DREAM2 Annual Report Program Year #1: March 2014 to March 2015

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I. DREAM2 Team Progress Report

Airless bodies are exposed directly to the harsh space environment, including space plasmas, UV- and x-rays, micro-meteoroid impacts, and high energy charged particle radiation. In direct response to this energy, bodies react by emitting neutral and ion vapors, by altering the flow of the surrounding space plasma, and by creating high energy secondary radiation. To understand the connection between the space environment's coupled and dynamic interactions with exposed rocky bodies and human systems, SSERVI's center called the Dynamic Response of the Environment at Asteroids, the Moons and moons of Mars (DREAM2) advances key science environmental themes that seamlessly intertwine into exploration applications.

The DREAM2 center or space environment studies advances the understanding of the following question: **"How does the highly-variable environmental energy at an airless body affect volatiles, plasma, new chemistry, and surface micro-structure?".** To pursue this question DREAM2 has 6 themes that are common to exposed bodies: Plasma interaction, exosphere formation, radiation interaction, surface modification, effects from extreme events, and finally human interactions (in the form of missions and exploration). **Figure 1** illustrates the overlapping fundamental themes.

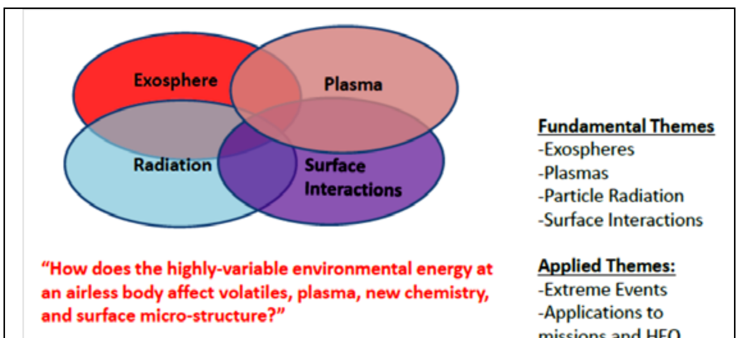


Figure 1- Overlapping DREAM2 themes

In the first year, the DREAM2 Program Office established 9 cooperative agreements with our expert partners and initiated funding. The Program Office also updated its webpage (http://ssed.gsfc.nasa.gov/dream/) and continued to fund support services of the DREAM2 Polycomm equipment located in the dedicated DREAM2 room at GSFC.

However, DREAM2's most critical element was the initiation of the team's science tasks, and this first year has been very successful with publication of numerous new findings, the inclusion of early career scientists, and successful demonstration on how science can support exploration – especially in the area of space environments.

Theme 1. Plasma Interactions at Small Bodies

The plasma provides the first interface to the surface of the Moon and other airless (or nearly airless) small bodies. Energy from plasma of solar and/or magnetospheric origin interacts directly with the surface, and also with exospheric gases derived from the surface. The result of this interaction is a bubbling cauldron of dynamic activity, with electrons, neutrals, and ions all blasted from the surface, charge layers built up on and above the surface, and nascent shocks and foreshock-like interactions developing as material derived from this interface feeds back on the incoming plasma. Understanding these interactions not only lays the groundwork for future exploration, but also strengthens our grasp of fundamental processes, with implications for other planetary bodies throughout our solar system and beyond.

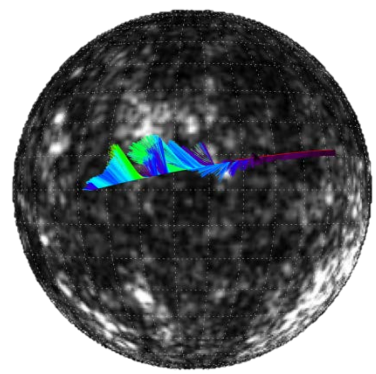


Figure 2: Solar wind magnetic field lines (color) distorted and shocked by their interaction with lunar crustal magnetic fields (grey-scale).

Only a few years ago, many researchers thought that the Moon merely provided a quiescent solid obstacle to the plasma flow, producing a downstream wake and little else. Then, in the late 2000's, high quality data from a host of new missions brought a revolution in our understanding of Moon-plasma interactions, showing that reflected and secondary particles from the Moon in fact significantly affect a region many tens of thousands of km in extent, with disturbances extending far upstream from the surface. A corresponding scientific surge awaits us at small bodies, and the DREAM2 team, with its combination of simulation experts and leading experimentalists, is poised to lead that surge. To fulfill this goal, DREAM2 proposed an investigation with the following topics, all of which we have made great progress on in the first year of performance.

Plasma Interactions Topic	Progress in Year One
Plasma Interaction vs. Body Size	Zimmerman and Fatemi et al. simulations of plasma interactions with small-scale magnetic fields, Halekas et al. observations of the smallest shocks in the solar system, Poppe et al. Phobos simulations and small-body interactions. Lipativ and Cooper have been developing hybrid models of pickup ions at the Moon.
Volatile/Plasma Connections and Exo-Ionosphere	Poppe and Sarantos anisotropic sputtering, Farrell and Hurly proton implantation studies, Halekas/Poppe/Sarantos LADEE plasma-exosphere coupling studies, Collier ROSAT X-Ray observations, Jordan & Stubbs breakdown weathering in lunar polar cold traps.
Plasma Grounding and Electrical Interaction	Jackson and Farrell human system-plasma electrical interaction modeling.
Effects of Composition, Conductivity, Magnetic Field	Poppe and Sarantos sputtering in crustal magnetic field regions, Collier & Newhart ALSEP magnetotail ion investigations, Halekas et al. mini-shock observations, Sarantos et al. exospheric modeling.
Special Regions around Small Bodies	Zimmerman et al. tree-code simulations of plasma and surface charging at small irregular bodies.
Dust Around Small Bodies	Hartzell and Zimmerman plasma and dust simulations around small bodies.

Key plasma highlights from DREAM2's Year One include the first resolved observations of shock-like structures (**Figure 2**) forming above magnetic anomalies at the Moon by DREAM2 researchers using ARTEMIS data (resolving a 40-year old debate about the existence of shocks at the Moon), arriving hand in hand with two first-of-kind simulations of these dynamic regions, both from DREAM2 researchers.

Other highlights include a model of astronaut charging as they push themselves around shadowed regions of an asteroid (Jackson et al, 2014) and the transport of lunar polar crater volatiles from crater floors to topside adjacent regions by impact vaporization and sputtering (Farrell et al., 2015).

Theme 2. Exospheres and Corona at Exposed Bodies

A rocky body expose directly to the space environment will emit atoms and molecules from its surface due to interactions with high-speed particulates, plasmas, and radiation. On larger bodies like the Moon and Mercury, these free atoms and molecules can become gravitationally bounded – never quite leaving the body's gravity pull- forming a surface bounded exosphere. However, on small bodies the gravitational forces are small thereby allowing the atoms/molecules to escape from the body, forming a corona of escaping gas about the body.

The topics studied by DREAM2's exospheres team fall into five broad categories: 1) To study the effects of body mass and size on the characteristics of its exosphere, 2) To examine drivers of dynamics as a function of distance from the sun. 3) To consider the corona as a medium to determine the underlying composition. 4) To determine water production and migration as a function of heliocentric distance. 5) To determine the nature of the exo-ionosphere vs. body size and heliocentric distance. 6) To determine the relative delivery of noble gases from the solar wind vs. the interior. 7) To determine the production and loss of hydrogen -bearing and carbon-bearing compounds.

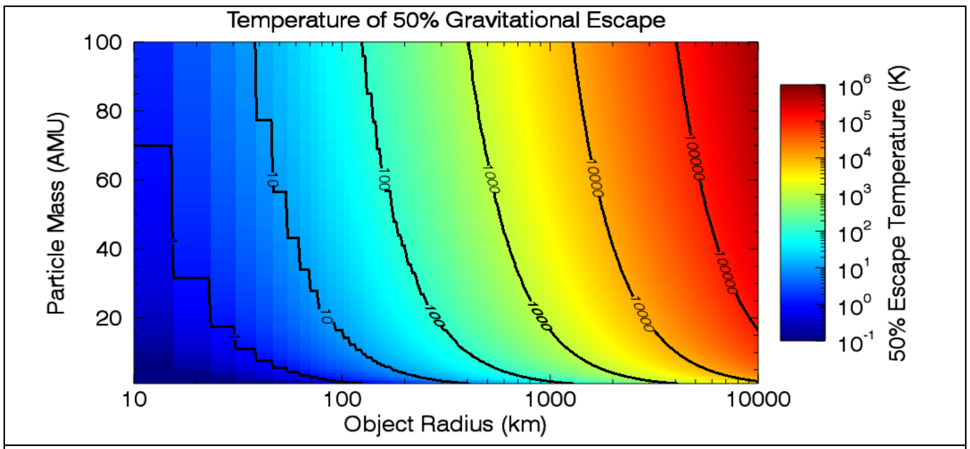


Figure 3 – Results from the generalized exosphere model showing the 50% escape energy as a function of atom mass and object size. The contours show where 50% of the gas in the Maxwellian distribution escapes into free space for a given temperature (on contour), AMU (y-axis) and body size (x-axis).

In DREAM2's first year of study significant advances in each of these topics were made. These include the following:

- Initiated a study of the universal exosphere character as a function of AMU, physical process energy, and exposed body size (from Mercury sized to 10 km). For example, results of this 'Generalized Exosphere Model (GEM)' clearly show that ~50% of water molecules (AMU = 18) stay bounded to a Moon-sized body when released by impact vaporization (T~4000K), but completely escape for a small body (**Figure 3**). The study was presented at ASM2014 (Killen, Burger, et al. 2014)

- DREAM2 Co-Is Collier et al discovered that the lunar exosphere emits x-rays detectable by ROSAT. The x-ray emission profile at locations just nightside ot the terminator appeared to be consistent with model exosphere density profiles provided by Sarantos.
- DREAM2 and VORTICES team members examined the effect of Orion out gassing on a small body like that expected during the ARM mission. They concluded that Orion water should stick to the space weathered asteroid surface, but the amount that sticks depends on the number and nature of the defects which create more potent adsorption sites. \
- In anticipation of MAVEN's arrival, Poppe and Curry (2014) developed a model of surface sputtering from Phobos, and presented the concept that Phobos should have an exosphere/corona driven in part by the heavy O+ ions from Mars' own atmosphere. The moon-emitted atoms were shown to form a donut-like torus about Mars, similar to the Enceladus neutral torus about Saturn.
- Team members examined MESSENGER observations and found an effect in Mercury exospheric concentration in association with impacts from meteor streams (Killen and Hahn, 2014). In essence, as the stream passes the exospheric content should increase and is congruent with recent LADEE results (Colaprete et al., 2015, LPSC 2015, abstract 2364) where substantially greater exospheric content in O, OH, Ti and Fe was observed at the Moon during the Geminid shower.
- Continue ongoing work by Sarantos and Killen on improving the surface interaction of their exosphere code, including more advanced modeling of the effect of impacts and the surface-atom binding energy (i.e., activation energy). This work was presented at the DREAM F2F meeting on October 2014.
- DREAM2 co-I Hodges continues to apply his Lunar Exosphere Simulator (LExS) code to LADEE observations, especially in support of the NMS team.
- Co-I Hurley leads the Friends of Lunar Volatiles fosus group, and recently organized a special issue of Icarus devoted to lunar volatiles.

Theme 3. Radiation interactions at Exposed Surfaces

Airless bodies like the Moon, the moons of Mars, or near earth asteroids (NEAs), are exposed to an energetic particle radiation environment that can significantly affect their surfaces. This environment comprises slowly varying, yet highly energetic galactic cosmic rays (GCRs) and sporadic, lower energy solar energetic particles (SEPs). These particles are energetic enough to penetrate the regolith of airless bodies: GCRs down to ~1 m and SEPs to ~1 mm. GCRs can eject energetic protons from lunar regolith, which can then be detected and mapped. GCRs and SEPs both deep dielectrically charge the subsurface regolith. SEPs, in particular, may create electric fields strong enough to cause breakdown (i.e., sparking). Throughout the Moon's history, this breakdown may have weathered the regolith within permanently shadowed regions.

<u>Tools</u>

- **Lunar albedo proton map:** Co-I Wilson has developed techniques to map and analyze albedo protons spalled by GCRs from lunar regolith. These protons are detected by the Cosmic Ray Telescope for the Effects of Radiation (CRaTER) on-board the Lunar Reconnaissance Orbiter (LRO).
- **Deep dielectric charging model:** Co-I's Jordan and Stubbs have created a time-dependent, data-driven, deep dielectric charging model to estimate the magnitudes of subsurface electric fields created by GCRs (detected by LRO/CRaTER) and SEPs (detected by LRO/CRaTER and the Electron, Proton and Alpha Monitor (EPAM) on-board the Advanced Composition Explorer, or ACE).
- **PREDICCS (Predictions of Radiation from REleASE, EMMREM, and Data Incorporating the CRaTER, COSTEP, and other SEP measurements):** Co-I Schwadron is leading the effort to continue developing this online system for now- and forecasting the GCR and SEP radiation environment at the Earth, Moon, and Mars.

Applying these tools, the radiation team have:

- *Completed:* A deep dielectric charging model to calculate the strength of electric fields created in the polar lunar regolith by the penetration of GCRs and SEPs. GCRs create a continuous electric field of ~700 V/m, and large SEP events can cause sporadic electric fields of $\geq 10^7$ V/m—large enough to cause dielectric breakdown [Jordan et al., 2014].
- *Completed:* An estimated the number of breakdown-causing SEP events experienced by the gardened regolith near the lunar poles. Regolith within PSRs may have experienced $>10^6$ events [Jordan et al., 2015].
- *Ongoing:* Currently working to predict the effects of "breakdown weathering" by estimating how sparking fragments lunar regolith grains in PSRs.
- *Ongoing:* Improving our deep dielectric charging model to better understand how the subsurface electric field varies with depth.
- *Ongoing:* Discover whether breakdown in PSRs may be observed from lunar orbit with LRO or ARTEMIS or with ground-based instruments. Post-doc Winslow is analyzing lunar surface charging detected using ARTEMIS data during large SEP events to find whether it could be affected by deep dielectric charging and/or breakdown.

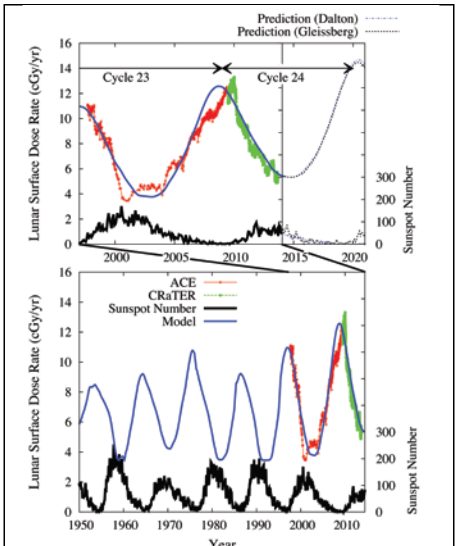


Figure 4- Variation of sunspot number and GCR dose, showing the increase of GCRs in the recent weakened solar cycle (Schwadron et al., 2014)

- *Ongoing:* Improving the statistics of our map of lunar albedo protons and have shown that the maria have a higher albedo than the highlands. We are attempting to establish whether possible albedo features correlation with geological features [Wilson et al., to be submitted to *J. Geophys. Res. Planets*].
- *Ongoing:* Schwadron et al. (2014) used results of PREDICCS to understand implications of the changing space environment for human exploration. Several key results are shown in **Figure 4**, which shows the evolution of GCR dose over time

based on modeling and data from CRaTER and ACE. The implication of the weakening heliospheric magnetic field is that the observed dose rates at successive solar minima and successive solar maxima have been increasing with time. It remains to be seen whether these changing conditions will persist. The latest trends demonstrate that the space environment at solar min is becoming increasingly hazardous and present a limiting factor for human exploration beyond LEO.

- *Ongoing:* Significant progress has been made with PREDICCS (Predictions of Radiation from REleASE, EMMREM, and Data Incorporating the CRaTER, COSTEP and other SEP measurements, http://prediccs.sr.unh.edu), which is an online system that utilizes data from various satellites in conjunction with numerical models to produce a near-real-time characterization of the radiation environment of the inner heliosphere. PREDICCS offers the community a valuable tool in forecasting events and improving risk assessment models for future space missions, providing up to date predictions for dose rate, dose equivalent rates and particle flux data at Earth, Moon and Mars. Joyce et al. [2014] presented a comparison between lunar dose rates and accumulated doses predicted by the PREDICCS system with those measured by the Cosmic Ray Telescope for the Effects of Radiation (CRaTER) instrument aboard the Lunar Reconnaissance Orbiter (LRO) spacecraft during three major solar events in 2012.
- *Ongoing:* Co-I Zeitlin is examining energetic ion transport in lunar regolith using new 'Particle and Heavy Ion Transport System (PHITS) code to derive total (primary and secondary) dose rates and aid in understanding proton albedo.

Theme 4: Surface Response to the Space Environment

As the harsh elements of the space environment interact with the surface, the energy leaves a modifying signature on the surface structure. For example, space plasmas amorphize the regolith crystal structure in the first 100 nm, creating defects that can trap solar wind protons and and 'hopping' water or OH on the airless body. Radiation alters the surface by creating streaking defects and charge buildup which also may be sites for solar wind hydrogen trapping.

To test this, DREAM2 is building a lab experiment in GSFC's radiation facility to first irradiate a stimulant surface with high energy radiation (> 1 MeV) to create defects in the material, then perform (under the same vacuum) a second irradiation of the sample by 1 keV D_2 or protons that simulate the solar wind protons. We will determine if the additional defects from the high energy radiation affects the creation of OD or OH. A special beam line for the DREAM2 study is under construction (nearly complete) at GSFC **(Figure 5)** and the integration of the high and low energy beams is being designed. We anticipate to initiate the first tests in PY2 (Loeffler, Hudson, McClain, Keller).

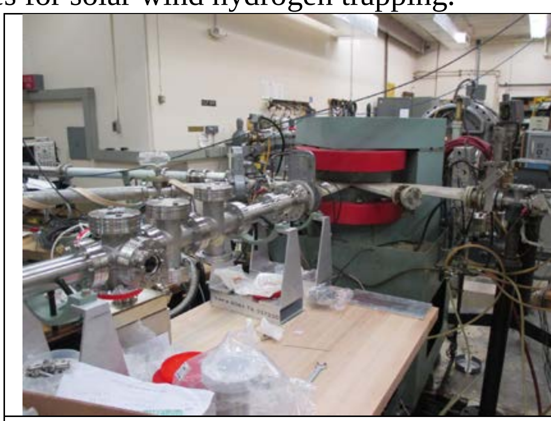


Figure 5- New high energy beam line at GSFC radiation facility

Other surface interaction studies include:

- The publication of a model of solar wind hydrogen implantation in material of varying defect structure. The strength of the defects were modeled as a Gaussian distribution of activation energies, and the amount of H trapping as a function of specific distributions was quantified. It was found that solar wind implanted H's (and thus OHs) can display a diurnal effect when there are a modest amount of defects (Farrell, Hurley, Zimmerman).
- SETI institute investigators performed a set of lab studies on dust cohesion, including the testing of the fracture and stability of cohesive dust conglomerates that would be found at low gravity small body asteroids (Marshall). A theoretical model predicts the cone-shaped failure of dust masses above a trapdoor orifice is dependent on the thickness of the dust layer (**Figure 6**). Experiments confirm the model and are being used as a representation of the internal packing angle of grains in a dust mass. The experimental data are also being combined with dust 'balling' experiments in order to calculate van der Waals adhesion forces between dust grains.

- Poppe et al (2014) examined the solar wind inflow into magnetic anomalies and found that the solar wind ion speed to the surface can be slowed by an ambipolar Efield that form within the anomaly retards ion motion. As a consequence, the associated ion sputtering yields in magnetic anomalies are vastly reduced, possibly creating reduced weathering. This work connects plasma to the extended geological environment to the surface in a rich and unique way.
- In the lab, a GSFC team (McLain, Keller, Collier) are examining solar wind-like 1 keV proton interactions with lunar-like surface material, demonstrating that a surprisingly large fraction of the incoming ions convert and backscatter as energetic neutral hydrogen. They leave the surface at energy far greater than simple thermal energy –suggesting these H's do not dwell in the surface and undergo numerous collisions but instead are immediate scattered from the first nucleus they encounter.

Figure 6- Regolith fails to maintain stability (creates a hole) when underlying surface has a hole. This effect does not occur if the regolith layer is thicker – due to more surrounding grains creating greater cohesion

- A model of the removal and transport of volatiles from lunar polar crater floors was developed, demonstrating that impact vaporization and sputtering are continually weathering and liberating volatiles to topside regions adjacent to the craters (Farrell, Hurley, Zimmerman).
- Tribochrging models: Human systems roving at the Moon and at asteroids will charge up via contact electrification between dusty surfaces and the human system. Jackson et al. (2014) has been developing these surface-dust charging models of wheel-regolith interactions, astronaut walking interactions and next drill-regolith interactions.

Theme 5: Integration and Extreme Events

In the upcoming last three years of DREAM2, the team plans to have a coordinated modeling effort on the effect of extreme environments at small bodies and the Moon. This effort is called the DREAM2 Extreme Environment Program (DEEP). In this program, our models will be integrated to be run in a given sequence on a common event. This activity is similar to our 2010 SSLAM (Solar Storm- Lunar Atmosphere Model) effort under DREAM.

The three DEEP studies are 1) The effect of a solar storm at an exposed small body, 2) The space environment in Phobos' Stickney Crater, and 3) Human 'first contact' with a small body/NEA.

While these team-integration and coordinated efforts are planned for the last three years of DREAM2, we are currently developing and testing (and publishing) components of these models to be used. The components include:

- Laboratory studies at ORNL (Meyer) on the sputtering losses from heavy ions. This work will be integrated into the solar storm/small body DEEP study, since a passing CME is in fact rich in heavy ions, like He^{++}, O^{+7}, etc. Meyer's team lab study provided insight into these sputtering yields, which are many times greater than proton sputtering.

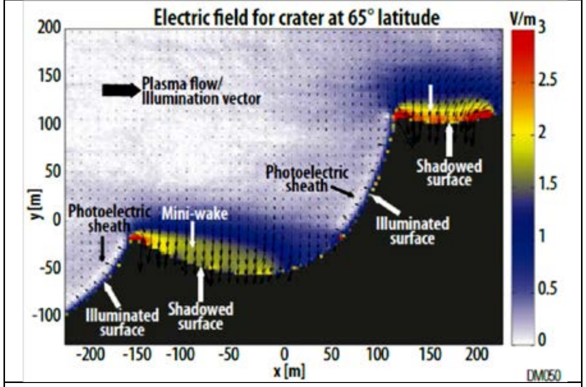


Figure 7 – A model of the plasma inflow at a crater with oblique orientation relative to the solar wind, from Zimmerman Tree Code model

- Modeling of the Orion water gas and ion cloud in the vicinity of a small body. Both analytical and simulation work is ongoing to understand how the spacecraft-produced outgassing ater and new water ions may affect the surface of the small body. This work has been presented in past Exploration Science Forums and is a prelude to the DEEP workshop on 'first contact'.
- Continued modeling of solar wind flow in and around regional features like magnetic anomalies and craters by Zimmerman, Poppe, Fatemi and Lipativ. Such work feeds forward to the Stickney crater studies (see **Figure 7**).
- Glenar and Stubbs (2014) recently placed upper limits on electrostatically lofted dust based on the Clementine star camera light levels.
- Discussions are underway to merge CCMC magneto-hydrodynamic (MHD) models of the inner heliosphere during solar storms to local particle-in-cell codes to understand the solar storm/CME effect from its birth at the sun to its incidence at a small exposed body (Zheng, Pulkkinen)

Theme 6: Mission and Exploration Applications

DREAM2's study of the space environment has direct and immediate applications to numerous SMD and HEOMD missions. The most active involvement includes:

The Lunar Atmosphere and Dust Environment Explorer (LADEE). DREAM2 Co-Is Colaprete, Delory, and Elphic all continue to be involved in the LADEE mission during its data analysis phase. Rick Elphic remains the project scientist, with Greg Delory the Deputy project scientist, while A. Colaprete is the UVS instrument PI. Co-Is Delory and Elphic are currently overseeing the generation of revised datasets, including the generation of higher level derived data products, to the Planetary Data System. DREAM2 Co-Is Halekas, Poppe, Hurley, Stubbs, Sarantos, and Glenar continue to work with LADEE as Guest Investigators.

Acceleration, Reconnection, Turbulence, and Electrodynamics of the Moon's Interaction with the Sun (ARTEMIS). As LADEE Guest Investigaotrs, DREAM2 Co-Is Halekas and Poppe have sustained a productive collaboration between LADEE and ARTEMIS. Along the way they have pioneered unique methods to support the interpretation of LADEE data using coincident measurements of lunar pick-up ions and the lunar plasma environment. These measurements have had measurable impact on both LDEX and NMS data processing. Additional work by DREAM2 Co-I Delory is using two of the ARTEMIS spacecraft in a study of induced magnetic fields at the Moon. This work also involved significant graduate student involvement (H. Fuqua).

ARM Mission. As described above, DREAM2 team members have initiated a set of studies on the Orion and Astronaut interaction with a small body. These include the Orion outgassed water cloud with an exposed small body, the water ion cloud with the body, and astronaut/body charging studies. These have been presented at conferences like LPSC and ESF and were recently highlighted in the SSERVI's Director Seminar.

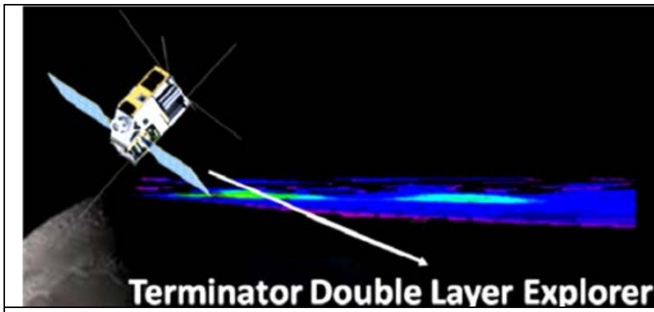


Figure 8: A Cubesat concept to examine the edge of the plasma wake, based on DREAM2 models of the plasma expansion process

Resource Prospector (RP). With FINESSE team members, DREAM2 co-is Elphic and Colaprete are instrument leaders of the HEOMD-funded RP mission to explore and prospect the lunar polar regions for volatiles. DREAM2 has contributes to this effort by provide models of volatile transport and redistribution that identify locations where RP might prospect. Models of rover wheel charging are also applicable to the RP rover system.

OSIRIS-REx. DREAM2 team Marshall is the leader of the OSIRIS Regolith Working Group (RWG) and his dust cohesion work (described above) has direct implications on regolith stability anticipated at any small asteroid, including Bennu.

LRO. DREAM2 team members continue to support LRO. DREAM2 co-is Keller and Vondrak are leads on the LRO Project Science team and there is continual DREAM2/LRO discussion on the latest finding especially on volatiles.

Additional Discovery and other mission proposals. Many DREAM2 Co-Is have had significant involvement in emerging mission proposals ranging from Discovery to cubesat-class that involve the physics of small-body/solar wind and plasma interactions. This participation has been significantly enhanced and strengthened by ongoing DREAM2 activities, which provide a deep knowledge base for the relevant science questions involved in these proposals (e.g., **Figure 8**). DREAM2 team members have submitted lunar cubesat proposal to both HSD's HTIDeS program and PSD's SIMPLEX program.

DREAM Co-I Clark continues the lead the community the Lunar Cubesat workshops which are has held annually over the last 4 years. These efforts are specifically designed to enable the community in anticipation of planetary cubesat proposal calls, like the recent SIMPLEX solicitation.

II. Inter-team Collaborations

DREAM2 team members are in continual contact and collaboration with other SSERVI teams, science mission team, and Exploration architecture teams. Examples of DREAM2 interactions with other SSERVI teams include:

VORTICES: Strong collaborating work on solar wind/body interactions, volatile interactions, and Orion/asteroid interactions and lunar pits. Strongest collaborations with individuals like Zimmerman, Hurley, Bussey, Orlando, Hibbitts.

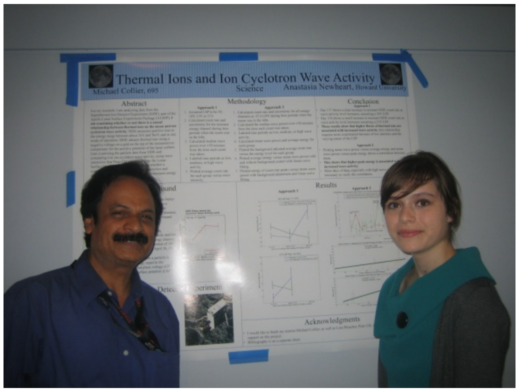
RISE4: Strong collaborating work on lunar pits, with the RISE4 field team providing lidar input to pit environment models shared by DREAM2 and VORTICES. Work with RISE4 team to pursue opportunities to architecture, design and build future exploration-oriented field instrumentation for astronaut use.

IMPACTS: PIs Hornayi and Farrell co-lead the SSERVI Dust and Atmosphere Focus Group. Strong cross-team collaboration including post-doc opportunities for students, like A. Poppe who did his thesis work under CCLDAS and is now a key DREAM2 team member.

FINESSE: We share co-is in Colaprete and Elphic, who under FINESSE perform field studies for their Resource Prospector mission, while DREAM2 provides supporting modeling studies on wheel-regolith interactions and volatile transport modeling.

III. E/PO Report (L. Bleacher, A Jones, P. Misra)

The keystone component of the DREAM2 E/PO program is a partnership with Howard University (HU), a Historically Black College and University located in D.C. The partnership spans higher education and formal education, and allows DREAM2 and SSERVI-related content to reach students and educators underrepresented in science. In Year 1, DREAM2 hosted two undergraduate students from the HU Physics and Astronomy Department as summer interns. In addition to their research, the students participated in monthly DREAM2 team meetings, met with other planetary scientists, and participated in tours and additional learning opportunities. They presented their completed projects through poster (**Figure 9**) and oral presentations that were open to the entire GSFC community. Both students elected to continue their research during the ensuing academic year and presented updates on their work at the DREAM2 science team meeting in October 2014.



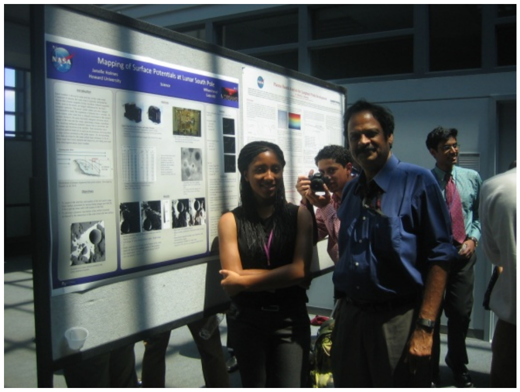


Figure 9- Students from Howard University displaying their project work as GSFC interns

The DREAM2 education team also began designing their DREAM2Explore workshop series for grade 6-9 pre- and in-service science teachers, the pilot of which will take place in Year 2. Team members visited the HU Middle School of Mathematics and Science to meet with the school's science teacher coordinator and professors in the HU Department of Curriculum and Instruction to discuss teachers' needs with respect to professional development and to begin recruiting participants. A draft of the workshop agenda was developed and is currently being refined. DREAM2 team members also led hands-on activities and shared information about DREAM2 and SSERVI at outreach events, such as the University of Maryland's annual Maryland Day event and International Observe the Moon Night.

IV. Publications

Davis, S, Marshall, J. Richard, D, Adler, D. Adler, B. (2014). Scattering properties of lunar dust analogs. Planet. Space Sci. , 90, 28-36 . **SSERVI-2014-008**

Stubbs, T. J., W. M. Farrell, J. S. Halekas, J. K. Burchill, M. R. Collier , M. I. Zimmerman , R. R. Vondrak , G. T. Delory , and R. F. Pfaff (2014), Dependence of lunar surface charging on solar wind plasma conditions and solar radiation, Planet. Space Sci., 90, 10-27, **SSERVI-2014-009**

Zimmerman, M. I., W. M. Farrell, and A. R. Poppe (2014), Grid-free plasma simulations of the complex interactions between the solar wind and small, near-Earth asteroids, Icarus, 238, 77-85. **SSERVI-2013-030**

Lipatov, A. S., J. F. Cooper, E. C. Sittler Jr., and R. E Hartle (2013), The light (H+, H2+, He+) and heavy (Na+) pickup ion dynamics in the lunar plasma environment: 3D hybrid kinetic modeling, Adv. Sp. Res. (Advances in Space Research) , 52, 1929-1938. **SSERVI-2013-031**

Poppe, A.R., J.S. Halekas, M. Sarantos, and G.T. Delory (2013), The self-sputtered contribution to the lunar exosphere, J. Geophys. Res.: Planets, 118, 1934-1944, DOI: 10.1002/jgre.20148 **SSERVI-2013-032**

Feldman, P. D., D. A. Glenar, T. J. Stubbs, K. D. Retherford, P. F. Miles, T. K. Greathouse, D. E. Kaufmann, J. W. Parker, and S. A. Stern (2014) , Upper limits for a lunar dust exosphere from far-ultraviolet spectroscopy by LRO/LAMP, Icarus, 233, 106-113. **SSERVI-2013-033**

Farrell, W. M., D. M. Hurley, R. R. Hodges, R. M. Killen, J. S. Halekas, M. I. Zimmerman, and G. T. Delory (2013), Redistribution of lunar polar water to mid-latitudes and its role in forming an OH veneer, Planet. Space Sci, 89, 15, **SSERVI-2013-029**

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V. <u>Conference papers, extended abstracts, posters and presentations</u>.

Total Number:~35

Recent DREAM2 LPSC 2015 Abstract Titles:

THE FEASIBILITY OF ELECTROSTATIC DUST LEVITATION IN SMALL BODY PLASMA WAKES.
C.M. Hartzell1 and M. Zimmerman2, 1Department of Aerospace Engineering, University of Maryland (hartzell@umd.edu), 2Johns Hopkins University Applied Physics Laboratory (Michael.Zimmerman@jhuapl.edu)

LUNAR PROTON ALBEDO ANOMALIES: SOIL, SURVEYORS, AND STATISTICS
J. K. Wilson et al.

Dielectric breakdown weathering of the Moon's polar regolith, A. P. Jordan et al.

Modeling the Phobos and Deimos Neutral Gas Tori: Implications for Detection by MAVEN, A. R. Poppe, S. M. Curry, S. Fatemi, J. P. McFadden, and G. T. Delory.

LRO/CRATER DISCOVERIES OF THE LUNAR RADIATION ENVIRONMENT AND LUNAR REGOLITH ALTERATION BY RADIATION
N. A. Schwadron1, H. E. Spence1, J. K. Wilson1, A. P. Jordan1, R. Winslow1, C. Joyce1, M. D. Looper2, A. W. Case3,N. E. Petro4, M. S. Robinson5, T. J. Stubbs4, C. Zeitlin6, J. B. Blake3, J. Kasper3,7, J. E. Mazur3, S. S. Smith1, L. W.Townsend8,

ROVER WHEEL CHARGING ON THE MOON AND THE EFFECTS OF ADHERING DUST. T. L. Jackson[1] , W. M. Farrell[1] , M. I. Zimmerman[2], [1]NASA Goddard Space Flight Center (Telana.L.Jackson@nasa.gov), Greenbelt, MD 20771, [2]Johns Hopkins Applied Physics Laboratory, Laurel, MD 20723.

VI. Students, Postdocs, New Faculty

2014 Undergrad Interns/Students
Ana Newheart, St. Marys
Janelle Holmes, Howard U
Robin Leiter, U. Virginia

Graduate Students
Heidi Fuqua, UCBerkeley
Colin Joyce, U. New Hampshire

DREAM2 Post-Docs
Shahab Fatemi, UCBerkeley
Reka Wilson, U. New Hamphire

Enabling New Faculty
Jasper Halekas has moved from a research scientist at UCB to a tenure track faculty position at Iowa. His strong activity in DREAM and DREAM2 were cited as evidence of his outstanding capabilities.