks of Home Plate are interpreted to be volcanic deposits similar to tuff rings on Earth. Pancam false color image (sol 774, P2381, filters L2, L5, L7, R1).

***Opportunity* on Meridiani Planum:** Meridiani Planum was chosen as a landing site in part because orbital spectroscopic study had shown that this region was rich in the ferric iron mineral hematite, $Fe_2O_3$, which forms in oxidizing aqueous environments. *Opportunity*'s first look showed a terrain quite different from that at Gusev crater. The region is composed of bright-colored, flattish, layered rock outcrops and dark drift sand. This terrain occupies the entire area *Opportunity* has traversed. Because we have examined rocks in cross section within craters, and laterally across Meridiani Planum, we have been able to develop a fairly detailed picture of the geologic history of these units (Fig. 5).

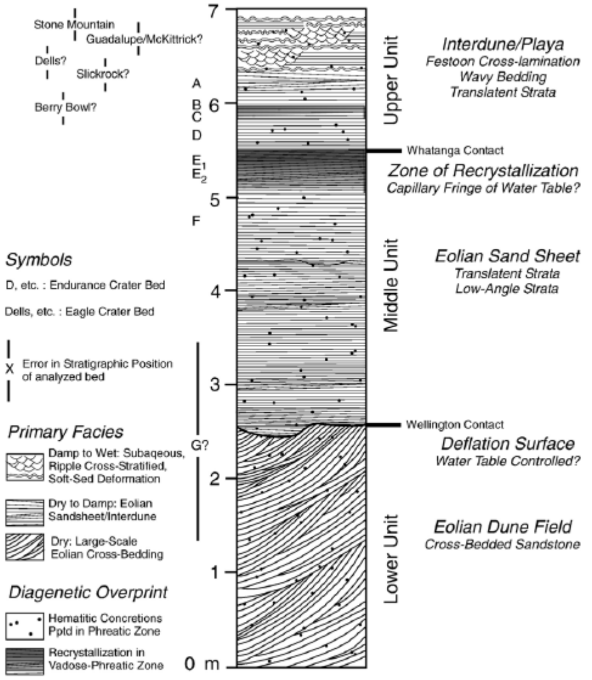


Figure 5. Interpretation of the stratigraphic section near the *Opportunity* landing site in Meridiani Planum. Figure from Grotzinger et al. (2005) *Earth and Planetary Science Letters* **240**:11.

The outcrops are composed of sedimentary rocks containing three main components; silicate sands, evaporite mineral sands, and hematite concretions. The first two components are reworked clastic materials; mineral and rock fragments from older rock units including weathered basalt and evaporites. Structures in the outcrops show that these sands were moved by wind, the same process that creates sand dunes and some types of sandstone on Earth. (The sandstones in Zion National Park, Utah, are a spectacular example.) The upper part of the rock sequence was formed in wetter conditions; structures in the rocks suggest deposition in moving water. But this was not potable water by any means. Meridiani rocks contain the mineral jarosite, a potassium-ferric iron-sulfate. Jarosite is stable only in oxidizing, acidic solutions. Thus, if the upper sandstone units studied by *Opportunity* had been deposited in "fresh" water, the jarosite would have dissolved away.

The hematite concretions, called "blueberries", were formed in situ in the rocks by deposition from oxidizing aqueous solutions that saturated the sandstones. These concretions are more resistant to weathering and erosion, and are liberated from the outcrops as they degrade. Because they are denser than silicate or evaporite minerals, and generally larger in size, they lag behind and are concentrated as martian winds move the sands and dust across the surface. The hematite signature observed from orbit is a lag pavement of these concretions (Fig. 6).

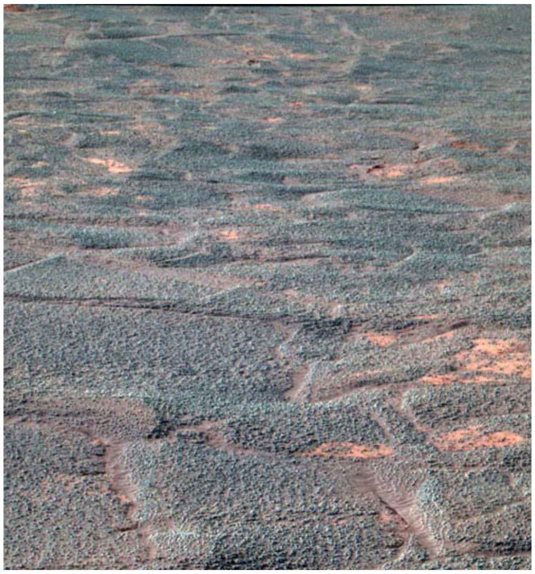


Figure 6. A surface paved with blueberries – hematite concretions weathered out of rock outcrops. Pancam false color image (sol 188, P0050, filters L2, L5, L7).

**Summary:** One key goal of the NASA Mars exploration program is to determine the role of water in early Mars history, and the nature of aqueous environments that could have been hospitable to life. The MER rovers have done an admirable job of working towards that goal. They have shown that differing degrees of involvement of water are recorded, from just small amounts of alteration indicating low water/rock ratios, to sedimentalogical evidence for flowing water on the surface. In all cases, however, the solutions were oxidizing and acidic. The data returned by the rovers provides important information for assessing the potential for life on Mars.

## *Radiogenic Isotope Studies at ARES Using New Generation Thermal Ionization Mass Spectrometry*

***Alan D. Brandon***

My research is presently directed towards a greater comprehension of the following processes in our Solar System:

⊕ **Chemical heterogeneity in the solar nebula**

⊕ **Formation of terrestrial bodies in the solar system**

⊕ **Mechanisms and conditions for early differentiation of terrestrial bodies**

*These processes are inter-related. Conditions present in the solar nebula prior to, during, and immediately following the formation of a terrestrial body will dictate early differentiation and evolution over the history of the solar system. Key factors that dictate the present-day compositions of terrestrial* *planets are the composition and distribution of materials within the solar nebula, the material accretion rate, and the size of the body. These processes also control the rate at which terrestrial bodies cool and sustain magmatism. Hence, the present state of each terrestrial body is a record of their formation, early differentiation, and evolutionary histories. Earth is the largest terrestrial body, and hence, has cooled the slowest, and remains dynamically active to present. The compositions of Earth materials present a record of this slow cooling history so that much of the information on the early formation and differentiation processes have been overprinted by later processes. In contrast, smaller bodies such as Mars, Moon and asteroids, underwent more rapid cooling. These bodies have retained compositional information on processes acting in the earliest history of our solar system.*

The isotopic compositions of rocks from the Moon and meteorites preserve evidence on the types of pre-solar and solar materials present in our solar system, nebular processes, the earliest differentiation history of their parent bodies, and how their parent bodies have evolved to the present. In my lab here at Johnson Space Center, I precisely measure the isotopic compositions of different elements from these materials, taking advantage of a new generation thermal ionization mass spectrometer (TIMS), the Thermofinnigan Triton modified to my particular specifications, that was installed when I arrived in the fall of 2001. This Triton was the first to be installed in the United States for basic research applications, and was the 17th manufactured in the Thermofinningan plant in Bremen, Germany. Through Os and Nd isotope measurements, I have established that this particular Triton can measure the isotopic compositions of materials to better than 3 times more precisely than earlier generation TIMS. These better precisions in isotopic measurements have revealed new insights into the earliest processes in our solar system and there is much more to examine taking advantage of this new technology. I have also established many national and international collaborations through the use our new TIMS facility. Three research areas are highlighted with key collaborators listed in the following paragraphs.

***High precision Os isotopic measurements of meteorites.***

Collaborators: Igor Puchtel (University of Maryland), Munir Humayun (Florida State
University), Ingo Leya (Universität Bern)

The degree of isotopic mixing in the solar nebula and the nature of solar and pre-solar components that have contributed to our solar system remain subjects of vigorous debate. Osmium is one of the first elements to condense from the solar nebula and therefore provides a distinct perspective on the debates over nebular heterogeneity compared to other elements studied to present. High precision measurements on the JSC Triton (Figure 1, where $\varepsilon_{Os} = 10^4$ parts deviation from average solar values) indicate that some bulk carbonaceous chondrites have Os isotopic compositions consistent with a 'missing' s-process component when compared solar isotopic abundances as exemplified by ordinary chondrites and mantle-derived materials from Earth shown as shaded envelopes (Brandon et al., 2005). We interpreted this heterogeneity as resulting from incomplete access of a pre-solar s-process carrier phase during digestion of the meteorites. Interestingly, the s-process carrier necessary to balance the Os isotopes to the solar abundances is deficient in $^{186}$Os and provides clues to the conditions within the star where this s-process component was produced.

This investigation will be expanded for the next several years. High precision Os isotope measurements employing the JSC Triton will be obtained on a comprehensive suite of chondrites, ureilites, and iron meteorites, to assess the extent of this heterogeneity and its origin(s). My collaborators I will use these new data to examine the affects of cosmic ray exposure on Os isotopic compositions, as well as to further address the issues of isotopic heterogeneity in the solar nebula, with ramifications on nebular mixing models and the types of pre-solar components that contributed to our solar system with implications for nucleosynthesis.

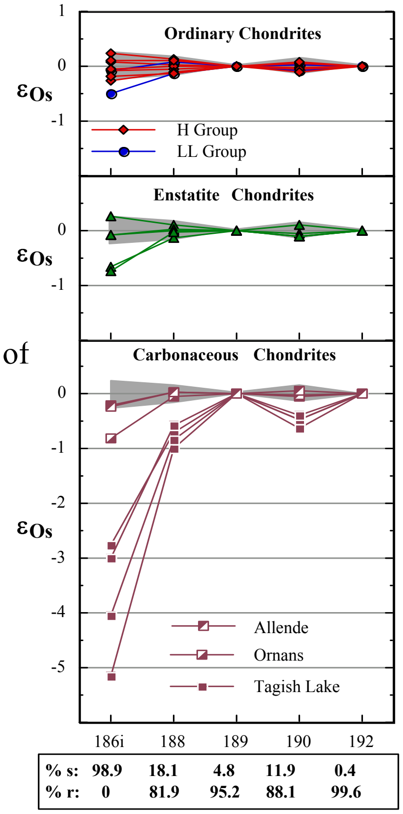


**Figure 1.**

### *Re-Os isotope geochemistry of achondrites.*

Collaborators: Kai Rankenburg (NASA, Johnson Space Center), Richard Walker (University of Maryland), Vinciane Debaille (Lunar and Planetary Institute)

The Re-Os isotope and related platinum element concentrations of ureilites, lunar basalts, and Martian meteorites are being measured following the preliminary work of Brandon et al. (2000) on Martian meteorites. This will be the first study to measure Os isotopes (none exist to present) and comprehensive platinum group element concentrations for these achondrites. These data will provide new insights into the earliest differentiation histories and chemical evolutions of their parent bodies, as well as the chemical behavior of these elements during magma production and crystallization on differentiated terrestrial bodies.

In particular, the Re and platinum group element concentrations for these rocks will provide a direct comparison of the geochemical behavior of these elements in small to large terrestrial bodies and from lower to higher oxygen fugacities. The Os isotopic compositions will be used to fingerprint the type of parent body ureilites were derived from, and to aid in constraining petrogenetic models for SNC meteorites and lunar basalts. For Mars, previous models proposed to explain the variations observed in the isotopic systematics for Martian meteorites fall into two classes: early formation of a juvenile Martian crust in relation to early mantle melting; isolation of cumulate piles from a magma ocean which mix with various amount of evolved melts derived from the magma ocean. In addition, the meteorite parental melts may have been contaminated by Martian crust. Constraining the extent of crustal contamination signatures in the Martian meteorites is crucial for determining which of these classes of early differentiation models, or alternative models, are best explained by these data.

### *Rb-Sr and Sm-Nd Isotope Geochronology of Achondrites.*

Collaborators: Kai Rankenburg (NASA Johnson Space Center), Marc Norman, Victoria Bennett (Australian National University), Mukul Sharma (Dartmouth University)

We are examining the geochemical characteristics of the newly discovered lunar meteorite LAP 02205 for comparison to other lunar meteorites and Apollo basalts. The Rb-Sr and Sm-Nd isotopic systematics have been obtained (Figure 2, Rankenburg et al., 2006a). These data provide the crystallization age, its relation to other lunar basalts, and aids in constraining lunar sources and mantle evolution models.

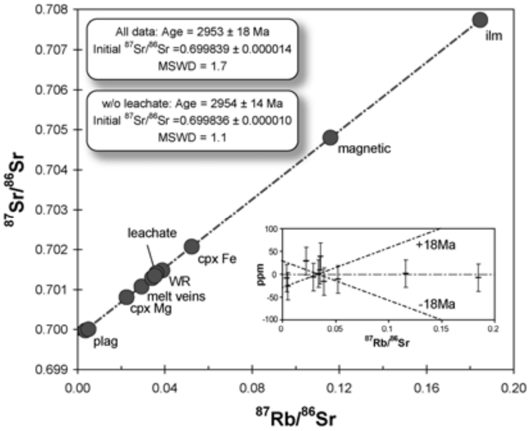


Figure 2.

This investigation sets the framework for future geochronological work on achondrites from differentiated terrestrial bodies, taking advantage of the new Triton that provides an ability to obtain more precise isotopic compositions and subsequent crystallization ages of achondrites. The Rb-Sr isochron age we have obtained for LAP 02205 (Figure 2) is approximately an order of magnitude more precise (2946±14 Ma) than those previously obtained for Apollo basalt samples. These studies will be performed not only on newly discovered meteorites, but also the goal is to measure materials from sample return missions from the Moon, Mars, and potentially, smaller bodies. This more precise geochronological information will provide an assessment of the timing and duration of lunar magmatism in relationship to early formed lunar mantle sources, and the thermal evolution of the interior of the Moon.

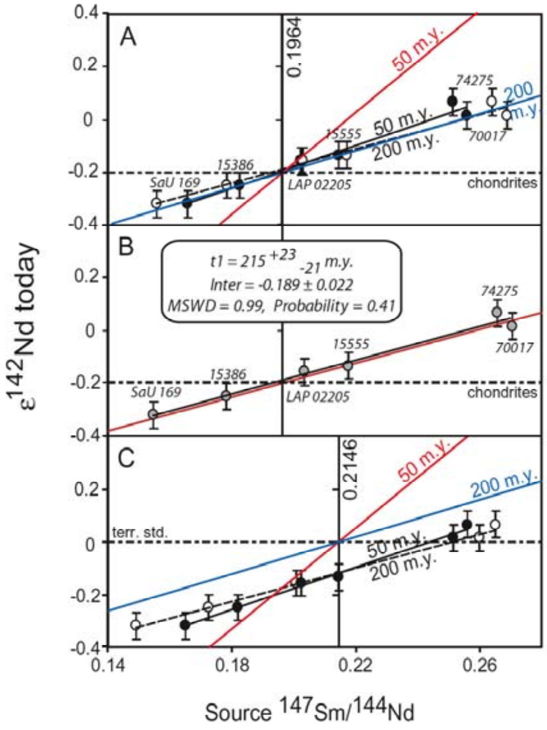


**Figure 3.**

In addition, I have developed techniques for precise measurement of $^{142}$Nd/$^{144}$Nd for constraining Sm/Nd fractionation during early (i.e. within 500 million years of accretion, 5 half-lives of parent $^{146}$Sm @ 103 Ma) differentiation of the Moon, Mars, and the eucrite parent body, employing the new Triton. This took two years of development work, to reach an external precision that is 4-6 times more precise than data obtained from previous generation mass spectrometers. With the recent revelation that terrestrial basalts are not chondritic in $^{142}$Nd/$^{144}$Nd (Boyet and Carlson, 2005), important new insights into early planetary differentiation and dynamics are to be gleaned from precise measurement of this ratio. Our results for lunar basalts (Figure 3) reveal two key constraints on early differentiation of the Earth-Moon (Rankenburg et al., 2006b). First, the Moon must have started out chondritic at $\varepsilon^{142}$Nd = -0.2 rather than at $\varepsilon^{142}$Nd = 0, the latter which presently defines the Earth (Boyet and Carlson, 2005). Second, the closure time for Sm/Nd fractionation in the early Moon was at approximately 215±20 Ma. In an impact model where a Mars-sized impactor hits the Earth and the debris from this event accretes to form the Moon, this means that either the Moon came from material of the impactor that was different than Earth with respect to Nd isotopes, or Earth and Moon are identical, the Earth differentiated only following the impact event, such that a missing Nd isotope reservoir is present somewhere in the Earth. Also, the late closure time for Sm/Nd in the Moon shows that the magma ocean took much longer to crystallize than presently thought. The implications of these conclusions have tremendous ramifications to our understanding in the earliest differentiation histories of terrestrial planets. These precise measurements have opened up a new line of inquiry. Hence, I plan to extend this work on materials from other parent bodies in the next several years.

In summary, the measurements of isotopic compositions of elements in lunar materials and meteorites here at JSC using a new generation thermal ionization mass spectrometer with high precision capability has revealed new insights into the formation of our solar system and its terrestrial bodies. Over the coming years, we plan to extend this work in collaboration with a team of internationally recognized scientists who will visit our facility and take advantage of the special capabilities the Triton and our lab facility can offer. In addition, as new missions return unique extra terrestrial materials for investigation, we will have the capability to perform careful measurements of radiogenic isotopes of different elements for the purpose of age dating and fingerprinting the origins of these materials in the context of nebular accretion and early differentiation of terrestrial bodies.

## *Catching Pieces of a Comet*

***Lindsay Keller***

In the early morning of January 15, 2006, a small spacecraft named Stardust completed its seven year mission to a comet and returned to Earth delivering a precious cargo of dust samples from the tail of Comet Wild-2 – the first solid samples brought back to Earth by NASA since the Apollo missions to the Moon. Scientists from around the world were eagerly awaiting a chance to get a detailed glimpse of the dusty material that was a witness to the very birth of our solar system. ARES scientists played key roles in the recovery of the spacecraft after its fiery descent onto a dry lake bed in Utah and in transporting the samples back to the Stardust Laboratory at the Johnson Space Center where the sample collection canister was opened and we had our first look at the samples.

The comet particles were trapped in an exotic material – silica aerogel – an extremely low density and transparent solid. The special properties of aerogel allowed the comet particles to be stopped and preserved even though they hit the aerogel with a velocity six times faster than a speeding bullet. To the surprise and delight of Stardust mission members, many large dust impacts were easily visible with the naked eye. In the Stardust Laboratory, Fred Hörz and ARES

Curation staff members Tom See, Ron Bastien, and Jack Warren photographed and documented the entire collection. Keiko Messenger took the lead in the 'heavy lifting,' deftly extracting, and subdividing numerous microscopic comet particles from the aerogel, providing samples for dozens of scientists all over the world.

In a first for a sample return mission, a large segment of the scientific community was involved in the initial analyses of the samples including nearly 200 scientists from around the world. ARES laboratories were ready for the preliminary analysis of Stardust samples with an array of state-of-the-art instruments provided by Stardust Mission grants won by ARES scientists Scott Messenger, Lindsay Keller, Simon Clemett and Mike Zolensky. The transmission electron microscope installed by Keller was used to probe the mineralogy and chemistry of the Stardust samples at nearly the scale of individual atoms, while critical isotopic measurements were made by Messenger with a first-of-its-kind ion microprobe to determine the origin of grains a 1000 times smaller than the diameter of a human hair. Analyses of the molecular make-up of the organic matter in Stardust grains were obtained using a sophisticated mass spectrometer built by Clemett.

What have we learned from the Stardust samples? One of the most important discoveries thus far was the identification of minerals in some of the comet particles that could only have formed at extremely high temperatures very close to the early Sun. How did mineral grains that formed so close to the Sun end up in a comet that came together in the icy region beyond the orbit of Neptune? Earlier models had predicted that turbulence within the disk of gas and dust that became the planets would mix together these hot and cold grains, while other models required that some grains formed close to the Sun could be blown out and scattered onto the disk by stellar winds. The Stardust samples will allow us to test these models for the first time and to develop new ones because the samples are on Earth and available for additional study now and in the future when even more sophisticated analyses will be obtained by future generations of scientists.

Another major discovery from the analysis of the comet samples was finding particles rich in organic matter. Comets are believed to have brought water and organic matter to the early Earth and it is important to understand the nature of these materials because they are necessary ingredients for the origin of life. One of the first analyses obtained on the samples using the ARES infrared microscope showed abundant hydrocarbons in many of the particles. Subsequent analyses revealed that some of this organic matter formed in the cold cloud of dust and gas that was the precursor to the solar system.

Figure 1. A bulbous track (C2054,0,35) in aerogel from the Stardust samples. The particle entered the aerogel at the top, shed part of its mass through interaction and deceleration in the aerogel, and the larger intact grains traveled the furthest, with solid mineral grains typical at the terminus of the track. The total track length here is ~11 mm.

Figure 2. ARES scientists Fred Horz and Lindsay Keller along with Tom See and mission PI Don Brownlee examine the entire Stardust collector in the JSC Stardust Laboratory.

# *Astromaterials Acquisition and Curation Office (KT)*

***Carlton C. Allen, Ph.D., Manager***
***http://curator.jsc.nasa.gov/***

JSC and the Curation Team are responsible for the curation of NASA's current collection of astromaterials that includes lunar samples collected by the Apollo astronauts, meteorites collected in Antarctica, cosmic dust collected in the stratosphere, solar wind samples collected by the Genesis spacecraft, comet and interstellar dust particles collected by the Stardust spacecraft, and hardware exposed to the space environment. Curation comprises initial characterization of new samples, preparation and allocation of samples for research and education, and clean, secure storage of samples at JSC or remote sites. The foundations of our curation are the specialized cleanrooms (class 10 to 10,000) for each of the specific types of materials, the supporting facilities, and the people, many of whom have been doing detailed work in ultraclean environments for many years.

JSC is also responsible for curation of extraterrestrial samples collected on all future NASA missions. The Curatorial team is preparing to curate the next generation of extraterrestrial samples. JSC has been designated as the curation site for a small amount of the asteroid samples collected by the Japanese Hayabusa spacecraft. Missions have been proposed to sample the far side of the Moon, several asteroids, the Martian moon Deimos, the dust and gas in the atmosphere of Mars, and the surface of a comet. ARES is also involved in planning for post-mission sample handling and curation of samples returned by future Mars surface missions and the planned human exploration of the Moon.

***The following reports give updates on curation of current astromaterials collections and plans for future collections.***

***Curators: Carlton Allen, Judith Allton, Gary Lofgren, Kevin Righter, Michael Zolensky***

Astromaterials curation is a cornerstone of the NASA Cosmochemistry research program. ARES staff curates the existing collections and distributes them to researchers worldwide to investigate the origin and evolution of the solar system.

## Lunar Samples

*Gary E. Lofgren, Andrea B. Mosie and Linda A. Watts*

The Apollo astronauts collected 2196 Moon rock and soil samples having a total mass of 382 kg. They are the only documented samples yet returned from another body in the solar system. The JSC Astromaterials staff curates this national treasure in the Lunar Sample Facility, a suite of class 1000 cleanrooms and secure vaults constructed in 1979. The collection now comprises approximately 100,000 subsamples, many of which are located in research laboratories and museums worldwide. The bulk of the collection, including pristine samples and material returned following analysis, is stored at the JSC facility. Even 34 years after the Apollo missions, lunar sample research is active, with new techniques yielding new insights into the history of the Earth-Moon system.

*Lunar Sample Laboratory*

## Antarctic Meteorites

*Kevin Righter, Cecilia E. Satterwhite and Kathleen McBride*

Meteorites are rocks from space that have fallen on Earth. Since 1976, the U.S. has sent yearly expeditions to Antarctica to recover meteorites. (Glacial movement concentrates meteorites on icefields near mountain ranges.) The Antarctic Meteorite Program is a collaboration between the National Science Foundation (NSF), the Smithsonian Institution (SI), and NASA in which NSF is responsible for collection and NASA and SI share curation duties.

*Meteorite Collecting in Antarctica*

ARES' role is initial description, temporary storage, and distribution of samples to investigators. This is performed in a dedicated suite of class 1000 cleanrooms. The meteorites are eventually sent to the Smithsonian Institution for permanent storage after demand for an individual sample has decreased, but JSC curates over 4,000 specimens at any one time. The number of new samples collected by a single field team and delivered to JSC each year has ranged from approximately 200 to well over 1000, including meteorites from Mars and from the Moon.

## ***Cosmic Dust***

*Michael E. Zolensky and Jack L. Warren*

Microscopic particles of comets and asteroids, captured by the Earth and suspended in the stratosphere, are collected by dedicated equipment on two NASA aircraft. The collectors are prepared at JSC, and returned to the JSC Cosmic Dust Laboratory, a class 100 cleanroom, where individual particles are retrieved, documented, and distributed to researchers. The Cosmic Dust program has operated since 1981.

*Cosmic Dust Laboratory*

## ***Space-Exposed Hardware***

*Michael E. Zolensky, Karen M. McNamara, Jack K. Warren and Thomas H. See*

Since 1970, JSC has prepared and distributed a diverse collection of materials that have been exposed to the space environment. These have included pieces of the Surveyor 3 spacecraft returned by the Apollo 12 astronauts, the Long-Duration Exposure Facility, several commercial satellites retrieved by the Space Shuttle, and materials from the Mir space station. The Genesis and Stardust sample return capsules were recently transferred to JSC. Documentation, sampling and storage of these materials is done in the new Space-Exposed Hardware Laboratory.


*Stardust Sample Return Capsule*

## *Genesis — Solar Wind Sample Return*

***Eileen K. Stansbery and Judith H. Allton***

Genesis is a spacecraft mission to collect atoms and ions of the solar wind, the extended atmosphere of the Sun. When it returned to Earth in 2004, Genesis brought NASA's first spacecraft-collected samples since Apollo 17 in 1972, and the first ever material returned from deep space. ARES curation personnel are essential members of the Genesis Science Team. ARES responsibilities are contamination control and curation. To accomplish these tasks JSC built two ultraclean class 10 cleanrooms, NASA's cleanest laboratories. Prior to launch the Genesis payload was dismantled, cleaned, and reassembled in these special cleanrooms (see photo in curation overview).

After its August 2001 launch, the Genesis spacecraft began its journey sunward. It was placed in a stable orbit at a point in space, about 1 million miles from Earth in the direction of the Sun, where the gravities of Earth and the Sun balance. The spacecraft unfolded its collectors and "sunbathed" for two years, collecting atoms from the solar wind.

Genesis carried four instruments: bicycle-tire-sized solar-wind collector arrays, made of materials such as diamond, gold, silicon and sapphire, and designed to entrap solar wind particles; an ion monitor, to record the speed, density, temperature and approximate composition of the solar wind ions; an electron monitor, to make similar measurements of electrons in the solar wind; and an ion concentrator, to separate and focus elements like oxygen and nitrogen in the solar wind into a special collector.

*Genesis Spacecraft*

Sample collection concluded in April 2004, when the spacecraft began its return to Earth. In September of that year, the spacecraft reentered Earth's atmosphere. Unfortunately the parachutes failed to open and the spacecraft impacted the ground at the Utah Test and Training Range. The recovery team placed the badly damaged spacecraft and samples in a temporary cleanroom, where the Science and Curation team members worked tirelessly for a month at documentation, preservation and packaging. The samples were finally brought to the Genesis laboratory at JSC in October.

The Genesis Science and Curation Teams continue to work closely developing techniques to assess and remove contamination, as well as to verify the identity of collector fragments. The first analyses of solar wind ions imbedded in the Genesis collectors were recently presented at international science conferences.

This treasured sample of the Sun will be processed and preserved in the JSC Genesis laboratory, and distributed for study to scientists in the next decade and over the next century. The atoms and ions will help scientists understand the composition of the original solar nebula that formed the planets, asteroids, comets and the Sun we know today.

## *Stardust — Comet and Interstellar Sample Return*

***Michael E. Zolensky and Friedrich P. Hörz***

Comets are believed to be the oldest, most primitive bodies in the solar system, possibly comprised of some of the basic building blocks of life. They contain the remains of materials from the formation of stars and planets, holding volatile, carbon-based rich elements that are likely to provide clues about the nature of early solar system. Comets may have been the major source of water on the Earth, Mars and other worlds, making life possible.

With the prospect of comets offering this treasure house of ancient information, there is significant anticipation about what findings scientists will be able to extrapolate from a firsthand examination of cometary materials. Because the Stardust spacecraft has now returned samples of material from a comet's dusty coma, and provided real-time in-flight data about what it encountered, there is a real possibility of scientific findings that will change the way we view our origins.

The Stardust spacecraft was launched in February 1999. In January 2004, Stardust flew approximately 200 km in front of the nucleus of Comet Wild 2, through the halo of gases and dust. During this passage the spacecraft collected dust and volatiles. The comet samples are thought to consist of ancient pre-solar interstellar grains and nebular condensates that were incorporated into comets at the birth of the solar system.

In addition to the cometary samples, the spacecraft also collected interstellar grains during the cruise phase of the mission. This material flows into our solar system in a great river of dust and gas. Analysis of this material will permit us to greatly expand our knowledge of the evolution of stars, the birth of the chemical elements, and the history of our galaxy. This mission was the first sample return mission launched in 30 years and it collected the first material from deep space, yet because it is traveling a much greater distance than its sister Genesis mission, it returned two years later with its precious cargo.

The Stardust spacecraft returned to Earth in January 2006. Reentry and recovery were perfect, and the spacecraft and its precious samples were soon transported to the Curation labs at JSC. The Science Team and Curation Team worked diligently to prepare and analyze the comet particles, and the first scientific results were reported within two months. A dedicated effort is now underway to locate and identify the extremely small and rare interstellar grains.

*Stardust Sample Tray in JSC Curation Laboratory*

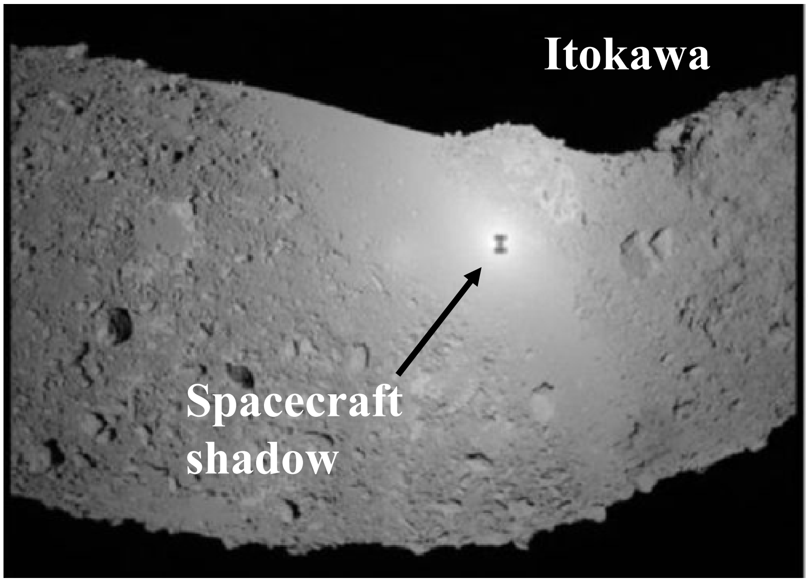
ARES scientists are key members of the Stardust Science Team. They helped develop and test the silica aerogel that is the magic material that will capture and hold the comet coma grains. This team has developed exacting techniques for the removal and analysis of captured grains from the silica aerogel. These scientists also oversaw construction of the Stardust Curation lab which received the samples, and prepared for preliminary analyses which are revealing the true nature of comets, their role in the early history of the solar system, and possibly, the origin of water and organic matter on Earth and Mars.

## *Hayabusa — Asteroid Sample Return*

***Michael E. Zolensky and Faith Vilas***

The Hayabusa mission will be the first sample return mission by Japan's space science agency, The Japanese Aerospace Exploration Agency (JAXA), and has been developed jointly with NASA. The goal of the mission is to return chipped samples from the surface of a small near-Earth asteroid called Itokawa.

The spacecraft left Earth in May 2003, and rendezvoused with the near Earth asteroid in the summer of 2005. The entire spacecraft briefly touched down twice on the surface and attempted to collect samples, but the success of these efforts is unknown. The liberated sample could be powder, or chips if bedrock is exposed. In any case, on the order of 1g of material may have been collected into a horn-shaped receptacle at each of the different sites.



*Hayabusa at Asteroid Itokawa*

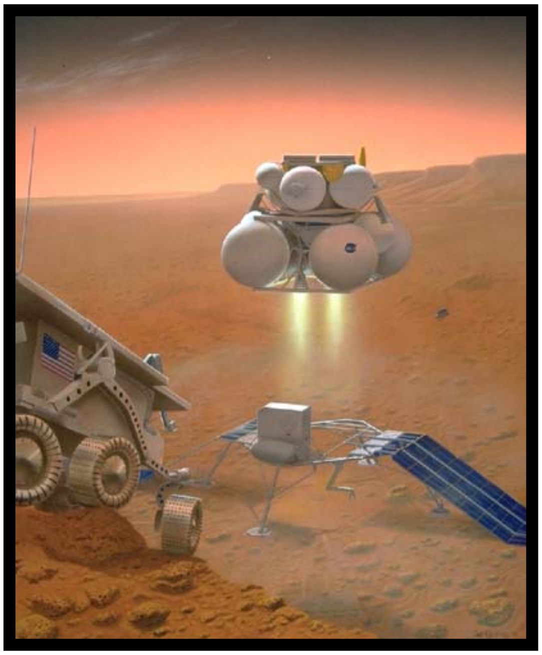
In 2010 the samples are due to be returned to Earth within a hermetically-sealed capsule, and flown to a laboratory in Japan for 1 year of preliminary investigation. Following this period the samples will be made widely available, with approximately 10% of the sample mass coming to JSC for curation and distribution. ARES scientists are members of the Hayabusa Science Team and are involved in both sample curation and characterization of the target asteroid.

## *Mars Returned Sample Handling*

***Carlton C. Allen***

NASA's Mars Exploration Program will eventually include robotic sample acquisition missions to return samples to Earth for detailed study, probably sometime in the next decade. The Astromaterials Acquisition and Curation Office is working to prepare for all of the activities to be done once the sample-containing spacecraft returns to Earth, ranging from recovery of the spacecraft to ultimate distribution of samples to scientists for study.

One of the strong scientific reasons for returning samples from Mars is to search for evidence of current or past life in the samples. Because of the remote possibility that the samples may contain life


***Mars sample return concept***

forms that are hazardous to the terrestrial biosphere, NASA's Planetary Protection Officer (guided by a National Research Council study) has specified that all samples returned from Mars must be kept under strict biological containment until tests show that they can safely be released to other laboratories. It is also important to ensure that scarce or subtle traces of Martian life not be overwhelmed by contamination from terrestrial microbes. Thus, the facilities used to contain, process, and analyze the samples must maintain standards of biological and chemical cleanliness that are unprecedented in high-level biocontainment facilities.

In planning for the processing of Mars samples, the ARES curation staff has built on its experience in preliminary characterization, hazard testing, and distribution of lunar, meteorite, and cosmic dust samples to scientists worldwide. Unique requirements for the processing of Mars samples inspired an active program to develop sample handling techniques that are much more precise and more reliable than the approach (currently used for lunar samples) of using human hands in nitrogen-filled gloveboxes. Individual samples from Mars are expected to be much smaller than lunar samples, the total mass of samples returned by each mission being 0.5-1 kg, compared with many tens of kg of lunar samples returned by each of the six Apollo missions. Smaller samples require much more processing to be done under microscopic observation. In addition, the requirements for cleanliness and high-level containment would be difficult to satisfy while using traditional gloveboxes.

## *Human Exploration Science Office (KX)*

***Gregory Byrne, Ph.D., Manager***
***http://ares.jsc.nasa.gov/HumanExplore/intro.html***

The Human Exploration Science Office conducts space science research and provides support to human spaceflight through the disciplines of exploration planning, space debris research, hypervelocity impact test and analysis, and image science and analysis.

Exploration planning focuses on the science to be done during future human exploration of the Moon, Mars, or asteroids. This function provides communication and coordination between the scientific community and the mission planning and technology communities and provides input to forums on space policy.

The space debris research function provides measurements and modeling of the Earth's orbital debris environment. NASA's Orbital Debris Program resides within the Office and is recognized internationally for its leadership in orbital debris research and in the development of national and international space policies on orbital debris.

The hypervelocity impact test and analysis function provides evaluations of the risks to spacecraft posed by orbital debris and meteoroid impacts through laboratory testing and software modeling predictions. This function also contributes to spacecraft protection and crew safety by identifying meteoroid/debris risk drivers and providing guidance for advanced shielding designs and mission operations options to reduce impact risks.

Image science and analysis provides state-of-the-art engineering imagery analysis of spacecraft including Shuttle, ISS, and the Hubble Space Telescope to assess vehicle performance and anomalies. This function also provides the Crew Earth Observations payload onboard the ISS; the source for Earth imagery acquisition by astronauts, image interpretation, cataloging, and web-based access to the Earth imagery.

***Reports on several projects are given in the following pages.***

# *Instability of the Current Orbital Debris Population*

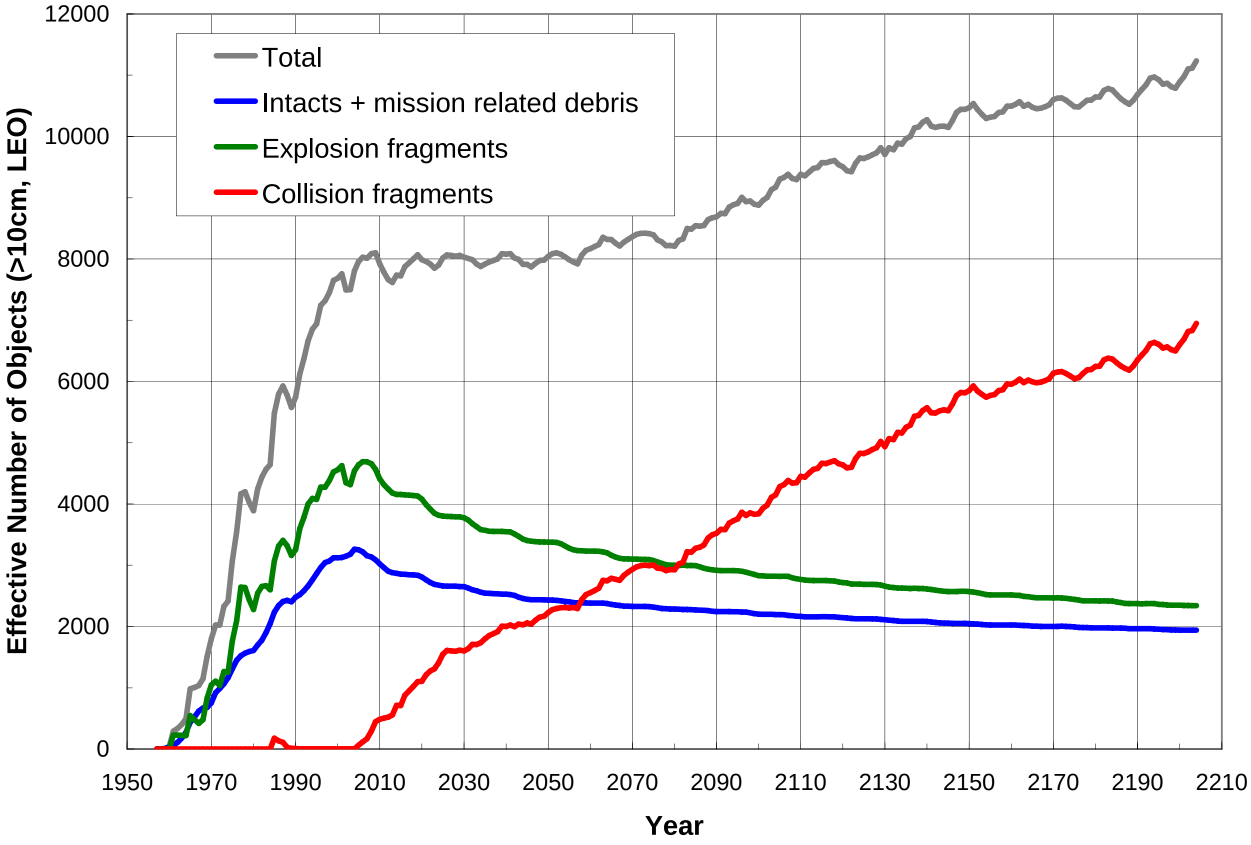
***Jer-Chyi Liou and Nicholas L. Johnson***

Currently more than 9000 objects, with a combined mass exceeding 5 million kilograms, are tracked by the U.S. Space Surveillance Network and maintained in the U.S. satellite catalog. Several environment projection studies conducted between 1991 and 2001 indicated that with various assumed future launch rates, the debris populations at some altitudes in low Earth orbit (LEO) will become unstable. Collisions would take over as the dominant debris generation mechanism, and the debris generated would feed back to the environment and induce more collisions. Research by personnel of the NASA Orbital Debris Program Office, published in *Science* (20 January 2006), indicates that this instability is now present and will lead to an increase in the Earth satellite population, even with a complete cessation of new space missions.

Using a recently developed, high fidelity debris evolutionary model (LEGEND) with an updated debris population, the new study made a key assumption: no new launches after 1 January 2005. This assumption eliminated several major uncertainties in future projection simulations, including future launch frequency, types of satellites launched, their physical and orbital specifications, and the effects of self-induced explosions of future satellites. Although “no new future launches” is unrealistic, it does provide a baseline assessment of the current debris environment. In other words, the study results represent a best-case scenario with direct intervention.

An analysis of the simulated 10 cm and larger satellite population in LEO indicates that collision fragments replace other decaying debris (due to atmospheric drag) through 2055, keeping the total LEO populations approximately constant. Beyond 2055, however, new collision fragments outnumber decaying debris and force the total population to increase. Detailed analysis shows that the predicted future catastrophic collisions and the resulting population increase are non-uniform throughout LEO. The most active region is between 900 and 1000 km altitudes. Even without any new launches, this region is highly unstable. Debris populations in this “red zone” will approximately triple in the next 200 years, leading to a factor of 10 increase in collision probability.

In reality, the future debris environment is likely to be worse than the study suggested, since satellites continue to be launched into space. The paper concludes that to better limit the growth of future debris populations, active removal of objects from space needs to be considered. ♦



**Effective number of LEO objects, 10 cm and larger, from the LEGEND simulation.**

## *Assessing the Survibility of Satellites during Reentry*

***N. L. Johnson***

Out of the more than 29,000 man-made objects cataloged in Earth orbit since the launch of Sputnik 1 in 1957, approximately 18,000 have fallen back to Earth in an uncontrolled manner. Whereas the majority of the these objects completely burn up during reentry and most of the surviving debris fall into the oceans, some potentially hazardous debris does impact the Earth in a manner which might pose a risk of human casualty. In January, 2005, a 50-kilogram (110-pound) casing of a solid rocket motor landed near Bangkok, Thailand.

NASA Safety Standard (NSS) 1740.14 requires that each NASA reentering spacecraft and launch vehicle orbital stage be assessed for debris which might survive reentry and pose a human casualty risk anywhere in the world. The high fidelity Object Reentry Analysis Survival Tool (ORSAT) is employed by the Orbital Debris Program Office to evaluate these risks. Various versions of this state-of-the-art code have been used during the past 10 years to perform over 20 different satellite reentry analyses. In 2006 a major upgrade of ORSAT, ORSAT 6.0, was completed and accepted for use in all NASA space programs.

The ORSAT model uses integrated trajectory, atmospheric, aerodynamic, aerothermodynamic, and thermal/ablation models to perform a complete component analysis of the reentering object to determine survivability and subsequent human casualty risk. New features of the code include improvements of the trajectory and the gravitational models; incorporation of additional atmospheric models; 2-D heating rate and temperature variation around spheres, cylinders, cones, and flat plates; drag coefficients for cones; and general program improvements. Additional new capabilities include gas cap radiation effects at very high entry velocities, recession for non-metallic insulation materials, calculation of structural failure of solar array hinges, tank bursting, an expanded materials property database, and trajectory mapping on a world map.

*Solid rocket motor casing found near Bangkok in January, 2005.*

# *Measurements of the Orbital Debris Environment*

***Eugene G. Stansbery***

For more than a quarter century, NASA has taken the international lead in orbital debris environment characterization and in developing the technical consensus for adopting mitigation measures to protect users of near-Earth space. Work at NASA continues with the development of improved understanding of the risks of orbital debris and the implementation of design and operational countermeasures.

Measurements are the foundation of our understanding of the current and future debris environment. The Orbital Debris Program Office uses a wide variety of measurements, each with its own area or size regime of applicability, in order to fully characterize the total debris environment. In order to avoid duplication of effort, NASA relies on the U.S. Space Surveillance Network to track orbiting objects larger than about 10-cm. diameter in low earth orbit and 1-m. in near geosynchronous orbit. Objects much smaller than this size can damage operational spacecraft because of the high relative velocities between orbiting objects (average collision velocity = 10 km./sec.) The Orbital Debris Program Office statistically measures the debris environment for small objects.

## ***Measurements in Low Earth Orbit (LEO)***

NASA has used the Haystack Observatory, including both the Haystack and HAX radars, since 1990 to sample the debris environment at low Earth orbit (LEO) altitudes. The Haystack radar is a high power, X-band (3-cm wavelength) radar with very high sensitivity. It is capable of detecting debris as small as 0.5 cm diameter at an altitude of 500 km. HAX can detect 2 cm diameter debris at 500 km but has a larger field of view. Rather than tracking individual objects, these radars are used in a non-tracking, or “staring,” mode which allows debris to pass through the radar’s field of view. The rate at which objects are detected can then be related to the density or flux of particles in orbit. NASA collects 600 hours of data from each of the two radars each year.

***The Haystack (large dome) and Haystack Auxiliary (HAX) Radar (small dome) located in Tyngsboro, Massachusetts, northwest of Boston.***

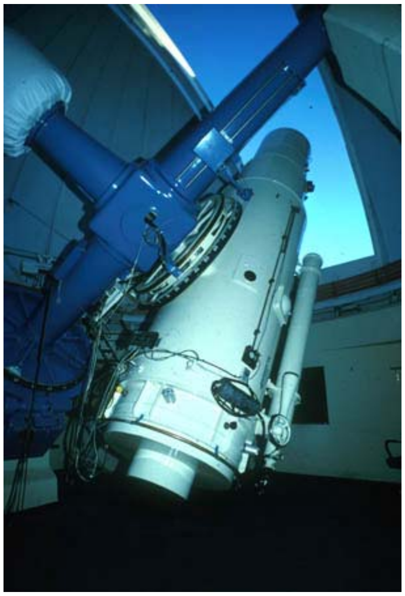
NASA also collects debris data from the Goldstone radar located in California. This radar operates in a bi-static mode which means that it transmits its radar signal on one antenna (70-m. diameter) and receives the reflected signal on a separate antenna (36-m. diameter). The improved isolation provided by separating the transmitted and received signals results in improved signal-to-noise. This, coupled with the larger antenna gain provided by the 70-m. antenna, allows Goldstone to detect debris objects even smaller than Haystack. NASA is collecting statistics on debris as small as 3-mm. diameter at 500 km. altitude. Even though the Goldstone antenna is highly subscribed with planetary mission support, debris data is collected on an as-available basis with almost 120 hours of data collected in FY2005.

***The 70-m. Goldstone transmit antenna on the left and the 36-m. receive antenna are located near Barstow, CA and can detect debris as small as 3-mm. diameter.***

Debris data collected from these on-going measurements is supplemented with data collected during specific, short duration measurement campaigns. During the past two years, NASA has collected data from the Cobra Dane radar located in Alaska in the Aleutian Islands and from the Ground Based Radar – Prototype (GBRP) radar located in the Pacific on the island of Kwajalein.

## ***Optical Measurements***

NASA is collaborating with the University of Michigan operating its 0.6/0.9-m classical Schmidt telescope located at the Cerro Tololo Inter-American Observatory, Chile. The facility is capable of detecting a 10-cm. object at GEO, assuming an albedo of 0.2. In FY2005 the telescope received a major upgrade which put the telescope mount under computer control. This allows near-GEO objects discovered during survey operations to be tracked in order to refine estimates of their orbital elements.



*The University of Michigan 0.6/0.9 Schmidt telescope located at the Cerro Tololo Inter-American Observatory in Chile.*

## ***Meter-Class Autonomous Telescope (MCAT)***

NASA and the Air Force Maui Optical and Supercomputing (AMOS) site are cooperating to place a wide field-of-view, meter aperture telescope on Kwajalein Atoll for space debris research. The telescope system, designated the Meter-Class Autonomous Telescope (MCAT), will be deployed as part of the High Accuracy Network Orbit Determination System (HANDS). The telescope will operate in two different modes. During twilight hours it will sample low inclination orbits in a “track before detect” mode. In the middle of the night it will perform a more standard GEO search. Kwajalein Atoll was chosen as the location for MCAT because: 1) its low latitude location is necessary for sampling low inclination orbits, 2) its location allows it to measure a part of the GEO belt not covered by other optical sensors, and 3) it has a technically skilled workforce which can act in a caretaker capacity.

***Telescope dome on the island of Roi-Namur in the Kwajalein Atoll awaiting installation of the first MCAT prototype.***

## ***Physical Properties of Orbital Debris***

NASA is seeking to refine its characterization of the orbital debris environment by examining the physical properties of debris such as shape and material composition.

In the early 1990s, a selection of debris fragments taken from a ground hypervelocity collision test were measured in a controlled radar range to develop the NASA Size Estimation Model (SEM) which related the physical size of the debris to its radar signal return, or radar cross section (RCS). Currently, a similar task is being pursued for optical measurements. The study takes brightness measurements of debris of various shapes and sizes at different phase angles and orientations to determine the effect of size, shape and orientation on the optical signal. The experiment uses a Xenon lamp to simulate solar illumination, a CCD (charge coupled device) camera to digitally record all images, and a programmable robot arm to vary the object's orientation and phase angle. The debris pieces are selected from ground test breakups of mock satellites from explosions and hypervelocity impacts.

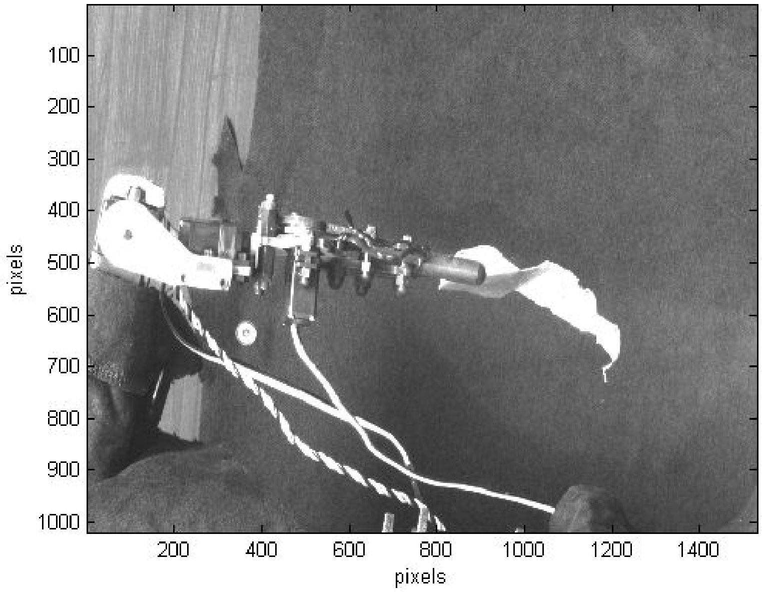


***Photo of the robotic arm holding a debris fragment from a ground test explosion of a mock satellite.***

Material composition of orbital debris is being studied in several ways. NASA is looking at the distribution of materials from design-related data on launched objects and the distribution of materials from a ground-based hypervelocity impact test conducted on an actual surplus satellite. Returned surfaces of spacecraft show small impact features from collisions with small debris or micro-meteoroids. The material composition of the impactors can be determined using mass spectrometers and other instruments operated by ARES. NASA is also looking at the optical spectra of on-orbit debris. Low resolution reflectance spectra of orbiting satellites, rocket bodies, and debris are compared with a database of spectra from commonly used spacecraft materials. The absorption features and overall shape of spectra are used to determine material.

## *Revision of Space Shuttle Wing Leading Edge Reinforced Carbon-Carbon Failure Criteria Based on Hypervelocity Impact and Arc-Jet Testing*

***E. Christiansen, J. Hyde, D. Lear, T. Prior, & F. Lyons***

As part of the Shuttle Return-to-Flight (RTF) effort, the NASA Johnson Space Center's Hypervelocity Impact Technology Facility (JSC/HITF) performed hypervelocity impact (HVI) testing and analysis of Shuttle wing leading-edge (WLE) reinforced carbon-carbon (RCC) test samples to update WLE threshold failure criteria. After the hypervelocity impact tests, the samples were exposed to typical reentry heating conditions at the NASA JSC Arc-Jet (AJ) Facility to determine the extent of heating-induced damage growth. It was found from the HVI/AJ testing that non-penetrating pits would lead to burn-through in some areas of the WLE where burn-through can lead to loss-of-vehicle (LOV) during reentry. Figure 1 shows the resulting damage caused by a 0.8 mm diameter aluminum hypervelocity impactor and subsequent damage growth due to AJ testing.

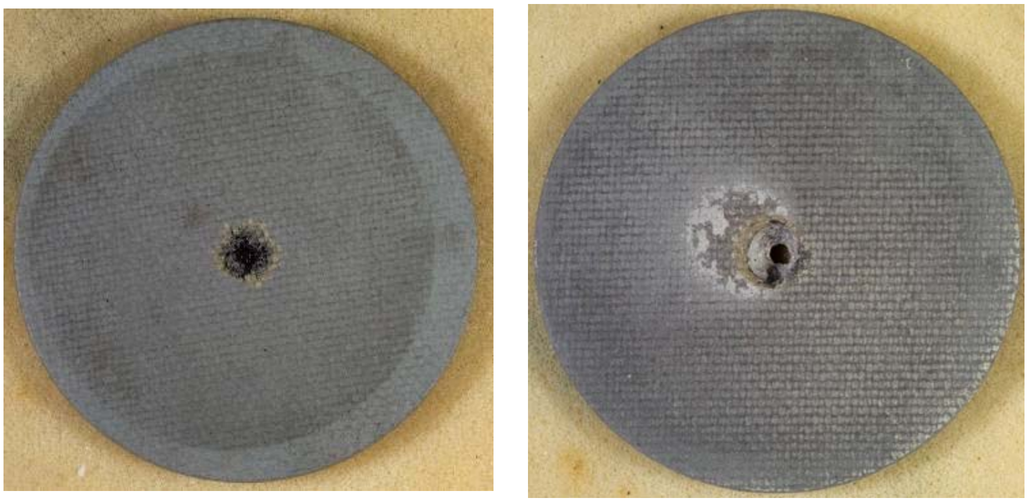


**Figure 1. Results HVI testing (Test #6) of RCC (on left) and after AJ test (on right) Impact by 0.8mm diameter Aluminum sphere at 7.07km/s and 0$^o$, 10.7mm diameter coating damage and 6.5mm coating loss on impact side, AJ conditions: 2700degF, 98psf, 15min, fail: hole at 830sec.**

For STS-107 and previous missions, WLE failure threshold consisted of 1" diameter allowable hole sizes in RCC on the upper surface and ¼" hole size on the lower surface. The results of the recent RCC/AJ testing indicated that the WLE failure criteria for loss-of-vehicle should be reduced for MMOD assessments on STS-114 and future missions. Figures 2 and 3 show the WLE failure criteria map before and after the recent changes for STS-114. The reduction in allowable damage results in increased MMOD risks for future missions, if all other things remain constant.

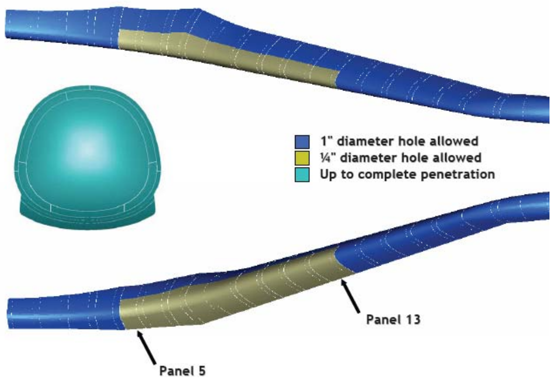


**Figure 2. Pre-STS-107 Failure Criteria Map**

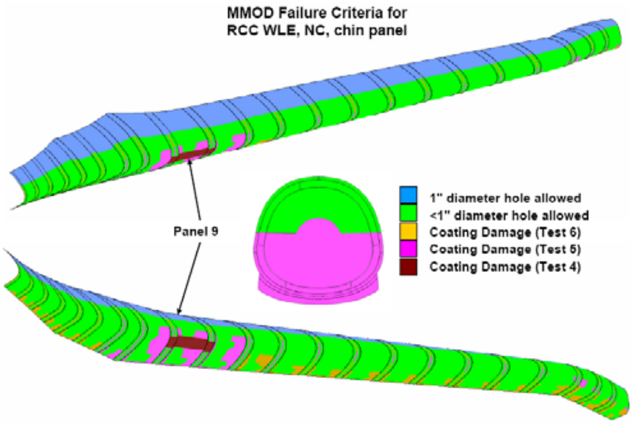
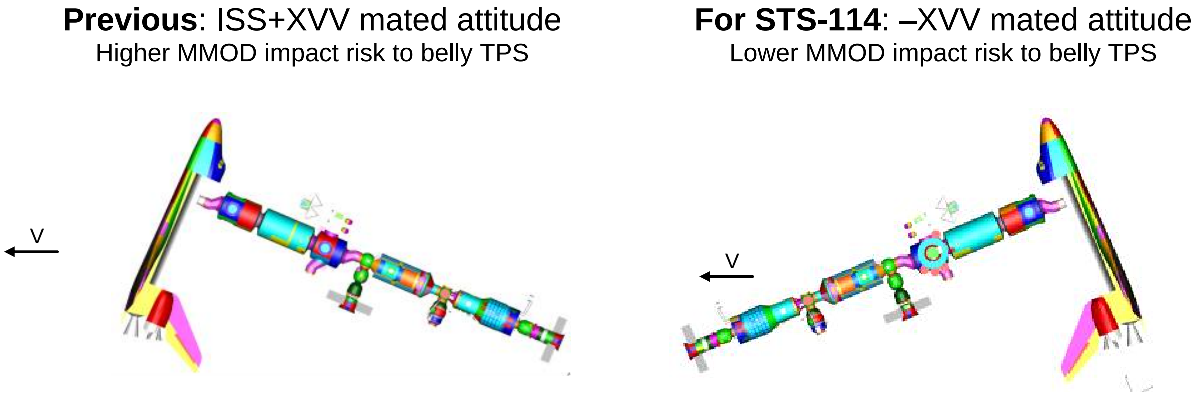


**Figure 3. Post-STS-107 Failure Criteria Map**

The Shuttle and International Space Station (ISS) Programs decided to decrease MMOD impact risks to STS-114 and subsequent flights by reversing the orientation of ISS during the ISS docking phase of the Shuttle mission. The change in orientation – essentially flying the ISS "backwards" – provided incidental shielding to the Shuttle as well as directing MMOD sensitive areas of the WLE and nose cap away from the majority of the MMOD particle flux. Figure 4 shows the Shuttle-ISS docked orientation change with respect to the ISS velocity direction. In all ISS missions prior to STS-114, the belly of the vehicle faced into the ram "velocity" direction of ISS motion and highest MMOD impact flux. The change for STS-114 orients the bottom of the Shuttle in the wake direction of ISS reducing MMOD impacts to the most vulnerable surfaces of the vehicle and improving crew safety and mission success.


**Previous**: ISS+XVV mated attitude
Higher MMOD impact risk to belly TPS

**For STS-114**: –XVV mated attitude
Lower MMOD impact risk to belly TPS

**Figure 4. Shuttle-ISS docking and flight orientations before and after**

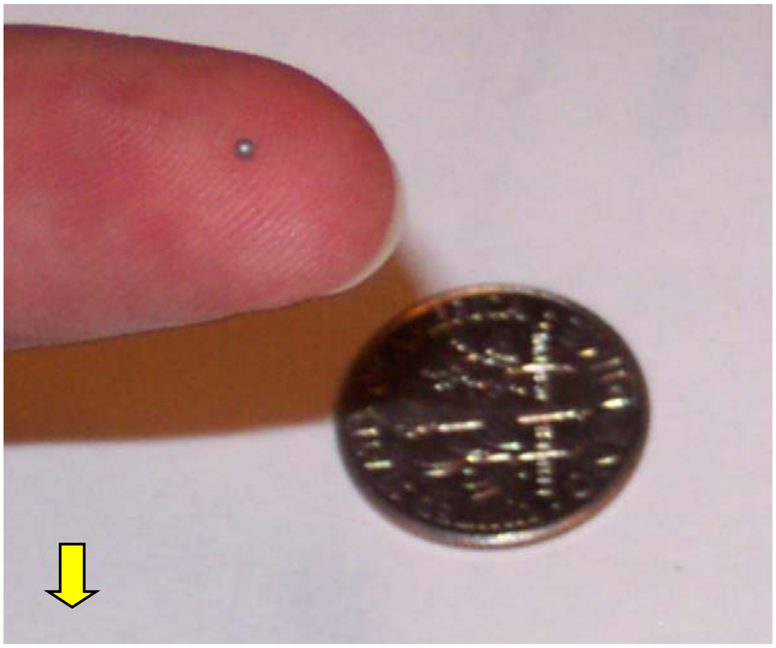


**Figure 5. This 1mm aluminum sphere is larger than the critical impactor size for hot zones of the WLE RCC (refer to "Test 4", "Test 5" and "Test 6" regions in Figure 3). This particle can penetrate an RCC panel at 7 km/s.**

# *Imagery Analysis in the Space Shuttle's Return to Flight*

***Gregory J. Byrne, Cindy A. Evans***

The July, 2005 launch of the Space Shuttle *Discovery* heralded new, critical roles for imagery analysis in the conduct of Shuttle missions. Real-time imagery acquisition and analyses were key factors in the safety and mission success criteria for the Shuttle's Return-to-Flight (RTF). With near-continuous camera coverage from lift-off to landing (only the entry phase was uncovered) *Discovery* was by far the most thoroughly imaged spacecraft to date. During the mission, ARES' image analysts on the ground poured over the vast amounts of downlinked imagery to inspect the vehicle in unprecedented detail.

In the two-and-a-half-year hiatus in Shuttle missions following the STS-107 *Columbia* accident, members of the ARES Image Science and Analysis Group (ISAG) were key players in the RTF development effort. Some of the highest priority objectives for RTF missions were an outgrowth of new vehicle imagery and inspection requirements, stemming from recommendations of the Columbia Accident Investigation Board (CAIB) - and ISAG was in the critical path for defining and developing the necessary mission operations and analysis capabilities. JSC's new state-of-the-art facility, the Image Science and Analysis Laboratory (see Evans and Byrne, this issue), was also developed to accommodate the greatly increased demand for ISAG's services.

### *The STS-114 Mission*

After extensive planning and preparations for the STS-114 *Discovery* mission, ISAG contributed directly to its success with analyses derived from the launch, ascent, and on-orbit imagery.

One mission priority was to assess the performance of the External Tank (ET) and modifications made to minimize shedding of its insulating foam. During ascent, several incidences of ET foam loss were captured on downlinked imagery. ISAG was instrumental in the ensuing investigation. Real-time analyses characterized the foam loss and determined that the debris did not impact *Discovery*. ISAG also generated 3-dimensional contour maps of the areas of foam loss (Figure 1) using specialized stereo photogrammetry tools to aid in identifying the failure mechanisms, prompting further modifications to the ET for future missions.

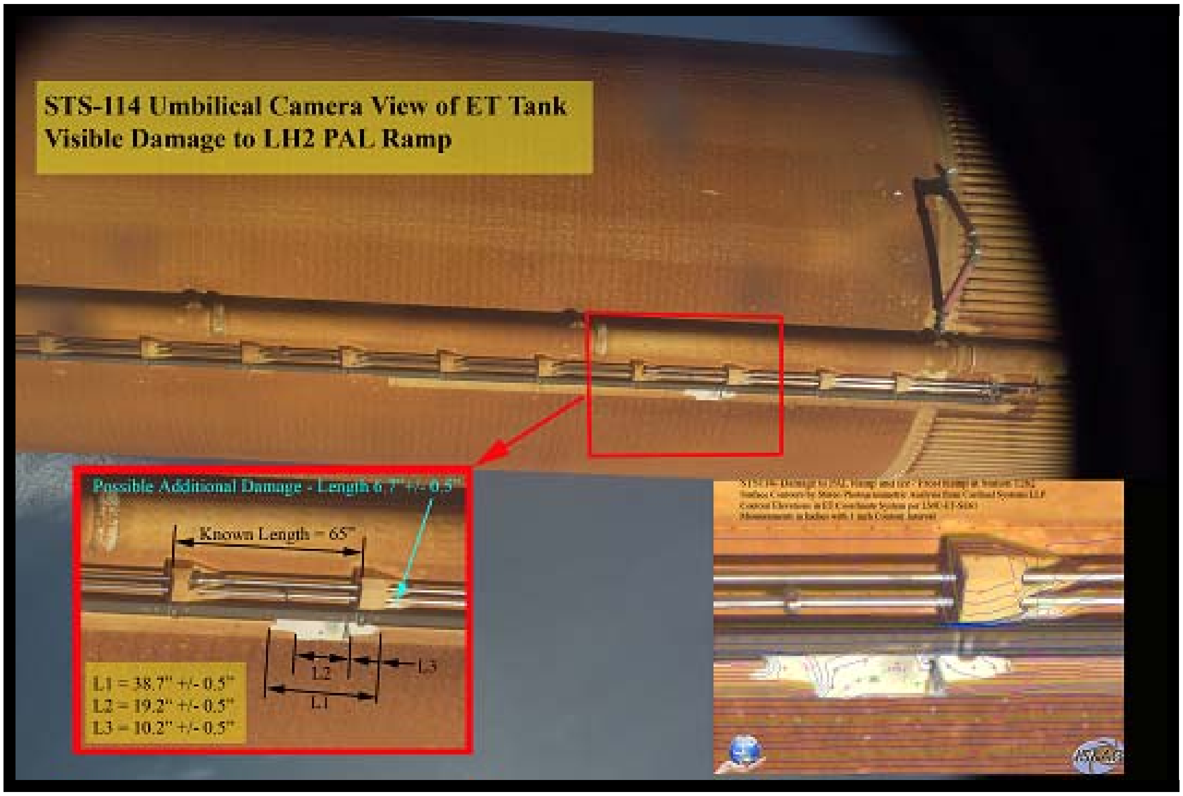


*Figure 1. Foam loss damage identified on the STS-114 External Tank. Examples of 2-dimensional measurements and 3-dimensional contour mapping are shown in the insets.*

Another prime mission objective was an on-orbit inspection of the entire outer surface of *Discovery* through a sequence of surveys using ISS and Shuttle cameras and sensor systems. The surveys were designed to detect and measure any areas of damage to *Discovery's* Thermal Protection System (TPS) surfaces. ISAG reviewed and analyzed all of the inspection data. One component of the inspection involved acquiring high-resolution digital images of the Orbiter from the ISS during rendezvous maneuvers (Figure 2). These images afforded a complete inspection of the Shuttle thermal tile surfaces, with resolution to detect and measure anomalous features smaller than one inch. Additional surveys of the critical wing leading edge surfaces using new Orbiter imaging systems afforded detection of features smaller than one quarter of an inch.

ISAG led the inspections, identifying and characterizing several areas of TPS damage that were of safety concern. In one case, a damaged thermal blanket was detected on the outside of the crew cabin – ISAG characterized the damage in three dimensions using its stereo photogrammetry capability. The measurements were used to recreate the condition for wind tunnel testing. Based on the tests, an EVA repair was deemed unnecessary, and the blanket was cleared to re-enter in an as-is condition. In another case, two tile gap fillers were detected protruding from the belly tile surface (Figure 2). ISAG's measurements were instrumental in the decision by mission management for an EVA repair to remove the gap fillers prior to re-entry.

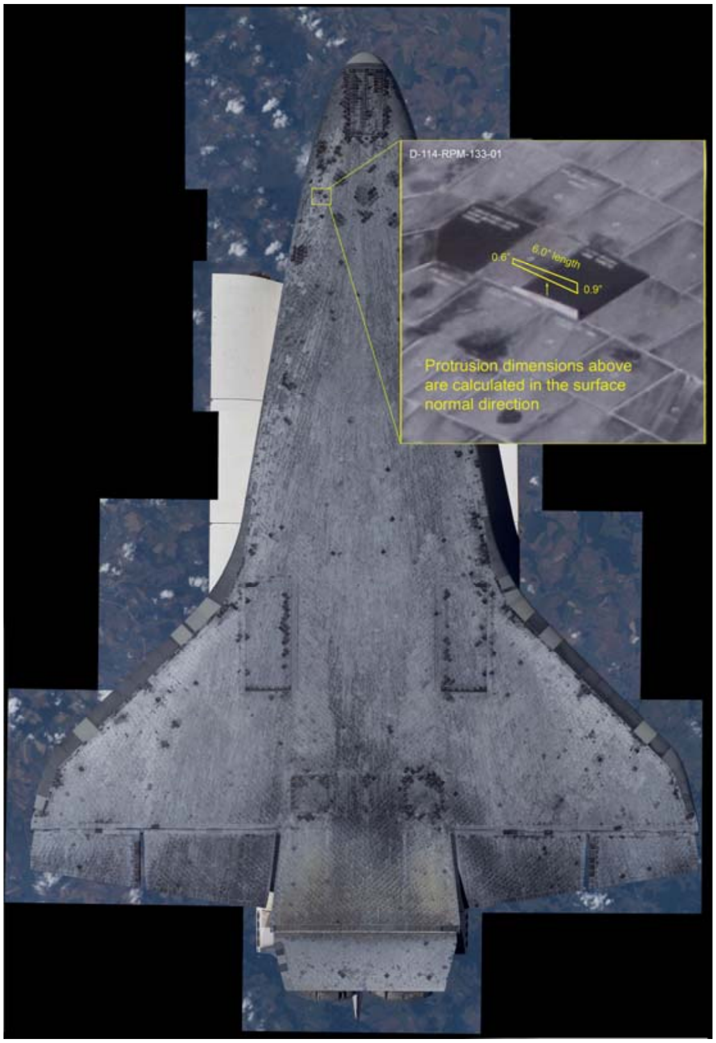


*Figure 2. A mosaic of images taken from the ISS showing the complete Orbiter belly tile surfaces. A close-up view of protruding tile gap filler is shown in the inset.*

Prior to STS-114, ISAG's staff worked closely with sensor and TPS engineers, the Flight Control Team, and the Shuttle Program to develop procedures and criteria for imagery collection and analysis, ensuring that the critical data on the condition of the TPS would be available for rapid decision-making during mission operations. After the mission, ISAG "ground-truthed" their mission analyses by comparing their on-orbit measurements of damage sites with measurements conducted during a post-mission mapping of the TPS surfaces. The results validated the inspection methods and real-time analyses conducted by the team. The successful outcome of ISAG's mission support provided confidence that ISAG's observation and measurement techniques are robust and dependable for future spaceflight missions.

## *JSC Image Science and Analysis Laboratory (ISAL)*

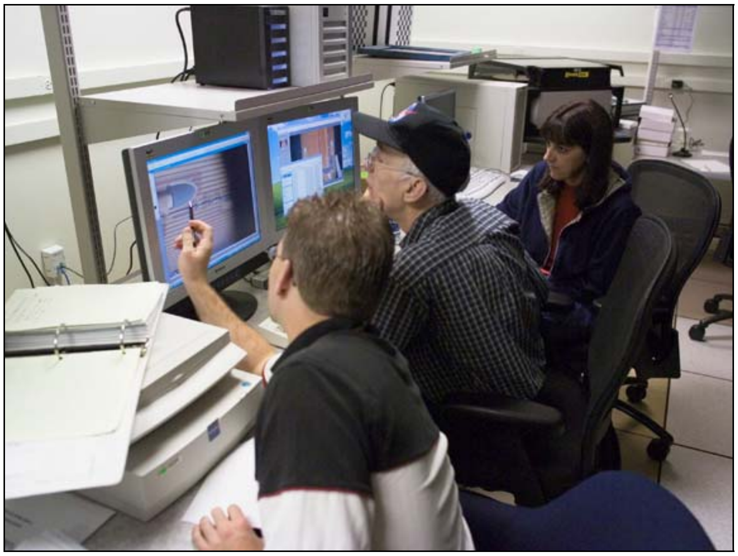
***Cindy A. Evans, Gregory J. Byrne***

For 20 years – since the *Challenger* accident – JSC's Image Science & Analysis Group (ISAG) has provided engineering support to human spaceflight missions through review and analysis of imagery products from the Space Shuttle, *Mir*, and International Space Station (ISS). In 2003, ISAG's staff of imagery analysts provided critical support to the Columbia Accident Investigation Board (CAIB). As a result of the investigation and CAIB recommendations, the Space Shuttle Program outfitted the Shuttle and the launch facilities with several new imaging systems. Enhanced image analysis capabilities were also necessary to support new vehicle inspection requirements. ARES' Image Science & Analysis Laboratory (ISAL) in Building 36 was built to answer those requirements, and to also support the ISS and other NASA Programs with state-of-the-art image processing and analysis tools. The ISAL replaces ISAG's former lab, the Video Digital Analysis System (VDAS) in Building 31.

*Image Analysts review mission data in the new Image Science & Analysis Lab*

### *Mountains of data*

A cornerstone of the ISAL is the new capability to receive and analyze HDTV (High Definition Television) videos of the launch and ascent of each Shuttle mission. The Shuttle Program mandates a rapid review and assessment — within 12-16 hours of launch — of videos from about 20 cameras mounted on the launch pad and tracking telescopes around the launch facility. While this early HDTV review is followed by a more exhaustive review of 35 mm motion picture films of the launch, the HDTV provides superior quality data compared to the NSTC-format (analog) videos collected before the *Columbia* accident. The ISAG analysts can provide a much more thorough assessment of launch and ascent events very early in the mission, enabling quick decisions by the Shuttle Program management team.



*Digital data sources enable near real-time analysis of mission data*

The ISAL's first step to accomplish this task is to receive roughly 100 GB of HDTV and other imagery within a few hours of launch, and quickly transfer the data to recorders capable of reading and displaying the videos. In fact, today, ISAL receives a total of about 200 GB of digital imagery data for each Shuttle mission — nearly 100 times the amount of digital data processed and reviewed by ISAG scientists prior to the *Columbia* accident. ISAL hosts a dedicated server that is connected to the NASA institutional network, allowing the launch team at KSC to push the HDTV video data directly to the ISAL at a high data rate immediately after launch. The HDTV data is stored as compressed digital files on the server that can be transferred to ISAL workstations and networked digital disk recorders in the new ISAL video racks. In addition, the ISAL video racks contain multiple analog (NTSC) video feeds, and HD-SDI video and digital (SDI) video feeds from the JSC Video Distribution Center, allowing the lab to receive video data in multiple formats.

*The ISAL video racks (along back wall) are the lab's central nervous system, facilitating the receipt and distribution of digital imagery data.*

Within the video stacks are several tools for interpreting and displaying the imagery data. These include a variety of high-end digital and analog video recorders, broadcast quality high-resolution monitors, time base correctors, timecode readers, patch panels with distribution amps and a new router system allowing users full flexibility to distribute video signals in and out of the stack components to a host of high-end workstations and display projectors and screens. Together, the servers and the video rack comprise the backbone of the ISAL.

### *Tools of the Trade*

When visitors enter the lab, the features they immediately notice are the theater-like display screens placed around ISAL. These high-resolution, wide screen monitors display any of the imagery coming in to the lab, but most importantly, allow screening of the HDTV imagery of the Shuttle launches.

ISAL also maintains film screening capabilities that allow movie film screening for review and analysis of imagery from the various launch camera films (35 and 16 mm) for each Space Shuttle mission. The hardware used to support film screening consists of a professional movie projector (Kinoton studio stop action motion picture projector with variable speed control for both 16 mm and 35 mm films), laptops, a camera for image capture, and printers. A l6/35-mm film-to-digital scanner/workstation allows measurements made from film imagery.

The image analysis workstations include features not found on common desktops. Selected workstations have video capture cards and software that allow for grabbing individual frames or a sequence of frames in real time. Lots of memory, lots of speed, high capacity raid disk arrays, top-of-the-line graphics cards, and specialized software together optimize analysis of the imagery.

*Image analyst dons special glasses for viewing data in 3D for performing photogrammetric analyses.*

The lab maintains a modular arrangement of workstations to preserve flexibility for supporting other analysis tasks as they arise during the mission. High-end workstations and displays, and a suite of professional image processing software tools are used for analysis. Commonly used capabilities include

- Image enhancements, including standard spatial and frequency domain filtering techniques, image registration/stabilization, image restoration, and super-resolution.
- Two-dimensional and three dimensional measurement capabilities.
- Photogrammetric analyses.
- Motion tracking of objects in a video or digital movie.
- Feature/blob analysis

ISAL maintains web tools and web-based mission imagery for managing and communicating imagery and analysis results. The databases are designed to provide wide access to analyses and reports, and allow sorting and filtering of the mission data. Links to these databases, reports and other ISAG projects are accessible through the ISAG website at http://isag.jsc.nasa.gov.

The workstations and servers within the ISAL are networked and linked to the JSC network together using high speed (Gigabit) Ethernet network links and switches, allowing optimal connectivity to the JSC Video Distribution Center and the Mission Control Center (MCC).

The ISAL network communications with other space centers is provided via the Internet using the imagery mirrored server system, World Wide Web browsers, e-mail and File Transfer Protocol. Video communication is provided via fiber-optic link to the JSC Television Office. During missions, a Digital Voice and Information System (DVIS) unit provides communications with the MCC and other mission support organizations.

**<u>Other ISAL facilities</u>**

Today, the ISAL extends to an on-orbit Shuttle Thermal Protection System (TPS) inspection analysis lab located in the MCC. The primary purpose for the on-orbit inspection lab is to review and analyze remote sensor data of the vehicle obtained during surveys while the Shuttle is on-orbit. The current configuration provides the tools required to analyze data from the Orbiter Boom Sensor System (OBSS) and any other inspection imagery obtained by Shuttle or Station video or digital cameras or crew EVA.

The video stacks and analysis workstations in the on-orbit MCC facility have much the same capability as the ISAL, but are dedicated to the analysis of real-time data from the Space Shuttle. The facility is also configured to support review of data from other non-optical sensors such as lasers.

Finally, to better manage and organize in real time the vast amounts of data acquired during missions, ISAG operates an imagery coordination console in the MCC Mission Evaluation Room

(MER) equipped with MCC consoles and workstations, and supported with video feeds, video monitors, laptops (JSC network), a server, and recorders. The MER console position serves as the communications hub between the ISAL, MCC, and other support organizatons.

*ISAG staff reviews imagery of the Shuttle RCC panels in their lab in the MCC*

The ISAL, together with its staff of professional image analysts, provides the Johnson Space Center with a state-of-the-art imagery analysis facility. The lab is soundly established to support NASA's human spaceflight programs well into the future.

## *Participation in the International Polar Year*

***Susan K. Runco, Cindy A. Evans, Gregory J. Byrne***

Beginning in March 2007, the international polar research community will join together in a global campaign of coordinated polar observations and analyses, comprising the International Polar Year (IPY) 2007-08. Previous IPYs have led to major breakthroughs in understanding the unique environment of the Polar Regions, their interactions with the Earth system, and their influence on global processes such as climate change. IPY 2007-08 offers an even greater opportunity to increase our understanding of polar processes by drawing upon technological advancements and satellite observations that were not available in previous campaigns - the most recent was fifty years ago (IPY 1957-58).

The ARES Image Science and Analysis Group (IS&AG) will participate in IPY 2007-08 by offering its Crew Earth Observations (CEO) services for acquiring images from the International Space Station (ISS) relevant to other IPY field observations. With its orbit of 51.6° inclination and 400 km altitude, the ISS provides a platform for human-guided observations of large-scale polar phenomena in both hemispheres, such as aurora and noctilucent clouds.

*Rays of green and red aurora australis illuminate the Earth's horizon as viewed from the ISS*

The ISS observations will provide a valuable resource for the IPY community to complement other ground site observations and satellite data, synchronized in location and time. The resulting CEO imagery from ISS will be distributed using IS&AG's "Astronaut Photography of the Earth" website (http://eol.jsc.nasa.gov).

*Noctilucent clouds in the Earth's mesosphere and a crescent Moon grace this northern hemisphere view from the ISS*

# *ARES Education and Public Outreach*

***Jaclyn Allen***

***[http://ares.jsc.nasa.gov/Education/outreach.htm](http://ares.jsc.nasa.gov/Education/outreach.htm)***

Sharing our science with the public is an essential part of ARES programs in Earth and space science. As the small enclave of physical scientists at a NASA engineering and space flight center, our staff is frequently called upon to support science presentation and interview requests from the JSC public affairs or education offices. Staff members are active volunteers in the JSC Speaker's Bureau, Digital Learning Network, Texas Aerospace Scholars program, JSC education workshops, and National Engineers Week programs. Scientists and staff support local science fairs and give presentations at many local schools. Our scientists are frequent mentors for university faculty and students in programs sponsored by the NASA education or equal opportunity offices. ARES staff provides frequent tours of our research and curatorial laboratories for JSC personnel and visitors.

## ***Earth Observations E/PO***

http://eol.jsc.nasa.gov

Astronaut photography of Earth is extremely popular with students, teachers, and the general public, and this interest is used to leverage interest in science and exploration. ARES provides at least one human space flight image headline per week to "Earth Observatory," NASA's Earth science education flagship website (<<http://earthobservatory.nasa.gov>> ). Over 500,000 astronaut photographs of Earth are downloaded each month by educators and the public from the "Gateway to Astronaut Photography of Earth," which has received numerous educational citations (<<http://eol.jsc.nasa.gov>>).

## ***Human Exploration E/PO***

ARES exploration staff participates in NASA studies related to future human exploration of the Moon and Mars. They are frequent speakers at public and education venues on the topics of planetary sciences and space farming, resource utilization, early outposts, colonization, and space policy. The intrinsic appeal of humans exploring the solar system is strengthened by our work in the technology of living on other worlds and the science that they might do while there.

## ***Planetary Science E/PO***

ARES staff shared science with formal and informal educators as well as with many others in the public sector. Our long-term planetary science and exploration education and public outreach efforts are partnerships with high local and national leverage. Local partnerships involve ARES scientists and educators working with universities, school districts, museums, and the Lunar and Planetary Institute (LPI) to share the content and excitement of space science research. Through a NASA Minority University Initiative grant to the University of Houston-Downtown, ARES co-investigator staff trained student ambassadors, as well as Houston and Brownsville teachers in space science activities. Our strong partnership with LPI included a variety of solar system educator workshops at Texas science teacher conferences and Harris County Education Services. We also teamed with LPI to provide space science events at LPI and Girl Scouts of San Jacinto venues.

National programs are an important vehicle for our education and public outreach efforts. The Astromaterials Acquisition and Curation Office loaned lunar rock thin sections to universities around the country and shipped hundreds of Mars soil simulant samples to museums and educators. The ARES education team is involved in several national efforts to reach informal audiences in community based groups. As partners with the Science Mission Directorate (SMD), Solar System Exploration Forum, ARES organized and hosted a NASA Explorer Institute, Jan. 2006, involving staff and Girl Scouts representing seven NASA centers. A Memorandum of Understanding between NASA and Girl Scouts of the USA is a recent culmination of efforts of our partnership with SMD Solar System Education Forum staff and the NASA Informal Education Office. Through the Mars Engagement Program's Imagine Mars project, our team assisted with major program design and curriculum development. ARES education personnel trained Housing and Urban Development staff to engage youth in Mars, Imagine Mars, and solar system activities. A highlight of the formal education program was an educator event hosted at JSC for over sixty Stardust educators.

The team of ARES staff and key local educators worked on three major curriculum projects in Fiscal Year 2006.

1) Mars Soil Sleuths – testing and revising activities for elementary classrooms
   These activities will be used with Mars Phoenix Mission Education.
2) Imagine Mars – activities development with Mars Public Engagement Program The Imagine Mars program is a major focus of Mars education.
3) Robotic Exploration for the 21st Century – product research and development for informal settings funded by NASA Exploration Systems Mission Directorate.

NASA Education Program projects included:

1) NASA Explorer Institute -*Lunar Education for Museums*
   Role-presenter and facilitator
2) NASA Explorer Institute-- *Growing the NASA-GSUSA Relationship Through Professional Development*
   Role-development team, host team, facilitators
2) NASA Explorer Schools – educator workshops
   Role-workshop design and presentation

Science education for formal educators and classrooms is important to our team. We presented twenty-five educator trainings or presentations at national, regional, and local educator or science events. All of these workshops focused on Solar System Exploration including ARES research, Mars, and moon. Our curriculum products and the primary resources used for training are posted on the ARES Education website. Two major formal education projects for the Mars Engagement Program included a week of classroom visits in Brevard County, Florida and two events in North Carolina and Texas for thousands of students.

FY06 funding for ARES planetary science education team came from NASA Science Mission Directorate SMD, Mars Public Engagement Program, and the Exploration Systems Mission Directorate (ESMD).

Mars Soil Sleuths
http://ares.jsc.nasa.gov/Education/index.cfm
Exploring Meteorite Mysteries
http://ares.jsc.nasa.gov/Education/Activities/ExpMetMys/ExpmetMys.htm
Exploring the Moon
http://ares.jsc.nasa.gov/Education/activities/ExpMoon/ExpMoon.htm
Fingerprints of Life?
http://ares.jsc.nasa.gov/Education/websites/astrobiologyeducation/index.html
Space Rocks Tell Their Secrets-the slide show only
http://ares.jsc.nasa.gov/Education/spacerocks.htm
Destination: Mars!
http://ares.jsc.nasa.gov/Education/activities/destmars/destmars.htm
Modeling the Solar System
http://ares.jsc.nasa.gov/Education/modelingsolarsystem.pdf

***Publications List 2005 – 2006***
**(ARES staff in bold)**

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## ARES Resources

### *Personnel*

Personnel within ARES are our most valuable resource including civil servants, support contractors, and post-doctoral fellows. In addition we host numerous visiting scientists, interns, and students that collaborate with our scientific staff and use our research facilities. The civil service staff has the responsibility for scientific and technical leadership, direction, and strategic vision. To this end, the staff is overwhelmingly technical and highly educated (see figure 1) with a small administrative support staff to address the numerous requirements of a federal facility. The technical and research staff continues to perform exciting research and exceptional analyses due to the initiative, enthusiasm, and ability of the staff to not simply have good ideas, but bring those ideas to fruition.

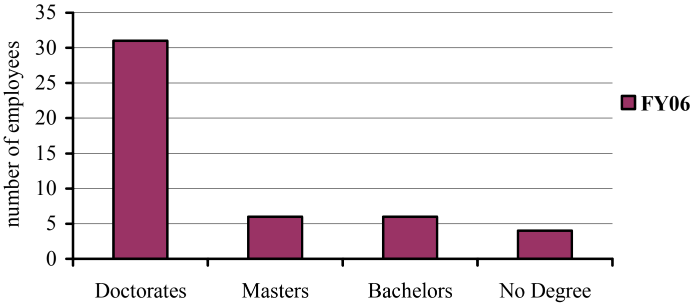

Figure 1: Education level of ARES Civil Servants

As with many organizations, ARES is concerned with maintaining a vibrant organization with a mature workforce. We have attempted to temper our aging workforce with strategic addition of early- and mid-career scientists as hiring opportunities occurred, but continue to have an average workforce age of 53 (see figure 2) with average federal service time of almost 20 years. This has resulted in 25% of the workforce as eligible for retirement with another 25% eligible for retirement within 5 years. The advent of a full-cost financial management philosophy within NASA has resulted in additional challenges in hiring scientific staff.

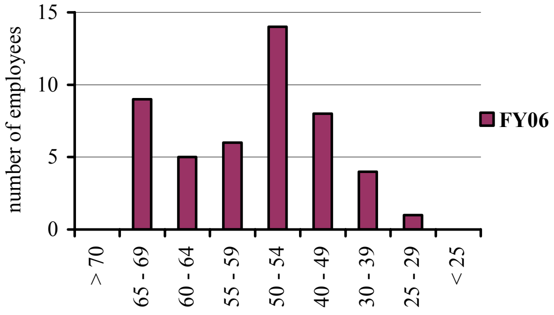

Figure 2: Age Distribution of ARES Civil Servants

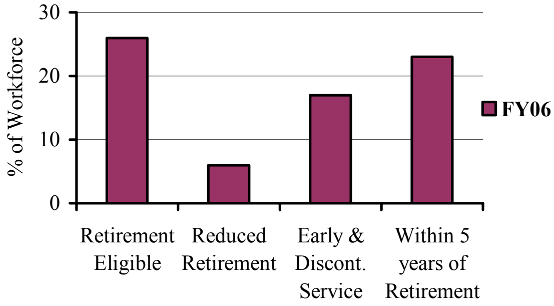

Figure 3: Retirement Eligibility

### *Finances*

ARES receives funding from many different programs and is managed by "Business Units" or functional disciplines (see figure 4). Activities in support of the Shuttle, International Space Station, and Constellation programs are defined and performed according to Internal Task Agreements and primarily comprise the Image Science and Analysis, Hypervelocity Impact Technology and Risk Assessment, and Exploration business units. Orbital Debris activities are performed on behalf of the agency according to an agreement with NASA HQ Office of Safety and Mission Assurance (OSMA). Support to Science Mission Directorate activities comes from successful peer-reviewed proposals whether for individual research initiatives or flight mission participation. Sample Mission support for FY06 primarily concerned the recovery and preliminary examination support to the Stardust Mission. Genesis mission support is now included within the general Astromaterials Curation business unit. Our support to the Mars missions is managed through the Mission Support business unit and includes not only the current Mars Exploration Rover activities, but also our support to future missions like the Phoenix Scout, Mars Reconnaissance Orbiter, and Mars Science Laboratory missions. The Management business unit provides for the basic Infrastructure required to run ARES including such items as the cost of information technology (network, email, and telephone backbone), facility maintenance, basic equipment repair and obsolescence, overhead, small institutionally selected development projects, and salary subsidies for administrative and under-funded personnel.

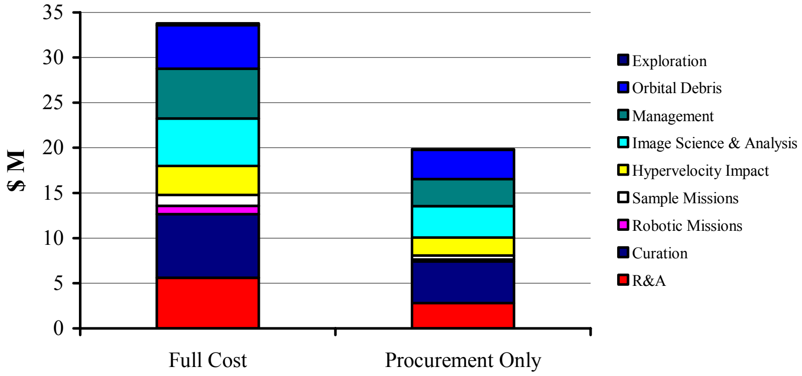

Figure 4: Overall Finances by Business Unit

Figure 4 shows both the full cost income for ARES as well as procurement only income. The full cost values include center-level overhead charges and civil service salaries for project personnel. In this era of full cost accounting within the government, a number of financial challenges face the management of researchers dependent upon successful selection of peer-reviewed proposals. In addition, the overall Planetary Science R&A budget cut of 15% resulted in several programs that staff scientists had proposed to were either cancelled without funding or selections postponed to next fiscal year.

### *Facilities*

Significant effort has been expended in the past few years in upgrading our facilities. The building which houses most of our research facilities is over 30 years old and has undergone minimal preventive maintenance for the previous decade. Significant issues with the electrical and plumbing infrastructure called for a systematic effort of modernization. The electrical system within the building has been thoroughly investigated and updated to meet current electrical code. We are just beginning an effort to review the building plumbing system with special attention to possible leaks affecting our delicate major instruments. Additional basic infrastructure obsolescence actions included the installation of a new liquid nitrogen tank and associated gas plumbing (see figure 5), connecting the HVAC systems to the center-wide operations control, renovating the basic wet chemistry laboratory, and replacing the antiquated CO monitoring system in the experimental petrology laboratory.

Figure 4: Liquid Nitrogen Tank and Delivery System

A major effort to expand the Image Science and Analysis Laboratory began after the Columbia mishap resulting in the tools necessary to perform our expanded role in Shuttle imagery analysis and damage inspections.

Figure 6: Image Science and Analysis Laboratory

In preparation for the return of the Stardust Mission in January 2006, a processing and curation laboratory was completed (see figure 7). The operation of the new NanoSIMS and STEM in time for Stardust sample analysis was a highlight for the staff (see figure 8). Figure 9 shows the renovated Multi-Anvil and High Pressure laboratory.

Figure 7: Stardust Curation Facility

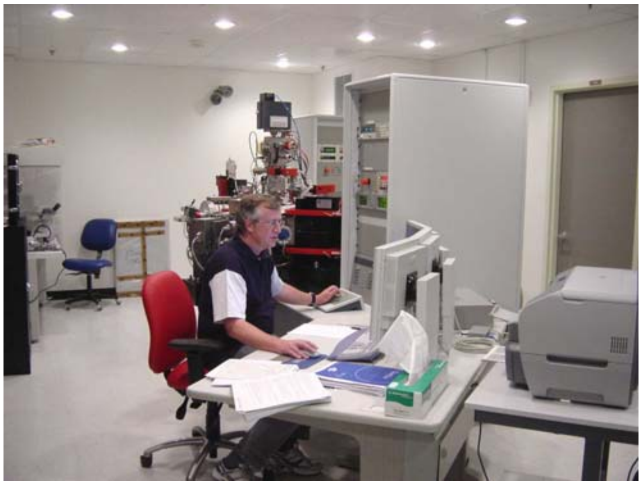

Figure 8: NanoSIMS Lab

Figure 9: Multi-Anvil and High Pressure Laboratory

We intend to continue the current obsolescence planning and facility renovations on a regular schedule to maintain the strong analytical capability that keeps our research efforts successful.

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# *ARES Award Recipients 2005-2006*

## *NASA Honor Awards*

### ***Exceptional Achievement***

KT/Karen McNamara
KX/Kamlesh Lulla

### ***Group Achievement Award***

KX/Wendell Mendell (Exploration Systems Architecture Study – 2006)

### ***NASA Space Act Award***

Gregory Byrne
Eric Christiansen

### ***Space Flight Awareness Award***

Gregory Byrne
Dan Smith

### ***NASA Software Awards***

Eric Christiansen – BUMPER Micrometeoriod Orbital Debris Risk Assessment

## *NASA Johnson Space Center Honor Awards*

### ***Superior Accomplishment Award***

Kamlesh Lulla – Biennial Research and Technology Report

### ***Going the Extra Mile (GEM) Award***

Mary Drake
Suzanne Summers
Lisa Vidonic
Joni Homol

### ***Special Act or Service Award (Individual)***

Gregory Byrne (Return to Flight)
Eric Christiansen (Return to Flight
Cindy Evans (Return to Flight)
Kamlesh Lulla
Susan Runco (Return to Flight)

**_Source Evaluation Board (SEB) Award_**
Mario Runco

## *Engineering and Services Contract (ESC) Awards*

**_ESC Best Technical Paper Award (1st Place)_**
J.C. Liou/ERC

**_Individual Outstanding Performance_**
James Holder/Jacobs
Thomas See/Barrios
Jack Warren/Jacobs
Keiko Messenger/Jacobs
Kira Abercromby/JS
Kevin Beaulieu/Barrios
Justin Wilkinson/JS
Michale Snyder/ERC
Chris Cloudt/HS
Donn Liddle/MEI
Robert Scharf/ERC
David Bretz/Barrios
Jon Disler/JS
John Michale Rollins/JS

**_NASA Award_**

**_Test and Development /Wing leading Edge Impact Detection System Award_**
Jim Hyde/Barrios
Frankel Lyons/Hamilton
Freeman Bertrand/Jacobs

**_Public Service Medal_**
Justin Wilkinson/JS

**_NASA Silver Snoopy_**
Frankel Lyons/Hamilton
Eric Nielsen/ERC

**_NASA Space Flight Awareness_**
Robert Scharf/ERC (STS-115)
Eric Nielsen/ERC (STS-121)
Freeman Bertrand/Jacobs (STS-121)

***NASA Exceptional Engineering Achievement Medal***
Dr. Claude Bryant/Barrios
***NASA Exceptional Software of the Year***
Dana Lear/ERC
Jim Hyde/Barrios
Tom Prior/Hamilton

***Outstanding Group Achievement***
Paula Krisko/Jacobs
David Whitlock/Hamilton
Matt Horstman/ERC
John Opiela/Jacobs
Chris Stokely/Barrios
Quanette Juarez/Jacobs

***Outstanding Superior Performance Award***
Daniel Garrison/Barrios

***President's Award***
Frankel Lyons/Hamilton
Daniel Garrison/Barrios

***Senior Engineering Assistant of the Quarter***
Ron Bastien/Jacobs

***STS 114 Retun to Flight Digital ET TPS Camera Projects for launch Window & ET Lighting Assessment Team***
Jon Disler/JS
Chris Cloudt/HS

***STS 121 Crew Group Achievement Award***
John Michael Rollins/JS
Dan Smith/LZ Technologies
David Bretz/Barrios