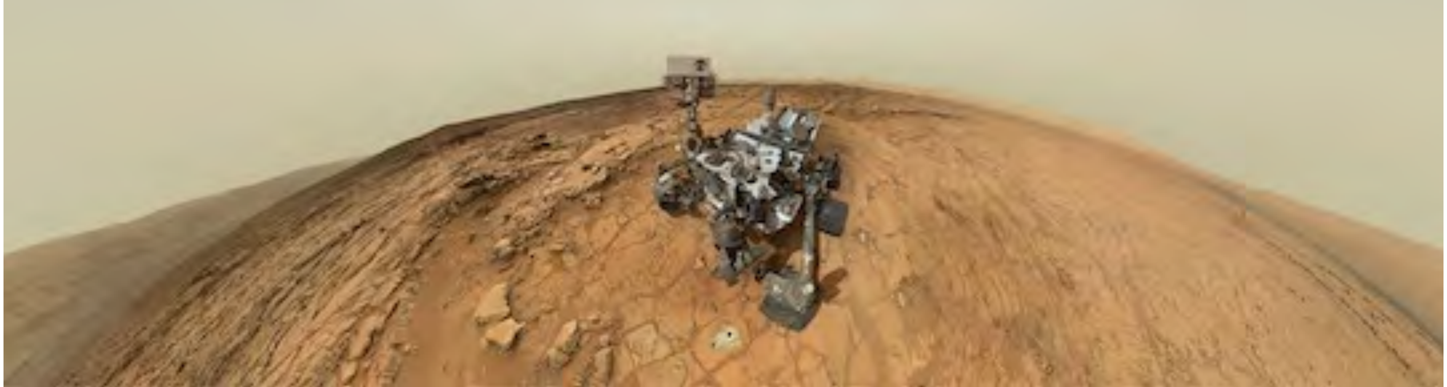
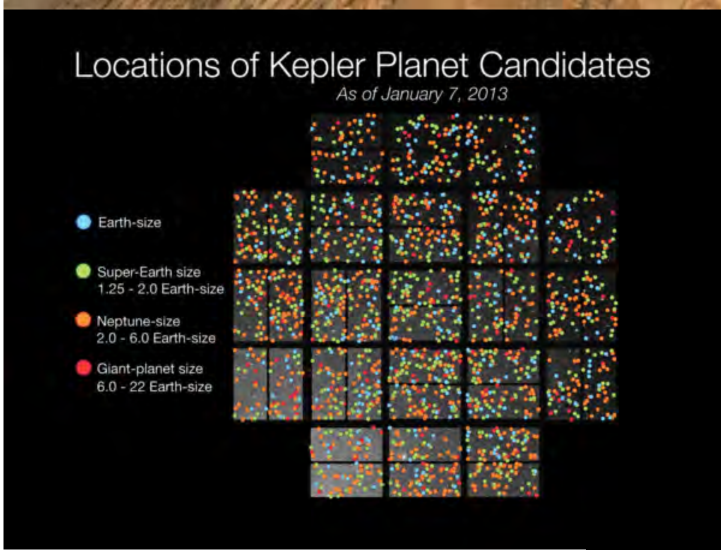
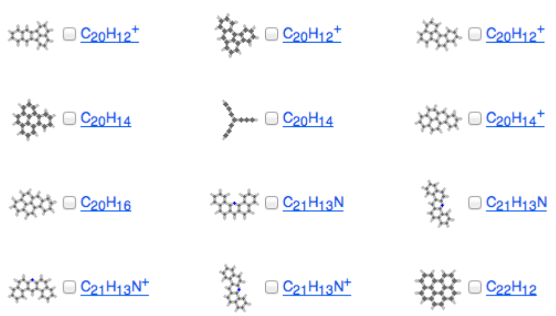
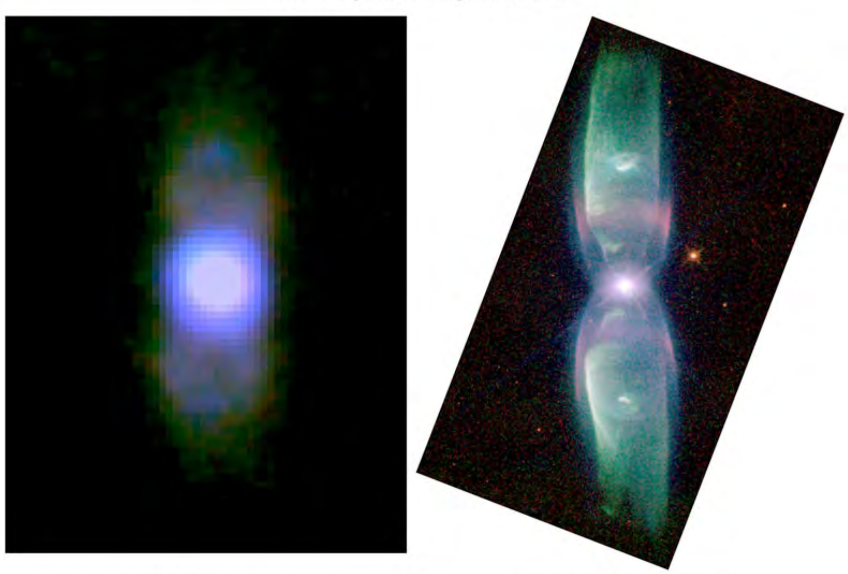
NASA Ames Space Science and Astrobiology Symposium
March 12, 2013







M2-9 planetary nebula



SOFIA infrared image | Hubble visual-wavelength image

(Infrared and visual-wavelength images presented with the same orientation and scale.)

Welcome to the Ames Space Science and Astrobiology Symposium!

The Space Science and Astrobiology Division at NASA Ames Research Center consists of over 50 Civil Servants and more than 110 contractors, co-ops, post-docs and associates. Researchers in the division are pursuing investigations in a variety of fields including exoplanets, planetary science, astrobiology and astrophysics. In addition, division personnel support a wide variety of NASA missions including (but not limited to) Kepler, SOFIA, LADEE, JWST, and New Horizons. With such a wide variety of interesting research going on, distributed among three branches in at least 5 different buildings, it can be difficult to stay abreast of what one's fellow researchers are doing. Our goal in organizing this Symposium is to facilitate communication and collaboration among the scientists within the division, and to give center management and other ARC researchers and engineers an opportunity to see what scientific research and science mission work is being done in the division.

We also wanted to start a new tradition within the Space Science and Astrobiology Division to honor one senior and one early career scientist with the Pollack Lecture and the Early Career Lecture, respectively. With the Pollack Lecture, our intent is to select a senior researcher who has made significant contributions to any area of research within the space sciences, and we are pleased to honor Dr. Dale Cruikshank this year. With the Early Career Lecture, our intent is to select a young researcher within the division who, by their published scientific papers, shows great promise for the future in any area of space science research, and we are pleased to honor Dr. Rus Belikov this year.

We hope you can take advantage of the day to learn something new and meet some new faces!

Sincerely,

Science Organizing Committee

Tim Lee
Mark Fonda
Jessie Dotson
Jeff Hollingsworth
Orlando Santos

First Annual Space Sciences Symposium March 12, 2013	
8:00	registration & poster setup
8:30	Michael Bicay: Welcome
8:45	Outstanding Early Career Space Scientist Lecture: Rus Belikov: Beyond Kepler: Direct Imaging of Earth-Like Planets
9:45	Jack Lissauer: Accretion of Water by Exo-Earths
10:05	Jason Rowe: Mapping the Surface of a Rocky Extrasolar Planet: Kepler-10b
10:25	Poster Session (odd number posters) & Coffee Break
11:10	Philippe Sarrazin: The development of CheMin, it's employment on the MSL rover Curiosity and first quantitative mineralogical results from Mars
11:30	Thomas Bristow: Ancient Cold-Seep Deposits as Paleoenvironmental Indicators of the Late Precambrian to Early Paleozoic Biosphere
11:50	Richard Quinn: Perchlorate Radiolysis on Mars and the Origin of Martian Soil Reactivity
12:10	Poster Session / Lunch
13:15	David Des Marais: Microbial mats offer insights about our early biosphere and its biosignatures
13:35	Lee Bebout: Microbial Systems: Nexus roles for Astrobiology, Energy and Space
13:55	Nathalie Cabrol: Exploring Planetary Lakes
14:15	Pamela Marcum: Extremely Isolated Early-Type Galaxies: Benchmarks of Galaxy Evolution
14:35	Hans Zinnecker: SOFIA mid-infrared observations of the Orion Nebula region
14:55	Cesar Contreras: Laboratory Studies of the Formation of Carbonaceous Dust from PAH Precursors
15:15	Poster Session (even number posters) & Coffee Break
16:00	Rick Elphic: The Lunar Atmosphere and Dust Environment Explorer (LADEE): T-minus 6 months and counting
16:20	Pollack Lecture: Dale Cruikshank: Planetary Chemistry: Ices to Organics
17:20	Remove Posters

id	Title	Corresponding Author
Astrobiology Posters		
AB.1	Anomalous mirror-image ratios of meteoritic sugar derivatives	George Cooper
AB.2	The Sutter's Mill CM Chondrite and the Tissint Shergottite: First Data from The NASA Ames Thermoluminescence Laboratory	Derek Sears
AB.3	High-throughput comparative sequence analysis of in vitro RNA evolution	Mark Ditzler
AB.4	Sugars, the Carbon Group Molecular Battery of Biotic and Abiotic Synthesis	Art Weber
AB.5	How Proteins Became Functional?	Mike Wilson
AB.6	Energy Transduction in Vesicles, Reduction of Important REDOX Carriers Such as Qui- nones and NAD+	David Summers
AB.7	Photochemistry of Pyrimidine in Astrophysical Ices: Formation of Nucleobases and Other Prebiotic Species	Michel Nuevo
AB.8	Anoxygenic growth of cyanobacteria on Fe(II) and their associated biosignatures: Implications for biotic contributions to Precambrian Iron Formations	Mary Nichole (Niki) Parenteau
AB.9	Biosignatures for Chemo- and Photo- Synthetic Systems: Early Earth and Mars?	Linda Jahnke
AB.10	Towards Understanding the Dry Limit of Life	Alfonso Davila
AB.11	Ice Dragon: A Mission to address Science and Human Exploration Objectives on Mars	Carol Stoker
AB.12	Landing site analysis to support a Mars extant life and biomarker detection mission	Jennifer Heldmann
AB.13	The Icebreaker Life Mission to Mars: A search for biomolecular evidence for life	Chris McKay
AB.14	The search for organics on Mars	Chris McKay
AB.15	Gene Expression Measurement Module (GEMM) - a Fully Automated, Miniaturized Instrument for Measuring Gene Expression in Space	Andrew Pohorille
AB.16	The ORGANIC Experiment on EXPOSE-R on the ISS: A Space Exposure Experiment	Kathryn Bryson
AB.17	SEVO (Space Environment Viability of Organics): Results from NASA's First Astrobiology Small Payloads Mission	Andy Mattioda
AB.18	SEVO (Space Environment Viability of Organics) Laboratory Control Experiments: Supporting Data for the O/OREOS Mission	Amanda Cook
AB.19	OREOcube: ORganics Exposure in Orbit	Richard Quinn
AB.20	Tackling SMD and HEOMD interests one field deployment at a time The Pavilion Lake Research Project	Darlene Lim
AB.21	Astrobiology Field Analog Research, Education, and Conservation at the Ubehebe Volcanic Field (Death Valley National Park, CA): Discovery and Awareness for a possible tomorrow	Rosalba Bonaccorsi
AB.22	Astrobiology field research in a High-Fidelity Desert Analog Site: The Ubehebe Volcanic Field (Death Valley, California)	Rosalba Bonaccorsi
AB.23	Microbiological Genetic Inventory within the NASA Ames Research Center High Bay Cleanroom	Fathi Karouia
Astrophysics Posters		
AP.1	In-flight Performance of the Water Vapor Monitor Onboard the SOFIA Observatory	Thomas Roellig
AP.2	The Echelon-Cross-Echelle Spectrograph (EXES) is one of the first generation instruments for the Stratospheric Observatory for Infrared Astronomy (SOFIA).	Curtis DeWitt
AP.3	Adventures High Energy Astrophysics: From the Sun to the Crab Nebula and Beyond	Jeff Scargle

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AP.4	Sounding the Stars: Asteroseismology with the Kepler Space Telescope	Daniel Huber
AP.5	Astrophysics from Kepler: The Radii of Low-Mass Stars in Long-Period Eclipsing Binaries	Jeffrey Coughlin
AP.6	Star formation in nearby early-type galaxies	Alexandre Amblard
AP.7	Multiwavelength Diagnostics of a Late-stage Galaxy Merger Sequence	Michael Fanelli
AP.8	Extragalactic detection of CH 532/536 GHz lines from Herschel: NGC 1068, M82, Arp 220 and NGC 253	Naseem Rangwala
AP.9	Variations of Mid and Far-IR Luminosities Among Early-Type Galaxies: Relation to Stellar Metallicity and Cold Dust	Pasquale Temi
AP.10	Differential Heating of Magnetically Aligned Dust Grains	John Vaillancourt
AP.11	Observational Constraints on Interstellar Grain Alignment Mechanisms	B-G Anderson
AP.12	How empty are the dust holes in the inner regions of evolved protoplanetary disks?	Uma Gorti
AP.13	Multi-wavelength Survey of W40: A Star-Forming Region	Sachin Shenoy
AP.14	Mid-infrared Imaging Of The W40 Star Forming Region Using	Ralph Shuping
AP.15	Spatial Analysis of the Polycyclic Aromatic Hydrocarbon Features Southeast of the Orion Bar	Lou Allamandola
AP.16	Analysis of Spitzer IRS Spectral Maps of the Reflection Nebula NGC7023 with the NASA Ames PAH Spectroscopic Database	Jesse Bregman
AP.17	The NASA Ames PAH IR Spectroscopic Database V 2.0 – Spectroscopic Fitting Tools and More	Christiaan Boersma
AP.18	The Infrared Spectra of Polycyclic Aromatic Hydrocarbons with Excess Peripheral H Atoms (Hn-PAHs) and their Relation to the 3.4 and 6.9 µm PAH Emission Features	Scott Sandford
AP.19	Formation routes for pure polycyclic aromatic hydrocarbon (PAH) molecules and N- and O-substituted PAH molecules in the outflows of carbon stars	Partha Bera
AP.20	Polycyclic Aromatic Hydrocarbon Clusters in the Interstellar Medium	Joseph Roser
AP.21	Recent Progress in DIB Research: A Survey of PAHS and DIBS	Farid Salama
AP.22	Quartic Force Fields and Dipole Surfaces for Accurate Computational Rovibrational Reference Data for Interstellar Studies	Ryan Fortenberry
Exoplanet Posters		
EP.1	Discovery of the smallest known exoplanet	Tom Barclay
EP.2	Accretion of Water by Exo-Earths	Jack Lissauer
EP.3	Confirmation of Kepler Hot Jupiters via Phase Curve Analysis	Elisa Quintana
EP.4	High Resolution Imaging at Gemini-N: Exoplanets and Beyond	Steve Howell
EP.5	Obtaining sub-uas astrometry on a wide-field, coronagraph equipped, space telescope using a diffractive pupil	Eduardo Bendek
EP.6	Experimental study of a low-order wavefront sensor for a high-contrast coronagraphic imager at 1.2 lambda/D	Julien Lozi
EP.7	Achromatic Focal Plane Mask for Exoplanet Imaging Coronagraphy	Kevin Newman
EP.8	Improving image contract for the direct detection of exoplanets	Sandrine Thomas
EP.9	A Framework for Characterizing the Performance of the Kepler Exoplant Search and Data Products	John Jenkins
EP.10	Removing the Noise While Preserving the Signal – An Empirical Bayesian Approach to Kepler Light Curve Systematic Error Correction	Jeffrey Smith

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EP.11	Dynamic Black-Level Correction and Artifact Flagging for Kepler Pixel Time Series	Bruce Clarke
EP.12	Transit Model Fitting in the Kepler Science Operations Center Pipeline	Jie Li
EP.13	A $\chi 2$ Discriminator for Transiting Planet Detection in Kepler Data	Shawn Seader
EP.14	The Kepler Pipeline Data Validation Report	Joseph Twicken
Planetary Atmosphere & Climate Posters		
PA.1	Transport in the early Solar Nebula: Follow the Water	Sanford Davis
PA.2	CO2 and SO2 IR Line Lists for Venus/Mars and Exo-planet Atmosphere Studies	Xinchuan Huang
PA.3	Investigating Titan's Atmospheric Chemistry at Low Temperature with the NASA Ames Titan Haze Simulation Experiment	Ella Sciamma-O'Brien
PA.4	Are Water Ice Grains on the Martian North Pole Growing? Did Talc-Caronate Hydrothermal Alteration occur at NILI FOSSAE, MARS?	Adrian Brown
PA.5	Analysis of TES FFSM Eddies and MOC Dust Storms, MY 24 - 26	John Noble
PA.6	What Is the Curiosity Rover Telling Us About the Climate of Mars?	Robert Haberle
PA.7	Waiting for O2	Kevin Zahnle
PA.8	Characterizing Venus' Upper Atmosphere: VTGCM Simulations	Amanda Brecht
PA.9	Investigating the asymmetry of Mars' South Polar Cap using the NASA Ames Mars General Circulation Model with a CO2 cloud microphysics scheme	Julie Dequaire
PA.10	Large-Scale Extratropical Weather Systems in Mars' Atmosphere	Jeff Hollingsworth
PA.11	The Early Martian Atmosphere: Investigating the role of the dust cycle in the possible maintenance of two stable climate states	Melinda Kahre
PA.12	Transient climate effects of large impacts on Titan	Kevin Zahnle
Planetary Surfaces & Interiors Posters		
PS.1	The Crystalline Fraction in Cometary Grains: Forsterite of Polyhedral Shapes and Forsterite in Porous Aggregates	Diane Wooden
PS.2	High Resolution Simulations of the Giant Impact Formation	Luis Teodoro
PS.3	Prospecting for Polar Volatiels: Results from the Resolve Field Test	Rick Elphic
PS.4	Hydrocarbon ices in extra-red TNOs and Centaurs	Cristina Dalle Ore
PS.5	Hydrocarbons on Phoebe, Iapetus, and Hyperion: Quantitative Analysis	Dale Cruikshank
PS.6	Evidence for an extremely short period of hydrologic activity in Newton crater, Mars near the Hesperian-Amazonian transition	Reid Parsons
PS.7	RESOLVE: A Lunar Volatiles Prospecting Mission	Anthony Colaprete
PS.8	Estimating Optical Constants of Solar System Materials	Ted Roush
PS.9	Radiative transfer in complex media	Sanaz Vahidinia
PS.10	A High Resolution Map of the Martian Hydrogen Distribution	Luis Teodoro
PS.11	Laboratory Studies of the effect of Gases on Activated Lunar Simulant	Claire Ricketts
PS.12	Space Suit Impact on Efficiency and Performance of Field Science Tasks	David Wilson
PS.13	Mars science in the ice-cemented ground of University Valley Antarctica	Chris McKay
PS.14	The New Horizons Pluto Fly-By Mission – Coming to a New World 32 AU away – Jul 14, 2015	Kimberly Ennico

Title: "Beyond Kepler: Direct Imaging of Earth-like Exoplanets"
Rus Belikov
Abstract:

Is there another Earth out there? Is there life on it? People have been asking these questions for over two thousand years, and we finally stand on the verge of answering them. The Kepler space telescope is NASA's first mission designed to study Earthlike exoplanets (exo-Earths), and it will soon tell us how often exo-Earths occur in the habitable zones of their stars. The next natural step after Kepler is spectroscopic characterization of exo-Earths, which would tell us whether they possess an atmosphere, oxygen, liquid water, as well as other biomarkers. In order to do this, directly imaging an exo-Earth may be necessary (at least for Sun-like stars).

Directly imaging an exo-Earth is challenging and likely requires a flagship-size optical space telescope with an unprecedented imaging system capable of achieving contrasts of 1e10 very close to the diffraction limit. Several coronagraphs and external occulters have been proposed to meet this challenge and are in development. After first overviewing the history and current state of the field, my talk will focus on the work proceeding at the Ames Coronagraph Experiment (ACE) at the NASA Ames Research Center, where we are developing the Phase Induced Amplitude Apodization (PIAA) coronagraph in a collaboration with University of Arizona, Lockheed Martin, and JPL. PIAA is a powerful technique with demonstrated aggressive performance that defines the state of the art at small inner working angles. At ACE, we have achieved contrasts of 2e-8 with an inner working angle of 2 lambda/D and 8e-7 at 1.2 lambda/D. On the path to exo-Earth imaging, we are also pursuing a smaller telescope concept called EXCEDE (EXoplanetary Circumstellar Environments and Disk Explorer), which was recently selected for technology development (Category III) by NASA's Explorer program. EXCEDE will do fundamental science on debris disks as well as serve as a technological and scientific pathfinder for an exo-Earth imaging mission.

Oral Presentation: 9:45am

Accretion of Water by Exo-Earths

Jack J. Lissauer and Elisa V. Quintana

By cosmic standards, Earth is highly deficient in volatiles. The condensed component of a solar composition mixture that is cool enough for all of the water to be in solid form is over 50% ice by mass. In contrast, the Earth's oceans and other near-surface reservoirs represent only 0.03% of our planet's mass, with a comparable amount of water thought to lie in the mantle. So Earth was very inefficient in accreting water from the protoplanetary disk. To investigate how the type of star and giant planet configurations can affect the ability of Earth-size planets to accumulate and retain volatiles, we numerically model the late stages of terrestrial planet growth. We follow the evolution of numerous disks of planetesimals and embryos around a Sun-like star, and compare the effects of various giant planet or stellar companions on the accretion process. Our approach employs moderate-resolution simulations that have sufficiently modest computational requirements to allow us to perform the dozens of simulations required to disentangle effects of the companion body from stochastic variations that are an important aspect of terrestrial planet growth.

Oral Presentation: 10:05am

Mapping the Surface of a Rocky Extrasolar Planet: Kepler-10b

Rowe, Jason; Barclay, T.; Batalha, N. M.; Quintana, E. V.; Roberts, J.; Mission, Kepler

Kepler-10b is a terrestrial planet orbiting its host star every 20 hours. At semi-major axis of 0.017 AU the planet receives a substantial amount of energy that heats the surface to approximately 2000 K. Data from the Kepler photometer with its wide band-pass provides a clear detection of thermal emission from the planet. Additionally, a secondary eclipse is clearly observed with a depth of 8 parts-per-million. We also also confirm the detection of a phase curve with a shape dominated by the day-night cycle of the planet. However, we also see a significant asymmetry in the phase curve. We put forth planetary surface thermal emission and reflection models which explain the asymmetry and present a surface brightness map of a rocky extrasolar planet.

Oral Presentation: 11:10am

The development of CheMin, its deployment on the MSL rover *Curiosity* and first quantitative mineralogical results from Mars

David Blake
SSX

The proof of concept CheMin X-ray Diffraction / X-ray Fluorescence instrument was first developed in 1991 as a Director's Discretionary Fund project. This instrument utilized a modified commercial X-ray source and a cooled CCD imager that was directly exposed to the X-rays and operated in single photon counting mode so that the energies of individual X-ray photons could be retained, along with their x,y position on the detector. Powdered samples were prepared by manual grinding and pressing the material into a thin film attached to an electron microscope sample grid. From this crude start, refinements were made to the hardware, including miniaturization of the X-ray source and power supply, and optimization of the geometry of the instrument first by trial and error, and later through the use of Monte Carlo modeling techniques. The difficult problem of sample preparation was simplified considerably through the use of a piezovibration system which shook loosely packed powder in such a way that it flowed like a liquid, presenting all of the individual grains to the beam in random orientations over time. CheMin was accepted for flight in 2003, and the flight model was delivered to the MSL project in 2008.

An X-ray diffraction pattern was obtained by CheMin from an aeolian dune named "Rocknest" on Oct. 18th, 2012. The results of this experiment represent the first quantitative mineralogical analysis on another planetary surface, and the first quantitative mineralogical analysis of the global Mars soil. The bulk composition of Rocknest soil is nearly identical to bulk soil compositions measured at Gusev by the MER *Spirit* rover. CheMin's mineralogical results should therefore be considered relevant beyond a single, localized region of Gale Crater, providing key insights into local, regional and planetary scale processes.

Oral Presentation: 11:30am

Ancient Cold-Seep Deposits as Paleoenvironmental Indicators of the Late Precambrian to Early Paleozoic Biosphere

Thomas F Bristow – NPP Fellow, Exobiology Branch

Cold-seep deposits are the remnants of ancient chemosynthetic ecosystems that derive energy from microbial anaerobic oxidation of methane (AOM) using seawater sulfate. They provide a physical record of a microbial process that may have been more prevalent on oxygen deficient early Earth, playing a critical role in the regulation of biospheric methane. Although highly ^{13}C-depleted kerogen suggests that AOM dates back 2.7 Gyr, puzzlingly, the oldest reported cold-seeps only appear at 635 Myr and lack carbon isotopic signals (<-30 ‰ PDB) that are diagnostic of AOM in seep examples younger than 350 Myr. Using a 1D biogeochemical reaction-transport model, we confirm that these discrepancies are an expected consequence of changes in seawater chemistry. More specifically, sub-mM to mM seawater sulfate ($[SO_4^{2-}]_{SW}$) and elevated concentrations of dissolved inorganic carbon (DIC) that characterized seawater through much of the Precambrian, limited AOM driven carbonate supersaturation and $\delta^{13}C$-depletion, making seep carbonates less likely to form and more challenging to identify. Moderate $\delta^{13}C$-depletions observed in 420 to 370 Myr old cold-seep carbonates (independently identified by fossil assemblages, contextual and textural observations) indicate $[SO_4^{2-}]_{SW}$ <5 mM in this interval. This is significant because low $[SO_4^{2-}]_{SW}$ has been linked to widespread ocean anoxia in the early Paleozoic, a environmental condition thought to have influenced the evolution, extinction and recovery of early animals.

Oral Presentation: 11:50am

Perchlorate Radiolysis on Mars and the Origin of Martian Soil Reactivity

Richard Quinn, Daniel Pacheco and Hana Martucci

We have reevaluated the results of the Mars Viking experiments in the context of the discovery of soil perchlorate at the Mars Phoenix and Mars Science Laboratory (MSL) landing sites [1]. In the Viking Gas Exchange (GEx) experiment, oxygen gas was released when soils were exposed to water and in the Labeled Release (LR) experiment an aqueous mixture of organic compounds was partially decomposed when added to the soil [2]. Although perchlorate salts are strong oxidants, their stability under aqueous conditions preclude them from being a direct explanation of the GEx and LR results. However, we demonstrate that when perchlorate is exposed to ionizing radiation in a simulated martian atmosphere, it decomposes to form hypochlorite, oxygen, and chlorine dioxide. We show that the GEx and LR results can be explained by the release of trapped oxygen from radiation-damaged perchlorate salts and the reaction of hypochlorite with amino acids that were added to Viking soils. Our results indicate that that neither hydrogen peroxide nor superoxide is required to explain the results of the Viking biology experiments as has been previously suggested.

Additionally, following the discovery of perchlorates in martian soil, the generation of chloromethanes in the Viking gas chromatograph mass spectrometer (GCMS) was attributed to the thermally induced reaction of soil organics with perchlorate [3]. More recently, chloromethanes were detected during thermal analysis of martian soils using the Sample Analysis at Mars (SAM) instrument suite on the MSL rover [4]. We show, using Viking protocols, that the thermal decomposition of carbonates in the presence of metal catalysts can, in some cases, result in methane formation and, when perchlorate is present, in the formation of chloromethanes. Although terrestrial organic contamination may have provided the dominant carbon source for the production of chlorinated hydrocarbons during the Viking GCMS and SAM analyses, based on our results, it appears that a contribution from inorganic carbonates is also possible.

References: [1] Hecht, M. H. et al. (2009) Science 325, 64–67. [2] Klein, H. P. et al. (1976) Science 194, 99–105. [3] Navarro-González R. et al. (2010) JGR 115, E12010. [4] Mahaffy P. R. et al. (2010) Press Conference 45th AGU Meeting, San Francisco CA.

Acknowledgements: This research is supported by the NASA Astrobiology: Exobiology and Evolutionary Biology Program.

Oral Presentation: 1:15pm

Microbial mats offer insights about our early biosphere and its biosignatures

David J. Des Marais, Exobiology Branch
plus MANY collaborators

Microbial mats are structurally coherent macroscopic accumulations of microorganisms and their associated structures. Photosynthetic mats offer an opportunity to examine the dynamics of a complete microbial ecosystem. Microbial mats construct laminated “miniature reefs” called stromatolites; their ancient equivalents occur typically as carbonates in ancient rocks and are among the oldest most abundant fossil evidence of early life on Earth. Mats built by cyanobacteria created the most obvious and best-studied stromatolites in the fossil record. In order to interpret this record we must understand the dynamic relationships between the microbial populations that maintain community structure and create and preserve “biosignatures” in the geologic record. Research by my group and others in the Exobiology Branch has gained multiple insights into these fascinating communities. Since 1984 we have studied cyanobacterial mats in an arid coastal environment at the Exportadora de Sal, S.A. (ESSA) salt works, Guerrero Negro, Baja California Sur, Mexico. Arid coastal environments and their microbiota are well represented in Earth’s ancient geologic record. Precambrian sabkha (evaporitic) deposits range from the 3,500 million-year-old Warrawoona Group of Western Australia to the late-Neoproterozoic to Cambrian age Salt Range of Pakistan, among other localities.

We focused most of our field studies on the well-developed (about 4 to 8 cm-thick) permanently submerged (0.5 to 1 m water depth) cyanobacterial mats that developed in the salinity range 65 to 120 parts per thousand solutes (about 2X to 4X seawater salinity). Very high rates of oxygenic photosynthesis in the mat’s shallow photic zone create steep and variable gradients in pH and in concentrations of dissolved inorganic carbon and O_2. The oxygenated zone reflects a dynamic balance between photosynthetic O_2 production and O_2 consumption by a host of sulfide-oxidizing and heterotrophic bacteria. During the day most of the O_2 produced was recycled within the mat by O_2 respiration and, to a lesser degree, by sulfide oxidation. At night, O_2 was consumed principally by sulfide oxidation near the mat-water interface. Accordingly, mat cyanobacteria employed fermentation reactions in order to obtain energy at night and thereby produced an array of low-molecular-weight compounds. Anoxygenic phototrophs and sulfate-reducing bacteria (SRB) were quantitatively important consumers of dissolved organic matter in these mats. The principal source of DIC at night was microbial sulfate reduction.

Analyses of small-subunit rRNA gene sequences and lipid biomarkers helped to assess the diversity and distribution of microorganisms in these mats. In the mats that we studied most extensively (in brines at 2X to 3X seawater salinity), *Microcoleus chthonoplastes* and *Oscillatoriales* were by far the most diverse and abundant cyanobacteria in the photic zone near the mat surface (0 to 5 mm). *Chloroflexi*, *Proteobacteria*, *Bacteroidetes, Spirochetes and Planctomycetes* maintained high relative abundances throughout the topmost 6 cm of mat, although distinct zones delineated by O_2 and H_2S concentration gradients with depth harbored distinctly different bacterial communities. Populations of SRB varied with depth in the mats and were probably influenced by the O_2 and H_2S concentration gradients. Populations of archea were delineated using archeal lipid biomarkers. Archaeol was the most abundant archaeal lipid throughout the mat. Additional archaeal lipids included caldarchaeol, phytane, biphytane, a novel C_{30} isoprenoid (squalane), pentamethylicosane and crocetane. Crenarchaeota from marine benthic group B were generally present below 17 mm. Halobacteriaceae dominated the archeal populations near the mat surface. Methanogens belonging to Methanosarcinales were identified, and the distributions of various members of this group varied with mat depth, perhaps due to the availability of key carbon substrates. Bacterial populations decreased markedly with depth whereas the overall abundances of archea remained remarkably constant. The diversity of eukarya is very low in comparison to that of the bacteria and archea. Nematodes constituted more than half of the gene sequences identified. Several previously unknown sequences of bacteria and eukarya have been identified, indicating that these mats offer great potential to extend our understanding of the diversity and early evolution of benthic microbial communities.

Efforts continue to further identify microbial populations and chart their distribution. We are also cataloging the diversity of lipid biosignatures, how their distributions are related to microbial populations, and how they might be preserved in the geologic record.

Oral Presentation: 1:35pm

Microbial Systems: Nexus roles for Astrobiology, Energy and Space

Leslie (Lee) Prufert-Bebout

Life on Earth is dominated by microbes, in terms of biomass, overall rates of activity, use of potentially available habitats, and length of time on the planet. Microbial ecosystems are the loci where the myriad processes necessary for regenerative cycling of energy and elements on the Earth occur. *Only through the activity of microbes activity can this planet support higher life (including our own).* Microbial systems themselves exhibit a dazzling array of diversity in composition and metabolic capability. Increasingly this diversity is being explored and applied to address current day challenges in sustainability of renewable energy sources. These capabilities also make microbial ecosystem management an essential component of future space exploration technologies. This presentation will take a broad view of microbes' current and potential roles in Astrobiology, Space Exploration and Renewable Energy, touching on some of the specific projects ongoing in our labs at Ames.

Exploring Planetary Lakes

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1. Project Overview – The Planetary Lake Lander project (PLL) is funded by the NASA (ASTEP) Program. It deploys an adaptive robotic lake lander in the Central Andes of Chile where ice is melting at an accelerated rate. Deglaciation subjects lakes to interannual variability and impacts metabolic activity and biogeochemical cycles, lake habitat, ecosystem, and biodiversity. Documenting the deglaciation process contributes to a better understanding of the changes affecting Earth's glacial lake ecosystems here and now, and may shed light on how life adapted during past deglaciations. From an astrobiological perspective, it brings new insights into the evolution of Mars habitability during comparable geological periods, and into its remote and *in situ* signatures. Further, the robotic exploration of lakes confronts us with challenges analogous to those faced by future planetary missions to Titan's lakes and seas.

2. Astrobiology Science – The Impact of Deglaciation on Planetary Lake Habitats. During the 2011 and 2012 field campaigns, PLL characterized the physical, geological, and biological environment of Laguna Negra (33.65S - 70.13W) a 6-km large, 1.7 km long, and 300 m deep glacial lake. Time series show changes in precipitation, temperature, and relative humidity over the past decades. Meteorological stations and stream gauge track daily and seasonal changes at high resolution. Data are correlated to daily vertical profiles performed by the lake lander to monitor physicochemical changes, and show the impact of melting ice on microbial organisms type, abundance, and migration over the water column. Bathymetric surveys reveal the bottom topography, and isolated habitats. Light profiles show exceptional transparency: Damaging UV reaches down to 15 m below the surface; Video exploration down to ~200 m depth shows that complete light extinction does not occur before ~100 m. Critical thermal transitions as well as turbididy and light changes occur between 15-25 m. Changes in archea and bacteria populations are observed from 0-20 m. Water column and sediment samples collected are analyzed by sandwich microarray immunoassays, and by cloning and sequencing bacterial and archaeal 16SrRNA gene. Biomarker and microbial profiles are obtained by using a Life Detector Chip (LDChip450), extracellular polymers, exopolysaccharides, universal biomarkers like DNA, amino acids, and other biomolecules.

3. Remote Sensing Signatures of Deglaciation – Most dominant spectral units around the lake have been defined in ASTER near- and thermal infrared orbital imagery, and their texture defined using ground FLIR thermal imagery. Twenty-four time-lapse thermal videos show changing surface temperature conditions around the lake, which are controlled by solar radiation, surface moisture content, grain size, slope, and/or geology. Regular monitoring of changes in these signatures provides a method to remotely survey the impact of deglaciation on habitats, and provides a regional perspective to changes in the lake ecosystem.

4. Technology Pathways to Planetary Lake Exploration. PLL ultimate goal is to develop and field test operational scenarios relevant to future missions to Titan. It carries a science payload comparable to that of the Titan Mare Explorer (TiME) mission project. During the first two field campaigns, we generated an environmental database to baseline the adaptive system that will be used in 2013 by the lake lander to autonomously explore the lake. The results will help us obtain the first quantification of science return and operational constraints of such mission. It will provide critical information on where adaptive science and system can maximize mission productivity. Adaptive science is currently being designed and developed for onboard and off-board operations, and data analysis and management. Adaptive sampling capabilities should allow the lake lander to make decision on its own about the nature of changes it observes in the lake (e.g., temperature and turbidity), and to decide what sampling templates and data rates to utilize to document these changes. Ultimately, PLL aims at producing a new generation of robots that can accumulate knowledge about their environment; understand mission priorities, and the concepts of nominal and off-nominal environmental conditions; and make and evaluate observations as events happen *in situ*, and not only when receiving commands from Earth. PLL is a first step toward planetary robot awareness and decision-making without constant human oversight. Finally, PLL uses an Exploration Ground Data Systems (xGDS) developed at NASA Ames to handle science data.

Oral Presentation: 2:15pm

Pamela M. Marcum
Michael N. Fanelli

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ABSTRACT

Extremely isolated early-type galaxies (IEGs) hold great promise in defining the zero-interaction baseline necessary to distinguish physical properties effectuated by environment from those that are intrinsic (nurture versus nature). Unlike their cluster counterparts, whose histories are complicated by their surroundings, there are two straightforward evolutionary paths for an IEG: (1) an isolated remnant of a coalesced group of galaxies ("a fossil group"), or (2) a passively-evolving primordial elliptical created by gravitational collapse in isolation early in cosmic time. The first possibility predicts several observational signatures, including tidal features, unusual colors, "shell" structures, multiple nuclei, unusual light profiles, and a spatially-extended X-ray halo. Verification of either formation scenario would provide significant insight into galaxy evolution. Galaxies found to be intermediate-aged fossil groups would be a missing link between recent mergers (<1 Gyr) and old elliptical galaxies. The identification of additional representatives of "middle-aged" mergers would provide understanding of the timescales involved in the merger process. Identification of IEGs with no evidence for interactions over a significant fraction of the age of the universe provides a powerful tool for disentangling the relative roles of environment and purely internal processes in the origin and subsequent evolution of early-type galaxies.

We describe an ongoing investigation of IEGs using optical (SDSS, HST), infrared (2MASS, IRAS), X-ray (ROSAT, CHANDRA), and UV (GALEX) datasets. We use the Sloan Sky Survey to select extremely isolated galaxies in the nearby Universe. Redshifts from the SDSS spectra permit 3D mapping of the local environment surrounding candidate isolated systems; the lack of redshifts has strongly limited prior searches for isolated systems. We describe the morphological, photometric and star formation properties of the most isolated systems found within the SDSS footprint. Sample galaxies are isolated from nearest neighbors more luminous than $M_V = -16.5$ by a minimum distance corresponding to 2.5 Mpc and 350 km s^{-1} in redshift space. Highly isolated systems are extremely rare, and exhibit a number of unusual features as compared to bulge-dominated galaxies in cluster and group environments. Such peculiarities include blue colors that are indicative of recent global star formation, and small physical sizes. We also discuss an object discovered serendipitously and interesting in its own right: an apparently merging compact group of dwarf galaxies.

To provide a more complete perspective of isolated galaxies and their relationship to compact and fossil groups, we compare the diffuse X-ray emission amongst these three classes of objects using archival data from the Chandra X-ray Observatory. The X-ray luminosity and gas temperature of the soft (0.3 - 2.5 keV) emission are used to assess a possible evolutionary connection between these systems. The ranges of X-ray luminosity and temperature displayed by the compact group and isolated elliptical samples significantly overlap, supporting the hypothesis that isolated ellipticals are remnants of collapsed compact groups. The fossil groups exhibit a bimodal temperature distribution. One fossil group population shares X-ray properties with those of isolated elliptical and compact group samples, while the second population may be the remains of more massive systems.

Oral Presentation: 2:35pm

SOFIA mid-infrared observations of the Orion Nebula region

Hans Zinnecker, Jim de Buizer, Eric Becklin, Ralph Shuping, Bill Vacca (SOFIA Science Center at Ames)

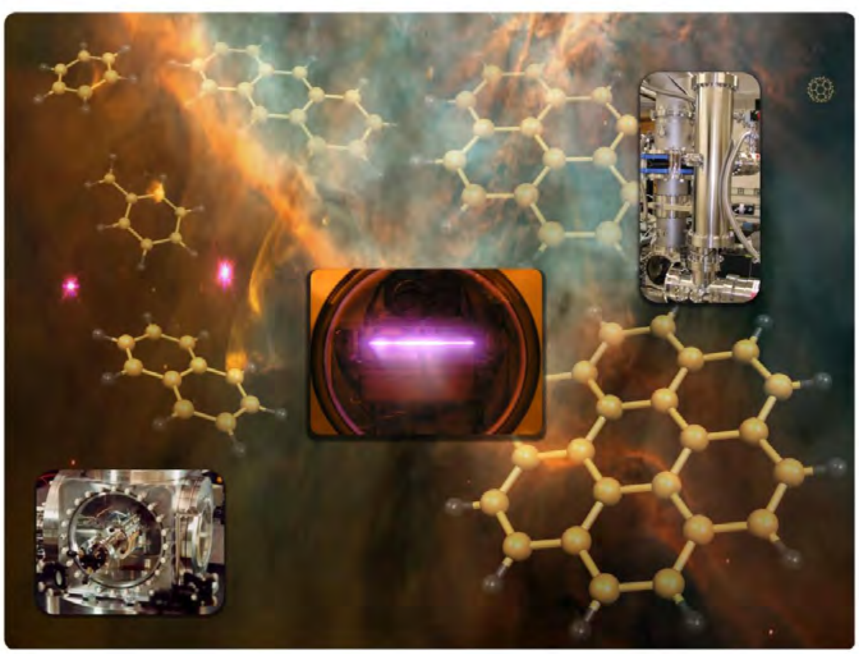
The Becklin-Neugebauer/Kleinmann-Low (BN/KL) region of the Orion Nebula is the nearest region of high-mass star formation ino our galaxy. As such, it has been the subject of intense investigation at a variety of wavelengths, which have revealed it to be brightest in the infrared to sub-millimeter wavelength regime. Using the 2.5m SOFIA airborne telescope equipped with the 5-40 micron camera FORCAST (PI: T. Herter, Cornell Univ.), mid-infrared images of the entire BN/KL complex as well as the Trapezium Cluster region in the Orion Nebula have been acquired.
The diffraction-limited 31.5 and 37 micron represent the highest resolution (~4") observations ever obtained of this region at these wavelengths. We will discuss these new SOFIA Orion data as well as other related Orion observations from the Keck and VLT telescopes.
A number of unexpected and surprising results have been found, among them a new dominant luminosity source (a dust-enshrouded high-mass star in the making, with a brightness of >30,000 suns).

Oral Presentation: 2:55pm

LABORATORY STUDIES OF THE FORMATION OF CARBONACEOUS DUST FROM PAH PRECURSORS

CESAR S. CONTRERAS AND FARID SALAMA, Space Science and Astrobiology Division, NASA-Ames Research Center, Moffett Field, CA, USA.

The study of formation and destruction processes of cosmic dust is essential to understand and to quantify the budget of extraterrestrial organic molecules. Although dust with all its components plays an important role in the evolution of interstellar chemistry and in the formation of organic molecules, little is known on the formation and destruction processes of carbonaceous dust. PAHs (broadly defined) are important chemical building blocks of interstellar dust. They are detected in interplanetary dust particles and in meteoritic samples. Additionally, observational, laboratory, and theoretical studies have shown that PAHs, in their neutral and ionized forms, are an important, ubiquitous component of the interstellar medium. Also, the formation of PAHs from smaller molecules has not been extensively studied. Therefore, it is imperative that laboratory experiments be conducted to study the dynamic processes of carbon grain formation from PAH precursors. Studies of interstellar dust analogs formed from a variety of PAH and hydrocarbon precursors as well as species that include the atoms O, N, and S, have recently been performed in our laboratory under conditions that simulate interstellar and circumstellar environments. The species formed in the pulsed discharge nozzle (PDN) plasma source are detected and characterized with a high-sensitivity cavity ringdown spectrometer (CRDS) coupled to a Reflectron time-of-flight mass spectrometer (ReTOF-MS), thus providing both spectroscopic and ion mass information in-situ. We report the first set of measurements obtained in these experiments. Studies with hydrocarbon precursors will show the feasibility of specific molecules to form PAHs, while those that contain carbon ring systems (benzene and derivatives, PAHs) precursors provide information on pathways toward larger carbonaceous molecules. From these unique measurements, we derive information on the size and the structure of interstellar dust grain particles, the growth and the destruction processes of interstellar dust and the resulting budget of extraterrestrial organic molecules.



Oral Presentation: 4:00pm

THE LUNAR ATMOSPHERE AND DUST ENVIRONMENT EXPLORER (LADEE): T-MINUS SIX MONTHS AND COUNTING. R. C. Elphic[1], B. Hine[1], G. T. Delory[2], J. S. Salut[3], S. Noble[3], A. Colaprete[1], M. Horanyi[5], P. Mahaffy[4], D. Boroson[6], [1]Planetary Systems Branch, NASA Ames Research Center, MS 245-3, Moffett Field, CA, 94035-1000, [2]Space Sciences Laboratory, University of California, Berkeley CA 94720, [3]Planetary Science Division, Science Mission Directorate, NASA, Washington, DC 20546, [4]NASA Goddard Space Flight Center, Greenbelt, MD, 20771, [5]Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder, CO 80309, [6]Lincoln Laboratory, Massachusetts Institute of Technology, Lexington MA 02421

Introduction: 40 years have passed since the last Apollo missions investigated the mysteries of the lunar atmosphere and the question of levitated lunar dust. The most important questions remain: what is the composition, structure and variability of the tenuous lunar exosphere? What are its origins, transport mechanisms, and loss processes? Is lofted lunar dust the cause of the Surveyor and astronaut horizon glow observations? How does such levitated dust arise and move, what is its density, and what is its ultimate fate?

Past National Research Council decadal surveys, and the "Scientific Context for Exploration of the Moon" (SCEM) report have identified studies of the pristine state of the lunar atmosphere and dust environment as among the leading priorities for future lunar science missions. These measurements have become particularly important since recent observations by the Lunar Crater Observation and Sensing Satellite (LCROSS) mission point to significant water and other volatiles sequestered within polar lunar cold traps. Moreover, Chandrayaan M^3/EPOXI/Cassini VIMS identifications of H_2O and OH on surface regolith grains hint at variability in time and space; these species are likely present in the exosphere, and thus constitute a source for the cold traps.

The LADEE Mission: The Lunar Atmosphere and Dust Environment Explorer (LADEE) is currently in integration and test, aiming for launch in August of 2013. LADEE will determine the composition of the lunar atmosphere and investigate the processes that control its distribution and variability, including sources, sinks, and surface interactions. LADEE will also determine whether dust is present in the lunar exosphere, and reveal its sources and variability. These investigations are relevant to our understanding of surface boundary exospheres and dust processes occurring at many objects throughout the solar system, address questions regarding the origin and evolution of lunar volatiles, and have potential implications for future exploration activities.

The LADEE Payload: LADEE employs a high heritage instrument payload: a Neutral Mass Spectrometer (NMS) from Goddard Space Flight Center, an Ultraviolet/Visible Spectrometer (UVS) from Ames Rsearch Center, and a dust detection experiment (LDEX) from the University of Colorado/LASP. It will also carry the Lunar Laser Communications Demonstration (LLCD) as a technology demonstration. The LLCD is funded by the Space Operations Mission Directorate (SOMD), managed by GSFC, and built by the MIT Lincoln Labs.

The LADEE NMS instrument for LADEE draws its design from the MSL/SAM, CONTOUR and MAVEN projects, and covers the 2-150 Dalton mass range. The UVS instrument is a next-generation, high-reliability redesign of the LCROSS UV-Vis spectrometer, spanning 250-800 nm wavelength, with high (<1 nm) spectral resolution. UVS will also perform dust occultation measurements via a solar viewer optic.

Fig. 1. LADEE in preparation for environmental testing. The neutral mass spectrometer is the large silver-colored box on the right. The lunar dust detector is at top right.

LDEX senses dust impacts in situ, at LADEE orbital altitudes, with a particle size range of between 100 nm and 5 μm. Dust particle impacts on a large spherical target surface create electron and ion pairs. The latter are focused and accelerated in an electric field and detected at a microchannel plate.

Status of LADEE Mission: As of early January 2013, LADEE is going into thermal vacuum testing. Integrated observatory testing will continue until LADEE is shipped to Wallops for launch processing in June 2013. The first launch opportunity is currently August 10, 2013. In the meantime, the LADEE Guest Investigator Program (GIP) has been approved. Details can be found on NSPIRES; proposals are due by March 29, 2013:

http://science.nasa.gov/researchers/sara/grant-solicitations/roses-2012/2012/12/21/amendment-31-new-opportunity-roses-12-appendix-c27-ladee-guest-investigator-program/

Pollack Lecture: 4:20pm

Planetary Chemistry: Ices to Organics

Dale P. Cruikshank, SSA

The first detections of planetary ices were enabled by the development of near-infrared detectors that became available to astronomers following WW II; Kuiper and Moroz first found water ice on two Galilean satellites and Saturn's rings in the1950s and early 1960s. Major improvements in detectors and the availability of large telescopes have expanded our knowledge of the distribution of H_2O ice, and have revealed ices of different compositions in different planetary settings. Methane ice was found on Pluto (1976) and then on Triton (1979), and SO_2 was found on Io (1978-1979). Subsequently, frozen N_2, CO, CO_2, C_2H_6, CH_3OH, and HCN have been identified on planetary satellites, Centaurs, and transneptunian objects. Planetary surfaces containing these ices in various combinations are exposed to their local space environments (charged particles in magnetospheres, cosmic rays, solar and galactic ultraviolet). Some of these bodies have atmospheres that are also irradiated. Consequently, chemical reactions occur both in the atmospheres and in the surface ices, producing more complex materials, some of which are organic and can be broadly identified as aliphatic and aromatic hydrocarbons. Other reaction products are relatively refractory materials that give distinctive colors to such objects as the Saturnian satellites, Pluto, Triton, and some Centaurs and transneptunian bodies. The identification of specific molecules in these refractory materials is difficult, but progress is being made. As NASA's *New Horizons* spacecraft approaches the Pluto system for its July, 2015 encounter, we are giving special attention to the chemistry of the surface of the planet and its satellites in a laboratory study in the Ames Astrochemistry Lab. Because complex organics are also common in comets, meteorites, and in interstellar dust, the relationships among the compositions and origins of these materials are of continuing importance and interest.

Anomalous mirror-image ratios of meteoritic sugar derivatives

George Cooper, Jendai Robinson, Malika Carter

Exobiology Branch, Space Science Division

Carbonaceous meteorites contain a diverse suite of soluble organic compounds. These compounds were delivered to the early Earth in asteroid (and possibly comet) fragments and were therefore likely to have played an important role in the origin and/or evolution of life. Among the classes of organic compounds found in meteorites are keto acids, tricarboxylic acids, amino acids, amides, purines and pyrimidines. The majority of indigenous meteoritic compounds are racemic, i.e., their D/L mirror-image (enantiomer) ratios are 50:50. Previously known was that a few of the more unusual (non-protein) amino acids contain slightly more of one enantiomer (usually the L) than the other. This presentation will focus on our results that show more unusual enantiomer ratios of meteoritic sugar acids (i.e., compounds closely related to ribose, glucose, etc.). The origins of such enrichments are still unknown, however, the findings may have implications for the origin of life's homochirality.

THE SUTTER'S MILL CM CHONDRITE AND THE TISSINT SHERGOTTITE: FIRST DATA FROM THE NASA AMES THERMOLUMINESCENCE LABORATORY. Derek W. G. Sears, Space Science and Astrobiology Division, MS245-3, NASA Ames Research Center, Moffett Field, Mountain View, CA 94035. (Derk.Sears@NASA.gov).

Introduction: Studies of the natural TL of meteorites provides information on their recent thermal and radiation history and have application in the study of terrestrial age, orbit, and – in the case of Antarctic meteorites – concentration mechanisms. On the other hand, studies of the induced TL provide unique insights into metamorphic history of meteorites. TL sensitivity (induced TL normalized to the induced TL of the Dhajala H3.8 chondrite) has a dynamic range and precision not matched by any other technique [1]. During the installation of a TL laboratory at NASA Ames Research Center two meteorites with considerable community interest became available for research and these are the subject of the present report. They were Tissint, a martian meteorite that fell in Morrocco in July 2011 and was found three months later [2], and Sutter's Mill, a CM-like regolith breccia that fell in northern California in April 2012 [3].

Metamorphic History of the Tissint Martian Meteorite: The background to the TL properties of martan meteorites were described in some detail at last year's LPSC [4]. Two 50 mg chips of Tissint (provided by L. A. Taylor of the University of Tennessee), with very different appearance under the low-powered binocular microscope (one was richer in black glass), were ground, any magnetic material removed with a hand magnet, and their TL measured in the normal way [1]. Here we focus on the induced TL.

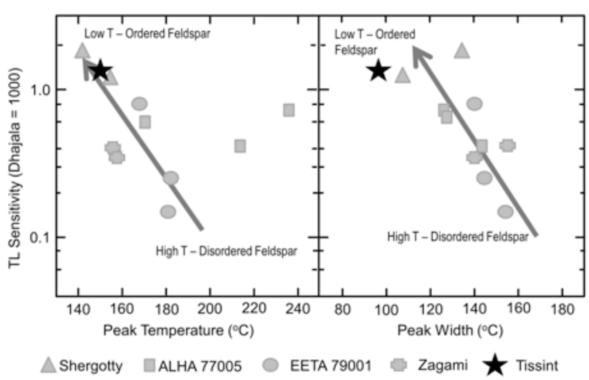


Fig. 1.. TL sensitivity vs peak temperature (left) and peak width (right) for five martian meteorites including Tissint. Tissint has TL properties suggesting that it cooled more slowly following ejection from Mars than ALHA 77005, EETA 79001, and Zagami, and similar to Shergotty. This would be consistent with a larger ejected mass.

The two fragments gave almost identical results, the only difference being the presence of high- temperature induced TL in the glass-rich fragment. The TL sensitivities and peak temperatures for the two chips were identical within experimental limits, but the high temperature component precluded measuring peak width in the glass-rich sample. The data are plotted in Fig. 1, along with meteorites for which data currently exist [5]. The TL sensitivitiy, TL peak temperature and TL peah width of Tissint are very similar to those of Shergotty. The TL sensitivity of Tissint, while low in comparison to most meteorites, is at the high end of the range observed for shergottites. Conversely, TL peak temperature and width are at the low end of the range observed for shergottites.

The TL carrier in shergottites is traces of crystalline feldspar in the maskelynite, the low TL sensitivity reflecting the extremely small amounts of crystalline material present. The temperature and width of the TL peak reflect the level of structural disordering in the crystals, disordered feldspar having high peak temperatures and widths (both ~200°C) while ordered feldspars have low peak temperatures and widths (both ~100°C).

Thus as the maskelynite cooled, following its formation by the shock event that liberated the meteorites from Mars, the first feldspar formed was in small amounts and in the high-temperature (disordered) form being above the order-disorder transition temperature. The order-disorder transition temperature (~500°C) corresponds to shock pressures of ~25 GPa [6]. With decreasing temperature, more feldspar formed and the TL sensitivity went up, but as the temperature dropped below the order-disorder temperature the feldspar formed was in the low-temperature (ordered) form.

Thus the shergottites define a trajectory (the arrows in Fig. 1) representing a cooling series with closure setting in at decreasing temperature as they moved along the trajectory. Such differences in closure are most reasonably interpreted as due to different cooling rates and fragment size. Thus for the shergottites currently discussed, Tissint and Shergotty cooled most slowly and therefore were probably the largest fragments ejected from Mars.

Thermal and Metamorphic History of the Sutter's Mill Meteorite: Nearly 20 CM chondrites examined as part of the Antarctic Meteorite Natural TL Survey had undetectable TL signals [1]. This is also true of Murchison [7]. It is therefore significant that Sutter's Mill meteorite, which appears to be resemble CM chondrites in many ways, produced weak but detectable TL. The raw TL data (i.e. glow curves, plots of light emitted against laboratory heating temperature) are shown in Fig.2. Our sample is from SM-2, which was found as about a dozen fragments totaling ~4 gram in a parking lot, presumably crushed by a car. Several of the fragments contained fusion crust. In fact, all of the 70 Sutter's Mill meteorites are fully crusted individuals only one is greater than ~30 gram. Thus our sample will have come a few millimeters from the fusion crust.

The natural TL glow curve consists only of a signal at high glow curve temperatures where it is significantly higher than background (black body). There are no obvious peaks, the induced TL consisting of a broad band extending from ~300°C to ~450°C. In contrast to the natural TL, the induced TL starts at ~100°C. It then continues to ~450°C, being broad and somewhat hummocky, suggesting many unresolved peaks.

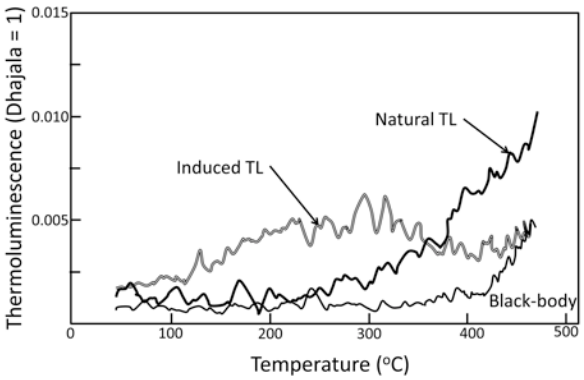


Fig. 2. Glow curves for the natural and induced TL of the Sutter's Mill meteorite compared with the black body (background) signal.

The customary way of determining the thermally stable region of the natural glow curve, for dosimetry of pottery dating purposes for instance, is to plot the ratio of the natural to induced TL as a function of glow curve temperature. A leveling off, or a plateau, suggests that the TL signal was stable in this region and may be used for dating. When this is done for Sutter's Mill (Fig. 3) it is clear that the natural TL below 300°C has been removed. Theory and experiment shows that this is the result of heating to ~300°C, and the heating may have been just momentary. This heating event was relatively recent, since in only ~10^5 years the meteorite would have recovered from the heating event.

There are several possibilities for the heating event. It may have been during (1) the atmospheric descent, (2) a passage close to the Sun, (3) during a stochastic event such as shock heating event. This shock heating event may have been a collision, or even the event that ejected the meteorite from its parent body.

The smallness of the size of the fragment measured here and the known thermal gradients in meteorites caused by atmospheric heating suggest that the heating event suffered by our sample of Sutter's Mill was passage through the atmosphere. However, the Sutter's Mill meteorite had an orbit with a particularly small perihelion and several other meteorites with a 300°C step in their plateau are thought to have entered the atmosphere on an orbit with a small perihelian. There is nothing in the data to preclude such an explanataion for the Sutter's Mill natural TL data. The third explanation is also a possibility. If we assume that the very short cosmic ray exposure ages for this meteorite (0.05 – 0.1 Ma [3]) reflects the date at which Sutter's Mill was ejected from its parent object, with an associated shock heating, then this event may or may not have been shorter than the natural TL recovery time. Precise measurements of the kinetics of the natural TL of Sutter's Mill are required.

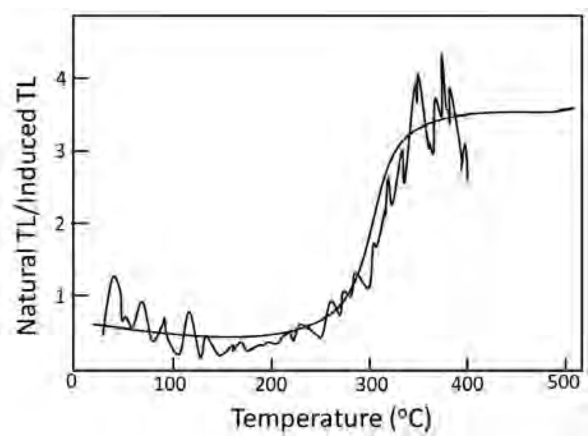


Fig. 3. Ratio of natural TL to induced TL as a function of glow curve temperature. The step at 300°C indicates that the meteorite has been heated to this temperature sufficiently recently that it has not had time to recover (~10^5 years).

The TL sensitivity of Sutter's Mill is comparable to very low metamorphic grade ordinary, CO, and CV chondrites, say 3.0. As mentioned above, however, the glow curve shape is unique and does not match any other class. This points to a fundamental difference between Sutter's Mill and the normal CM chondrites consistent with a lower degree of aqueous alteration or a metamorphic overprint.

[1] Sears et al. (2013) Chemie d'Erde (in press). [2] Aoudjehane et al. (2012) Science 338, 785. [3] Jenniskens et al. 2012. Science 338, 1583-1587. [4] Sears (2012) LPSC Abs #1853. [5] Hasan et al 1986 GCA 50, 1031. [6] Hartmetz et al 1986 JGR 91, E263. [7] Sedaghatpour and Sears 2009 MAPS 44, 653.

Astrobiology Poster: AB.3

Author: Mark Ditzler

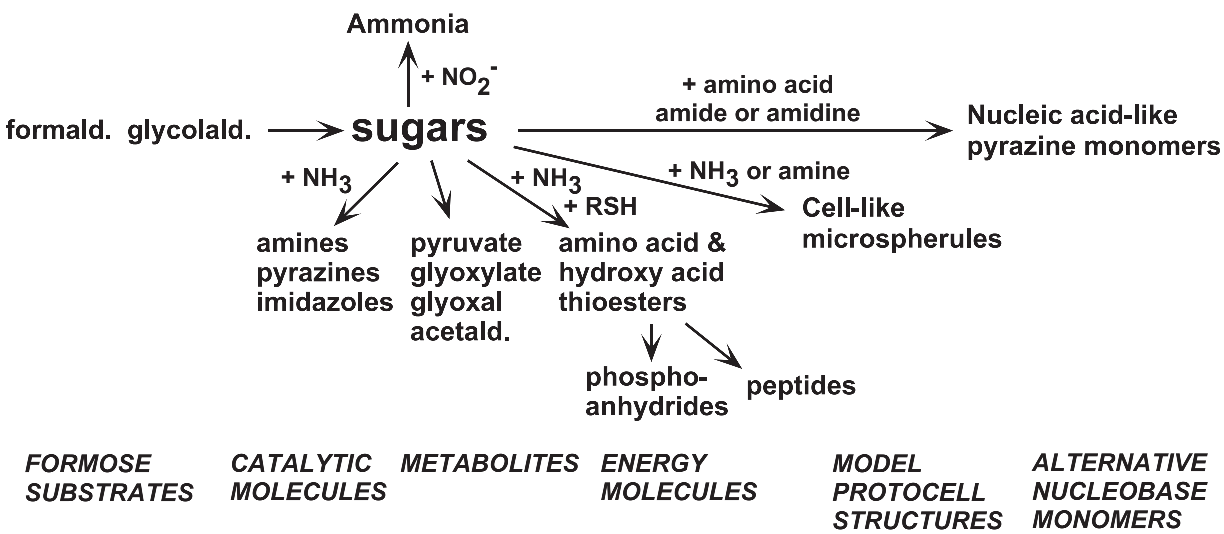
High-throughput comparative sequence analysis of *in vitro* RNA evolution

The evolution of polymers occurs on complex fitness landscapes that reflect the conformational dynamics and folding of individual sequences along their respective free energy landscapes. Evaluating these landscapes is critical to both understanding the origin and evolution of life and developing tools for synthetic biology. For RNA, the complexity of both of these landscapes has been illuminated by numerous investigations involving both natural and artificially evolved systems. *In vitro* evolution is a well-established method for exploring fitness landscapes and it has been used to generate populations of nucleic acids that are enriched for a variety of functions. While standard low-throughput sequencing methods have proven successful in extracting valuable information from these populations, the small size of the data sets places significant limitations on their ability to fully describe the enriched populations. Here, we use high-throughput comparative sequence analysis to evaluate multiple artificially evolved RNA populations that were evolved to bind two distinct molecular targets: coenzyme A (CoA) and HIV-1 reverse transcriptase (RT). These populations are enriched in RNAs of independent lineages that converge on shared motifs and in clusters of RNAs with nearly identical sequences that share common ancestry. Both of these features inform inferences of the secondary structures of enriched RNAs, their minimal structural requirements, and their stabilities in RNA-target complexes. Differences between these populations reflect their distinct evolutionary trajectories. For example, the populations evolved to bind CoA exhibit less sequence diversity than those evolved to bind RT. The approach presented here can readily be generalized for the efficient and systematic evaluation of *in vitro* evolved nucleic acid populations.

Sugars, the Carbon Group Molecular Battery of Biotic and Abiotic Synthesis.

Arthur L. Weber, SETI Institute, NASA Ames Research Center, Moffett Field, CA, USA

Life requires a source of carbon and chemical energy to drive synthetic processes needed for its cellular existence. Furthermore, the chemical energy must be sustained and effectively coupled to synthetic reactions, and capable of driving synthesis at a rate that counters chemical degradation. Energy coupling would have been especially difficult during the origin of life before the development of powerful enzyme catalysts with evolved 3-D substrate binding sites. To solve this energy-coupling problem we have studied abiogenesis using sugar substrates that possess energized carbon groups capable of undergoing spontaneous synthetic transformation reactions without any other source of energy (1,2). Sugars are considered plausible substrates for prebiotic synthesis because they are easily formed by formose aldol condensations of formaldehyde and glycolaldehyde, a small 2-carbon hydroxyaldehyde. As shown below, our studies have shown that spontaneous sugar transformation reactions yield (a) a variety of molecules useful for abiogenesis (small catalytic molecules, monomers, metabolites, energy molecules, and ammonia (3-6)), (b) pyrazines that could have acted as complementary nucleobases of a primitive replicating polymer that preceded the modern nucleic acids (7), and (c) cell-like organic microspherules considered models of primitive protocells (8).



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How Proteins Became Functional?

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Proteins are the main functional polymers in contemporary cells. They carry out, for example, catalysis, energy transduction and transport across cell walls at remarkable levels of efficiency and accuracy in ways that appear effortless. However, dissection of these functions reveals great complexities that are involved. This opens a question: how a simple, ancestral system could have acquired functions? Other questions follow. What were the chances that a functional protein emerged at random? What was the minimum structural complexity of a protein to carry out a function at a reasonable level of efficiency? These and similar questions are at the core of the issue: how soulless chemistry became life?

The emergence of protein functions is a puzzle. It is widely accepted that a well-defined, compact structure (fold) is a prerequisite for function. Function, in turn, is a prerequisite for evolution. In other words, non-functional entities are not subjected to evolutionary optimization. It is equally widely accepted that compact folds are rare among random amino acid chains. Then, how did protein functionality start?

One hypothesis holds that folded proteins were preceded by their poorly folded, yet still functional ancestors. Only recently, however, we obtained experimental evidence supporting this hypothesis. A small enzyme that ligates two RNA fragments with the rate of 10^6 above background was evolved *in vitro* (Seelig and Szostak, 2007). This enzyme does not resemble any contemporary protein (Chao et al, 2012). It consists of a flexible loop, a part of which is responsible for catalytic activity, a small, rigid core containing two zinc ions coordinated by neighboring amino acids and two highly flexible tails. In contrast to all proteins from modern organisms, this enzyme does not contain any standard structural elements, such as α-helix or β-sheet. The loop structure is kept together by just two interactions of a charged residue and a histidine with a zinc ion, which they coordinate on the opposite side of the loop. Such structure appears to be very fragile. Surprisingly, this is not the case. As a coordinating residue is mutated to alanine, another, nearby charged residue takes its place, thus keeping the structure and function nearly intact. High flexibility of the protein facilitates this adjustment.

A similar picture emerges from studies of simple transmembrane channels that mimic those in ancestral cells. One of them is formed through the aggregation of antiamoebin, a non-ribosomally synthesized peptide that consists of only 16 amino acids. Interestingly, the peptide contains non-standard amino acids, such as α-aminoisobutyric acid and isovaline, which are believed to have been common on the early earth. Recently we found that the antiamoebin channel, in contrast to all known genomically coded, well structured channels, is extremely flexible and does not form a conventional pore (Wilson et al. 2013). Yet, it efficiently mediates ion transport.

Taken together these results show that simple, highly flexible proteins or protein assemblies that do not resemble their contemporary counterparts could carry out functions quite efficiently. They might be the "missing link" on a continuous evolutionary trajectory between very short, but only weakly active oligopeptides and well-folded proteins similar to those found in modern organisms.

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Energy Transduction in Vesicles, Reduction of Important REDOX Carriers Such as Quinones and NAD+. D. P. Summers[1], J. Noveron[2], Ranor C. B. Basa[3], and David Rodoni[3], [1]Carl Sagan Center, SETI (c/o NASA Ames Res. Center, MS 239-4, Moffett Field, CA, David.P.Summers@nasa.gov), [2]University of Texas at El Paso, [3]Foothill College.

Introduction: A number of theories on the origin and early evolution of life have focused on the role of lipid bilayer membrane structures often called vesicles (Deamer 1997; Szostak et al. 2001). These vesicles are similar to modern cellular membranes , and have been postulated to have been abiotically formed and spontaneously assemble on the prebiotic Earth to provide compartments for early cellular life (Deamer 1985; Dworkin et al. 2001). They can contain water-soluble species, concentrate species, and have the potential to catalyze reactions. The origin of the use of photochemical energy to drive metabolism (ie. energy transduction) is also one of the central issues in our attempts to understand the origin and evolution of life. When did energy transduction and photosynthesis begin? What was the original system for capturing photochemical energy? How simple can such a system be?

It has been postulated that vesicle structures developed the ability to capture and transduce light, providing energy for reactions. It has been shown that pH gradients can be photochemically created, but it has been found difficult to couple these to drive chemical reactions. Minerals can introduce a number of properties to a vesicle system. The incorporation of clay particles into vesicles can provide catalytic activity that mediates both vesicle assembly and RNA oligomerization (Hanczyc et al. 2003; Hanczyc et al. 2007).

It has been shown that mineral semiconducting particles can act as photocatalysts, driving electrochemical reactions. The encapsulation of these particles can provide a simple energy transduction system for vesicles that could have formed at almost any stage of the origin of life.

Results: We have shown that titanium dioxide particles will be encapsulated as vesicles form, or reform after dehydration/rehydration cycles, without interference in either lipid or semiconductor properties. Reduction of a redox indicator shows that they can be concentrated in vesicles by dehydrate/rehydrate cycles and that they retain the ability to drive photoelectrochemical reactions when encapsulated.

Current work has shown that this chemistry can be used to drive the reduction of biochemical species such NAD+ to NADH. Work has shown that we can form NADH inside vesicles by mediation with $Rh(bipy)_3^{+3}$, the NADH produced has been shown to be enzymatically active. We have also shown the prebiotic plausible mediators, such as quinones, can also produce enzymatically active NADH.

This system demonstrates a simple energy source inside vesicles/protocells suitable either for simple prebiotic systems and/or for more complex “protobiochemical” systems. It could act as a precursor to metabolic systems and provide a model of how metabolism could have developed prebiotically in a vesicle based “protocell origin of life”. It can provide a source of prebiotic compounds inside vesicles, an environment considered to be of great importance for the origin of life. This would demonstrate a possible path for the origin and early evolution of photosynthesis. A vesicle-based photo-metabolism could help support the formation of an RNA "world", support the formation, growth, and/or stability of vesicles, or otherwise lead to the next step in the origin of life.

Photochemistry of Pyrimidine in Astrophysical Ices: Formation of Nucleobases and Other Prebiotic Species

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Nucleobases are *N*-heterocycles that are the informational subunits of DNA and RNA. They are divided into two molecular groups: pyrimidine bases (uracil, cytosine, and thymine) and purine bases (adenine and guanine). Nucleobases have been detected in meteorites,[1,2] where their extraterrestrial origin has been confirmed by isotopic measurements.[3] Although *N*-heterocycles have not been observed in the ISM,[4,5] the positions of the 6.2-μm interstellar emission features suggest a population of such molecules is likely to be present.[6]

Laboratory experiments have shown that the ultraviolet (UV) irradiation of pyrimidine in ices of astrophysical relevance such as H_2O, NH_3, CH_3OH, CH_4, CO, or combinations of these at low temperature (≤20 K) leads to the formation of several pyrimidine derivatives including the nucleobases uracil[7,8,9] and cytosine,[8] as well as precursors such as 4(3*H*)-pyrimidone and 4-aminopyrimidine.[7,8,9] Quantum chemical calculations on the formation of 4(3*H*)-pyrimidone and uracil from the irradiation of pyrimidine in pure H_2O ices are in agreement with their experimental formation pathways.[10] In those residues, other species of prebiotic interest such as urea and small amino acids (glycine and alanine) could also be identified.[8,9]

However, only very small amounts of pyrimidine derivatives containing CH_3 groups could be detected after UV photo-irradiation of CH_3OH:pyrimidine and CH_4:pyrimidine ices, suggesting that the addition of methyl groups to pyrimidine is not an efficient process, as opposed to what is observed for aromatic hydrocarbons.[11] This could explain why thymine, the third pyrimidic nucleobase, was only unambiguously detected in a very small number of samples.[9]

In this work, we study the formation of pyrimidic nucleobases and other photo-products of prebiotic interest from the UV irradiation of pyrimidine in ice mixtures containing H_2O, NH_3, CH_3OH, and/or CH_4.

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Anoxygenic growth of cyanobacteria on Fe(II) and their associated biosignatures: Implications for biotic contributions to Precambrian Iron Formations

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Banded Iron Formations (BIFs) are widespread Precambrian sedimentary deposits that accumulated in deep ocean basins or shallow platformal areas with inputs of reduced iron (Fe(II)) and silica from deep ocean hydrothermal activity. There is debate as to whether abiotic or biotic mechanisms were responsible for the oxidation of aqueous Fe(II) and the subsequent accumulation of ferric iron (Fe(III)) mineral assemblages in BIFs. Biotic Fe(II) oxidation could have occurred indirectly as a result of the photosynthetic production of oxygen by cyanobacteria, or could have been directly mediated by purple sulfur, purple non-sulfur, green sulfur bacteria or chemolithotrophs.

The anoxygenic use of Fe(II) as an electron donor for photosynthesis has also been hypothesized in cyanobacteria, representing another biotic mechanism by which Fe(II) could be oxidized in BIFs. This type of photoferrotrophic metabolism may also represent a key intermediate step in the evolution of oxygenic photosynthesis. There is a large difference in the redox potentials between water used as an electron donor by cyanobacteria and hydrogen and sulfide commonly used by the more ancient anoxygenic photosynthesis. Members of our group have speculated that an intermediate reductant such as Fe(II) could have bridged the gap and acted as a transitional electron donor before water. The widespread abundance of Fe(II) in Archean and Neoproterozoic ferruginous oceans would have made it particularly suitable as an electron donor for photosynthesis.

We have been searching for modern descendants of such an ancestral "missing link" cyanobacterium in the phototrophic mats at Chocolate Pots, a high-iron hot spring in Yellowstone National Park. In our physiological ecology study of the cyanobacterial mats, we have found evidence that this type of metabolism is occurring *in situ* using carbon-14 bicarbonate uptake experiments and autoradiography. We have detected a stimulation of C-14 uptake in the presence of Fe(II) in lower light adapted cyanobacteria that inhabit the lower end of the photic zone in microbial mats. We are currently probing the metagenomic data obtained from the JGI Yellowstone National Park Community Sequencing Project for the molecular underpinnings of this process.

A complimentary study of the microbial biosignatures produced in these mats revealed iron-permineralized carbonaceous microfossils of the candidate photoferrotrophs. Lipid biomarkers were used to characterize the community composition of the microbial mats, investigate the impact of iron mineralization on the lipid biomarker signature of the community, and link source organisms to geologically significant biomarkers in this high-iron system. Diagnostic lipid biomarkers of the cyanobacteria included mid-chain branched mono- and dimethylalkanes and, most notably, 2-methylhopanoids. This is the first documentation of 2-methylhopanoids in a modern iron-mineralized cyanobacterial mat where the cyanobacteria have been shown to grow anoxygenically using Fe(II) as an electron donor for photosynthesis.

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Biosignatures for Chemo- and Photo- Synthetic Systems: Early Earth and Mars?

Microbial communities dominated early environments on Earth and possibly Mars Modern microbial ecosystems serve as analogs for their ancient counterparts. Evaporitic ecosystems are a particularly important analog in that mineralization is thought to aide perservation of biosignatures. Although mineral depositing environments were prevalent in the Precambrian, few such environments are now available for study. We have investigated the lipid biomarker and phylogenetic properties of a fine-grained, gypsarenite microbial community found in Guerrero Negro, Mexico. 16S RNA phylogenetic findings for this endoevaporitic ecosystem support the presence of a complex trophic structure and are consistent with a universal structure for gypsum-hosted mats. Membrane fatty acids indicated cell densities in the surface tan/orange and lower green layers of $1.6E^9$ and $4.2E^9$ cells cm^{-3}, respectively. Several biomarker fatty acids, Δ7,10-hexadecadienoic, *iso*-heptadecenoic, 10-methylhexadecanoic and a Δ12 methyloctadecenoic, correlated well with OTU distributions for *Halothece*, *Stenotrophomonas*, *Desulfohalobium* and *Rhodobacterales*, respectively. Chl *a* and cyanobacterial OTUs were present throughtout the entire mat depth. Bchl *a* and Bchl *c* were first detected in the oxic-anoxic transition zone and increased with depth. A series of monomethylalkanes (MMA), 8-methylhexadecane, 8-methylheptadecane and 9-methyloctadecane were present in the surface crust but increased in abundance in the lower anoxic layers. The MMA structures are similar to those identified in *Ca.* Chlorothrix halophilia cultures and may represent the Bchl *c* community. Novel 3-methylhopanoids were identified in cultures of marine purple nonsulfur bacteria and as a probable biomarker for this group in the lower anoxic purple and olive-black layers.

Towards Understanding the Dry Limit of Life

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It is now well established that liquid water is the single, most important requisite for life. This is why "Follow the water" has become a mantra in the effort of searching for life on Mars and other planetary bodies. However, the question still remains: How much water is necessary to sustain life? Answering this question is important in order to address other important question such as: What is the dry limit of life? When was the last time that Mars contained habitable environments? Are there habitable environments on Mars today?

To address this key question we turn to the Atacama Desert in Chile, the oldest and driest desert on Earth. Endolithic cyanobacteria are found inside halite nodules in the hyperarid core of the Atacama Desert. Using Pulse Amplitude Modulated Fluorometry, we show that these cyanobacteria actively photosynthesize when the relative humidity rises above 70%, and the salt becomes wet by way of deliquescence. This is the first recognized active ecosystem in the hyperarid core of the Atacama, and the first example of a microbial community sustained by mineral deliquescence. Our results expand the water activity envelope of life, and show that an active microbial population can exist in the absence of rain, fog, dew or snow. Additionally our work suggests that evaporitic deposits on Mars might have been the last habitats for life, up to very recent times.

ICE DRAGON: A MISSION TO ADDRESS SCIENCE AND HUMAN EXPLORATION OBJECTIVES ON MARS

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***Summary**:* We present a mission concept where a SpaceX Dragon capsule lands a payload on Mars that samples ground ice to search for evidence of life, assess hazards to future human missions, and demonstrate use of Martian resources.

***Introduction**:* The search for life on Mars is a priority for NASA's Science Mission Directorate, a pivotal question of the Astrobiology Program and the ultimate goal of the Mars Exploration Program (MEPAG 2010). Assessing the presence or absence of life on Mars is a pre-requisite for human exploration to identify potential threats to planetary protection. Human exploration will also be enabled by the characterization of water resources, such as ground ice, that provide the basis for sustained human presence. Finally, a future human Mars exploration program requires clear demonstration that humans can land and safely operate on the surface of Mars.

***Mission and Systems Concept*:** The Ice Dragon mission uses landing system called "Red Dragon"[1] that is based on a SpaceX Dragon crew capsule to land on Mars. Launched by a Falcon Heavy, this spacecraft is capable of delivering more than 1000 kg of analytical and engineering payload to the surface of Mars at low cost. The large interior volume allows a variety of possibly payloads to be delivered.

The Ice Dragon mission concept focuses on three key questions: (1) Is there life on Mars? (2) Are there viable and accessible resources for humans? (3) Is it safe to land humans on Mars?

These are logically addressed by studying martian ground ice. The subsurface environment provides protection from radiation to shield organic and biologic compounds from destruction. The ice-rich substrate is also ideal for preserving organic and biologic molecules and provides a source of H_2O for any biologic activity. Examination of martian ground ice can test the hypotheses of whether ground ice supports habitable conditions, that ground ice can preserve and accumulate organic compounds, and that ice contains biomolecules that show past or present biological activity on Mars. Furthermore, water on Mars, in the form of ground ice and hydrated minerals may provide a valuable resource to enable long-term human exploration. Water can provide the raw materials for rocket propropellant, other fuels, and life support consumables for future human Mars missions.

Ground ice is expected to be fairly common in mid to high latitudes on Mars based on Gamma Ray Spectrometer data, geomorphology, and numerical modeling. Subsurface ice has been directly observed in two locations: the Phoenix landing site (68^{o}N) and Amazonis Plantia (~45^{o}N) [2].

Mission objectives and payload elements of Ice Dragon include:

Objective 1—Determine if life ever arose on Mars. Ice Dragon will search for evidence of life using two different strategies: 1) searching for complex biomolecules that constitute definite evidence of biological activity (*proof of life*), accomplished using SOLID2 [3], a TRL-5 immunoassay instrument capable of detecting a broad range of biologically produced compounds. 2) search for simple organic molecules that might be linked to biological (or nonbiological) processes (*indicators of life*). The TRL-9 TEGA instrument used on Phoenix performed organic analysis [4] but could not uniquely detect organics in perchlorate-rich Mars soil. An alternative candidate instrument, currently at TRL-4, uses Laser Desorption Mass Spectrascopy.

Objective 2—Assess subsurface habitability. The habitability of ground ice is assessed by evaluating the availability of water, energy, and nutrients to support life. Payload elements that can achieve this objective are TRL-9 and include the Wet Chemistry Laboratory flown on Phoenix [5] and APXS flown on Mars Exploration Rovers [6] to identify the presence of nutrient elements and ions important for life.

Objective 3—Establish the origin, vertical distribution and composition of ground ice. Ice Dragon will sample ground ice and determine whether liquid water processes were involved in its implacement or diagenesis by imaging the ice within the borehole, determining the water content of drilled samples, and measuring mechanical properties while drilling the ice.

Objective 4— Assess potential human hazards in dust, regolith and ground ice, and cosmic radiation. Biological and chemical hazards to humans are assessed using the same instruments that addresses objectives 1 and 2. A candidate instrument to characterize the radiation environment on the martian surface is the TRL-9 CRaTER instrument flown on Lunar Reconnaissance Orbiter [7].

Objective 5— Demonstrate ISRU for propellant production on Mars. Systems can be carried to demonstrate the collection of carbon dioxide from the Mars atmosphere and subsequent catalytic processing into methane and water. Atmospheric collection will also allow for incorporation of a dust measurement instrument (size and count rate). The demonstration uses existing TRL 4/5 hardware as a starting point. In addition to atmospheric ISRU, utilizing water from hydrated material and/or near surface ice could be game-changing. Determining soil properties, water/ice quantity, contaminants and other volatiles in the soil, and evaluating cleaning techniques, are required to utilize these resources in future missions. Payload elements that can demonstrate water extraction are currently TRL-5.

Objective 6—Conduct human relevant EDL demonstration. Ice Dragon enters and lands on Mars using an EDL system that is relevant to spacecraft that may land humans on Mars in future missions, but has not previously been demonstrated in flight.

Payload implementation: Samples are obtained using a rotary percussive drill [8] capable of retrieving cuttings from up to 2 meters depth in ice-cemented ground. The 2 m depth allows access to materials that have not been sterilized by ionizing cosmic radiation over geologic timescales [9], and will allow ice to be sampled at midlatitude sites where it may be covered by up to 1 m of dry soil. The drill is a larger and deeper version of the Icebreaker drill that has been tested to TRL-6. Figure 1 illustrates a concept for implementing the drill and instruments in a Dragon capsule. Icy regions on Mars are protected from contamination by terrestrial microbes by steralizing all elements that touch samples and keeping them within a sterile chamber housed in the capsule center. Instrument sample acceptance ports penetrate this chamber but the instruments and support hardware remain outside of it. The height of the capsule allows a single drill string capable of 2 m depth to fit vertically within it. The single drill string approach is simpler and lower risk than an approach requiring multiple drill strings to achieve depth. Openings in the capsule base allow allow drill use inside the capsule. Cuttings samples from the drill are provided to the instruments aseptically.

Conclusions: The payload and landing system we identify for Ice Dragon addresses high priority scientific and human exploration goals. The mission seeks to bridge the gap between science and human exploration, at low cost, by targeting key Strategic Knowledge Gaps. The mission can be scaled up in cost from Discovery-class to New Frontiers-class, and is easily adjustable to budget limitations. However for each class Red Dragon can deliver to Mars more science and technology than previous landing systems. Based on preliminary studies Ice Dragon could become a high pay-off mission as early as the 2018 launch opportunity.

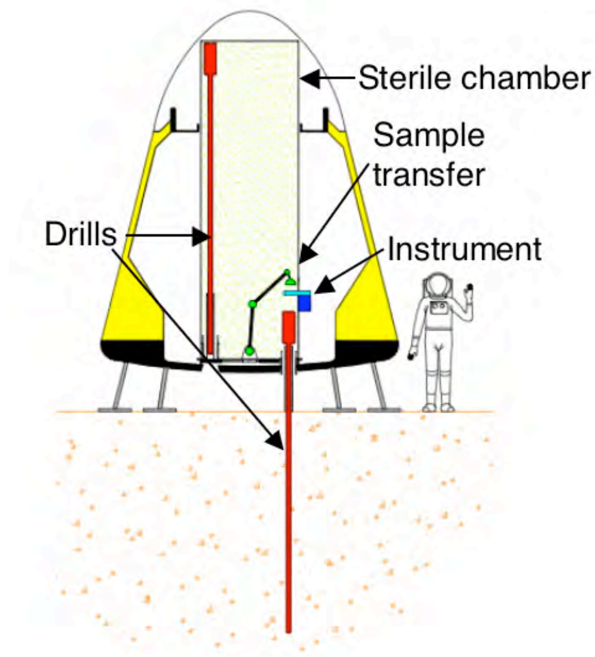

Figure 1: Schematic illustrating payload accommodation within the SpaceX Dragon capsule. Two drills (one deployed to depth, one stowed, shown in red) are housed within a sterile chamber. Instruments are mounted around the circumference of the chamber with sample ports extending inside. A sample transfer system (green) moves cuttings from the drill to the instrument ports. A human is shown for scale.

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Landing site analysis to support a Mars extant life and biomarker detection mission

The search for extant life requires a location with water and highlights the importance of investigating martian ground ice for enhanced preservation of martian biomarkers. A realistic mission to Mars within the next decade would have the ability to drill 1-2 meters into the martian subsurface and thus we search for ice with a measured depth compatible with the ice access capabilities.
Ground ice is expected to be fairly common in mid to high latitudes on Mars given a variety of indirect measurements such as Gamma Ray Spectrometer (GRS) analysis, geomorphology, and numerical modeling. However, there are only three regions on Mars where subsurface ground ice has been directly observed: 1) the Phoenix lander site, 2) the martian polar caps, and 3) the mid-latitudes of Utopia, Arcadia, and Amazonis Planitias. The polar sites are not a high priority for astrobiology since cryogenic temperatures and a lack of a water-soil interface to support microbial life in the more pure polar cap ice is not conducive to supporting extant life or future human exploration. For these reasons we focus our landing site selection study on the mid-latitude ice sites.
In Utopia, Arcadia, and Amazonis Planitias recent impact craters have exposed subsurface water ice within the upper meter, and often within a few 10s of cm. Our region of interest (ROI) for this study is from 40°N-60°N and 130°E-190°E. This ROI encompasses these excavated icy craters and is consistent with the GRS, morphologic, and numerical modeling results suggesting the presence of near-surface ground ice. In this study, surface characteristics of the ROI are assessed using data from the High Resolution Imaging Science Experiment (HiRISE) camera aboard the Mars Reconnaissance Orbiter (MRO). HiRISE collects the imagery with 25.5 to 130 cm/pixel resolution and there are over 300 HiRISE images within our ROI. We have developed a ranking system to quantitatively rank sites based on the presence of visible landing dangers and evidence of subsurface ice. We use the following categories to assess the science and engineering aspects of each site: polygonal ground (proxy for subsurface ice) and indicators of landing hazards including rough topography, boulders, craters, and rock density. For all of the HiRISE images in the ROI, we analyze each image and assign numerical values for each assessment category based on our predetermined assessment scale. A nominal landing site has ubiquitous defined polygons, minimal rough topography, minimal boulders, minimal large craters, few to no small craters, and minimal rock density. Amazonis Planitia hosts an ideal landing site based on these criteria.

The Icebreaker Life Mission to Mars: A search for biomolecular evidence for life.

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Abstract
The search for evidence of life on Mars is the primary motivation for the exploration of that planet. The results from previous missions, and the Phoenix mission in particular, indicate that the ice-cemented ground in the north polar plains is likely to be the most recently habitable place that is currently known on Mars. The near-surface ice likely provided adequate water activity during periods of high obliquity, ~ 5 Myr ago. Carbon dioxide and nitrogen is present in the atmosphere, and nitrates may be present in the soil. Perchlorate in the soil together with iron in basaltic rock provides a possible energy source for life. Furthermore, the presence of organics must once again be considered, as the results of the Viking GCMS are now suspect given the discovery of the thermally reactive perchlorate. Ground-ice may provide a way to preserve organic molecules for extended periods of time, especially organic biomarkers. The Mars Icebreaker Life mission focuses on the following science goals: 1. Search for specific biomolecules that would be conclusive evidence of life. 2. A general search for organic molecules in the ground ice. 3. Determine the processes of ground ice formation and the role of liquid water. 4. Understand the mechanical properties of the Mars polar ice-cemented soil. 5. Assess the recent habitability of the environment with respect to required elements to support life, energy sources, and possible toxic elements. And 6. Compare the elemental composition of the northern plains with mid-latitude sites. The Icebreaker Life payload has been designed around the Phoenix spacecraft and is targeted to a site near the Phoenix landing site. However, the Icebreaker payload could be supported on other Mars landing systems. Preliminary studies of the SpaceX Dragon lander show that it could support the Icebreaker payload for a landing either at the Phoenix site or at mid-latitudes. Duplicate samples could be cached as a target for possible return by a Mars Sample Return mission. If the samples were shown to contain organic biomarkers interest in returning them to Earth would be high.

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The search for organics on Mars

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The combination of the Viking GCMS results and the Phoenix discovery of perchlorate suggests that the simplest explanation for the Viking results is the presence of a few ppm organics in the soil at both VL1 and VL2 sites. SAM on MSL will be able to detect these organics directly because it has three capabilities that the Viking GCMS did not have. First, unlike Viking in which the analysis occurred only after thermal processing, SAM can monitor the head space gases during the pyrolysis steps and organic fragments can be trapped at selected temperatures for GCMS analysis. Organic fragments may be detected before they react with the breakdown products of the perchlorate. Secondly, SAM has a mode in which the total organics are combusted with O2 to CO2 before detection. This mode should be completely independent of the presence of perchlorate which also causes oxidation to CO2. In fact the perchlorate will assist in the oxidation. A key prediction is that some chlorinated organics will also be formed in the combustion mode. Finally, SAM has the capability for liquid extraction using derivitizing agents and this mode should not cause reactive perchlorate products to form. Thus, it is likely that the SAM instrument on MSL will be able to confirm the presence of organics at low levels in the Martian soil. Results from the first analysis of Martian soil by SAM confirms the presence of perchlorates.

Gene Expression Measurement Module (GEMM) – a Fully Automated, Miniaturized Instrument for Measuring Gene Expression in Space

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One of the central, long-standing goals of the NASA Astrobiology Program that holds promise for both major scientific discoveries and exciting the general public is to understand life in space. One strategy towards achieving this goal is to determine the potential for terrestrial microbial life to adapt and evolve in space environments. Identifying the limits of terrestrial life in space and the accompanying molecular adaptations is a prerequisite for developing predictions and hypotheses about life on other worlds. If microorganisms showed the ability to survive in a wide range of conditions encountered in space it would indicate that terrestrial life might not be a local planetary phenomenon, but instead could expand its evolutionary trajectory beyond its planet of origin. This would in turn support the notion that terrestrial life may not be unique and similar life forms might exist elsewhere in the Universe.

Supported by funding from the NASA Astrobiology Science and Technology Instrument Development (ASTID) and Exobiology Programs, we are developing the Gene Expression Measurement Module (GEMM), a fully automated, miniaturized, integrated fluidic system for small spacecraft capable of measuring *in-situ* microbial expression of thousands of genes from multiple samples. The instrument that is scheduled for completion later this year will be capable of automatically (1) lysing even the most robust bacterial cell walls, (2) extracting and purifying RNA released from cells, (3) hybridizing it on a microarray and (4) providing electrochemical readout of the expression levels of thousands of genes, all in a microfluidics cartridge. GEMM will represent a major scientific and technological advancement in our ability to understand the impact of the space environment on biological systems by providing comprehensive information about acclimation and adaptation processes during space flights that are orders of magnitude richer than what is currently available.

Once developed, the system can be used with minor modifications for multiple experiments on different platforms in space, including extensions to higher organisms and microbial monitoring on the International Space Station (ISS). The first target application is to cultivate and measure gene expression of the photosynthetic bacterium *Synechococcus elongatus, i.e.* a cyanobacterium known for its remarkable metabolic diversity and resilience to adverse conditions, exposed to light and dark cycles on a nanosatellite for a period of 6 months in a high-altitude, high-inclination low Earth orbit.

The integration and end-to-end technological and biological validation of this instrument will be discussed. A proposed version of the GEMM that is capable of handing both microbial and tissue samples on the ISS will be briefly summarized.

The ORGANIC Experiment on EXPOSE-R on the ISS: A Space Exposure Experiment

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Aromatic networks are among the most abundant organic material in space. PAHs and fullerenes have been identified in meteorites and are thought to be among the carriers for numerous astronomical absorption and emission features. Thin films of selected PAHs and fullerenes have been subjected to the low Earth orbit environment as part of the ORGANIC experiment on the multi-user facility EXPOSE-R onboard the International Space Station. The ORGANIC experiment monitored the chemical evolution, survival, destruction, and chemical modification of the samples in space environment.

EXPOSE-R with its experiment inserts was mounted on the outside of the ISS from March 10, 2009 to January 21, 2011. The samples were returned to Earth and inspected in spring 2011. The 682-day period outside the ISS provided continuous exposure to the cosmic-, solar-, and trapped-particle radiation background and >2500 h of unshadowed solar illumination. All trays carry both solar-irradiation-exposed and dark samples shielded from the UV photons, enabling discrimination between the effects of exposure to solar photons and cosmic rays.

The samples were analyzed before exposure to the space environment with UV-VIS spectroscopy. Ground truth monitoring of additional sample carriers was performed through UV-VIS spectroscopy at regular intervals at NASA Ames Research Center. During the exposure on the ISS, two control sample carriers were exposed with a slight time shift in a planetary simulation chamber at the Microgravity User Support Center (MUSC) at DLR. Vacuum, UV radiation, and temperature fluctuations are simulated according to the telemetry data measured during flight. The spectroscopic measurements of these two carriers have been performed together with the returned flight samples.

We report on the scientific experiment, the details of the ground control analysis, and preliminary flight sample results. We discuss how extended space exposure experiments allow to enhance our knowledge on the evolution of organic compounds in space.

SEVO (Space Environment Viability of Organics): Results from NASA's First Astrobiology Small Payloads Mission

A. Mattioda, A. Cook, P. Ehrenfreund, R. Quinn, A. Ricco, N. Bramal, J. Chittenden, K. Bryson[1], G. Minelli

The Space Environment Viability of Organics (SEVO) experiment was one of two astrobiology experiments onboard NASA's Organism/Organics Exposure to Orbital Stresses (O/OREOS) cubesat, NASA's first Astrobiology Small Payloads Mission. The goal of the SEVO experiment was to monitor the chemical evolution of astrobiologically relevant molecules under a variety of relevant environments when exposed to the ionizing radiation of space. As such, SEVO consisted of four astrobiologically relevant organic thin films housed in each of four separate micro-environments: an atmosphere containing CO_2 and O_2, a low relative humidity (~2%) atmosphere, an inert atmosphere representative of interstellar/interplanetary space, and a SiO_2 mineral surface to measure the effects of surface catalysis on airless bodies. The UV/Vis spectrum of each sample was monitored *in situ*, with a spectrometer onboard the satellite. Ground control studies of both unphotolyzed and photolyzed samples were conducted to help interpret the chemical changes witnessed in the orbital experiments.

This presentation will discuss the time-evolved spectra of both the orbital and ground control data, focusing primarily on the chemical behavior of the polycyclic aromatic hydrocarbon (PAH), isoviolanthrene (IVA), and the iron tetraphenylporphyrin chloride (FeTPPCl) in the four separate micro-environments. PAHs have been detected ubiquitously in astronomical observations of dust clouds and represent the largest reservoir of organic carbon in interstellar space. In the presence of water and ionizing radiation, PAHs have been shown to produce compounds of interest to biochemistry, including quinones. Porphyrins are a class of naturally occurring compounds with many important biological representatives including chlorophylls and hemes (the pigment in red blood cells). The UV-Vis flight spectra of IVA and FeTPPCl will be presented as well as the UV-Vis and FTIR spectra of the ground control results. Future work based on the SEVO experiment will also be discussed.

SEVO (Space Environment Viability of Organics) Laboratory Control Experiments: Supporting Data for the O/OREOS Mission

Amanda M. Cook, Andrew L. Mattioda, Antonio J. Ricco, Richard C. Quinn, Pascale Ehrenfreund, Giovanni Minelli, Emmett Quigley, Ryan Walker, Robert Walker

ABSTRACT

SEVO (Space Environment Viability of Organics) is one of two science experiments flown onboard NASA's O/OREOS (Organism/Organics Exposure to Orbital Stresses) cubesat, the first Astrobiology Small Payload mission. The experiment exposed four astrobiologically relevant molecules to solar radiation in low-earth orbit. Each type of molecule was deposited as a thin film and contained in four separate micro-environment cells representing a CO_2 atmosphere, H_2O atmosphere, interstellar space, or a mineral surface. The degradation and/or alteration of each sample on the satellite was monitored in situ, with UV/Vis spectroscopy.

To complement flight data, laboratory controls have been designed for exposure to a Solar simulator at regular intervals matching the exposure experienced onboard the satellite. We will present details of the control experiment design, to include the following:

(1) environmental control in a glove box
(2) proper calibration of irradiation sources, particularly H_2/He discharge lamps, to match the Solar spectrum
(3) establishing a protocol for collecting reproducible data from our samples.

A comparison will be made between the control and flight data. Science highlights include chemical changes to a large polycyclic aromatic hydrocarbon and a metalloporphyrin (important for biomarker research) due to UV/Vis irradiation and environmental effects.

OREOcube: ORganics Exposure in Orbit

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The ORganics Exposure in Orbit (OREOcube) experiment is designed to measure chemical changes in organic samples in contact with inorganic substrates to investigate the role solid mineral surfaces may play in the (photo)chemical evolution and distribution of organics in the interstellar medium, comets, meteorites, and other bodies. Currently under development for a 12-month deployment on an International Space Station (ISS) external platform, OREOcube uses UV/visible/near-IR spectroscopy for *in situ* sample measurement. Based on technology developed by NASA Ames Research Center's Small Spacecraft Payloads and Technologies Team, OREOcube is comprised of two 10-cm cubes each containing a highly capable spectrometer for the monitoring of samples held in a 24-sample cell carrier. Each cube is an autonomous stand-alone instrument package, requiring only a standard power-and-data interface, with integrated electronics, a microcontroller, data storage, and optics to enable the use of the Sun for photochemical studies (124 to 2600 nm) and as a light source for spectroscopy. Samples are housed in hermetically sealed reaction cells containing an internal test environment that allows control of headspace gases including the partial pressure of water vapor. The sealed sample cells also allow for the study of chemical processes related to planetary atmospheres, including Titan.

In an OREOcube experiment, an adsorbate-substrate interface is defined by depositing organic samples as thin films onto solid substrates. This provides a controlled method to examine organic samples and inorganic surface interactions. Surfaces provide multiple mechanistic pathways that can drive chemical transformations of organic molecules exposed to radiation. Depending on the substrate, both physi- and chemisorption can result in new photochemical processes in both the adsorbate and the surface. A large number of different adsorbate-substrate photochemical processes can occur, including the creation of new excitation or de-excitation pathways, photoinduced polymerization, bimolecular surface reactions initiated by dissociation of an adsorbed species, electron hole capture by the adsorbed molecule resulting from photon absorption by the substrate and the formation of substrate electron–hole pairs, and photocatalysis.

We report on verification and validations studies of the OREOcube samples and experiment in preparation for ISS deployment.

Acknowledgements: U.S. science team participation in OREOcube is funded by the NASA Astrobiology Science and Technology Instrument Development Program. The European OREOcube science team includes: A. Elsaesser, H. Cottin, E. Dartois, L. d'Hendecourt, R. Demets, B. Foing, Z. Martins, M. Sephton and M. Spaans.

Tackling SMD and HEOMD interests one field deployment at a time

The Pavilion Lake Research Project

Presenter: Darlene Lim, SST, Darlene.lim@nasa.gov, 4-0098, N245/rm283

When humans ultimately venture beyond Low Earth Orbit (LEO), the design principles and operational methodologies required to manage unavoidable time-delayed communications during human scientific exploration, will be critical to our future successes in human space flight. Given that science will undoubtedly be a key driver in future human exploration of the Moon, NEOs or Mars, the effects of time-delayed communications on science, science operations and productivity, mission operations and technological management require focused examination as these effects are not yet understood.

The Pavilion Lake Research Project (PLRP) team is about to embark on Phase 3 of its research program, which is focused on understanding the morphogenesis of modern microbialites in Pavilion and Kelly lakes in British Columbia, Canada. Through this non-simulated science and exploration program, the team will also continue to examine the impact of time-delayed communications on scientifically driven exploration. To date, other NASA SMD/HEOMD analog activities (DRATs, NEEMO) have experimented only with Near Earth Object mission communication delays with crews, and in all cases the experiments have been under simulated conditions. No NASA human mission analog has yet executed multiple deep-space communication delays while crews are conducting real scientific operations. This is a critical research path to understanding how operations will be incrementally impacted by the communications delays, and the knowledge is fundamental to framing future human missions farther and farther from Earth.

The PLRP Phase 3 activities will involve multiple moving parts in the field from science and support divers, to a remote Science Backroom Team (SBT), remotely operated vehicles (ROVs), and a complex web of terrestrial and underwater communications that will link all participants in real and time delayed modalities. The physical, mental and operational challenges associated with the human scientific exploration of underwater environments are directly analogous to those we will encounter during future human space flight architectures. Underwater, humans must, as they do in space, contend with limits in their 1) connection to colleagues, 2) protection/isolation from the environment, and 3) life support systems (LSS), all while exploring and conducting science in variable and unfamiliar terrains. These working constraints are not simulated, but real and inextricable from the proposed science and exploration activities.

Darlene will present a synopsis of the upcoming 2013-2017 PLRP science and exploration research activities and discuss results to date.

Astrobiology Field Analog Research, Education, and Conservation at the Ubehebe Volcanic Field (Death Valley National Park, CA): Discovery and Awareness for a possible tomorrow

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How Can Astrobiology Help Save the World? We outline and integrate here several aspects concurring to answer this question:

First, we briefly introduce an example of Astrobiology Field Analog work under way at the Ubehebe Volcanic Field (UVF) [e.g., 1] in Death Valley National Park (California).

Second, we outline the relevance of cross-disciplinary and multi-component investigations to themes such as climate change and water resources monitoring, environmental sustainability, and preservation of cultural and natural heritage values.

Third, we offer examples of interactions between NASA- and Death Valley-sponsored EPO programs [3], i.e., Spaceward Bound and ROCKS (Recreation Outdoors Campaign for Kids though Study), as well as interactions between researchers conducting planetary analog fieldwork and general visitors. Based on our last three-year experience we have reasons to believe that such synergistic and inclusive interactions can contribute to rising park visitors' awareness on the above themes, which could ultimately lead to a better possible future for individuals and society.

In the northern half of the Death Valley we are studying a high-fidelity site with fascinating geological features: the Ubehebe Volcanic Field. This site includes a dozen craters grouped by different size and depth and formed during subsequent hydro magmatic explosions occurred sometime between less than 2 thousand (Ka) and 6 Ka years ago [1-2].

The UVF comprises the highest number of features that lends itself toward a good analog for upcoming astrobiology-driven missions at several Martian sites, including the Mars Science Laboratory (MSL) Mission [e.g, 4].

For instance, this cratered terrain (~ 3 Km^2) presents a variety of old and recent lithologies, e.g., coarse-grained fluvial deposits, clay-bearing lake deposits, and volcanic ashes, providing parent materials to intra-crater fill deposits (Figure 1) occasionally flooded (i.e., clay ponds). Furthermore, each crater represents an individual natural laboratory where to test for different hypotheses on the origin and distribution of sediment and mineral types seen, or expected on Mars. Finally, we can study and quantify source to sink sediment processes occurring under hydro-climatic desert conditions in analogy to a sometime "wetter and warmer" early Mars.

The interdisciplinary aspect of this study is centered, but not limited to, on understanding the relationship among precipitations (amounts, intensity, and frequency of rainfall), erosion, and formation of sediments and minerals of astrobiological interest (e.g., sulfates, clays, carbonates) in cratered terrains, and particularly at the Ubehebe Crater (Figure 1). This understanding is the cornerstone for formulating hypotheses concerning the potential of minerals, rocks, and sediment to support microbial life (habitability potential) in arid/hot deserts on Earth [e.g., 5] and, possibly, sometime on a past/recent Mars.

Beyond Astrobiology: Science experiments and data acquired to test Astrobiology-driven science hypotheses can have relevant cross-disciplinary applications (Figure 2).

* Supporting Mars Analog Missions research and elements of the Astrobiology Roadmap.
* Monitoring of a sensitive and fragile area (e.g., visitor impact mitigation).
* Long-term monitoring of weather/microclimate conditions, water resources, and landscape erosion.
* Addressing amplitude of ecological change from drying climate in Southwest North America (soil/air moisture and temperature monitoring).
* Rising awareness of Native American Cultural Heritage (archeological and sacred sites), and engaging local communities.
* Enhancing the overall visitors' experience and awareness at the analog site (Figure 2).
* Supporting park resource management decision-making and strategic plans.

Figures

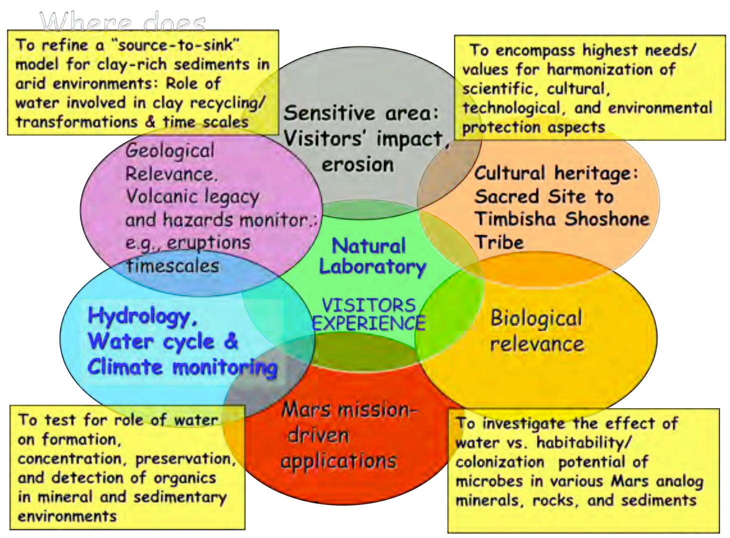

Figure 1 (left-hand side): Main view if the Ubehebe Crater, the largest within the UVF.
Figure 2 (right-hand side): Cross-disciplinary applications of Astrobiology research conducted at the UVF and relevant objectives (rectangular boxes).

References

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Astrobiology field research in a High-Fidelity Desert Analog Site: The Ubehebe Volcanic Field (Death Valley, California)

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Astrobiology science missions are planned to search for potentially habitable, ancient geological environments on Mars. For instance, the Mars Science Laboratory (MSL) Mission will require a highly-integrated science approach to understand the role of (liquid) water/climate, and time scales involved in weathering processes, as well as formation of sediment and minerals conducive to life (as we know it) as a preliminary step to future life detection missions. Clays and clay-rich sediments are unambiguous indicators of past aqueous activity on Mars [3-7] and of particular interest due to their high preservation potential. Understanding the environmental and climatic context under which clay-rich fine grain sediments are formed and recycled on Earth is the cornerstone for understanding the astrobiology potential of analog sedimentary and mineral environments on a wetter warmer early Mars [1-2]. In the above context we have identified high-fidelity analog sites at the Ubehebe Volcanic Field (UVF), in Death Valley Natl. Park. The UVF is a cratered terrain formed by subsequent phreatomagmatic eruptions (caldera), which occurred sometimes between less than 2 thousand (Ka) and 7 Ka years ago.

Overall, this site combines multiple analogies of setting and processes argued for a variety of past and proposed and future Martian landing sites (Mawrth Vallis, Eberswalde, Holden and Gale craters) [3-4] including the MSL Gale Crater [5]. The UVF comprises three main sites.

1. The Ubehebe Crater (UC), the largest in the area, is ~0.8 km-wide, 150 to 237 m-deep. The exposed wall lithology consists of hundreds meters-thick heterogeneous layered materials i.e., conglomerates (fluvial) and red mudstone (lake deposits) overlain by a thinly bedded pyroclastic-surge deposit (pumice and basaltic ash) of Recent age. Wall deposits supply weatherable material to bottom sediments (intra-crater fill deposits) containing Al- and perhaps Fe/Mg- bearing smectites (nontronite). In analogy to the UC, Gale Crater alluvium bears a nontronite signature formed by erosion, transport, and re-deposition of materials from the layered mound deposit and/or crater walls by liquid runoff on a "Early, Wet" Mars.

2) The Southern Craters Group (SCG) has a shallow drainage and more extended alluvial features with respect to the other sites; and

3) The Little Hebe (LH) is a spatter cone displaying a mineralogical variability greater than elsewhere. A complex rim of molten scoriaceous lava, partly oxidized to hematite, comprises a small outcrop of layered sulfates, and it is overlain by pyroclastic material.

We have been conducting several field campaigns (2009-present) centered on the long-term monitoring of weather and moisture conditions in sediments and in relation to possible formation of clay minerals.

Comparison of bulk mineralogical composition (XRD data) of crater wall and fill deposits indicates that major detrital components i.e., quartz, carbonates, plagioclase, K-feldspar, are over-represented in the red mudstones wall units relative to the floor units (mud: ~99wt.%, N=5); minor inherited clays are also present (chlorite+kaolinite, muscovite/illite, and possible smectites) in wall and floor deposits. This may imply that some smectite clays are currently forming in crater floor sediments/ephemeral ponds under current desert hydro-climatic conditions (e.g., ~50mm to >250 mm/y rainfall in WY 2004-2012).

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Microbiological Genetic Inventory within the NASA Ames Research Center High Bay Cleanroom.

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Space exploration goals over the coming decades place a high priority on the search for life in the universe, and space agencies have set in place ambitious endeavors to investigate environments relevant to possible past, or even present life on Mars. A broad diversity of microorganisms have been detected in cleanrooms where spacecraft are assembled, and these contaminants can be broadly divided into two different types, those that are human commensals and/or pathogens, and those that simply thrive in the harsh cleanroom environment. The later, depicted as oligotrophs, are of special concern, as they are capable of colonizing inorganic surfaces like metal, and have been shown to be a concern for forward contamination of other planets, and by complicating testing for extraterrestrial life forms. Subsequently, information on microbial diversity is essential for making data-based decisions about the implementation of bioburden reduction measures and interpretation of life detect ion experiments. Comprehensive, DNA sequence based surveys of spacecraft assembly, integration, and test (AI&T) facilities are needed to identify all microorganisms present; as has been suggested by the National Research Council.

The NASA Ames Research Center High Bay Clean Area (HBCA) and Clean Room (HBCR) certification to ISO class 8 and 7, respectively, has recently been performed prior to the arrival of the Lunar Atmosphere and Dust Environment Explorer (LADEE) spacecraft for final assembly. This provided a unique opportunity to assess the total bioburden and perform a genetic microbiological inventory of the HBCA prior to (where limited maintenance has been performed), and after its certification.

In order to assess the changes induced by the cleaning and recertification of the HBCA on microbial diversity, samples were collected and analyzed by hybridizing target sequences to a universal 16S rRNA gene microarray (Phylochip) that provides a rapid and comprehensive view of prokaryotic community composition. Preliminary results comparing the genetic profile of the clean room pre- and post-certification will be discussed. To our knowledge, this will be the first such study. This assessment will be extremely valuable in our understanding of how the environment and cleaning procedures impact microbial diversity in NASA spacecraft AI&T facilities.

Supported by the NASA Planetary Protection and the Exobiology Programs.

In-flight Performance of the Water Vapor Monitor Onboard the SOFIA Observatory

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NASA's Stratospheric Observatory for Infrared Astronomy (SOFIA) airborne observatory flies in a modified B747-SP aircraft in the lower stratosphere above more than 99.9% of the Earth's water vapor. As low as this residual water vapor is, it will still affect SOFIA's infrared and sub-millimeter astronomical observations. As a result, a heterodyne instrument has been developed to observe the strength and shape of the 183 GHz rotational line of water, allowing measurements of the integrated water vapor overburden in flight. In order to be useful in correcting the astronomical signals, the required measured precipitable water vapor accuracy must be 2 microns or better, 3 sigma, and measured at least once a minute. The Water Vapor Monitor has flown 22 times during the SOFIA Early Science shared-risk period. The instrument water vapor overburden data obtained were then compared with concurrent data from GOES-V satellites to perform a preliminary calibration of the measurements. This presentation will cover the results of these flights. The final flight calibration necessary to reach the required accuracy will await subsequent flights following the SOFIA observatory upgrade that is taking place during the spring and summer of 2012.

Astrophysics Poster: AP.2

Curtis DeWitt

Abstract:

The Echelon-Cross-Echelle Spectrograph (EXES) is one of the first generation instruments for the Stratospheric Observatory for Infrared Astronomy (SOFIA).

The primary goal of EXES is to provide high-resolution, cross-dispersed spectroscopy, with resolutions of 50,000-100,000 and wavelength coverage of 0.5-1.5% in the mid-infrared (MIR), between 4.5 μm and 28.3 μm. SOFIA will nearly eliminate the impact of atmospheric water vapor on MIR observations. EXES will be the first high-resolution MIR spectrometer located above most of the atmosphere, enabling a new window for astronomical observing. We discuss one science application, the chemical evolution of high mass pre-stellar cores.

Astrophysics Poster: AP.3

Title: Adventures High Energy Astrophysics: From the Sun to the Crab Nebula and Beyond.

Abstract: Current and planned astrophysics observations, for example from the Kepler and Fermi Gamma Ray Space Telescope, are yielding long, precise, and finely sampled time series ushering in the Age of Digital Astronomy. Analysis of these data is uncovering and elucidating energetic dynamical processes throughout the Universe. Fulfilling these opportunities requires effective data analysis techniques that can rapidly and automatically implement advanced concepts. With various colleagues I have developed tools ranging from simple but optimal histograms to time and frequency domain analysis for arbitrary data modes and time sampling. Examples to be shown include more than three cycles of solar chromospheric variability, gamma-ray activity in the Crab Nebula, active galactic nuclei and gamma-ray bursts.

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Sounding the Stars: Asteroseismology with the Kepler Space Telescope

Daniel Huber
NASA Postdoctoral Program Fellow

Abstract

The measurement of stellar oscillations - also called asteroseismology - is among the most powerful observational tools to study the structure and evolution of stars. The continuous high-precision photometry collected by the Kepler space telescope has revolutionized asteroseismology over the past few years by boosting the number of stars with detected oscillations by nearly two orders of magnitude over ground-based efforts, and delivering data with unprecedented signal-to-noise. In this talk I will highlight some of the recent breakthrough discoveries in stellar astrophysics by the Kepler Mission, focusing in particular on the determination of the internal composition and rotation of red giant stars and asteroseismic studies of exoplanet host stars.

Astrophysics from *Kepler*: The Radii of Low-Mass Stars in Long-Period Eclipsing Binaries

Jeffrey L. Coughlin
SETI / NASA AMES

An outstanding problem in stellar astrophysics is that the radii of low-mass, main-sequence stars in eclipsing binary systems are consistently 10-15% larger than predicted by stellar models. This inflation is hypothesized to be primarily due to enhanced magnetic activity as a result of their binarity, and thus artificially enhanced rotation rates. Thus, such an effect should diminish with increasing period, but only a small number of low-mass eclipsing binary systems are known in general, fewer are well-studied with precise light and radial-velocity curves, and barely any of these are at long periods. In addition to exploring the physics of low-mass stars, research into this area helps to better characterize the radii of extrasolar planets around low-mass stars, whose values are dependent on those assumed for the host star.

Using *Kepler*, we have identified 100^+ low-mass, main-sequence eclipsing binaries suitable for ground-based follow-up, with 30 of them having periods greater than 10 days. We obtained follow-up ground-based spectroscopy for 10 of these long-period systems, and combined it with the *Kepler* light curves to obtain values for the absolute masses, radii, and temperatures of these stars. Surprisingly, the preliminary evidence indicates that low-mass stars in long-period systems are as inflated as those in short-period systems, and thus rotation and activity may not be the principal factors in explaining the radii discrepancy. More systems still need to be observed, and the modeling of low-mass stellar interiors may need further improvement.

A. Amblard, L. Riguccini, P. Temi and S. Im

Elliptical (E) and lenticular (S0) galaxies, both early-type galaxies (ETGs), are among the most massive galaxies today. Their poorly known formation is subject to much debate. Temi et al. 2009 showed that S0 have a larger Far-Infrared luminosity when normalized with their K-band luminosity. This larger emission indicates a stronger specific star formation rate. In this work we investigate differences between Elliptical and Lenticular local galaxy populations. We compute the properties of a sample of 221 local early-type galaxies with a spectral energy distribution (SED) modelling software, CIGALEMC. Concentrating on the star forming activity and dust contents, we derive parameters such as the specific star formation rate, the dust luminosity, dust mass and temperature. We find that S0 galaxies have a larger specific star formation rate (sSFR) and larger specific dust emission than E galaxies. The stronger activity of S0 galaxies is also confirmed by a larger amount of dust. We investigate the proportion of Active Galactic Nucleus (AGN) and Star-Forming (SF) galaxy in our sample using spectroscopic SDSS data and near-infrared selection, and find a larger proportion of AGN dominated galaxy in the S0 sample than the E one. This could corroborate a scenario where blue galaxies evolve into red ellipticals by passing through a S0 AGN active period while quenching its star formation.

Multiwavelength Diagnostics of a Late-stage Galaxy Merger Sequence

Michael N. Fanelli
Pasquale Temi
Alexandre A. Amblard
Laura A. Riguccini

NASA Ames Research Center

ABSTRACT

We discuss the evolutionary state of five gas-rich early-type galaxies whose integrated properties suggest that these systems are mid-to-late stage mergers, extending beyond the Toomre sequence. A variety of multiwavelength data are utilized to explore diagnostics of the merger process, including imaging photometry derived from observations with *GALEX, SDSS, WISE* and *Spitzer*. In particular, we interpret mid-infrared spectra (5-14 μ) obtained with the Infrared Spectrograph on *Spitzer*. Unusual for early-type galaxies, we find strong emission from polycyclic aromatic hydrocarbons bands and singly-ionized atomic lines, likely caused by low-level star formation in these systems. The overall strength of the PAH emission appears correlated with morphologically signatures defining the timescale since the merger/accretion event. We present feature strengths and ratios derived from the mid-infrared spectra together with estimates of their star formation rates using GALEX FUV and Spitzer 24μ continuum data to intrepret the stellar content and history of these systems.

Astrophysics Abstract: AP.8

Title: Extragalactic detection of CH 532/536 GHz lines from Herschel: NGC 1068, M82, Arp 220 and NGC 253

Naseem Rangwala

We will present the first extragalactic detection of CH 532/536 GHz lines from SPIRE Fourier Transform Spectrometer (FTS) and HIFI on Herschel. These CH lines are detected in Arp 220, M82, NGC 1068 and NGC 253. Observations at UV/visible wavelengths show that CH is an excellent tracer of molecular gas in the diffuse interstellar medium. In this work we estimate the column densities of the CH from the sub-mm lines and investigate its strength as a tracer of molecular gas in comparison to CO; i.e., can CH lines that fall in the sub-mm waveband be used to reliably trace molecular gas and do these lines trace the cold or the warm molecular gas?

Pasquale Temi, William G. Mathews, Fabrizio Brighenti, Alexandre Amblard

Variations of Mid and Far-IR Luminosities Among Early-Type Galaxies: Relation to Stellar Metallicity and Cold Dust

The Hubble morphological sequence from early to late galaxies corresponds to an increasing rate of specific star formation. The Hubble sequence also follows a banana-shaped correlation between 24 and 70 micron luminosities, both normalized with the K-band luminosity. We show that this correlation is significantly tightened if galaxies with central AGN emission are removed, but the cosmic scatter of elliptical galaxies in both 24 and 70 micron luminosities remains significant along the correlation. We find that the 24 micron variation among ellipticals correlates with stellar metallicity, reflecting emission from hot dust in winds from asymptotic giant branch stars of varying metallicity. In some elliptical galaxies cold interstellar dust emitting at 70 and 160 microns may arise from recent gas-rich mergers. However, we argue that most of the large range of 70 micron emission in elliptical galaxies is due to dust transported from galactic cores by feedback events in (currently IR-quiet) active galactic nuclei. AGN-heated gas can transport cold dust 5-10 kpc out into the hot gas atmospheres before it is destroyed by sputtering. Apparently, elliptical galaxies undergo large transient excursions in the banana plot in short times, 10 Myrs, comparable to the sputtering time or AGN duty cycle. Cold dust and gas naturally accumulates in the cores of elliptical galaxies due to local stellar mass loss and over time may result in low-level star formation.

Astrophysics Poster: AP.10

Title: Differential Heating of Magnetically Aligned Dust Grains

Authors: John E. Vaillancourt and B-G Andersson (SOFIA/USRA/NASA-Ames)

Abstract: We use far-infrared photometric maps from IRAS and Herschel to search for the differential heating of asymmetric dust-grains aligned with respect to an interstellar magnetic-field and heated by a localized radiation source. The grains are known to be asymmetric and have a net alignment of their axes from observations of background starlight polarization. For grains also near stars embedded in Galactic dust clouds, incident photons are primarily from a single localized source. Such a region has consequences for the distribution of grain heating if the local magnetic field is fairly uniform in direction. For example, asymmetric grains whose largest cross-sections are normal to the incident stellar radiation will reach warmer equilibrium temperatures compared to grains whose largest cross-section is parallel to that direction. This should be observed as an azimuthal dependence of the dust color-temperature. We present evidence of such a dependence using IRAS data at 60 and 100 micron. We expect this effect to be stronger using longer wavelength (i.e., 160 micron) data better coupled to the "big-grain" dust population, grains which are also more efficiently aligned with the local magnetic field. Here we also present the results of our on-going work to search for this signal using Herschel maps towards three candidate stars.

Observational Constraints on Interstellar Grain Alignment Mechanisms

B-G Andersson
SOFIA/USRA

Optical polarization was discovered over 60 years ago, and was from the start recognized to be due to the alignment of asymmetric dust grains with the magnetic field. However, up until very recently the physics of the grain alignment has been poorly understood. The "text book" theory for grain alignment; paramagnetic relaxation has, by now, been shown, both theoretically and observationally to be unviable. Fortunately, an alternative theory, based on direct radiative mechanisms has now been developed, providing a number of specific predictions amenable to observational tests. I will review the state of these tests, many of which our group has been leading, to show that - while not yet fully established - Radiative Alignment Torque (RAT) theory is by now the leading candidate to solve this long standing enigma of interstellar astrophysics.
A quantitative, observationally supported, theory of grain alignment will not only address a long standing mystery of astrophysics but will allow more reliable probes of the interstellar magnetic field and of the microphysics of interstellar dust.

How empty are the dust holes in the inner regions of evolved protoplanetary disks?

Uma Gorti

Abstract:

Protoplanetary disks evolve from a primordial stage where gas dominates the mass (gas/dust mass ratio ~ 100), to a stage where the gas is depleted, while the initially sub-μm sized dust grains undergo repeated collisions to grow and form larger objects and planetesimals. Some disks, called transition disks, develop central cavities during their evolution and the dust content in these holes often drops by orders of magnitude. These holes have been variously interpreted as being caused by grain growth and settling, torques on disk material due to planet formation, or photoevaporation due to heating of the disk surface and consequent erosion. The distribution of gas in the inner disk is expected to differ in each case but is however largely *unknown*. Morevoer, the availability of sufficient gas mass for an extended period of time in these inner regions is a critical factor in determining the likelihood of planet formation and migration.

I will discuss how studies of line emission spectra can reveal the dominant mechanisms that cause holes in transition disks by mapping out their gas content. Observed emission lines range from the optical (e.g., [OI] 6300Å) to near-infrared (e.g., CO ro-vibrational lines), mid-infrared (e.g., H_2, [NeII]12.8μm) and sub-millimetre wavelengths (CO rotational lines) — all tracing different spatial locations in the disk. Comparing observational data with gas line emission spectra calculated from thermochemical models, we constrain the *gas* distribution in the inner regions of some transition disks, calculate the photoevaporation rates, and set mass constraints on any embedded planets.

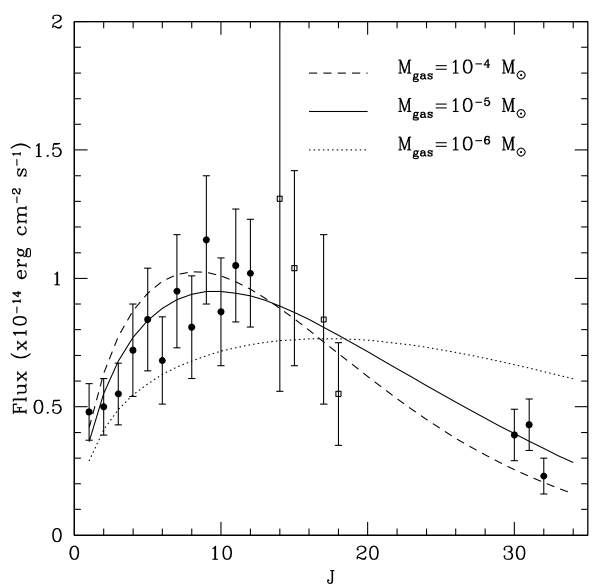

Figure 1: *Calculated CO_{rovib} flux vs. rotational quantum number J for three inner disk masses in TW Hya. Data are from Rettig et al. 2004 (open squares) and Salyk et al. 2007 (filled circles). A disk mass of $10^{-5}M_\odot$ is seen to be the best fit. (From Gorti et al. 2011)*

Multi-wavelength Survey of W40: A Star-Forming Region

Sachindev S. Shenoy[*], Ralph Y. Shuping[† *], and William D. Vacca[*]

[*]USRA - Sofia Science Center, NASA ARC, Moffett Field, CA
[† *]Space Science Institute, Boulder, CO

Abstract

W40 is an HII region (Sh2-64) behind the Serpens molecular cloud in the Aquila rift region. Recent near-infrared spectroscopic observations of the brightest members of the central cluster of W40 reveal that the region is powered by three early B-type stars and one late O-type star. Near and mid-infrared spectroscopy and photometry, combined with SED modeling of these sources, suggest that the distance to the cluster is between 455 and 535 pc, with about 10 mag of visual extinction (Shuping et al., 2012).

Here we present some preliminary results of a multi-wavelength survey of the central cluster and the extended emissions of W40. We used Spitzer IRAC data (Allen et al., 2006) to measure accurate photometry of the point sources within 4.32 pc of W40 via PRF fitting. The Spitzer photometry are band-merged with publicly available near and mid-infrared photometry in 2MASS and WISE archives. These data are used to model the YSOs in this region. The near-infrared colors and modeling of the SEDs of the point sources should allow us to determine the age and evolutionary state of the central cluster of W40. The results from this work will provide us with a complete census of YSOs in the W40 and put it in a proper stellar evolutionary context.

After subtracting the point sources from the IRAC images, we plan to study the extended emissions, free from point source contamination. We choose a few morphologically interesting regions in W40 and use the data to model the dust emission. The results from this effort will allow us to study the correlation between dust properties and the large scale physical properties of W40.

References

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Shuping, R. Y., Vacca, W. D., Kassis, M., & Yu, K. C. 2012, AJ, 144, 116

Mid-infrared Imaging Of The W40 Star Forming Region Using SOFIA-FORCAST

R. Y. Shuping[1,2], William D. Vacca[2], T. L. Herter[3], and J. D. Adams[3]

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NASA Ames Research Center

Space Science and Astrobiology Division

Science Symposium

12 March 2013

Abstract

We present mid-infrared images (5–40 μm) of the central portion of the W40 star forming region using the FORCAST instrument on SOFIA. These data were obtained as part of the SOFIA Basic Science Guest Investigator program during the summer of 2011, and are the highest resolution images of this region in the 20–40 micron wavelength range to date. Our images reveal a handful of protostellar sources in addition to diffuse emission from warm dust in the background nebula. We combine the SOFIA results with ground based photometry and spectroscopy to generate full optical/near-IR to mid-IR spectral energy distributions for the sources detected and compare them to standard models for young stellar objects of various masses and ages. We also discuss the nature of the mid-IR emission for IRS 3A, an early-B star that appears to be located within a small cocoon of warm dust.

Astrophysics Poster: AP.15

Type : Poster
Authors : Dr. Christiaan Boersma(1,2), Dr. Robert H. Rubin(1,3), Dr. Louis J. Allamandola(1)
Affiliations : (1) NASA Ames Research Center, MS 245-6, Moffett Field, CA 94035, USA (2) San José State University Research Foundation, 210 N. Fourth Street, Fourth Floor, San José, CA 95112 (3) Orion Enterprises, MS 245-6, Moffett Field, CA 94035, USA

Title : Spatial Analysis of the Polycyclic Aromatic Hydrocarbon Features Southeast of the Orion Bar

Polycyclic aromatic hydrocarbon (PAH) and dust emission features between 10 - 37 μm, observed with Spitzer at 11 positions southeast of the Bright Bar (BB) in Orion, are analyzed and connected to atomic and H_2 lines reported earlier. Variations at these positions indicate changes in local conditions and materials sampled. The major findings are: (1) PAH erosion and destruction are important from the BB out to about 5 minutes of arc. (2) The ionized PAH fraction, inferred from the 11.0 μm PAH band, increases from the BB out to 6.5 minutes of arc. This counterintuitive behavior is linked to PAH dehydrogenation. (3) The "11.2" μm PAH band profile shifts from class $A_{11.2}$ to $A(B)_{11.2}$ between 9 and 10 minutes of arc, indicating these lines-of-sight probe a different environment, likely shielded molecular cloud material. (4) The different spatial behavior of the PAH bands and the 10 - 15 μm plateau supports the view that the plateau originates from a separate carrier. (5) The fullerene/PAH band strength ratio decreases out to about 7 minutes of arc, increases between 9 and 10 and drops at 12 minutes of arc. The first region is where PAHs are dehydrogenated and eroded whereas the second, shielded zone, is where the "11.2" μm profile shifts and PAH erosion is unlikely. This suggests fullerenes are intimately mixed with PAHs in shielded regions. Taken together, the observations suggest three different regimes are sampled: (1) the H II region–photodissociation region (PDR) interface directly southeast of the BB, (2) shielded molecular cloud material farther out, and (3) the H II region–PDR interface seen limb brightened at the outermost position.

Type: Poster
Authors: Dr. Jesse Bregman (1,2), Dr. Christiaan Boersma (1,3), Dr. Louis Allamandola (1)
Affiliations: (1) NASA Ames Research Center, (2) Bay Area Environmental Research Institute, (3) San Jose State University Research Foundation

Title: Analysis of Spitzer IRS Spectral Maps of the Reflection Nebula NGC7023 with the NASA Ames PAH Spectroscopic Database

PAH emission in the Spitzer-IRS spectral map of the northwest PDR in NGC 7023 was analyzed using exclusively PAH spectra from the NASA Ames PAH IR Spectroscopic Database (www.astrochem.org/pahdb). The 5 – 15 µm spectrum at each pixel is fitted using a non-negative-least-square fitting approach. The fits are of good quality, allowing decomposition of the PAH emission into four subclasses: size, charge, composition and hydrogen adjacency (structure). Maps tracing PAH subclass distributions across the region paint a coherent astrophysical picture. Once past some 20 seconds of arc from HD 200775, the emission is dominated by the more stable, large, symmetric, compact PAH cations; with smaller, neutral PAHs taking over along the lines-of-sight towards the more distant molecular cloud. The boundary between the PDR and the denser cloud material shows up as a distinct discontinuity in the breakdown maps. Noteworthy is the requirement for PANH cations to fit the bulk of the 6.2 and 11.0 µm features and the indication of PAH photo-dehydrogenation and fragmentation close to HD 200775. The data were also grouped into similar spectral classes using a k-means clustering algorithm. The class maps show spectral changes parallel to the PDR-diffuse region boundary rather than as a function of the projected distance from the exciting star, HD 200775. Traditional band strength extractions were then combined with the information from the database fits and the k-means clustering to reveal trends in the data not seen in previous analyses of this region.

Type : Poster

Authors : Dr. Christiaan Boersma(1,2), Dr. Louis J. Allamandola(1), Dr. Charles W. Bauschlicher Jr.(3), Dr. Alessandra Ricca(3,4), Prof. Jan Cami(1,4,5), Prof. Els Peeters(1,4,5), Fernando Sanchez(4), Gerardo Puerto(4), Dr. Andrew L. Mattioda(1), Dr. Douglas M. Hudgins(6)

Affiliations : (1) NASA Ames Research Center, MS 245-6, Moffett Field, CA 94035, USA (2) San José State University Research Foundation, 210 N. Fourth Street, Fourth Floor, San José, CA 95112 (3) NASA Ames Research Center, MS 230-3, Moffett Field, CA 94035, USA (4) SETI Institute, 515 N. Whisman Road, Mountain View, CA 94043, USA (5) Department of Physics and Astronomy, PAB 213, The University of Western Ontario, London, ON N6A 3K7, Canada (6) NASA Headquarters, MS 3Y28, 300 E St. SW, Washington, DC 20546, USA

Title : The NASA Ames PAH IR Spectroscopic Database V 2.0 – Spectroscopic Fitting Tools and More

Polycyclic Aromatic Hydrocarbons (PAHs), omnipresent across the Universe, play an intrinsic part in the formation of stars, planets and possibly even life itself. While PAH infrared (IR) emission features are now routinely used as tracers of star formation and redshift indicators for distant, dust obscured, galaxies, there is a wealth of information in the PAH spectra that remains untapped. This information reveals subtle details about the PAH population within an object, details which, in turn probe local conditions in the object. We continue to develop the experimental and computational PAH spectra collected at NASA Ames into such diagnostics. This coherent, large (some 700) collection of IR spectra from the single ring aromatic molecule benzene to PAHs containing 386 carbon atoms is now part of the NASA Ames PAH IR Spectroscopic Database (PAHdb). PAHdb can be accessed at www.astrochemistry.org/pahdb, where its contents can be browsed and/or downloaded along with advanced on- and off-line tools that allow astronomers to work with the spectroscopic data. Since it's initial release in 2010, new spectra have been added, the website has been improved and the tools expanded. It is now possible to upload astronomical spectra to the website in several common formats e.g., fits and VOTable, and fit them with the spectra in PAHdb, several PAH emission models are also available with which one can compute the emission expected from complex PAH mixtures, animations of the molecular vibrations corresponding to individual modes are available, etc. These newly added tools, together with the enlarged set of PAH spectra, allow astronomers to analyze and probe the conditions in a multitude of very different astronomical objects in new ways. This poster summarizes the updated contents of PAHdb, the improved website with its expanded tools and demonstrate fitting an astronomical spectrum. Employing these spectral fitting techniques on the Spitzer-IRS map of the reflection nebula NGC7023 is demonstrated, showcasing the variations in PAH subpopulations.

The Infrared Spectra of Polycyclic Aromatic Hydrocarbons with Excess Peripheral H Atoms (H_n-PAHs) and their Relation to the 3.4 and 6.9 μm PAH Emission Features

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Abstract

Polycyclic aromatic hydrocarbons (PAHs) and related materials are thought to be responsible for the family of infrared emission features that are seen in a wide variety of astrophysical environments. A potentially important subclass of these materials are polycyclic aromatic hydrocarbons whose edges contain excess H atoms (H_n-PAHs). While it has been suggested that this type of compound may be present in the interstellar population [1], it has been difficult to properly assess this possibility because of a lack of suitable infrared laboratory spectra to assist with analysis of the astronomical data. We present the 4000-500 cm^{-1} (2.5-20 μm) infrared spectra of 23 H_n-PAHs and related molecules isolated in argon matrices, under conditions suitable for use in the interpretation of astronomical data [2].

The spectra of molecules with mixed aromatic and aliphatic domains show unique characteristics that distinguish them from their fully aromatic PAH equivalents. We will discuss the changes to the spectra of these types of molecules as they transition from fully aromatic to fully aliphatic forms. Two important changes that occur as PAHs acquire additional H atoms are: (1) the rapid conversion of aromatic C-H stretching mode bands near 3.3 μm to the asymmetric and symmetric stretching modes of aliphatic –CH_2- groups in the 3.4 μm region (H_n-PAHs have no -CH_3 groups), and (2) the decrease in aromatic C-H out-of-plane bending mode bands in the 11-15 μm region with the concurrent growth of a strong methylene deformation mode band near 6.9 μm. In addition, the exact positions of these bands provides some information on the degree of H addition.

The implications for the interpretation of astronomical spectra are discussed with specific emphasis on the 3.4 and 6.9 μm features. Laboratory data will be compared with emission spectra from IRAS 21282+5050, an object with normal PAH emission features, in addition to IRAS 22272+5435 and IRAS 0496+3429, two protoplanetary nebulae with abnormally large 3.4 μm features. We will show that ‘normal’ PAH emission objects contain relatively few H_n-PAHs in their emitter populations, but less evolved protoplanetary nebulae may contain significant abundances of these molecules. However, the data suggest that even in those objects that do show evidence for H_n-PAHs, the overall population is still dominated by aromatic, not aliphatic materials. Various details in the spectra indicate that most of the H_n-PAHs probably have light excess H coverage, i.e., the population of molecules responsible for the protoplanetary spectra probably consist of normal PAHs mixed with moderate amounts of H_n-PAHs with a few excess H atoms, not PAHs mixed with a smaller amount of fully hydrogenated polycyclic aliphatic hydrocarbons.

H_n-PAHs are formed when PAHs are irradiated in ices [3], so these molecules may be present in reflection nebula, but astronomical data are currently insufficient to address this issue.

References: [1] Bernstein, M. P., Sandford, S. A., & Allamandola, L. J. (1996) *Astrophys. J.* **472**, L127-L130; [2] Sandford, S. A., Bernstein, M. P., & Materese, C. K. (2013) *Astrophys. J. Suppl. Ser.*, in press; [3] Bernstein, M. P., Sandford, S. A., Allamandola, L. J., Gillette, J. S., Clemett, S. J., & Zare, R. N. (1999) *Science* **283**, 1135-1138.

Formation routes for pure polycyclic aromatic hydrocarbon (PAH) molecules and N- and O-substituted PAH molecules in the outflows of carbon stars

Partha P. Bera

Astrophysics, Space Science and Astrobiology Division, NASA Ames Research Center

Abstract

Large polyatomic carbonaceous molecules, known as polycyclic aromatic hydrocarbons, are known to exist in the outflows of carbon stars. How these large polyatomic molecules are synthesized in such exotic conditions is, thus far, unknown. Molecular ions are in relative abundance in the radiation fields of the ISM. Hence, barrierless ion-molecule interactions play a major role in guiding molecules towards each other and initiating reactions. Can these cold condensation pathways be viable means of forming large pure hydrocarbon molecules, and nitrogen and oxygen containing carbonaceous chains, stacks, and even cyclic compounds? Some of the observed carbon, hydrogen, nitrogen, and oxygen containing molecules, both neutral and ions, are paired with each other to investigate the nature of bonding and spectra of the resulting cationic molecular complexes. We studied ion-neutral association of pure-carbon molecules e.g. acetylene and ethylene and characterized oxygen and nitrogen atom incorporation in the carbon ring. We have used accurate *ab initio* density functional theory, Møller-Plesset perturbation theory and coupled cluster theoretical methods along with large correlation consistent basis sets in these investigations. We also employed time-dependent density functional theory and equations-of-motion coupled cluster theory to compute electronic excitation energies and oscillator strengths of the products of the ion-molecular reactions. We obtained accurate vibrational frequencies under the harmonic approximation and vibrational intensities using the double harmonic approximation for fundamental molecular vibrations. We identified three types of bonding motifs with strong, moderate, and weak binding energies among the carbonaceous complexes. Both linear and cyclic isomers identified on the potential energy surface of these molecular complexes are expected to form rather easily due to electrostatic interactions. Some of these complexes have large oscillator strengths for charge-transfer type electronic excitations in the near infrared and visible regions of the electromagnetic spectrum. As part of a combined experimental/theoretical effort, we are trying to understand the formation, evolution, and destruction, i.e. the lifecycle of carbon and small to large carbonaceous species in our Milky Way galaxy. In conjunction with molecular/ion plasmas and ice irradiation experiments performed by the Laboratory Astrochemistry groups in Ames, we have explored, by quantum chemical methods, the association processes, structures, mechanisms, and spectroscopic properties of the ensuing species in order to identify the pathways of formation of small PAH molecules and the molecules of life.

Abstract title: Polycyclic Aromatic Hydrocarbon Clusters in the Interstellar Medium

Authors: Joseph E. Roser, Alessandra Ricca, and Louis J. Allamandola

Affiliations: NASA Ames Research Center (J. Roser, L. Allamandola), SETI Institute (J. Roser, A. Ricca)

Abstract: The interstellar medium consists of the complex network of atoms and molecules, dust particles and gas, and energetic processes that inhabits the space between stars in the Galaxy. Key players in this interstellar ecosystem are the polycyclic aromatic hydrocarbons (or PAHs), which consist of planar networks of fused benzene rings with perimeter bonding to hydrogen atoms. The PAHs are believed to be robust and abundant in the interstellar medium, their van der Waals clusters are a possible intermediate stage in the transition from molecular gas to dust grains, and, in particular, they are candidate emitters for a number of interstellar emission phenomena. Here we compare laboratory infrared absorption spectra of aggregated PAH molecules embedded in solid argon with synthetic spectra of PAH clusters computed using density functional theory with dispersion correction (DFT-D). We discuss the possibility that these PAH clusters also contribute to the so-called "aromatic infrared emission bands" that are ubiquitous in the Galaxy and the possible connection between PAH clusters and the blue luminescence and extended red emission phenomena most famously seen in the Red Rectangle nebula.

RECENT PROGRESS IN DIB RESEARCH: A SURVEY of PAHS AND DIBS

Farid Salama[1], G. Galazutdinov[2], J. Krelowski[3], L. Biennier[4], Y. Beletsky[5], I. Song[6]

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[2]*Instituto de Astronomia, Universidad Catolica del Norte, Chile*
[3]*Center for Astronomy, Nicolaus Copernicus University, Poland*
[4]*Institut de Physique de Rennes, UMR 6251 du CNRS, France*
[5]*European Southern Observatory, Chile*
[6]*Korea Science Academy, KAIT, Republic of Korea.*

The spectra of several neutral and ionized PAHs isolated in the gas phase at low temperature have been measured in the laboratory under experimental conditions that mimic interstellar conditions and are compared with an extensive set of astronomical spectra of reddened, early type stars [1, 2]. The comparisons of astronomical and laboratory data provide upper limits for the abundances of *specific* neutral PAH molecules and ions along *specific* lines-of-sight. Something that is not attainable from infrared observations alone. We present the characteristics of the laboratory facility (COSmIC) that was developed for this study and discuss the findings resulting from the comparison of these unique laboratory data with high resolution, high S/N ratio astronomical observations. COSmIC combines a supersonic free jet expansion with discharge plasma and high-sensitivity cavity ringdown spectroscopy and provides experimental conditions that closely mimic the interstellar conditions. The column densities of the individual neutral PAH molecules and ions probed in these surveys are derived from the comparison of these unique laboratory data with high resolution, high S/N ratio astronomical observations. The comparisons of astronomical and laboratory data lead to clear and unambiguous conclusions regarding the expected abundances for PAHs of various sizes and charge states in the interstellar environments probed in the surveys. Band profile comparisons between laboratory and astronomical spectra lead to information regarding the molecular structures and characteristics associated with the DIB carriers in the corresponding lines-of-sight. These quantitative surveys of neutral and ionized PAHs in the optical range open the way for unambiguous quantitative searches of PAHs and complex organics in a variety of interstellar and circumstellar environments.

Acknowledgements: F.S. acknowledges the support of the Astrophysics Research and Analysis Program of the NASA Space Mission Directorate and the outstanding technical support provided by R. Walker. J.K. acknowledges the financial support of the Polish State. The authors are deeply grateful to the ESO archive as well as to the ESO staff members for their active support.

References
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[2] F. Salama et al. (2012) Bull. Amer. Astron. Soc. 44 (4), 209

Quartic Force Fields and Dipole Surfaces for Accurate Computational Rovibrational Reference Data for Interstellar Studies

Ryan C. Fortenberry, Xinchuan Huang, and Timothy J. Lee

The use of quartic force fields in the prediction of fundamental vibrational frequencies and spectroscopic constants has given valuable insights into interstellar and atmospheric spectra where the newest generation of space telescopes is generating tremendous amounts of unassigned data. Coupled cluster-based quartic force fields, vibrational perturbation theory and vibrational configuration interaction theory, dipole surfaces, and simulated spectra have recently been employed to analyze various molecules. One of the most exciting systems studied is the potential interstellar anion CH_2CN^-, which has been suggested as a carrier for one of the diffuse interstellar bands. Other examples of interesting interstellar and atmospheric molecules examined include 1 $^3A'$ HCN and HCO^+; the *cis*- and *trans*-HOCO radicals, anions, and trans cation; and the *cis*- and *trans*-HSCO/HOCS radicals and cations. The data generated by these methods helps to sort out a few of the unwanted interstellar spectral weeds and attempts to assist in the discovery of a few of the interstellar spectral flowers.

Discovery of the smallest known exoplanet

Tom Barclay

Since the discovery of the first exoplanet we have known that other planetary systems can look quite unlike our own. However, until recently we have only been able to probe the upper range of the planet size distribution. The high precision of the Kepler space telescope has allowed us to detect planets that are the size of Earth and somewhat smaller, but no prior planets have been found that are smaller than those we see in our own Solar System. Here we report the discovery of a planet significantly smaller than Mercury. This tiny planet is the innermost of three planets that orbit the Sun-like host star, which we have designated Kepler-37. Owing to its extremely small size, similar to that of Earth's Moon, and highly irradiated surface, Kepler-37b is very likely a rocky planet with no atmosphere or water, similar to Mercury. The detection of such a small planet shows that stellar systems host planets much smaller than anything we see in our own Solar System.

Accretion of Water by Exo-Earths

Jack J. Lissauer and Elisa V. Quintana

By cosmic standards, Earth is highly deficient in volatiles. The condensed component of a solar composition mixture that is cool enough for all of the water to be in solid form is over 50% ice by mass. In contrast, the Earth's oceans and other near-surface reservoirs represent only 0.03% of our planet's mass, with a comparable amount of water thought to lie in the mantle. So Earth was very inefficient in accreting water from the protoplanetary disk. To investigate how the type of star and giant planet configurations can affect the ability of Earth-size planets to accumulate and retain volatiles, we numerically model the late stages of terrestrial planet growth. We follow the evolution of numerous disks of planetesimals and embryos around a Sun-like star, and compare the effects of various giant planet or stellar companions on the accretion process. Our approach employs moderate-resolution simulations that have sufficiently modest computational requirements to allow us to perform the dozens of simulations required to disentangle effects of the companion body from stochastic variations that are an important aspect of terrestrial planet growth.

Confirmation of Kepler Hot Jupiters via Phase Curve Analysis

Elisa Quintana, Jason Rowe, and the Kepler Science Team

We present high precision photometry of Kepler-41, a giant planet in a 1.86 day orbit around a G6V star that was recently confirmed through radial velocity measurements (Santerne et al. 2011). We have developed a new method to confirm giant planets solely from the photometric light curve, and we apply this method herein to Kepler-41 to establish the validity of this technique. We generate a full phase photometric model by including the primary and secondary transits, ellipsoidal variations, Doppler beaming and reflected/emitted light from the planet. Third light contamination scenarios that can mimic a planetary transit signal are simulated by injecting a full range of dilution values into the model, and we re-fit each diluted light curve model to the light curve. The resulting constraints on the maximum occultation depth and stellar density combined with stellar evolution models rules out stellar blends and provides a measurement of the planet's mass, size, and temperature. We expect about two dozen Kepler giant planets can be confirmed via this method.

High Resolution Imaging at Gemini-N: Exoplanets and Beyond

Steve B. Howell, NASA Ames Research Center, Moffett Field, CA 94035

ABSTRACT

I will report on my speckle imaging program using the Gemini-N telescope. Using the DSSI speckle instrument and the 8-m Gemini mirror, this observing program has opened a new window on ground-based high resolution imaging. The initial run on Gemini-N produced ∼16 mas (diffraction limited) images and obtained the highest resolution ever ground-based image of the planet Pluto. Deep speckle images of exoplanet host stars allowed validation of Earth-size planets for the Kepler and CoRot space missions. The two-dimensional speckle reconstructed image of Pluto and its largest moon Charon represent a new capability at Gemini-N suggesting many additional applications of 2-D imaging for this instrument and telescope combination. Opportunities for the community to use this instrument at Gemini-N will occur in observing semester 2013B.

First choice oral talk, second choice poster.

NASA Ames Space Sciences Symposium
March 12, 2013

Talk abstract:

“Obtaining sub-uas astrometry on a wide-field, coronagraph equipped, space telescope using a diffractive pupil”

Eduardo A Bendek

Detection and mass measurement of earth-size exoplanets using the astrometric signal of the host star requires sub-uas measurement precision. One major challenge in achieving this precision using medium-size space telescopes is the calibration of dynamic distortions. To solve this problem, we propose a diffractive pupil approach in which an array of dots on the primary mirror generates polychromatic diffraction spikes in the focal plane used to calibrate the distortions in the optical system. According to our simulations, this technique enables 0.2microarcsecond or better single-visit precision astrometric measurements on a 2.4m wide-field (>0.1deg^2) space telescope. We present the laboratory results of the diffractive pupil concept performed at the University of Arizona, showing that this approach can calibrate dynamic distortion errors even for wide field applications. Also, this technique can be used simultaneously with a high-performance coronagraph to determine/constrain the masses, composition, atmospheric properties, and planetary system architectures. Numerical simulations and experiments performed at the NASA Ames ACE test bed have shown that the diffractive pupil does not affect the coronagraph performance. Finally, we assess the compatibility of a diffractive pupil telescope with a general astrophysics mission, showing that the spikes are too faint to impact wide field observations.

Experimental study of a low-order wavefront sensor for a high-contrast coronagraphic imager at 1.2 lambda/D

Julien Lozi [1], Ruslan Belikov [2], Glenn Schneider [1], Olivier Guyon [1], Eugene Pluzhnik [2], Thomas Greene [2], Fred Witteborn [2], Dana Lynch [2], Paul Davis [2], Sandrine Thomas [2], Eduardo Bendek [2], Kevin Newman [1], Domenick Tenerelli [3]

1 : University of Arizona
2 : NASA Ames Research Center
3 : Lockheed Martin

The mission EXCEDE (EXoplanetary Circumstellar Environments and Disk Explorer), selected by NASA for technology development, is designed to study the formation, evolution and architectures of exoplanetary systems and characterize circumstellar environments into stellar habitable zones. It is composed of a 0.7 m telescope equipped with a Phase-Induced Amplitude Apodization Coronagraph (PIAA-C) and a 2000-element MEMS deformable mirror, capable of raw contrasts of 1e-6 at 1.2 lambda/D and 1e-7 above 2 lambda/D. One of the key challenges to achieve those contrasts is to remove low-order aberrations, using a Low-Order WaveFront Sensor (LOWFS). An experiment simulating the starlight suppression system is currently developed at NASA Ames Research Center, and includes a LOWFS controlling tip/tilt modes in real time at 500 Hz. The LOWFS allowed us to reduce the tip/tilt disturbances to 1e-3 lambda/D rms, enhancing the previous contrast by a decade, to 8e-7 between 1.2 and 2 lambda/D. A Linear Quadratic Gaussian (LQG) controller is currently implemented to improve even more that result by reducing residual vibrations. This testbed shows that a good knowledge of the low-order disturbances is a key asset for high contrast imaging, whether for real-time control or for post processing.

Exoplanet Poster: EP.7

Title: Achromatic Focal Plane Mask for Exoplanet Imaging Coronagraphy

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Abstract:
Recent advances in coronagraph technologies for exoplanet imaging have achieved contrasts close to 1e-10 at 4 λ/D and 1e-9 at 2 λ/D in monochromatic light. A remaining technological challenge is to achieve high contrast in broadband light; a challenge that is largely limited by chromaticity of the focal plane mask. The size of a star image, and therefore the inner working angle of a coronagraph, scales linearly with wavelength. Focal plane masks are typically the same size at all wavelengths, and must be sized for the longest wavelength to avoid starlight leakage. However, this blocks useful discovery space from the shorter wavelengths.

We present here the design, development, and testing of an achromatic focal plane mask based on the concept of optical filtering by a diffractive optical element (DOE). The mask consists of an array of DOE cells, the combination of which functions as a wavelength filter with any desired amplitude and phase transmission. The effective size of the mask varies nearly linearly with wavelength, and allows significant improvement in the inner working angle of the coronagraph at shorter wavelengths. The design is applicable to almost any coronagraph configuration, and enables operation in a wider band of wavelengths than would otherwise be possible.

Exoplanet Poster: EP.8

Improving image contrast for the direct detection of exoplanets

The detection of extrasolar planets, using both space- and ground-based telescopes, is one of the most exciting fields in astronomy today. Driven by the vision of directly detecting exoplanets in the habitable zone of distant solar systems, the Exoplanetary Circumstellar Environment and Disk Explorer (EXCEDE) was designed. It has recently been selected by NASA for further technology development. By combining a 0.7 m telescope with a Phase-Induced Amplitude Apodization Coronagraph (PIAAC) and a 2000-element MEMS deformable mirror, EXCEDE will be capable of producing raw contrasts of 1e-6 at 1.2 lambda/D and 1e-7 beyond 2 lambda/D. Obtaining such contrasts requires precise wavefront control algorithms. In contrast to optical systems whose design focuses on achieving the best overall image quality, we optimize our system such that the light coming from a parent star is nulled leading to an easier detection of potential relatively faint planets. Using the NASA Ames Center for Exoplanet Studies (ACES) testbed, our team demonstrated that we meet the required contrast in monochromatic light. We are now working towards implementing similar wavefront control algorithms in polychromatic light with 20% bandwidth around visible wavelength.

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Exoplanet Poster: EP.9

A Framework for Characterizing the Performance of the Kepler Exoplanet Search and Data Products

Jon Jenkins, Jessie Christiansen, Chris Burke, Sean McCauliff, Jeffrey Van Cleve, and the Kepler SOC and SO

Since launch in March 2009, the Kepler spacecraft has delivered >8.5 billion brightness measurements over a set of ~200,000 stars at a 29.4 minute cadence of phenomenal quality and completeness. Over 2,300 planet candidates and ~2,000 eclipsing binaries have been identified to date and a great wealth of astrophysics has been exposed to plain view that was previously unavailable to the community. The detailed behavior of the instrument and the stunning variety of the intrinsic stellar variations exhibited in the data have caused major rework and development of new algorithms for extracting the photometric time series from the data, correcting instrumental effects, searching for planets and constructing diagnostic metrics for the candidate planetary signatures. It has also proven to be a very intensive process to manually review the science pipeline output to generate the planet candidate catalogs.

The effort to characterize the fidelity of the light curves and the reliability and completeness of the exoplanet candidates identified in the data requires a broad spectrum of activities. Some of these activities are in early stages of development, including a machine learning approach to identifying Kepler Objects of Interest automatically from an analysis of diagnostics and information from the Kepler data themselves. Another example is the capability to inject transit signatures and stellar variability signatures into the data to learn to what degree these signatures are preserved in the output light curves. We describe a framework for laying out the activities required to accomplish these goals to ensure that the various tasks completely cover the problem space.

Kepler was selected as the 10th mission of the Discovery Program. Funding for this mission is provided by NASA’s Science Mission Directorate.

Exoplanet Poster: EP.10

Removing the Noise While Preserving the Signal – An Empirical Bayesian Approach to Kepler Light Curve Systematic Error Correction.

Jeffrey C. Smith, et al.

We present a Bayesian Maximum A Posteriori (MAP) approach to systematic error removal in Kepler photometric data where a subset of highly correlated and quiet stars is used to generate a cotrending basis vector set which is in turn used to establish a range of "reasonable" robust fit parameters. These robust fit parameters are then used to generate a "Bayesian Prior" and a "Bayesian Posterior" PDF (Probability Distribution Function). When maximized, the posterior PDF finds the best fit that simultaneously removes systematic effects while reducing the signal distortion and noise injection which commonly afflicts simple Least Squares (LS) fitting. A numerical and empirical approach is taken where the Bayesian Prior PDFs are generated from fits to the light curve distributions themselves versus an analytical approach, which uses a Gaussian fit to the Priors.

Dynamic Black-Level Correction and Artifact Flagging for Kepler Pixel Time Series

B. D. Clarke , J. J. Kolodziejczak and D. A. Caldwell

Instrument-induced artifacts in the raw *Kepler* pixel data include time-varying crosstalk from the fine guidance sensor (FGS) clock signals, manifestations of drifting moiré pattern as locally correlated nonstationary noise and rolling bands in the images which find their way into the calibrated pixel time series and ultimately into the calibrated target flux time series. As the *Kepler Mission* continues to improve the fidelity of its science data products, we are evaluating the benefits of adding pipeline steps to more completely model and dynamically correct the FGS crosstalk, then use the residuals from these model fits to detect and flag spatial regions and time intervals of strong time-varying black-level which may complicate later processing or lead to misinterpretation of instrument behavior as stellar activity.

The FGS crosstalk pixels are present in 20-25% of targets but typically vary slowly enough to create a very small risk of reduced sensitivity or increased false positive rate in the transit search. However, they do have the potential to complicate or reduce the effectiveness of cotrending algorithms by introducing additional cotrending terms into the light curves which are not associated with prior relations. We will present results regarding the improvement in cotrending performance as a result of including FGS corrections in the calibration.

The rolling bands appear in only ~10% of channels and are present only in 3% of the total exposure, but we estimate that, because of the rotation of stars through the affected sky groups, about 30% of light curves are ultimately affected. Thus the utility of rolling band flagging is expected to be high. We will discuss the effectiveness of the proposed flagging and illustrate with some affected light curves.

Funding for the *Kepler Mission* has been provided by the NASA Science Mission Directorate.

TRANSIT MODEL FITTING IN THE KEPLER SCIENCE OPERATIONS CENTER PIPELINE

J. Li, C. J. Burke, J. M. Jenkins, E. V. Quintana, J. F. Rowe, S. E. Seader, P. Tenenbaum, J. D. Twicken

SETI Institute/NASA Ames Research Center

We describe the algorithm and performance of the transit model fitting of the *Kepler* Science Operations Center (SOC) Pipeline.

Light curves of long cadence targets are subjected to the Transiting Planet Search (TPS) component of the *Kepler* SOC Pipeline. Those targets for which a Threshold Crossing Event (TCE) is generated in the transit search are subsequently processed in the Data Validation (DV) component. The light curves may span one or more Kepler observing quarters, and data may not be available for any given target in all quarters.

Transit model parameters are fitted in DV to transit-like signatures in the light curves of target stars with TCEs. The fitted parameters are used to generate a predicted light curve based on the transit model. The residual flux time series of the target star, with the predicted light curve removed, is fed back to TPS to search for additional TCEs. The iterative process of transit model fitting and transiting planet search continues until no TCE is generated from the residual flux time series or a planet candidate limit is reached.

The transit model includes five parameters to be fitted: transit epoch time (i.e. central time of first transit), orbital period, impact parameter, ratio of planet radius to star radius and ratio of semi-major axis to star radius. The initial values of the fit parameters are determined from the TCE values provided by TPS. A limb darkening model is included in the transit model to generate the predicted light curve.

The transit model fitting results are used in the diagnostic tests in DV, such as the centroid motion test, eclipsing binary discrimination tests, etc., which helps to validate planet candidates and identify false positive detections.

Funding for the *Kepler* Mission has been provided by the NASA Science Mission Directorate.

Exoplanet Poster: EP.13

Author: Shawn Seader

The *Kepler Mission* continuously observes a host of target stars in a 115 square-degree field of view to discover Earth-like planets transiting Sun-like stars through analysis of photometric data. The *Kepler* Science Operations Center at NASA Ames Research Center processes the data with the Science Processing Pipeline, which is composed of several modules including the Transiting Planet Search (TPS). To search for transit signatures, TPS employs a bank of wavelet-based matched filters that form a grid on a three dimensional parameter space of transit duration, period, and epoch. Owing to non-stationary and non-Gaussian noise, uncorrected systematics, and poorly mitigated noise events of either astrophysical or non-astrophysical nature, large spurious Threshold Crossing Events (TCE's) can be produced by the matched filtering performed in TPS. These false alarms waste resources as they propagate through the remainder of the Pipeline, and so a method to discriminate against them is crucial in maintaining the desired sensitivity to true events. Here we describe four separate χ^2 tests which represent a novel application of the formalism developed by Allen for false alarm mitigation in searches for gravitational waves. The basic idea behind these vetoes is to break up the matched filter output into several contributions and compare each contribution with what is expected under the assumption that a true signal is present in the data. Vetoes can then be constructed which, under certain assumptions, have been shown to be χ^2 distributed with expectation values that are independent of whether or not a true signal is present, thereby making them useful discriminators. The four different ways of breaking up the output and forming χ^2 vetoes illustrated here, allow discrimination against different classes of false alarms. *Kepler* was selected as the 10th mission of the Discovery Program. Funding for this mission is provided by NASA's Science Mission Directorate.

The *Kepler* Pipeline Data Validation Report

Joseph D. Twicken[1], H. Wu[1], B. Wohler[2], F. Girouard[2], J. Li[1], B.D. Clarke[1], P. Tenenbaum[1], E.V. Quintana[1], T. Klaus[2], M.T. Cote[3], S. McCauliff[2], J.M. Jenkins[1], D.A. Caldwell[1], J.F. Rowe[1], S.T. Bryson[3], C.J. Burke[1]

[1]SETI Institute, [2]Orbital Sciences Corporation, [3]NASA Ames Research Center

Kepler's automated Data Processing Pipeline identifies thousands of potential transiting planet candidates, known as Threshold Crossing Events. Many of these are instrument artifacts, eclipsing binaries, or other astrophysical false positives. In order to aid in the discrimination between true planets and false positives, planet models are fitted and a suite of automated tests is performed on all planet candidate time series data. The iterative model fitting and transiting planet search is capable of identifying multiple planet candidates per solar system. Results for each planetary system are written to a comprehensive document, called the Data Validation (DV) Report. The DV Report presents a summary of the primary findings, detailed model fit and test results based upon prior stellar parameters, and a variety of diagnostic figures. The transition from a 3.5-year baseline to an extended *Kepler* mission occurred in October 2012. DV Reports and one-page summaries for current and new planet candidates identified in the Pipeline during the extended mission are now distributed to the science community and the public at large through the Exoplanet Archive (http://exoplanetarchive.ipac.caltech.edu) hosted by the NASA Exoplanet Science Institute (NExScI). We present an overview of the DV Report with the purpose of informing users about the wealth of information that is now available to them for vetting planet candidates identified in the *Kepler* Pipeline. Specific examples are highlighted that demonstrate the utility of the DV Report for distinguishing between valid planet candidates and astrophysical false positives. Funding for the *Kepler Mission* has been provided by the NASA Science Mission Directorate.

2013 Space Science and Astrobiology Symposium

Transport in the early Solar Nebula: Follow the Water

Sanford Davis

(Prefer oral talk)

I will describe work under the Astrobiology program concerning the distribution of water in a protoplanetary disk. The presence of water in all three phases (gas, ice and liquid) seems to be the primary determinant of a habitable planet and the distribution of this substance in disks should yield important clues to the location of such planets. The boundary ("snow") line separating gas and ice (liquid water is not present in the disk due to low pressure) is complicated by the competing influence of thermal radiation from the central star and internal viscous heating. A two dimensional disk model was developed to model this effect. The result is an odd shaped boundary with a "cloud" like feature over the region where habitable planets form in a model solar system. This work is to be expanded to extra solar systems, but will need to overcome the lack of information concerning the primeval disk underlying the thousands of new planetary systems being discovered.

Since the role of disk opacity is so important for the temperature distribution, this parameter was investigated in detail. It has been known for decades that the condensation sequence in a disk affects the grain size distribution so that micron sized grains in the disk grow to millimeters due to successive mantles of condensed species overlying the smaller particles. Another factor affecting grain growth is coagulation, settling, and migration. A common opacity model uses the grain size distribution from interstellar space, a spatially uniform model consisting of grains of sub-micron to micron in size. Some indication is given of recent work on expanding this model to include time dependent spatially variable grain sizes up to millimeters and their effect on the opacity.

CO_2 and SO_2 IR Line Lists for Venus/Mars and Exo-planet Atmosphere Studies

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ABSTRACT

Atmospheric studies of both solar system planets and extra-solar planets need accurate spectra data input and analysis from planetary missions and astronomical observations. Accurate infrared (IR) line lists of critical species are necessary to determine the physical conditions and compsitions of atmospheres. Here we demonstrate an example of how theoretical chemistry can help in this regard. By combining the state-of-the-art *ab initio* theory, the quantum exact rovibrational CI approach, and selected reliable high resolution experimental data, we have successfully generated the most complete and reliable IR line lists for Carbon Dioxide and Sulfur Dioxide (and their isotopologues) with accuracies of 0.01-0.02 cm^{-1},[1,2] or ~10 MHz for microwave spectra. Agreements for observed intensities are around 90%. Our approach not only automatically fills in all the missing bands (especially those weaker, difficult bands) below the highest experiment energies, but also safely extrapolates beyond those with still reliable predictions. Reliability and accuracy of our IR line lists have been verified by very recent experiments.[2,3] The CO_2 line list extends beyond 20,000 cm^{-1} and is applicable for early planets with temperatures as high as 1000 – 1500K.[4] The SO_2 line list covers 0 – 8000 cm^{-1} and J up to 80-120.[2] These line lists should facilitate the atmospheric analysis and models of both planets and moons within our solar system and beyond to extra-solar planets.

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Investigating Titan's Atmospheric Chemistry at Low Temperature with the NASA Ames Titan Haze Simulation Experiment

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Titan, Saturn's largest satellite, possesses a dense atmosphere (1.5 bar at the surface) composed mainly of N_2 and CH_4. The solar radiation and electron bombardment from Saturn's magnetosphere induces a complex organic chemistry between these two constituents leading to the production of more complex molecules and subsequently to solid aerosols. These aerosols in suspension in the atmosphere form the haze layers giving Titan its characteristic orange color. Since 2004, the instruments onboard the Cassini orbiter have produced large amounts of observational data, unraveling a chemistry much more complex than what was first expected, particularly in Titan's upper atmosphere. Neutral, positively and negatively charged heavy molecules have been detected in the ionosphere of Titan[1,2], including benzene (C_6H_6) and toluene ($C_6H_5CH_3$)[3]. The presence of these critical precursors of polycyclic aromatic hydrocarbon (PAH) compounds suggests that PAHs might play a role in the production of Titan's aerosols. The aim of the Titan Haze Simulation (THS) experiment, developed at the NASA Ames COSmIC facility, is to study the chemical pathways that link the simple molecules resulting from the first steps of the N_2-CH_4 chemistry to benzene, and to PAHs and nitrogen-containing PAHs (PANHs) as precursors to the production of solid aerosols. In the THS experiment, Titan's atmospheric chemistry is simulated by plasma in the stream of a supersonic expansion. With this unique design, the gas mixture is cooled to Titan-like temperature (~150 K) before inducing the chemistry by plasma discharge. Due to the short residence time of the gas in the plasma discharge, the THS experiment can be used to probe the first and intermediate steps of Titan's chemistry by injecting different gas mixtures in the plasma. The products of the chemistry are detected and studied using two complementary techniques: Cavity Ring Down Spectroscopy[4] and Time-Of-Flight Mass Spectrometry[5]. Thin tholin deposits are also produced in the THS experiment and can be analyzed by Gas Chromatography-Mass Spectrometry (GC-MS), Scanning Electron Microscopy (SEM) and IR spectroscopy. Here we present the results of a systematic mass spectrometry study using N_2-based, Ar-based and N_2-CH_4 (90:10)-based mixtures with several hydrocarbon precursors to investigate specific pathways associated with the presence of these trace elements in Titan's atmosphere[6]. These results show the uniqueness of the THS experiment to help understand the first and intermediate steps of Titan's atmospheric chemistry as well as specific chemical pathways leading to Titan's haze formation. We will also present the first results of ex situ analyses performed on tholins produced in the THS experiment with different gas mixtures.

Acknowledgments

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ARE WATER ICE GRAINS ON THE MARTIAN NORTH POLE GROWING? DID TALC-CARBONATE HYDROTHERMAL ALTERATION OCCUR AT NILI FOSSAE, MARS? A.J. Brown[1] [1]SETI Institute, 189 N. Bernardo Ave Mountain View, CA 94043, abrown@seti.org, Author website: http://abrown.seti.org

Introduction: In this abstract I will give some background into three big Mars science questions that I am fascinated by and how I intend to attack these problems in the coming years.

Question 1. The growth of ice grains in the Martian North Pole: I used CRISM (a VNIR spectrometer on Mars Reconnaissance Orbiter) to map the surface CO_2 and H_2O ice cap springtime recessions for the north and south polar cap over the past 3 Mars Years [1,2]. Grain size estimates were made of the surface ice, enabling us to constrain the thermodynamics of the Martian polar caps.

Fig. 3. Shows the 1.25 micron water ice absorbtion band depth during late spring for the north pole. Red indicates strong band depths, and these predominate aroundt eh edge of the cap at this time. Previous workers had suggested that the growth in water ice absorption bands over summer was due to exposure of older grains and not thermal metamorphism [3], however our work has shown that there is a polewide pattern of high rates of absorption band growth around the edge of the cap and slower growth in the colder interior. This is certainly suggestive of a temperature controlled grain growth process [2].

Question 2. Talc-carbonate alteration on Mars: Again using CRISM, we have published an investigation into carbonates ound at Nili Fossae [4]. We suggested that minerals previously identified as saponite by Ehlmann et al. [5] are most likely actually talc. Based on terrestrial field experience in the Archean

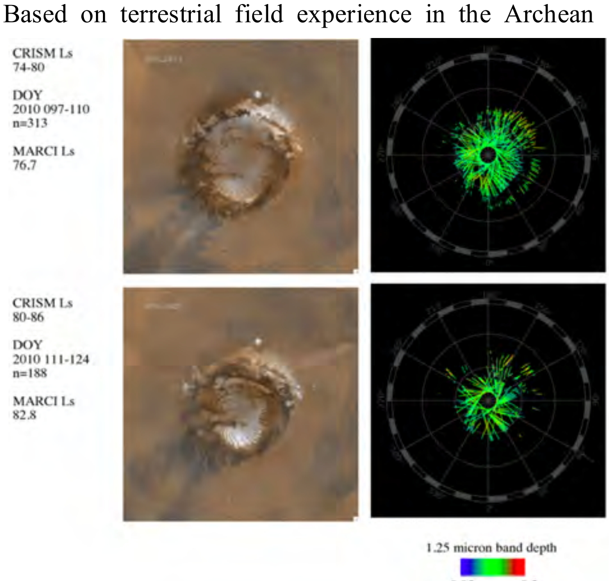

Figure 1. MARCI (left) and CRISM (right) Water ice 1.25 micron band depth map for late spring period in north polar region.

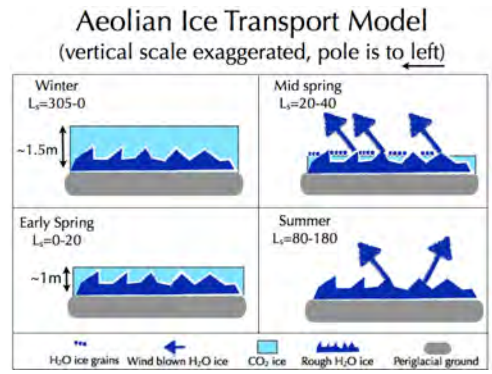

Figure 2. Proposed model for aeolian water ice deposition during the mid spring period in north polar region [2].

Greenstone Western Australian Pilbara region, we suggested that the presence of talc and carbonate in the same location is an indicator of ancient low temperature hydrothermal alteration. The implications for life on Mars abound. Recently, our suggestions have been reinforced from an unpected quarter [6].

Question 3. Can we model Houben events on the north polar retreating cap? I have been very interested recently in the transport of water ice over CO_2 ice during the springtime retreat of the north polar cap. Fig. 2 shows a suggested model for how this aeolian process might occur in the interior of the cap [2]. We have been using the Ames GCM to attempt to model the Houben process [7] and most likely will use a mesoscale model in the near future.

Atmospheric Polar Work: Mike Wolff and myself continue the work started in [8,9] to document the dust and ice opacity of the atmosphere in the polar regions for Martian Years 28/29 and 30.

Acknowledgements: My thanks to Mike Wolff, Jeff Hollingsworth, Melinda Kahre, Allyn Durbin and Bjorn Mellem for working with me on these projects over the past two years. I also thank Scott Murchie (CRISM PI) and the CRISM science operations team at JHU APL for their great work on CRISM.

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John Noble

TITLE: Analysis of TES FFSM Eddies and MOC Dust Storms, MY 24 - 26

ABSTRACT:
Mars Global Surveyor (MGS) orbiter observed a planet-encircling dust storm (PDS) in Mars year (MY) 25 from Ls=176.2-263.4°. We present an examination of Mars Orbiter Camera (MOC) dust storms and transient baroclinic eddies identified from Fast Fourier Synoptic Mapping (FFSM) of Thermal Emission Spectrometer (TES) temperatures for the first two phases of the storm: precursor, Ls=176.2- 184.7°, and expansion, Ls=184.7-193°. FFSM analysis of TES 3.7 hPa thermal data shows the presence of eastward- traveling waves at 60° S with a period of about three sols. We hypothesize that these waves are transient baroclinic eddies that contributed to the initiation of precursor storms near Hellas. Integration of FFSM and MOC MY 24 and 25 data shows interesting temporal and spatial associations between the evolution of eddies and storms, including: 1) comparable periodicities of travelling waves and pulses of storm activity; 2) concurrent eastward propagation of both eddies and storms; and 3) structured spatial relationship where high-latitude storms tend to occur on the eastern side of the eddy, while lower (and some middle) latitude storms occur on the western. These results suggest a causal relationship between baroclinic eddies and local storm initiation.

What Is the Curiosity Rover Telling Us About the Climate of Mars?

Robert M. Haberle

This can be a poster or a talk.

Assessing the habitability of Gale Crater is the goal of the Curiosity Rover, which has been gathering data since landing on the Red Planet last August. To meet that goal, Curiosity brought with it a suite of instruments to measure the biological potential of the landing site, the geology and chemistry of its surface, and local environmental conditions. Some of these instruments illuminate the nature of the planet's atmosphere and climate system, both for present day conditions as well as for conditions that existed billions of years ago. For present day conditions, Curiosity has a standard meteorology package that measures pressure, temperature, winds and humidity, plus a sensor the measures the UV flux. These data confirm what we learned from previous missions namely that today Mars is a cold, dry, and barren desert-like planet. For past conditions, however, wetter and probably warmer conditions are indicated. Curiosities cameras reveal gravel beds that must have formed by flowing rivers, and sedimentary deposits of layered sand and mudstones possibly associated with lakes. An ancient aqueous environment is further supported by the presence of sulfate veins coursing through some of the rocks in Yellowknife Bay where Curiosity is planning its first drilling activity.

Title: Waiting for O2.

Kevin Zahnle

Abstract:

Oxygenic photosynthesis appears to be necessary for an oxygen-rich atmosphere like Earth's. But available geological and geochemical evidence suggest that at least 200 Myr, and possibly more than 700 Myr, elapsed between the advent of oxygenic photosynthesis and the establishment of an oxygen atmosphere. The interregnum implies that at least one other necessary condition for O$_2$ needed to be met. Here we argue that the second condition was the oxidation of the surface and crust to the point where O$_2$ became more stable than competing reduced gases such as CH$_4$, and that the cause of Earth's surface oxidation is the same cause as it is for other planets with oxidized surfaces: hydrogen escape to space. The duration of the interregnum would have been determined by the rate of hydrogen escape and by the size of the reduced reservoir that needed to be oxidized before O$_2$ became favored. Finally, we speculate that, because continents are more oxidized than the mantle, hydrogen escape may also have determined the history of continental growth.

Characterizing Venus' Upper Atmosphere: VTGCM Simulations

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Venus is a unique planet because its atmospheric dynamics are mainly driven by thermal heating and the very low rotation rate. Many details of the middle and upper atmospheric dynamics can be determined from observing temperature, composition, and nightside airglow emissions. The nightside airglow emissions serve as effective tracers of Venus' middle and upper atmosphere global wind system.

Currently, Venus Express (VEx; ESA Venus orbiter) has been monitoring key atmospheric features (e.g. O_2 IR nightglow, NO UV nightglow, nightside/terminator temperatures, and CO_2 density) of Venus. Along with VEx observations, ground-based observations have been made in conjunction for comparisons. These observations are utilized as constraints for modelers in an effort in understanding Venus' atmosphere.

The National Center for Atmospheric Research (NCAR) Venus Thermospheric General Circulation Model (VTGCM) is examining the underlying processes that control the thermospheric circulation of Venus by comparing simulations to observations. The VTGCM model has been reconstructed and revised in order to address key observations and provide diagnostic interpretation. Specifically, the VTGCM simulations capture the statistically averaged mean state of the night airglow emissions and night temperatures. The correlation between the simulation results and the VEx data sets implies a weak retrograde superrotating zonal flow (RSZ) from ~80 km to 110 km with the emergence of modest RSZ winds approaching 60 m s above ~130 km. This RSZ flow is superimposed upon a strong subsolar-antisolar flow from day-to-night. VTGCM sensitivity tests were subsequently preformed using two tunable parameters (nightside eddy diffusion and wave drag) to examine corresponding variability within the VTGCM and these nightglow distributions.

More recently, VTGCM simulations are being compared to ground-based dayside temperature observations and SOIR (Solar Occultation in the Infrared instrument aboard VEx) terminator temperatures and CO_2 densities. The latest results from these comparisons will be shown. The VTGCM is providing new insights into understanding the circulation and variability of the large scale dynamics in Venus' upper atmosphere.

Investigating the asymmetry of Mars' South Polar Cap using the NASA Ames Mars General Circulation Model with a CO_2 cloud microphysics scheme

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One of the most intriguing and least understood climate phenomena on Mars is the existence of a perennial south polar CO_2 ice cap that is offset from the pole in the western hemisphere. Colaprete et al. (2005) hypothesize that since the process by which CO_2 surface frost accumulates (i.e., precipitation or direct vapor deposition) affects the albedo of the ice, the atmosphere can play a role in the stability and asymmetry of the cap. They show that the stationary wave pattern set up by the Argyre and Hellas basins results in a colder western hemisphere in which atmospheric CO_2 condensation and precipitation is favored. Because precipitated CO_2 is brighter than directly deposited CO_2, they suggest that the topographically forced atmospheric circulation maintains the asymmetry of the residual cap and creates a high enough albedo ice sheet over the SPRC to account for its year-long survival. However, Colaprete et al (2005) do not explicitly model the albedo of the south cap to demonstrate the viability of their hypothesis. We build on their study with a version of the NASA Ames GCM that includes a newly incorporated CO_2 cloud microphysics scheme. Simulated results compare well to observed temperatures, pressures, cap recession rates and cloud occurrence. Precipitation and direct vapor deposition are predicted in the model and our snowfall pattern supports the hypothesis of an asymmetric atmospheric circulation over the South pole due to the neighboring topography: we obtain higher cloud cover and snowfall rate over a longitudinal corridor encompassing the SPRC. We also find that the radiative effects of dust within the polar night emphasize this asymmetry and greatly increase snowfall over the SPRC. The next steps will be to further study the sensitivity to dust loading, as well as design schemes to model the cap albedo based on known physical quantities such as precipitated particle number and size (snow/frost), surface ice metamorphism due to solar radiation and dust content. We hope to reproduce the observed asymmetrical cap albedo and account for the SPRC. The goal of this work is to develop a more complete understanding of the asymmetry of the south residual CO_2 cap and of the Martian CO_2 cycle.

Planetary Atmospheres & Climates Poster: PA.10

Abstract #222753

Large-Scale Extratropical Weather Systems in Mars' Atmosphere

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During late autumn through early spring, extratropical regions on Mars exhibit profound mean zonal equator-to-pole thermal contrasts. The imposition of this strong meridional temperature variation supports intense eastward-traveling, synoptic weather systems (i.e., transient baroclinic/barotropic waves) within Mars' extratropical atmosphere. Such disturbances grow, mature and decay within the east-west varying seasonal-mean midlatitude jet stream (i.e., the polar vortex) on the planet. Near the surface, the weather disturbances indicated large-scale spiraling "comma"-shaped dust cloud structures and scimitar-shaped dust fronts, indicative of processes associated with cyclo-/fronto-genesis. The weather systems occur during specific seasons on Mars, and in both hemispheres. The northern hemisphere (NH) disturbances are significantly more intense than their counterparts in the southern hemisphere (SH). Further, the NH weather systems and accompanying frontal waves appear to have significant impacts on the transport of tracer fields (e.g., particularly dust and to some extent water species (vapor/ice) as well). And regarding dust, frontal waves appear to be key agents in the lifting, lofting, organization and transport of this particular atmospheric aerosol. In this paper, a brief background and supporting observations of Mars' extratropical weather systems is presented. This is followed by a short review of the theory and various modeling studies (i.e., ranging from highly simplified, mechanistic and full global circulation modeling investigations) which have been pursued. Finally, a discussion of outstanding issues and questions regarding the character and nature of Mars' extratropical traveling weather systems is offered.

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The Early Martian Atmosphere: Investigating the role of the dust cycle in the possible maintenance of two stable climate states.

M.A. Kahre, S.K. Vines, R.M. Haberle, and J.L. Hollingsworth

Abstract

Leovy (personal communication, 2007) speculated that interactions between the dust and CO_2 cycles early in Mars' history could have resulted in two stable climate states near the Noachian/Hesperian boundary for moderately massive atmospheres (<100 mbar): an inflated, high-pressure atmosphere with a highly active dust cycle; and a collapsed, low-pressure atmosphere with a quiescent dust cycle. In the first case, a thicker, more massive atmosphere would cause high dust lifting rates and an atmosphere dustier than it is today. The high levels of atmospheric dust (> a few visible optical depths globally) would increase the heat transport of the atmosphere and would inhibit CO_2 condensation by increasing the downward IR flux at the surface. In the second case, dust lifting would not be efficient enough to maintain high levels of atmospheric dust and the atmosphere would collapse, further decreasing the efficiency of dust lifting. This idea raises the possibility that not only could two stable states exist but also that transitions from one stable state to another could occur by the perturbing the system in some way.

We present results from an initial general circulation modeling study to assess whether the dust cycle could have led to two stable climate states on early Mars. For dust to stabilize a moderately thick (80 mbar) atmosphere, increasing the atmospheric dustiness must act to prevent CO_2 caps from persisting year-round. A range of dust loadings, CO_2 ice cap albedos, and obliquities is explored to study how increasing atmospheric dust affects atmospheric stability for moderately thick (80 mbar) atmospheres. Of the simulations conducted, increasing the dustiness of the atmosphere stabilizes an otherwise unstable atmosphere when the CO_2 ice cap albedo and the obliquity are both high (0.7 and 60°, respectively). Although our preliminary conclusion is that two stable states are possible for a limited set of conditions, further work must be done to know if the conditions necessary are physically plausible.

Planetary Atmospheres & Climates Poster: PA.12

Title: Transient climate effects of large impacts on Titan

Kevin Zahnle

Titan's thick atmosphere and volatile surface cause it to respond to big impacts in a somewhat Earth-like manner. Here we construct a globally-averaged model that tracks the energy flow through the environment in the days, months, and years after a very big comet strikes Titan. The model Titan is endowed with a 1.4 bar N_2 atmosphere with 5% CH_4, methane lakes, a water ice crust, and enough methane to saturate the upper (porous) crust. We find that Menrva was big enough to raise the surface temperature by $\sim$80 K. If methane in the regolith is generally as abundant as it was at the Huygens landing site, Menrva would have doubled the amount of methane in the atmosphere. The extra methane would have drizzled out of the atmosphere over hundreds of years. The putative Hotei impact (a possible 800-1200 km diameter basin, Soderblom et al 2009) would have raised the average surface temperature to 350-400 K. Water rain would have fallen and global meltwaters could have been 50 m deep or more than a kilometer deep, depending on the details. Global meltwaters may not have lasted more than a few decades or centuries at most, but are interesting to consider given Titan's organic wealth. Impacts also create local crater lakes set in warm ice but these quickly sink from sight; whether the cryptic waters quickly freeze by mixing with the ice crust (our belief) or whether they long endure under the ice remains a open question.

The Crystalline Fraction in Cometary Grains: Forsterite of Polyhedral Shapes and Forsterite in Porous Aggregates

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Computations of polyhedral-shaped forsterite crystals and porous aggregate grains with crystal inclusions are contributing to our understandings of comet dust grain compositions and grain aggregate structures, and thereby impacting our understanding of cometary origins. Cometary crystal mass fractions are the benchmarks for radial transport models of the protoplanetary disk. Cometary aggregate grain structures are emerging also as a critical component in models that seek to replicate grain agglomeration and grain compaction processes in the protoplanetary disk prior to their incorporation into comet nuclei. We discuss computations of optical properties of comet grain analogs using the Discrete Dipole Approximation (DDA) method via the DDSCAT code parallelized on the NAS supercomputer at NASA Ames. Specifically, we present in brief computations of (1) polyhedral shaped forsterite (Mg_2SiO_4) crystals (Lindsay, 2012; Lindsay et al., 2013a), as well as (2) aggregates with forsterite crystal monomers with spherical and tetrahedral shapes, and characterized by two porosities as well as three crystal mass fractions ranging from 0% to 25%. Strong crystalline forsterite features, especially at 11.2, 19, and 23.5 μm of comets Hale-Bopp, 17P/Holmes and 9P/Tempel 1, drive the spectral fits. We highlight that fact that comets Hale-Bopp, 17P/Holmes and 9P/Tempel 1 have forsterite spectral features with remarkably similar wavelengths, relative intensities and feature shapes, so we hypothesize that the crystals in their comae have similar non-spherical polyhedral shapes. The best-fit polyhedral shapes for the forsterite crystals can be linked to the high temperatures at which the crystals condensed and or experienced post-condensation evaporation by comparison with published laboratory experiments.

High Resolution Simulations of the Giant Impact Formation

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Kevin Zahnle (NASA Ames Research Center), Michael S. Warren (Los Alamos National Laboratory) and Christopher Fryer (Los Alamos National Laboratory)

We are curently performing a new series of numerical simulations of unprecedentedly high resolution to study the outcomes of collisions between terrestrial planets. The best studied example is the putative Earth-Moon-forming impact, but this kind of impact is widely thought to be common to the origin and evolution of all terrestrial planets, and probably common to many other classes of planet. We are using a well-tested SPH (Smoothed Particle Hydrodynamics) code. SPH codes are Lagrangian codes well-suited to computing gravitational interactions and tracking provenance; they are also, unlike Eulerian codes, well-suited to parallelization. We have available for use in this project computational facilities at the Institute for Computational Cosmology with as many as a few thousand cores.

The current suite of simulations use 10^8 particles to achieve spatial resolutions on the order of 20 km in the planets and 100 km in the moon-forming disk, which is ~ 5 times finer than the current state-of-the-art simulations (the most recent highest resolution SPH models use 10^6 particles [1, 2]; published studies use $\sim 10^5$ [3, 4]; a recent Eulerian simulation uses a 98 km cubic grid to match and test against the published SPH results [5]). We are not attempting to innovate with equations of state (EOS), which are used to obtain pressure and temperature from density and specific energy. Results are known to be sensitive to the EOS [6] – in particular vapour production. We are currently using ANEOS for iron, dunite, basalt and granite, as available. We are also considering very simple and very fast EOSs for testing purposes, and use end-member EOSs to bracket the range of outcomes.

We expect to address with this suite of simulation several problems that are either important to study with high resolution (the putative Moon-forming impact in particular), or novel because they were not addressable at lower resolution:

(i) High resolution simulations of the canonical Moon-forming impact. The focus here is on whether higher resolution has an effect on the predicted provenance of the Moon. This addresses the apparent discordance between models that make the Moon from the mantle of the impacting planet and isotopic data that suggest the Moon is mostly made from the mantle of the Earth. The higher resolution proposed here introduces new physics (e.g., it vertically resolves the Moon-forming disk) that may lead to different gross outcomes.

(ii) The ~ 20 km resolution of a 10^8 particle simulation allows us to address, for the first time, the effects of an interplanetary collision on a differentiated planetary crust. Crusts have highly distinctive elemental compositions. It has been suggested that planets lose crust-forming elements preferentially during accretion because of their exposed position [6].

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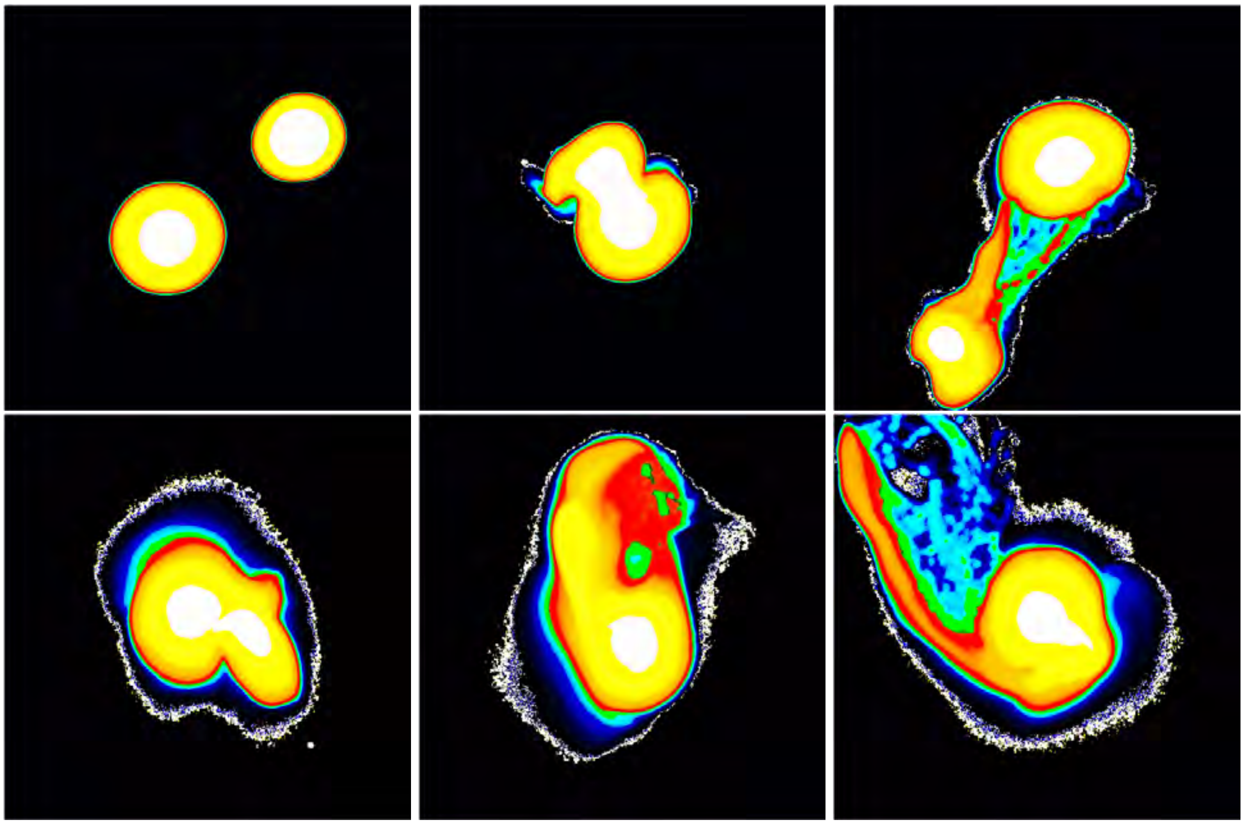

Figure 1: Snapshot images rendered from our planetary collision simulation. Colors represent the logarithm of projected density. White and blue denote the high- and low-density regions, respectively. The images are chronologically ordered from the left to the right and from the top to the bottom. The initial Mars-sized object comes into the system from the upper-right, making initial contact with the proto-Earth. In the center, the "impactor" and initial debris approaches for a secondary collision. In the bottom row, the cores of the proto-planets have merged, leaving an orbiting stream of iron-poor material and a vapour cloud which evolves to form the Moon. This simulation used over 1 million particles with a Tillotson (1962) EOS [7] and the images show the first $\sim$5 hr after the Giant Impact.

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PROSPECTING FOR POLAR VOLATILES: RESULTS FROM THE RESOLVE FIELD TEST. Richard C Elphic[1], Anthony Colaprete[1], Matthew Deans[1], Jennifer Heldmann[1], Gerald Sanders[2], William Larson[3], [1]NASA Ames Research Center, Moffett Field, CA, United States. [2]NASA Johnson Space Center, Houston, TX, United States, [3]NASA Kennedy Space Center, FL, United States,

Introduction: Both the Moon and Mercury evidently host ice and other volatile compounds in cold traps at the planets' poles. Determining the form, spatial distribution, and abundance of these volatiles at the lunar poles can help us understand how and when they were delivered and emplaced. This bears directly on the delivery of water and prebiotic compounds to the inner planets over the solar system's history, and also informs plans for utilizing the volatiles as resources for sustained human exploration as well as the commercial development of space.

Temperature models and orbital data suggest near-surface volatile concentrations may exist at polar locations not strictly in permanent shadow. Remote operation of a robotic lunar rover mission for the 7-10 days of available sunlight would permit key questions to be answered. But such a short, quick-tempo mission has unique challenges and requires a new concept of operations. Both science and rover operations decision-making must be done in real time, requiring immediate situational awareness, data analysis, and decision support tools.

RESOLVE Prototype and Mission Simulation: The Regolith and Environment Science and Oxygen & Lunar Volatile Extraction (RESOLVE) project aims to demonstrate in situ resource utilization (ISRU). RESOLVE is developing a rover borne payload that (1) can locate near subsurface volatiles, (2) excavate and analyze samples of the volatile-bearing regolith, and (3) demonstrate the form, extractability and usefulness of the materials. Here we describe an analog field demonstration of the prospecting approach RESOLVE would use for lunar mission. To meet mission requirements, a third generation RESOLVE payload and rover was developed and used in a roughly one-week field exercise simulating a mission.

The mission simulation was performed in July 2012 at 2470-m elevation on the south flank of Mauna Kea, in the vicinity of Pu'u Haiwahine (+19° 45' 41.09"N, -155° 28' 4.86"E). The test was carried out from a Mission Operations Center (MOC) located at Hale Pohaku about 1.3 km to the east (+19° 45' 41.46"N, -155° 27' 20.86"E). Additional support was provided by networked teams at NASA Ames Research Center, the Canadian Space Agency, NASA KSC and JSC.

Site Preparation: The test site was cleared of vegetation to the maximum extent possible, and targets were placed along the pre-planned traverse paths. The traverse plans were developed on the basis of interesting features identified in orbital imagery; after arrival in Hawai'i, a subset of the team emplaced targets. To avoid the difficulties of using water ice as prospecting targets, buried polyethylene sheets were used as ice proxies. Other materials (eg., camouflage netting) were used for near-IR targets. It was not practical to populate the entire test site with randomly distributed targets, so these were placed at selected points along the traverse paths; their locations were not known to the prospecting ops team. These targets would be "discovered" by the prospecting instruments, and real-time decisions would have to be made, whether to stop and investigate further, or continue along the planned traverse. A mockup lander was utilized to 'deliver' the RESOLVE/rover to the mission start location and provide communication, situational awareness, and relative navigation to the RESOLVE/rover mission team (Figure 1). All operations were performed remotely from either the main MOC near the test site, or by personnel at the control centers in the US and Canada.

Fig. 1. RESOLVE payload aboard Artemis Jr. rover, near lander mock-up.

Traverse Execution and Re-planning. The mission simulation used a realistic process of pre-mission activity planning and scheduling, together with real time monitoring of status and progress through the activity plans. The Flight Control Team, led by the Flight Director, was responsible for executing the daily plan, and included a Timeline coordinator, as well as Systems, Rover and Science consoles. The latter were in turn supported by other consoles monitoring subsystem health and status.

Under Science, the prospecting activity was monitored via a Spectrometer console and a Real-Time Science console position, responsible for recommending rover operations modifications (e.g., rover all-stop when traversing a high-volatile content area, hydrogen hotspot localization to map the volatile distribution at high resolution, drill/auger procedure to sample the subsurface, rover speed adjustment based on spectrometer readings as needed, etc). Locating Real-Time Science position next to the Rover Navigation console position was key to enabling rapid and efficient updates changes to the traverse plan, especially when a volatile hotspot was found. Supporting these real-time positions was a Science Backroom at NASA Ames Research Center tasked with monitoring real-time data, conducting in-depth data analysis to support mission decision-making, and conducting any rover traverse replanning as required based on the data and information gleaned from prior roving activities.

Results: Figure 2 shows maps of all the traverses executed during the seven days of operations. In all, a total traverse distance of over 1 km was achieved. The maps also show color coded measurements by the neutron and near-IR spectrometers, and an inset shows the detail of a hotspot localization procedure. Nine "water ice" hotspots were identified, and seven of these were characterized by the localization procedure. Both augering and coring were performed at a subset of these sites.

These real-time science operations activities required innovative software to enable real-time monitoring of the prospecting data to support science decision-making. RESOLVE utilized customized exploration ground data system software (xGDS, used to make the maps in Figure 2) to monitor rover navigation telemetry, spectrometer data feeds, etc. Rover traverse plans as well as the paths actually executed by the rover were updated in real-time superimposed on a satellite image for context. Data displays included color-coded paths following the rover traverse which indicated relative amounts of volatile abundances with respect to geographic location and continually-updated strip charts plotting the instrument data as a function of time. Neutron data was displayed in terms of neutron count rate (directly proportional to hydrogen content). For the near-infrared data the raw spectra were monitored and data band depth algorithms were employed to automatically calculate and display the strength of several water bands for rapid assessment of water content.

Overall, the operation of the Field Demonstration was very successful. The infrastructure of the Flight Control team allowed for remote commanding and end-to-end operation of the RESOLVE payload and

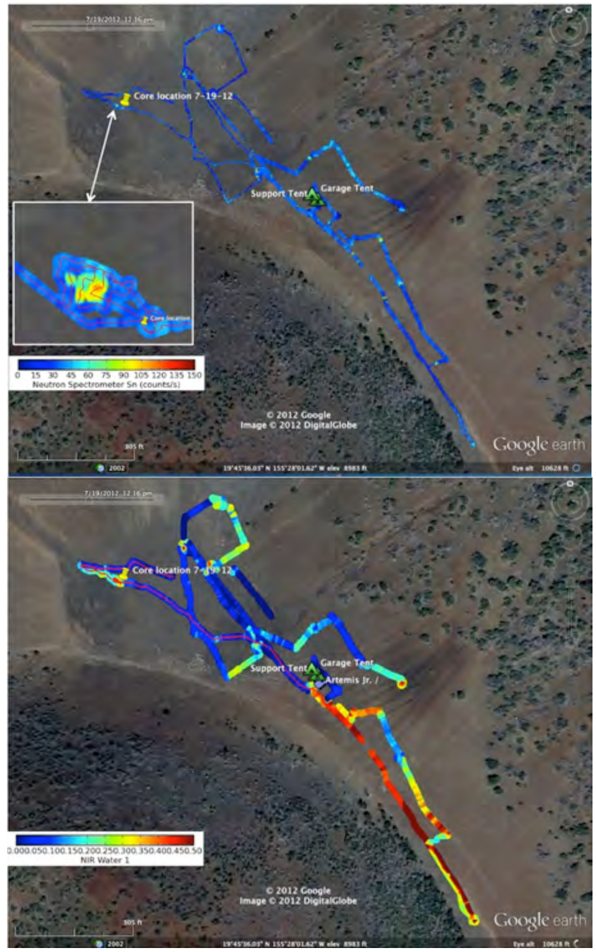

Fig. 2. (Top) Neutron spectrometer count rates mapped along traverse paths. Inset shows hotspot localization. Higher count rate means higher water-equivalent hydrogen abundance. (Bottom) Near-IR spectrometer band depth for 1.5 microns, corresponding to surficial hydration.

Artemis Jr. rover. Console tools, including software and console displays, were vital to the situational awareness in the Mission Operations Center. All operational objectives and the majority of the mission objectives were also met or exceeded.

Acknowledgments: We thank Jackie Quinn for her management of the RESOLVE project. We thank Katie Rogers, Greg Mattes, and Jennifer Clevenger (all NASA JSC) for their role in organizing the mission operations and serving as Flight Controllers during the RESOLVE mission simulation.

Hydrocarbon ices in extra-red TNOs and Centaurs

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We present an analysis of the reddest trans-neptunian objects (TNOs) and Centaurs – those belonging to the RR taxon. The RR class contains more than ¼ of the population of TNOs for which photometric colors are available, including a variety of dynamically different objects. The available data cover the spectral range from 0.3 to 2.2μm.

In a sample of 76 objects for which visible and near-IR spectroscopic measurements are available, CH_3OH ice was detected only on three objects belonging to the RR taxonomic class (5145 Pholus, 55638 2002 VE95 and 90377 Sedna). These three objects are among the reddest, they belong to different dynamical classes, and they have different dimensions. However, all three have similar compositions with Sedna showing a more significant heterogeneity in the kind of hydrocarbon ices found on its surface than the others. To further investigate the presence of ices, and in particular CH_3OH, as part of the composition of the RR taxon we used Spitzer IRAC data available for a subgroup of ten objects. Both methanol and methane have a strong absorption at 3.6 μm, the first of the Spitzer IRAC channels, and a much higher albedo at the following channel at 4.5 μm. This albedo pattern is characteristic of some hydrocarbon ices and is very different from H_2O ice that shows instead very low albedos at both channels. Our technique makes use of a large database of models including H_2O, CH_3OH, CH_4, and N_2 ices combined with tholins, amorphous carbon, hydrogenated amorphous carbon, serpentine and olivine in different combinations of relative abundances and grain sizes. We automatically extract the models that match the observations at all color wavelengths therefore obtaining for each object a set of compositions that are consistent with its colors. We detect one or two of a variety of ices on most objects in our sample.

The presence of methanol on these extra red objects could imply that they exhibit an almost primordial surface. In fact, laboratory experiments of irradiation of compounds rich in methanol show strong reddening. The reddening effect on a Centaur or TNO depends on the composition of the object and on the irradiation history while the thickness of the organic crust depends on the irradiation dose. These objects, following the hypothesis of Brown et al (2011) that objects that formed farther away might be able to retain their methanol ice, have the surface composition and colors set by formation-location-dependent volatile loss in the early solar system. The results of the current work also support the hypothesis that a substantial mixing has occurred after the TNOs formation and does not exclude the hypothesis of initial heterogeneity.

Planetary Surfaces & Interiors Poster: PS.5

Abstract for Symposium, March 12, 2013

TITLE: Hydrocarbons on Phoebe, Iapetus, and Hyperion: Quantitative Analysis

AUTHORS: Dale P Cruikshank, Cristina Morea Dalle Ore, Yvonne J Pendleton, Roger Nelson Clark

ABSTRACT: We present a quantitative analysis of the hydrocarbon spectral bands measured on three of Saturn's satellites, Phoebe, Iapetus, and Hyperion. These bands, measured with the Cassini Visible-Infrared Mapping Spectrometer on close fly-bys of these satellites, are the C-H stretching modes of aromatic hydrocarbons at ~3.28 µm (~3050 cm^{-1}), and the are four blended bands of aliphatic -CH_2- and -CH_3 in the range ~3.36-3.52 µm (~2980-2840 cm^{-1}). In these data, the aromatic band, probably indicating the presence of polycyclic aromatic hydrocarbons (PAH), is unusually strong in comparison to the aliphatic bands, resulting in a unique signature among Solar System bodies measured so far, and as such offers a means of comparison among the three satellites. The ratio of the C-H bands in aromatic molecules to those in aliphatic molecules in the surface materials of Phoebe, N_{Aro}:N_{Aliph} ~24; for Hyperion the value is ~12, while Iapetus shows an intermediate value. In view of the trend of the evolution (dehydrogenation by heat and radiation) of aliphatic complexes toward more compact molecules and eventually to aromatics, the relative abundances of aliphatic -CH_2- and -CH_3- is an indication of the lengths of the molecular chain structures, hence the degree of modification of the original material. We derive CH_2:CH_3 ~2.2 in the spectrum of low-albedo material on Iapetus; this value is the same within measurement errors to the ratio in the diffuse interstellar medium. The similarity in the spectral signatures of the three satellites, plus the apparent weak trend of aromatic/aliphatic abundance from Phoebe to Hyperion, is consistent with, and effectively confirms that the source of the hydrocarbon-bearing material is Phoebe, and that the appearance of that material on the other two satellites arises from the deposition of the inward-spiraling dust that populates the Phoebe ring.

Evidence for an extremely short period of hydrologic activity in Newton crater, Mars near the Hesperian-Amazonian transition

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Hesperian/Amazonian-aged martian valleys and alluvial fans distributed in regional clusters throughout the southern mid- to low-latitudes were formed during a period of fluvial runoff and erosion which acted over a smaller spatial and temporal scale than the older, "classical" martian valley networks which are dated to the Noachian-Hesperian boundary. In order to elucidate the source of water which formed these younger valleys, we calculated the expected sediment transport and water discharge rates for a valley and alluvial fan located in Newton crater (40^oS, -159^oE) over a wide range of water-filled channel depths and sediment grain sizes in order to constrain the formation timescale and required water volume. Depending on the depth of the water-filled channel within the valley, the alluvial fan was likely emplaced over ~0.1 to ~10 years of fluvial activity involving between 1.8 and 5.7 km^3 of water. These results imply water runoff rates of between 1 to 10 cm/day over a typical, 300 km^2, drainage area. If these runoff rates and timescales are representative of activity elsewhere, then the distribution of post-Noachian fluvial features suggest either a brief, dramatic global warming event melted a distributed population of high elevation snowpacks, or that ice was more uniformly distributed at low- to mid-latitudes and local melting events resulted in the observed spatial distribution. Although the ~10 m thick layer of water needed to form these valleys may have taken the form of a thick snowpack deposited during high obliquity, the rapid melting required to transport and deposit sediment in Newton crater indicates that another/additional mechanism contributed to the formation of these valleys. Candidate mechanisms for inducing a global warming event include a large (~100 km diameter crater) impact, or large volcanic eruptions releasing greenhouse gasses - perhaps accompanied by outflow channel formation. Alternatively, many instances of local melting caused by a temporally and spatially distributed set of impact and/or volcanic events could explain both the observed distribution and the calculated runoff rates.

RESOLVE: A Lunar Volatiles Prospecting Mission A. Colaprete[1], R. Elphic[1], J. L. Heldmann[1], G. Mattes[2], K. Ennico[1], E. Fritzler[1], M. Marinova[1], R. McMurray[1], S. Morse[1], T. Roush[1], C. Stoker[1], Jerry Sanders[2], Jackie Quinn[3], Bill Larson[3], M. Picard[4], [1]NASA Ames Research Center, Moffett Field, CA, [2]NASA Johnson Space Center, Houston, TX, [3]NASA Kennedy Space Center, FL, [4]Candian Space Center, Québec, Canada.

Introduction: Over the last decade a wealth of new observations of the moon have demonstrated a lunar water system dramatically more complex and rich than was deduced following the Apollo era. Observation from the Lunar Prospector Neutron Spectrometer (LPNS) revealed enhancements of hydrogen near the lunar poles. This observation has since been confirmed by the Lunar Reconnaissance Orbiter (LRO) Lunar Exploration Neutron Detector (LEND) instrument. Observations from the Lunar Crater Observation and Sensing Satellite (LCROSS) mission, which impacted into Cabeus, a shadowed crater showing enhancements of hydrogen, showed that at least some of the hydrogen enhancement was in the form of water ice and molecular hydrogen (H2). Other volatiles were also observed in the LCROSS impact cloud, including CO2, CO, an H2S. These volatiles, and in particular water, have the potential to be a valuable or enabling resource for future exploration. In large part due to these new findings, the NASA Human Exploration and Operations Mission Directorate (HEOMD) has selected a lunar volatiles prospecting mission for a concept study and potential flight in CY2017. The mission includes the RESOLVE (Regolith and Environment Science and Oxygen & Lunar Volatile Extraction) payload, rover (provided by the Canadian Space Agency (CSA), and a lander (lead by MFSC and JSC). RESOLVE is a rover-borne payload that (1) can locate near subsurface volatiles, (2) excavate and analyze samples of the volatile-bearing regolith, and (3) demonstrate the form, extractability and usefulness of the materials.

Real-time Prospecting and Combined Instrument Science: Temperature models and orbital data suggest near surface volatile concentrations may exist at briefly lit lunar polar locations outside persistently shadowed regions. A lunar rover could be remotely operated at some of these locations for the 4-7 days of expected sunlight at relatively low cost.

Given the relatively short time period this lunar mission is being designed to, prospecting for sites of interest needs to occur near real-time. The two instruments which are being used for prospecting are the neutron and NIR spectrometers (Fig. 1). A neutron spectrometer will be used to sense hydrogen down to concentrations as low as 0.5WT% to a depth of approximately 80 cm. This instrument is the principle instrument for identifying buried volatiles. A NIR spectrometer, which includes its own light source, will look at surface reflectance for signatures of bound H2O/OH and general mineralogy. Once an area of interest is identified by the neutron and/or NIR spectrometer (what was referred to as a "hot spot") the option to drill is considered. The drill can either auger or core. The auger drill can excavate samples to a depth of 50 cm and is monitored with a drill camera, the NIR spectrometer and thermal radiometer. If a particular location is considered of high-interest then the decision to core could be made. The coring drill (a push-tube) allows a 1-meter sample to be acquired and then processed by the OVEN/LAVA system.

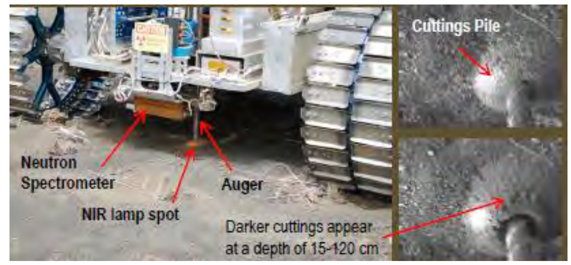

Figure 1. The RESOLVE Payload on the Artemis Jr. rover: Shown is an augering activity with the NIR lamp illuminating the drill spot the view from the Drill Camera.

RESOLVE Field Test: In July 2012 the RESOLVE project conducted a full-scale field demonstration. In particular, the ability to perform the real-time measurement analysis necessary to search for volatiles and the ability to combine the various measurement techniques to meet the mission measurement and science goals. With help from the Pacific International Space Center for Exploration Systems (PISCES), a lunar rover prototype (provided by the Canadian Space Agency) was equipped with a suite of prospecting instruments (neutron spectrometer and near-infrared spectrometer), subsurface access and sampling tools, including both an auger and coring drill (provided by CSA) and subsurface sample analysis instrumentation, including a sample oven system, the Oxygen and Volatile Extraction Node (OVEN), and Gas Chromatograph / Mass Spectrometer system, the Lunar Advanced Volatile Analysis (LAVA) system.

This presentation will describe the RESOLVE mission, the payload and measurments, and concept of operations.

Estimating Optical Constants of Solar System Materials. Ted L. Roush

The wavelength dependent real (n) and imaginary (k) parts of the index of refraction are the fundamental properties that describe how electromagnetic radiation interacts with various materials. They are the crucial input values necessary for theoretical modeling of observational data obtained for interstellar materials, cometary objects, and the surfaces and atmospheres of planets and satellites, including the Earth.

Various approaches to estimating the optical constants of candidate materials have been applied over the past decades to address the growing need associated with the continued extension of the observational data to broader wavelength ranges and to candidate materials whose optical constants are poorly characterized, or unknown.

A review of these approaches is provided along with a comparison between the results for the same materials.

Planetary Surfaces & Interiors Poster: PS.9

Radiative transfer in complex media

Sanaz Vahidinia/SST

Abstract: Our research involves developing radiative transfer tools for applications in planetary surfaces, atmospheres, and biological tissue. We will showcase our newly developed numerical Regolith Radiative Transfer (RRT) model for scattering calculations in complex planetary surfaces such as: (a) thermal emission spectroscopy of granular surfaces and (b) the role of nano-scale inclusions of different composition within regolith grains. We will also show the effects of complex soot aggregates in our atmosphere and the role of specialized cells in aiding photosynthesis in giant clams.

A High Resolution Map of the Martian Hydrogen Distribution

Luís F. A. Teodoro (BAER Institute/NASA Ames Research Center), Richard C. Elphic (NASA Ames Research Center), Vincent R. Eke (Institute for Computational Cosmology, Durham University), William C. Feldman (Planetary Science Institute), and Sylvestre Maurice (Université Paul Sabatier)

Mars Odyssey carries a Neutron Spectrometer (MONS) that has been gathering information for more than a decade. The neutrons leaking from the Martian surface provide information about the hydrogen distribution in the top few decimeters [2]. The global MONS hydrogen map is complementary to the local ones that will be measured by MSL and ExoMars. In brief, deposits ranging between 20% and 100% Water-Equivalent Hydrogen (WEH) by mass are found pole-ward of 55 deg. latitude, and less rich, but still significant deposits are found at near-equatorial latitudes.

Recently, [3] have re-analyzed the MONS epithermal data and significantly lowered the statistical systematic data reduction uncertainties that plagued previous versions of the data. However, MONS counting-rate data have a FWHM of $\sim$ 550 km, which is sufficiently broad to contain several Gale craters in it. In this study, we choose the PIXON numerical deconvolution technique [4, 1]. This algorithm removes the point spread function without introducing spurious features in the presence of noise. We have previously carried out a detailed study of the martian polar regions applying this methodology to Martian epithermal neutrons near both poles (e.g. [5]) and have been able to reach a resolution of $\sim$ 45 - 100 km. In the present study, we will apply this technique to the latest MONS epithermal CO_2 frost-free data over the full surface of Mars.

To map the martian near-surface hydrogen distribution accurately is central to the study of volatiles delivery and retention in the terrestrial planets of the Solar System. It is also a crucial ingredient in the planning/management of current and future missions to the Mars surface.

Our preliminary results of the epithermal neutron leakage reconstruction at the Gale Crater neighborhood in 40×40 km^2 pixels show that the dynamical range and the sharpness of the features are enhanced. Although the reconstruction's resolution is not as small as the polar counterparts it is still considerably smaller than the instrumental blurring ($\sim$ 550 km).

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Laboratory Studies of the effect of Gases on Activated Lunar Simulant

Claire L. Ricketts, Ella M. Sciamma O'Brien, Cesar S. Contreras, Farid Salama,

Amanda M. Cook, Andrew L. Mattioda, Emma L. Yates, Laura T. Iraci,

Alessandra Ricca and Robert L. Walker

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The lunar surface is constantly 'activated' through bombardment of solar radiation and micrometeorites. This 'activation' is significant enough to affect the surface dust by creating free radicals, dangling bonds and lattice defeats. Hence, the reactive effect of the dust particles on spacecraft instrumentation and human toxicology is a concern. There is currently little information on the surface chemical activation of lunar regolith after exposure to gases brought to the Moon by human activities. Information is needed in order to understand the regolith toxicity, effect on spacecraft, determine lunar dust exposure limits and meet the needs of the technological development of appropriate physical/chemical tools for regolith passivation.

In this experimental study, we grind JSC-1af lunar simulant to simulate micrometeorite impacts and expose the simulant to vacuum ultraviolet (VUV) light to simulate solar radiation. We then flow a variety of gases (N_2, CO_2, CH_4) over the simulant to simulate the exposure of the activated dust to gases humans would bring to the Moon. Mass spectra are taken using the Reflectron Time-Of-Flight Mass Spectrometer at NASA Ames' Cosmic Simulation facility (COSmIC), before, during and after exposure to VUV and the various gases. Infrared spectra and Scanning Electron Microscope images of the simulant are taken, before and after activation and gas exposure. Future plans include theory and replicating these experiments using real lunar dust. Here we describe our new custom built lunar dust holder, experimental procedure and latest results.

Acknowledgements: NASA LASER supports this research. E.S.O. and C.S.C. acknowledge the support of the NASA Postdoctoral Program.

SPACE SUIT IMPACT ON EFFICIENCY AND PERFORMANCE OF FIELD SCIENCE TASKS

Willson, D.[1] and Stocker, C.R.[2].
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Introduction: We conducted field trials at the Mars Desert Research Station (MDRS) near Hanksvill in Utah (USA) focusing on the ability and efficiency of field scientists to: survey endoliths on the ground and in rock walls, collect data in the samples, and core drilling while wearing a pressurized spacesuit. The field trials used the North Dakota Experimental-1 (NDX-1) pressurizable spacesuit system [1].

Off-world field science experience is limited to six Apollo lunar missions where lunar field science practice evolved successively to extensive field surveys in many locations, kilometers from the Lunar Module. Astronaut Schmitt [2] described performing field geology on the moon as: requiring faster mental iterations compared to terrain exploration, is more physically demanding than on Earth inducing fatigue that could be fatal, subject to strict time constraints (due to limited space suit consumables), and dictated by knowledge that returning to the location is unlikely.

The physically and mentally demanding EVAs undertaken by the Apollo astronauts were arguably successful because of years of training focused on a maximum of three Lunar EVAs over 3 day visits. Future off-world missions to Mars or the Moon are likely to be in the paradigm of "go to stay" with astronauts undertaking many EVAs probably with most planned during the mission. Thus understanding the requirements for field science spacesuit performance through simulated field trials is an important step to developing new technologies and skills for future human planetary exploration.

Objective: Our objective was to quantify the scientist astronaut performance while wearing a spacesuit during simulated off-world field science doing: data collection, documentation tasks for surveying endoliths and for drilling using a core sample and rotary percussive drill.

Methodology: Five subjects, geology and astrobiology post graduate students donned the NDX-1 space suit and undertook:

(1) Endolith surveys on the ground and on a rock wall unit (fig 2) at previously identified locations. The properties documented were: position, strike/dip, rock type, rock color, rock hardness, color, sky angle, endolith presence, endolith color, endolith depth, endolith thickness and a visual survey of associated biology.

(2) Core sample drilling and rotary percussive drilling (fig 1), collecting and storing the core and cutting samples for each drill type.

In addition we measured during all trials, while wearing and not wearing the space suit: bio-medical data including heart-rates, observational accuracy, task duration, and, drill hole depths in the case of drilling. In particular, we compared heart-rates – a measure of human effort, and calculated time metrics, factors that compare task duration while suited to when not suited.

The University of North Dakota's NDX–1 space suit. The North Dakota Experimental-1 (NDX-1) space suit system [1] is a pressurized planetary space suit concept demonstrator for analog Moon and Mars testing, made by the University of North Dakota in 2005. The space suit is part of an iteration of planetary suit concepts designed to be analog test-beds trialling new materials and component assemblies. The space suit systems include a water cooling garment, a wireless communications headset, a biomedical logger monitoring heart ECG (measuring effort), breathing mixture and body temperature, respiration rate, pressure, humidity, O_2, CO_2 and time. NDX-1 is a separable two- piece suit with lower fabric trousers and upper composite hard torso assemblies.

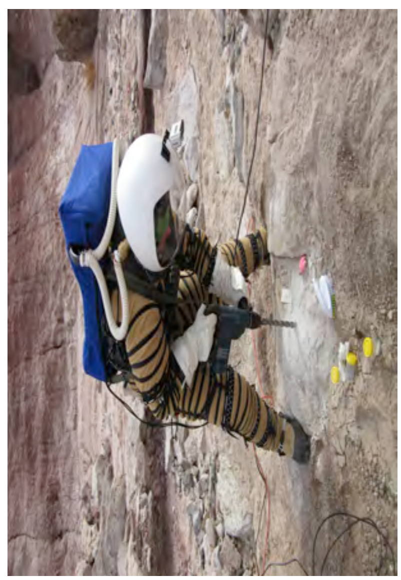


Figure 1: Rotary Percussive drilling while in suit. Note the cuttings around the hole.

Results:

Drilling Results. Core sample drilling required considerable more effort than rotary percussive drilling (fig 1), due to conserving and documenting the core. Drilling pulse rates, depths drilled in suit and no suit are listed in Table 1. The time metric was calculated as:

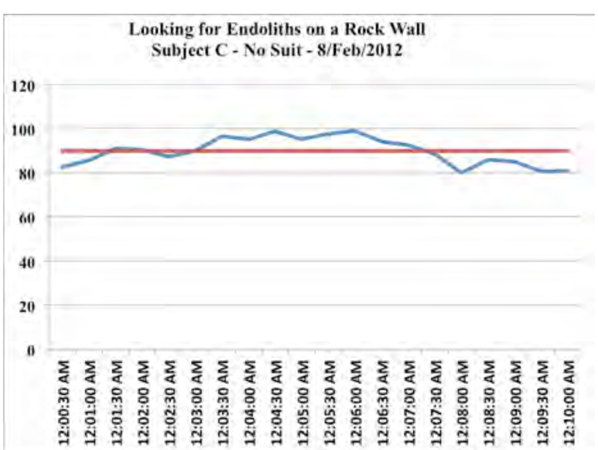
Drilling Time metric = (Duration: in Suit/ No suit) x (Drill depth: no suit/in suit)

Drill	Average Pulse Rate		Duration (min)		Depth Drilled (mm)		Time Metric
	No Suit	Suit	No Suit	Suit	No Suit	Suit	Suit/ No suit
Core sample drilling	97	119	18:30	41	185	127	3.26
Rotary Percussive	99	105	33.50	34	150	150	1.01

Table 1: Drilling biomedical data and time metrics for no suit and suit.

Endolith Surveys Results. Surveying and sample collecting on the ground was significantly more difficult and exhausting than surveying the rock wall unit. The observational accuracy was consistant at 90%. Heart-rates were on average 33 pulses per minute higher while surveying on the ground (graph 1) and an average of 21 pulses per minute higher while surveying on a rock wall.

Figure 2: Surveying endoliths on the ground **(**left); Surveying endoliths on a rock wall (right).



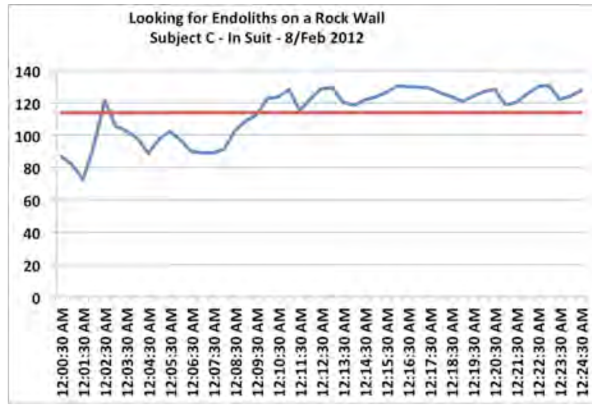


Figure 3: Heart rate of a subject while surveying and sample collecting endoliths on the ground with no suit (top) and in suit (bottom) where x axis is time, y axis is heart-rate, red line is average heart-rate. Note the higher average heart-rate while in a suit compared to no suit.

Conclusion: We find that while undertaking 'endolith type' surveys while suited, a time metric of at least 1.6 be multiplied to the equivalent survey with no suit (baseline) and, scientist astronauts could, on average, have 33 pulses/minute higher heart rate doing this activity in suit compared to baseline to achieve 90% observational accuracy.

Likewise for core drilling the time metric is 3.3 and the average heart rate could be 23 pulses/minute higher compared to baseline where sample handling cores was a major part of the effort. However the rotary percussive drilling was done in similar time and effort due to a second person capturing the cuttings.

Thus we argue technological solutions for sample handling cores from the drill string will reduce effort for core drilling.

Acknowledgements:
The authors wish to thank P. De León from The University of North Dakota Space Suit Lab, M.B. Wilhelm, C. Haberle and A. Wargetz.

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Mars science in the ice-cemented ground of University Valley Antarctica
C.P. McKay, J.L. Heldmann, A.F. Davila, M.M. Marinova, B.J. Glass
NASA Ames Research Center

The ground ice on Mars is expected to be present as ice-cemented ground underlying a layer of dry soil with the stability of, and depth to, ground ice determined by vapor exchange with the atmosphere.

In the regions on Mars where the Phoenix mission landed, the thermal and moisture content define three key zones in the shallow subsurface. The active layer is the uppermost soil layer in which summer temperatures rise above freezing. Below this there is expected to be a layer in which temperatures never rise above freezing but contain no ice – dry permafrost. Further down there may be a layer of ice-cemented ground or in some cases massive ice. Ice in the ice table exchanges with the atmosphere via vapor diffusion.

Dry permafrost with ice-cemented ground and exchange dominated by vapor diffusion is the norm on Mars but is rare on Earth. In fact this type of ground ice is only found in the upper elevations of the McMurdo Dry Valleys in Antarctica. We have been studying one scuh valley, University Valley, a small hanging valley above Beacon Valley in the Quarterman Mountains of the Dry Valleys. This valley floor is at an elevation of ~1650 m and ground and air temperatures should be close to those measured at Linnaeus Terrace which is at a similar elevation. This glacier is sustained by snow blown into the valley from the Polar Plateau.

The glacier has been present in the valley for at least the past 27 years based on personal observation. Personal observation also indicates that there is often snow on the floor of the valley away from the glacier, with the persistence and thickness of the snow diminishing away from the glacier.

The depth to the ice table in University Valley increases as a function of the distance from the glacier. This is consistent with snow recurrence determining the average surface frost point and thus the depth to ice. The transect shown in Figure 1 is an ideal test of the role of snow recurrence in setting the depth to the ice table. The distances involved are too small for any significant change in climate and there is no systematic change in surface albedo, aspect, or rock abundance.

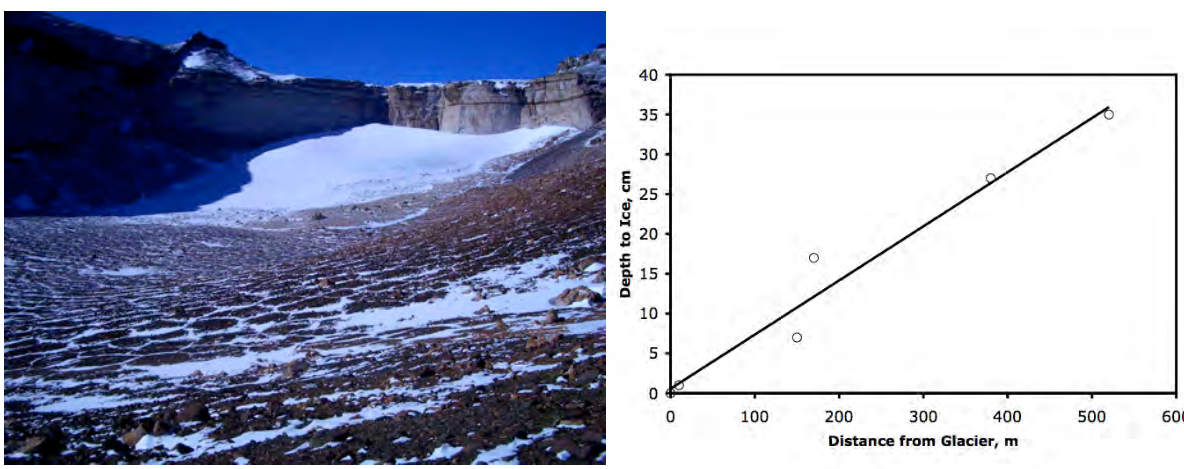

Figure 1. View of University Valley, January 2008, showing the glacier at the end of the valley. Length across the glacier is ~ 1 km. Panel on the right shows the depth to ground ice as a function of distance from the small glacier at the end of the valley.

The New Horizons Pluto Fly-By Mission – Coming to a New World 32 AU away – Jul 14, 2015

Dr. Kimberly Ennico (Code SSA)

In this talk, I will present an overview of the science enabled by the Pluto fly-by mission New Horizons. New Horizons, selected for flight in November 2001, and grandfathered into NASA's New Frontiers program, launched over 7 years ago, on January 19, 2006. After a successful instrument checkout and a gravity boost from Jupiter on February 28, 2007, the ~400 kg spacecraft has been in a long cruise period en route to a destination never visited before, the icy dwarf planet Pluto and its moons. New Horizons' Pluto Science Encounter begins on April 12, 2015, with closest approach to the Pluto-Charon system on Tuesday, July 14, 2015.

New Horizons' Mission Objectives are to (1) Map surface composition of Pluto and Charon, (2) Characterize geology and morphology ("the look") of Pluto and Charon, (3) Characterize the neutral atmosphere of Pluto and its escape rate, (4) Search for an atmosphere around Charon, (5) Map surface temperatures on Pluto and Charon, and (6) Search for rings and additional satellites around Pluto.

Traveling at nearly 14 km/s (31,000 mph) and flying within 12,500 km (7,770 mi) of Pluto's surface, the New Horizons spacecraft with its suite of seven science instruments, will obtained a sequenced intense series of images, spectra, and particle measurements spanning Pluto-7 days to Pluto+2 days, in addition to complementary observations further out in the Pluto approach and departure phases. New Horizons' on-board high-resolution imager's resolution exceeds Hubble's resolution ~70 days out, in early May 2015.

At closest approach, the RTLT (round trip light time) to Earth is nearly 9.5 hours, for which rehearsed uplink and downlink observations of occultations by Pluto and Charon obtained with the Radio Experiment instrument on New Horizons and NASA's Deep Space Network are carefully choreographed. At closest approach, Pluto (Charon) will be imaged panchromatically at 0.1-0.5 (0.15-0.16) km/pixel and in color at 0.6 (1.4) km/pixel resolution, with NIR spectra taken with 2.7-6.0 (4.7-8.4) km/pixel footprint. UV spectroscopy and three particles and plasma instruments complete the science instrument suite.

New Horizons' science goals are architected into three groups: Group 1 (required), Group 2 (important) and Group3 (desired). Science measurements are mapped to four science themes: Geology & Geophysics, Composition, Atmospheres, and Particles & Plasma. The designed observational sequence meets or exceeds all the objectives either with multiple measurements at different times and/or with different instruments to allow for built-in redundancy.

It's been over 23 years since a spacecraft visited a previously unmapped world, Voyager 2's Neptune fly-by on August 25, 1989. Traveling now at about 1 million miles per day, New Horizons each day maps unchartered territory. When it encounters the Pluto-Charon system in July 2015, Pluto is certainly expected to shed some surprises of its own.

The Johns Hopkins University Applied Physics Lab manages New Horizons. The Principal Investigator, Alan Stern, is at the Southwest Research Institute, Boulder, CO campus. The latest mission updates can be found at http://pluto.jhuapl.edu/.