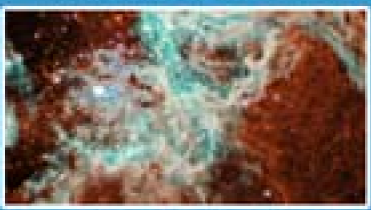
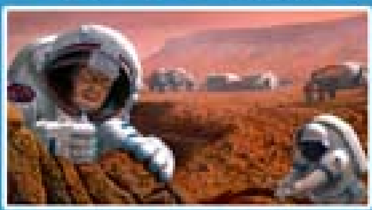
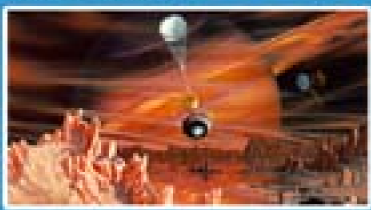
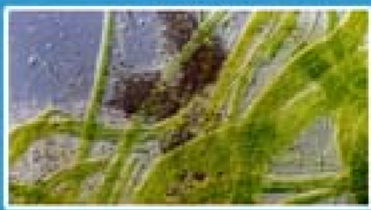
Space Science Division

2001 Annual Report

GRAPHICS AND PRODUCTION:

James Schilling
ManTech International Corporation

COVER ART: (Artwork: James Schilling)
A collage of images representing the Space Science Division's search for life in, and the understanding of, the universe.

Images:

-Background: Horsehead Nebula (NASA)

Left to right:

-The 30 Doradus Nebula (NASA, Space Telescope Science Institute, La Plata Observatory)
-Artist rendition of human exobiologist and geologist on Mars (NASA / Pat Rawlings)
-Artist conception of Huygens Saturn Probe Titan delivered by Cassini (Craig Attebery, JPL)
-Cyanobacteria (L. Prufert Bebout)

Space Science Division

2001 Annual Report

National Aeronautics and
Space Administration

Ames Research Center
Moffett Field, CA 94035-1000

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Space Science Division (SS) Overview

The Space Science Division at NASA's Ames Research Center conducts research and mission-related activities that are structured around the study of the origins and evolution of stars, planetary systems, and life, and that address some of the most fundamental questions pursued by science, questions that examine the origin of life and our place in the universe, and questions that lie at the heart of the emerging discipline of Astrobiology.

Ames is recognized as a world leader in Astrobiology, defined as the study of life in the universe and the chemical and physical forces and adaptations that influence life's origin, evolution, and destiny. In pursuing this primary Center mission in Astrobiology, scientists in the Space Science Division perform pioneering basic research and technology development to advance fundamental knowledge about the origin, evolution, and distribution of life within the context of cosmic processes. To accomplish this objective the Division has assembled a multidisciplinary team of scientists including astronomers, astrophysicists, chemists, microbiologists, physicists, and planetary scientists. This objective also requires access to the space environment, since many of the critical data needed to elucidate the evolutionary steps outlined above are only available in space in star-forming regions, in the interstellar medium, and in and around planetary environments.

Major elements of the Space Science Division's program include the study of the interstellar gas and dust that form the raw material for stars, planets, and life; the processes of star and planet formation; the evolution of planets and their atmospheres; the origin of life and its early evolution on the Earth; the search for past or present life throughout the solar system with emphasis on Mars; and advanced technologies for robotic and human exploration of space.

Space Science Division personnel participate in a variety of major NASA space missions. Division scientists are / were Investigators, Team Members, or Interdisciplinary Scientists on Pioneer, Voyager, Viking, Galileo, the Kuiper Airborne Observatory, Mars Pathfinder, the Infrared Space Observatory, the Cassini mission to Saturn, Stardust, Mars Global Surveyor, and Kepler. Division scientists are also involved in the development of experiments for International Space Station, the Stratospheric Observatory for Infrared Astronomy (SOFIA), Astrobiology Explorer, several Mars Scout missions, the Space Infrared Telescope Facility (SIRTF), and Next Generation Space Telescope (NGST).

The programs in the Space Science Division are international in scope, ranging from active participation in international scientific meetings and societies, to collaborative ground-based research projects, to scientific investigations on international flight missions and projects.

Extensive ties are maintained with the academic community through collaborative research programs and development of science curricula materials, and additionally, students at all levels represent a significant component of the Division's on-site research work force.

The Space Science Division represents a unique resource for NASA's Astrobiology thrust and for the Agency's current and future manned and unmanned missions. The total science and mission capability of the Space Science Division described here is unmatched by any other NASA Center or national laboratory.

The Division is organizationally divided into four Branches named according to the focus areas of the research conducted by the scientists in those Branches: Astrophysics, Astrobiology Technology, Exobiology, and Planetary Systems (see Figure 1).

In 2001, the Division employed approximately 75 civil service personnel, about 45 of whom are Ph.D. scientists. This core permanent staff is augmented with approximately 125 non-civil servant scientists and technical support personnel who are resident in Division facilities through mechanisms such as grants, cooperative agreements, support contracts, fellowships, visiting scientist positions, and student internships.

It is common for visiting scientists to spend their summer research or sabbatical time in the Division's laboratories and facilities. Extensive ties are maintained with the academic community through collaborative research programs and also through the development of science curricula materials. The Space Science Division is dedicated to fostering greater interest in careers in the sciences and provides unique opportunities for training the next generation of scientists. Students at all levels – high school, undergraduate, graduate, and post-doctoral – represent a significant component of the Division's on-site research work force. In 2001, approximately 20 National Research Council Postdoctoral Fellows and 10 undergraduate students were resident in the Division. Division personnel also mentored students in the Astrobiology Academy, a competitive program for college undergraduates to participate in hands-on research projects here at Ames Research Center.

In the following section of the Annual Report, the research programs of each Branch are summarized. Within each area, several examples of 2001 research topics have been selected (from a total of approximately 130 tasks) for more detailed description. Following that section is a list of publications authored by Division personnel with 2001 publication dates. Finally, if a particular project is of interest, the organization chart on page 8 and the personnel roster that begins on page 79 are reasonably current and may be used to contact individual scientists. ❑

Donald L. DeVincenzi
Chief, Space Science Division
http://www-space.arc.nasa.gov
October 2002

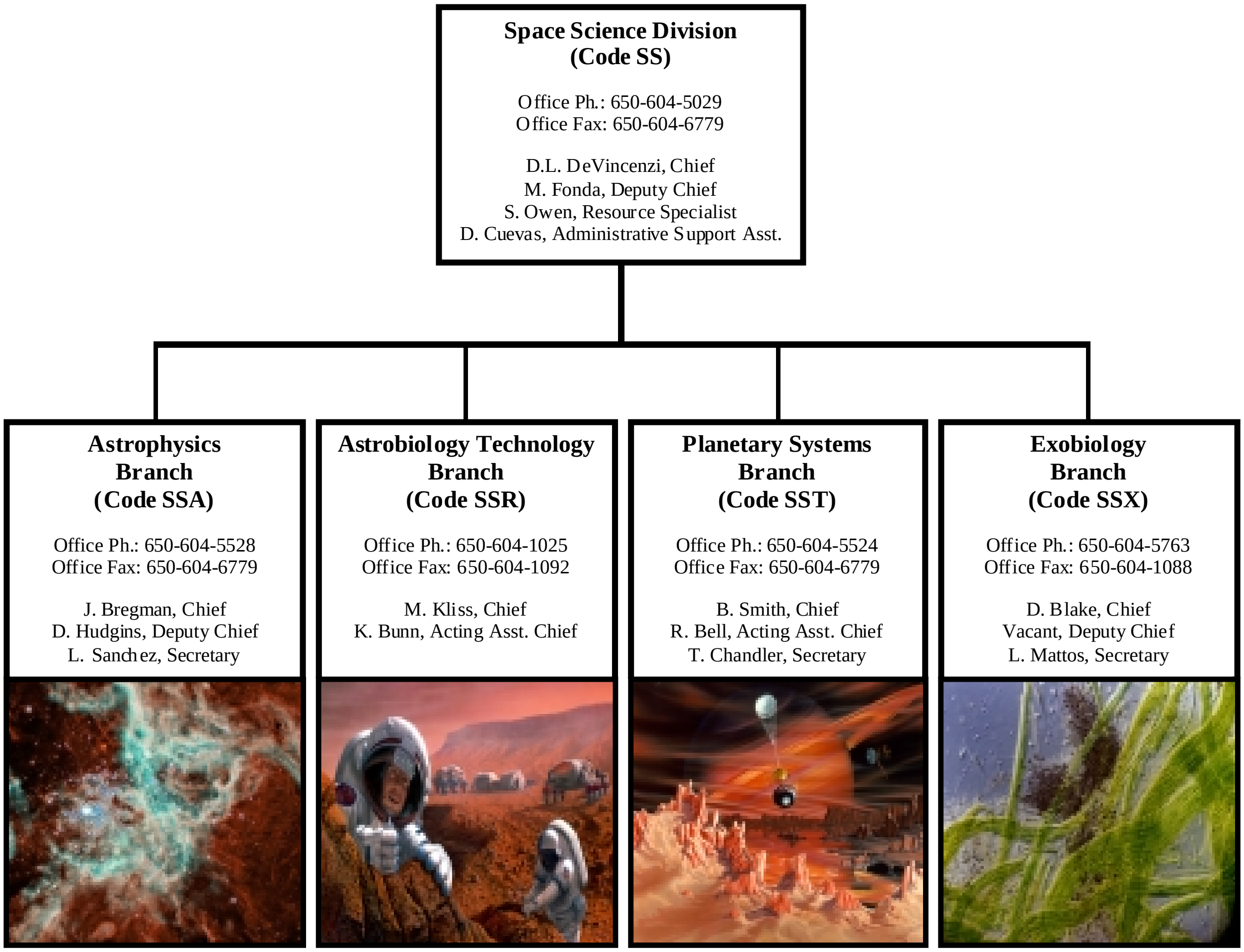
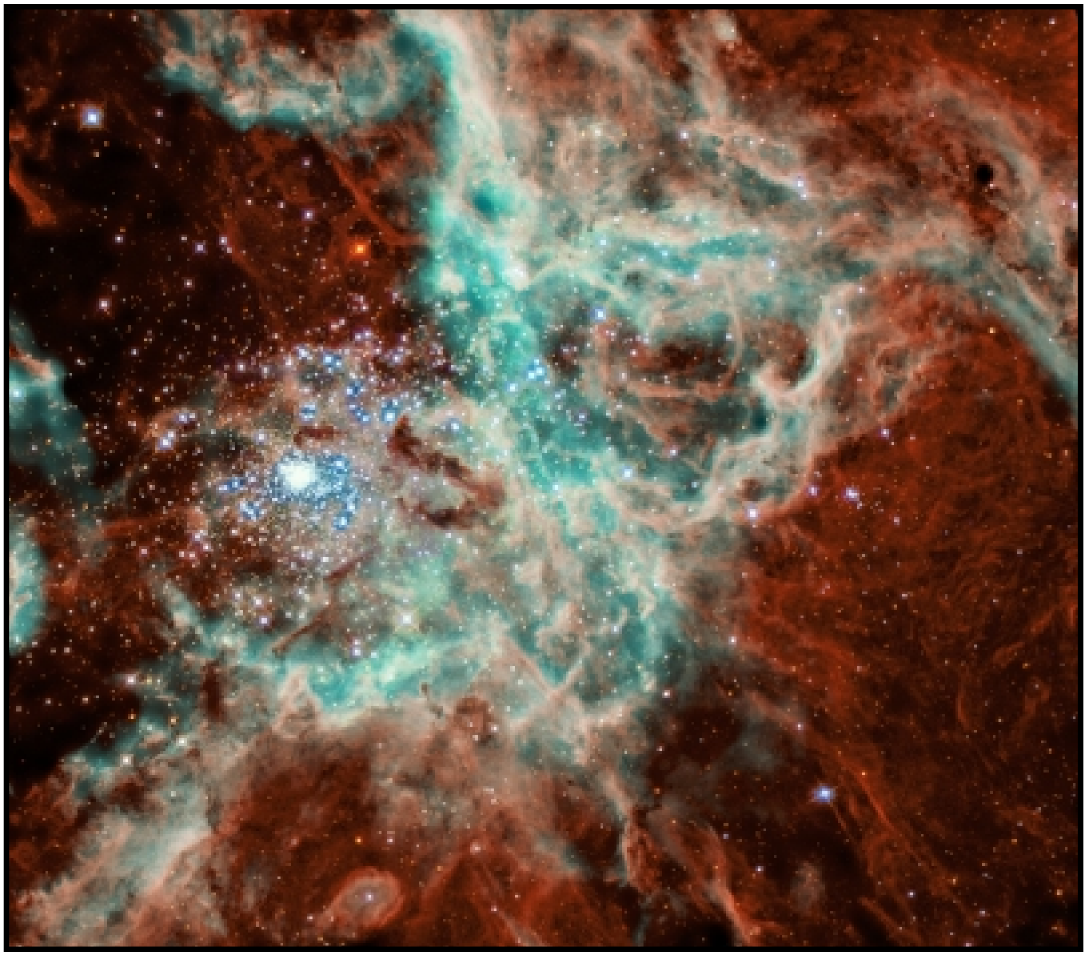


Figure 1: Space Science Division Organization Chart



The 30 Doradus Nebula.
Credit: NASA, N. Walborn and J. Ma'iz-Apell'aniz (Space Telescope Science Institute), R. Barb'a (La Plata Observatory, La Plata, Argentina)

Astrophysics Branch (SSA) Overview

Scientists in the Astrophysics Branch pursue a wide range of laboratory and observational astronomy research. The Branch is particularly interested in studying the physical and chemical properties of astronomical phenomena by observing their radiation at infrared (and ultraviolet) wavelengths, beyond the range of visible light.

Planets, stars, and the interstellar medium of the Milky Way and other galaxies are rich in infrared spectral features which provide clues to their origins, physics, chemistry, and evolution. SSA researchers use state-of-the-art laboratories, ground-based, airborne, and space-based observatories to conduct their research. Astrophysics Branch scientists, engineers, and technicians also play key roles in developing new NASA space and airborne missions and instruments such as SIRTF, NGST, and SOFIA. The primary products of the Astrophysics Branch are new observations and interpretations of the universe and new instrumentation developed to make these observations.

Jesse Bregman
Chief, Astrophysics Branch (SSA)

ORGANIC SOLIDS COLOR THE ICY BODIES IN THE OUTER SOLAR SYSTEM

Dale P. Cruikshank and Bishun N. Khare

Many of the objects in the outer parts of the Solar System (at Jupiter and beyond) have surfaces (and interiors) composed largely of ordinary water ice, which can be readily identified by remote sensing observations. These bodies include the large satellites of the giant planets, Jupiter through Neptune, the rings of Saturn, the comets, Pluto-Charon, and the objects that populate the Kuiper disk and the Oort cloud. None of these bodies can be sampled directly at the present time, and we rely upon remote sensing to learn about their compositions and history of formation. The techniques of near-infrared spectroscopy, accomplished with large telescopes or by planetary probes, reveal the presence of water ice by showing characteristic absorption bands in the spectral region 1-5 micrometers.

While pure water ice is highly reflective of the sunlight incident on Solar System bodies, and is neutral in color, all of the ice-rich objects have distinct color, and many are nearly black. The coloration of the ice in the short wavelength region, 0.2-1.0 micrometers, has been especially difficult to model quantitatively, because minerals, a logical and naturally occurring contaminating material, do not have the appropriate optical properties.

We have succeeded in modeling the observed color in icy planetary satellites using mixtures of ice and complex organic materials. The organic material is synthesized in the laboratory in experiments that approximate the conditions of formation of similar material in various environments in space, usually by irradiating a mixture of simple gases (methane and nitrogen) or ices (water plus methanol, carbon dioxide, etc.) with ultraviolet light and charged particles from a plasma. The resulting brown-colored substance is termed “tholin”, and is structurally similar to some of the carbon-rich material found in carbonaceous meteorites. It is also similar in its optical properties to the organic-rich aerosol haze in the atmosphere of Saturn’s satellite Titan.

Specifically, we have successfully modeled the spectra of Saturn’s icy satellites Rhea and Iapetus, as well as Uranus’ satellite Titania and the moon of Neptune called Triton, by incorporating small amounts (<1 %) of various organic solid materials in the surface ices. All of these objects are key to understanding the origin of their respective satellite systems, the nature and timescale of geological activity on them, and the space environments in which they have evolved. The occurrence of complex organic materials in the surface ices of these bodies, spread throughout the planetary system, tells us that the products of prebiotic organic chemical processes occur in diverse environments far beyond Earth, and have existed from the beginnings of the Solar System to the present. ❑

FIGURE 2: Tholin, this orange-brown material produced by exposing a mixture of nitrogen and methane gases to ultraviolet light and charged particles from a plasma discharge, has optical properties similar to those of Saturn's satellite, Rhea. Modeling studies of the spectra of Rhea and other icy bodies in the outer Solar System suggest that tiny quantities of complex organic material of this kind occur as a contaminant on their surfaces. That organic matter may arise from meteoric infall of interplanetary dust, or it may be produced in situ *in the ice, by the influence of energetic particles in the space environment.*

A CRYOGENIC MULTIPLEXER FOR FAR-INFRARED ASTRONOMY

Jessie Dotson, Edwin Erickson, and Christopher Mason

The instruments for a new generation of large far-infrared telescopes, such as SOFIA, the Stratospheric Observatory for Infrared Astronomy, will require detector arrays with small enough pixels (picture elements) to exploit the improved angular resolution and a sufficient number of pixels to take advantage of the large fields of view. In order to make the step to arrays with more pixels, it is essential to develop suitable multiplexing amplifiers, or multiplexers. With this need in mind, we collaborated with personnel from University of Arizona and Raytheon Infrared Center for Excellence to develop the SBRC 190, a cryogenic multiplexer for far-infrared (FIR) photoconductor detectors operating at moderate backgrounds.

The circuit is based on the 32-channel CRC 696 CMOS device used on SIRTF, the cryogenic Space Infrared Telescope Facility. For applications such as those encountered on SOFIA or Herschel (the far infrared and submillimeter space observatory), the new device permits higher backgrounds, a wider range of backgrounds, faster sampling, and synchronization of sampling with chopping. Major design differences relative to the CRC 696 which have been incorporated in the SBRC 190 are: (a) an AC coupled, capacitive feedback transimpedence unit cell, to minimize input offset effects, thereby enabling low detector biases, (b) selectable feedback capacitors to enable operation over a wide range of backgrounds, and (c) clamp and sample & hold output circuits to improve sampling efficiency, which is a concern at the high readout rates required.

We have developed an end to end system suitable for testing the multiplexers in conditions similar to their eventual applications. This includes a photoconductor detector array, test dewar, driving electronics and the required software. The photoconductor array is composed of 2 rows of 24 Ge:Sb detectors mounted in integrating cavities. Incoming radiation is coupled to the cavities by light collecting cones. The liquid helium test dewar has room for the necessary optics and can achieve a range of operating temperatures from 2.0K to 4.2K. The driving electronics provides the bias voltages and clock signals required to drive the multiplexers. The electronics also contain 16 analog to digital converters to process the signals coming out of the multiplexers. We have developed software to control the driving electronics, receive the results and write them into a FITS (flexible image transport system) file. We have also developed software to analyze the obtained data.

Testing is currently underway. Initial results imply that the multiplexers are suitable for use in far-infrared instruments, but additional tests are necessary to fully examine their operation at faster rates and with novel read out strategies. ❑

SCIENTIFIC REQUIREMENTS OF THE NGST MID-IR INSTRUMENT

Thomas Greene

The Next Generation Space Telescope (NGST) will be the successor of the Hubble Space Telescope and is scheduled for launch in the year 2008. NGST will make unprecedented discoveries in the realms of galaxy formation, cosmology, stellar populations, star formation, and planetary systems. NGST is currently in the conceptual design phase of development, and Ames has been involved in defining and the scientific instrumentation it will need to conduct its observations. NGST will have 3 instruments: a near-IR camera (NIRCAM), and near-IR spectrometer (NIRSPEC), and a mid-IR instrument (MIRI).

MIRI will be the only NGST instrument built in a joint NASA – ESA (European Space Agency) collaboration. It must function as both a wide-field camera and a moderately-high resolution spectrograph over the wavelength range 5 – 28 microns (about 10 – 40 times longer than visible to the human eye). Ames personnel have contributed to planning its scientific observations, developing its infrared detectors, and determining its scientific requirements.

The Mid-IR Steering Committee (MISC) was constituted in the year 2001 to determine MIRI's detailed scientific requirements and oversee its conceptual design. This was an international scientific committee which included Ames representation. The MISC evaluated the MIRI scientific objectives and studied the instrument concept presented by the consortium of ESA states which will participate in MIRI development (the UK, France, Germany, Italy, and the Netherlands). The scientific objectives were translated into requirements for the instrument which were consistent with the MIRI instrument concept.

MIRI will consist of three optical subsystems, all employing reflective optics. A common set of fore optics will relay images from the NGST telescope focal plane to the MIRI camera and spectrograph subsystems. The fore optics will also provide a common focus mechanism, while the camera and spectrograph subsystems each have their own dedicated mirrors, field masks, filters, and detectors. The camera module images a field of 1.7 arc-minutes by 1.7 arc-minutes onto a 1024 x 1024 pixel detector. It includes a selection of filters and a coronagraphic mask which will allow suppressing the light of bright objects so that fainter ones close to them may be seen. This device will be used for searching for planets around nearby stars.

The spectrograph channel will take the light from every point in a small field (4 arc-seconds by 4 arc-seconds) and disperse it into a spectrum. The first element is an integral field unit which relays and realigns the small field into an image onto slits which are followed by optics and diffraction gratings which disperse the light. A multi-element camera then images the resultant spectra onto a dedicated infrared detector that is at least 1024 x 1024 pixels in size (preferably larger).

The MIRI subsystems will be built by ESA contractors and will be delivered to NASA once they are integrated and tested. The Jet Propulsion Laboratory will integrate this assembly with US infrared detectors and will test the entire instrument before delivering it to Goddard Space Flight Center for integration with the other NGST instruments. A new international mid-IR Science Team will provide scientific oversight for these activities. ❑

AN INTERSTELLAR ROSETTA STONE: A DATABASE OF THE INFRARED SPECTRA OF POLYCYCLIC AROMATIC HYDROCARBONS (PAHS)

Douglas M. Hudgins and Louis J. Allamandola

In recent years, a host of observations at infrared wavelengths has revealed the unmistakable fingerprint of polycyclic aromatic hydrocarbons (PAHs) in the spectra of objects at all stages of the lifecycle of matter in the interstellar medium (ISM). Moreover, analyses of meteorites and interplanetary dust particles have demonstrated that PAHs are also commonplace within our own solar system. Enormous molecules by interstellar standards, PAHs are composed of varying arrays of fused hexagonal rings of carbon atoms. Not only do these species hold tremendous potential as probes of the ISM, they also represent the single largest reservoir of prebiotic organic carbon in developing planetary systems.

Unfortunately, only rarely do scientists have the luxury of directly analyzing samples of extraterrestrial materials. Instead, they must rely heavily on spectroscopic data from remote sensing platforms such as NASA's Infrared Telescope Facility (IRTF), and the upcoming SOFIA (Stratospheric Observatory For Infrared Astronomy) and SIRTF (Space InfraRed Telescope Facility) missions for clues to the nature of these materials. The complete interpretation of these data, in turn, requires a thorough knowledge of the spectroscopic properties of PAHs — information obtainable only through appropriate laboratory studies. Toward this end, researchers in the Astrochemistry Laboratory at NASA Ames Research Center have been actively engaged in a systematic study of the infrared spectroscopic properties of PAHs under conditions that mimic those of interstellar space. The long-range goal of this work has been to compile a comprehensive infrared spectral database and to apply that data to model the observed interstellar spectra.

The diverse physical and chemical conditions in different astronomical objects give rise to variations in the native PAH population. These variations are reflected by (often subtle) differences in the observed infrared spectrum of the objects. By carefully modeling interstellar spectra using the spectra of a wide variety of PAHs representing a broad cross-section of sizes, structures and stabilities, scientists can determine which PAH structures are favored in a particular region. The power of this process is illustrated in Figure 3 below, which shows a comparison of the infrared spectrum of a star-forming region to a model spectrum generated by co-adding the spectra of species drawn from the database. In such a region, the interstellar material is bathed in the harsh, ionizing radiation of the adjacent hot young O- and B-type stars. The composition of the mixture that provides the best fit to the Orion spectrum is quite revealing about the nature of the PAH population there. 63% of the PAHs in the model mixture have highly stable, "condensed" structures — that is, the most compact arrangement of the hexagonal rings. Also, 70% of the model mixture is contributed by PAHs in their ionized forms. The PAH population reflected in the model spectrum is entirely consistent with what one would expect given the nature of this object. The molecules found in this region are those which have survived the fierce radiation from the nearby hot stars. Lesser stable components of the population have long since been 'weeded out', and a substantial fraction of the population has been ionized by the harsh ultraviolet radiation from the nearby cluster of hot stars. Thus, it is entirely reasonable that the model PAH mixture reflects a disproportionately large contribution from the hardiest species and from ionized species.

To date we have measured the infrared spectra of more than 100 neutral, cationic and anionic PAH species ranging in size from $C_{10}H_8$ to $C_{48}H_{20}$, and much of the wide acceptance and utility that the PAH model enjoys today rests upon these data. Amongst the species currently represented in the dataset are: (1) the thermodynamically most stable PAHs through coronene, $C_{24}H_{12}$; (2) species from the fluoranthene family, aromatic hydrocarbons which incorporate a five-membered ring in their carbon skeleton; (3) a variety of large PAHs ("LPAHs") having between 36 and 50 carbon atoms; and (4) a variety of "aza-PAHs", polycyclic aromatic compounds with a nitrogen atom incorporated into their carbon skeleton. This is the most extensive compilation of astrophysically relevant spectral data on PAHs available. Most of these spectra are available in the peer-reviewed chemical literature, and we are preparing an extensive review of this work's astrophysical implications for publication in the astronomical literature. Much of the data is also available to the astronomical community on the web at http://www.astrochemistry.org/pahdata/index.html.

Today, scientists around the world are incorporating these data into comprehensive new astrophysical models — models far more sophisticated and physically realistic than the crude illustrative example above. Those models use the measured absorption data to calculate PAH *emission* spectra as a function of such astrophysical parameters as radiation field intensity, charge balance, extinction, and density. Models such as this hold the key to unlocking the potential of PAHs as probes of the interstellar medium, and it is the through the availability of this database that that goal will be realized. ❑

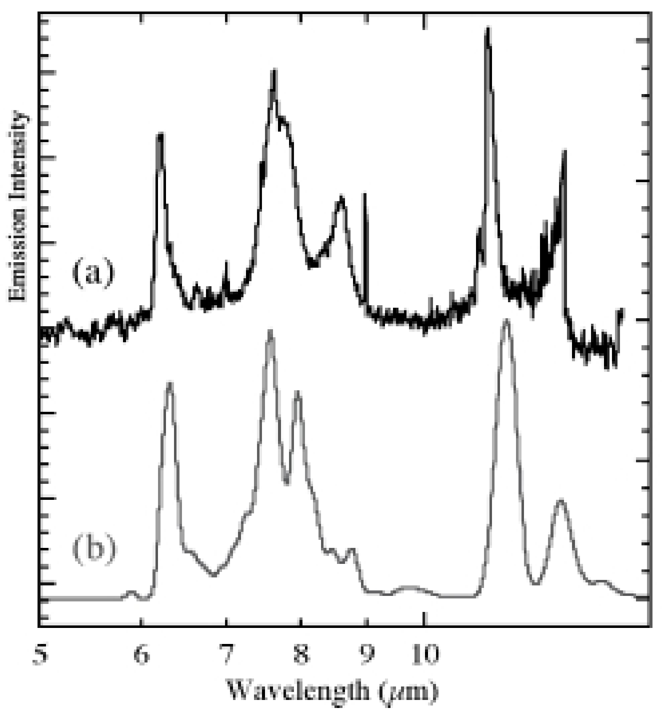


Figure 3: Comparison of a typical ISM infrared emission spectrum with the composite absorption spectrum generated by coadding the individual spectra of 11 PAHs. Figure adapted from Peeters et al., Astron.Astrophys., (2002, in press).

THE SOFIA WATER VAPOR MONITOR NEARS COMPLETION

Thomas L. Roellig, Robert Cooper, Brian Shiroyama, Regina Flores, Lunming Yuen, and Allan Meyer

The Stratospheric Observatory for Infrared Astronomy (SOFIA), a 3-meter class telescope mounted in a Boeing 747 aircraft, is being developed for NASA by a consortium consisting of the University Space Research Association, Raytheon E-Systems, and United Airlines. This new facility will be a replacement for the retired Kuiper Airborne Observatory that used to fly out of Moffett Field. As part of this development, NASA Ames Research Center is providing an instrument that will measure the integrated amount of water vapor seen along the telescope line-of-sight. Since the presence of water vapor strongly affects the astronomical infrared signals detected, such a water vapor monitor (WVM) is critical for proper calibration of the observed emission. The design and engineering model development of the water vapor monitor is now complete and the hardware to be used in the flight unit has been fabricated and is now being tested. Since the SOFIA observatory will be certified under Federal Aeronautics Administration (FAA) Part 25, extensive analysis and testing is needed, much more extensive than was required for earlier Ames airborne observatories that flew under an FAA research aircraft certification.

The SOFIA water vapor monitor measures the water vapor content of the atmosphere integrated along the line-of-sight at a 40° elevation angle by making radiometric measurements of the center and wings of the 183.3 GHz rotational line of water. These measurements are then converted to the integrated water vapor along the telescope line-of-sight. The monitor hardware consists of three physically distinct sub-systems:

1) The Radiometer Head Assembly, which contains an antenna that views the sky, a calibrated reference target, a radio-frequency (RF) switch, a mixer, a local oscillator, and an intermediate-frequency (IF) amplifier. All of these components are mounted together and are attached to the inner surface of the aircraft fuselage, so that the antenna can observe the sky through a microwave-transparent window. The radiometer and antenna were ordered from a commercial vendor and have been rebuilt and modified at Ames to include an internal reference calibrator and to meet FAA Part 25 requirements.

2) The IF Converter Box Assembly, which consist of IF filters, IF power splitters, RF amplifiers, RF power meters, analog amplifiers, A/D converters, and an RS-232 serial interface driver. These electronics are mounted in a cabinet just under the radiometer head and are connected to both the radiometer head and a dedicated WVM computer (CPU). All of the flight electronics boards have been fabricated and have been shown through testing to meet their requirements. A small micro-processor that handles the lowest level data collection and timing has been programmed in assembly language to collect and co-add the radiometer data and communicate with the software residing in the WVM CPU.

3) A dedicated WVM CPU that converts the radiometer measurements to measured microns of precipitable water and communicates with the rest of the SOFIA Mission and Communications Control System (MCCS). A non-flight version of this computer hardware has been procured for laboratory testing and the flight software is finishing its development, with approximately 95% of the software coded and unit-tested. Proper command and data communications between the Water Vapor Monitor and the SOFIA MCCS have been demonstrated using an MCCS simulator that has been developed by the SOFIA development team. ❑

USING DEUTERIUM TO TRACE THE LINKS BETWEEN INTERSTELLAR CHEMISTRY AND THE ORGANICS THAT SEEDED THE EARLY EARTH

Scott A. Sandford, Louis J. Allamandola, Max P. Bernstein, and Jason P. Dworkin

The objective of this research is to investigate the importance of interstellar chemistry in the origin and early evolution of life. The interstellar medium (ISM) mediates gas phase, gas-grain, and solid state chemical processing that produce a variety of new molecules. Since new stellar and planetary systems are produced in dense molecular clouds in the ISM, these molecules may have become incorporated into, and aided in the formation of, the early biosphere on Earth. Many of these organic compounds are relatively complex and of potential prebiotic importance. For example, we have shown that the UV irradiation of ices condensed onto grains in dense molecular clouds should produce quinones, amphiphiles, and amino acids—all compounds crucial for life.

These important compounds are irrelevant to the origin of life if they cannot survive the transition from the general dense cloud through the stellar / planet formation stage to subsequent infall onto a planetary surface. The best evidence that interstellar organics survive this process is the presence of complex organics enriched in deuterium (D) in primitive meteorites. The presence of excess D is generally taken to indicate an interstellar chemical heritage, since it has long been known that interstellar gas phase ion-molecule chemistry produces D-enriched products. In the past year we have examined the various chemical processes which can make or alter organics in the ISM (Figure 4). All of these processes should yield products enriched in D, with each process producing a unique “signature” with regards to the extent and molecular distribution of the excess D.

This work strengthens the interpretation that D enrichments in meteorites indicate the presence of organic species made in the ISM and provides a fundamental framework for the investigation of the nature of the links between interstellar chemistry, the organics in meteorites, and the origin of life on Earth, and by extension, planets in other stellar systems. ❑

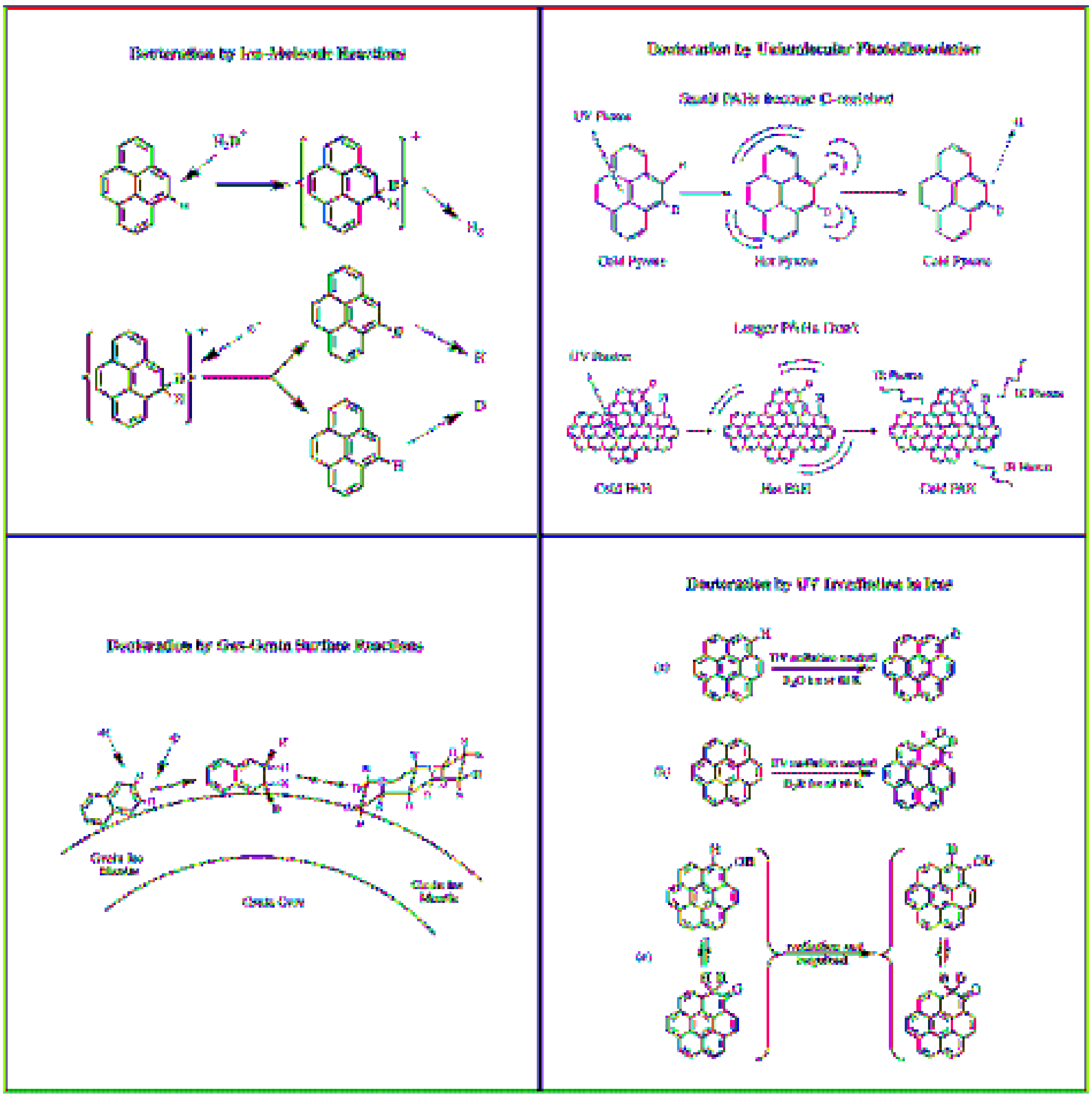


Figure 4: Examples of how interstellar processing by ion-molecule reactions, gas-grain surface reactions, unimolecular photodissociation, and solid state ice irradiation can result in D enrichment of the products. Each process leaves a unique signature in the placement of excess D. Polycyclic aromatic hydrocarbons (PAHs) are used to illustrate each process.

Artist rendition of human exobiologist and geologist on Mars.
Credit: NASA/Pat Rawlings

Astrobiology Technology Branch (SSR) Overview

The Astrobiology Technology Branch supports fundamental research and the development of advanced technologies in astrobiology as they relate to the exploration of space and understanding life in the universe. Current branch efforts encompass research and technology development for advanced life support, utilization of planetary resources, and astrobiology. Advanced Life Support focused research is directed primarily at physicochemical processes for use in regenerative life support systems required for future human missions and includes atmosphere revitalization, water recovery, waste processing/resource recovery, and systems modeling, analysis and controls associated with integrated subsystems operation. In-Situ Resource Utilization (ISRU) technologies will become increasingly important on every Mars lander between 2003 and a human mission to Mars. The branch focus is on the development of technologies for Mars atmosphere acquisition, buffer gas production, and CO_2 compression. Research and technology development for astrobiology includes understanding the physical and chemical limits to which life has adapted on Earth, the molecular adaptations that have allowed living systems to inhabit extreme environments, and the application of this knowledge to biotechnology, nanotechnology, and planetary protection. Researchers in the branch also develop flight experiments and associated hardware for shuttle, ISS, and unmanned NASA missions.

Mark H. Kliss

Chief, Astrobiology Technology Branch (SSR)

ATMOSPHERIC RESOURCES FOR EXPLORATION OF MARS

John Finn, Dave Affleck, and Lila Mulloth

The atmosphere of Mars has many of the ingredients needed to support human exploration missions. It can be "mined" and processed to produce oxygen and buffer gas for breathing (used to dilute oxygen). With lightweight hydrogen transported from Earth, or using water found in local deposits as a hydrogen source, storable methane rocket fuel can also be produced. The use of local materials, called ISRU (for *in situ* resource utilization), is an essential strategy for a long-term human presence on Mars from the standpoints of self-sufficiency, safety, and cost. It is a key cost-reduction element of NASA's Strategic Plan.

The atmosphere of Mars is roughly 95% carbon dioxide, 3% nitrogen, and 2% argon. There are also trace amounts of other gases. Carbon dioxide is the resource for oxygen and also provides the carbon that can be used in methane production. The production of these gases will likely dominate any early Mars manufacturing plant because of the quantity of materials needed to return samples or humans to orbit or to Earth. However, it is important to recognize that buffer gas also represents a considerable launch mass, estimated on the order of two to three tons for a human mission (mainly due to airlock activity). With the proper selection of gas acquisition and processing technology, a more optimal ISRU plant can be designed that will provide all these resources with minimal mass and power consumption.

For example, carbon dioxide must be acquired from the Mars atmosphere, purified, and pressurized in order to be useful in a propellant production plant. Buffer gas is a potential by-product of the purification process. NASA Ames developed a process whereby the small amount of nitrogen and argon present in the atmosphere are efficiently separated from the carbon dioxide during an adsorption compression process (see Figure 5). Carbon dioxide adsorbs in the first bed, while nitrogen and argon pass through and are collected in a separate adsorption bed. When the first bed is heated, carbon dioxide is driven off at elevated pressure. Similarly, the nitrogen and argon are driven off at pressure when the second bed is heated. Such temperature-swing adsorption compression and separation processes are highly efficient and are expected to work well on the cold Martian surface. Being virtually solid-state, they do not suffer the wear and reliability problems associated with operating mechanical pumps in that hostile environment. ❑

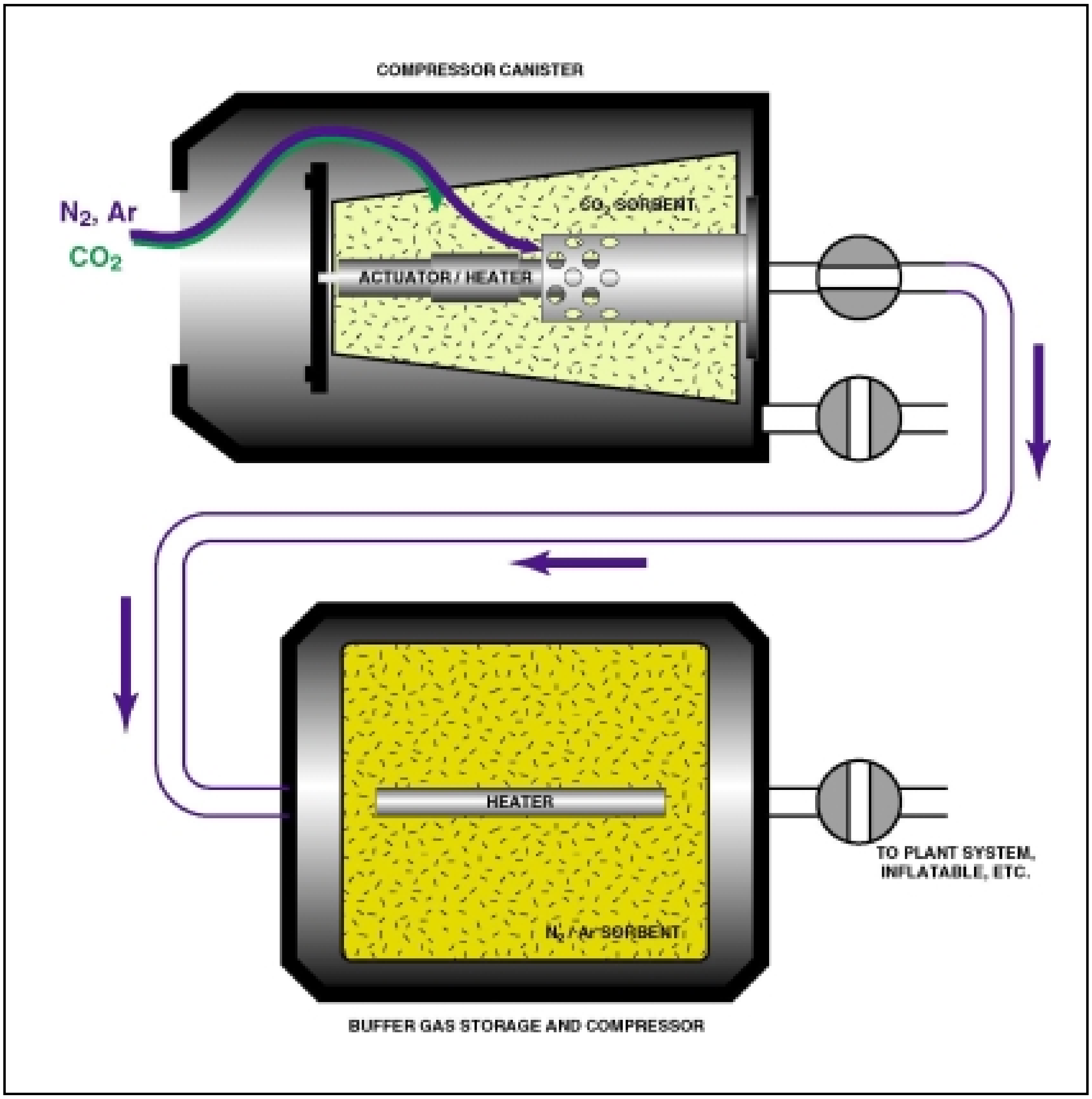


Figure 5: Flow diagram of an adsorption-based CO_2 compression and N_2-Ar separation device for the Mars atmosphere.

CLEAN INCINERATION FOR SPACE MISSIONS

John W. Fisher and Suresh Pisharody

One of the research objectives at NASA Ames Research Center is the development of solid waste processing technologies for long duration exploration missions. A major part of this research effort entails the recovery of resources from life support wastes, such as the recovery of carbon dioxide and water from waste biomass via incineration. Carbon dioxide and water can be used as part of a regenerative life support system to grow plants for food. One of the central problems associated with incineration is the production of undesirable or toxic byproducts of combustion. Ames has developed an incineration flue gas cleanup system that allows use of the carbon dioxide in a plant growth system and that allows release of the remainder of the clean flue gas back to the crew cabin.

As space missions increase in duration, there will be an increased need to transition from life support systems using stored life support materials to life support systems using recycled life support materials. For instance, for short duration missions food can be stored, however, for missions lasting several years, food will need to be provided from a number of possible sources. One viable source is a plant growth chamber. Growing food in space will require recycling waste materials for the raw materials necessary for plant growth: carbon dioxide, water, and nutrients. Incineration offers a method of converting waste materials such as inedible biomass (the part of a plant that can not be eaten) back into carbon dioxide, water, and nutrients (ash).

The process of combustion of biomass in an incinerator operates in a way similar to the combustion of wood in a fireplace – the biomass is almost completely oxidized to gaseous carbon dioxide and water vapor, and only a small residue of inorganic substances (ash) is left. Even in the best of combustors, however, some unoxidized material remains, and toxic byproducts and / or contaminants such as nitrogen and sulfur oxides are formed.

In recent years, research at Ames has focused on developing methods to eliminate the undesirable combustion byproducts. One approach has been to use reductive catalytic systems to convert the nitrogen and sulfur oxides to nitrogen and elemental sulfur, innocuous materials at room temperature. Oxidative catalysts can then oxidize the remaining hydrocarbon contaminants to very low levels. In collaboration with outside university and corporate organizations, an integrated incineration system has been developed and tested that utilizes a fluidized-bed combustor followed by a catalytic cleanup system. In the past year, this system has demonstrated the ability to burn inedible biomass and produce a very clean exit flue gas. The concentration of contaminants in the gas exiting the incinerator is generally less than a few parts per million. Except for the carbon dioxide, which is toxic to humans at high concentrations, the exit stream from the incinerator is able to meet the Space Maximum Allowable Contaminant (SMAC) standards for clean air in a spacecraft.

A second research effort at Ames is investigating the use of waste material to prepare the flue gas cleanup system. A pyrolytic process converts inedible biomass to char, and the char is then converted to activated carbon. The activated carbon is used to remove contaminants such as nitrogen oxide and sulfur dioxide from the incinerator flue gas by adsorption followed by chemical reaction with the carbon. The contaminants are thus converted to innocuous nitrogen gas and elemental sulfur. In the past year, the process of producing activated carbon from wheat straw has been demonstrated, and the activated carbon produced from wheat straw has been used to reduce the concentration of nitrogen oxides in incinerator flue gas from 300 ppm (parts per million) to less than 1 ppm. This meets the SMAC limits within the crew cabin.

With the development of energy efficient, optimized incineration and flue gas cleanup systems, NASA will have the technology necessary to “close the loop” on carbon. Ultimately, carbon will move within the system from plant to person and/or incinerator and back to the plant without ever becoming a stored waste, achieving a significant milestone in the development of advanced life support systems which approach self-sufficiency. ❑

ROTATING-DISK ANALYTICAL SYSTEM (R-DAS)

Michael Flynn and Bruce Borchers

One of the main limitations in increasing the scientific return from fundamental biology and life sciences experiments onboard the International Space Station (ISS) is the inability to conduct a variety of biological and analytical assays in flight. The Rotating-Disk Analytical System (R-DAS) is an automated analytical/cell culture laboratory that has been developed as a biotech and chemical analytical instrument for use on ISS and other space flight platforms. R-DAS uses a microfluidics rotating disk and predetermined spinning profiles to accomplish complex fluid management tasks. Analysis is accomplished through the use of a custom optical imaging system. The instrument can conduct a wide range of protocols on orbit with onboard 1-g and micro-g controls without the need for the ISS centrifuge.

The system has a variety of unique design features such as automated microgravity environment assays and optical detection schemes which support natural and induced fluorescence. It is capable of conducting calorimetric, spectral, and image analysis. It will provide in-flight 1-g control studies without the need for the ISS centrifuge. It uses sealed and disposable sample disks which are preconfigured with all necessary reagents. The use of centrifugal force to control fluid flow minimizes acceleration velocities and shear forces and creates an environment which is insensitive to two-phase microgravity flow restrictions thereby simplifying sample preparation and introduction procedures.

The system is designed to fit into a double mid-deck locker (1/4 Space Station rack). It is designed to remain on orbit with only the disks being transported back and forth to orbit. A disk storage/holding system will be provided in order to allow for multiple disks processing. Operational protocols can be written on CD disks and experimental results can be re-written on the CD disks.

Ames Research Center has recently completed a rapid system prototype development effort. This six-month effort has resulted in the development of the prototype R-DAS system. The prototype is shown in Figure 6. This system is fully automated and uses a single microfluidic disk (single assay) with six parallel flow paths. The disk is shown in Figure 7. A florescent microscope is incorporated into the design in order to image samples and provide complete image analysis. The system is portable, having dimensions of only 8 in. x 20 in. x 20 in. The prototype was completed on January 1, 2002, and is currently being validated against standard laboratory protocols. In order to provide a first demonstration assay, a unique microfluidic disk was fabricated using the Molecular Probes Live / Dead stain assay.

Live / Dead Bacterial Viability Kit stains are based on the use of SYTO 9 green fluorescent nucleic acid stain and the propidium iodide red-fluorescent stain. Live / Dead kits are also available for animal cells and yeast assays, both of which will work in the existing R-DAS disk system.

Initial test results from the prototype system Live / Dead assay are encouraging. In addition, the system design is such that R-DAS is readily adaptable to a variety of other assays / disks being evaluated. With further development, R-DAS promises to usher in previously unavailable biological laboratory analysis capability onboard ISS and other future space flight platforms. ❏

Figure 6: R-DAS Instrument

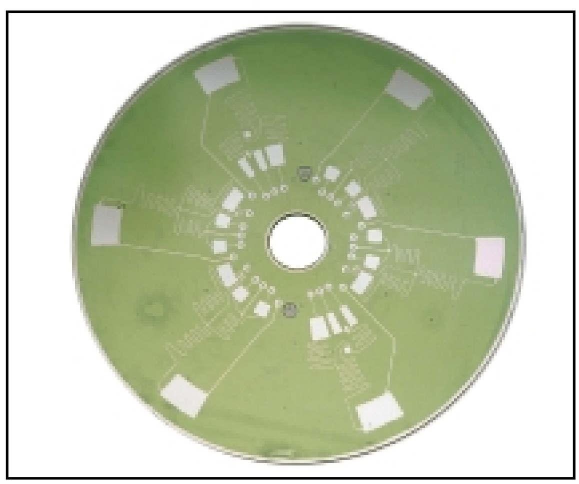


Figure 7: R-DAS Microfluidic Disk.

PROTEIN NANOTECHNOLOGY

Jonathan Trent, Andrew McMillan, and Chad Paavola

In support of NASA's efforts to improve mission success, there is a growing need for the development of smaller, stronger and 'smarter' scientific probes compatible with space exploration. The necessary breakthroughs in this area may well be achieved in the revolutionary field of nanotechnology. This is technology on the scale of molecules, which holds the promise of creating devices smaller and more efficient than anything currently available. Although a great deal of exciting research is developing around carbon nanotubes-based nanotechnology, investigators at NASA Ames Research Center are also exploring biologically inspired nanotechnology.

The biological 'unit', the living cell, may be considered the ultimate nano-scale device. Cells, which are constructed of nano-scale components, are extremely sensitive, highly efficient environmental sensors capable of rapid self-assembly, flawless self-repair, and adaptive self-improvement; not to mention their potential for nearly unlimited self-replicate. Ames is focusing on a major component of all cells (proteins) that are capable of self-assembling into highly ordered structures. A protein known as HSP60 is currently being studied that spontaneously forms nano-scale ring structures (Figure 8A, end view; B, side view), which can be induced to form chains (Figure 8C) or filaments (Figure 8D).

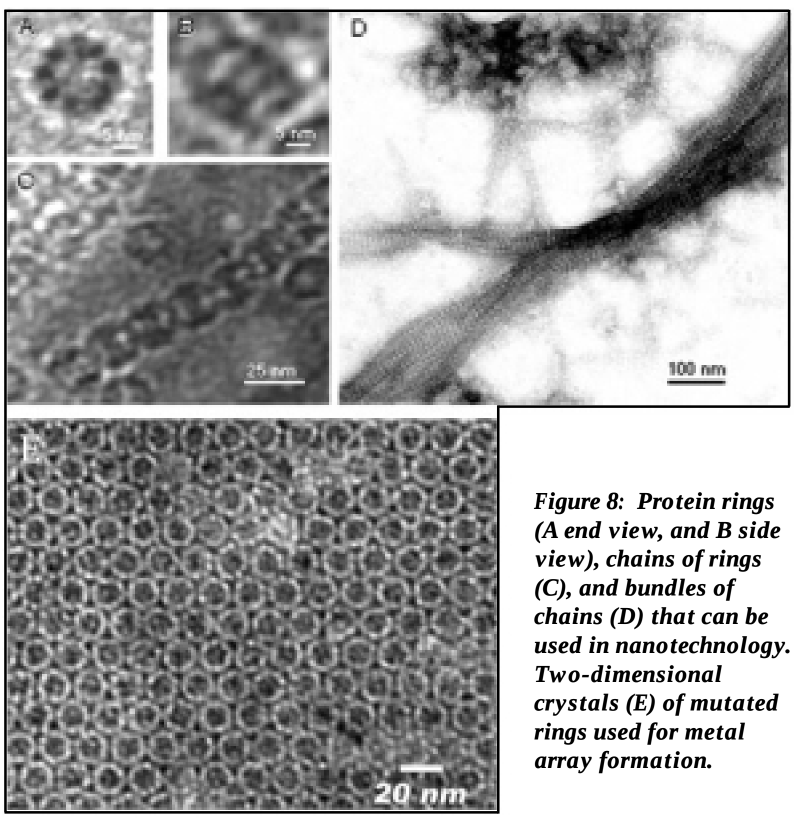


Figure 8: Protein rings (A end view, and B side view), chains of rings (C), and bundles of chains (D) that can be used in nanotechnology. Two-dimensional crystals (E) of mutated rings used for metal array formation.

By using thermostable HSP60s, highly efficient methods have been developed for purifying large quantities of these proteins and by using the ‘tools’ of molecular biology, their composition and structure-forming capabilities are being currently modified.

Recently, progress has been made in evolving the HSP60 into a structural subunit that can be manipulated in such a way as to utilize it for the formation of ordered arrays. Ordered arrays of metals are of interest in the semiconductor engineering community for the fabrication of devices that can be addressed and further assembled into logical circuits. To this end, a portion of the wild-type HSP60 subunit identified as contributing to the formation of filaments, or end-on structures, has been removed at the genetic level. The removal of this region of DNA directs the expression of a protein incapable of organizing into filaments; however, it possesses the ability to crystallize in two dimensions in a highly ordered hexagonally packed array (Figure 8E). This ordered array is being used to direct deposition of metals by templating. This process takes advantage of both the propensity of the modified subunit to self-assemble into a highly ordered array and the ability to site-specifically functionalize the protein. Using this approach, specificity for metals can be engineered into the protein that will subsequently localize the metals at defined intervals along the protein and hence into an ordered array (Figure 9). A simple removal of the protein leaves the ordered array of metal on the substrate with nanometer scale feature resolution. ❑

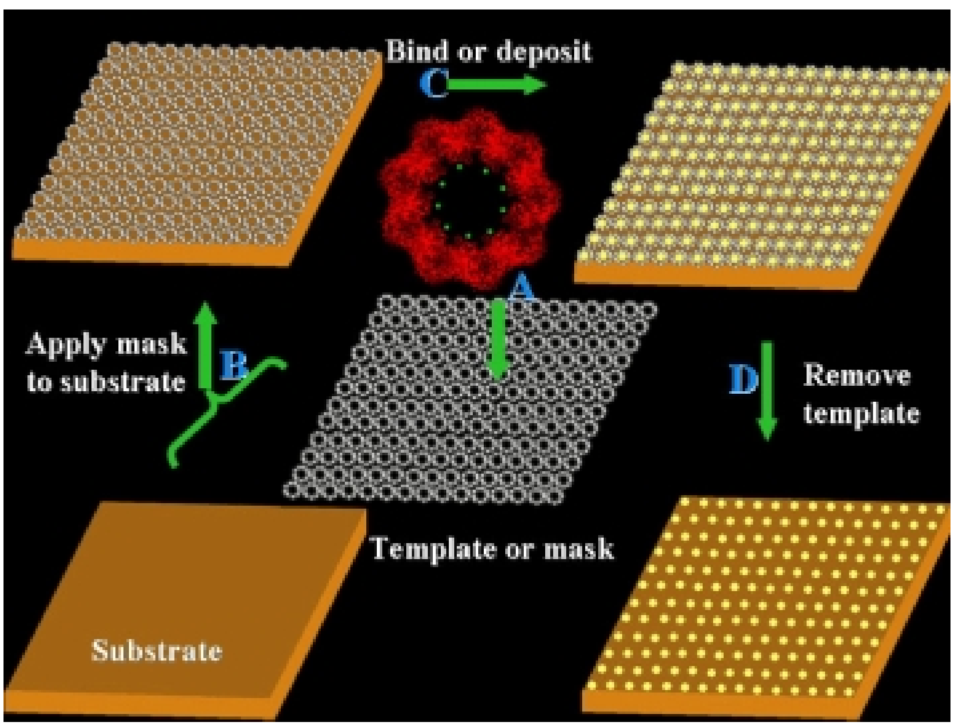
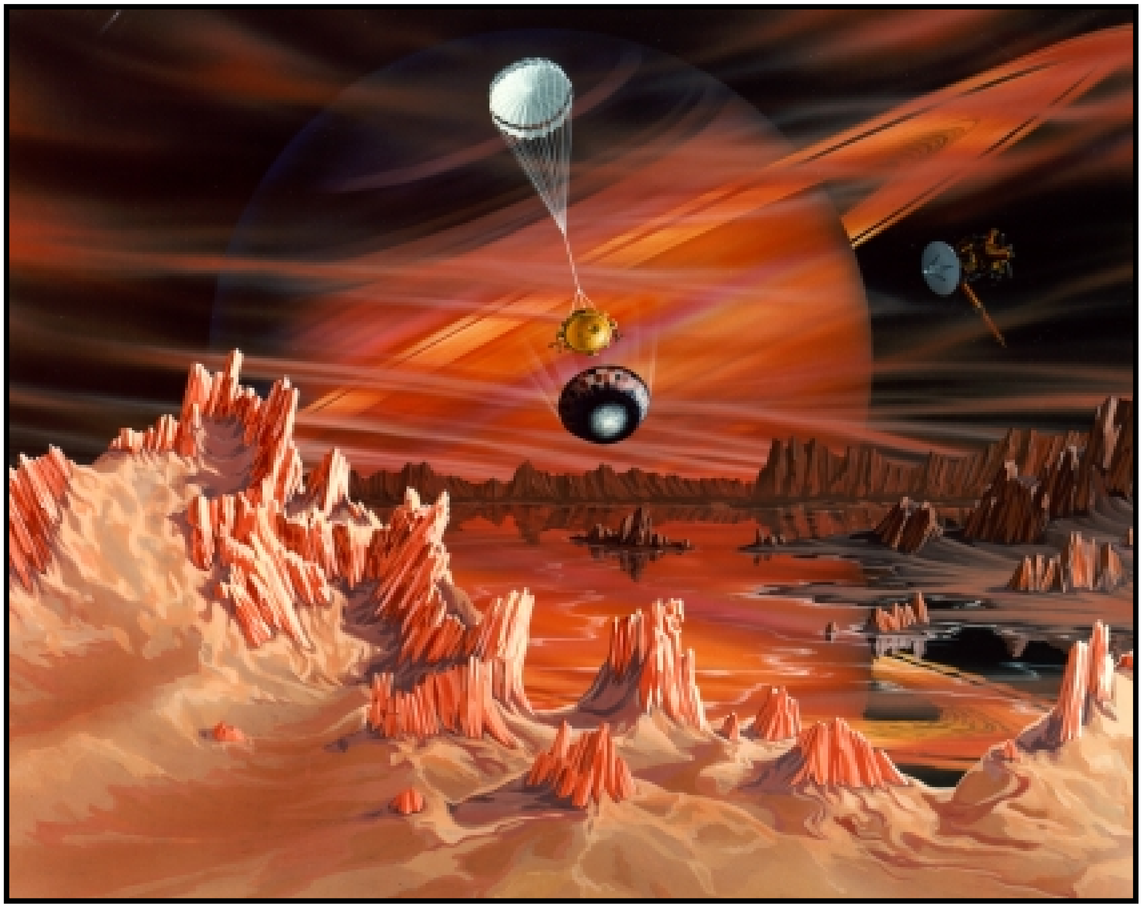


Figure 9: Mutant forms of HSP60 possess genetically engineered chemical reactivity at specific sites on the rings (A, green dots). These rings are crystallized (A) in two dimensions forming a highly ordered template. The template is applied to the surface of a substrate (B), and metals are bound that specifically attach to defined sites throughout the crystal (C). Finally, the template is removed (D), and the ordered array remains bound to the substrate.



Artist conception of Huygens Saturn Probe Titan Delivered by Cassini.
Credit: Craig Attebery, courtesy JPL

Planetary Systems Branch (SST) Overview

The overall research effort in the Planetary Systems Branch is directed at acquiring new, fundamental knowledge about the origins of stars and planetary systems and life itself. These studies are an integral part of NASA's overarching thrust in Astrobiology. Principal research programs include studies of the formation of stars and planets and the early history of the solar system, studies of planetary atmospheres and climate, investigation of the dynamics of planetary disks and rings, work on problems associated with the Martian surface including resource utilization and environments for the origin of life, and other programs (chiefly theoretical) involving stellar and planetary dynamics, radiative processes in stars and the interstellar medium, and investigation of the physical and chemical conditions in molecular clouds and star formation regions. Recent research involves development of informatics techniques to extract scientific information from modern large datasets. Scientists in the branch also support NASA flight missions through participation on various mission science teams. The primary product of the Branch is new knowledge about the nature of the universe, presented and published in the open literature.

Bruce F. Smith

Chief, Planetary Systems Branch (SST)

ORGANIC CHEMISTRY LEADING TO LIFE

Emma Bakes, Alexander Tielens, Charles Bauschlicher, Christopher P. McKay, Stephen Walch, William Borucki, Robert Whitten, Bishun Khare, Louis Allamandola, Douglas Hudgins, Sebastien Lebonnois and Hiroshi Imanaka

Work has been done by Principal Investigator Bakes and collaborators on three primary research topics.

1. The Formation of the Building Blocks of Life in Space
   Emma Bakes, Stephen Walch and Charles Bauschlicher

Our Solar System was formed from the primordial ISM when it collapsed to form a disk of gas and dust grains. Everything that comprises the solid material in our planetary system originates from primordial interstellar dust. There is increasing evidence that primordial interstellar material is intimately related to cometary and meteoritic matter in our Solar System. Amino acids are termed “prebiotic” because they precede the formation of all biological life. Historically, amino acids were thought to reside on our planet only. Recently, however, they have been discovered not only in solid chunks of meteoritic rock from the outer Solar System, but in the material between the stars (the “interstellar medium” or ISM). This has profound and far reaching implications for the origins of life. If the molecules which precede life exist between the stars, then life is a potentially universal phenomenon.

The primary goals of the proposed research were to 1) predict the chemical pathways and energetics for amino acid synthesis under astrophysically relevant conditions, 2) provide evidence of the survivability of amino acids in the hostile environment of interstellar space 3) predict infrared spectra for of the relevantspecies and 4) insert the results of (1), (2) and (3) into an astrochemical model to interpret and analyze astrophysical infrared data from the chemically richest region of our Galaxy, Sagittarius B2, where a possible detection of glycine, the simplest amino acid, was made. This work has shown that it is possible to make amino acids in interstellar space on solid interstellar dust grains (but not in the gas). The amino acids on these dust grains may then become part of a new solar system when the solid grains collapse to form planets and rocky bodies in the planetary system. In short, it is possible that some of the amino acids found on Earth today originated in the harsh and cold reaches of interstellar space.

2. The Formation of Macromolecules and Precursors to Biology in the Titan Haze
   Emma Bakes, Charles Bauschlicher, C.P. McKay, William Borucki, Robert Whitten, Bishun Khare, Sebastien Lebonnois and Hiroshi Imanaka

This research has begun to bridge the gap existing in current models of Titan chemistry. It has established that it is possible to form both neutral and cationic, pure and nitrogenated macromolecules containing up to 10 carbon atoms so far. Larger molecules are on the way to being analysed using quantum chemical techniques. This knowledge represents an enormous breakthrough, advocating the ease and energetically favorable formation of macromolecules which can then play a key part in Titan's thermodynamics, chemistry and aerosol formation. 2) Experiment have been initiated in the laboratory to investigate the chemical scheme detailed in (1) to investigate how the starting mixture, temperature, pressure and molecular complexity alter the final products. Results so far back up quantum chemical breakthroughs made in (1). 3) The formation of molecular hydrogen via aerosol surface catalysis has been investigated and found to play a significant role in the formationand subsequent escape of this molecule from Titan's atmosphere, solving a longstanding problem in the Titan haze composition. 4) The charging and agglomeration of Titan haze aerosols has been investigated and it can account for daily and (potentially) seasonal variations in the haze albedo. This occurs via the agglomeration of anionic PAHs and highly positively charged aerosols during the daytime or summer phases of Titan. It is erroneous to consider a monodisperse aerosol population with one charge - the situation is much more complex and dramatically changes our view of Titan's atmosphere. This is very controversial and will likely cause a storm in the field. 5) The above discoveries may radically change Titan haze conductivity and a new model is currently being formed of the charging of the Titan haze aerosols. This will help revise the results intended to guide the Cassini Huygens probe, which drops into the Titan haze in 2004.

3. Solving the Thirty Year Old Problem of the Unidentified Interstellar Infrared Emission Features
Emma Bakes, Alexander Tielens, Charles Bauschlicher, Louis Allamandola and Douglas Hudgins

Strong infrared emission features between 3.3 and 12.7 microns are ubiquitous and are the most luminous mid-IR spectral features originating from the ambient interstellar medium (ISM). They are valuable diagnostics of its chemical composition, thermal excitation and evolution. These features are observed in many astronomical sources at various stages of evolution, including reflection nebulae, HII regions, young stellar objects, photodissociation regions, post asymptotic giant branch stars, planetary nebulae, transition objects, novae, the Galactic disk and even extragalactic sources. These mysterious features are generally attributed to polycyclic aromatic hydrocarbon (PAH) molecules, although exact identification of the carriers of these IR features with specific molecules has remained elusive, leading to their being termed the "unidentified infrared (UIR) emission features". This research has made substantial inroads into clarifying the nature of the carriers of the "UIR" emission. A state of the art model of interstellar IR emission and macromolecular chemistry was constructed. The inclusion of quantum chemistry has taken the prediction of IR emission and the chemical evolution of PAHs to a superior level of theory surpassing former studies. It has also enabled a logical and systematic search for the "UIR" emission carriers in a variety of star forming regions, guided by the fundamental laws of quantum physics. The answer to one of the key questions in astrophysics, "What is the nature of the carriers of the UIR emission features?" is within our grasp. We are on the verge of a breakthrough in solving this 30 year old problem. ❑

PROBING DUST PROCESSING EVENTS IN ACCRETION DISK ATMOSPHERES USING TWO-DIMENSIONAL RADIATIVE TRANSFER MODELS

K. Robbins Bell, Diane Wooden, David Harker, and Charles Woodward

Progress has been made in observing and modeling temporally variable dust emission features in young stars surrounded by protoplanetary accretion disks. Multi-epoch mid-infrared spectrophotometry of pre-main sequence (PMS) stars, including low mass PMS T Tauri stars and intermediate mass PMS Herbig Ae / Be stars, with the Ames Hi-efficiency Faint Object Grating Spectrometer (HIFOGS) over the 7.5 – 13.5 micron wavelength range has confirmed the measurement of variable dust emission features. The HIFOGS spectrophotometric observations reveal changes in strength in either the 9.7 micron amorphous silicate resonance or the 8.6 micron and / or 11.25 micron polycyclic aromatic hydrocarbon (PAH) bands in a half dozen PMS stars. While the dust emission features change on timescales of months to years, the underlying infrared continua remain constant in flux density. The interpretation of this variability is that dust in the tenuous regions above the optically disks is being chemically altered through exposure to stellar radiation. These processing events appear to be occurring at disk radii comparable to or larger than the Earth's orbit of 1 astronomical unit (AU) and may provide clues to the dynamics of the active planet-forming region below the disk photosphere.

Two-dimensional radiative transfer models have been developed and are being used to model these time variable spectra. These new models allow synthesis of spectral energy distributions of complex disk geometries that include inner gaps and disk swelling due to local opacity effects such as expected from vertical structure models. The 2-d radiative transfer models are being used to interpret data from broad wavelength spectral energy distributions derived from ground-based photometry and HIFOGS time variable spectroscopy as well as from the Infrared Space Observatory (ISO) Short Wavelength Spectrometer (SWS) 6 – 45 micron spectra. ❑

THE KEPLER MISSION: A PHOTOMETRIC MISSION TO DETERMINE THE FREQUENCY OF EARTH-SIZE PLANETS IN THE HABITABILITY ZONE OF SOLAR-LIKE STARS

William Borucki and David Koch

Kepler is a Discovery-class space mission designed to detect and characterize Earth-size planets around solar-like stars. The sizes of the planets are determined from the decrease in light from a star that occurs during planetary transits and the orbital period is determined from the repeatability of the transits. The orbital radius and the nearness of the planet to the habitability zone is estimated from ancillary measurements of the stellar mass and brightness. Such measurements determine the spacing of planets, their distribution of size with orbital distance, and their variation with stellar type and multiplicity. Because thousands of stars must be continually monitored to detect the transits, extensive information on the stars can be obtained on their rotation rates and activity cycles. Observations of p-mode oscillations also provides information on age and metallicity of the parent stars.

These goals are accomplished by continuously and simultaneously monitoring a single field of 100,000 solar-like stars for evidence of brightness changes caused by transits of Earth-size or larger planets. To obtain the high precision needed to find planets as small as the Earth and Venus, a wide field of view, 0.95m aperture Schmidt telescope with an array of CCD detectors at its focal plane must be located outside the Earth's atmosphere. Both SMM (Solar Maximum Mission) and SOHO observations of the low-level variability of the Sun (~1:100,000) on the time scales of a transit (4 to 16 hours), and our laboratory measurements of the photometric precision of charge-coupled devices (1:100,000) show that the detection of planets as small as the Earth is practical. If most solar-like stars have terrestrial-size planets in their habitable zone, then several hundred planetary systems should be detected. Many additional planets should be detected with shorter orbital periods. Planets as small as Mars or even Mercury could be found if they have orbital periods of a week or less. Based on the Doppler velocity data obtained by Marcy and Butler, approximately 1000 giant inner planets should be discovered from their reflected light.

The Kepler Mission was selected on 21 December 2001 for a launch opportunity and is expected to be launched into a heliocentric orbit in 2007. A four year mission is planned with the capability of operating for an additional two years. The additional two years would nearly double the number of detections of planets in the habitable zone of G-dwarf stars like our Sun.

The spacecraft and instrument will be build by Ball Aerospace Technology Corp. (BATC) of Boulder, CO. BATC has built most of the optical instruments used in the Hubble Space Telescope and is the industrial partner for the Deep Impact Discovery Mission. The Space Telescope Science Institute (STScI) is a partner on the Kepler Mission. Ron Gilliland is in charge of calibrating and archiving the data as well as using acoustic mode data to determine the age and composition of the brighter stars. His method of frame subtraction will be used to remove the effects of dim background stars.

Dave Latham and his colleagues at the Smithsonian Astrophysical Observatory will perform ground-based spectroscopy on the 225,000 stars in the Cygnus star field that Kepler will view. These data will be used to select the target stars by culling out evolved stars that are too large to show planetary transits. They will also examine candidate planets to remove false positives caused by the presence of white dwarf companions.

Alan Gould from the Lawrence Hall of Science and Edna DeVore from the SETI Institute are leading the education and outreach programs to bring the Kepler discoveries into class rooms and to the attention of the general public. ❏

EFFECT OF NEGATIVE IONS ON THE CONDUCTIVITY OF TITAN'S LOWER ATMOSPHERE

William J. Borucki, Emma L. Bakes, and Robert C. Whitten

In a paper published in 1984, Borucki and colleagues calculated the electrical conductivity and electrical charge on aerosols in Titan's atmosphere due to the ionization by galactic cosmic rays and electron precipitation from Saturn's magnetosphere. Based on these calculations, an experiment was designed to fly on entry probe of the Cassini Mission to measure Titan's conductivity. The calculations showed that the lower atmosphere must be substantially more conducting than the atmospheres of Earth and Venus because of the high concentration of free electrons. The prediction of a high conductivity is based on the lack of electrophillic species which could form negative ions with low mobility and thereby reduce the number of free electrons. At that time, no molecular species capable of forming negative ions in concentrations sufficient to perturb the atmospheric conductivity were identified. Recently, E. Bakes and her colleagues have been investigating the formation of polycyclic aromatic hydrocarbons (PAH) using quantum mechanical methods. Their calculations indicate that these molecules will be highly electrophillic and are likely to be present in the atmosphere at mixing ratios of order one part per ten million. Revision of the atmospheric model is underway to account for the presence of the negative ions formed from the PAHs and to predict their effect on Titan's atmospheric conductivity. ❑

THE VULCAN PHOTOMETER: A DEDICATED PHOTOMETER FOR EXTRASOLAR PLANET SEARCHES

William Borucki, Douglas Caldwell, David G. Koch, and Jon Jenkins

A small dedicated photometer to detect extrasolar planets has been constructed and tested at Mt. Hamilton, California. It simultaneously monitors 3000 stars brighter than 12th magnitude within each star field in the galactic plane. Observations are conducted all night every clear night of the year. A single field is monitored at a cadence of eight images per hour for a period of about three months. When the data are folded and phased to discover low amplitude transits, the relative precision of one-hour samples is about 1 part per thousand. This precision is sufficient to find jovian-size planets orbiting solar-like stars, which have signal amplitudes from 5 to 50 parts per thousand depending on the sizes of the planet and star.

Nearly one hundred variable stars are found in each star field in each of the two star fields observed. About fifty of these are eclipsing binary stars, some with amplitudes of only a few percent. Three of these showed transits signatures like those expected from planetary companions. These stars were then observed with high-precision spectroscopy at other observatories to determine the mass of the secondary object. The spectra indicate that two candidates are nearly identical stars in binary pairs in grazing orbits. Spectroscopic observations showed the third object to be a high mass-ratio single-lined binary with a stellar companion similar in size to a jovian-size planet. Detection of the extrasolar planet orbiting the star HD209458 produced an easily recognized signal proving that the photometer has the necessary relative precision to find planetary companions. ❑

EXTRASOLAR PLANET DETECTOR FOR THE SOUTH POLE

Douglas A. Caldwell, Robert L. Showen, Kevin R. Martin, William J. Borucki, and Zoran Ninkov

Recent discoveries of a wide variety of planetary systems highlight the need for statistical information on the numbers and properties of extrasolar planets in order to understand planetary formation and evolution. Transit photometry (observing a planet pass in front of its star) can reveal a wealth of information for ~10% of those planets with orbital periods of one week or less. Observations of the transit of the extrasolar planet HD 209458b have resulted in the first unambiguous determination of mass and density, as well as the first detection of the atmosphere of an extrasolar planet. The goal of this work is to extend the transit photometry being done at Ames by developing a photometer for use at the South Pole.

Reliable detection of a transiting extrasolar planet requires observations of at least three transits in order to confirm the periodic nature of the signal. Therefore, the detection rate depends strongly on the duration and phase coverage of the observations. In the ideal case of continuous observation three transits could be seen in three times the longest period to be detected (~7 days). The closest one can get to continuous observation on Earth is the long winter night at the poles. The South Pole is more practical because of its permanent station, favorable weather, and excellent astronomical conditions. The three-transit detection rate at the South Pole is three times better than that of a mid-latitude site, even with time lost due to bad weather - historically estimated at 50%. In one month of observation the detection-rate is equivalent to that from three months of mid-latitude observation. The Poles have the added advantage of constant elevations for the stars being monitored, thereby eliminating the large nightly flux changes as the stars rise and set.

A prototype photometer for use at the South Pole has been constructed and tested at Ames Research Center. It is based on the Ames Vulcan photometer, which has been in operation at Lick Observatory for several years. The prototype, ‘Vulcan-South,’ was designed with the goal of understanding the operating environment at the South Pole. In particular, the system must be able to operate largely unattended in the extreme cold and blowing snow. The prototype was designed to be as close as possible to a fully-capable transit detection system, including a science-grade charge coupled device (CCD) camera, full-motion mount, and wide field-of-view optics. The mount and camera-frame were designed to work at –45º Celsius (the late-summer temperature at the Pole), using low-thermal-expansion material and dry lubrication. A heating and insulation system was designed to keep the CCD and mount electronics within operating specifications as well as to protect moving parts from blowing ice crystals. The photometer was instrumented to monitor temperatures throughout. Subsystems were tested in a cold-chamber during the design and construction phase.

The Vulcan-South photometer was deployed to Antarctica in the austral summer of 2001. The system was installed on the roof of the astronomy building approximately 1 kilometer from the geographic South Pole and operated for five days. The heating and insulation system worked as designed, keeping the CCD camera, optical, and mechanical systems between –5 and –15 Celsius, with ambient near –35 Celsius. Based on the results of deployment, and using automation developed for the Vulcan project, the design of a winter-over photometer for the South Pole has been completed. ❑

CIRCUMSTELLAR CARBONACEOUS DUST

Jean E. Chiar and Alexander G.G.M. Tielens

Aromatic (chain-like) hydrocarbon material is present in both circumstellar and interstellar environments. Its presence is evidenced by either emission or absorption features, depending on the excitation conditions, at wavelengths corresponding to the fundamental vibrational frequencies of carbon-carbon and carbon-hydrogen bonds. An infrared absorption feature has been detected at 6.2 microns towards several objects that sample large path lengths of diffuse interstellar medium dust. It was originally proposed that the aromatic materials were thus residing in the diffuse interstellar medium, and were not related to the objects themselves.

However, our study shows that the 6.2 micron absorption feature is actually circumstellar in nature and is produced by the WC-type Wolf Rayet stars being used to probe the diffuse interstellar medium along their line of sight. These results have implications for dust nucleation in the hostile environment around these hot stars, a topic that has only recently been theoretically explored. Since the circumstellar visual extinction toward these objects is minimal (around 1 magnitude), these dust grains have to be rather large (around 1 micron) and point toward dense clumps as the sites of dust formation.

Late-type WC stars, massive hot stars with fast dense stellar winds, are undergoing extensive mass loss and show the products of helium burning at the surface. Since their circumstellar material is carbon-rich and hydrogen poor, we attribute the absorption feature at 6.2 microns in their spectra to circumstellar amorphous carbon dust.

The 6.2 micron absorption feature is also detected toward the enigmatic cocoon stars in the Galactic Center Quintuplet Cluster. Thus, as a corollary, our results support a previous suggestion that these sources are themselves late-type WC stars. This absorption feature is not detected in the diffuse interstellar medium toward lines of sight which sample only interstellar dust, with no possible contribution from the circumstellar dust of dusty late-type WC Wolf-Rayet stars. ❑

ORGANICS AND ICES TOWARD THE GALACTIC CENTER

Jean E. Chiar, Andrew J. Adamson, Yvonne J. Pendleton, and Douglas C.B. Whittet

High-quality, spatially resolved spectra were obtained with the mid-infrared spectrometer CGS4, on the United Kingdom Infrared Telescope, in order to disentangle absorption components due to dense cloud material and diffuse interstellar medium dust along the line of sight toward the Galactic Center. We find that both absorption components vary significantly across the small 2-parsec field studied implying small-scale inhomogeneity in both the (foreground) diffuse interstellar medium and the dense molecular clouds. Figure 10 shows that our data are uniquely suited to defining the profiles of the dense cloud water-ice feature and the diffuse interstellar medium 3.4 micron aliphatic (chain-like) hydrocarbon feature, compared with previous studies which relied on fitting local continua over a small wavelength range. A new diffuse ISM absorption feature at 3.3 microns is revealed. The central wavelength is indicative of polycyclic aromatic hydrocarbons (PAHs), however its width is broader than the well-studied PAH emission features and the absorption feature seen toward the Galactic Center Quintuplet sources to the north. The difference in profile could be due to differences in temperature and / or carrier(s) present in these regions. ❑

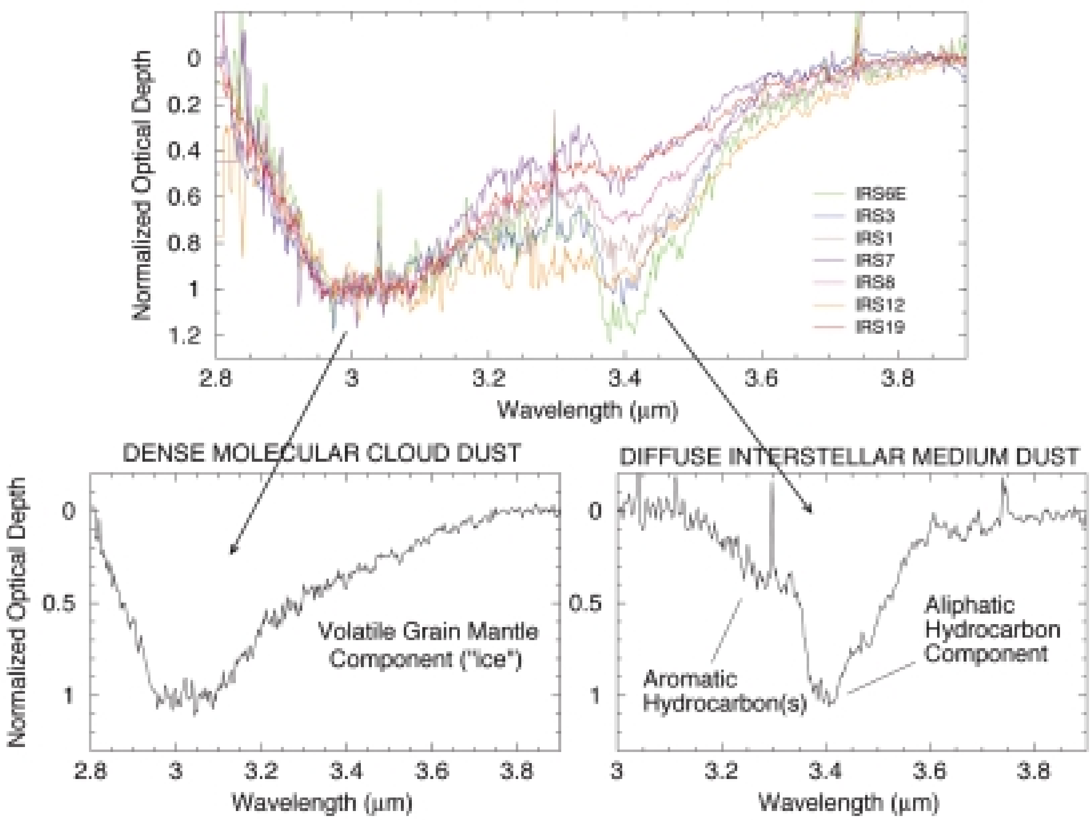


Figure 10: The spectroscopic signatures of key ice and organic dust components along the Galactic Center line of sight. Ice and hydrocarbon absorption vary independently of each other.

ARTIFICIAL INTELLIGENCE TECHNIQUES FOR LARGE-SCALE SURVEYS OF SPACE SCIENCE DATA

Paul R Gazis, Aaron Barnes, and Clark Glymour

Many problems in space physics require large-scale surveys of extensive data sets to identify and classify qualitative features such as shocks, discontinuities, energetic particle enhancements, or specific types of spectra. Such surveys can be difficult to accomplish using conventional programming techniques and the manpower requirements associated with direct physical examination of the relevant data sets can be prohibitive. Artificial intelligence (AI) techniques provide a potential solution to many of the problems associated with large-scale surveys. This is a mature technology for which the relevant techniques are well-documented and understood, but as yet, the space science community has made little use of AI techniques.

Investigators at the Ames Space Science Division, in collaboration with Carnegie Mellon University, have been examining a broad range of different AI techniques to evaluate their effectiveness for large-scale surveys of space science data. These techniques include traditional Expert Systems, statistical methods, and different neural network-based approaches. Unsupervised classification using self-organizing maps (SOMs) has proved particularly productive. A suite of tools have been developed, tested, and applied to a wide range of problems that involve one-dimensional pattern recognition, such as the classification of visual and infra-red spectra and the identification of events in time series of stellar occultation or solar wind plasma and interplanetary magnetic field (IMF) data. These tools have already produced valuable results in surveys of interplanetary shocks observed by the Voyager 1 and 2 and Pioneer 10 and 11 spacecraft. These tools should be immediately useful for many problems involving large-scale surveys of extended data sets that would be difficult or impossible to perform using any other means. ❏

ORIGIN OF THE THERMAL INERTIA CONTINENTS ON MARS

Robert M. Haberle

The surface of Mars can be classified into two major "continents" which are distinguished by the ability of their surface material to respond to solar heating. Low thermal inertia continents respond rapidly to solar heating and experience significant daily variations in surface temperature. High thermal inertia continents do not respond rapidly to solar heating and experience much more subdued temperature swings. These different behaviors are due to the nature of the surface materials comprising these continents. The low thermal inertia continents contain fine sandy materials (poor thermal conductors) while the high thermal inertia regions consist of hard consolidated rocky materials (good thermal conductors). These continents have fairly well defined boundaries and occupy vast regions of the planet. The question is how did they come about?

The answer appears to be related to the planets global scale wind systems, which in turn are strongly controlled by topography. The low thermal inertia continents represent accumulations of fine particles, which settle out of the atmosphere. In these regions, winds are relatively calm and once the dust settles to the surface it tends to stay there. On the other hand, the high thermal inertia regions experience strong winds, which scour the surface clean and expose the underlying bedrock.

This hypothesis was tested with the Ames Research Center Mars General Circulation Model (GCM). The GCM predicts Martian wind systems using state-of-the-art numerical methods. These winds were then used to estimate how much dust could be lifted annually from the surface, a quantity called the "deflation potential". The spatial distribution of the deflation potential was examined for a variety of orbital configurations since Mars' orbit properties are known to oscillate considerably on time scales ranging from tens of thousands of years to millions of years. In particular, the planets obliquity (the angle between its spin axis and orbit plane) may have varied anywhere from almost 0° to as high as 60° during the past 20 or 30 million years or so. Such changes were found to have a profound effect on the planets climate system. Yet, surprisingly, the regions of low thermal inertia never experienced significant deflation events regardless of the planets orbital configuration. Figure 11 shows a typical spatial pattern of the deflation potential as simulated by the GCM. Also shown is the present day distribution of thermal inertial. The correlation is remarkable.

If surface winds never get strong enough to erode away the fine material in the low thermal inertia regions, then it implies that these "continents" are old, much older than previously thought. In fact, these accumulations must have begun very early in the planet's history - 3.5 billion years ago - when its topography stabilized to near its present elevation. This notion can be easily tested with future landers and / or sample return missions. If correct, it means there is a readily accessible climate record that dates all the back to very early in the planet's history. ❑

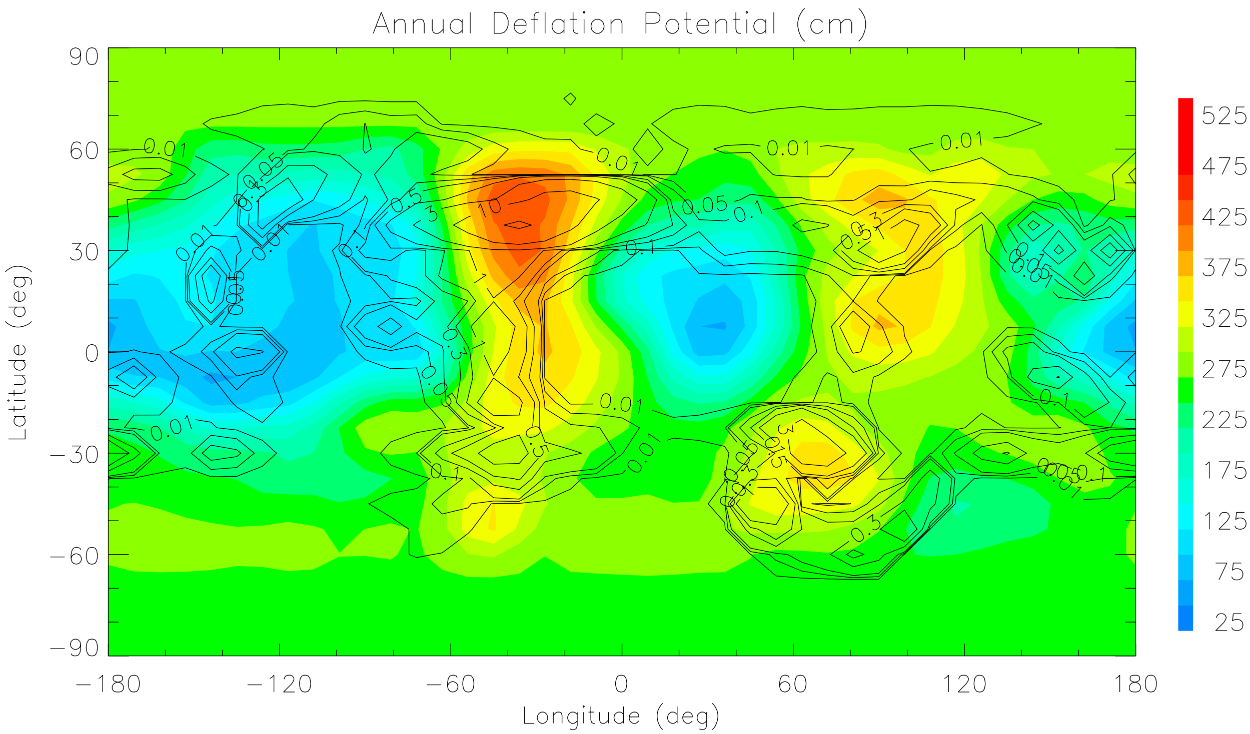


Figure 11: Color shading indicates thermal inertia in SI units. Scale bar is on the right. Black contours represent GCM prediction of the deflation potential in cm. Note the high positive correlation between the deflation potential and thermal inertia.

THE CENTER FOR STAR FORMATION STUDIES

D. Hollenbach and K. Robbins Bell

The Center for Star Formation Studies, a consortium of scientists from the Space Science Division at Ames and the Astronomy Departments of the University of California at Berkeley and Santa Cruz, conducts a coordinated program of theoretical research on star and planet formation. The Center, under the directorship of D. Hollenbach (NASA Ames), supports postdoctoral fellows, senior visitors, and students, meets regularly at Ames to exchange ideas and to present informal seminars on current research, hosts visits of outside scientists, and conducts a week-long workshop on selected aspects of star and planet formation each summer.

In July 2001 the Center held an international workshop entitled “Star Formation in the Galactic Context” on the University of California / Santa Cruz campus. The weeklong workshop had approximately 130 attendees, and included an invited talk by D. Hollenbach on “Neutral Phases of the Interstellar Medium: Is Star Formation Self Regulated by the Ultraviolet Field in a Galaxy?”.

One focus of the NASA Ames portion of the research work in the Center in 2001 involved the study of the thermal balance, chemistry, dynamics, and spectra of disks of gas and dust orbiting young stars. These disks, called “protoplanetary disks”, are the birthplaces of planets, and originally consist primarily of molecular hydrogen gas, with small amounts of other gaseous species such as carbon monoxide and a small admixture of dust particles. A number of processes heat the gas and dust in these disks, including radiation from the central star, radiation from a nearby luminous star, and the gravitational energy released as the gas and dust spirals toward the star. Previous researchers have focuses on the heating of the dust and the infrared spectrum of the dust; Ames researchers focused on the gas and the infrared and millimeter wavelength emission from the gas. Comparison of data from NASA missions (see below) with these models provides constraints on the distribution of gas and dust and the likelihood and duration of planet formation. In addition, the heating in the outer regions of the disks can be sufficient to drive evaporation of the outer disk regions in times short compared to the times required for planet formation, and thus thwart or modify planet formation in the outer parts of the disk. These models were used to explain the smaller size and lack of hydrogen in Uranus and Neptune compared with Saturn and Jupiter.

Another focus of the Ames portion of the Center research in 2001 involved a study of dust particles in the optically thin dust layer at the surfaces of these protoplanetary disks. Only a very thin layer of dust particles is directly exposed to radiation from the central star; the rest of the disk is heated by the emission of infrared photons from this dust layer. Because dust absorbs stellar radiation efficiently but radiates only inefficiently in the infrared, this dust layer is typically hotter than the underlying disk photosphere and thus may dominate the emission from the entire system at certain wavelengths. In order to use observations to understand processes occurring in the underlying disk, emission from this dusty surface layer must be accounted for. In addition, these dust particles produce features in the infrared that reveal the mineralogical, chemical and geometric properties of the disk’s grain population, thus providing clues to processes occurring in the disk below.

The theoretical models of the Center have been used to interpret observational data from such NASA facilities as the Infrared Telescope Facility (IRTF), the Infrared Astronomical Observatory (IRAS), the Hubble Space Telescope (HST), and the Infrared Space Observatory (ISO, a European space telescope with NASA collaboration), as well as from numerous ground-based radio and optical telescopes. In addition, they have been used to determine requirements on future missions such as the Stratospheric Observatory for Infrared Astronomy (SOFIA) and the Space Infrared Telescope Facility (SIRTF). ❑

UNDERSTANDING THE CLOUDY SKIES OF BROWN DWARFS

Mark Marley, Andrew Ackerman, and Richard Freedman

Unlike a star, the temperatures and pressures inside a brown dwarf are too small to ever ignite its nuclear furnace. Hence as it ages, a brown dwarfs cools by radiating its primordial energy away to space. During this process a number of important species condense and form clouds within the object's visible atmosphere. First iron, then silicates, and later water form thick clouds. With over 200 brown dwarfs now known, an understanding of these clouds is critical to modeling brown dwarf atmospheres and interpreting their spectra. An innovative collaboration between space and atmospheric scientists at Ames has focused on understanding these unusual clouds in the atmospheres of brown dwarfs. The lessons gained from modeling cloudy brown dwarf atmospheres will also be directly applicable to the first observations of extrasolar giant planets, which are expected to also have cloudy atmospheres.

Whether for a planet's or a brown dwarf's atmosphere, an atmospheric model predicts the variation in temperature and chemical composition with height. Coupled with a description of any clouds this information allows model spectra to be computed and compared with observations. For cloudless atmospheres the modeling procedure is relatively straightforward. Adding clouds to the modeling mix, however, severely complicates the calculation. Previously workers studying brown dwarfs have either ignored the effects of clouds completely or included extraordinarily simplistic clouds that did not behave as do real clouds in the solar system. Both approaches failed to reproduce the characteristics of observed brown dwarfs. Specifically they predict infrared colors for the warmer class of brown dwarfs known as 'L dwarfs' that are either much redder or bluer than is observed. Secondly the simplistic models cannot reproduce the change in color, from red to blue, as the L types evolve to the cooler T type brown dwarfs.

The new cloud model captures some of the most important physics that governs clouds in Earth's atmosphere. Most importantly the model includes the effects of sedimentation of cloud particles, essentially rainfall. Models that include sedimentation produce physically thinner clouds with larger particles than those postulated by other research groups. Unlike complex terrestrial cloud models the new brown dwarf model has only a small number of free parameters, one of the most important of which is a 'sedimentation efficiency factor'. Interestingly efficiency factors of three to five can reproduce some essential aspects of both deep cumulus clouds on Earth and ammonia clouds in the atmosphere of Jupiter.

When used in brown dwarf atmosphere models the new cloud formulation produces much better results than previous efforts. The model not only reproduces the red colors of the L dwarfs and the blue colors of the T dwarfs, it also allows for the first time a consistent explanation for the transition between the two brown dwarf types. As iron and silicate clouds form progressively deeper in cooling brown dwarfs, they sink from sight. The removal of silicate and iron grains then allows water and methane atmospheric absorption to pull brown dwarf colors blueward. Previous models that ignored sedimentation produced clouds that were much too thick; thick clouds prevented the color transition from ever occurring in those cases. Interestingly the same sedimentation efficiency factor that best reproduces some terrestrial and Jovian clouds also best describes 'rainfall' in the atmospheres of brown dwarfs. ❑

THE UV PHOTODECOMPOSITION OF MARTIAN CARBONATES

Richard C. Quinn, Aaron P. Zent, and Christopher P. McKay

The effect of UV light on the stability of calcium carbonate in a simulated martian atmosphere was experimentally investigated. Sample cells containing ^{13}C-labeled calcite were irradiated with a Xe arc lamp in 10 millibars of simulated martian atmosphere and a mass spectrometer was used to monitor the headspace gases for the production of $^{13}CO_2$. We have seen no evidence of UV-decomposition of $CaCO_3$ when the calcite sample is exposed to UV light in a simulated martian atmosphere at 10 mbar. Based on the experimental lower limit of detection, the upper limit of photodecomposition on Mars is 3.5×10^{-8} molecules / photon. However, it is most likely that UV photodecomposition of $CaCO_3$ does not occur on Mars due to the high pressure of atmospheric CO_2. In vacuum, the decomposition of $CaCO_3$ may occur due to the photodetachment and photodissociation of CO_3^- radical defects generated by UV light. In a CO_2 atmosphere, the decomposition of $CaCO_3$ is suppressed by the reformation of the UV-generated CO_3^- by adsorbed CO_2 and surface O^- radicals.

In the event that photodecomposition is occurring at rates below 3.5×10^{-8} molecules / photon, the depth to which carbonate is decomposed in the regolith will be limited by the rate at which unreacted material is exposed through wind abrasion and the rate at which mechanical mixing of the regolith can cycle carbonates to the surface. Based on our upper limit of photodecomposition on Mars, the maximum depth of a carbonate-free zone in the regolith would be 10 meters. However, assuming the formation of a carbonate-free zone is limited by the photodecomposition rate and not by the erosion rate, the actual depth of the zone will depend on the rate and depth of mechanical mixing of the soil. If the mixing zone is less than 10 meters deep, the depth of the carbonate-free zone will equal the depth of the mixing zone. If the mixing zone depth exceeds ten meters, the amount of carbonate moved to the surface will exceed the total load of carbonate that can be removed from the surface over geological time, resulting in a nonzero gradient which will move carbonate back into the upper ten meters of the regolith. ❑

REFLECTANCE SPECTRA OF TITAN THOLINS AT CRYOGENIC TEMPERATURES

Ted L. Roush and James B. Dalton

Compositional interpretation of remotely obtained reflectance spectra of outer solar system surfaces is achieved by a variety of methods including matching spectral curves, matching spectral features, quantitative spectral interpretation, and theoretical modeling of spectra. All of these rely upon laboratory measurements typically obtained with the sample at ambient temperatures and pressures. However, surface temperatures of objects in the outer solar system are significantly cooler than ambient laboratory conditions. It has been clearly illustrated that the infrared spectra of silicate materials change as a function of sample temperature, and that these changes can have a significant impact on compositional interpretations.

The optical constants of Titan tholin, a solid residue created by energetic processing of H-, C-, and N-bearing gases, have been used as a coloring agent in compositional models of several outer solar system surfaces. Because these surfaces are well below room temperature we have undertaken a laboratory study to measure the reflectance spectra of Titan tholin with the sample at temperatures of approximately 310, 300, 280, 270, 250, 200, 150, and 100∞K. A subset of these spectra are shown in Figure 12.

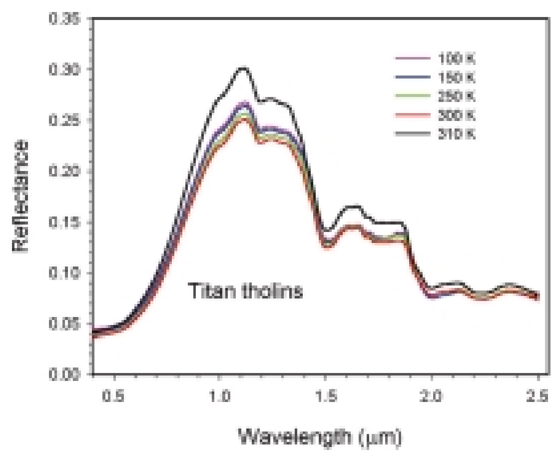


Figure 12: Measured reflectance spectra of Titan tholins at various temperatures.

At low temperature the visual and near-infrared colors of Titan tholin become redder, i.e. the reflectance increases more at longer wavelengths (to ~1.3 mm) than it does at shorter wavelengths, by ~5% as the material cools from 300∞K to 100∞K.

We estimate the effects of temperature on compositional interpretation as follows. The observed ~5% color change is used as a guide to adjust the Titan tholin optical constants reported by Khare et al. The imaginary index of refraction was decreased chiefly in the 0.6-1.3 mm wavelength region corresponding to the most noticable spectral changes in the reflectance data.

Cruikshank et al. used Titan tholin in their models of the surface of the Centaur Pholus. We repeated the calculations of Cruikshank et al. and the results are shown in Figure 13. We then replaced the original Titan tholin optical constants with our values altered to account for temperature effects. The results are also shown in Figure 13. Comparing the results leads us to conclude that, unless there is a sudden change at even lower temperatures, the temperature effects will likely have little influence on the compositional interpretation of the Pholus spectrum.

Acknowledgements: We thank Bishun Khare for supplying the Titan tholin sample and Roger Clark, USGS Denver, for use of the environmental chamber and spectrometer facilities. ❑

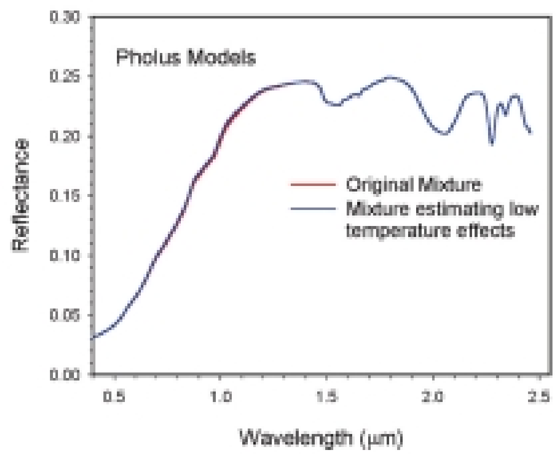


Figure 13: Estimate of the influence of temperature effects on model spectra of Pholus. The red curve is based upon the original model of Cruikshank et al. and the blue curve includes the estimated influence of low temperatures on the optical constants of Titan tholin within the same mixture.

NEW ALGORITHMS FOR MINING TIMESERIES AND IMAGE DATABASES

Jeffrey D. Scargle

A collection of algorithms for extracting structural information from time series and image data has been developed, based on Bayesian segmentation theory. Once the observational errors in the data have been modeled, the procedure is fully automatic, yielding high-level feature information. The software has been tested on synthetic data of known properties, and applied to the analysis of time series data from the Compton Gamma-Ray Observatory's Burst and Transient Source Experiment (BATSE) and two-dimensional positional data from the Palomar Distant Cluster Survey. Application is in progress to spatial power spectrum data on the cosmic background radiation, the solar neutrino flux as a function of time, the detection of planetary transits in various datasets, and other astrophysical problems. Extension to cluster analysis in high- dimensional data sets and other data mining contexts is under way. ❑

GRAIN PROPERTIES OF SOLAR SYSTEM COMETS

Diane Wooden, David Harker, and Charles Woodward

The observation of solar system comets yields insight in the conditions of the primordial solar nebula before the gas and ices were swept up into cometesimals. Mid-infrared observations provide information on the mineralogical content and size distribution of the dust in comets.

Modeling of the thermal properties of dust grains has been successfully performed on several solar system comets including comet Hale-Bopp. Since Hale-Bopp was an extraordinarily bright comet, the Ames Hi-efficiency Faint Object Grating Spectrometer (HIFOGS) obtained spectrophotometric data at mid-infrared wavelengths of 7.5 - 13.5 microns at epochs pre- and post-perihelion. In addition, far-infrared spectra were obtained at 15 - 22 microns post-perihelion. Modeling of the dust grains in Hale-Bopp showed that: 1) the amorphous dust grains became more porous as the comet approached perihelion; 2) the amount of crystalline dust grains increased with a decrease in heliocentric distance; and 3) the dust grains became less porous as the comet receded from perihelion. The latest observations of short-period comet 19P / Borrelly show that the dust grains from this comet are much larger than those from Hale-Bopp.

Learning about the mineralogical content of comets such as Hale-Bopp yields insight into solar nebula processes. For example, the existence of crystalline silicate in comets suggests that amorphous grains (which all but dominate the interstellar medium, out of which the solar nebula formed) have to be processed at temperatures greater than 1000K to form crystalline silicates. Such a processing mechanism implies that either the grains needed to be transported close to the Sun to be heated, crystallized, and then transported out to the comet forming zones where they formed icy mantles before being incorporated into cometary bodies, or some process, such as a nebular shock wave which is the result of gravitational instabilities in the early protoplanetary disk, heated the amorphous silicate grains to a high enough temperature for a sufficient amount of time that the grains were crystallized.

Constraining the properties of dust grains in comets in conjunction with studies of the chemical make-up of solar system bodies leads to a better understanding of the thermal processing, radial transport, and structure of protoplanetary accretion disks.

The NASA Ames HIFOGS continues its mid-infrared spectrophotometric observations of comets including C / 2000 WM1 (LINEAR) in October 2001 and February 2002 at the NASA InfraRed Telescope Facility (IRTF) on Mauna Kea, Hawaii. ❏

STATIC STABILITY OF JUPITER'S ATMOSPHERE

Richard E. Young, Julio A. Magalhães, and Alvin Seiff

One of the particular scientific objectives of the Galileo Probe Mission to Jupiter was to determine the static stability of Jupiter's atmosphere. Static stability is defined as the difference between the vertical gradient of temperature in an atmosphere, called the temperature lapse rate, and the adiabatic lapse rate. The adiabatic lapse rate is the rate of change of temperature with height that would occur if temperature depended on pressure in the same way as it would for an adiabatic compression or expansion of atmospheric gas parcels.

One of the most fundamental properties of a planetary atmosphere is the static stability, which represents the stability of the atmosphere to vertical overturning or mixing. The characteristics of the dynamic meteorology of an atmosphere directly depend on how large or small the static stability is. An atmosphere having zero static stability will exhibit large vertical mixing of air parcels, such that for example, a parcel of air near the surface can easily be carried to high altitudes by winds. On the other hand, if the atmosphere has large static stability, it is quite difficult for an air parcel originally near the surface to be lifted to high altitudes, and therefore that parcel will tend to remain near the surface.

When the Galileo probe, which was managed by Ames, entered Jupiter's atmosphere on December 7, 1995, instruments onboard measured the temperature and pressure of Jupiter's atmosphere as the probe descended. Although this data has previously been analyzed to try to compute the static stability of Jupiter's atmosphere, error sources associated with the pressure sensors, caused by unpredicted thermal excursions in the probe interior, cast serious doubt on the results.

Since the static stability of a planetary atmosphere is such an important quantity affecting the dynamic meteorology of the planet's atmosphere, during this past year a method was developed which avoided completely the errors induced in the probe atmospheric pressure sensors. For a hydrostatic, ideal gas atmosphere, it can be shown that for a probe in equilibrium descent (aerodynamic drag balanced by gravity), the temperature measurements alone can be used to derive the static stability. Unlike the pressure sensors, the Galileo probe atmospheric temperature sensors were unaffected significantly by the thermal excursions which occurred in the probe interior. Thus this method has been applied using only Galileo probe atmospheric temperature data to deriving the jovian atmospheric static stability.

Based on radiative convective models of Jupiter's atmosphere, it was anticipated that the atmosphere was neutrally stable, i.e. had zero static stability. However, observed dynamical features in the atmosphere seemed to imply a small positive static stability. The results from the analysis show that the atmosphere to a depth corresponding to about 20 bars pressure generally is statically stable, exhibiting a static stability of the order of 0.2 K km^{-1}. The stability varies with pressure, such that over limited altitude regions the stability becomes small, but in general the stability is positive.

The implications of a stable jovian atmosphere are significant. The tidal energy dissipation which is associated with orbital evolution of the Galilean moons of Jupiter, and in particular the volcanism on the moon Io, depends on the stability of the jovian atmosphere. The banded structure of Jupiter associated with east-west jet streams requires a stable atmosphere if the winds extend to large depths. Atmospheric wave modes observed to occur at many locations are sensitive functions of the stability. The mode of transport of internal heat flux from the deep interior of Jupiter, ie convective versus radiative heat transport, depends on whether the atmosphere is neutrally stable or statically stable, as does the latitudinal distribution of the heat flux. For all these reasons the derivation of a positive static stability in Jupiter’s atmosphere to at least 20 bars pressure is an important finding. ❏

CARBON DIOXIDE CYCLING AND THE CLIMATE OF EARLY EARTH

Kevin Zahnle and Norm Sleep

The continental cycle of silicate weathering and metamorphism dynamically buffers atmospheric CO_2 and climate on geological time scales. In this cycle, silicate rocks and atmospheric carbon dioxide react with the aid of water to form, ultimately, silica and carbonate rocks. The cycle is balanced by the metamorphic branch of the rock cycle, in which carbonate rocks are cooked under pressure to release carbon dioxide gas back into the atmosphere. The carbonate cycle acts as a negative feedback loop that limits climate change on time scales of a hundred million years. Carbon dioxide is an important greenhouse gas. When the climate is warm, carbon dioxide and silicate rocks react more quickly. Meanwhile the continental rock cycle produces metamorphic carbon dioxide gas from old carbonates at a more-or-less constant rate. Thus on net carbon dioxide in the air decreases, and so the climate is cooled. On the other hand, when the climate is cold, the reaction between CO_2 and silicate rocks slows down and CO_2 builds up in the atmosphere and the climate warms. Because the reaction rate between CO_2 and silicates is exponentially sensitive to temperature, the negative feedback is strong, and the climate stays temperate.

Over still longer time scales–billions of years–two other factors become important. The first is the sun evolves. When the Earth was young the sun was only about 70% as luminous as it is today. As the orbit of the Earth is not expected to have changed much since the Earth was fully accreted some 4.4 billion years ago, the early Earth presents a puzzle: geological evidence suggests that Earth has usually been warm enough to have had liquid water oceans, with temperatures and hydrologic cycles not grossly different from those today. Yet the early sun was so faint that, without a significantly stronger greenhouse than today, the Earth should have been encased in ice.

The traditional view has been that the continental weathering cycle described above keeps pace with the evolving sun to keep climate clement. Atmospheric CO_2 levels would have been 100-1000 times higher than today. However, geological evidence, albeit scant, indicates that there was not nearly this much CO_2 during the Archean Eon ca. 2.5-3.8 billion years ago.

The second important difference on billion-year time scales is that the fluxing of carbon dioxide into and out of the mantle becomes important. In the mantle branch of the cycle, CO_2 is outgassed at mid-ocean ridge axes where mantle rocks well up to the surface, while subduction of cold carbonatized oceanic basalt and pelagic sediments returns CO_2 to the mantle. This too is a negative feedback loop, because the amount of basalt carbonatization depends on CO_2 in seawater and therefore on CO_2 in the air. However this feedback cycle does not depend on the climate. The mantle cycle would have kept atmospheric and oceanic CO_2 reservoirs at levels where the climate was cold before ca. 2 billion years ago unless another greenhouse gas was important. At times when life was present on Earth, an attractive candidate greenhouse gas is methane, which the biota produce in vast amounts and which makes a very effective greenhouse gas. But before life arose, Earth was likely to have been on average quite cold.

The earliest Earth, the time before 3.8 billion years ago called the Hadean, is contemporaneous with the heavy impact bombardment of the Moon. Earth was subject to many and frequent impacts by large asteroids and / or comets. Chemical reaction of CO_2 with voluminous impact ejecta and its eventual subduction imply very low levels of atmospheric CO_2 and small crustal carbonate reservoirs in the Hadean. Despite its name, the Hadean climate would have been freezing unless tempered by other greenhouse gases. ❏

THE MARTIAN REGOLITH AND CLIMATE

Aaron P. Zent and Richard C. Quinn

Our objectives in FY01 have been to elucidate the role of the martian regolith in controlling and recording the history of, the martian climate. During FY01, we addressed the question of whether or not water vapor finds a substantial diurnal reservoir in the Martian regolith. Observations disagree on whether or not the atmospheric column abundance of H_2O varies as a function of time of day. Some observations, chiefly from ground-based telescopes, and Russian spacecraft, indicate a tremendous variation over the course of the day. Other observations, specifically those from Pathfinder and the Viking Orbiters, are most easily interpreted to indicate no diurnal variations in H_2O column abundance. Computer models of the atmosphere are unable to predict diurnal variations in atmospheric H_2O abundance. The simplest way to force substantial exchange is to posit that the Martian surface is locally covered with a highly adsorbing clay. These clays have larger adsorptive capacity than ordinary silicates, because they have interlayer sites that are available for adsorption.

In order to force computer models to predict strong diurnal H_2O exchange, the clays must equilibrate with the surrounding pore gases rapidly. However, the equilibration process is temperature dependent, and it is not clear that clays can play a role in exchanging a substantial fraction of the atmospheric column.

To address this issue, we measured adsorption uptake in sodium-rich clay from Wyoming. In Figure 14, we show the results of the uptake experiments. The simplest interpretation of the data is evident in the equilibration time of the two lowest curves. When the soil is held at 211 K, the adsorbed population continues to increase throughout the experimental period, up to 50 hours. In contrast, the case where the soil temperature is held at 273 K, and the R_H is held at 4%, appears to equilibrate over the course of a few hours. Adsorption on martian clays is not a plausible mechanism by which to account for strong diurnal variations in the H_2O column abundance of the martian atmosphere.

Also in FY01, in collaboration with Dr. Robert Haberle, we completed a study of H_2O melting on the martian surface. The times and locations where the surface pressure and surface temperature meet the minimum requirements for this metastability of liquid water were calculated. These requirements are that the pressure and temperature must be above the triple point of water, but below its boiling point. There are five regions on Mars where these requirements are periodically satisfied: in the near equatorial regions of Amazonis, Arabia, and Elysium, and in the Hellas and Argyre impact basins. Whether liquid water ever forms in these regions depends on the availability of ice and heat, and on the evaporation rate. The latter is poorly understood for low pressure CO_2 environments. ❑

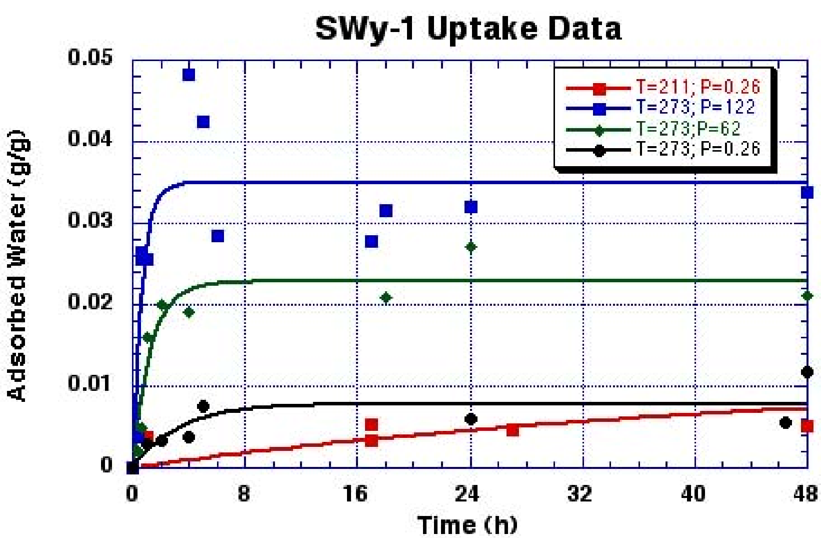
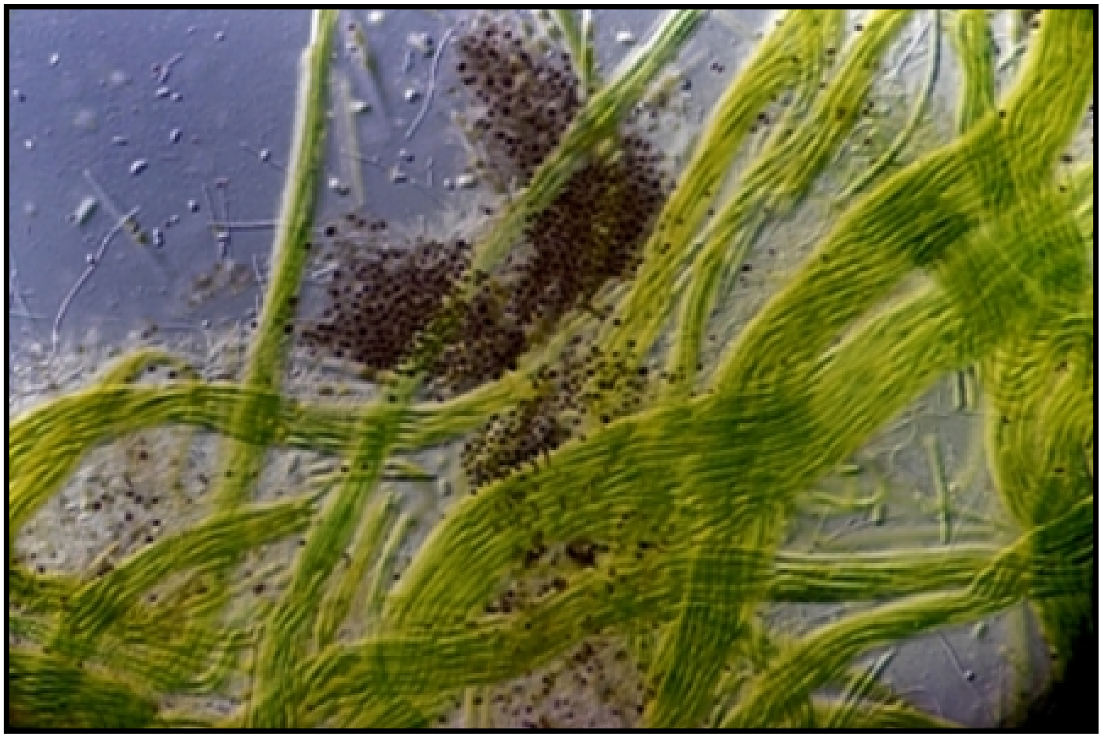


Figure 14: The uptake of water by Mars-analog clays



Cyanobacteria. Credit: L. Prufert-Bebout

Exobiology Branch (SSX) Overview

The Branch's research focuses on the advancement of the scientific understanding of the origin and distribution of life by conducting research on the cosmic history of biogenic compounds, prebiotic evolution, and the early evolution of life. This is accomplished via laboratory experiments, theoretical studies/computational modeling, and field investigations. Branch personnel are also involved in the development of flight instruments, experiments, and small mission definition with particular emphasis being placed on studies of Mars and the development of instrumentation for martian flight missions. Several Branch scientists are part of a task module that is a component of the Ames membership in the Astrobiology Institute. Branch scientists provide expertise in exobiology, astrobiology, planetary protection, and other areas of planetary science to NASA Headquarters and external review and advisory panels, and some serve as editors and associate editors of scientific journals.

Exobiology studies includes the history, distribution, and chemistry of biogenic elements in the solar system; prebiotic chemical evolution and the origin of life; and the history of Earth's early biosphere as recorded in microorganisms and ancient rocks. The research is conducted both on Earth and in space. The Branch also serves as the center of expertise within the agency for issues of planetary protection. As the agency lead center in exobiology, Branch exobiologists exercise a leadership role in NASA's Exobiology Program through program planning, performance reviews, advisory services to related NASA programs, and external relations.

David F. Blake

Chief, Exobiology Branch (SSX)

EMERG GREENHOUSE ONE: SIMULATIONS OF REMOTE AND ANCIENT EARTH ENVIRONMENTS AT AMES

Brad Bebout

The Ames Microbial Ecology / Biogeochemistry Research Lab, in combination with the Early Microbial Ecosystems Research Group (EMERG), has completed a greenhouse simulation facility designed to enable the maintenance and manipulation of microbial mat communities. Microbial mat communities are extant representatives of the oldest forms of life on Earth. Two major experiments, a salinity manipulation, and a sulfate manipulation, have now been conducted. These experiments have demonstrated that the facility is capable of maintaining these complex communities of microorganisms for periods of over a year, while enabling experimental manipulations and the collection of high quality data. The experimental apparatus notably enables the collection of measurements of the distribution of important chemical and biological parameters within the communities on the microscale (sub millimeter).

The salinity manipulation, in which the salinity of half of the experimental microbial mats was raised by a factor of about 30 per cent, provided the important result that the community composition of the major photosynthetic population in the mats (cyanobacteria), as revealed using molecular biological methods, is essentially identical to that of field collected populations. Increased salinity reproduced cyanobacterial community changes that are also observed with increases in salinity in the natural environment. The importance of this result is a validation of the methods being using to conduct manipulations.

The sulfate manipulation, in which the sulfate concentrations of half of the experimental mats was reduced by a factor of nearly 1000, recreates conditions which were important early in Earth's history, but which are not presently found in the natural environment. This manipulation has produced a number of fundamental changes in the microbial mats, including changes in sulfate reduction, oxygen distribution within the mat, and photosynthetic efficiency. In addition, changes in important biomarker gases were observed between the treatments, including higher rates of methane and dimethyl sulfide production in mats incubated at lower sulfate concentrations. These results will be important in evaluating the strategy of looking at biomarker gases in the atmospheres of extrasolar planets. ❑

A TERRESTRIAL ANALOG FOR THE MARTIAN METEORITE ALH84001

David Blake, Allan H. Treiman, Hans E.F. Amundsen and Ted Bunch

Carbonate minerals present in the ancient Mars meteorite ALH84001 may hold clues to the processing and fate of volatiles and the potential for primitive life on early Mars. However, because ALH84001 is separated from its surrounding rocks, the context of its formation and processing is unknown and the origin of the carbonate globules has therefore been controversial — scenarios range from groundwater deposition through high-temperature shock metamorphism. In terrestrial field geology, such rocks are called “float” when they are found removed from their original setting. The ALH84001 meteorite is an extreme example of “float”, having been separated from its source locality (Mars) by hundreds of millions of miles.

One way to investigate the origin of rocks whose context to the surrounding strata has been lost is to find and study analogous rocks where field relationships can be obtained. Igneous rocks from volcanoes on northern Spitsbergen (Svalbard, Norway) contain carbonate globules strikingly similar to the globules in ALH84001 (see Figure 15). Field and laboratory data suggest that the Spitzbergen carbonates formed as a result of late-stage hydrothermal (i.e., hot springs) activity. The ALH84001 carbonates probably formed in a similar environment.

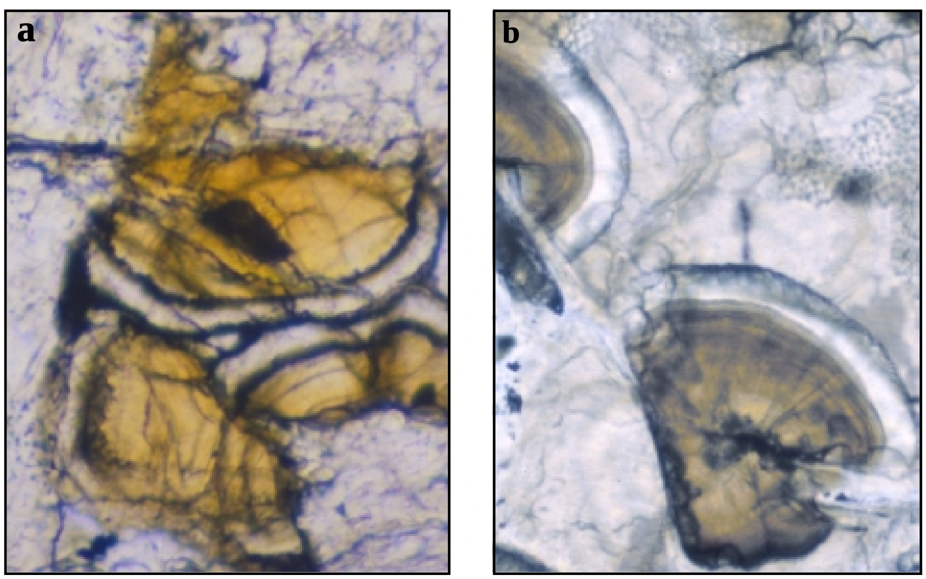


***Figure 15:** Optical microscope views of carbonate globules from Mars and Earth. Semicircular globules, ~ 200 μm diameter, have cores of ankerite and siderite carbonates (brown, Fe- and Ca-rich), and rims of magnesite (clear, Mg-rich) [a] Mars. Meteorite ALH84001. Black layers are magnetite-rich (originally were siderite, Fe-rich carbonate). Globules surrounded by orthopyroxene and feldspathic glass. [b] Earth. Spitsbergen xenolith, sequence of carbonate minerals similar to ALH84001 globule. Globules surrounded by olivine, orthopyroxene, clay, and silica; globules cut by clay-filled veinlets.*

Xenoliths (rock fragments dislodged and entrained in rising magma) comprise up to 20% of the exposed volumes of basalt from several volcanos on Spitsbergen. The mantle xenoliths within the basalt include rock types similar to ALH84001. Globules of carbonate minerals occur in the xenoliths and their host lavas along cracks, in vesicles, and as replacements of olivine. Typical carbonate globules in the Spitsbergen rocks are ellipsoids cored by ankerite, siderite, and magnesite (ASM), carbonate minerals also present in ALH84001.

Results suggest that the ASM carbonates were deposited *in situ*, in restricted areas, in the volcanic centers by hydrothermal fluids. The ASM carbonate globules from the Spitsbergen volcanos are similar to the carbonate globules in ALH84001, having similar sizes, shapes, chemical compositions, general patterns of chemical zoning, and host rock compositions. These similarities suggest that the Spitsbergen and ALH84001 carbonate masses formed in comparable geological environments.

The current focus of Mars exploration is water and ancient environments where life may have prospered, including hydrothermal systems. The ALH84001 carbonates are critical to this search, almost by default, as they are our only direct clues about ancient Martian aqueous environments and geochemistry. Further study of the Spitsbergen rocks will help clarify the formation conditions for the carbonates, provide a sound terrestrial basis for interpreting the carbonates in ALH84001, and aid in planning geological and geochemical studies of the Martian highlands. ❏

MICROBIAL MATS AND THE ORIGINS OF PHOTOSYNTHESIS

David Des Marais, Dan Albert, Brad Bebout, Mykell Discipulo, Tori Hoehler, and Kendra Turk

The Ames microbial ecology laboratory (EMERG) is defining the structure and function of microbial biofilm (mat) communities. Recent observations of aerobic and anaerobic processes within these communities offer clues about our earliest origins and about the nature of Earth’s ancient atmosphere. Such studies contribute directly to NASA missions that seek to chart the distribution of habitable planets and biospheres beyond Earth.

When our biosphere developed photosynthesis, probably in microbial mats, it tapped an energy resource that was orders of magnitude larger than the energy available from oxidation-reduction reactions associated with weathering and hydrothermal activity. The onset of oxygenic photosynthesis most probably increased global organic productivity by more than two orders of magnitude. This productivity materialized principally because oxygenic photosynthetic bacteria can capture hydrogen for organic biosynthesis by cleaving the water molecule. This virtually unlimited supply of reduced hydrogen forever freed life from its sole dependence upon abiotic sources of reducing power such as hydrothermal emanations and weathering. Communities sustained by oxygenic photosynthesis thrived wherever supplies of sunlight, moisture and nutrients were sufficient. The microfossil record of cyanobacteria is evident for more than 2.5 billion years, and their ancient stromatolitic reefs rival modern reefs in size. Vast sedimentary deposits of organic carbon, reduced sulfide, and ferric iron on continental platforms and margins are among the most prominent and enduring legacies of billions of years of oxygenic photosynthetic activity. The biosphere passed through an earlier stage where even its photosynthetic populations depended exclusively upon nonbiological sources of reducing power from hydrothermal emanations and rock weathering. Can we recognize such a stage? In order the chart the development of oxygenic photosynthesis as well as its impact upon the atmosphere and ancient sediments, it is important to learn how to discriminate between the fossil remains of aerobic versus anaerobic populations.

The Ames team examined modern descendants of these ancient mats in subtidal and intertidal marine environments at Guerrero Negro, BCS, Mexico, specifically those dominated by *Microcoleus* (subtidal) and *Lyngbya* (intertidal to supratidal) cyanobacteria. Differences in the aerobic versus anaerobic communities were observed that indeed might be preserved in the sedimentary record. The exchange of O_2 and dissolved inorganic C (DIC) between mats and the overlying water, during diel (24hr .) cycles. *Microcoleus* mats assimilated near-equal amounts of DIC during the day as they released at night, but *Lyngbya* mats typically showed net uptake of DIC over the diel cycle. Patterns of O_2 daytime release and nighttime uptake mirrored these DIC trends in both mat types. Nighttime DIC effluxes from *Microcoleus* mats were equivalent in the presence versus absence of O_2, whereas nighttime DIC effluxes from *Lyngbya* mats dropped markedly in the absence of O_2. Thus, aerobic diagenesis was more important in *Lyngbya* mats than in *Microcoleus* mats, perhaps because trapped O_2 bubbles persist only in *Lyngbya* mats at night and thus sustain populations of aerobes. In both mat types, effluxes of H_2, CH_4 and short-chain fatty acids were much greater at night in the absence of O_2, emphasizing the importance of fermentation reactions. Differences observed between *Microcoleus* versus *Lyngbya* mats forecast differences in their microbiota and in their patterns of gene expression. ❑

LARGE-MAGNITUDE BIOLOGICAL INPUT OF HYDROGEN TO THE ARCHAEAN ATMOSPHERE

Tori M. Hoehler, Brad M. Bebout, and David J. DesMarais

Earth’s earliest biosphere is often thought to have depended primarily on chemicals vented from deep underground (as in volcanoes or hydrothermal vents) as its primary source of energy. Before long, however, life “learned” how to use solar radiation (light) as the primary energy source. Because light provides a much more abundant supply of energy, the new photosynthetic biosphere had the potential to be more productive than the earlier biosphere by as much as two or three orders of magnitude. Accordingly, the capacity of life to alter the chemistry of our planet’s surface must have increased by a similar magnitude. The Early Microbial Ecosystems Research Group (EMERG) at Ames Research Center is studying modern relatives of Earth’s ancient photosynthetic biosphere in order to understand the possible biological impacts on planetary chemistry during the early stages of our history.

Some of our recent studies have focused on the production of hydrogen gas, H_2, by modern microbial mats (analogs for ancient photosynthetic communities). During photosynthesis, microbial mats break water, H_2O, into its compent elements of hydrogen and oxygen. Ordinarily, the H_2 is used to turn carbon dioxide from the atmosphere into sugar-like materials – which are subsequently used to synthesize the complex organic molecules that comprise living organisms. However, when microbial mats are exposed to a simulated Archaean (early Earth) atmosphere that is very low in oxygen, they instead release much of this hydrogen to the environment. Without this mechanism, the primary source of H_2 to the Archaean atmosphere would have been geothermal venting (e.g., volcanic emissions); our studies suggest the biological release of hydrogen may have exceeded the geological one by 100 to 10,000 times.

Such a profound addition of hydrogen to the Archaean environment could have had important implications for both biology and chemistry on a global scale. Hydrogen is widely utilized as a food source by many of the organisms thought to have comprised the early biosphere. The numbers and global distribution of such organisms could have been greatly enhanced by an atmosphere containing significant quantities of H_2. Each of the particular chemistries mediated by these organisms could thereby have a proportionately larger impact on the local or global environment than in the absence of a photosynthetic H_2 flux. In addition, H_2 itself can have an important impact on atmosphere and ocean chemistry. Hydrogen is “light” enough to escape to space, and in the process, carries electrons with it. The removal of electrons from our planet in this fashion would serve to facilitate the oxidation of our oceans and atmosphere from an intially reducing or neutral condition to the highly oxidized and oxygenated state that permits the existence of multi-celled life forms – including us! ❑

ANALYSIS OF THE TAGISH LAKE METEORITE

Sandra Pizzarello, Yongsong Huang, Luann Becker, Robert J. Poreda, Ronald A. Nieman, George Cooper, and Michael Williams

Carbonaceous meteorites provide an important record of organic compounds that were synthesized very early in the Solar System and delivered to the planets. Because a goal of NASA is to understand the origin and evolution of life, it is desirable to analyze a variety of such meteorites for their organic content.

The Tagish Lake meteorite fell in Canada in 2000 and was kept frozen until analysis. It may provide the most pristine material of its kind. Analyses have shown this carbonaceous meteorite to contain a suite of soluble organic compounds (~100 parts per million) that includes mono- and dicarboxylic acids, dicarboximides, pyridine carboxylic acids, a sulfonic acid, and both aliphatic and aromatic hydrocarbons. Surprisingly, some of the most abundant organic compounds of the well-studied Murchison meteorite were found to be very scarce in Tagish Lake. Amino acids, mono-carboxylic acids and amines are three orders of magnitude less abundant than in Murchison.

The difference between the two meteorites is also qualitative and very few species were found for each class of Tagish Lake compounds, contrary to Murchison's large isomerism. For example, while there is a series of straight chain carboxylic acids from formic to nonanoic acid, of the many possible branched isomers only isobutyric acid was detected. For amino acids and amines the list of identified compounds are few: glycine, alanine, _lpha-amino iso- and n-butyric, and _amma-amino butyric acids; and methyl, ethyl and isopropyl amines. In addition only the first two members of each series, e.g., acetic and formic acids, are present above trace levels. Also in contrast to Murchison, the abundance ratio of the first or second member of each series to the third ranges from approximately 10 to 100 (2 to 4 is typical Murchison).

The case of Tagish Lake sulfonic acids (organic sulfur compounds) is an extreme example as they were found to be represented in the meteorite by just methane sulfonic acid (MSA). MSA was found to be several times more abundant than in Murchison. Although other members of the series may ultimately be found it is apparent that the ratio of MSA to the other sulfonic acids would still be much higher in Tagish Lake than in Murchison. In Murchison sulfonic acids are present as a homologous series that extends to at least 4 carbons. MSA was found to be different from its homologs in having much higher amounts of carbon-13 and the heavier isotopes of sulfur. The present findings in Tagish Lake may be consistent with these isotopic differences.

The finding of just one suite of organic compounds matching those of Murchison and of some (but not all) the carbonaceous phases and compounds seen in other meteorites demonstrates the presence of distinct organic synthetic processes in primitive meteorites. It also implies that the more complex organic matter of heterogeneous meteorites may result from multiple, separate evolutionary pathways. ❏

COMPUTATIONAL MODELING OF REGULATORY NETWORKS IN CELLS

Andrew Pohorille, Stephen Bay, Pat Langley and Jeff Shrager

Understanding how an organism regulates its level of gene expression in response to external stimuli is a central problem in molecular biology. Although scientists understand the basic mechanisms through which DNA produces proteins and thus biochemical behavior, they have yet to determine most of the regulatory networks that control the degree to which each gene is expressed. This knowledge is necessary for understanding effects of space environments on cells and explaining interactions of organisms in ecosystems. Faulty cellular regulation is responsible for numerous diseases, of which cancer is the best known example. The BioLingua project, described here, provides interactive computational tools for biologists to build regulatory models using microarray data, which measure gene activity in terms of RNA expression levels in an organism. When the data are ambiguous, BioLingua relies on biological knowledge in the form of initial models and information about plausible causal relations between gene products.

The approach to discovering regulatory networks is based on linear causal models. In this approach, each variable is represented as a linear function of its direct causes plus an error term. Variables correspond to the expression levels of genes or measurements of external quantities. A regulatory network is represented as a graphical model, in which each variable is a node and causal influences are represented as arrows from the cause to the effect. The structure of the initial model can be obtained from constraints imposed by partial correlations between experimentally measured values of different variables. For example, a zero partial correlation between two variables means that they are connected through the third variable. A non-zero partial correlation implies that the variables are directly causally connected. The initial model is further refined through a search in the space of models consistent with biological knowledge to ensure that the predicted directions of changes in gene expression (up and down regulation) match those measured in experiments.

The methodology described above is illustrated in the example of photosynthesis regulation in Cyanobacteria, which are ubiquitous organisms in terrestrial, marine and freshwater ecosystems. Over 25% of the oxygen in the atmosphere is generated by Cyanobacteria. The model, shown in Figure 16, was generated on the basis of the recent microarray studies. It explains why Cyanobacteria exposed to high light conditions bleach and how this protects the organism. The model states that changes in light level modulate the expression of a protein dspA, which serves as a light sensor. This in turn regulates NBLR and NBLA proteins, which then reduce the number of phycobilisome (PBS) rods that absorb light. The reduction in PBS protects the organism's health by reducing absorption of light, which can be damaging at high levels. The sensor dspA impacts health through a second pathway by influencing an unknown response regulator RR, which in turn down regulates expression of the gene products psbA1, psbA2, and cpcB, which are all needed to form a functional shotosystem. However, only the first protein was found to regulate the level of photosynthetic activity (Photo). High levels of photosynthetic activity would also damage the organism in high light conditions. ❏

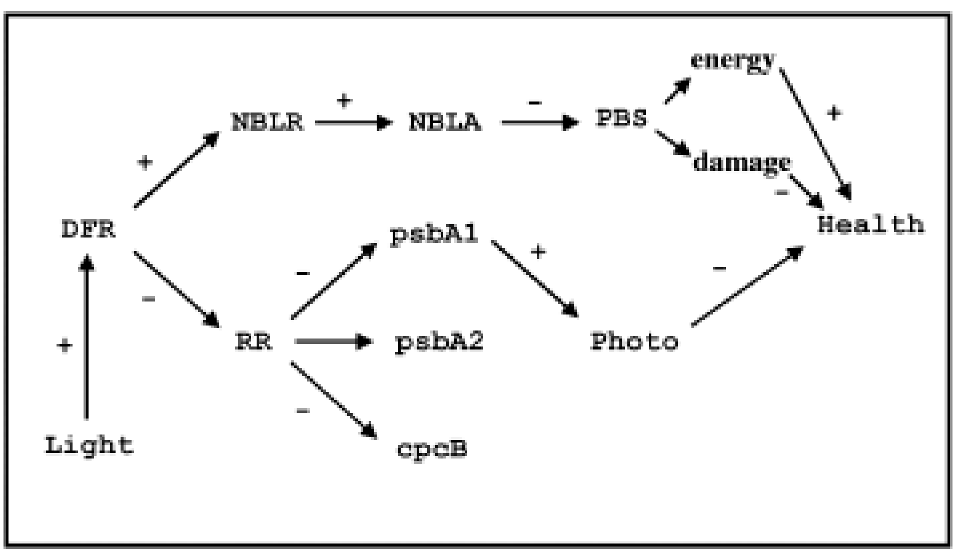


Figure 16: The proposed regulatory model of photosynthesis in Cyanobacteria.

A HIGH PERFORMANCE, LOW COST LINUX CLUSTER FOR GENOMICS

Karl Schweighofer and Rick Graul

In support of genomics research at NASA, the newly formed bioinformatics group (under the title of the NASA Center for Astrobioinformatics) has developed a Linux-based computer cluster configured with genomics tools. The cluster, also known as a Linux farm, is to serve as a test platform for developing genomics tools, and as an integral component of the newly formed bioinformatics infrastructure to support NASA specific research and missions. Such an infrastrucure is justified due to the large number of scientists whose research employs the direct use of genomic information, and who are currently relying on outside resources to perform their analysis.

The Linux farm, called GRETEL, consists of 10 dual processor Pentium II 400 MHz processors, with an average of approximately 500 Mbytes of memory per node. The network topology employs a single network card in each node, each of which is connected to a local 100 Mbit switch. Of the 10 nodes, one is configured to be “Mother Superior”, and the others act as slaves, although each node has it’s own disk, operating system, and local copies of important databases. Mother Superior also acts as a web server, PBS batch server, and will allow remote logins for users who wish to have command line access to tools, or to develop their own code. Login access (ssh), and http requests are forwarded by a Linux-based firewall, which insulates the farm network from the outer ARC LAN. This is performed by network address translation, which masquerades the nodes so that each one has only a private network address. This allows for a high degree of reliability, since jobs started on the farm will continue even if the outer network experiences an interruption.

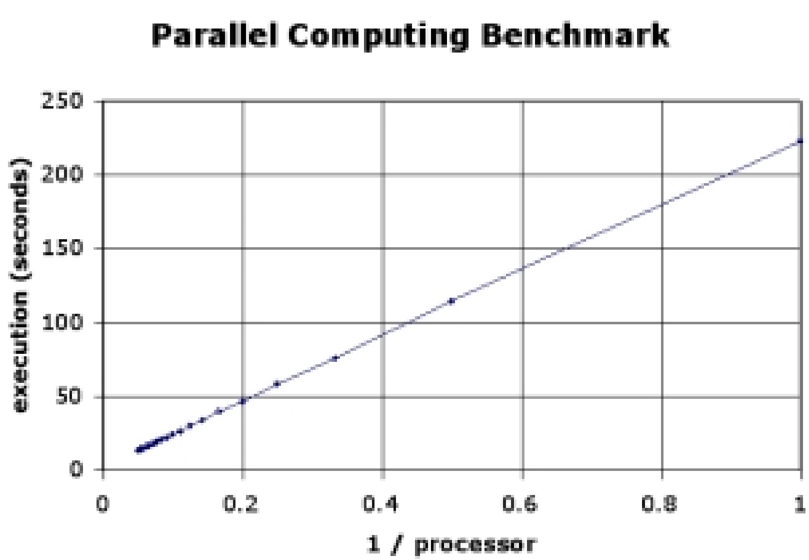


Figure 17: The linearity in the time for job completion with the number of processors.

Genomics tools are mostly centered around biological sequence analysis algorithms. In a typical analysis, a database of sequences is searched against a query sequence whose function may be unknown. If the search yields a set of “hits” from the database, and if these hits are similar in function, then one can infer the function of the unknown sequence by similarity. This type of search is highly parallel, since the comparison of the query with each sequence in the database is an independent calculation. Thus, an algorithm for splitting up the database, and submitting N searches to N nodes, is an effective parallelization method for these type of tools.

A benchmark of GRETEL was performed using a common sequence search algorithm known as HMMER, which operates under PVM (parallel virtual machine). HMMER consists of hidden markov modeling software, and the Pfam database, (a large set of HMM’s trained on alignments of known protein domains). These domains may be used to infer the function of a protein, it’s structure, or whether it is a known drug target, for example. For our benchmark we scored a single GPCR sequence against the entire Pfam database of about 3000 HMM’s. Figure 17 shows the linearity in the time for job completion with the number of processors. Figure 18 is a photo of the Farm. This method of low cost computing is proving to be a valuable resource for scientists, given the enormous size of datasets associated with the human genome project. The resource is available at http://genomics.arc.nasa.gov. ❏

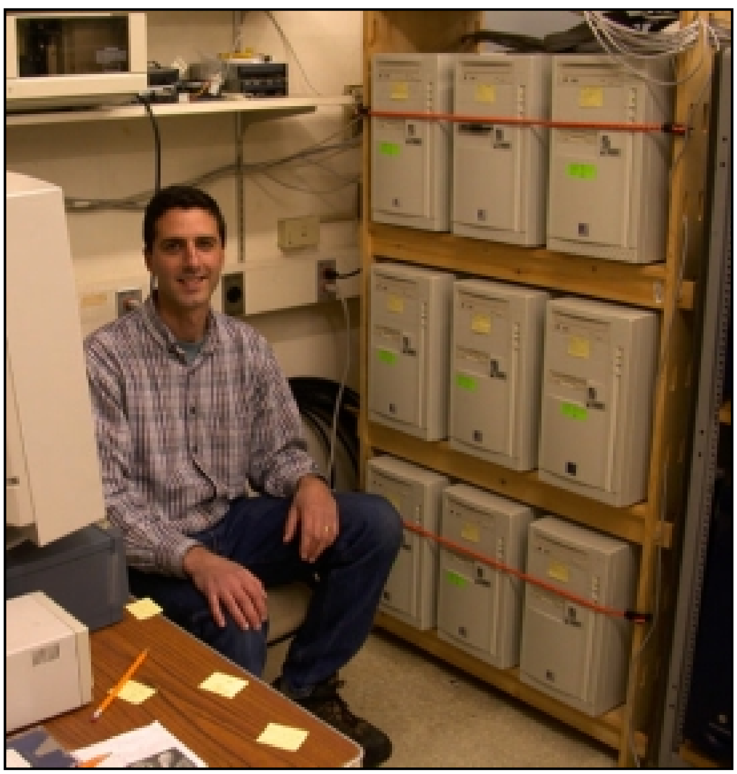


Figure 18: Photo of the Farm.

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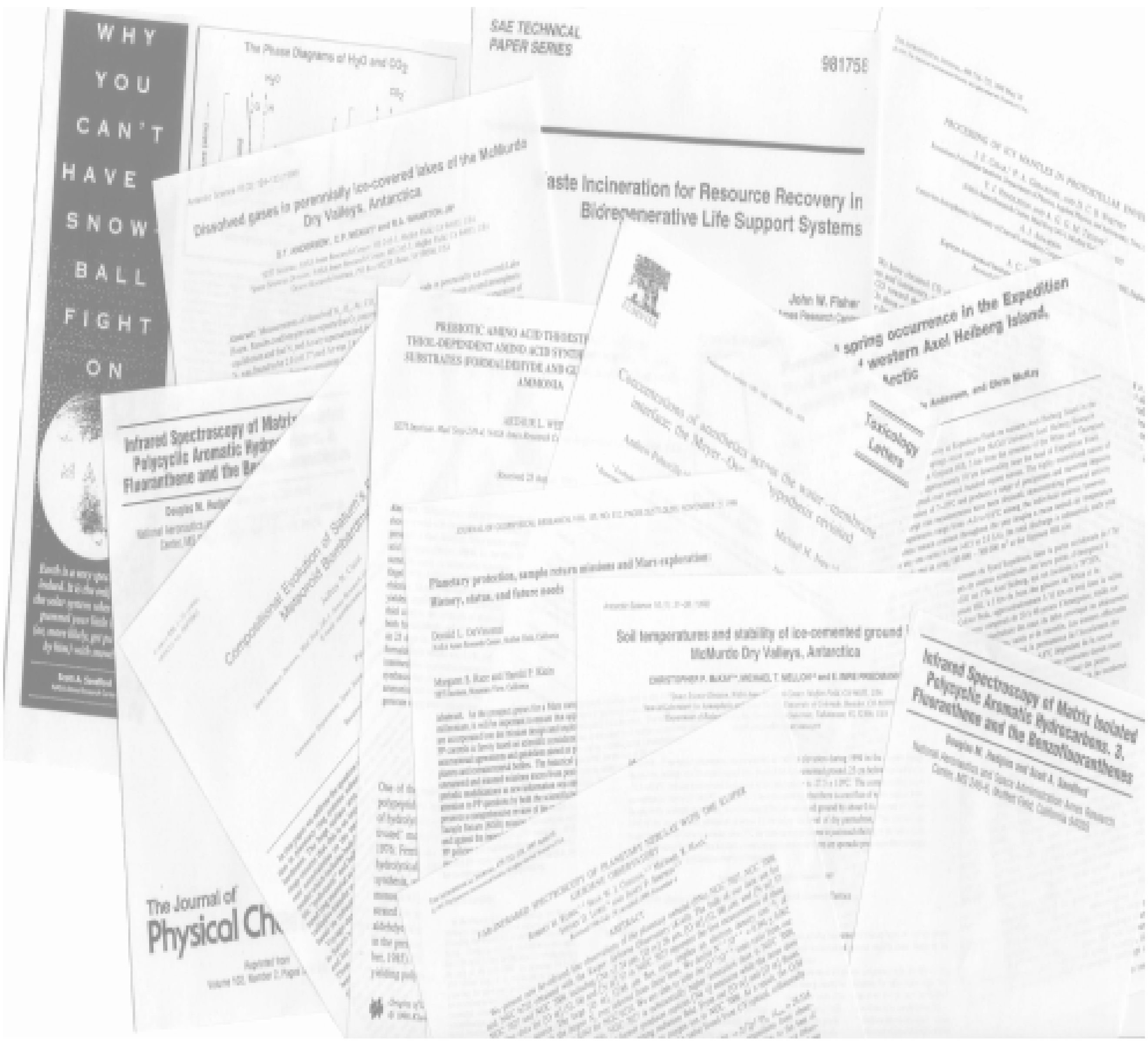
The following is a compilation of peer-reviewed publications, with a 2001 publication date, authored by Division personnel. Also included are patents, extended abstracts, chapters in books, etc.



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Space Science Division Personnel

The following is an alphabetical listing of all Division personnel current as of June 26, 2002. All Civil Servants are indicated with an asterisk (*) after their name and each person's Branch affiliation is listed at the far right (see the organization chart on page 8 for the code definitions). Individual members of the Division can be reached by telephone at (650) 60-[extension], by e-mail, or by writing to them at the following address:

NASA Ames Research Center
M.S. (enter 'Mail Stop' from roster list)
Moffett Field CA 94035-1000

Name	Extension	E-mail Address	Mail-Stop	Branch
Acevedo, Sara	Off-Site	sacevedo@mail.arc.nasa.gov	245-1	SS
Affleck, David	4-0276	daffleck@mail.arc.nasa.gov	239-7	SSR
Allamandola, Louis*	4-6890	lallamandola@mail.arc.nasa.gov	245-6	SSA
Asiyo, Cynthia	4-3110	casiyo@mail.arc.nasa.gov	239-4	SSX
Bakes, Emma	4-0787	bakes@shivakali.arc.nasa.gov	245-3	SST
Banin, Amos	4-2398	Not Available	239-4	SSX
Batalha, Natalie	4-0957	natalie@ssa1.arc.nasa.gov	245-3	SST
Bebout, Brad*	4-3227	bbebout@mail.arc.nasa.gov	239-4	SSX
Bebout, Lee*	4-3826	lbebout@mail.arc.nasa.gov	239-4	SSX
Becker, Joseph F.	4-3213	jbecker@mail.arc.nasa.gov	239-4	SSX
Belisle, Warren	4-5252	wbelisle@mail.arc.nasa.gov	239-11	SSR
Bell, Robbins*	4-0788	bell@cosmic.arc.nasa.gov	245-3	SST
Bernstein, Max	4-0194	mbernstein@mail.arc.nasa.gov	245-6	SSA
Biennier, Ludovic	4-4217	lbiennier@mail.arc.nasa.gov	245-6	SSA
Bishop, Janice	4-0297	jbishop@mail.arc.nasa.gov	239-4	SSX
Blackford, Cameron	4-5738	cblackford@mail.arc.nasa.gov	239-15	SSR
Blackwell, Charles	4-3208	cblackwell@mail.arc.nasa.gov	239-23	SSR
Blake, David*	4-4816	dblake@mail.arc.nasa.gov	239-4	SSX
Borchers, Bruce	4-3205	bborchers@mail.arc.nasa.gov	239-23	SSR
Borucki, Bill*	4-6492	wborucki@mail.arc.nasa.gov	245-3	SST
Borucki, Jerry*	4-3219	jborucki@mail.arc.nasa.gov	239-12	SSX
Boulanger, Richard	4-1418	rboulanger@mail.arc.nasa.gov	239-8	SSR
Bregman, Jesse*	4-6136	jbregman@mail.arc.nasa.gov	245-6	SSA
Bridger, Alison	4-5922	bridger@hellas.arc.nasa.gov	245-3	SST
Bunn, Karen*	4-1025	kbunn@mail.arc.nasa.gov	239-15	SSR
Cabral, Laura	4-6429	lcabral@mail.arc.nasa.gov	245-1	SS
Cabrol, Nathalie	4-0312	ncabrol@mail.arc.nasa.gov	245-3	SST
Caldwell, Douglas	4-3119	dcaldwell@mail.arc.nasa.gov	245-3	SST
Carpenter, Steven	4-0525	scarpenter@mail.arc.nasa.gov	239-4	SSX
Castellano, Tim*	4-4716	tcastellano@mail.arc.nasa.gov	245-6	SSA
Chambers, John	4-5515	john@mycenae.arc.nasa.gov	245-3	SST
Chan, Suzanne	4-0323	slchan@mail.arc.nasa.gov	239-15	SSR
Chandler, Trametria*	4-5524	tchandler@mail.arc.nasa.gov	245-3	SST
Charnley, Steve	4-5910	charnley@dusty.arc.nasa.gov	245-3	SST
Chavez, Carrie	4-0317	cchavez@mail.arc.nasa.gov	245-3	SST
Chen, Cameron	4-3298	Not Available	239-15	SSR
Chen, Kang	4-6074	kchen@mail.arc.nasa.gov	245-1	SS
Chiar, Jean	4-0324	chiar@misty.arc.nasa.gov	245-3	SST
Cho, Sheila	4-6590	sycho@mail.arc.nasa.gov	239-15	SSR
Colaprete, Anthony	4-2918	tonyc@hellas.arc.nasa.gov	245-3	SST

Name	Extension	E-mail Address	Mail-Stop	Branch
Colgan, Sean*	4-0420	colgan@cygnus.arc.nasa.gov	245-6	SSA
Conrad, Andrew	4-1189	aconrad@mail.arc.nasa.gov	245-3	SS
Cooper, George*	4-5968	gcooper@mail.arc.nasa.gov	239-4	SSX
Cooper, Robert	4-6264	cooper@ssa1.arc.nasa.gov	245-6	SSA
Cruikshank, Dale*	4-4244	dcruikshank@mail.arc.nasa.gov	245-6	SSA
Cuevas, Diana*	4-5029	dcuevas@mail.arc.nasa.gov	245-1	SS
Cullings, Kenneth*	4-2773	kcullings@mail.arc.nasa.gov	239-4	SSX
Cuzzi, Jeff*	4-6343	cuzzi@mail.arc.nasa.gov	245-3	SST
Dalle Ore, Cristina	4-6151	dalleore@misty.arc.nasa.gov	245-6	SSA
Dalton, Brad	4-3148	dalton@mail.arc.nasa.gov	245-3	SST
Davis, Sanford*	4-4197	sdavis@mail.arc.nasa.gov	245-3	SST
Davis, Wanda	4-3186	exobits@galileo.arc.nasa.gov	245-3	SST
De, Barna	4-3225	sde@mail.arc.nasa.gov	239-4	SSX
Delzeit, Lance*	4-0236	ldelzeit@mail.arc.nasa.gov	239-4	SSX
Des Marais, David*	4-3220	ddesmarais@mail.arc.nasa.gov	239-4	SSX
DeVincenzi, Donald*	4-5251	ddevincenzi@mail.arc.nasa.gov	245-1	SS
Discipulo, Mykell	4-6110	mdiscipulo@mail.arc.nasa.gov	239-4	SSX
Dobrovolskis, Tony	4-4194	dobro@cosmic.arc.nasa.gov	245-3	SST
Dotson, Jessie*	4-2041	dotson@cygnus.arc.nasa.gov	245-6	SSA
Doty, Moria	4-0784	mdoty@mail.arc.nasa.gov	239-4	SSX
Dworkin, Jason	4-0789	jdworkin@mail.arc.nasa.gov	245-6	SSA
Embaye, Tsegereda	4-6182	tembaye@mail.arc.nasa.gov	239-4	SSX
Engebretson, Pamela	4-6490	Not Available	245-3	SST
Ennico, Kimberly*	4-6067	kennico@mail.arc.nasa.gov	245-6	SSA
Erickson, Edwin F.*	4-5508	erickson@cygnus.arc.nasa.gov	245-6	SSA
Finn, Cory*	4-1027	cfinn@mail.arc.nasa.gov	239-8	SSR
Finn, John*	4-1028	jfinn@mail.arc.nasa.gov	239-15	SSR
Fisher, John*	4-4440	jfisher@mail.arc.nasa.gov	239-15	SSR
Flynn, Michael*	4-1163	mflynn@mail.arc.nasa.gov	239-15	SSR
Fonda, Mark*	4-5744	mfonda@mail.arc.nasa.gov	239-4	SS
Fontanilla, Anthony	4-0782	afontanilla@mail.arc.nasa.gov	245-3	SST
Forrest, Kindall	4-0390	kforrest@mail.arc.nasa.gov	239-7	SSR
Freedman, Richard	4-0316	freedman@darkstar.arc.nasa.gov	245-3	SST
Friedmann, E. Imre	4-1136	ifriedmann@mail.arc.nasa.gov	245-3	SST
Gazis, Paul	4-5704	pgazis@mail.arc.nasa.gov	245-3	SST
Goorvitch, David*	4-5502	dgoorvitch@mail.arc.nasa.gov	245-6	SSA
Gordon, Mitch	4-5529	mgordon@mail.arc.nasa.gov	245-3	SST
Gorti, Uma	4-3385	gorti@ism.arc.nasa.gov	245-3	SST
Graul, Rick	4-1292	graul@templar.arc.nasa.gov	239-4	SSX
Greene, Thomas*	4-5520	tgreene@mail.arc.nasa.gov	245-6	SSA

Name	Extension	E-mail Address	Mail-Stop	Branch
Grin, Edmond	4-2813	egrin@mail.arc.nasa.gov	245-3	SST
Gulick, Virginia	4-0781	vgulick@mail.arc.nasa.gov	245-3	SST
Haas, Michael*	4-5511	mhaas@mail.arc.nasa.gov	245-6	SSA
Haberle, Bob*	4-5491	bhaberle@mail.arc.nasa.gov	245-3	SST
Haisch, Karl E. Jr.	4-3571	khaisch@mail.arc.nasa.gov	245-6	SSA
Hammer, Nathan	Not Avail.	Not Available	239-15	SSR
Harker, David	4-5530	harker@corvus.arc.nasa.gov	245-3	SST
Heather, Neil	4-0319	neil@ringmaster.arc.nasa.gov	245-3	SST
Heyenga, Gerard	4-1258	gheyenga@mail.arc.nasa.gov	239-23	SSR
Hoehler, Tori*	4-1355	thoehler@mail.arc.nasa.gov	239-4	SSX
Hogan, Bob	4-0780	hogan@cosmic.arc.nasa.gov	245-3	SST
Hogan, Mary	4-0525	mhogan@mail.arc.nasa.gov	239-4	SSX
Hollenbach, David*	4-4164	hollenbach@ism.arc.nasa.gov	245-3	SST
Hollingsworth, Jeff	4-6275	jeffh@humbabe.arc.nasa.gov	245-3	SST
Houben, Howard	4-3381	houben@humbabe.arc.nasa.gov	245-3	SST
Howell, Colleen	4-3658	chowell@mail.arc.nasa.gov	239-4	SSX
Howard, Jeanie	4-1257	jhoward@mail.arc.nasa.gov	239-7	SSR
Hubickyj, Olenka	4-5727	hubickyj@pollack.arc.nasa.gov	245-3	SST
Hudgins, Douglas*	4-4216	dhudgins@mail.arc.nasa.gov	245-6	SSA
Humphry, Donald	4-6760	dhumphry@mail.arc.nasa.gov	239-12	SSX
Jahnke, Linda*	4-3221	ljahnke@mail.arc.nasa.gov	239-4	SSX
Johnson, Jeff	4-1264	jjohnson@mail.arc.nasa.gov	239-23	SSR
Jones, Harry*	4-5518	hjones@mail.arc.nasa.gov	239-8	SSR
Kagawa, Hiromi	4-3683	hkagawa@mail.arc.nasa.gov	239-15	SSR
Kahl, Nicole	4-6530	Not Available	239-4	SSX
Kato, Katharine	4-5218	kkato@mail.arc.nasa.gov	239-14	SSX
Kaufman, Michael	4-0320	kaufman@ism.arc.nasa.gov	245-3	SST
Khan, Ariful	4-5537	akhan@mail.arc.nasa.gov	235-6	SSA
Khare, Bishun	4-2465	bkhare@mail.arc.nasa.gov	239-11	SST
Kliss, Mark*	4-6246	mkliss@mail.arc.nasa.gov	239-15	SSR
Koch, David*	4-6548	dkoch@mail.arc.nasa.gov	245-6	SSA
Koerber, Chris	4-0367	ckoerber@mail.arc.nasa.gov	245-6	SSA
Kojiro, Daniel*	4-5364	dkojiro@mail.arc.nasa.gov	239-12	SSX
Kubo, Michael	4-6110	mkubo@mail.arc.nasa.gov	239-4	SSX
Kuschill-Gobin, Deb	4-6197	dkuschill@mail.arc.nasa.gov	245-3	SS
Lamparter, Richard*	4-1159	rlamparter@mail.arc.nasa.gov	239-15	SSR
Last, Robert	4-1504	last@cosmic.arc.nasa.gov	245-3	SST
Lau, Evan	4-6941	elau@mail.arc.nasa.gov	239-4	SSX
Lebonnois, Sebastien	4-0321	lebonnoi@dusty.arc.nasa.gov	245-3	SST
Lee, Pascal	4-0315	pclee@earthlink.net	245-3	SST

Name	Extension	E-mail Address	Mail-Stop	Branch
Lesberg, David M.*	4-5970	dlesberg@mail.arc.nasa.gov	245-6	SSA
Levri, Julie*	4-6917	jlevri@mail.arc.nasa.gov	239-8	SSR
Lissauer, Jack*	4-2293	lissauer@ringside.arc.nasa.gov	245-3	SST
Lissol, Peter	4-6318	plissol@mail.arc.nasa.gov	T3B-4	SSA / FEE
Litwiller, Eric	4-5673	elitwiller@mail.arc.nasa.gov	239-8	SSR
Makhija, Shilpa	4-6179	smakhija@mail.arc.nasa.gov	239-4	SSX
Mancinelli, Rocco	4-6165	rmancinelli@mail.arc.nasa.gov	239-4	SSX
Marinova, Margarita	4-6874	mars@gal.arc.nasa.gov	245-2	SST
Marley, Mark*	4-0805	mmarley@mail.arc.nasa.gov	245-3	SST
Mason, Chris	4-4079	mason@cygnus.arc.nasa.gov	245-6	SSA
Mattioda, Andrew	4-1075	amattioda@mail.arc.nasa.gov	245-6	SSA
Mattos Saguindel, Lori*	4-5763	lmattos@mail.arc.nasa.gov	239-4	SSX
McKay, Chris*	4-6864	cmckay@mail.arc.nasa.gov	245-3	SST
McMillan, Andrew*	4-0474	amcmillan@mail.arc.nasa.gov	239-15	SSR
Mogul, Rakesh	4-2344	rmogul@mail.arc.nasa.gov	239-15	SSR
Moller, Ken	4-2111	kmoller@mail.arc.nasa.gov	245-3	SS
Monaco, Regina	4-5766	Remonaco@groucho.arc.nasa.gov	239-4	SSX
Montgomery, Leslie	4-0414	lmontgomery@mail.arc.nasa.gov	239-15	SSR
Moore, Jeff*	4-5529	jmoore@mail.arc.nasa.gov	245-3	SST
Moore, Liz	4-3718	moore@cygnus.arc.nasa.gov	245-6	SSA
Morris, Robert L.	4-5499	rlmorris@mail.arc.nasa.gov	239-20	SST
Mosqueira, Ignacio	4-2797	mosqueir@cosmic.arc.nasa.gov	245-3	SST
Mulloth, Lila	4-1904	lmulloth@mail.arc.nasa.gov	239-7	SSR
New, Mike*	4-4762	mnew@mail.arc.nasa.gov	239-4	SSX
Ng, Hou Tee	4-6146	hng@mail.arc.nasa.gov	229-1	SSX
Nottage, Julie	4-3711	jnottage@mail.arc.nasa.gov	245-3	SS
Ocampo-Friedmann, Roseli	4-1136	ifriedmann@mail.arc.nasa.gov	245-3	SST
Orphan, Victoria	4-0892	vorphan@mail.arc.nasa.gov	239-4	SSX
Owen, Sandra*	4-1281	sowen@mail.arc.nasa.gov	245-1	SS
Paavola, Chad*	4-5647	cpaavola@mail.arc.nasa.gov	239-15	SSR
Palmer, Gary H.*	4-3668	ghpalmer@mail.arc.nasa.gov	239-4	SSX
Parravano, Antonio	4-3120	parravan@ism.arc.nasa.gov	245-3	SST
Pendleton, Yvonne*	4-4391	ypendleton@mail.arc.nasa.gov	245-3	SST
Pisharody, Suresh	4-1859	spisharody@mail.arc.nasa.gov	239-7	SSR
Pohorille, Andrew*	4-5759	pohorill@raphael.arc.nasa.gov	239-4	SSX
Poulet, Francois	4-6001	poulet@cosmic.arc.nasa.gov	245-3	SST
Quigley, Emmett*	4-5970	equigley@mail.arc.nasa.gov	245-6	SSA
Quinn, Richard	4-6501	rquinn@mail.arc.nasa.gov	239-12	SST
Quintana, Elisa	4-0329	equintan@estrellas.arc.nasa.gov	245-3	SST
Rages, Kathy	4-6735	krages@mail.arc.nasa.gov	245-3	SST

Name	Extension	E-mail Address	Mail-Stop	Branch
Raleigh, Chris	4-3782	craleigh@mail.arc.nasa.gov	239-4	SSX
Rau, Greg	4-6110	rau4@llnl.gov	239-4	SSX
Reynolds, Ray	4-5532	reynolds@cosmic.arc.nasa.gov	245-3	SST
Rivera, Eugenio	4-0322	rivera@epimethius.arc.nasa.gov	245-3	SST
Rodgers, Steve	4-0331	rodgers@dusty.arc.nasa.gov	245-3	SST
Roellig, Thomas L.*	4-6426	troellig@mail.arc.nasa.gov	245-6	SSA
Roush, Ted*	4-3526	troush@mail.arc.nasa.gov	245-3	SST
Rubin, Robert	4-6450	rubin@cygnus.arc.nasa.gov	245-6	SSA
Ryan, Michael	4-4884	mryan@mail.arc.nasa.gov	245-3	SS
Salama, Farid*	4-3384	fsalama@mail.arc.nasa.gov	245-6	SSA
Sanchez, Lupe*	4-5528	lcsanchez@mail.arc.nasa.gov	245-6	SSA
Sandford, Scott*	4-6849	ssandford@mail.arc.nasa.gov	245-6	SSA
Sarrazin, Philippe	4-5733	psarrazin@mail.arc.nasa.gov	239-4	SSX
Sauke, Todd B.	4-3213	tsauke@mail.arc.nasa.gov	239-4	SSX
Scargle, Jeff*	4-6330	jeffrey@cosmic.arc.nasa.gov	245-3	SST
Schaeffer, Jim	4-6078	jschaef@mintz.arc.nasa.gov	245-3	SST
Schilling, James	4-2796	jschilling@mail.arc.nasa.gov	245-3	SS
Schulte, Mitch*	4-0527	mschulte@mail.arc.nasa.gov	239-4	SSX
Schweighofer, Karl	4-1292	karl@templar.arc.nasa.gov	239-4	SSX
Scimeca, David C.*	4-5970	dscimeca@mail.arc.nasa.gov	245-6	SSA
Shah, Kinjal	4-6110	ksshah@mail.arc.nasa.gov	239-4	SSX
Showalter, Mark	4-3382	mshowalter@mail.arc.nasa.gov	245-3	SST
Simpson, Janet	4-1613	simpson@cygnus.arc.nasa.gov	245-6	SSA
Smernoff, David	4-1230	dsmernoff@mail.arc.nasa.gov	239-4	SSX
Smith, Bruce*	4-5515	bfsmith@mail or smith@humbabe	245-3	SST
Stassinopoulos, Dimitris	4-5766	stassi@raphael.arc.nasa.gov	239-4	SSX
Steiman-Cameron, Tom	4-0328	tomsc@shevek.arc.nasa.gov	245-3	SST
Steinacker, Adriane C.	4-2308	adriane@duras.arc.nasa.gov	245-3	SST
Stevens, Judy	4-4014	jkstevens@mail.arc.nasa.gov	245-3	SS
Stoker, Carol*	4-6490	cstoker@mail.arc.nasa.gov	245-3	SST
Stone, Brad	4-5495	bstone@science.sjsu.edu	245-6	SSA
Summers, David	4-6206	dsummers@mail.arc.nasa.gov	239-4	SSX
Sutter, Brad	4-2983	bsutter@mail.arc.nasa.gov	245-3	SST
Takeuchi, Nori	4-3214	ntakeuchi@mail.arc.nasa.gov	239-12	SSX
Taylor, Cindy	4-3027	ctaylor@mail.arc.nasa.gov	239-12	SST
Temi, Pasquale	4-1841	temi@ssa1.arc.nasa.gov	245-6	SSA
Trent, Jonathan*	4-3686	jtrent@mail.arc.nasa.gov	239-15	SSR
Tsairides, Catherine	4-0808	tsairides@mail.arc.nasa.gov	239-4	SSX
Turk, Kendra	4-1430	kturk@mail.arc.nasa.gov	239-4	SSX
Urquhart, Mary	4-1794	murquhart@mail.arc.nasa.gov	239-20	SST

Name	Extension	E-mail Address	Mail-Stop	Branch
Verma, Sunita	4-6051	sverma@mail.arc.nasa.gov	239-15	SSR
Walker, Robert*	4-4811	bwalker@mail.arc.nasa.gov	245-6	SSA
Walton, Barbara	4-6055	bwalton@mail.arc.nasa.gov	239-23	SSR
Warren-Rhodes, Kimberley	4-0489	kwarren-rhodes@mail.arc.nasa.gov	245-3	SST
Way, Michael*	4-5115	mway@mail.arc.nasa.gov	245-6	SSA
Webb, Richard	4-6857	rwebb@mail.arc.nasa.gov	245-6	SSA
Webbon, Bruce*	4-6646	bwebbon@mail.arc.nasa.gov	239-15	SS / SSR
Weber, Arthur L.	4-3226	aweber@mail.arc.nasa.gov	239-4	SSX
Weber, Esther	4-3226	eweber@mail.arc.nasa.gov	239-4	SSX
Wignarajah, K. “Wiggy”	4-5201	wwignarajah@mail.arc.nasa.gov	239-8	SSR
Wilson, Mike	4-5496	mwilson@mail.arc.nasa.gov	239-4	SSX
Wisniewski, Richard*	4-1024	rwisniewski@mail.arc.nasa.gov	239-23	SSR
Witterborn, Fred C.	4-4393	fwitteborn@mail.arc.nasa.gov	245-6	SSA
Wooden, Diane H.*	4-5522	wooden@delphinus.arc.nasa.gov	245-3	SST
Yergovitch, Steve	Not Avail.	Not Available	245-6	SSA
Young, Richard E.*	4-5521	reyoung@mail.arc.nasa.gov	245-3	SST
Yuen, Lunming	4-3146	lyuen@mail.arc.nasa.gov	245-6	SSA
Zahnle, Kevin*	4-0840	kzahnle@mail.arc.nasa.gov	245-3	SST
Zent, Aaron*	4-5517	azent@mail.arc.nasa.gov	245-3	SST