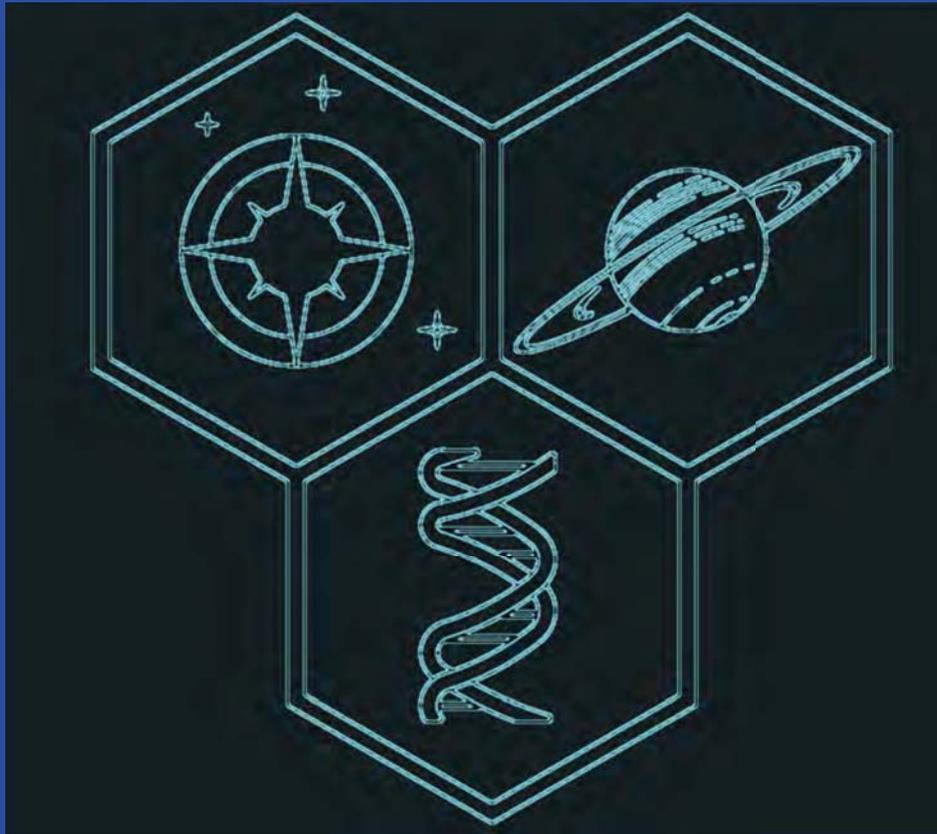


Second Annual NASA Ames Space Science and Astrobiology Jamboree



March 4, 2014

Welcome to the Second Annual Ames Space Sciences and Astrobiology Jamboree!

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 continue a new tradition created last year 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. Jeff Cuzzi 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. Ella Sciamma-O'Brien 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
Linda Janke

Second Annual Space Sciences Jamboree
March 4, 2014

8:00	Registration & Poster Setup
8:15	Pete Worden: Center Overview
8:30	Michael Bicay: Welcome & Announcements
8:45	<i>Outstanding Early Career Space Scientist Lecture:</i> Ella Sciamma-O'Brien: The NASA Ames Titan Haze Simulation Experiment on COSMIC
9:45	Kevin Zahnle: Venus, Earth, Xenon
10:05	Melinda Kahre: Coupling the Mars Dust and Water Cycles: The Importance of Radiative-Dynamic Feedbacks During Northern Hemisphere summer
10:25	Poster Session (odd number posters) & Coffee Break
11:10	Thomas Bristow: Implications of Clay Minerals from Gale Crater for the Habitability of Ancient Mars
11:30	Tori Hoehler: Serpentinization and Life
11:50	Michael Wilson: Flexibility of the Earliest Proteins
12:10	Poster Session / Lunch
13:15	Erin Smith: The SOFIA Science Instrument Suite: Status, Results, and Plans
13:35	Jeff Van Cleve: Red Dwarfs Rock! SOFIA Characterization of the planets of Small Stars Discovered by the Kepler K2 Extended Mission
13:55	Elisa Quintana: An Earth-sized planet in the habitable zone of a cool star
14:15	Mark Marley: Understanding the Directly Imaged Planets
14:35	Christiaan Boersma: Machine analysis of the interstellar PAH emission spectra with the NASA Ames PAH IR Spectroscopic Database
14:55	Uma Gorti: The Impact of Dust Grain Growth on Protoplanetary Disk Evolution and Photoevaporation
15:15	Poster Session (even number posters) & Coffee Break
16:00	Tom Greene: Getting protostars to talk: Applying enhanced interrogation techniques
16:20	<i>Pollack Lecture:</i> Jeff Cuzzi: Saturn's Rings
17:20	Remove Posters

id	Title	Corresponding Author
Astrobiology Posters		
AB.1	Photosynthetic Microbial Mats are Exemplary Sources of Diverse Biosignatures	David Des Marais
AB.2	Lipid biomarker production and preservation in acidic ecosystems: Relevance to early Earth and Mars	Niki Parenteau
AB.3	Lake Untersee Antarctica: A model for Europa and Enceladus	Dale Anderson
AB.4	Habitability redefined: don't forget biological requirements	Sanjoy Som
AB.5	Hydrogen Production and Habitability on non-ultramafic Geologic Systems	Kirsten Fristad
AB.6	Elucidation of Biohydrogen Production in Hypersaline Microbial Mats Leads to a Focus on the Role of Photosynthate and Carbon Storage	Jackson Lee
AB.7	Understanding the carbon and hydrogen flow in constructed H ₂ -producing microbial mats and co-cultures	Craig Everroad
AB.8	Salt Crust Ecology as a function of seasonal change	Heather Smith
AB.9	Expanding the environments of RNA in vitro evolution	Milena Popović
AB.10	Precursors to the citric acid cycle and metabolism: A mecanistic investigation on the formation of some key metabolic intermediates detected in carbonaceous meteorites	Andro C. Rios
AB.11	Photo-Induced Deuterium Enrichment in Residues Produced from the UV Irradiation of Pyrimidine in H ₂ O Ices	Michel Nuevo
AB.12	Ground Control Experiments and Flight Sample Preparation for the International Space Station OREOCube: Organics Exposure in Orbit Experiment	Richard Quinn
AB.13	The Solubility of Titan Tholin in liquid Ethane; are the seas of Titan a prebiotic soup	Chris McKay
AB.14	Chance and necessity in biochemistry: Implications for the search of extraterrestrial biomarkers in Earth-like planets	Alfonso Davilla
AB.15	Preservation and detectino of organics in ancient fluvio-lacustrine sediments -- lessons for MSL	Eldar Noedobrea
AB.16	Possible Hypolith on Mars	Heather Smith
Astrophysics Posters		
AP.1	Luminous Blue Compact Galaxies: Probes of Galaxy Assembly	Michael Fanelli

id	Title	Corresponding Author
AP.2	The Evolutionary Connection between Compact Groups and Isolated Galaxies: Diffuse X-Ray Gas Halos	Pamela Marcum
AP.3	Mid-Infrared Brightness Enhanced Galaxies in the Coma Cluster compared to the Virgo Cluster	Laurie Riguccini
AP.4	Extended dust emission in IC1459 and NGC2768 as seen by PACS	Alexandre Amblard
AP.5	ALMA Observations of Warm Molecular Gas in Arp 220	Nasseem Rangwala
AP.6	A Kepler Galaxy Survey: Establishing the Temporal Baseline for Extragalactic Systems	Michael Fanelli
AP.7	Using Kepler to Predict the Variable Sky for GAIA and LSST	Steven Ridgway
AP.8	Reviving Dead Zones - A New Potential Source of Activity in Cold Protoplanetary Disks	Orkan Umurham
AP.9	Temperature, Density, and Collision Rates in the IC63 Nebula	John Vallancourt
AP.10	Observational testing of interstellar grain alignment -- why everything you learned in grad school [about this] is wrong	B-G Andersson
AP.11	Using SOFIA, Herschel and HST observations to address the Nebular Abundance Problem	Elizabeth Mittmann
AP.12	EXES, the Echelon cross echelle spectrograph for SOFIA	Curtis DeWitt
AP.13	Semi-Empirical IR Line Lists for 13 CO ₂ Isotopologues: Up to 1500K and 20,000 cm ⁻¹	Xinxchuan Huang
AP.14	The ORGANIC Experiment on EXPOSE-R on the ISS: Mission Results	Kathryn Bryson
AP.15	Polycyclic Aromatic Hydrocarbon Clusters: Theory and Experiment	Joe Roser
AP.16	Carbonaceous Grain Formation for Circumstellar Studies	Cesar Contreras
AP.17	Formation of N- and O- heterocyclic molecules from the photolysis of PAHs in H ₂ O- and NH ₃ -containing ices	Chris Materese
AP.18	Formation Routes for Pure and N-substituted Cyclic Hydrocarbon Molecules in the Ionosphere of Titan and in the Interstellar Medium	Partha Bera
Exoplanet Posters		
EP.1	Is there an exo-Earth around Alpha Centauri? (And how a cubesat-sized telescope may give us an answer.)	Rus Belikov
EP.2	Experimental study of a low-order wavefront sensor for high-contrast coronagraphic imagers: results in air and in vacuum	Julien Lozi

id	Title	Corresponding Author
EP.3	A focal plane mask for PIAA Complex Mask Coronagraph	Kevin Newman
EP.4	Enhancing direct-imaging exoplanet detection using astrometry and its application for AFTA	Eduardo Bendek
EP.5	Measuring the masses and radii of sub-Neptunes with transit timing variations	Daniel Jontof-Hutter
EP.6	Stellar Properties of Kepler Targets for the Q1-Q16 Planet Detection Run	Daniel Huber
Planetary Atmosphere & Climate Posters		
PA.1	Exploring Mars' Atmosphere from the Surface to the Middle Atmosphere: NASA Ames Marsh General Circulation Model	Amanda Brecht
PA.2	Investigating the Asymmetry of Mars' South Polar Cap with a CO ₂ Cloud Microphysics Scheme	Julie Dequaire
PA.3	Formation timescales of water-ice clouds on MARS in the NASA Ames Mars GCM	Richard Urata
PA.4	Modeling Mars Cyclogensis and Frontal Waves: Seasonal Variations and Implications on Dust Activity	Jeff Hollingsworth
PA.5	Analysis and Characterization of Titan Aerosol Simulants	Kate Upton
PA.6	Dynamical Evolution of the Earth-Moon Progenitors	Billy Quarles
Planetary Surfaces & Interior Posters		
PS.1	Terrestrial analog field investigations to enable science and exploration studies of impacts and volcanism on the Moon, NEAs, and moons of Mars	Darlene Lim
PS.2	Helene: The Face that Launched a Thousand Slips	Jeff Moore
PS.3	Particle Size Distributions Impact on Determination of Mars Analog Materials Optical Constants	Ted Roush
PS.4	Crater Relaxation and heat Flow on Dione and Tethys: Near Cousins of Enceladus?	Oliver White
PS.5	The Ponds on Eros: Possible New Insights from Experiment, Vesta, Mars, and Terrestrial Analogs	Derek Sears
PS.6	Drill Embedded Nanosensors for Planetary Subsurface Exploration	Jing Li
PS.7	The Map-X instrument proposed for the Mars 2020 Mission	David Blake
PS.8	Ice Chemistry on Outer Solar System Bodies: Carboxylic acids, Nitriles, and Urea Detected in Refractory Residues Produced from the UV-photolysis of N ₂ :CH ₄ :CO Containing Ices	Chris Materese
PS.9	Interstellar Organics, the Solar Nebula, and Saturn's Satellite Phoebe	Yvonne Pendleton

id	Title	Corresponding Author
Displays		
D.1	Planetary Analog Research and Climate Change Monitoring in a Land of Extremes: The Ubehebe Volcanic Field, Death Valley, California	Rosabla Bonaccorsi
D.2	Gene Expression Measurement Module (GEMM_ - the door to high-throughput in-situ analyses of biological systems in space	Fathi Karouia
D.3	Introducing SSERVI	Yvonne Pendleton
D.4	Where your Ideas Become Reality: The Space Science and Airborne Instrument Development Lab	Emmett Quigley

The NASA Ames Titan Haze Simulation Experiment on COSmIC: Multiphase Simulation of Titan's Early Stage Chemistry at Low Temperature. (Science Topic: Planetary Atmosphere & Climate)

Ella Sciamma-O'Brien^{1,2}, Cesar S. Contreras^{1,2}, Kate T. Upton³, Jack L. Beauchamp³, Farid Salama¹, ¹NASA ARC, Moffett Field, CA; ²BAER Institute, Sonoma, CA; ³Noyes Laboratory of Chemical Physics, Caltech, Pasadena, CA.

Introduction: Titan, Saturn's largest moon, is the only solid body in the outer solar system with a dense atmosphere. Because Titan's atmosphere is mostly composed of nitrogen and methane, it is often considered as a cold primordial Earth analog. Titan's atmosphere is the site of a complex organic chemistry that occurs at temperatures lower than 200 K and leads to the production of heavy molecules and subsequently solid aerosols that form the orange haze surrounding Titan. Because the reactive carbon and nitrogen species present in Titan's aerosols could meet the functionality requirements for precursors to prebiotics (the ingredients for the building blocks of life), the study of Titan's aerosol has become a topic of extensive research in the fields of astrobiology and astrochemistry. Experiments have been developed in several laboratories in the past 30 years in order to understand Titan's gas phase chemistry and the production processes and composition of the atmospheric organic aerosols.

The Titan Haze Simulation (THS): The THS experimental setup was developed at the NASA Ames Cosmic simulation facility (COSmIC) to study Titan's atmospheric chemistry at low temperature. The chemistry is simulated by plasma in the stream of a pulsed, supersonic jet-cooled expansion. The unique characteristic of the COSmIC/THS is that it cools down the gas to Titan-like temperature (150 K) *before* inducing the chemistry by plasma^[1], and that the pulsed nature of the plasma allows for a truncated chemistry that can be used to study the early stages of aerosol production, which has not been readily accomplished so far using other production methods. In addition, because the COSmIC/THS uses a plasma jet expansion, the gas and solid phase products of the chemistry are accelerated to supersonic speeds before being detected and/or deposited for future analyses, which is the closest laboratory simulation of a probe descent in Titan's atmosphere. Different N₂-CH₄-based gas mixtures can be injected in the plasma, with or without the addition of trace elements present on Titan. Both the gas and solid phase products resulting from the plasma-induced chemistry can be monitored and analyzed using different *in situ* and *ex situ* diagnostics. Here we present and discuss the results of two recent, complementary studies performed on the COSmIC/THS and the important implications for the analysis of Cassini's return data.

Gas Phase Analysis: An *in situ* mass spectrometry analysis of the gas phase has demonstrated the unique advantage of the COSmIC/THS to look at the first and intermediate steps of the N₂-CH₄ chemistry, as well as potential chemical pathways in Titan's atmospheric chemistry^[2]. Due to the short residence time of the gas in the pulsed plasma discharge, only the first steps of the chemistry have time to occur in a N₂-CH₄ discharge. However by adding heavier hydrocarbon trace elements to the initial N₂-CH₄ mixture (acetylene, benzene...), we can observe a chemical growth evolution and study the intermediate steps of Titan's atmospheric chemistry. The results of this gas phase study have been compared to observational data from the Cassini Plasma Spectrometer – Ion Beam Spectrometer (CAPS-IBS) and have provided very encouraging results that illustrate the unique power of the COSmIC/THS laboratory approach to help analyze and better understand return data from Cassini's instruments.

Solid Phase Analyses: An extensive study of the solid phase products has confirmed the results of the gas phase analysis. COSmIC/THS Titan aerosol simulants deposited on a variety of substrates have been analyzed using complementary analytical techniques: infrared (IR) spectroscopy, scanning electron microscopy (SEM), nuclear magnetic resonance (NMR) spectroscopy, Direct Analysis in Real Time (DART-MS) and Electron Spray Ionization (ESI-MS) mass spectrometry, and visible reflectance spectroscopy for the determination of the aerosols' optical constants. IR spectra of N₂-CH₄ THS aerosols show the typical spectral features observed with other Titan aerosol analogs. Both DART-MS and ESI-MS spectra of THS simulants produced in a N₂-CH₄ mixture show, in agreement with the gas phase, that the THS aerosols are made of less complex molecules than other Titan simulants. SEM images show that grains are produced in volume in the expansion and then jet deposited onto the substrate. The grains produced in N₂-CH₄-C₆H₆ mixtures are much larger than those produced in N₂-CH₄ mixtures, consistent with a more complex chemistry when adding heavier precursors. The NMR results also support a growth evolution of the chemistry when adding heavier species to the initial N₂-CH₄ mixture. Finally, and more importantly, the THS aerosol's optical constants, derived from reflectance measurements in the visible, are similar to Titan aerosols' optical constants derived from observational data. Moreover, the experimental values derived from this study are closer to the observational values than any previously reported optical constants of Titan simulants produced in other experimental setups.

References: [1] Biennier et al., 2006. *Chem. Phys.* 326, 445-457. [2] Sciamma-O'Brien et al. (*submitted to Icarus*).

Acknowledgements: This research is supported by the NASA SMD Planetary Atmospheres Program. K. T. Upton acknowledges the support of the NASA JFPF Program. The SEM images were obtained at the UCSC MACS Facility at Ames (NASA grant NNX09AQ44A to UCSC). The authors acknowledge the outstanding technical support of R. Walker and E. Quigley.

Title: Venus, Earth, Xenon

Author: Kevin Zahnle

Science Topic: Planetary Atmospheres & Climate

Method: This review works well as a 15-20 minute talk, because it can be given as a series of overlays that start at a relatively simple place and then build. A poster would perforce have to show everything all at once, which could prove bewildering.

Abstract:

Despite its being the heaviest gas found in natural planetary atmospheres, there is more evidence that Xe escaped from Earth than for any element apart from helium: (i) Atmospheric Xe is very strongly mass fractionated (at about 4% per amu) from any known solar system source. This suggests fractionating escape that preferentially left the heavy Xe isotopes behind. (ii) Xe is underabundant compared to Kr, a lighter noble gas that is not strongly mass fractionated in air. (jiii) Radiogenic Xe is strongly depleted by factors of several to ~100 compared to the quantities expected from radioactive decay of primordial solar system materials. In these respects Xe on Mars is similar to Xe on Earth, but with one key difference: Xe on Mars is readily explained by a simple process like hydrodynamic escape that acts on an initially solar or meteoritic Xe. This is not so for Earth. Earth's Xe cannot be derived by an uncontrived mass fractionating process acting on any known type of Solar System Xe. Earth is a stranger, made from different stuff than any known meteorite or Mars or even the Sun.

Who is in Earth's family? Father Zeus? We do not know. Data from Jupiter are good enough to show that jovian Xe is not strongly mass-fractionated but not good enough to determine whether Jupiter resembles the Earth or the Sun. Sister Venus? Noble gas data from Venus are incomplete, with Kr uncertain and Xe unmeasured. Krypton was measured by several instruments on several spacecraft. The reported Kr abundances are discrepant and were once highly controversial. These discrepancies appear to have been not so much resolved as forgotten. Xenon was not detected on Venus. Upper limits were reported for the two most abundant xenon isotopes ^{129}Xe and ^{132}Xe . From the limited data it is not possible to tell whether Venus's affinities lie with the solar wind, or with the chondrites, with Earth, or with none of the above. Modern spacecraft mass spectrometers are at least 100-fold more sensitive to noble gases. Sending such an instrument to Venus may be the last best hope for decrypting what Earth's noble gases have been trying to tell us.

Title: Coupling the Mars Dust and Water Cycles: The Importance of Radiative-Dynamic Feedbacks During Northern Hemisphere Summer.

Authors: Melinda A. Kahre, Jeffery L. Hollingsworth, and Robert M. Haberle, Planetary Systems Branch

Topic: Planetary Atmospheres and Climate

Abstract: Temperature observations made by the Mars Climate Sounder (MCS) on board the Mars Reconnaissance Orbiter (MRO) have revealed a strong polar warming during equinoctial and winter seasons in both hemispheres (McCleese et al., 2010). Until recently, Mars Global Climate Models (MGCMs) have tended to under predict this polar warming, particularly during the equinoctial seasons over both poles and during northern hemisphere (NH) summer over the south (winter) pole. However, recent modeling studies that have included fully radiatively active aerosols—dust and water ice—are able to better represent the winter-pole thermal structure at this season due to an enhanced overturning circulation (Madeleine et al., 2012). Here we use the NASA ARC MGCM to isolate how the couplings between the dust and water cycles combine to produce the observed degree of polar warming during NH summer. Two simulations have been conducted with the MGCM: one simulation includes an interactive dust cycle (i.e., the lifting, transport, and sedimentation of radiatively active dust) and the formation of radiatively active clouds, and one simulation includes only an interactive dust cycle (Figure 1). While the simulation that does not include cloud formation predicts a polar warming that is too weak compared to observations, the simulation that includes cloud formation produces a polar warming that is in much better agreement with the observations. The enhanced polar warming in the presence of cloud formation is caused by a radiative-dynamic feedback between a strengthened circulation due to cloud radiative effects, vertical dust transport, and an even more intensified circulation.

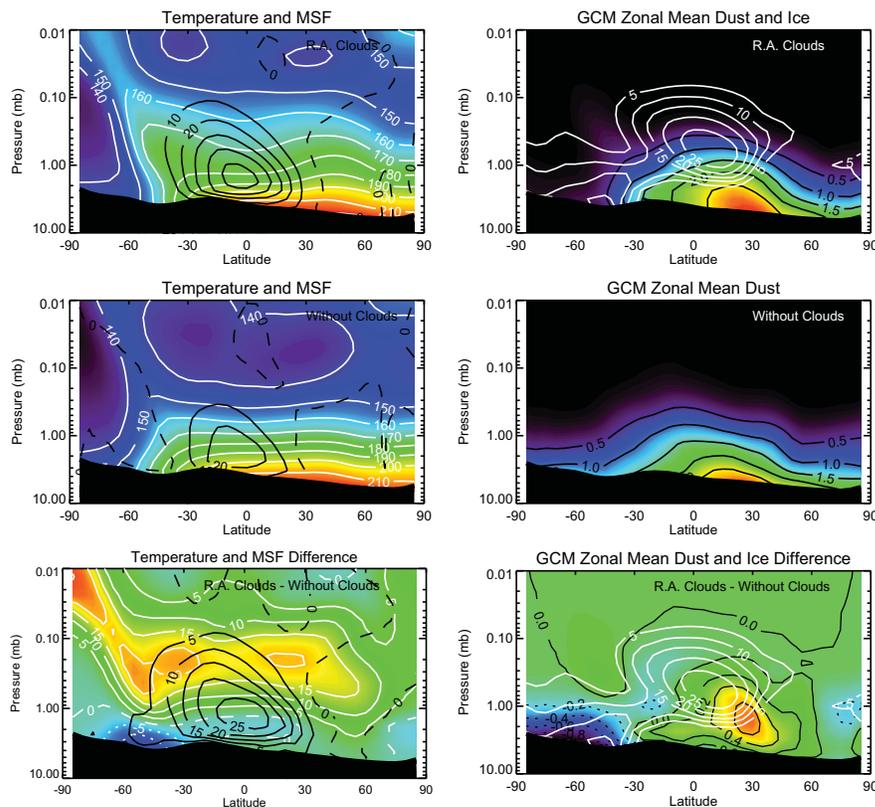


Figure 1: Temperature structure and mass stream function for the simulation with clouds (top left) and without clouds (middle left), temperature and mass stream function differences between the two simulations (bottom left), dust and cloud structure for the simulation with clouds (top right) and without clouds (middle right), and dust and cloud differences between the two simulations (bottom right).

Science Topic: Astrobiology

Implications of Clay Minerals from Gale Crater for the Habitability of Ancient Mars

^{1,2}Thomas Bristow, ²David Blake, ³David Bish, ⁴David Vaniman, ²David Des Marais, ⁵Joy Crisp and the MSL Science Team

¹SETI Institute, Mountain View, CA, ²NASA Ames Research Center, Moffett Field, CA,

³Indiana University, Bloomington, IN, ⁴Planetary Science Institute, Tucson, AZ, ⁵JPL, Pasadena, CA.

The Mars Science Laboratory (MSL) Rover, Curiosity spent ~150 sols at Yellowknife Bay (YKB) studying a section of fluvio-lacustrine sedimentary rocks informally known as the Yellowknife Bay formation. YKB lies in a distal region of the Peace Vallis alluvial fan, which extends from the northern rim of Gale Crater toward the dune field at the base of Mt Sharp. Sedimentological and stratigraphic observations are consistent with the Yellowknife Bay formation being part of a distal fan deposit, which could be as young as middle Hesperian to even early Amazonian in age (~3.5 to 2.5 Ga). The Yellowknife Bay formation hosts a unit of mudstone called the Sheepbed member. Curiosity obtained powdered rock samples from two drill holes in the Sheepbed member, named John Klein and Cumberland, and delivered them to instruments in Curiosity. Data from CheMin, a combined X-ray diffraction (XRD)/X-ray fluorescence instrument (XRF), has allowed detailed mineralogical analysis of mudstone powders revealing a clay mineral component of ~20 wt.% in each sample. The clay minerals are important indicators of paleoenvironmental conditions and recorders of post-depositional alteration processes.

The XRD patterns of John Klein and Cumberland both contain 02l bands indicative of trioctahedral phyllosilicates. A broad peak at ~10Å with a high angle shoulder indicates the presence of 2:1 type clay minerals in John Klein. The trioctahedral nature of the clay minerals, breadth of the basal reflection, and low-angle shoulder suggests that John Klein contains a trioctahedral smectite (probably saponite), whose interlayer is largely collapsed because of the low-humidity conditions. A similarly broad peak at 14Å, observed from the Cumberland sample is also consistent with trioctahedral smectite, albeit with the interlayer kept open by intercalated metal-hydroxyl groups, the result of incipient chloritization.

Our preferred explanation for the origin of trioctahedral smectites in the Sheepbed mudstone is *in situ* production via reaction of olivine, water and Si-bearing amorphous material, an important mudstone component detected by XRD. Elevated levels of magnetite in the Sheepbed mudstone and the homogeneous clay mineral assemblage support this model. These observations, combined with previous studies of olivine stability, indicate the persistence of circum-neutral aqueous conditions for thousands of years at YKB – critical evidence supporting the idea that an ancient lake in Gale Crater could have supported life.

Serpentinization and Life

Topic: Astrobiology

Tori Hoehler, Dawn Cardace, Kirsten Fristad, Mike Kubo, and Sanjoy Som

Serpentinizing systems -- in which aqueous alteration of ultramafic rocks yields highly reducing and alkaline fluids -- have been suggested as possible niches for photosynthesis-independent ecosystems on Earth and beyond. To date, most research has focused on systems characterized by extremes of pH or redox potential, and on surface expressions (e.g., springs or vents) where deeply-sourced fluids mix with the surface chemistry. To capture a broader cross-section of the geochemical diversity in serpentinizing systems, and to assess the biological potential of unmixed subsurface fluids, we established the Coast Range Ophiolite Microbial Observatory, a series of wells drilled into the actively serpentinizing subsurface of the McLaughlin Natural Reserve (Lake County, California). Observations of mineralogy and microbial community composition in cored materials, aqueous geochemistry in recovered well fluids, and biological process rates in fluids and cored materials were combined with geochemical and bioenergetic models that relate host-rock composition and hydrology to biological potential. Both modeled and observational results indicate that natural variability in serpentinizing systems can generate a broad spectrum of geochemical conditions, and correspondingly wide range of biological potential. This range of conditions appears to cross the boundary from habitable to uninhabitable with regard to biological energy requirements, tolerance to extremely alkaline pH, or both.

Science topic: Astrobiology

Flexibility of the Earliest Proteins

M.A. Wilson¹, T. H. Nguyen¹, B. Seelig² and A. Pohorille¹

¹Exobiology Branch, NASA Ames Research Center

²Dept. of Biochemistry, Molecular Biology and Biophysics, University of Minnesota

Proteins are the main functional polymers in contemporary cells, performing functions such as catalysis, energy transduction and transport across cell membranes at remarkable levels of efficiency and accuracy. However, the functional units of modern proteins are complex, raising questions such as how a simpler, ancestral system might become functional? What were the chances that a functional protein could have emerged at random? What is the minimum structural complexity for a protein to function at a reasonable level of efficiency? These and similar questions are at the core of understanding how life arose from chemistry?

The emergence of functional proteins 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 also widely accepted that compact folds are rare among random amino acid chains. How then did functional proteins begin?

One hypothesis holds that folded proteins were preceded by poorly folded, but still functional ancestors. Only recently have we obtained experimental evidence supporting this hypothesis: A small enzyme that ligates two RNA fragments with a 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 probably responsible for catalytic activity, a small, rigid core containing two zinc ions coordinated by neighboring amino acid side chains and two highly flexible tails that might be unimportant for protein function. In contrast to other proteins, this enzyme does not contain any ordered secondary structure 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 would appear to be very fragile

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 anti-amoebein, 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 anti-amoebein channel, in contrast to genomically coded, well structured channels, is extremely flexible and does not form a conventional pore. Yet, it still efficiently mediates ion transport.

These results show that highly flexible model proteins or protein assemblies are capable of carrying out the same functions that modern proteins perform. They might be the “missing link” on a continuous evolutionary trajectory between simple, but only moderately active oligopeptides and well-folded proteins similar to those found in modern organisms.

References:

Chao FA, Morelli A, Haugner JC, Churchfield L, Hagmann LN, Shi L, Masterson LR, Sarangi R, Veglia G, Seelig B (2012) Structure and dynamics of a primordial catalytic fold generated by *in vitro* evolution. *Nature Chem Biol*, Dec 9. doi: 10.1038/nchembio.1138.

Seelig B, Szostak JW (2007) Selection and evolution of enzymes from a partially randomized non-catalytic scaffold. *Nature* 448:828-831.

Second Annual Space Science and Astrobiology Jamboree on Tuesday March 4, 2014.

Title: “The SOFIA science instrument Suite: Status, Results and Plans”

Authors: Erin Smith (ARC-SSA), John Miles (USRA-SOFIA), Paul S Espinosa (ARC-PX)

Science topic: Astrophysics

Abstract: The Stratospheric Observatory for Infrared Astronomy (SOFIA) is the world’s largest airborne observatory, featuring a 2.5 meter telescope housed in the aft section of a Boeing 747sp aircraft. SOFIA’s current instrument suite includes: FORCAST (Faint Object InfraRed CAmera for the SOFIA Telescope), a 5–40 μm dual band imager/grism spectrometer developed at Cornell University; HIPO (High-speed Imaging Photometer for Occultations), a 0.3–1.1 μm imager built by Lowell Observatory; FLITECAM (First Light Infrared Test Experiment CAMera), a 1–5 μm wide-field imager/grism spectrometer developed at UCLA; FIFI-LS (Far-Infrared Field-Imaging Line Spectrometer), a 42–210 μm IFU grating spectrograph completed by University Stuttgart; and EXES (Echelon-Cross-Echelle Spectrograph), a 5–28 μm high-resolution spectrometer being completed by UC Davis and NASA Ames. A second generation instrument, HAWC+ (High-resolution Airborne Wideband Camera), is a 50–240 μm imager being upgraded at JPL to add polarimetry and new detectors developed at GSFC. SOFIA will continually update its instrument suite with new instrumentation, technology demonstration experiments and upgrades to the existing instrument suite. We detail instrument capabilities and status as well as plans for future instrumentation, including the call for proposals for 3rd generation SOFIA science instruments.

Oral Presentation: 1:35pm

Second Annual Space Science and Astrobiology Jamboree on
Tuesday March 4, 2014.

Title: "Red Dwarfs Rock! SOFIA Characterization of the Planets of Small Stars Discovered by the Kepler K2 Extended Mission"

Authors: Jeffrey Van Cleve (USRA-SOFIA) and the HIPO Team (Lowell Observatory): Ted Dunham, Georgi Mandushev, and Peter Collins

Science Topics: Exoplanets; Planetary Atmospheres & Climate

Abstract: One of the outputs of the proposed Kepler K2 extended mission -- a list of over 100 exoplanets the size of Neptune or smaller orbiting M dwarfs, with transits measured to 300 ppm photometric precision (S. Howell at Kepler Science Conference II) -- would be an excellent target list for SOFIA by mid 2015, well in advance of the catalog of ~1000 of such planets expected to be published by the TESS mission in ~2018. I present transit SNR calculations for Kepler (from my previous work), HIPO (from Dunham's radiometric spreadsheet validated by flight observations), and the public FLITECAM grism SNR estimator (W. Vacca) and outline the boundaries of planetary surface temperature, planet radius, and host star spectral type volume which can be discovered by K2, and characterized by SOFIA using HIPO and FLITECAM.

An Earth-sized planet in the habitable zone of a cool star

Elisa Quintana and the Kepler Team

Space Science and Astrobiology Jamboree
Science Topic: Exoplanets

January 25, 2014

In recent years we have seen great progress in the search for planets that, like our own, are capable of harboring life. Dozens of known planets orbit within the habitable zone (HZ), the radial annulus around a star where an Earth-like planet can sustain liquid water on its surface. Most of these HZ planets are gas giants, but a few such as Kepler-62f are potentially rocky despite being larger than Earth. Until now, the detection of an Earth-sized planet in the habitable zone of a main-sequence star has remained elusive.

We present the detection of Kepler-186f, a 1.11 ± 0.14 Earth radius planet that is the outermost of five planets - all roughly Earth-sized - that transit a star 47% the radius of our Sun. Despite receiving only one-third of the energy from its star that Earth receives from the Sun, Kepler-186f's 130-day orbit falls entirely within the habitable zone around its star. This planet likely formed from material that migrated inward before undergoing a phase of collision driven accretion and will have tidally evolved into near-perfect spin-orbit synchronization with its star. With a size comparable to Earth and an orbit within the habitable zone, Kepler-186f is a milestone discovery on the path toward finding life-bearing planets around other stars.

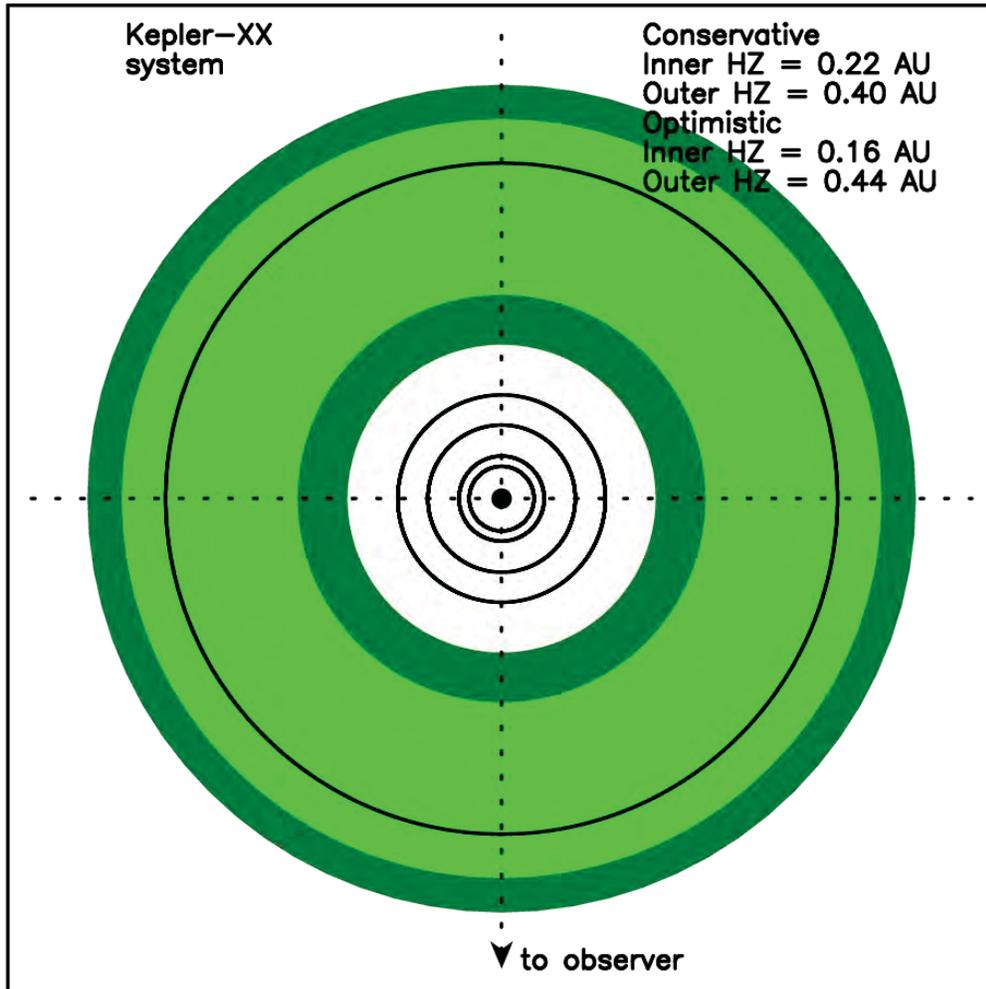


Figure 1: A top-down view of the orbits of the Kepler-186 system. The light green region represents a conservative estimate of the habitable zone. The dark green region represents an extension to the habitable zone from the optimistic model. The black concentric circles indicate the orbits of the planets computed using the maximum likelihood values. The outer planet spends 100% of its orbit within the conservative HZ.

Mark Marley

SST

Exoplanets

Understanding the Directly Imaged Planets

This year marks a shift in exoplanet discovery methods from the indirect (radial velocity, microlensing, transits) to the direct. Direct imaging methods have already uncovered a handful of young, glowing Jupiters, but in the next few months the Gemini Planet Imager on the Gemini-South telescope and SPHERE on the VLT will begin large surveys that aim to directly image dozens of such young giant planets. In order to constrain the mass, atmospheric temperature and composition of each new planet we must model its atmospheric structure and emergent spectra while accounting for clouds and chemical disequilibrium effects. As a member of the GPI Exoplanet Survey team with responsibility for planet theory, I am working to ensure that we have an adequate set of models that are up to this task. In my talk I will discuss the challenges of both modeling these objects and interpreting the limited spectral data we will receive for each planet. I will also look forward to the upcoming era of planet imaging from space and briefly consider the challenges of interpreting reflected light spectra of giant planets.

Title: Machine analysis of the interstellar PAH emission spectra with the NASA Ames PAH IR Spectroscopic Database

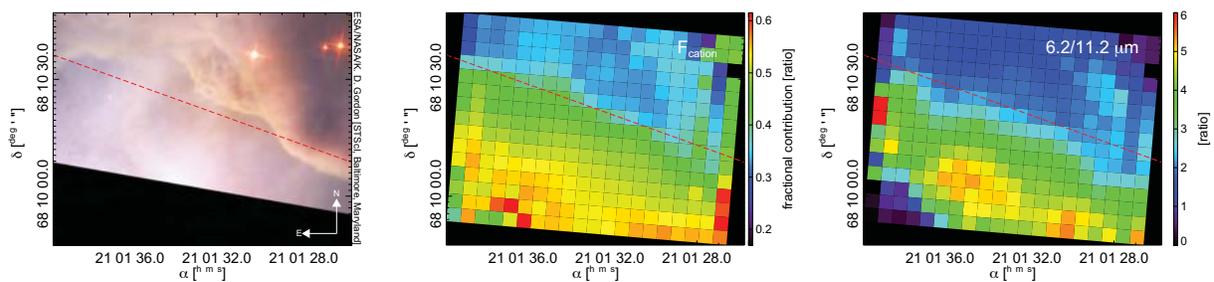
Science Topic: Astrophysics

Authors: Christiaan Boersma, Jesse D. Bregman and Louis J. Allamandola

Abstract:

Interstellar 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 to trace star formation and as redshift indicators for distant, dust obscured, galaxies, the PAH spectra still contain a wealth of untapped information. This treasure trove of information will expand enormously with the launch of JWST later this decade. With its extreme sensitivity and unprecedented spectroscopic resolution, JWST will measure PAH spectra from a wide variety of objects. The work presented here is an early step in developing tools that will help analyze these data.

Here, PAH emission in the *Spitzer*-IRS spectral map of the northwest photon dominated region (PDR) in the Iris nebula was analyzed using exclusively PAH spectra and tools of the NASA Ames PAH IR Spectroscopic Database (<http://www.astrochem.org/pahdb>). The 5–15 μm spectrum at each pixel was fitted using an algorithm driven, non-negative least-squares fitting approach. The fits are of good quality, providing 2D-maps of the region that show spatial evolution of PAH subpopulations broken down by size, charge, and composition. These maps paint a coherent astrophysical picture and are able to trace the subtle changes in morphology, radiation field, PDR boundary, etc. The boundary between the PDR and the denser cloud material shows up as a distinct discontinuity in the breakdown maps. The data were also analyzed using a more traditional approach in which the PAH bands are isolated and their strengths measured without regard of their molecular origin. Traditionally, band strength ratios are considered proxies for different aspects of the state of the PAH population, e.g., charge, size, structure and composition. Combining these data with the results from the database fits allows the first quantitative calibration of PAH proxies and makes a direct link with astrophysical conditions.



Left: Composite *HST* image of the northwest photon dominated region (PDR) in the Iris nebula. PAH emission originates from the entire region. The PDR straddles the boundary between the molecular cloud material (top) and the diffuse medium (bottom) and is highlighted by the red dashed line, reproduced across all maps. **Middle:** Fractional contribution from PAH cations to the total PAH emission as determined with an algorithm driven, machine analysis of the *Spitzer* spectral maps using the spectra and tools of the NASA Ames PAH IR Spectroscopic Database. **Right:** Distribution of the 6.2/11.2 μm PAH band strength ratio, typically considered a proxy for PAH charge. Note the similarity between the map in the middle and the one to the right.

Title: The Impact of Dust Grain Growth on Protoplanetary Disk Evolution and Photoevaporation

Authors: Uma Gorti (ARC/SETI), D. Hollenbach (SETI), C. Dullemond (Univ. of Heidelberg)

Science Topic: Astrophysics

Abstract

Protoplanetary disks are dispersed by viscous evolution and photoevaporation in a few million years, before which small sub-micron sized dust grains must grow and form planets. The evolution of dust via grain growth lowers disk opacity and significantly increases the penetration of far-ultraviolet photons into the disk, heating denser gas to higher temperatures and affecting photoevaporation rates. Photoevaporative flows, in turn, selectively carry small dust grains leaving the larger particles—which decouple from the gas—behind in the disk. We investigate the evolution of a disk subject to viscosity, photoevaporation, dust evolution and radial drift using a 1-D multi-fluid approach (gas + different dust grain sizes) to solve for the evolving surface density distributions. At each epoch, 1+1D models are constructed on the fly to obtain the instantaneous disk structure and the photoevaporation rates. Dust evolution is found to decrease disk lifetimes due to FUV photoevaporation by enhancing mass loss rates. We find significant enhancements in the gas/dust ratio in the inner planet-forming regions of the disk, with implications for theories of planetesimal formation.

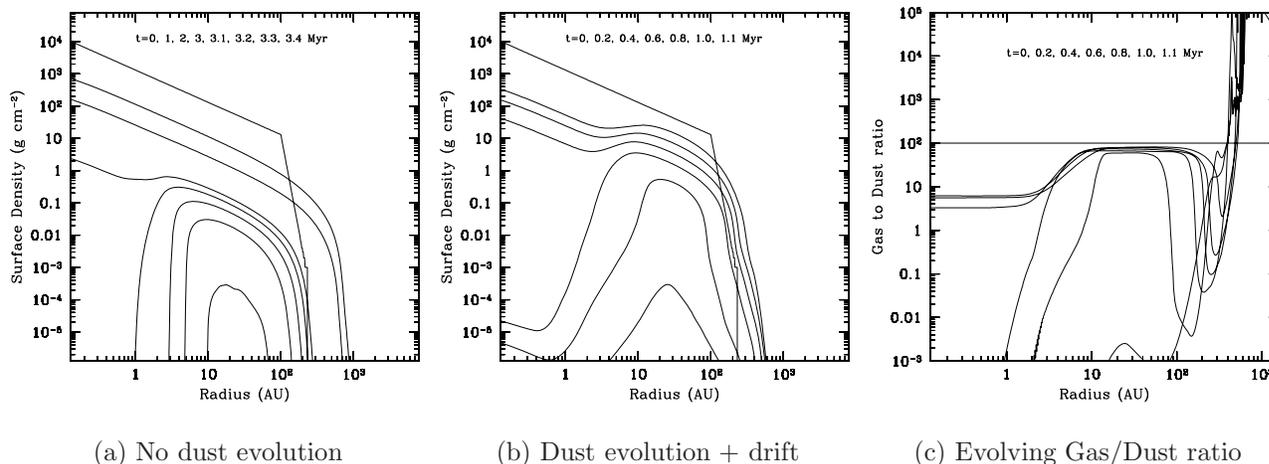


Figure 1: (a) The surface density evolution with radius for a reference disk model with a constant power-law dust distribution ($n(a) \propto a^{-3.5}$; $0.01\mu\text{m} < a < 1\text{cm}$) is shown. The disk expands viscously (α parameter set to 0.01) and photoevaporates due to EUV, FUV and X-ray photons. A gap opens at 1AU at ~ 3 Myrs due to photoevaporation and the disk dissipates rapidly thereafter. (b) The surface density evolution of a disk in a 2-fluid model where dust grains evolve due to fragmentation and coagulation, and are subject to radial drift and gas de-coupling. Dust evolution shortens the disk lifetime. (c) The gas/dust ratio in the disk also evolves with time due to selective photoevaporation of small dust grains and due to radial drift, creating conditions in the inner disk that favor planetesimal formation.

Talk request for SS / Astrobio Jamboree, March 4, 2014

Title: Getting protostars to talk: Applying enhanced interrogation techniques

Authors: Tom Greene (NASA ARC) and Mary Barsony (SETI Institute)

Topic: Astrophysics

Abstract:

Astronomers are still working on an age-old question: How did the Sun and its planets form? Our Milky Way galaxy still forms several stars per year, so we can address this question by observing nearby stars in the process of formation.

The effective temperatures and sizes of these protostars could be determined from visible light or near-infrared spectra. This has been worked out for adult stars (on the stellar Main Sequence, like the Sun) over the past century by identifying molecular and atomic absorptions that are sensitive to ionization (temperature) and pressure. Mass, gravity, and evolutionary status of stars can then be determined from theoretical models.

Observing protostars is not easy. Stars form in immense (radius $\sim 3 \times 10^{15}$ m) cores of gas and dust embedded within even bigger clouds that are at least 400 light years (4×10^{18} m) distant. Star forming cloud cores are composed of about 99% gas and 1% dust, and the dust is thick enough to dim the visible light of protostars by 10^{400} . This prevents any visible light from directly escaping.

However, all is not lost. During the past decade, the Spitzer Space telescope found that some protostars are 10 - 100 times brighter at near-infrared wavelengths (3 - 8 microns) than expected from their dusty surroundings. This brightening is likely enabled by small holes or asymmetries in the dusty cocoons surrounding protostars, allowing some light to escape via scattering in our direction.

We have taken advantage of such a favorable situation in the protostar S68N in the Serpens molecular cloud. This young star is known to be very bright at sub-millimeter wavelengths (sensitive to dust with $T \sim 30$ K), and it has yet to accumulate the majority of its final mass (a Class 0 protostar). Figure 1 shows that it is also very faint but not invisible at near infrared wavelengths. We are using the Keck II telescope in Hawaii to acquire its near-infrared spectrum, and I will explain what that spectrum is telling us about its physical conditions. This is the first time a Class 0 protostar has been observed in such detail, and I intend to observe more with the James Webb Space Telescope after its 2018 launch.

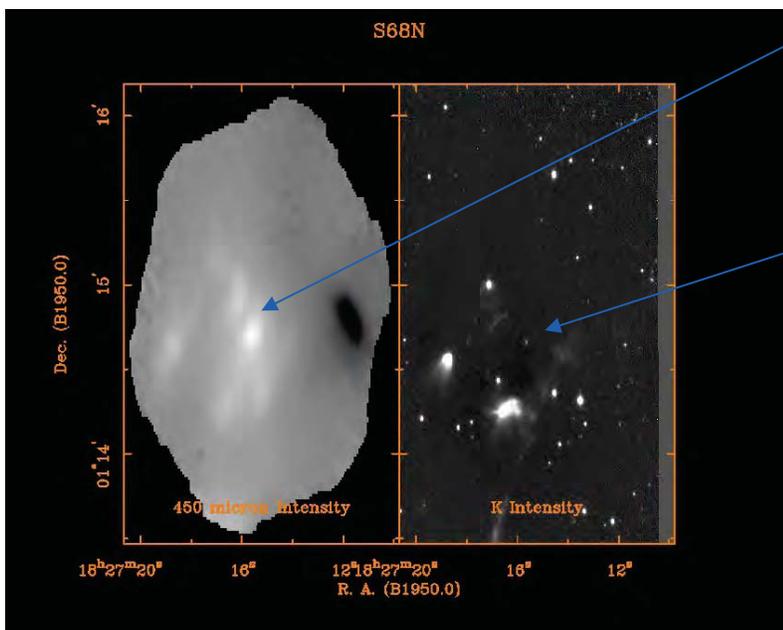


Figure 1: Sub-millimeter and near-infrared images of the Serpens S68N protostar. The left image shows that the protostar is bright at 450 microns wavelength as seen near the image center. The right panel is the K-band image at about 2 microns wavelength, 4 times redder than the eye can see. The protostar is very faint ($K \sim 17$ mag) but detectable. Figure from Wolf-Chase et al. (1998).

Title: Saturn's Rings
Jeff Cuzzi

Abstract:

Saturn and its amazing rings have been under study by Cassini for nearly a decade now. I'll give an overview of ring composition, structure, and dynamics, with highlights from what Cassini has learned in that time, including some connections with processes thought to operate in protoplanetary disks. I'll discuss some of the most important outstanding problems, and how they relate to the origin and evolution of the rings. Finally, I'll give a quick preview of what Cassini still hopes to accomplish before the mission ends (if all goes well) in 2017. For background see <http://adsabs.harvard.edu/abs/2010Sci...327.1470C>.

Photosynthetic Microbial Mats are Exemplary Sources of Diverse Biosignatures

David J. Des Marais and Linda L. Jahnke, Exobiology Branch, Ames Research Center

Marine cyanobacterial microbial mats are widespread, compact, self-contained ecosystems that create diverse biosignatures and have an ancient fossil record. Within the mats, oxygenic photosynthesis provides organic substrates and O₂ to the community. Both the absorption and scattering of light change the intensity and spectral composition of incident radiation as it penetrates a mat. Some phototrophs utilize infrared light near the base of the photic zone. A mat's upper layers can become highly reduced and sulfidic at night. Counteracting gradients of O₂ and sulfide shape the chemical environment and provide daily-contrasting microenvironments separated on a scale of a few mm. Radiation hazards (UV, etc.), O₂ and sulfide toxicity elicit motility and other physiological responses. This combination of benefits and hazards of light, O₂ and sulfide promotes the allocation of various essential mat processes between light and dark periods and to various depths in the mat. Associated nonphotosynthetic communities, including anaerobes, strongly influence many of the ecosystem's overall characteristics, and their processes affect any biosignatures that enter the fossil record. A biosignature is an object, substance and/or pattern whose origin specifically requires a biological agent. The value of a biosignature depends not only on the probability of life creating it, but also on the improbability of nonbiological processes producing it. Microbial mats create biosignatures that identify particular groups of organisms and also reveal attributes of the mat ecosystem. For example, branched hydrocarbons and pigments can be diagnostic of cyanobacteria and other phototrophic bacteria, and isoprenoids can indicate particular groups of archaea. Assemblages of lipid biosignatures change with depth due to changes in microbial populations and diagenetic transformations of organic matter. The ¹³C/¹²C values of organic matter and carbonates reflect isotopic discrimination by particular microorganisms as well as networks of C flow within mats; thus they offer insights about community structure. For example, relative ¹³C/¹²C values of individual lipid biosignatures can indicate trophic relationships between key groups of microorganisms. Mat microenvironments can affect the stability of authigenic minerals and alter the chemical compositions and crystal forms of carbonate, sulfate and metal oxide minerals. Interactions between low molecular weight organic compounds and sulfides in mat pore waters can produce alkyl sulfide gases. Processes associated with these physically coherent biofilms can trap and bind detrital grains, enhance mineral precipitation or dissolution, and stabilize sediment surfaces. Accordingly mats can create distinctive sedimentary fabrics and structures. Stromatolites are the most ancient, widespread examples of such fabrics and structures. Thus photosynthetic microbial mats create diverse biosignatures that, when preserved in the geologic record, can help to identify the former presence of key populations of microorganisms and reveal key processes that occurred within ancient mats as well as the interactions between those ecosystems and their environment.

Science topic: Astrobiology

Lipid biomarker production and preservation in acidic ecosystems: Relevance to early Earth and Mars

Niki Parenteau¹, Linda Jahnke², Thomas Bristow², Sandra Siljeström³, Megan Carlson⁴, Rachel Harris⁵, Jack D Farmer⁶, David Blake², David Des Marais²

¹SETI Institute, Mountain View, CA, ²NASA Ames Research Center, Moffett Field, CA, ³SP Technical Research Institute of Sweden, Borås, Sweden, ⁴Santa Clara University, Santa Clara, CA, ⁵Wellesley College, Wellesley, MA, ⁶Arizona State University, Phoenix, AZ

Compared to relatively benign carbonate buffered marine environments, terrestrial Archean and Paleoproterozoic life was forced to cope with a broader range of pH values. In particular, acidic terrestrial ecosystems arose from the oxidation of reduced species in hydrothermal settings and crustal reservoirs of metal sulfides, creating acid sulfate conditions. While oxidation of reduced species is facilitated by reactions with molecular oxygen, acidic conditions also arose in Archean hydrothermal systems before the rise of oxygen (Van Kranendonk, 2006), expanding the range of time over which acidophiles could have existed on the early Earth. Acidic terrestrial habitats would have included acidic hydrothermal springs, acid sulfate soils, and possibly lakes and streams lacking substantial buffering capacity with sources of acidity in their catchments.

Although acidic hot springs are considered extreme environments on Earth, robust and diverse microbial communities thrive in these habitats. Such acidophiles are found across all three domains of life and include both phototrophic and chemotrophic members. In this study, we characterize organic compounds (lipid biomarkers) produced by microbial communities living in acidic springs in Yellowstone and Lassen Volcanic National Park. We also examine the taphonomic processes governing the preservational fate of these lipids in mineral deposits. In particular, we discuss the capture and retention of hopanoids and sterols in the following geological/mineralogical settings: 1) rapid entombment of microbes and organic matter by predominantly fine-grained silica; 2) rapid burial of organic matter by clay-rich, silica poor sediments; 3) and the survival of organics in iron oxide and sulfate rich sediments.

It is critical to couple the lipid biomarker studies to a mineralogical characterization of the system to determine whether the compounds survive the recrystallization of the primary aqueous mineral precipitates to more thermodynamically stable phases, and to determine which types of minerals are best at preserving organics. We do this using a coupled mineralogy – organics analysis package such as is used on the Curiosity Rover (CheMin – the SAM GC-MS). In addition to using a conventional GC-MS, we have also explored other methods of organic analyses, namely *in situ* techniques that don't require sample preparation, such as time of flight secondary ion mass spectroscopy (ToF-SIMS). On Curiosity, this coupled mineralogy – organics package is powerful in assessing past or present habitability by identifying aqueous environments and chemistry relevant to life. We employ this same approach in modern hot springs, because hydrothermal processes associated with volcanism are common features of ancient habitable environments on Earth, and have been inferred for ancient Mars as well. Understanding the preservation of organics in modern hydrothermal settings thus helps inform the detection of these compounds in the ancient sedimentary record on Earth, and perhaps Mars. Van Kranendonk MJ (2006) . Earth-Science Reviews 74, 197-240.

Lake Untersee Antarctica: a model for Europa and Enceladus

Dale Andersen, SETI Institute; Christopher P. McKay NASA Ames
Science Scope: Astrobiology

In the outer Solar System there are two worlds that potentially have liquid water beneath surfaces of ice: Europa and Enceladus.

Europa is a large moon of Jupiter thought to be composed of a metallic core surrounded by a rocky interior and a global ocean beneath a thick (likely 20 ± 10 kilometres) shell of water ice. Enceladus is a small icy moon of Saturn, with a radius of only 252 km. Cassini data has revealed about a dozen or so jets of fine icy particles emerging from the south polar region of Enceladus. The jets have also been shown to contain simple organic compounds. Salt-rich ice particles were found to dominate the lower parts of the plume. These data strongly imply that a salt-water reservoir with a large evaporating surface is the source of the plume. Thus, it is likely that a liquid water environment exists beneath the south polar cap of Enceladus which may have been a site for the origin of life plausible ecosystems might exist

Analogues for Europa and Enceladus --- water habitats sealed with a permanent ice-cover --- are rare. Indeed, these are only known from the Antarctic. Here we report on a perennially ice-covered lake in the mountains of Queen Maud Land in East Antarctica, Lake Untersee ($71^\circ 20'S$, $13^\circ 45'E$, elevation 563 m). The lake occupies a basin dammed by the terminus of the Anuchin Glacier and has a 3 meter ice cover but does not form a summer moat. The lake is recharged by subaqueous melting of the glacier that intrudes into the northern end of the lake. Lacking significant surface meltwater input, and lacking a moat, this lake is tightly sealed from the environment except for the penetration of sunlight through the ice cover (6%). This results in a unique set of environments, in particular high pH (10.4), a deep anaerobic zone containing dissolved methane at a level >20 mmol/l (Wand *et al.* 2006), and the formation of modern, large conical stromatolites (Andersen *et al.* 2011). The exploration of Lake Untersee can provide important science returns on the physics and biology of ice-covered habitats; thus, providing a science and technology model for exploring Europa and Enceladus as well as providing astrobiology insights into life in virtually closed ice-sealed ecosystems.

References

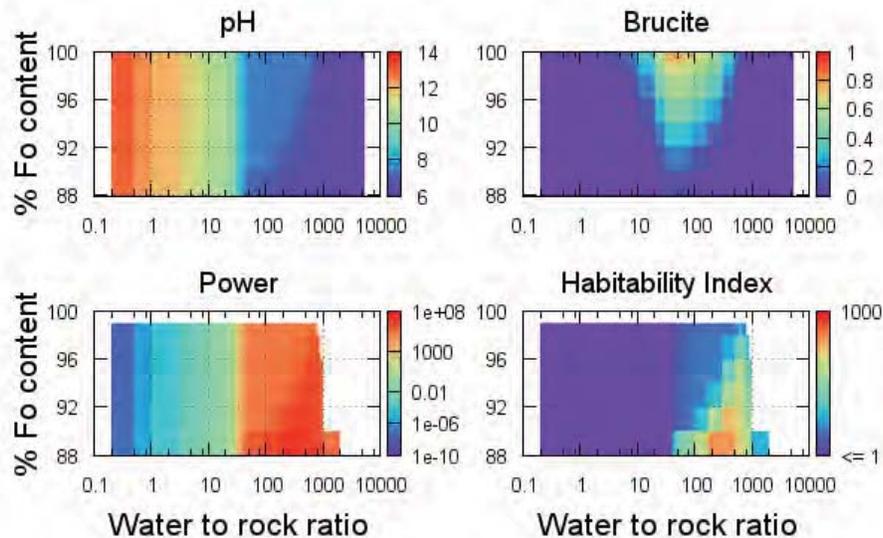
- Andersen, D. T., Sumner, D. Y., Hawes, I., Webster-Brown, J. and McKay, C. P. (2011), Discovery of large conical stromatolites in Lake Untersee, Antarctica. *Geobiology*, 9: 280–293.
- Wand U, Samarkin V, Nitzsche, H, Hubberten, H (2006) Biogeochemistry of methane in the permanently ice-covered Lake Untersee, central Dronning Maud Land, East Antarctica. *Limnology and Oceanography* 51, 1180–1194.

Habitability redefined: don't forget biological requirements!

Sanjoy Som and Tori Hoehler, Code SSX

Science topic: Astrobiology

Assessment of Gibbs Free Energy change (ΔG) alone is not sufficient to robustly assess habitability. Microbes require a minimum maintenance energy - the energy spent by cells to fix what the environment damages - in addition to any excess energy for growth. This maintenance energy requirement is expected to vary with environmental conditions, such as temperature and pH. From this, we define a habitability index as the ratio of the catabolic energy yield available through metabolism (H₂-consuming methanogenesis is considered in the present example) to the energy required for maintenance for the microbe and physicochemical environment in question. As such, it is both the energy made available by geochemistry and the energy required for biochemistry that define habitability. To efficiently investigate a large array of environmental parameters and their effect on habitability, we numerically couple a geochemical model of water-rock interaction (e.g., serpentinization) with that of single-cell methanogenesis and compute a habitability index for the given environment. In particular, we investigate the control that temperature, rock composition, water composition and water to rock ratio (dilution) has on biological potential.



Top row: pH and Brucite (Mol) produced by the serpentinization reaction where $T_{\text{serp}} = T_{\text{bio}} = 100^\circ\text{C}$ with varying water to rock ratio and %Fo content in the rock. Bottom row: Biological power production: energy released by the production of methane and Habitability Index (HI), where $\text{HI} = \text{Power} / \text{Maintenance_Energy}$.

Topic: Astrobiology

Hydrogen Production and Habitability in Non-ultramafic Geologic Systems

K. E. Fristad and T. M. Hoehler, Ames Exobiology Branch (SSX)

Dihydrogen (H_2) is a nearly ubiquitous product of water-rock interaction and is potentially an important reductant and source of energy for early life on Earth, for the rock-hosted deep biosphere, and for life beyond Earth. Previous studies on deep-sea hydrothermal vent systems suggest that H_2 produced by water-rock interaction feeds microbial ecosystems. However, such studies represent a small corner of physicochemical space where conditions are highly favorable for H_2 production. Dihydrogen (H_2) can be lithogenically produced by the hydrolytic oxidation of the ferrous iron component in Fe-bearing minerals as well as by radiolytic cleavage of water by α , β , or γ radiation produced during the decay of radioactive isotopes. Initial work on lithogenic H_2 production has focused on ultramafic serpentinization, as it is occurring on Earth, is known to have occurred on Mars, and is likely occurring on icy satellites such as Europa. Lithogenic H_2 production mechanisms, however, can operate across a range of rock types thus increasing the diversity of potential habitats on planetary bodies.

In order to assess the potential importance of H_2 -based metabolisms in geologic environments other than serpentinizing systems, a field sampling campaign was undertaken in 2013 to assess the variation in lithogenic H_2 abundance across a range spring waters hosted in non-ultramafic rocks. Aqueous H_2 concentrations were measured in spring waters across the western U.S. at sites including Yellowstone National Park, Lassen Volcanic National Park, Idaho Batholith, Oregon Cascades, and California's Long Valley Caldera. The springs at these sites are hosted in rocks ranging in composition from mixed alluvial sediments to rhyolite to andesite to basalt. Sampling of dissolved gases was accompanied by measurements of physicochemical parameters including pH, temperature, dissolved inorganic carbon, and major ion chemistry. Aqueous hydrogen concentration from this survey reveals that dissolved hydrogen concentration can vary across several orders of magnitude irrespective of host rock type, and absolute values overlap those found in serpentinizing ultramafic systems (Figure 1). Thus, this initial survey suggests the possibility for supporting H_2 -based metabolisms in a range of geologic environments beyond ultramafics.

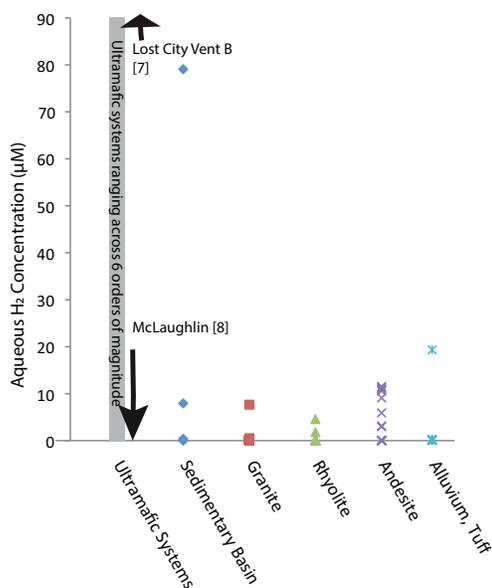


Figure 1. Aqueous H_2 concentration in μM across a range of host rock compositions based on 2013 field measurements. Hydrogen is found in comparable concentrations across a range of rock types.

Elucidation of Biohydrogen Production in Hypersaline Microbial Mats Leads to a Focus on the Role of Photosynthate and Carbon Storage

Jackson Z. Lee^{*a}, Rhona K. Stuart^b, R. Craig Everroad^a, Luke Burrow^a, Dagmar Woebken^a, Angela M. Detweiler^a, Mike D. Kubo^a, Tori M. Hoehler^a, Whitney Stannard^b, Leslie E. Prufert-Bebout^a, Xavier, Mayali^b, Jennifer Pett-Ridge^b, Michael Thelen^b, Peter K. Weber^b, Brad M. Bebout^a

Science Topic: Astrobiology, Display type: Poster

^aExobiology Branch, NASA Ames Research Center, ^bLawrence Livermore National Laboratory

Hypersaline cyanobacterial mats are diverse laminated microbial assemblages, thought to represent life on the early earth. Since these systems orchestrate cycles of carbon, oxygen, sulfur, and nitrogen on a millimeter scale, they are an ideal model system for 'omics and labeled isotope studies of biogeochemical cycling and microbially mediated energy flows, particularly biohydrogen. However, the mechanisms and magnitude of hydrogen cycling have not been extensively studied these systems. A systems-level understanding of the partitioning of light and geochemical energy into biomass in microbial mats was therefore the goal of this joint NASA-DOE collaboration.

Mats from Guerrero Negro, Mexico -- permanently submerged *Microcoleus* microbial mats (GN-S), *Lyngbya* intertidal microbial mats (GN-I) -- were used in microcosm diel manipulation experiments (with ammonium chloride) to determine mechanisms responsible for hydrogen cycling between mat microbes. H₂ production occurred under dark anoxic conditions with simultaneous production of a suite of organic acids. H₂ production appears to result from constitutive fermentation of photosynthetic storage products (glycogen) over the day night cycle. Fermentation released a majority (~90%) of the carbon fixed via photosynthesis during the preceding day, primarily as organic acids. Incubation with ¹³C-acetate and nanoSIMS (secondary ion mass-spectrometry) indicated higher uptake in both *Chloroflexi* and SRBs relative to other filamentous bacteria. These manipulations and diel incubations confirm that *Cyanobacteria* were the main fermenters in Guerrero Negro mats and that the net flux of nighttime fermentation byproducts (mostly acetate) was largely regulated by the interplay between *Cyanobacteria*, SRBs, and *Chloroflexi*.

These data suggest that light energy partitions primarily into the *Cyanobacteria* as stored glycogen photosynthate, and is then released into EPS (extracellular polymeric substance), perhaps as organic acids at night. A series of experiments underway will examine how this photosynthate is partitioned and the fate of carbon released into extracellular space. Analyses of the genome of ESFC-1-- a member of a newly described lineage of filamentous diazotrophic cyanobacteria important in the Elkhorn Slough system -- was used to identify EPS proteins and characterized EPS composition in both ESFC-1 and Elkhorn Slough mats. The most abundant of the extracellular proteins are predicted to be involved in protein and sugar degradation and putative structural components. This suggests that cyanobacteria may facilitate carbon transfer to other groups through degradation of their EPS components. To tease apart which organisms were responsible for glycogen formation and storage and which organisms were involved in organic acid uptake, a combined metagenomic / metatranscriptomic study was completed to track the transcript response of mat-associated organisms over the course of a day as energy passed from sunlight into fixed carbon and nitrogen and subsequently into nighttime fermentation products. A total of 4 metagenomes and 9 metatranscriptomes (over 9 time points of the day) were sequenced and are in progress.

Understanding the carbon and hydrogen flow in constructed H₂-producing microbial mats and co-cultures

R. Craig Everroad, Yongqin Jiao, Ali Navid, Jackson Z. Lee, Angela M. Detweiler, Benjamin J. Stewart, James B. McKinlay, Michael P. Thelen, Leslie Prufert-Bebout, Brad M. Bebout, Jennifer Pett-Ridge

Science Topic: Astrobiology, Display type: Poster

Microbial mat communities are analogs of ancient Earth communities, and so are of great astrobiological interest as the communities within which microbial and metabolic diversity evolved. Microbial mat communities have multiple pathways for energy conversion and nutrient transfer. The goal of this work is to develop genome-level models of carbon and energy flow within simplified microbial communities, with H₂ production as a metric for monitoring the overall state of the system. In order to develop a defined ecosystem and to study the metabolic interactions between members of the community in detail, we have begun isolating and characterizing microbial mat community members from the intertidal mats of Elkhorn Slough, CA. We have successfully isolated all major functional groups of the mat ecosystem, as well as the vast majority of the 15 most abundant taxa as determined by metagenomics analysis. Interactions in mixed cultures containing 2 or more different functional groups have resulted in the construction of a stable light-driven biological sulfur-cycle, and the construction of cyanobacterial/fermentative co-cultures with high potential for H₂-production.

We have also constructed an artificial co-culture containing *Clostridium cellulolyticum* H10 (CC) and the purple bacterium *Rhodospseudomonas palustris* CGA676 (RP) for H₂ production based on cellulose degradation. To understand this syntrophic metabolism, we examined and compared the kinetics of cellular growth, H₂ production, and metabolite production/consumption in the mono- and co-cultures. Both organisms have been fully sequenced, thus this co-culture is an ideal way to begin to understand the genomic underpinnings of syntrophic interactions. We investigated change in expression of CC genes when co-cultured with RP using microarrays. A number of the observed up-regulated genes are involved in translation, replication and cellulose breakdown, consistent with our observation of higher growth rate of CC under co-culture compared to the monoculture conditions. In addition, we observed significant increase in expression of a pyruvate kinase (16 fold) and a lactate dehydrogenase (8 fold), suggesting that CC produces more pyruvate and lactate in the co-culture compared to the monoculture.

We have also developed a system-level model of metabolism in RP and used this model to examine the modes of metabolism most conducive to H₂ production. The model's predicted behaviors have been compared with experimental observations to ensure accuracy. Our results indicate that H₂ production is closely linked with production of CO₂. Carbon fixation results in reduced production of H₂. Consumption of carbon sources like ethanol and acetate result in greater production of H₂ compared to compounds like pyruvate. Overall, since H₂ production is inversely linked to carbon fixation/conservation, increased H₂ yield adversely affects cellular growth.

Through the systems biology studies of these simplified co-cultures for hydrogen production, we have gained insights into key metabolic interactions and population dynamics in such co-cultures that are critical for improvement of syntrophic efficiency and H₂ productivity.

Title: Salt Crust Ecology as a function of seasonal change
Authors Heather Smith
Science Topic: Astrobiology

Abstract:

We investigate the adaptation and evolution of microbes to environmental changes, in particular those experienced with annual seasonal climate changes. It is unknown whether the microbial response to changes is cyclic, or evolves over time, or how the community structure changes in response changes in environmental parameters affecting the physical matrix supporting the community. For this research we measure the changes in microbial activity, by measuring the changes in photosynthetic response, as changes in seasonal conditions (light, salinity, oxygen, water) occur. We also measured the adaptation of the halophiles when exposed to simulated Mars conditions (temp, UV, pressure, etc). Our study site to investigate these interactions is the salt crust of the San Francisco National Wildlife refuge salt ponds.



Figure 1 The microbial ecology of the salt crust - black, green, and pink stratified layers of photosynthetic organisms (shown above) vary with depth as a function of seasonal conditions.

Expanding the environments of RNA *in vitro* evolution

Milena Popović and Mark A. Ditzler

Astrobiology

Prominent among the various models of the origin and early evolution of life is that of the RNA world. The RNA world hypothesis proposes that RNA molecules played a much larger role in early biology than they do now by acting as both the repository of genetic information and the dominant biocatalyst. Many features of the modern cell are potential fossils of the RNA world, such as the involvement of nucleotides in coenzymes, the existence of natural aptamers that bind these coenzymes, natural ribozymes, a biosynthetic pathway in which deoxynucleotides are produced from ribonucleotides, and the essential role of ribosomal RNA in protein synthesis. *In vitro* evolution of RNA offers insight into the potential roles of RNA in the very early evolution of life. However, ribozymes generated by this method are often exceedingly slow catalysts, and can involve structurally complex motifs that occur rarely in sequence space (all possible sequences of a given length). These ribozymes are usually evolved in the presence of millimolar concentrations of magnesium, at neutral pH. Many aspects of the environment of the early Archean eon in which life emerged are likely not represented by these “standard” conditions (*e.g.* none of these *in vitro* evolution experiments have been carried out in the absence of O₂). Fe²⁺, which is not included in standard *in vitro* evolution experiments, was abundant on the early earth. Fe²⁺ was likely used by RNA for folding and chemistry, and it has been suggested that magnesium took the place of iron with the rise of oxygen and subsequent drop in soluble iron. In an attempt to explore the potential impact of Fe²⁺ on the fitness landscape (functional capacity of all nucleotide sequences within a given selective environment), we have evolved self-cleaving ribozymes in an anoxic atmosphere and varying pH and metal ion composition. We show that Fe²⁺ substitutes for Mg²⁺ in self-cleaving reactions in a pH-dependent manner. Ribozymes evolved in the presence of Mg²⁺ at acidic conditions (pH 5) do not cleave in the presence of Fe²⁺ at pH 5; however, when the pH is raised to neutrality this population not only remains active in Mg²⁺ but also exhibits an even higher level of cleavage with Fe²⁺. Conversely, Mg²⁺ does not support activity of a population evolved in the presence of Fe²⁺ at either pH. These findings imply that iron can support the catalytic function of a larger number of RNA sequences than magnesium. The shape of RNA fitness landscapes can therefore be identified comprehensively only in the context of a variety of metal ions, ligands, and specific chemical environments. Our results suggest the possibility of new or enhanced capabilities for the RNA catalyst under “non-standard” conditions with implications for the role of RNA in the earliest life.

Precursors to the citric acid cycle and metabolism: A mechanistic investigation on the formation of some key metabolic intermediates detected in carbonaceous meteorites.

Andro C. Rios, NASA Postdoctoral Program Fellow, Oak Ridge Associated Universities

George Cooper, NASA Ames Research Center

Science Topic: Astrobiology

Abstract: The citric acid cycle is central to cellular metabolism. It is responsible for processing chemical energy and using intermediary metabolites as synthetic precursors for bio-molecular building blocks. A fundamental question to the origin of life problem is to understand how metabolism emerged in the prebiotic environment. It is thought that cycles related to that of the citric acid may have spawned a primitive metabolism. Previous work reported from our laboratory has included the detection of many citric acid cycle intermediates in carbonaceous meteorites. Carbonaceous meteorites are likened to time-capsules and are the only practical way to directly sample the organic chemical composition at the time of, or before, the origin of Earth and for prebiotic chemistry. The work we are doing is rooted in the search to explain the prebiotic origin of metabolic intermediates in a citric acid cycle predecessor. We previously reported that pyruvate (a citric acid cycle precursor) alone could lead to the formation of a vast majority of key metabolic intermediates (see Figure 1) but how such abiotic reactions proceed without the action of enzymes are unknown. Detailed investigations are being pursued to elucidate the chemical mechanisms of pyruvate chemistry leading to oxaloacetate, malate and fumarate under the reported conditions in addition to assessing their steady state abundance over extended periods of time. This work includes both synthetic and analytical experimentation to investigate the scenario that pyruvate may have been the progenitor to key metabolic intermediates on the early Earth.

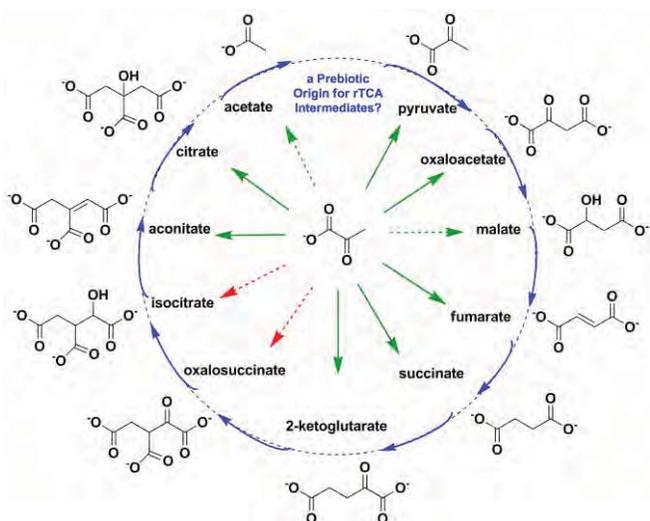


Figure 1. From alkaline solutions of pyruvate, most of the metabolic intermediates associated with the TCA cycle are produced non-enzymatically. The solid arrows in green are species that have been definitively detected in pyruvate only alkaline mixtures. The hashed green arrows are tentative assignments, or implied presence. The hashed red arrows are species not yet detected.

Photo-Induced Deuterium Enrichment in Residues Produced from the UV Irradiation of Pyrimidine in H₂O Ices

Michel Nuevo^{1,2,*}, Scott A. Sandford¹, and Jamie E. Elsila³

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Organic compounds found in meteorites often show isotopic signatures of their interstellar/protosolar heritage as enrichments in D and ¹⁵N. Meteoritic organics found to be enriched in D include amino acids, hydroxy and dicarboxylic acids, as well as polycyclic aromatic hydrocarbons (PAHs) and polycyclic aromatic nitrogen heterocycles (PAHNs). Processes that can produce isotopic enrichments in presolar/protosolar materials include gas-phase ion–molecule reactions, gas–grain surface reactions, and unimolecular photo-dissociation reactions involving PAHs. Because many molecules in interstellar clouds are enriched in D, the presence of D anomalies in meteorites is thought to originate from preserved or slightly altered interstellar/protostellar materials. However, the link between isotopic enrichments seen in space and those in meteoritic compounds and their relationship remain unclear.

In this work, we present results of hydrogen isotopic fractionation for compounds in organic residues produced from the UV irradiation using an H₂-discharge UV lamp of a series of H₂O:pyrimidine = 20:1 ice mixtures at low temperature (< 20 K). After irradiation, the resulting residues are dissolved in H₂O and analyzed with gas chromatography–mass spectrometry coupled with isotope ratio mass spectrometry (GC-MS/IRMS),¹ following a protocol similar to that used for previous analyses of comparable samples.^{2,3} We used this technique to measure compound-specific D/H isotopic ratios for the initial pyrimidine and H₂O, as well as for two photo-products present in the residues whose masses are consistent with bipyrimidine isomers with structures other than that of 2,2'-bipyrimidine.²⁻⁴ Measuring D enrichments in bipyrimidines has the advantage that the H atoms on these molecules are not easily exchangeable with other compounds, in particular the H₂O of the starting ices or the H₂O solvent used to extract the samples for GC-MS/IRMS measurements.

The δD value for the initial pyrimidine and H₂O used to prepare our ices, measured with a high-temperature conversion elemental analyzer connected to the IRMS, were found to be –133‰ and –120‰, respectively. Preliminary measurements made on a residue produced from the UV irradiation of several H₂O:pyrimidine = 20:1 ice mixtures indicate δD values ranging from –79‰ to –75‰ for the first bipyrimidine photo-product, and from –99‰ to –95‰ for the second bipyrimidine photo-product, showing a small but measurable D enrichment during the photo-processing and warm-up that lead to their formation.

References:

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- [2] Nuevo, M. et al. *Astrobiology*, **9**, 683 (2009).
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- [4] Bera, P.P. et al. *J. Chem. Phys.*, **133**, 104303 (2010).

Ground Control Experiments and Flight Sample Preparation for the International Space Station OREOcube: ORganics Exposure in Orbit Experiment. Richard C. Quinn (SST), Kathryn Bryson (SSA), Andrew Mattioda (SSA), Antonio Ricco (RD), Farid Salama (SSA), Orlando Santos (SSX), E. Sciamma-O'Brien (SSA)

Science Topic: Astrobiology

Introduction: 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 in preparation 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 the NASA Ames Research Center's Small Spacecraft Payloads and Technologies Team, OREOcube is comprised of two 10-cm cubes each containing a highly advanced 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 (in the 124 to 2600 nm range) and as a light source for spectroscopy (Fig. 1).

The OREOcube experiment: In an OREOcube experiment, an adsorbate-substrate interface is defined by depositing organic samples as thin films onto solid inorganic substrates. This provides a controlled method



Fig. 1. OREOcube payload. Two independent 10-cm cubes each containing a 24-sample cell carrier and an integrated UV/Vis/NIR spectrometer are used to measure changes in inorganic compounds exposed to low-Earth-orbit radiation conditions on an ISS external platform.

to examine organic samples and inorganic surface interactions. Surfaces provide multiple mechanistic pathways that can impact chemical transformations of organic molecules exposed to radiation. Depending on the nature of the substrate, both physisorption and chemisorption can result in new photochemical processes in both the adsorbate and the surface. 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 cell also allows for the study of chemical processes related to atmospheric chemistry (e.g., Titan).

Figure 2 shows a spectrum of an OREOcube ground control tryptophan sample deposited on hematite. Also shown, for reference, are spectra of the individual thin-film components (i.e., tryptophan and hematite). By using thin-film samples, changes in UV/Vis/NIR absorption bands can be measured as a function of time. By measuring chemical changes *in situ*, OREOcube will provide data sets that capture critical kinetic and mechanistic details of sample reactions in real time, something that is not obtainable with the current exposure facilities on the ISS.

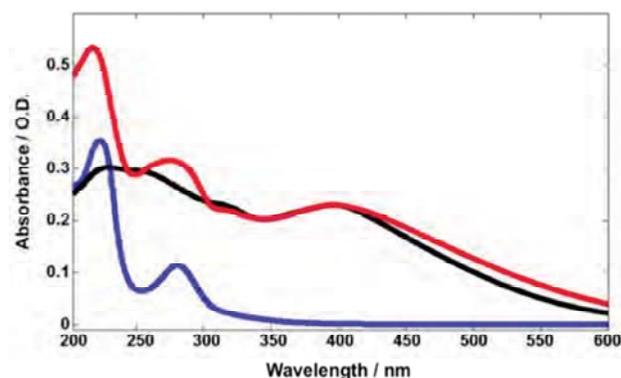


Fig. 2. Spectrum of an OREOcube tryptophan sample deposited on hematite (red). For comparison, tryptophan (blue) and hematite (black) spectra are also shown.

Acknowledgements: The OREOcube project is a ESA-NASA collaboration. U.S. science team participation in OREOcube is funded by the NASA Astrobiology Science and Technology Instrument Development Program. The authors thank student interns A. Breitenbach (SJSU) J. Chan (SJSU) and J. Alonzo (CalPoly Pomona). The ESA PI is P. Ehrenfreund and 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.

The Solubility of Titan Tholin in Liquid Ethane; are the seas of Titan a prebiotic soup

Christopher P McKay

Hiroshi Imanaka

Malika Carter

Photochemical processes in the upper atmosphere on Titan produce aerosols of complex organic material, tholin, which settles to the surface. The surface of Titan is the only place in the Solar System other than Earth that has a liquid present. Thus, there is considerable interest in the possibility of an interesting organic and possibly prebiotic chemistry in the liquid methane and ethane lakes. Here we report on the solubility of Titan tholin in liquid ethane. No solubility was detectable for tholin mixed directly in liquid ethane or liquid ethane with ammonia. When tholin was dissolved in isopentane to room temperature and then cooled and diluted with liquid ethane part of the tholin remained in solution in the final, predominantly liquid ethane solution. Soluble components included compounds up to C₁₀. Our results suggest that the solubility is low and is kinetically inhibited by the low temperature.

Chance and necessity in biochemistry: Implications for the search of extraterrestrial biomarkers in Earth-like planets.

Alfonso F. Davila, Christopher P. McKay

Astrobiology

Abstract

We examine a restricted subset of the question of possible alien biochemistries. That is we look into how different life might be if it emerged in environments similar to that required for life on Earth. We advocate a principle of chance and necessity in biochemistry. According to this principle biochemistry is in some fundamental way the sum of two processes: there is an aspect of biochemistry that is an endowment from prebiotic processes—this is the necessity, plus an aspect that is invented by the process of evolution—this is the chance (Figure 1A). As a result, we predict that life originating in Earth-like planets will share necessary biochemical motifs that can be traced back to the prebiotic world, but will also have intrinsic biochemical traits that cannot be duplicated elsewhere as they are combinatorially path dependent (Figure 1B). Effective and objective strategies to search for biomarkers in Earth-like planets can be built based on this principle.

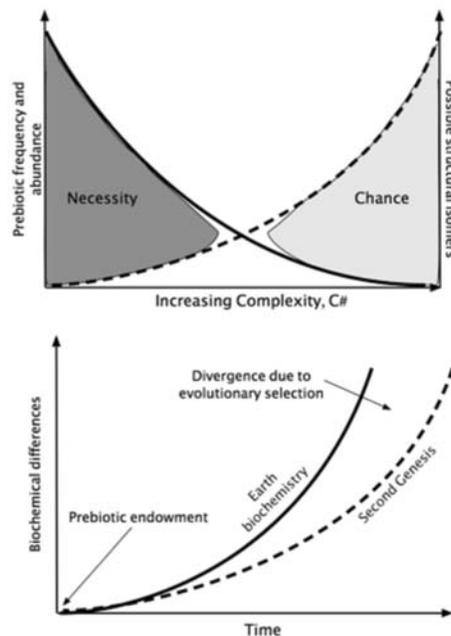


Figure 1. A. The concept of necessity and chance in biochemical traits. Simple biochemical monomers are frequent and abundant in the prebiotic world, and also have a small number of stable structural isomers. These are necessary (i.e., universal) biochemical traits in Earth-like planets. Complex biochemical monomers are rare in prebiotic chemistry, and have a large number of structural isomers. Their role in biology is a result of evolutionary selections (i.e., chance) and they must be considered, in principle, intrinsic to each planet. **B.** Biochemistry in Earth-like planets is a convergent phenomenon at the origin of life due to similar prebiotic endowment, but biochemistries in different planets will tend to diverge through time due to evolutionary processes.

Title:

Preservation and detection of organics in ancient fluvio-lacustrine sediments – lessons for MSL

Authors:

E.Z. Noe Dobrea, A.D. Aubrey, F., D.P. Glavin, F. Calef, M.R. Hamersley, A.C. McAdam, C. Freissinet, H. Franz, B. Parker

Science Topic:

Astrobiology

Abstract:

The Painted Desert of northern Arizona forms part of the Triassic Chinle formation, and consists of thick (ca. 100 m) layers of colorful bentonitic mudstones interbedded with sandstones and limestone. Black and purple layers in the formation have been postulated to be enriched in organic carbon derived from Late Triassic flora and fauna that were rapidly buried in the prograding beds and floodplains of the fluvio-lacustrine.

The spectral and morphological character of the Painted Desert appear analogous in many ways to that of the Al-phyllosilicate bearing units identified in Western Arabia Terra, Mars. Both regions present evidence for fluvial activity and have thick Al-phyllosilicate deposits containing Al-smectites, kaolins, hydrated silica, and jarosite. These similarities make the Painted Desert a potential geological and compositional analog of the Mars sites. In this study we characterize the preservation potential of organics in the 215 My old clay sediments of the Painted Desert using both laboratory techniques as well as equipment available to MSL in order to better understand the mechanism for organic preservation in fluvio-lacustrine systems, and to inform sample selection strategies for MSL.

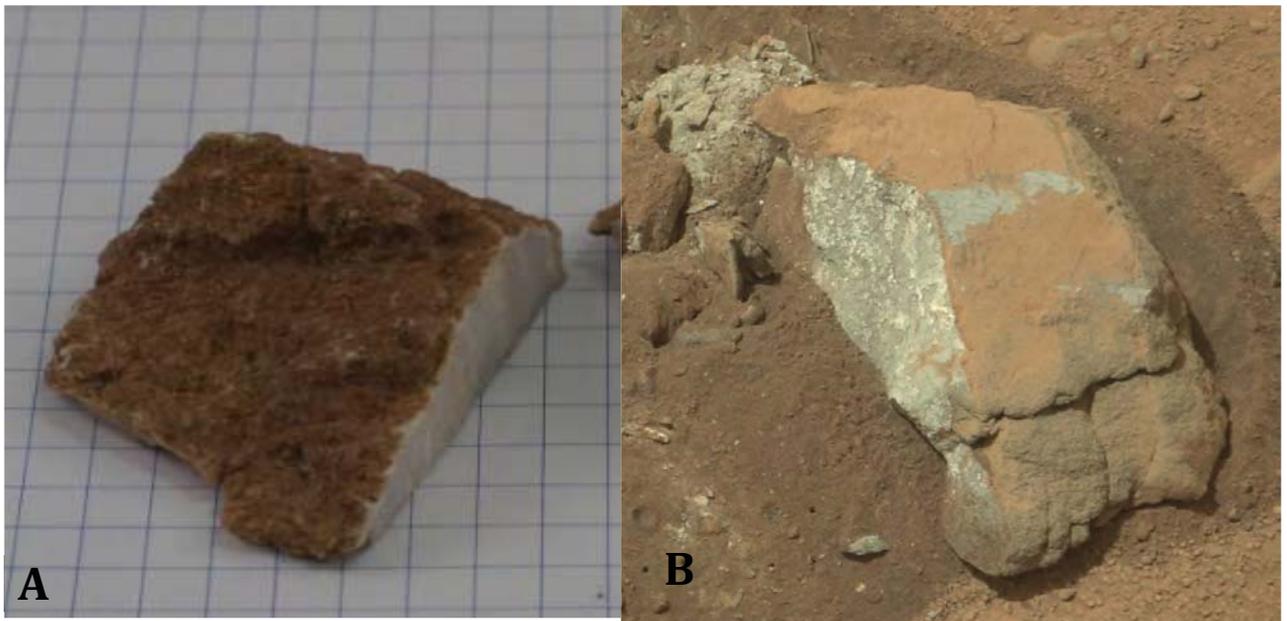
We have conducted a study on samples from the Painted Desert to detect organics and their isotopic composition within sequential depositional layers. The analytical experimental suite included (1) quantification of total organic carbon and nitrogen, (2) carbon and nitrogen stable isotope determination ($\delta^{13}\text{C}$, $\delta^{15}\text{N}$), (3) detection of aromatic and aliphatic hydrocarbons *via* thermal volatilization / mass spectrometer analyses, and (4) characterization of host mineral compositions.

Here, we report on a relationship between bulk organic carbon with mineralogy and grain size, and note a stark contrast between adjacent beds where sandstone units show extremely low levels of organics and clay-rich facies contain preserved organics. We have also found significantly higher (~100x) concentrations of organics in carbonate nodules that were encased in a jarosite rind. This rind is intriguing because it implies that acidic conditions (pH = ca. 1) were prevalent during the time of nodule formation. Together, these findings can serve as a cautionary example to the Mars community that localized jarosite deposits can be consistent with bentonite facies and may act to enhance organic preservation, despite acidic conditions being generally associated with poor organic preservation.

Title: Possible Hypolith on Mars
Authors: Heather Smith
Science Topic: Astrobiology

Abstract:

We discuss the plausibility of hypoliths on Mars, by comparing the red coated hypoliths from the Mojave with images from *Curiosity*, at Gale Crater, Mars. In the Mojave the rock protects the organisms by filtering the UV, while also trapping water providing a more suitable habitat in this arid region. We present light transmission properties, the microbial community, and the effect of Mars simulated environmental conditions on the microbial community inhabiting a hypolith from the Mojave which appears similar to a rock that *Curiosity* ran over.



A. Is a hypolithic carbonate rock from the Mojave, compared to B the “Sutton_Inlier” rock photographed by *Curiosity* ‘s MastCam on Sol 174 at Yellowknife bay, Gale Crater, Mars.

Luminous Blue Compact Galaxies: Probes of Galaxy Assembly

Michael N. Fanelli,
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Pamela M. Marcum
NASA Ames Research Center

Cassidy L. Newton
Texas Christian University

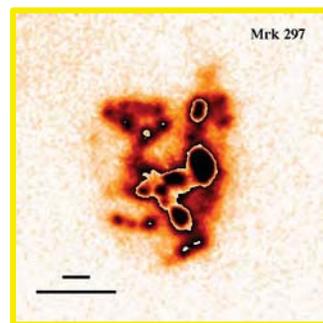
TOPIC: Astrophysics

ABSTRACT

To build the population observed now, galaxies experienced significantly larger star formation rates (SFR) at earlier epochs; the peak of global star formation appears to have occurred at $z \sim 2$. In this project we interpret the evolutionary state of a sample of Luminous Blue Compact Galaxies (LBCGs), morphologically complex galaxies in the local ($z < 0.05$) universe exhibiting unusually blue colors, $[(B-V) \leq 0.5]$, absolute luminosities comparable to bright galaxies, ($M_B < -19$), and high SFRs [$10\text{-}50 M_{\odot} / \text{yr}$]. Due to the scale of this star formation, LBCGs appear to be ideal local analogs to the early evolutionary phases of most galaxies. Their location in the near-field permits detailed investigation over a broad range of the electromagnetic spectrum with high spatial resolution, permitting the processes of galaxy assembly to be examined in great detail. While LBCGs appear to be rapidly evolving systems, the mechanisms driving this evolution, the progenitor population and final morphological state are poorly understood.

We combine optical imagery (UBVR, H α) obtained at McDonald Observatory with UV photometry from GALEX, thermal-infrared photometry from IRAS, and ancillary data from the 2MASS, SDSS and NVSS to investigate the structure and star formation history for ~ 50 LBCGs. Multi-band surface photometry is used to quantify the formation rate and spatial distribution of young stars, and assesses the degree to which these systems are or have interacted with nearby galaxies. While a substantial number of systems are mildly or strongly interacting, the sample is not dominated by interactions, indicating either internal processes or minor satellite accretion can trigger strong star formation episodes. Comparison of SFRs estimated using FIR and UV data generally finds infrared-derived rates significantly higher, with a clear trend of a decreasing infrared excess with increasing UV luminosity. Most LBCGs are strongly detected with GALEX, suggesting long-lived starbursts. We highlight possible evolutionary connections between LBCGs, ultraluminous infrared galaxies, and post-starburst systems.

This research was supported by NASA Astrophysics Data Analysis Program Grant **#NNX11AF75G**



Examples of LBCGs: **Mrk 1101**, SDSS *gri* composite (left); **Mrk 297**, H α (right).

TITLE:

The Evolutionary Connection Between Compact Groups and Isolated Galaxies: Diffuse X-ray Gas Halos

AUTHORS:

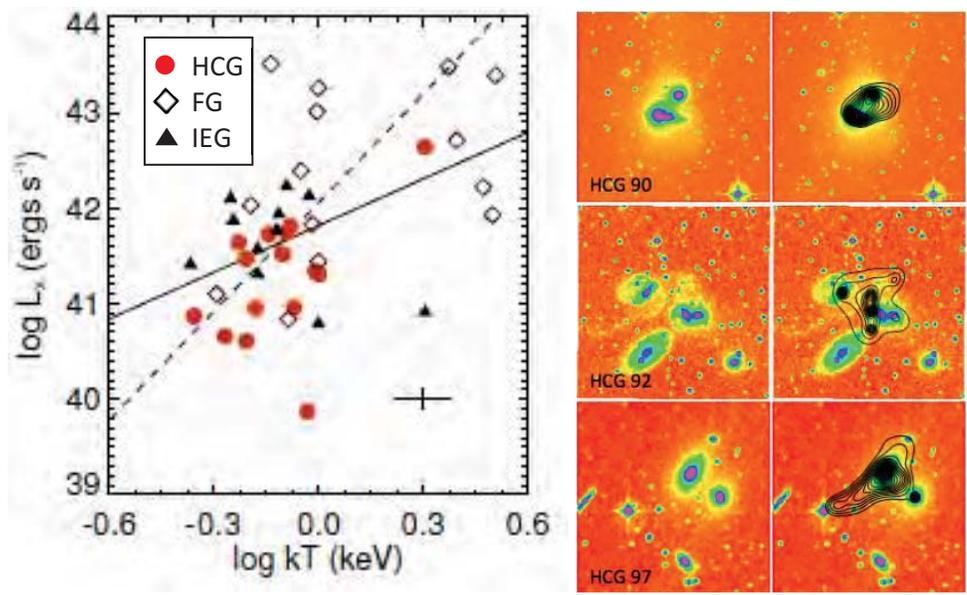
Marcum, Pamela (ARC); Fanelli, Michael (BAERI); Fuse, Chris (Rollins College)

SCIENCE TOPIC:

Astrophysics

ABSTRACT:

As part of a larger study to understand the evolution of highly isolated early-type galaxies, we compare the diffuse X-ray emission from samples of Hickson compact groups, fossil groups, and isolated elliptical galaxies 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 the evolutionary connection between these systems. The ranges of X-ray luminosity and temperature displayed by the compact group and isolated elliptical samples significantly overlap, suggesting that isolated ellipticals may be the remnants of collapsed compact groups. The fossil groups exhibit a bimodal temperature distribution. One fossil group population has X-ray features characteristic of the isolated elliptical and compact group samples, while the second population may be the remains of more massive systems.



Mid-Infrared Brightness Enhanced Galaxies in the Coma Cluster compared to the Virgo Cluster.

L. RIGUCCINI, P. TEMI, A. AMBLARD, M. FANELLI, S. IM

Science Topic : Astrophysics

Early-type galaxies (ETGs), including Ellipticals (E) and Lenticulars (S0) are among the most massive galaxies today. Their poorly known formation is still subject to much debate. First believed to have simple, static and old stellar populations, they actually present a complex star formation history. We decided to explore this complexity among rich environments such as clusters of galaxies (Virgo and Coma).

The L_{24}/L_K distribution of ETGs in both Virgo and Coma clusters shows that some Coma S0 have a much larger L_{24}/L_K ratios (0.5 to ~ 2 dex) than the bulk of the ETG population in Coma or even compared to the whole Virgo ETG population. This could mean an enhanced star formation for these lenticulars. We aim at characterize and understand these peculiar sources by comparing these two clusters.

We select ETGs based on their morphological type T ($-5 < T < 0$) in the Virgo cluster (from Temi et al. 2009 and Leipski et al. 2012 catalogs) and in the Coma cluster (from Mahajan et al. 2010 catalog). From a BPT analysis and an additional criteria for each galaxies, we are able to mark AGN sources among the two samples. We compare the optical colors of galaxies in these two clusters and investigate the nature of Coma sources with large L_{24}/L_K ratio by looking at their spatial distribution within the cluster, by analyzing their optical spectra and by looking at their optical colors compared to late-types in Coma.

We obtain 9 Coma sources with larger L_{24}/L_K ratios than the bulk of the population and those have been identified as star-forming by the BPT analysis. We call these sources Mid-Infrared Enhanced Galaxies (MIEGs). They are all located in the South-West part of the cluster where a substructure is infalling on the main cluster (e.g., Caldwell et al. 1993) and all the MIEGs are lenticulars. MIEGs present lower g-r color than the rest of the Coma ETGs sample, which might be explained by strong OII/OIII features present in their spectra that we do not observe in the rest of the ETG sample.

Coma, as many other clusters, is the theater of an ongoing merger with, in particular, an infalling substructure in the SW part of the cluster. Virgo has also a known ongoing merger activity, but in Coma we observe the following very interesting phenomenon : this infalling substructure enhances the star formation of lenticular sources in this region of the cluster. This could be explained by a compression of the gaz due to the infall of the substructure that would create a shock wave which would enhance star-formation in some sources.

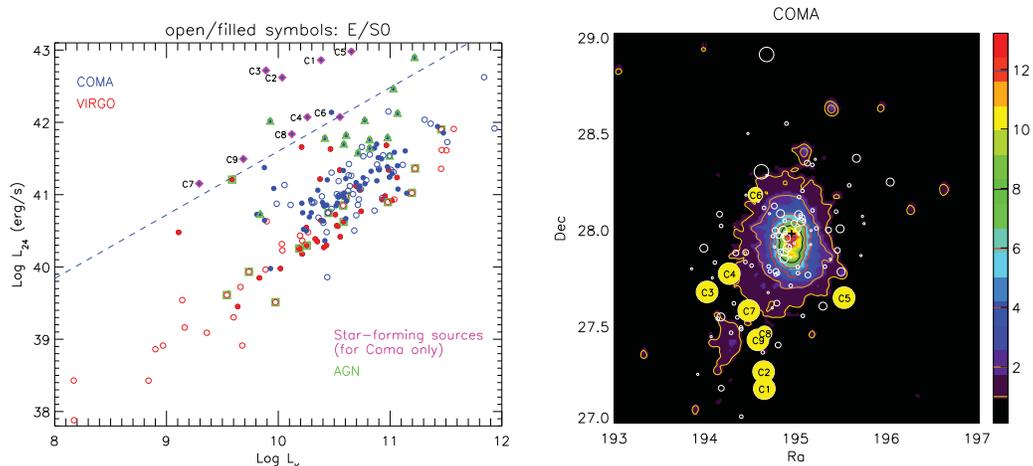


FIG. 1 — **Left** : Distribution of the Virgo ETGs (in red) and Coma ETGs (in blue) in a L_{24} - L_K diagram. The Mid-IR Enhanced Galaxies (MIEGs) are lying above the blue dashed line. **Right** : Distribution of the $24\mu\text{m}$ detected sources (white open circles and yellow filled ones) on top of the ROSAT map of the Coma cluster. Yellow filled circles represent the MIEGs and populate mainly the SW region of the cluster. The size of the circle is proportional to the ratio L_{24}/L_K .

Extended dust emission in IC1459 and NGC2768 as seen by PACS.

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

Science Topic : Astrophysics

Elliptical galaxies are considered red and “dead” galaxies, due to their typical color and star formation rate (SFR). However, far-infrared(IR) MIPS Spitzer observations from Temi et al. 2007 revealed that some local elliptical galaxies possess an amount of dust beyond what can be lost by their star population. These observations suggest a potential feedback mechanism between the central AGN and the dusty gas, that transports buoyantly the dust several kpcs away from the core.

To better understand this feedback, we obtained PACS Herschel (70 and 160 μm) data for two galaxies, IC1459 and NGC2768, these data allow to map the cold dust at higher angular resolution (5.6” & 11.4”) . These two galaxies present a disturbed morphology at these far-infrared wavelengths that is very different from the smooth stellar light distribution expected from elliptical galaxies and observed in the optical and IR wavelengths for these galaxies.

In this work, we present the spectral energy distribution (SED) analysis of IC1459 and NGC2768, two local elliptical galaxies. We performed a pixel-by-pixel SED fitting of each of these objects, allowing us to characterize the spatial distribution of such parameters as the stellar mass, the SFR, the specific SFR (sSFR), the D4000 age, etc. Combining Herschel PACS and SPIRE data, both available for NGC2768, we estimate the dust mass and temperature distribution of this galaxy.

Title: ALMA Observations of Warm Molecular Gas in Arp 220

Authors: Naseem Rangwala, Christine Wilson, Jason Glenn and Philip Maloney

Science Topic: Astrophysics

Abstract:

Arp 220, at a distance of 77 Mpc, is the most luminous local ultra-luminous infrared galaxy and has a high star formation rate. It is a system of two merging nuclei with high dust optical depth and a large reservoir of molecular gas concentrated in its nuclear region. These characteristics make Arp 220 a very complex but excellent laboratory to understand the star formation process in the most luminous galaxies in the universe both locally and at high-redshift. The star formation process inputs energy and momentum back into the gas -- and into the ISM in general -- through radiation, stellar winds, and supernovae. The impact of the feedback from both star formation and AGN activity on the ISM can be profound, and the resulting change in the physical state of the gas must in turn affect the star formation process. Therefore, determining the physical state (temperature, pressure, mass, luminosity/cooling) of gas reservoirs in galaxies is essential for understanding star formation and the effects of feedback, which determines the rate at which a galaxy depletes its gas, and its active phase star formation.

Our Herschel observations of some prominent nearby galaxies, including Arp 220, have conclusively determined that the warm component of their molecular gas, traced by multiple CO transitions, comprises a minority of the mass but dominates the CO luminosity and hence the energy budget. Comparison of the observed CO spectral energy line distributions and far-infrared luminosities to theoretical models indicates that the gas heating is dominated by some mechanism other than UV or X-ray photons or cosmic rays. Mechanical energy from shocks generated by supernovae and stellar winds is the most plausible source so far. Herschel observations have not spatially resolved most galaxies because of large beams, so only average properties have been inferred, and it has been difficult to associate the warm gas with the distributions of star formation, cool molecular gas, and nuclear activity. Our recent high-spatial-resolution ALMA observations of the CO J = 6-5 line in Arp 220 resolved the morphology of the warm molecular gas on a much finer scale than ever before, revealing interesting and unexpected features. The multiple components (emission and absorption associated with the two nuclei) seen in the resolved ALMA observations clearly suggest that modeling galaxy-integrated CO rotational lines is inadequate for deriving the detailed excitation and physical conditions of the gas. I will present the new CO and dust maps from ALMA including preliminary analysis and interpretation.

A Kepler Galaxy Survey: Establishing the Temporal Baseline for Extragalactic Systems

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Pamela M. Marcum
NASA Ames Research Center

Jeff Van Cleve
NASA Ames Research Center & Universities Space Research Association

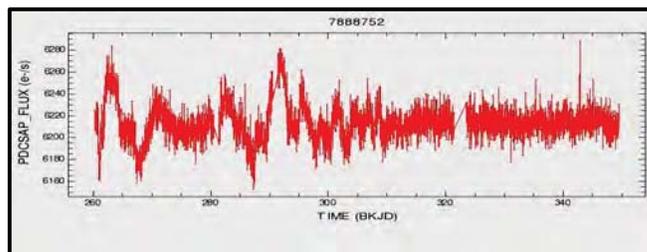
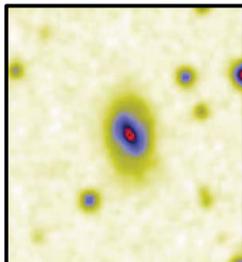
TOPIC: Astrophysics

ABSTRACT

Kepler's combination of high photometric precision and near-continuous observing cadence permits new insight on galaxies, by opening up the time domain in previously unavailable detail. We report on the analysis of ~1200 individual light curves of ~150 galaxies observed during Quarters 1-8. This survey is sensitive to both continuous variability, especially low-level variations from embedded active nuclei, and random episodic events, such as supernovae. Our goals are to (a) define the photometric baseline of galactic systems over a range of amplitudes and timescales, (b) quantify the existence and amplitude of AGN signals in galaxy cores, (c) provide a direct measure of supernovae rates across galaxy types, complementary to ground-based supernova searches, and (d) quantify the early brightening of detected supernova as the explosion rises to peak luminosity. In general, galaxies lacking active nuclei are not expected to be variable, constituting a population of quiescent sources useful for monitoring the photometric stability of Kepler. In this initial dataset we find on order 10 systems with excess variability, but caution that robust identification of low-level variations remains challenging in the context of systematic structure in the light curves. Several systems show variable behavior in 1-2 quarters but are otherwise quiescent in other quarters. These data provide an initial look at the temporal behavior of extragalactic systems.

As a step towards analysis of the entire Kepler galaxy database, 4-12 quarters of data for ~500 galaxies, we are constructing the Kepler Galaxy Legacy Archive. This archive federates the time series photometry with morphological and photometric parameters for each galaxy along with complete observing logs and photometric statistics derived from the light curves. In particular we collate data from several recently developed multiwavelength catalogs of the Kepler field to refine the properties of the observed galaxies. We also developing an associated software toolkit, written in IDL, for Kepler data analysis. Two examples of the procedures in this toolkit are: (a) a module to define the fractional area of a target galaxy within the optimal and full apertures, useful for supernova coverage statistics, and, (b) filtering of the entire observed pixel set for each source to identify transients occurring outside of the pipeline-defined optimal aperture.

This project is supported by NASA Astrophysics & Data Analysis Program Grant **NNX13AF17G**.



Title: Using Kepler to Predict the Variable Sky for GAIA and LSST
Authors: S. Ridgway, T. Matheson, K. Mighell, K. Olsen and S. Howell

Science Topic: Astrophysics

Abstract (one page or less; pictures and plots are great to include!)

Kepler light curve data and other sources are used to predict the variable sky that will be visible to the ESO GAIA mission and the Large Synoptic Survey Telescope (LSST). The discovery rate for variable targets and transients is presented. The rates begin very high, but with successful identifications, the discovery rates will decline rapidly over 1-2 years. Knowledge of these rates will inform early science requirements and programs for these two observatories.

Title: Reviving Dead Zones - A New Potential Source of Activity in Cold Protoplanetary Disks

Authors: O. M. Umrhan (SETI/NASA Ames), R. P. Nelson (Queen Mary University of London), O. Gressel (NORDITA)

Topic: Astrophysics

Abstract: The Dead Zones of protoplanetary disks are considered to be the places where planetesimals are aggregated and, ultimately, where rocky planets are assembled. Classical analysis have shown these regions of disks to be inactive as they are not sufficiently ionised for MHD processes to be relevant. We report recent theoretical and numerical investigations showing that disks can become unstable to the Goldreich-Schubert-Fricke (GSF) instability which is a process that destabilises axisymmetric rotating flows supporting vertical gradients of the mean rotating state. Axisymmetric simulations show that the GSF grows into periodic structures of alternating vertical jets (with respect to the disk midplane) with correspondingly large geostrophic secondary flows in the flow direction of the mean state. Fully nonlinear three-dimensional simulations indicate the onset of strong turbulence with significant disk turbulence measure ($\alpha \sim 10^{-3}$). The only conditions needed for the instability to operate is that there is an external thermal energy source providing a radial gradient in the mean disk temperature profile. Asymptotic linear theory analysis predicts the dominant growth rates observed in the simulations and, further, shows that the dynamics underpinning the mechanism are largely radially geostrophic with anelastic equation of state. We investigate the conditions under which we expect this process to operate and find that for a minimum mass solar nebula this instability should be active for distances where $R > 20$ AU. If this process is indeed active in real disks, it will have profound effects upon the distribution of micron to millimetre sized dust grains - likely lofting them up several local scale heights from the disk midplane. Time and space permitting, a discussion of the secondary transition of the primary instability will be presented.

Title: Temperature, Density, and Collision Rates in the IC63 Nebula

Authors: Vaillancourt, John E.; Andersson, B-G; Polehampton, E.; Sanders, J.; Widicus-Weaver, S.

Science topic: Astrophysics

Abstract:

The IC 63 reflection nebula provides a near-by, well characterized, laboratory for a number of astrophysical processes, including radiation driven chemistry, gas dynamics and grain alignment physics. To provide improved constraints on many of these phenomena we have acquired high-resolution maps of tracers of the gas density and temperature in the nebula. We will present initial results from mapping the (1,1) and (2,2) rotational inversion transitions in ammonia with the Green Bank Telescope, which trace the gas temperature, and observations of HCO⁺ ($J=1-0$ and $J=3-2$) with IRAM 30m/Plateau de Bure, which probe the gas density. Specifically, we discuss the impact of the variations in gas-grain collision rates on the dust grain alignment and the resulting polarization of background starlight that passes through the nebula.

Title: "Observational testing of interstellar grain alignment - Why everything you learned in grad school [about this] is wrong."

Author: B-G Andersson

Science Topic: Astrophysics

Abstract:

More than 60 years after the discovery of interstellar polarization, we are finally converging on an observationally tested, self-consistent theory of why asymmetric dust grains in the interstellar medium can become aligned with the magnetic field and thereby cause polarization. Not only does this allow us to better understand the line-of-sight sampling of the magnetic field from polarimetric observations, but it potentially also offers a new method to study the grain characteristics and dynamics. I will review recent observational progress indicating that the classical alignment mechanism (Paramagnetic relaxation alignment) is untenable and - largely based on observations by our group - that the Radiative Alignment Torque (RAT) paradigm provides a well supported quantitative theory for the grain alignment.

Title: Using SOFIA, Herschel and HST observations to address the Nebular Abundance Problem

Authors: Elizabeth Mittmann (Palo Alto High School), Ravi Sankrit (SOFIA Science Center), and Sean Colgan (NASA/Ames)

Science Topic: Astrophysics

Abstract: The emission line analysis of photoionized nebulae like Planetary Nebulae is one of the major tools used to obtain knowledge of elemental abundances in our own and other galaxies. These studies contain a long-standing, unsolved mystery - the 'abundance discrepancy problem' - wherein heavy element abundances relative to hydrogen as derived from optical recombination lines are generally higher than those obtained from collisionally excited lines. Here we report on Herschel, Hubble, and SOFIA observations of the three Planetary Nebulae NGC7009, NGC2392, and NGC6720. By comparing the measured distributions of spectral line intensities with the predictions from a bi-abundance model, we will ascertain whether the abundance discrepancies could be produced by the existence of two distinct emission regions within the objects: one of "normal" chemical composition and electron temperature and a second hydrogen-deficient region with correspondingly very low electron temperature.

Title: EXES, the Echelon-cross-echelle Spectrograph for SOFIA

Authors: Curtis DeWitt, Kristin Kulas, Matthew Richter, Mark McKelvey

Science Topic: Astrophysics

Abstract: EXES, the Echelon-cross-echelle Spectrograph, is a mid-infrared spectrograph built for the Stratospheric Observatory for Infrared Astronomy (SOFIA). The primary science driver for EXES is its high spectral resolution, $R=100,000$, which enables the study of line profiles and maximizes sensitivity to narrow features. The current schedule has EXES completing its first two flights on SOFIA in April, 2014. On these flights, we will have our first opportunity to examine EXES on-sky performance and its ability to exploit spectral regions made accessible by SOFIA. We present a summary of our demonstrated EXES performance from the lab and the commissioning and science goals for our first flights in April.

TITLE: Semi-Empirical IR Line Lists for 13 CO₂ Isotopologues: Up to 1500K and 20,000 cm⁻¹

AUTHORS: Xinchuan Huang, Robert R. Gamache, David W. Schwenke, and Timothy J. Lee

SCIENCE TOPIC: Exoplanet, Planetary Atmosphere & Climate

ABSTRACT BODY: Recently we have published two Infrared (IR) line lists, Ames-296K and Ames-1000K for ¹²C¹⁶O₂ using a highly accurate potential energy surface (PES) Ames-1 and an improved dipole moment surface, DMS-N2.[1] The Ames-1 PES was empirically refined with selected pure experimental energy levels to $\sigma_{\text{RMS}} = 0.016 \text{ cm}^{-1}$ for 6,873 $J=0$ -117 levels.[2] We compare the Ames line lists to other available CO₂ databases (including HITRAN, HITEMP and Wattson 750K), and conclude that our line lists can provide reliable predictions and simulations for T up to 1500K with a wavenumber range up to 20,000 cm⁻¹ above the zero-point level. In addition, comparison with recent room temperature[3] and high temperature[4] experiments have demonstrated that the Ames line lists based simulations can give the best or comparable predictions. Inspired by these comparisons, we have computed 296K and 1000K line lists for the other 12 minor isotopologues, including 636, 628, 627, 638, 637, 828, 728, 727, 838, 738, 737, and 646. These line lists provide scientists with the most reliable alternatives/predictions for many spectral ranges where HITRAN2012 does not have reliable data or any data. We believe these line lists will significantly help experimental IR analysis, CO₂ remote sensing, and atmospheric modelings. The line lists are available for distribution in compressed compact format, with line shape parameters included.

[1] Huang X, Freedman RS, Tashkun SA, Lee TJ. *J. Quant. Spectrosc. Radiat. Trans.* 2013, doi:10.1016/j.jqsrt.2013.05.018

[2] Huang X, Schwenke DW, Tashkun SA, Lee TJ. *J. Chem. Phys.* 2012;136:124311.

[3] Petrova TM, Solodov AM, Solodov AA, Lyulin OM, Tashkun SA, Perevalov VI. *J. Quant. Spectrosc. Radiat. Trans.* 2013;124:21–7.

[4] Evseev V, Fateev A, Clausen S. *J. Quant. Spectrosc. Radiat. Transfer* 2012;113:2222–33.

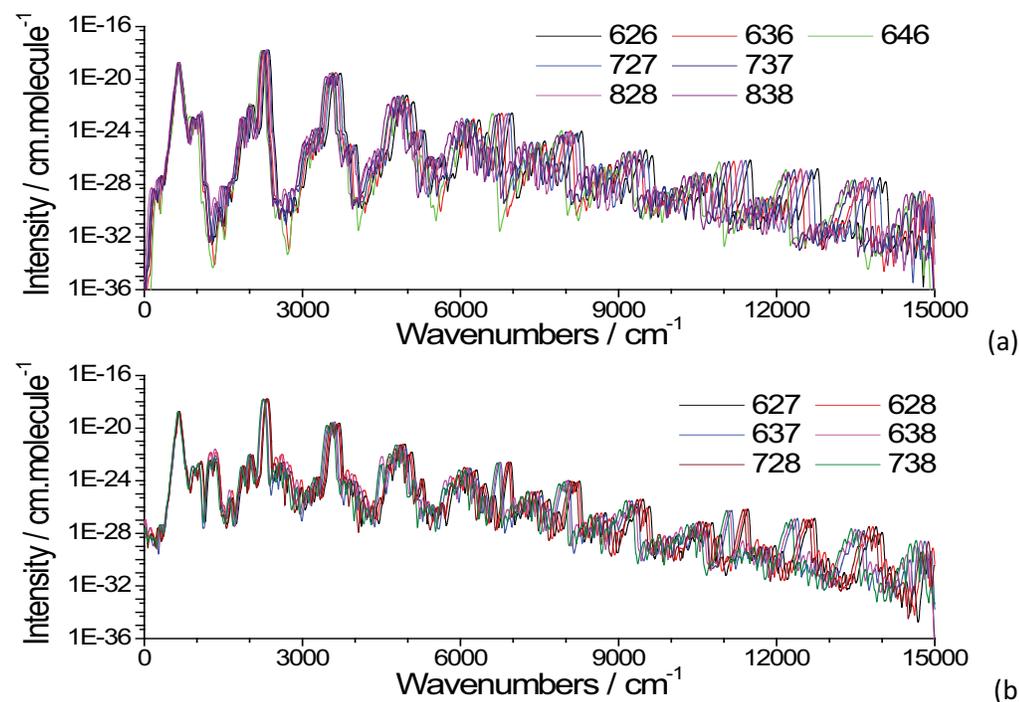


Fig.1 Ames-296K based IR simulations for 13 CO₂ isotopologues: (a) symmetric isos; (b) asymmetric isos

Title: The ORGANIC Experiment on EXPOSE-R on the ISS: Mission Results

Authors: K.L. Bryson^{a,c}, Z. Peeters^b, F. Salama^c, B. Foing^d, P. Ehrenfreund^{e,f}, A.J. Ricco^g, E. Jessberger^h, A. Bischoff^h, M. Breittellnerⁱ, W. Schmidt^j and F. Robert^k

^aBay Area Environmental Research Institute, ^bDepartment of Terrestrial Magnetism, Carnegie Institute of Washington, ^cSpace Science & Astrobiology Division, NASA Ames Research Center, ^dEuropean Space Agency, ^eLeiden Institute of Chemistry, ^fSpace Policy Institute, ^gSmall Spacecraft Division, NASA Ames Research Center, ^hInstitut für Planetologie, Westfälische Wilhelms-Universität Münster, ⁱEuropean Space Astronomy Centre (ESAC), ^jPAH Research Institute, ^kLaboratoire de Minéralogie et Cosmochimie du Muséum (LMCM)

Science Topic: Astrophysics

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 (Bryson et al. 2011). 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 the full assessment of the flight sample results. We discuss how extended space exposure experiments allow to enhance our knowledge on the evolution of organic compounds in space.

Bryson et al. 2001, *Advances in Space Research* 48 1980–1996

Title: Polycyclic Aromatic Hydrocarbon Clusters: Theory and Experiment

Authors: Joseph Roser and Alessandra Ricca

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

Science Topic: Astrophysics – Poster

Abstract: The polycyclic aromatic hydrocarbons (or PAHs) are abundant in the molecular interstellar medium and absolutely critical for understanding a number of interstellar phenomena, most prominently the ubiquitous interstellar mid-infrared emission bands. Clusters of PAHs are also important in the interstellar medium as both infrared emitters in their own right and as an intermediate stage in the formation of small dust grains.

Due to the difficulty in measuring the infrared emission spectra of PAHs, scientific investigations of the mid-infrared emission begin with more easily obtained absorption spectra. Here we present laboratory infrared absorption spectra of homogeneous mixtures of PAH molecules obtaining using the solid argon matrix isolation technique. We also compare the experimental spectra with theoretical spectra computed using density functional theory with a dispersion correction. We show that the C–H stretching and C–H out-of-plane bending modes are most affected by PAH clustering and that the pattern of spectral shifts in these modes identifies the cluster structures occurring within the matrix. Future experiments extending this work to PAH cluster cations will also be discussed.

CARBONACEOUS GRAIN FORMATION FOR CIRCUMSTELLAR STUDIES

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

Science Topic: Astrophysics

Abstract:

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. We report the progress that was recently achieved in this domain using NASA Ames' COSmIC facility (Contreras & Salama 2013). Polycyclic Aromatic Hydrocarbons (PAHs) 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. The formation of PAHs from smaller molecules has not been extensively studied. Therefore, we have performed laboratory experiments to study the dynamic processes of carbon grain formation, starting from the smallest hydrocarbon molecules into the formation of larger PAH and further into nanograins. 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 using the COSmIC facility to provide conditions that simulate interstellar and circumstellar environments (Ricketts et al. 2011). The species formed in the COSmIC chamber through a 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. Analysis of soot material was also conducted using scanning electron microscopy (SEM) at the UCSC/NASA Ames' Materials Analysis for Collaborative Science (MACS) facility. Studies of Ar-based gas mixtures containing hydrocarbon precursors such as acetylene show the feasibility to form PAHs from specific precursor molecules, while gas mixtures containing carbon ring systems (benzene and derivatives, PAHs) precursors provide information on pathways toward larger carbonaceous molecules. The SEM analysis of the deposition of soot from methane and acetylene seeded argon plasmas provide examples on the types of nanoparticles and micrograins that are produced in these gas mixtures under the COSmIC experimental conditions. 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.

References:

Contreras and Salama, *ApJS* **2013**, *208*, 6 – 23.
Ricketts et al. *IJMS* **2011**, *300*, 26 – 30.
UCSC MACS Facility (<http://macs.advancedstudieslabs.org/>)

Acknowledgements:

This work is supported by the NASA Science Mission Directorate (SMD) Astrophysical Research and Analysis (APRA) Program and NASA's Laboratory Astrophysics Carbon in the Galaxy's Consortium Grant. NASA grant NNX09AQ44A to University of California Santa Cruz is acknowledged for instruments in the UCSC MACS Facility within the UCSC/NASA-ARC ASL

Formation of *N*- and *O*-heterocyclic molecules from the photolysis of PAHs in H₂O- and NH₃-containing ices

Christopher K. Materese, Scott A. Sandford, and Michel Nuevo

Topic: Astrophysics

Code: SSA

Polycyclic aromatic hydrocarbons (PAHs) are known to exist in interstellar and circumstellar environments in the gas phase. Heterocyclic compounds are similar to PAHs structurally, except they have alternative atoms replacing the carbon atoms in the aromatic rings. Some small *N*-heterocyclic molecules such as purine and pyrimidine are especially interesting because of their biological significance as major components of the nucleobases in RNA and DNA. The presence of *N*-heterocycles in the gas phase in space has yet to be confirmed, although their presence has been inferred from the details of infrared emission spectra dominated by the classic 'PAH' features.

Here we present the results of laboratory experiments that demonstrate the production of *N*- and *O*-heterocyclic molecules from the photolysis of PAHs in H₂O- and NH₃-containing ices. In these experiments, ices were photolyzed with a hydrogen lamp at 15 K, and the resulting residues recovered at room temperature after slow warm-up were subsequently extracted for analysis by gas chromatography coupled with mass spectroscopy (GC-MS). The photolysis of ices containing H₂O and naphthalene (C₁₀H₈) showed the formation of *O*-heterocycles including phthalide (C₈H₆O₂) and coumarin (C₉H₆O₂). Similar experiments with NH₃ added to the mixture also yielded phthalide and coumarin in addition to quinoline and isoquinoline (both C₉H₇N). Similarly, photolysis of H₂O, benzene (C₆H₆), and ammonia (NH₃) showed the formation of pyridine (C₅H₅N).

These experiments indicate that photolysis of PAHs in ices can result in the substitution of a carbon atom in the rings with either oxygen or nitrogen. This suggests that, when PAHs are present, heterocyclic molecules can form and exist on the surface of interstellar ice grains regardless of their presence in the gas phase.

Formation Routes For Pure and N-substituted Cyclic Hydrocarbon Molecules in The Ionosphere of Titan and in the Interstellar Medium

Partha P. Bera¹, Roberto Peverati², Martin Head-Gordon² and Timothy J. Lee¹

1. Space Science and Astrobiology Division, NASA Ames Research Center
2. Department of Chemistry, University of California, Berkeley

Titan's upper atmosphere contains large carbonaceous molecules as has been observed by the instruments on board the CASSINI spacecraft. Large organic molecules including polycyclic aromatic hydrocarbons are omnipresent in the interstellar medium. How these large polyatomic molecules are synthesized in such exotic conditions is, thus far, unknown. Molecular ions are in relative abundance in the ionosphere of Titan. Hence, barrierless ion-molecule interactions may play a major role in guiding molecules towards each other and initiating reactions. We study these cold condensation pathways to determine whether they are a viable means of forming large pure hydrocarbon molecules, and nitrogen-containing carbonaceous chains, stacks, and even cyclic compounds. By employing accurate quantum chemical methods we have investigated the processes of growth, structures, nature of bonding, mechanisms, and spectroscopic properties of the ensuing ionic products after pairing small carbon, hydrogen, and nitrogen-containing molecules with major ions observed in the upper atmosphere of Titan, e.g. $C_2H_5^+$ and $HCNH^+$. We have also studied the ion-neutral association pathways involving pure-carbon molecules e.g. acetylene, ethylene and other hydrocarbons, and their dissociation fragments in a plasma discharge. Additionally, we have investigated how nitrogen atoms are incorporated into the carbon ring during growth. We have used accurate *ab initio* coupled cluster theory, Møller-Plesset perturbation theory and density functional theory quantum chemical methods together 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-molecule 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. We uncovered that a series of hydrocarbons with a specific stoichiometric composition prefers cyclic molecule formation rather than chains. Some of the association products we investigated have large oscillator strengths for charge-transfer type electronic excitations in the near infrared and visible regions of the electromagnetic spectrum. Our quantum chemistry computations complement well the results from the molecular/ion plasma experiments performed by the Laboratory Astrochemistry groups at Ames.

P. P. Bera, Martin Head-Gordon, and Timothy J. Lee *Astron & Astrophys.* 535, A74, (2011)

P. P. Bera, M. Head-Gordon, and T. J. Lee, 15, 2012-2023, *Phys. Chem. Chem. Phys.* (2013)

Partha P. Bera, Martin Head-Gordon, and Timothy J. Lee, *J. Chem. Phys.* 139, 174302 (2013)

P. P. Bera, Roberto Peverati, M. Head-Gordon, and Timothy J. Lee, To be submitted (2014)

Title: "Is there an exo-Earth around Alpha Centauri? (And how a cubesat-sized telescope may give us an answer.)"

Author: 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 has already revealed that roughly 22% of stars have planets close to Earth size in regions close to their habitable zones. 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 and small planets).

Directly imaging an exo-Earth is challenging and likely requires a 4m flagship-size optical space telescope with an unprecedented imaging system (a coronagraph) capable of achieving contrasts of $1e10$ very close to the diffraction limit. Such a telescope will probably not be launched until the 2030s at the earliest. On the path towards that mission, NASA is studying options for smaller missions, ranging from Explorer class to coronagraphic instruments on a 2.4m telescope.

However, if there is an Earth around Alpha Centauri (the closest star system to the Sun), it may be possible to detect and take its spectrum with a telescope as small as ~ 25 cm, which can potentially fit on a cube sat. The Alpha Centauri system is a particularly low hanging fruit compared to the other stars – all of the other nearby stars are much dimmer, and the nearest Sun-like star other than Alpha Centauri is about 3 times farther. There are still very significant challenges to overcome, such as outfitting such a small telescope with a coronagraph and wavefront control systems, none of which have been demonstrated on a small scale; as well as solving the challenge that the Alpha Centauri system has 2 bright stars to block instead of one. Furthermore, the ability to detect an Earth-like planet has not fully been demonstrated in the lab yet for any size telescope (although we are close). I will describe the work that has been done to date, focusing on the research at the Ames Coronagraph Experiment group, and how we are approaching solving all of these different challenges.

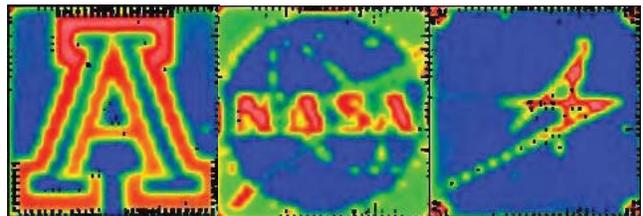
Experimental study of a low-order wavefront sensor for high-contrast coronagraphic imagers: results in air and in vacuum

Julien Lozi ¹, Ruslan Belikov ², Glenn Schneider ¹, Olivier Guyon ¹, Sandrine Thomas ^{2,3}, Eugene Pluzhnik ^{2,3}, Eduardo Bendek ²

1 : University of Arizona
2 : NASA Ames Research Center
3 : UARC/NASA Ames

SCIENCE TOPIC: Exoplanet

For the technology development of the mission EXCEDE (EXoplanetary Circumstellar Environments and Disk Explorer) – 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 $2 \lambda/D$ – we developed two test benches simulating its key components, one in air, the other in vacuum. To achieve this level of contrast, one of the main goals is to remove low-order aberrations, using a Low-Order WaveFront Sensor (LOWFS). We tested this key component, together with the coronagraph and the wavefront control, in air at NASA Ames Research Center and in vacuum at Lockheed Martin. The LOWFS, controlling tip/tilt modes in real time at 1 kHz, allowed us to reduce the disturbances in air to $1e-3 \lambda/D$ rms, letting us achieve a contrast of $2.8e-7$ between 1.2 and $2 \lambda/D$. Tests are currently being performed to achieve the same or a better level of correction in vacuum. With those results, and by comparing them to simulations, we are able to deduce its performances on different coronagraphs – different sizes of telescopes, inner working angles, contrasts, etc. – and therefore study its contribution beyond EXCEDE.



Logos drawn with the deformable mirror



Testbench in the vacuum chamber at Lockheed Martin



First vacuum test

Title: A focal plane mask for PIAA Complex Mask Coronagraph

Authors: Kevin Newman, Olivier Guyon, Kunjithapatham.Balasubramanian, Dan Wilson

Science Topic: Exoplanet

Abstract

The Phase Induced Amplitude Apodization Complex Mask Coronagraph (PIAACMC) can provide 50% throughput at $0.64 \lambda/D$ and nearly 100% throughput at large angular separations with total on-axis starlight extinction. These performance characteristics are close to the fundamental physical limit for any instrument. PIAACMC operates by applying a π phase shift to a portion of the on-axis starlight using a partially transmissive phase shifting focal plane mask. Design of the mask poses several challenges, especially to provide an achromatic phase shift over a large observational bandwidth. We discuss the design of the PIAACMC focal plane mask in monochromatic light, an optimization procedure for broadband, and considerations for fabrication limits.

Title: Enhancing direct-imaging exoplanet detection using astrometry and its application for AFTA
Authors: Eduardo A. Bendek, Olivier Guyon Ruslan Belikov
Science Topic : Exoplanets
Abstract: See below

Enhancing direct-imaging exoplanet detection using astrometry and its application for AFTA

Eduardo A. Bendek^c, Olivier Guyon^a Ruslan Belikov^c

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^cNASA Ames Research Center, Moffett Field, CA 94035, USA

^dUniversity of Arizona, College of Optical Sciences, 1630 E. University ave, Tucson, AZ, USA 85721;

ABSTRACT

The Ames Coronagraphic Experiment (ACE) is being enhanced with an astrometry module to validate the feasibility of performing simultaneous direct-imaging and astrometric observations with a single spacecraft. In this paper we report the design and results of this unique laboratory that summarizes the synergies and difficulties of obtaining both measurements simultaneously. This is a cost-effective approach to obtain the mass, orbits and chemical composition of single- and multiple- planetary systems around nearby stars. This is particularly relevant for detection and characterization of earth-like planets in longer period orbits where the radial velocity approach becomes insensitive. We use the results of this laboratory to study the trade-offs of implementing a diffractive pupil telescope on a general astrophysics mission and identify the critical system variables that define the system performance. We use a diffractive pupil to achieve high precision astrometric measurements by calibrating dynamic optical distortions. Our goal is to perform a medium fidelity demonstration that can achieve $2.3 \times 10^{-4} \lambda/D$ astrometric accuracy in the laboratory, which is equivalent to 10 μas on a 2.4-meter class space telescope. Simultaneously, the high-contrast imaging arm at ACE uses a PIAA coronagraph and a Kilo Deformable Mirror (DM), will be operated to simulate direct-imaging exoplanet detection. Currently ACE has achieved contrast levels of 2×10^{-8} at $2 \lambda/D$, allowing us to detect if there is any contamination of the coronagraph IWA caused by the diffractive pupil.

Keywords: High-contrast imaging, Distortion, diffractive pupil, high-precision astrometry, exoplanet detection

Measuring the masses and radii of sub-Neptunes with transit timing variations.

Daniel Jontof-Hutter¹, Jack Lissauer¹, Jason Rowe^{1,2}, Daniel Fabrycky³.

EXOPLANETS

The bounty of sub-Neptunes discovered by *Kepler* enables us to study a regime in planetary size and mass that is absent from the Solar System. This regime includes a transition from rocky planets to those with substantial envelopes of volatiles-- either ices or gases. Characterizing these worlds by their bulk densities can probe this transition, but this requires mass and radius determinations.

Outside our solar system, there is a small sample of planets with known masses and radii, mostly hot Jupiters whose radii are known from transit depths, and whose masses are determined from radial velocity spectroscopy (RV). In the absence of mass determinations via RV observations, transit timing variations (TTVs) offer a chance to probe perturbations between planets that pass close to one another or are near resonance, and hence dynamical fits to observed transit times can measure planetary masses and orbital parameters. Such modeling can probe planetary masses at longer orbital periods than RV targets, although not without some challenges. For example, in modeling pairwise planetary perturbations, a degeneracy between eccentricity and mass exists that limits the accuracy of mass determinations. Nevertheless, in several compact multiplanet systems, fitting complex TTV signals can break the degeneracy, permitting useful mass constraints.

The precision in measuring the radius of a transiting planet rests on the uncertainty in the stellar radius, which is typically $\sim 10\%$ for targets with spectral follow-up. With dynamical fits, however, solutions for the orbital parameters including the eccentricity vectors can, alongside the transit light curves, tightly constrain the stellar density and radius. Our dynamical fits to the TTVs of the four-planet system Kepler-79, alongside spectroscopic data, reduced the stellar and hence planetary radius uncertainties to just 2%, permitting useful planetary density determinations. In the case of Kepler-79, planetary bulk densities are remarkably low given the planetary masses. Indeed, several multiplanet systems characterized by TTV show much lower planetary densities than typical RV determinations in the same mass range. While this reflects the detection biases of both techniques, it also represents a growing sample of characterized systems of multiple planets, whose low densities and compact configurations provide a striking contrast to the Solar System.

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Title: Stellar Properties of Kepler Targets for the Q1-Q16 Planet Detection Run

Authors: Daniel Huber (NASA Ames) and the Kepler Star Properties Working Group

Science Topic: Exoplanets

Abstract: We present updated stellar properties for 196468 stars observed by the NASA Kepler Mission through Q16 and used in the Q1-Q16 planet detection run. The catalog is based on a compilation of literature values for atmospheric properties (temperature, surface gravity, and metallicity) derived from different observational techniques (photometry, spectroscopy, asteroseismology, and exoplanet transits), which are then homogeneously fitted to a dense grid of stellar isochrones. We characterize ~11500 targets which were previously unclassified in the Kepler Input Catalog and report the detection of oscillations in ~2700 of these targets, classifying them as giant stars and increasing the number of known oscillating giant stars observed by Kepler by ~20%. A comparison with the Q1-Q12 star properties catalog shows a significant decrease in radii for K-M dwarfs, while radii of F-G dwarfs remain roughly constant, with the exception of newly identified giant stars. The catalog will allow an improved identification of planet candidates orbiting in or near the habitable zones of their host stars, and is a first step towards an improved characterization of all Kepler target stars to support planet occurrence studies with the Kepler mission.

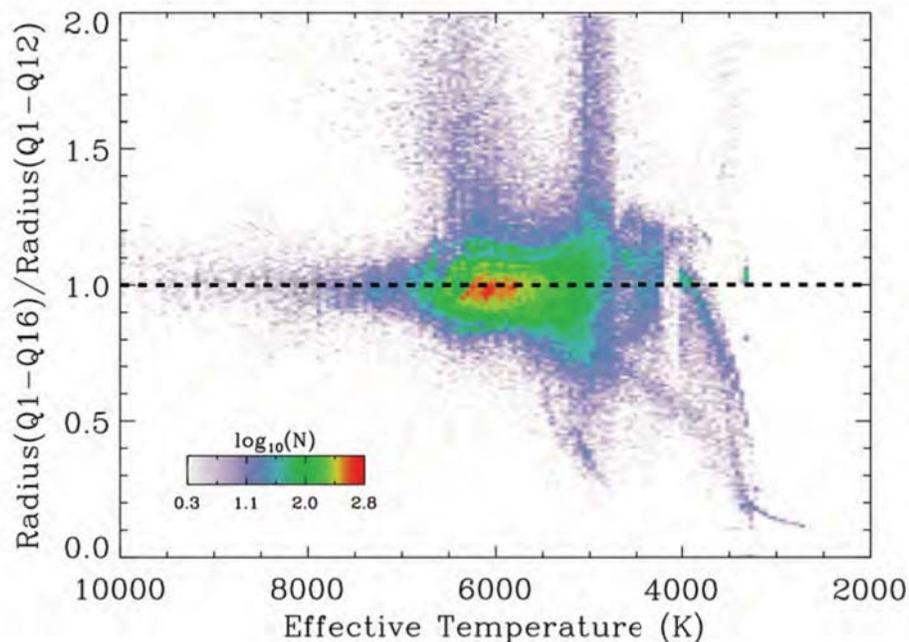


Figure: Ratio of stellar radii for Kepler targets in the Q1-16 and Q1-12 catalogs as a function of stellar effective temperature. Colors denote the logarithmic number density. Large radii changes can be observed due to the use of improved models for cool stars (<4500K) and the identification of new giant stars (Huber et al. 2014, ApJS, in press).

Title: Enhancing direct-imaging exoplanet detection using astrometry and its application for AFTA
Authors: Eduardo A. Bendek, Olivier Guyon Ruslan Belikov
Science Topic : Exoplanets
Abstract: See below

Enhancing direct-imaging exoplanet detection using astrometry and its application for AFTA

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ABSTRACT

The Ames Coronagraphic Experiment (ACE) is being enhanced with an astrometry module to validate the feasibility of performing simultaneous direct-imaging and astrometric observations with a single spacecraft. In this paper we report the design and results of this unique laboratory that summarizes the synergies and difficulties of obtaining both measurements simultaneously. This is a cost-effective approach to obtain the mass, orbits and chemical composition of single- and multiple- planetary systems around nearby stars. This is particularly relevant for detection and characterization of earth-like planets in longer period orbits where the radial velocity approach becomes insensitive. We use the results of this laboratory to study the trade-offs of implementing a diffractive pupil telescope on a general astrophysics mission and identify the critical system variables that define the system performance. We use a diffractive pupil to achieve high precision astrometric measurements by calibrating dynamic optical distortions. Our goal is to perform a medium fidelity demonstration that can achieve $2.3 \times 10^{-4} \lambda/D$ astrometric accuracy in the laboratory, which is equivalent to $10 \mu\text{as}$ on a 2.4-meter class space telescope. Simultaneously, the high-contrast imaging arm at ACE uses a PIAA coronagraph and a Kilo Deformable Mirror (DM), will be operated to simulate direct-imaging exoplanet detection. Currently ACE has achieved contrast levels of 2×10^{-8} at $2 \lambda/D$, allowing us to detect if there is any contamination of the coronagraph IWA caused by the diffractive pupil.

Keywords: High-contrast imaging, Distortion, diffractive pupil, high-precision astrometry, exoplanet detection

TITLE: INVESTIGATING THE ASYMMETRY OF MARS' SOUTH POLAR CAP WITH A CO₂ CLOUD MICROPHYSICS SCHEME.

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Topic: Planetary Atmospheres & Climate

An intriguing feature of the CO₂ cycle on Mars is the existence of a 500 km in diameter residual CO₂ ice cap that is offset to the north-west of the south pole of Mars. This residual ice sheet is characterized by a uniquely high albedo that increases from the end of the polar night into late spring and accounts for the residual cap's year-round survival. The rest of the ice cap is characterized by a lower albedo and experiences total sublimation. Although global climate models reproduce the CO₂ cycle well, ice albedos are a fixed parameter in time and space and the entire southern ice cap is predicted to completely sublimate by the end of southern spring.

Colaprete et al. (2005)¹ hypothesized that the high albedo of the SPRC could result from the existence of a bimodal climate originating from a topographic forcing on the south polar regional atmospheric circulation. This asymmetry would result in higher atmospheric precipitation and snowfall rates over the region of the SPRC compared to the rest of the cap. Since the albedo value of ice strongly depends on the type of surface deposition (*snowfall* versus surface *frosts*), this high snowfall rate would contribute to the observed albedo asymmetry and contribute to maintaining the SPRC at a high enough albedo to allow for its year-round survival.

To test this hypothesis, we incorporate advanced CO₂ cloud microphysics in the Ames GCM and analyze the southern circulation and snowfall patterns obtained. We find that the model not only reproduces well the CO₂ cycle and available CO₂ cloud observations, but also predicts an asymmetric cloud cover over the southern ice cap during southern fall and winter that produces enhanced snowfall over a region encompassing the residual cap region. The resulting ratio of snowfall to direct surface deposition pattern is strongly asymmetric (Figure 1, left panel).

¹Albedo of the south pole on Mars determined by topographic forcing of atmosphere dynamics, A.Colaprete, J.R. Barnes, R.M.

Haberle, J.L. Hollingsworth, H.H. Kieffer and T.N. Titus. Nature, May 2005

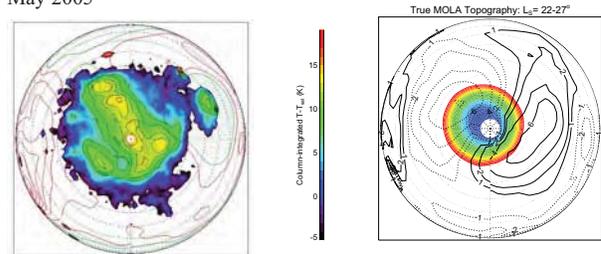


Figure 1: Left: ratio of total snowfall to total ice deposition throughout winter over the southern cap (high resolution run of 2° lat by 3° long. Right: column-integrated δT_{sat} (coloured contours) and temperature deviations from the zonal mean at pressure level 3.5 mbar around $L_s=22-27^\circ$ (full/dashed lines represent a positive/negative deviation to the zonal mean)

The asymmetric snowfall pattern is related to the cold phases of an atmospheric standing wave that develops throughout southern fall and winter as the seasonal flow encounters the asymmetric Martian topography (see also Colaprete *et al.*, 2005).

During late fall particularly ($L_s=22-27^\circ$), the predicted circulation is dominated by a strong wave number 1 pattern governed by Hellas and Argyre, which results in enhanced saturated temperatures at the vertical of the location of the SPRC (right of figure 1). This season corresponds to the southern ice cap seasonal maximum in cloud mass and radius over this same region. This result is in very good agreement with Giuranna et al. (2008)² and could play an important role in building up the asymmetry of the cap.

These promising results could lead to further interesting studies. For example implementing a more sophisticated ice albedo scheme dependant on the amount and size of aerosols falling onto the cap during fall and winter (snow, frost, dust) as well as surface metamorphism processes (due to sintering and incoming solar radiation for example) could further help understand the formation and current evolution of the southern residual ice cap.

²"PFS/MEX observations of the condensing CO₂ south polar cap of Mars", M. Giuranna et al., Icarus, 2008

Abstract:

Modeling the water cycle on Mars accurately is a complex problem that is difficult to solve. The water cycle is highly coupled to atmospheric temperature, dust, surface ice temperature, atmospheric mixing, and radiation, just to name a few. In particular, producing an accurate annual water cycle that models both water vapor and water-ice clouds is very problematic.

Common problems include a water vapor cycle that is too dry, or clouds that are too optically thick. Most often, either the water vapor or the clouds can be satisfied, but not simultaneously. Here, we present results from recent developments in the NASA Ames Mars GCM that improve water cycle simulations.

Part of the solution requires cloud nucleation and growth calculations to be performed on very short timescales. This is because the low temperatures in the Martian atmosphere lead to extremely low saturation vapor pressures of water, making high supersaturation very easy. Short timescales allow for the cloud particles to form normally, under slightly supersaturated conditions. This allows few cloud condensation nuclei (CCN) to be nucleated, which in turn grow to be large particles. Because the cloud particles are few and large, the clouds have smaller opacities, and also tend to fall out quicker.

1-dimensional simulations with short time steps show promising results. When running at 10 minute time steps the model reaches high supersaturation, and nucleates many particles (Fig. 1). However when running at 30 second time steps the saturation ratios are tame, and few particles are nucleated (Fig. 2).

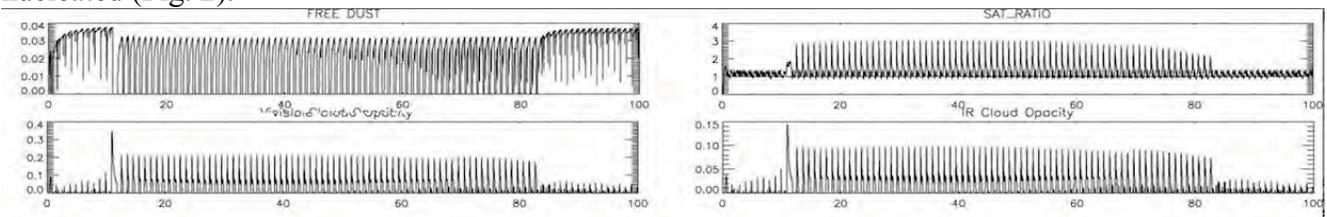


Figure 1. 100 sols of modeling with 10-minute time steps showing the mixing ratio of free dust (top left), water vapor saturation ratio (top right), visible cloud opacity (bottom left), and IR cloud opacity (bottom right).

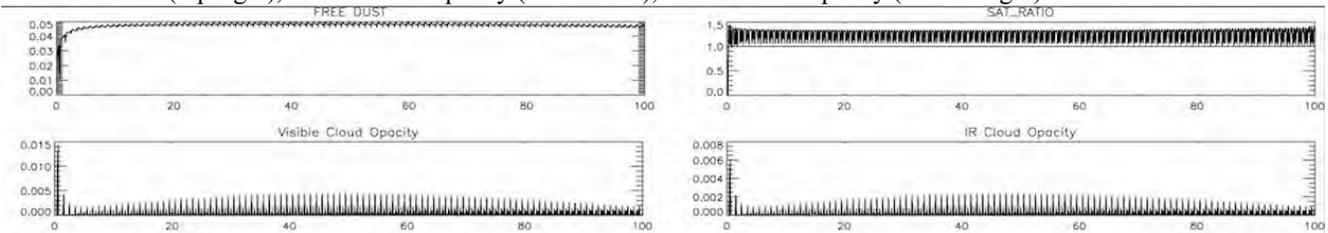


Figure 2. Same as Figure 1, except for 30 second time steps.

The 1-dimensional tests show that cloud formation requires short time steps, but running the full 3-dimensional model at these short timescales is impractical. Instead, a substepping method was implemented that only uses short time steps during cloud nucleation and growth, and lets the whole model run on longer time steps. The 1-dimensional results with substepping is shown in Figure 3.

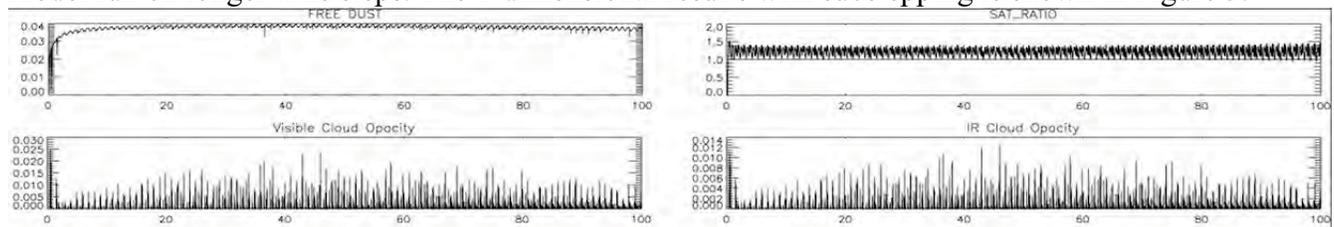


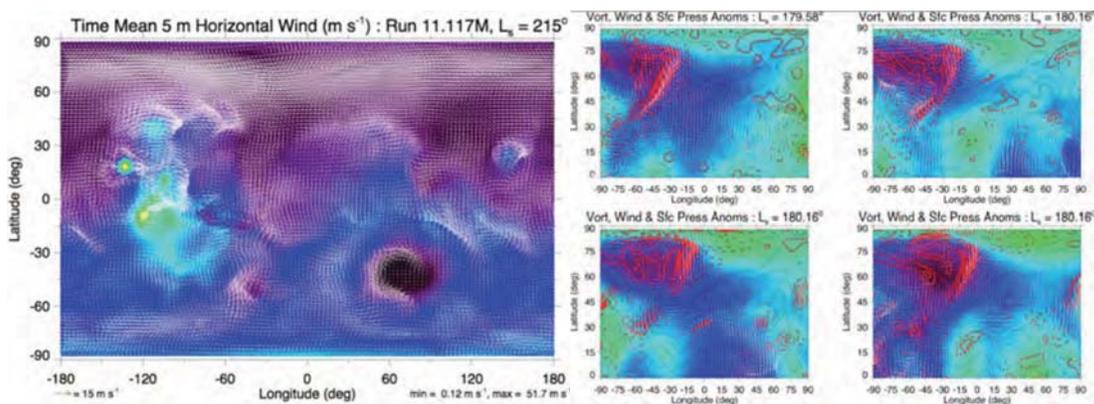
Figure 3. Same as Figure 1, with substepping on.

Title: Modeling Mars Cyclogenesis and Frontal Waves: Seasonal Variations and Implications on Dust Activity

Authors: J.L. Hollingsworth & M.A. Kahre, Planetary Systems Branch, NASA ARC, Moffett Field, CA 94035 USA

Topic: Planetary Atmospheres and Climate

Abstract: During late autumn through early spring, extratropical regions on Mars exhibit profound mean zonal equator-to-pole thermal contrasts associated with its waxing and waning seasonal polar ice caps. The imposition of this strong meridional temperature gradient supports intense eastward-traveling, synoptic-period weather systems (i.e., transient baroclinic/barotropic waves) within Mars' extratropical atmosphere. These disturbances grow, mature and decay within the east-west varying, seasonal-mean middle and high-latitude westerly jet stream (i.e., the polar vortex) on the planet. Near the surface, such weather disturbances indicated distinctive, spiraling "comma"-shaped dust cloud structures of large scale, and scimitar-shaped dust fronts, indicative of processes associated with cyclo- and fronto-genesis. The weather systems are most intense during specific seasons on Mars, and in both hemispheres. The northern hemisphere (NH) disturbances appear to be significantly more vigorous 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). Regarding dust, frontal waves appear to be key agents in the lifting, lofting, organization (i.e., confluence and diffluence) and transport of this atmospheric aerosol. A brief background and supporting observations of Mars' extratropical weather systems is presented. This is followed by various modeling studies (i.e., ranging from highly simplified, mechanistic and fully complex global circulation modeling investigations) that we are pursuing. In particular, transport of scalar quantities (e.g., tracers and high-order dynamically revealing diagnostic fields) are investigated. A discussion of outstanding issues and future modeling pursuits is offered related to Mars' extratropical traveling weather systems.



Analysis and Characterization of Titan Aerosol Simulants

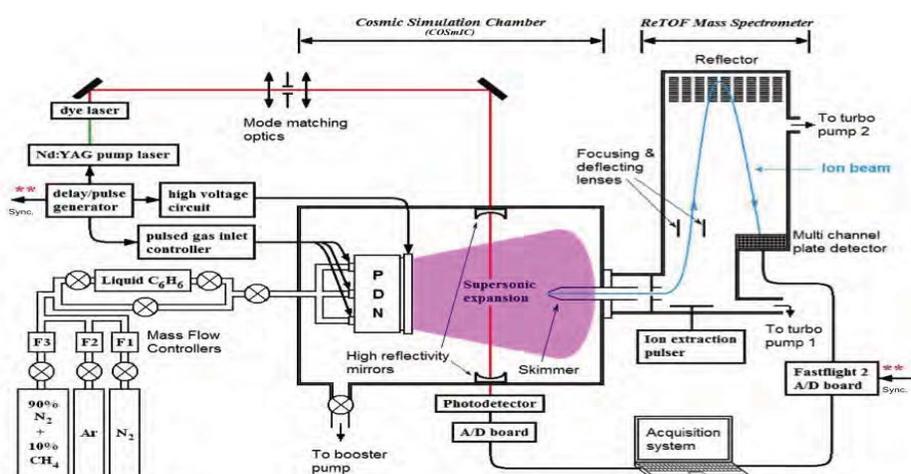
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Science Topic: Planetary Atmosphere & Climate

Titan, Saturn's largest moon, presents a unique research target in the solar system due to its dense atmosphere composed primarily of nitrogen and methane. Photochemistry and electron bombardment in Titan's atmosphere produce organic aerosols, which could contain precursors to prebiotics. The potential production of these molecules in Titan's aerosols is a topic of extensive research, leading to experimental production of simulant versions of these aerosols. The production methods rely on exposing a mixture of nitrogen and methane to an energy source such as a plasma or UV radiation. The experiments performed in this study utilize the Cosmic Simulation Chamber (COSMIC) to produce simulated aerosols in a supersonic cold plasma expansion with deposition on a variety of surfaces removed from the plasma discharge under a controlled environment. In the study presented here, these aerosols produced at Titan-like temperature (150-200K) were then analyzed using infrared spectroscopy and direct analysis in real time mass spectrometry (DART-MS). By examining the features in each of these spectra obtained through complementary analytical techniques, an idea of the functionalities present in the material can be obtained. This will allow for future prediction of likely compounds on Titan with important implications for the analysis of return data from Cassini and panning for future missions.

Figure 1: NASA Ames COSMIC



Ricketts, C.L., et al., The coupling of a reflectron time-of-flight mass spectrometer with a cosmic simulation chamber: A powerful new tool for laboratory astrophysics. *International Journal of Mass Spectrometry*, 2011. 300(1): p. 26-30.

Acknowledgements: K. T. Upton acknowledges the support of the NASA JFPF Program. The authors acknowledge the outstanding technical support of R. Walker and E. Quigley and the Caltech Glass Shop

Title: Dynamical Evolution of the Earth-Moon Progenitors

Authors: Billy Quarles and Jack J. Lissauer

Science Topic: Planetary Atmosphere & Climate

Abstract: In the Solar System's early history many processes have been proposed that depend on the dynamical state of the planets. Our study considers the possible dynamical states that produce a late Giant Impact (60 – 120 Myr) to form the Earth-Moon system. We investigate within the semimajor axis and eccentricity parameter space the possible outcomes of a 5 terrestrial planet model of the Solar System for 3 different mass ratios (8:1, 4:1, and 1:1) of the Earth-Moon progenitors. Using angular momentum conservation, an initial condition is prescribed for the progenitor masses while take initial conditions for the other Solar System bodies from a well-known common epoch. Additionally we test the 4:1 mass ratio with a different giant planet configuration akin to the Nice model.

We find local regions of our parameter space are more conducive to the outcome of a late Giant Impact. Mean motion resonances (MMRs) are identified between the terrestrial planets and used along with secular effects from the giant planets to indicate likely regions where a Giant Impact would occur. We characterize our results considering the estimated time of the Giant Impact, the resultant mass distribution of terrestrial planets, and the post collision mean angular momentum deficit (AMD). Case studies are presented illustrating the various possible outcomes with respect to their AMD relative to the current Solar System. Our statistical results show that a Nice model giant planet configuration can affect the occurrence of Giant Impacts. The implications on planet formation scenarios and implicit habitability will also be discussed.

Title:

Terrestrial analog field investigations to enable science and exploration studies of impacts and volcanism on the Moon, NEAs, and moons of Mars

Authors:

Darlene Lim¹, Jen Heldmann¹, Anthony Colaprete¹, Richard Elphic¹, Chris McKay¹, Derek Sears¹, Barbara Cohen², William Garry³, Kip Hodges⁴, Scott Hughes⁵, Kyeong Kim⁶, Gordon R. Osinski⁷, Noah Petro³, Steve Squyres⁸, Livio Tornabene⁷

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Science Topic:

Planetary Surfaces

Abstract:

Terrestrial analog studies are a critical component for furthering our understanding of geologic processes on the Moon, near-Earth asteroids (NEAs), and the moons of Mars. Carefully chosen analog sites provide a unique natural laboratory with high relevance to the associated science on these solar system target bodies. Volcanism and impact cratering are fundamental processes on the Moon, NEAs, and Phobos and Deimos. The terrestrial volcanic and impact records remain invaluable for our understanding of these processes throughout our solar system, since these are our primary source of firsthand knowledge on volcanic landform formation and modification as well as the three-dimensional structural and lithological character of impact craters. Regarding impact cratering, terrestrial fieldwork can help us to understand the origin and emplacement of impactites, the history of impact bombardment in the inner Solar System, the formation of complex impact craters, and the effects of shock on planetary materials. Volcanism is another dominant geologic process that has significantly shaped the surface of planetary bodies and many asteroids. Through terrestrial field investigations we can study the processes, geomorphic features and rock types related to fissure eruptions, volcanic constructs, lava tubes, flows and pyroclastic deposits. Also, terrestrial analog studies have the advantage of enabling simultaneous robotic and/or human exploration testing in a low cost, low risk, high fidelity environment to test technologies and concepts of operations for future missions to the target bodies. Of particular interest is the importance and role of robotic precursor missions prior to human operations for which there is little to no actual mission experience to draw upon. Also critical to understanding new worlds is sample return, and analog studies enable us to develop the appropriate procedures for collecting samples in a manner that will best achieve the science objectives.

Title: Helene: The Face that Launched a Thousand Slips

Authors: J.M. Moore (NASA Ames), O.M. Umurhan (SETI/NASA Ames), A.D. Howard (U. Va.), P.M. Schenk (LPI), P.C. Thomas (Cornell)

Topic: Planetary Surfaces and Interiors

Abstract: Helene, (~17.6 km mean radius) is a L4 Trojan co-orbital of Saturn's moon Dione. Its hemisphere features an unusual morphology consisting of broad depressions and a generally smooth surface patterned with streaks and grooves. The streaks appear to be oriented down-gradient, as are the grooves. This pattern suggests intensive mass-wasting as a dominant process on the leading hemisphere. Kilometer-scale impact craters are very sparse on the leading hemisphere other than the degraded km-scale basins defining the overall satellite shape, and many small craters have a diffuse appearance suggesting ongoing mass wasting. Thus mass wasting must dominate surface-modifying processes at present. In fact, the mass wasting appears to have been sufficient in magnitude to narrow the divides between adjacent basins to narrow septa, similar, but in lower relief, to the honeycomb pattern of Hyperion. The prominent grooves occur primarily near topographic divides and appear have cut into a broad, slightly lower albedo surface largely conforming to the present topography but elevated a few meters above the smooth surfaces undergoing mass wasting flow. Low ridges and albedo markings on the surface suggest surface flow of materials traveling up to several kilometers. Diffusive mass wasting produces smooth surfaces - such a pattern characterizes most of the low-lying surfaces. The grooves, however, imply that the transport process is advective at those locations where they occur, that is, erosion tends to concentrate along linear pathways separated by divides. In fact, in many places grooves have a fairly regular spacing of 125-160 m, defining a characteristic erosional scale. Several questions are prompted by the unusual morphology of Helene: 1) What is the nature of the surface materials? 2) Are the transport processes gradual or catastrophic motion from one or a few events? 3) What mechanisms drive mass wasting and groove development? 4) Have the formative processes been active in the recent past? 5) Finally, is the surface accreting or eroding? The smooth character of the leading edge hemisphere of Helene and the dominance of mass wasting suggest that the surface is composed of fine-grained debris, probably dominated by dust-size to small gravel particles. The Lagrangian points of saturnian satellites are locations where planetesimals might have accreted to form co-orbital satellites such as and they may capture ejecta from their master moon. Published models suggest that Helene is a site of net accretion, but we find no extant explanation for the dominance of fine grain sizes for the surface (and probable subsurface) composition of Helene and the other Lagrangian satellites. Observation of the mass wasting tracks on Helene suggests the presence of well-defined streams of debris with low bordering levees that may be depositional features or remnants of the dissected higher surface. Some flows in grazing illumination appear to have a convex cross-section. This mass-flow morphology might be consistent with the occurrence of large-scale flow events, but which might have occurred through rapid emplacement or slow glacier-like creep. On the other hand, small craters appear to have been "softened" by creep-like processes, indicating ongoing mass wasting.

Particle Size Distributions Impact on Determination of Mars Analog Materials Optical Constants. Ted L. Roush, Adrian J. Brown, Janice L. Bishop, David Blake, and Thomas Bristow.

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.

Among the various approaches used to estimate the optical constants of candidate materials over the past decades is Hapke's theory describing the scattered light from a particulate surface. A common assumption is to use the median grain size of a particulate sieve fraction to estimate n and k . Using SEM imaging we investigate the validity of this assumption for four Mars analog materials; palagonitic soil, orthopyroxene, and two smectite clays.

Our presentation will discuss estimated k -values using volumetric, areal, and numerical weighted particle size distributions and compare these to k -values estimated using the median sieve size.

Crater Relaxation and Heat Flow on Dione and Tethys: Near Cousins of Enceladus?

Oliver White¹, Paul Schenk², Andrew Dombard³

¹NASA Ames Research Center, Moffett Field, CA, United States. ²Universities Space Research Association, Houston, TX, United States. ³University of Illinois at Chicago, Chicago, IL, United States.

Science Topic: Planetary Surfaces and Interiors

Evidence for relaxation of impact crater topography has been observed on many icy satellites, including those of Saturn, and the magnitude of relaxation can be related to past heat flow. We have used stereo- and photogrammetry-derived global digital elevation models (DEMs) of the surfaces of eight Saturnian satellites that we have generated from Cassini data to obtain depth and diameter measurements for more than 500 craters. We have previously reported on relaxation simulations performed to determine what heat flow magnitudes and durations are necessary in order to achieve the current morphologies of certain relaxed and unrelaxed craters on Rhea and Iapetus (White et al., 2013). Combined with age estimates based on crater counting, we found that Iapetus has not experienced heat flows above radiogenic levels since formation of its basins, but that Rhea appears to have undergone a period of global elevated heat flow reaching 20-30 mW m⁻² that caused the relaxation of its largest impact basins. We now return our attention to Dione and Tethys, two satellites that show a more complex history of relaxation across their surfaces than either Rhea or Iapetus, with some areas showing extensive relaxation across a wide range of crater diameters, and other areas showing relatively little relaxation. Such a distribution would indicate a history of strongly differential heat flow across these satellites. New simulations of crater relaxation and associated heat flow on these satellites using crater profiles measured from our DEMs, in conjunction with new crater age estimates for the basins, allow us to map the history of heat flow variation across their surfaces. The results suggest that Tethys and especially Dione have been geologically active in their pasts, and that both may represent geologically less evolved cousins of Enceladus.

Reference: White, O., P. Schenk, & A. Dombard (2013) Impact basin relaxation on Rhea and Iapetus and relation to past flow. *Icarus*, 223, pp. 699-709, doi:10.1016/j.icarus.2013.01.013.

A talk is requested

THE PONDS ON EROS: POSSIBLE NEW INSIGHTS FROM EXPERIMENT, VESTA, MARS, AND TERRESTRIAL ANALOGS. Derek W.G. Sears^{1,2}, Livio L. Tornabene³, Gordon R. Osinski³, Scott S. Hughes⁴ and Jennifer L. Heldmann². ¹Bay Area Environmental Research Inst, 596 1st St West Sonoma, CA 95476, USA. ²NASA Ames Research Center, Mountain View, CA 94035, USA. ³Dept Earth Sciences/Physics and Astronomy/Centre for Planetary Science and Exploration, Univ Western Ontario, London, ON N6A 5B7, Canada. ⁴Dept Geosciences, Idaho State Univ, Pocatello, ID 83209, USA.

Introduction: One of the most intriguing features of the surface of near-Earth asteroid Eros are the so-called “ponds”, smooth areas at the bottom of craters (Fig. 1) [1]. Similar smooth areas have been observed on other asteroids [2]. The major properties of the Eros Ponds are that they (1) have distinctive flat floors sometimes showing non-central downside movement, (2) have sharp boundaries, (3) have uniform morphology, color and albedo, (4) typically have a radius $\sim 1/3$ the diameter and a $\sim 5\%$ of the depth of the host crater diameter and that they are not concentrations of a uniform widespread ejecta, and (5) can be seen on other (noncrater) depressions [3]. Additionally, (6) the Eros depressions appear preferentially at locus of



Fig. 1. Example of an Eros pond.

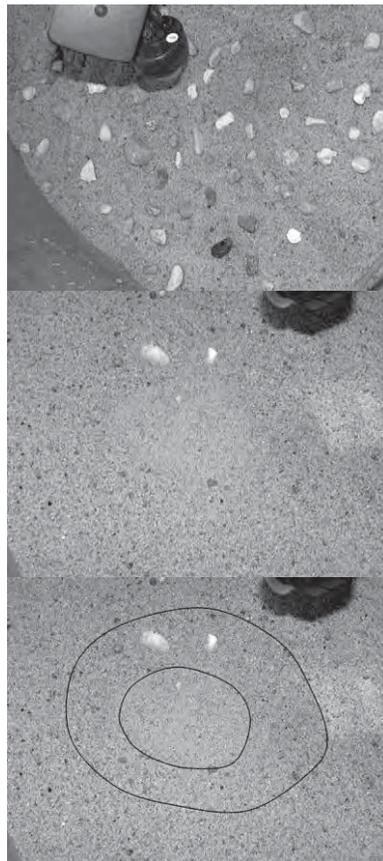


Fig. 2. One-g fluidization experiments on the surface of loose unconsolidated sand. Top, before. Middle, after. Bottom, crater-like depression (outer curve) and fine-grain “pond” (inner curve) shown.

sub-solar point and they are more abundant in regions of lower gravity. Regions of ponded regolith on asteroids were predicted by Cintala *et al.* [4] as a result of seismic shaking and this interpretation has been applied to the Eros ponds [5]. It has also been suggested that they are due to electrostatic processes occurring on the dry dusty microgravity environment [1]. With the recent discovery of water on Vesta’s surface, and its behavior during energetic events like impact, we suggest a role for volatiles in the formation of the Eros ponds.

Laboratory Simulations: Kareev *et al.* [6] and Hasseltine *et al.* [7] have reported experiments in which regolith simulants have been placed in a vacuum chamber and water or nitrogen allowed to flow through to the surface as the pressure was reduced (Fig. 2). Ice and water were placed 10 cm below the surface or nitrogen gas was bled in from a cylinder. The regolith simulant was an Hawaiian tephra or sand, of diverse grain size. Crater-like depressions were formed by the explosive release of volatiles or slow decrease in flow rate, and areas of flat fine-grained “pools” were made as the flow rate slowed and finally ended. The final features had a close resemblance to the Eros ponds and even “streaks” forming on “crater” walls.

Possible Martian Analog Observations: The recently observed pits observed on Mars may not be exactly analogous to the Eros ponds, but are features proposed to form when volatiles are released from impact melt-bearing deposits (Fig. 4)

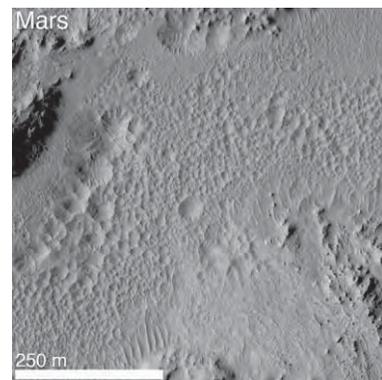


Fig. 4. Pitted terrain on Mars [9].

[8,9]. In this case the target surface contains a considerable amount of ice and there is a measurable atmosphere, although the latter is unimportant for pit formation based on current formation models.

Possible Vesta Analog Observations: It came as a considerable surprise when pits and pitted terrain [10] (and gullies [11]) were discovered on Vesta, as well as water-bearing regions [12] and dark areas [13]. These two observations were explained in terms of infall of CM chondrite material (which are a common meteoritic xenolith and can contain up to 10 vol% water). The Vesta pits, which resemble the pitted terrain on Mars, are interpreted as being caused by the release of volatiles from impact melts. The gullies may similarly be evidence for fluid-abetted mass wasting [11], but may also be explained as dry flows [14].

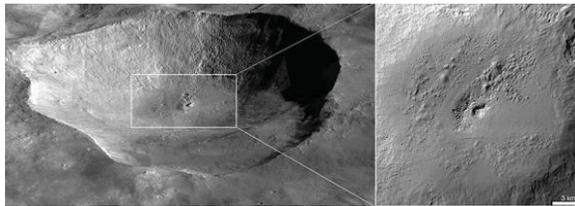


Fig. 5. Marcia crater on Vesta with a smooth plain at the bottom with numerous pits [10].

Possible Impact Analog Observations: Additional work over the last few years supports that volatiles can play a major part in the formation of impact craters on Earth [15,16]. One of the pioneering studies on this subject by Newsom et al. [17] indicated that volatiles were released during the formation of ‘suevite’ – clay-rich impact melt-bearing breccias – at the Ries Crater in southern Germany (Fig. 6). Fieldwork carried out by one of us (GRO) has shown that these features are not distributed evenly around the Ries structure and these ‘pipe structures’ are typically dm across and extend vertically for several m. We do not know the original scale of these features and their surface manifestations, as active meteorology and vegetation may have removed them in the case of the Ries, but clearly volatile release during impact is a process to be considered on impacted surfaces.

Possible Volcanic Analog Observations: Phreatic pits are formed when lavas flow over water-bearing sediments and are well-documented at the Craters of the Moon National Monument and Preserve [18]. They are usually formed explosively and there are numerous boulders scattered around the pit. Some have been smoothed over by loess and surrounded by subsequent flows (Sugar Bowl), some show evidence for multiple events (Split Butte), while others are deep rooted and expose underlying strata (King’s Bowl). All represent an interaction between volatiles and surface materials during energetic events.



Fig. 6. Channels caused by the release of volatiles during impact that formed the Ries Crater.



Fig. 7. Phreatic pits at the Crater of Moons National Monument and Preserve, Sugar Bowl, Split Butte, and King’s Bowl.

Discussion: At this point we are not inferring that the Eros ponds are simple analogs of the pits and phreatic structures, but we do point out that if Vesta contained sufficient exogenous water to produce these textures then S asteroids should also. Seismic shaking and electrostatic processes might well explain the Eros ponds, but in view of the prevalence of volatile interactions on these diverse planetary bodies we suggest that volatile driven processes should also be investigated in the case of the Eros ponds.

References: [1] Robinson et al., 2001. *Nature* **413**, 396-400. [2] Fujiwara et al., 2006. *Science* **312**, 1330-1334. [3] Robinson et al., 2002. *MAPS* **37**, 1651-1658. [4] Cintala et al., 1979. In *Asteroids*, 579-600. [5] Cheng et al. 2001. *MAPS* **37**, 1095-1105. [6] Kareev et al. 2002. *LPSC* #1610. [7] Hasseltine et al. 2006. *LPSC* #1103. [8] Tornabene et al. 2012. *Icarus* **220**, 348-368. [9] Boyce et al. 2012. *Icarus* **221**, 262-275. [10] Denevi et al. 2012. *Science* **338**, 246-249. [11] Scully et al. 2013. *LPSC* #1578. [12] McCord et al., 2012. *Nature* **491**, 83-86. [13] De Sanctis et al. 2012. *Science* **336**, 697-700. [14] Jaumann et al. 2013. *EPSC* #2013-307. [15] Kirsimäe and Osinsky, 2013. In *Impact Cratering*, 76-89. [16] Stöffler et al., 2013. *MAPS* **48**, 525-589. [17] Newsom et al. 1986. *JGR* **48**, E239-E251. [18] Hughes et al. 1999. In *Guidebook to the Geology of Eastern Idaho*, 143-168.

Title: Drill Embedded Nanosensors for Planetary Subsurface Exploration**Authors:** Li J.¹, Stoker R. C.², Lu Y.³, Willson D.⁴, Zhao B.⁵

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(4) KISS institute of Practical Robotics, Norman, OK. (5) Emory University, Atlanta, GA

Topic: Planetary Surfaces and interior

Abstract: We developed a carbon nanotube (CNT) sensor capable of detecting water vapor with very high sensitivity, in real time for ice detection while drilling into Mars subsurface icy regolith mixtures. The system was tested and calibrated in a simulated drill string and borehole.

Current methods for sensing icy deposits on Mars and the moon include: volume hydrogen measurements from a surface located neutron spectrometer, optical spectral measurements to identify water spectral lines, or direct analysis of samples using mass spectroscopy. The neutron spectrometer detects neutrons from of 1m^3 volume(s) of regolith, optical spectroscopy requires $\sim 1\%$ water ice before detection and mass spectroscopy has very high sensitivity but requires sample delivery to an instrument.

In contrast the CNT sensor's detection limit is $10^{-6} - 10^{-9}$ and the sensors are tiny with significantly lower power usage compared to other instruments and can be fitted inside a drill string. The sensor detects the very low concentration ice vaporized by the drilling action in real time, thus fine scale information on the ice vertical structure in the borehole can be obtained.

A CNT gas sensor that operated under Earth conditions was modified to detect water vapor in Mars conditions by adding a functional group to the CNT sidewall. It's performance was characterized under Mars pressure ($\sim 6\text{mbar}$) and temperature (-45°C) conditions in a simulated drill string and borehole, showing that it could detect small quantities of water vapor introduced into its vicinity (see graph figure 1 - left). The sensor was miniaturized, and data acquisition and wireless communication electronics were added to enable transmission of sensor data from the drill string in a borehole to a USB receiver plugged into a computer without bringing wires through the rotating interface.

Finally, the drill Bit was modified by adding two water vapor inlets providing water vapor access to the CNT sensor located inside the drill string. Regolith shields were installed over the inlets to prevent blockages while drilling (see figure 1 - right). The regolith shield concept will require further testing in ambient air conditions, drilling into analog Mars regolith. Once proven vacuum testing of the drill string and CNT assembly, in Mars conditions, can be undertaken. In particular these tests are to focus on the question: How much ice in the regolith is required for detection?

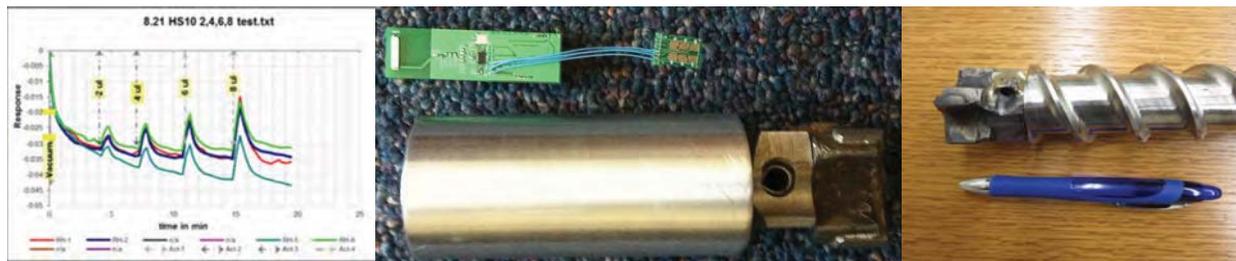


Figure 1: Left, Water detection at $\sim 6\text{mbar}$ & -45°C ; Middle, CNT with simulated Bit and hole. Electronics made to fit the drill string; Right, Modified drill string and Bit with a regolith shield covering a water vapor inlet.

The Map-X instrument proposed for the Mars 2020 Mission

Authors: David Blake, Philippe Sarrazin, Thomas Bristow, David DesMarais and Tori Hoehler

Science Topic: Planetary Surfaces and Interiors

Many planetary surface processes (like physical and chemical weathering, water activity, diagenesis, low-temperature or impact metamorphism, and biogenic activity) leave traces of their actions as features in the size range 10s to 100s of μm . For identifying these diagnostic features, it is crucial to acquire chemical compositional information on length scales that are less than or equal to the dimensions of grains or phases that are being imaged or analyzed. High-resolution chemical imagery and elemental analysis are important to planetary science, and currently there is no instrument capable of providing such data. The Mapping α -particle X-ray Spectrometer (“Map-X”) will provide chemical imaging at 2 orders of magnitude higher spatial resolution than previously flown instruments, yielding elemental chemistry at or below the scale length where many relict physical, chemical, and biological features can be imaged and interpreted in ancient rocks. Map-X has been proposed for Mars 2020, to satisfy one of the five “threshold” measurement requirements of the mission: *“To determine the fine-scale elemental chemistry of sedimentary, igneous, and diagenetic alteration features.”*

Map-X is an arm-based instrument placed on the surface of an object to be analyzed (e.g., pristine or abraded rock, soil, drill core on the observation tray) and held in registry with it through the use of touch sensors that physically touch the surface. During an analysis, a radioisotope source bombards the sample surface with α -particles and γ -rays, resulting in x-ray fluorescence from the sample. X-rays emitted in the direction of an X-ray sensitive CCD imager pass through an x-ray 1:1 focusing lens (called an X-ray μ -Pore Optic, MPO) that projects a spatially resolved image of the x-rays generated from the sample surface onto the CCD. The frame-transfer CCD is read at the rate of 1 frame per second. The images are stored in memory and processed in real time using algorithms parameterized from the ground. The source flux is designed and scaled such that during a single exposure, in the large majority of cases, no more than a single photon strikes each pixel between frame transfers. In this way, the energy of each x-ray photon can be measured and its source element in the sample identified. In a 2-3 hour experiment, several thousand frames are both stored and processed in real-time.

Primary data products include single-element maps for elements of interest with a lateral spatial resolution of $\leq 100 \mu\text{m}$ and an XRF spectrum from the area imaged. Additional data products include XRF spectra from ground-in-the-loop defined Regions of Interest (ROIs). XRF spectra from ROIs are processed on the ground to determine quantitative elemental compositions. Quantitative compositions from ROIs are compared with known rock and mineral compositions to extrapolate the data to rock types and putative mineralogies. A single Map-X experiment provides elemental and compositional maps and quantitative XRF spectra having a spatial resolution of $\leq 100 \mu\text{m}$, commensurate with other imaging instruments on the rover arm and mast.

**Ice Chemistry on Outer Solar System Bodies:
Carboxylic acids, Nitriles, and Urea Detected in Refractory Residues
Produced from the UV-photolysis of N₂:CH₄:CO Containing Ices**

Christopher K. Materese, Dale P. Cruikshank, Scott A. Sandford, Hiroshi Imanaka,
Michel Nuevo, Douglas W. White
Topic: Planetary Surfaces
Code: SSA

The outer Solar System (beyond 20 AU) is populated with cold icy bodies that are constantly exposed to various forms of radiation including high-energy photons and cosmic rays. This radiation can provide the energy to drive chemistry within ices even in these extremely cold conditions. This energetic processing of the ice results in the formation of new ions, radicals, and molecules, some of which are large, complex, and refractory. Additionally, even more complex compounds are made if these reactive ices are subsequently warmed.

Laboratory experiments used to simulate the conditions on these icy bodies can provide insight into this chemistry. Much progress has been made in the laboratory toward understanding the chemistry of energetically processed ices, but significantly less progress has been made in understanding the refractory material produced. Here we present the results of laboratory experiments involving the UV-photolysis of N₂-, CH₄- and CO-containing ices (100:1:1, respectively), a mixture analogous to what is known to exist on the surface of Pluto, with a focus on analysis of the refractory material. We use several chemical analysis techniques: infrared (IR) spectroscopic analysis of the resulting ice and refractory residue, X-ray Absorption Near Edge Structure (XANES) spectroscopic analysis of the refractory residue, and analysis of refractory residue with gas chromatography coupled with mass spectrometry (GC-MS). The IR data are useful for identifying some specific compounds and radicals in the ice phase while providing some general information the chemical moieties in the refractory material. The XANES measurements provide global information on the bonding present in the samples as well as constraints on its elemental composition. Finally, the GC-MS data provide a means for identifying specific compounds in the refractory material after it has been extracted from the vacuum chamber.

Infrared spectra of the refractory material indicate the presence of O–H, N–H, C≡N, and C=O functional groups. These bands suggest the presence of alcohols, carboxylic acids, ketones, aldehydes, amines, and nitriles. XANES spectra of the material indicate the presence of aromatic or olefinic carbons, nitriles, carboxyl groups, urea and nitriles, results consistent with the IR data. XANES data also provide atomic abundance ratios (N/C = 0.5±0.1, O/C = 0.3±0.1) of the material. Finally, the GC-MS reveals that the residues contain numerous carboxylic acids and urea.

These results can be the basis for the interpretation of spacecraft and telescopic spectral studies of the surfaces of objects in the outer Solar System, and ultimately the icy bodies in planetary systems discovered around other stars.

Title: Interstellar Organics, the Solar Nebula, and Saturn's Satellite Phoebe**Y. J. Pendleton¹, D. P. Cruikshank¹**¹NASA Ames Research Center, Moffett Field, CA 94035**ABSTRACT**

The diffuse interstellar medium inventory of organic material (Pendleton et al. 1994, Pendleton & Allamandola 2002) was likely incorporated into the molecular cloud in which the solar nebula condensed. This provided the feedstock for the formation of the Sun, major planets, and the smaller icy bodies in the region outside Neptune's orbit (transneptunian objects, or TNOs). Saturn's satellites Phoebe, Iapetus, and Hyperion open a window to the composition of one class of TNO as revealed by the near-infrared mapping spectrometer (VIMS) on the Cassini spacecraft at Saturn. Phoebe (mean diameter 213 km) is a former TNO now orbiting Saturn. VIMS spectral maps of Phoebe's surface reveal a complex organic spectral signature consisting of prominent aromatic (CH) and aliphatic hydrocarbon (CH₂, CH₃) absorption bands (3.2-3.6 μm). Phoebe is the source of a huge debris ring encircling Saturn, and from which particles (~5-20 μm size) spiral inward toward Saturn. They encounter Iapetus and Hyperion where they mix with and blanket the native H₂O ice of those two bodies. Quantitative analysis of the hydrocarbon bands on Iapetus demonstrates that aromatic CH is ~10 times as abundant as aliphatic CH₂+CH₃, significantly exceeding the strength of the aromatic signature in interplanetary dust particles, comet particles, and in carbonaceous meteorites (Cruikshank et al. 2013). A similar excess of aromatics over aliphatics is seen in the qualitative analysis of Hyperion and Phoebe itself (Dalle Ore et al. 2012). The Iapetus aliphatic hydrocarbons show CH₂/CH₃ ~4, which is larger than the value found in the diffuse ISM (~2-2.5). Insofar as Phoebe is a primitive body that formed in the outer regions of the solar nebula and has preserved some of the original nebula inventory, it can be key to understanding the content and degree of processing of that nebular material. There are other Phoebe-like TNOs that are presently beyond our ability to study in the organic spectral region, but JWST will open that possibility for a number of objects. We now need to explore and understand the connection of this organic-bearing Solar System material to the solar nebula and the inventory of ISM materials incorporated therein.

Planetary Analog Research and Climate Change Monitoring in a Land of Extremes: The Ubehebe Volcanic Field, Death Valley, California

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Astrobiology

We report results from our Astrobiology Field Analog work under way at the Ubehebe Volcanic Field (UVF) in Death Valley National Park. Furthermore, we outline the relevance of cross-disciplinary and multi-component investigations to themes such as climate change and water resources monitoring.

The Ubehebe Volcanic Field (UVF) (~15 Km²) includes a dozen craters formed during hydro magmatic explosions occurred sometime between 1 thousand (Ka) and 6 Ka years ago. Among these, the Ubehebe Crater (UC) encompasses several features seen at Gale Crater, the Mars Science Laboratory (MSL) Landing Site, including a variety of fine- to coarse-grained sediments (fluvial, alluvial, and lacustrine).

The UC represents an ideal natural laboratory to test hypotheses concerning the deposition of clay-rich crater fill sediments under analog hydro-climatic conditions [1-2] as found at Yellowknife Bay, Gale Crater [5]. For instance, here we can study the relationship among rainfall (amounts, intensity, and frequency), erosion, deposition of Gale Crater-like sediments, and formation of hydrated minerals (sulfates, clays) [3-4].

Clays are unambiguous indicators of past aqueous activity on Mars. Therefore, understanding the climatic context under which clay-rich sediments are formed and recycled in extreme terrestrial environments is the cornerstone for addressing the potential of sedimentary and mineral settings to support microbial life on Earth [e.g., 6] as well as, possibly, on a wetter warmer early Mars [1-2].

To date, the conditions conducive to possible in-situ formation/recycling of smectite clays at UC include: a) ~50mm to >250 mm/y rainfall in water years (WY) 2004-2013. In WY 2011, 2012, and 2013, Summer rainfalls accounted for ~30% and ~50% of the total annual precipitation, respectively. b) Ground moisture ranging from dry-very dry (1-<10 %Wt. water content for a. 87% of time, WY 2011) to wet-saturated (10-60 %Wt. water content for a. 10% of time). Ephemeral ponds appear to form once a year and can last for one-two weeks (2008-2011 study years). c) Ground temperature between -16°C and + 70°C. d) pH ~8-9.5.

References: [1] Barnhart et al., (2009). *J. Geophys. Res.* [2] Craddock & Howard, 2002 *Geophys. Res.*, 107(E11),5111. [3] Mustard et al., (2008) *Nature*, 454(7202):305-309. [4] Milliken and Bish (2010) *Phil. Mag.* 90(17-18):2293-2308. [5] Vaniman et al. 2014. *Science*, 343:1243480-1-1243480-8. [6] Bonaccorsi et al., 2010 *Phil. Mag.* 90(17-18):2309-2327.

Gene Expression Measurement Module (GEMM)- the door to high-throughput *in-situ* analyses of biological systems in space

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Science Topic: Astrobiology

A central, long-standing goal of the astrobiology program that holds promise for both major scientific discoveries and exciting the general public is to understand life in outer space and on other celestial bodies. 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. The ability of microorganisms to survive in a wide range of conditions encountered in space would support the hypothesis 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.

In order to facilitate studies on the impact of the space environment on biological systems, we have developed GEMM (Gene Expression Measurement Module) - an automated, miniaturized, integrated fluidic system for *in-situ* measurements of gene expressions in bacterial samples. The project has been funded through the ASTID program. The GEMM instrument is capable of (1) lysing bacterial cell walls, (2) extracting and purifying RNA released from cells, (3) hybridizing it to probes attached to a microarray and (4) providing electrochemical readout, all in a microfluidics cartridge. Its first application on a nanosatellite platform is to cultivate and measure gene expression of the photosynthetic bacterium *Synechococcus elongatus*, a cyanobacterium known for its metabolic diversity and resilience to adverse conditions, under light and dark cycles exposed to polar orbit for a period of 6 months. The 1U GEMM prototype for nanosatellite platform will be displayed. Furthermore, the integration and end-to-end technology validation of this instrument will be discussed. In particular, results demonstrating that the instrument properly measures gene expression after cellular lysis, nucleic acid extraction, its purification, and hybridization to an electrochemical array will be presented and compared to commercial microarray analysis. Finally, a proposed version of GEMM that is capable of handling both microbial and tissue samples on the International Space Station will be briefly reviewed.

Introducing SSERVI Yvonne Pendleton, Director

In the fall of 2013, NASA created the Solar System Exploration Research Virtual Institute (SSERVI) to address basic and applied scientific questions fundamental to understanding our Moon, Near Earth Asteroids, the Martian moons Phobos and Deimos, and the near space environments of these target bodies. SSERVI is jointly supported by NASA's Science and Human Exploration Missions Directorates (SMD and HEOMD), and is an expansion of the successful NASA Lunar Science Institute (NLSI).

The leadership and central office of the former NLSI, located at NASA Ames Research Center, now directs SSERVI, fostering collaborations within and among 9 new U.S. teams, the broader U.S. science and exploration research communities, and 7 international partners.

SSERVI's Mission is to:

- Conduct and catalyze collaborative research in lunar and planetary science, enabling cross-disciplinary partnerships throughout the science and exploration communities
- Provide scientific, technical, and mission-relevant analyses for appropriate NASA programs, planning, and space missions
- Innovatively use technology for scientific collaboration and information dissemination across geographic and contextual boundaries
- Train the next generation of scientific explorers through research opportunities, and encourage public engagement through informal programs and participatory public events.

Teams are competitively selected and funded for five years. Calls for new teams will be released midway through each five-year cycle to provide an overlap of new and existing teams within the Institute. Community members are encouraged to participate in SSERVI through virtual seminars and workshops, the annual Exploration Science Forum (July 21-23, 2014) at NASA Ames Research Center, and through the many SSERVI Focus Groups. Graduate students and young professionals are encouraged to participate in the LunarGradCon and NexGen conferences held before the Forum each year. Please visit sservi.nasa.gov for more information.

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Title: Where Your Ideas Become Reality, The Space Science and Airborne Instrument Development Lab.

Author: Emmett Quigley

Science Topic: All

The Space Science and Airborne Instrument Development Laboratory (SS AIDL) supports Code S researchers by designing, developing, constructing, testing and deploying instruments in laboratory, observatory, airborne and space environments. The capability to support instrument development from cradle to grave facilitates low-cost, rapid development of instrumentation. In addition to specializing in rapid development of ground equipment and prototypes, the SS AIDL has the ability to implement appropriate controls for development of flight hardware. The AIDL possesses a wide range of fabrication capabilities including a DMG DMU &70V three axis contouring and five axis positioning machining center, three and four axis CNC milling, CNC turning, CNC sinker EDM, surface grinding as well as manual machine tools. The lab also has reverse engineering capabilities. Recent projects supported by the SS AIDL include EXES, laboratory astrochemistry, EDSN, Lunar Plant Experiment, MARTE MDRS Rig Development, RESOLVE, SIERRA UAV, Alpha-Jet PICARRO, O3/CO2 and MMS integration, SOFIA Water Vapor Monitor, Ames Coronagraph.