1. DREAM2 Team Project Report

In its third year, the DREAM2 team continued its unique study of the space environmental effects at exposed bodies- with an emphasis on a universal approach (different bodies, different mass, different solar wind flow, etc). Herein, we outline our stunning research achievements over the past program year - many of which are also presented on the DREAM2 website (http://ssed.gsfc.nasa.gov/dream/). We first report on our DREAM2 themes, and then report on a large cross-team study of Phobos called 'The Space Environment in Stickney Crater (SEinSC)'.

Theme Reports

Space Plasmas & Surfaces. Every airless body in our solar system interfaces with a plasma (solar wind or magnetospheric plasma). Understanding the plasma-surface interactions not only lays the groundwork for future explorers who are also immersed in this conductive medium, but also strengthens our grasp of fundamental processes at airless bodies throughout our solar system.

The plasma team contributed to conducted fundamental data analysis and theoretical investigations focused on airless bodies. Highlights include fundamental investigations of pickup ion measurements from multiple spacecraft (Poppe et al., 2016a; Halekas et al., 2016; Collier et al., 2016), revealing new aspects of the structure and variability of both the tenuous exosphere and near-surface electromagnetic environment of the Moon. DREAM2 plasma team members also studied solar wind interactions with small-scale magnetic fields (with applications to space weathering) (Poppe et al., 2016) and solar wind interactions with the regolith (with applications to surface charging and dust levitation) (Zimmerman et al., 2016). DREAM2 members also made a first-of-kind measurement of heavy ion outflow from the Earth at the Moon, revealing a potentially important source of nitrogen and oxygen at the Moon (Poppe et al., 2016). The resulting paper was a GRL editor's highlight.

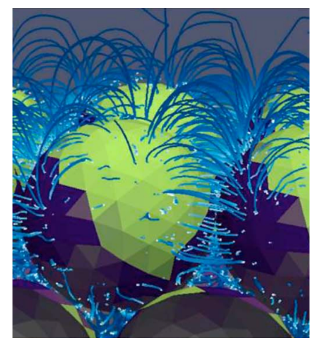

Figure 1. Model E-field about a surface dust grain

These investigations resulted not only in fundamental scientific advances, but also in advances in computational tools, with DREAM2 postdoc S. Fatemi creating the first three-dimensional self-consistent kinetic model of plasma that runs entirely on graphics processing units (GPUs) and only uses a single CPU, and DREAM2 Co-I M. Zimmerman creating a revolutionary grain charging model suitable for investigating a variety of regolith physics (see adjacent figure of E-field between grains).

Exospheres and Corona. Exospheres are a direct indication of the dynamics any exposed surface is undergoing via space environmental erosion. Space plasmas, micro-meteoroids, UV radiation and energetic particles all energize an exposed surface, and in response the surface will release neutral and ionized gases into the space above – forming an exosphere.

The DREAM2 exospheres team made several important contributions to the understanding of the lunar exosphere in PY3. One important result was the discovery of methane in the lunar exosphere (Hodges, 2016). It has a very short lifetime (about 1 day) and hence a low concentration, peaking at about 400 molecules/cc in early morning. Methane escape can account for 25-76% of the global influx of solar wind carbon. A second important result is the discovery of how surface composition and meteoroid impacts mediate sodium and potassium in the lunar exosphere (Colaprete et al., 2016) Observations of lunar exospheric helium from LRO/LAMP and ARTEMIS contributed to our understanding of the source and loss of Helium (Grava et al, 2016). Using simultaneous observations from LRO, LADDEE and ARTEMIS, it was shown that the primary driver for variability in the helium exosphere throughout the LADEE mission was the solar wind alpha flux. The solar wind contributes 64% of the helium to the lunar exosphere, with the remaining from radiogenic helium from the interior of the moon (Hurley et al., 2016). Hurley also developed a statistically based water plume model created by micro-meteoroid delivery for comparisons to LADEE NMS data. In support of the ARM mission, the gas-surface interaction of a human-occupied spacecraft with a near-Earth object was a timely study leading to understanding of contamination issues of human systems visiting small bodies (Farrell et al., 2016.) See adjacent figure. We continued our remote observations of the lunar sodium exosphere throughout 2016 via ground-based observatory.

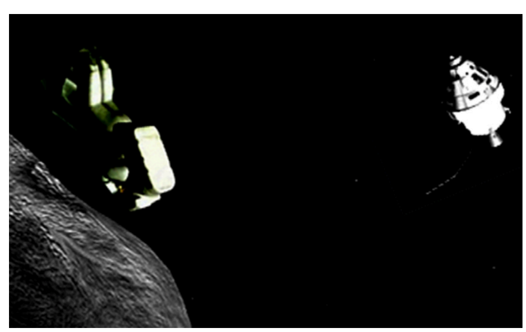

Figure 2. Outgassing human systems near a small body

Radiation at Exposed Surfaces. Particle radiation has significant effects for astronauts, satellites and planetary bodies throughout the Solar System. Acute space radiation hazards pose risks to human and robotic exploration. Radiation weathers the regolith of the Moon and other airless bodies, and is a source of chemical modification in the atmosphere of Earth, Mars, and other planets.

In PY3, the radiation team made a set of key advancements, including the publication of a set of papers on the deep dielectric discharge weathering of regolith at the Moon and Phobos (Jordan et al, 2016, 2017). The team also advanced their radiation propagation models for applications to the Moon and Mars (Schwadron), updated the Virtual Energetic Particle Observatory, examined the Ulysses-measured radiation environment at 1.5 AU for Phobos applications (Cooper), and discovered a possible enhanced proton albedo and diurnal effect associated with hydrated layers (Schwadron). They also examined radiation effects at Saturn's rings (Cooper) and the Earth (Joyce et al., 2016).

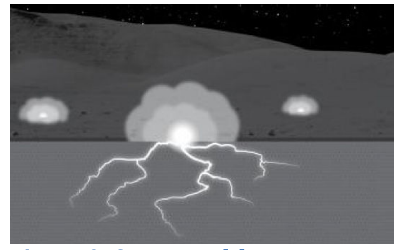

Figure 3. Cartoon of deep dielectric discharge at Moon

The team continues the critical examination Cosmic Ray Telescope for the Effects of Radiation (CRaTER) observations on the Lunar Reconnaissance Orbiter (LRO) to derive the implications of **the unusual weakening solar conditions over future solar cycles for human space exploration** and for planetary bodies throughout the inner solar system. Galactic cosmic ray radiation is expected to remain a significant and worsening factor during this weakening period that limits mission durations (as describe previously in Schwadron et al., 2014). As galactic cosmic ray fluxes rise, the GCR doses also increase down to ISS and aircraft altitudes. This work on the effect of the weakening solar cycles remains a very high priority DREAM2 science-exploration study.

Surface Response to the Space Environment. PY 3 saw the advancement of a number of surface interactions studies, including the completion of a dedicated Ar^+ 1 MeV beam line at the GSFC radiation facility. This DREAM2 funded 2 beam experiment lead by Loeffler and Hudson is designed to create crystal defects in lunar samples, to then determine if such defects affects the ability of the sample surface to retain low energy (1 keV) deuterium implantations. The low energy deuterium is the analog for solar wind hydrogen implantations. Farrell et al also created a model for hydrogen retention in defected silica to be used in conjunction with the lab experiments. This model was presented at LEAG and the paper is under review.

McLain and Keller are further advancing their adsorption chamber with the aid of some added DREAM2 funding (to supplement pilot study funding). The chamber is close to being an online system to examine atom and molecular sticking onto dusty smokes and other samples.

The team continues to interact with space suit designers at JSC on the development of a conductive space suit. DREAM2 models on astronaut and rover charging have been used in this effort. In June 2016, Farrell gave a SSERVI Director's Seminar at HQ on the space plasma charging and human system interaction detailing the need of the suit to electrically 'ground' itself to the conductive plasma (similar to spacecraft). The DREAM2 models were also recently applied to an explorer visiting Phobos (see below).

Team members Glenar and Stubbs continue to analyze LRO and LADEE observations for lofted dust, using Glenar's light scattering models as a basis. For example, DREAM2 funded Glenar's effort on the Wooden et al (2016) paper showing the possible presence of nanograins ejected detected by the LADEE UVS from the Moon during the Quadrantid meteoroid stream.

Mission Applications. DREAM2 Team members continue to have their feet firmly established in ongoing and future missions and HEOMD studies. Pamela Clark is the lead Science PI of the Lunar Icecube cubesat (see adjacent figure) to be released during the EM-1 mission spearheading the endeavor to obtain new measurements on the hydroxylation and hydration state of the Moon, Mike Collier and colleagues presented a novel new idea on the use of tethered cubesats at the Moon to obtain simultaneous high and low altitude observations over magnetic anomalies, cold polar traps, and terminator region. Many team members were active in the recent call for smallsat concepts –which indicated just how potent DREAM2 is in seeding new ideas. Team members continue to contribute to LRO especially LAMP (Hurley) and CRaTER (Jordan, Stubbs, Schwadron, Wilson, Spence, Winslow). Many DREAM2 team members provide critical support for LADEE (Elphic, Delory, Colaprete, Sarantos, Glenar, Stubbs, Hurley) and play major leadership and science roles on ARTEMIS (Halekas, Poppe, Fatemi, Delory). A mission that has provided stunning new insights into the Mars-Phobos space plasma environment is MAVEN with DREAM2 team members active therein (Halekas, Poppe, Fatemi, Delory).

Figure 4. Lunar Icecube

In the area of human exploration, DREAM2 team members are in collaboration with JSC's Space Radiation Analysis Group (SRAG), continuing their critical analysis of the radiation environment in the ever-weakening solar cycle conditions. Team members are also involved in updating the lunar strategic knowledge gaps (SKG studies), and interact with JSC space suit designers to provide environmental information in support of suit designs. Team members recently published an exosphere-surface paper on the effect the Orion volatile outgassing may have on the captured asteroids – and provide key recommendations to assess and limit such forward interactions. In our Phobos study (below), we as a team also assessed the harsh space environment that affects any future explorers.

Special Topic: DREAM2 Intramural Study on the Space Environment at Phobos

This intramural study on the space environment at Phobos involved over 30 investigators who are part of the DREAM2. The title of this intramural study is the 'Space Environment in Stickney Crater (SEinSC)' that addressed the space environment at Phobos. Stickney crater was targeted as an ideal regional scale feature for examination.

In 2015-2016, teammembers undertook a systematic study of the space environment at Phobos, including the development of plasma, exosphere, and surface interaction models, run in sequence and in common space environment conditions to understand the effect the radiation, space plasma, and micro-meteoroid environment has at and on this exposed irregularly-shaped ~22 km body. The team presented findings at an intramural workshop in April 2016.

Specifically, the SEinSC study used inputs from the Mars Atmosphere and Volatile Evolution (MAVEN) mission, models of the inner heliospheric solar wind from the Community Coordinated Modeling Center (CCMC), University of New Hampshire radiation propagation models, and data from the Virtual Energetic Particle Observatory. These contextual data sets were used as inputs to the detailed tactical DREAM2 models such as hybrid plasma simulations of the Mars-solar wind interaction, kinetic models of the Phobos-plasma interactions, neutral gas and photo-ion models, radiation-induced deep dielectric discharge models, and radiation/human effect modeling. Impact gardening and solar illumination/temperature models of Phobos were also developed to examine volatile retention and longevity. Models of solar wind hydroxylation at Phobos were also developed to better understand the previous observations of a 2.8 micron absorption feature in the NIR spectra from a possible OH veneer (Fraeman et al., 2014). Possible Phobos missions that might provide validation or further context of the SEinSC findings were also discussed.

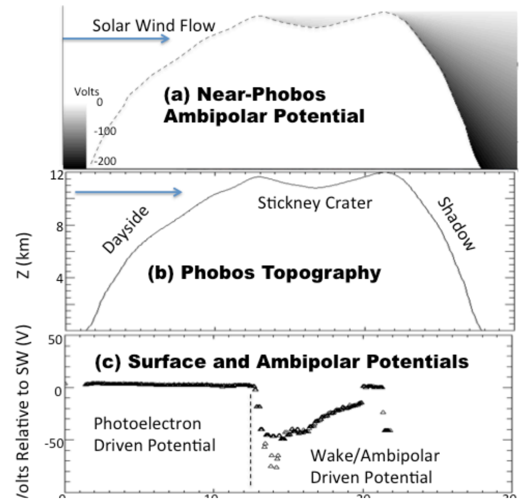

Figure 5. The electrostatic potential in the shadowed regions of Phobos (moon located at 10 hr LT in from of Mars)

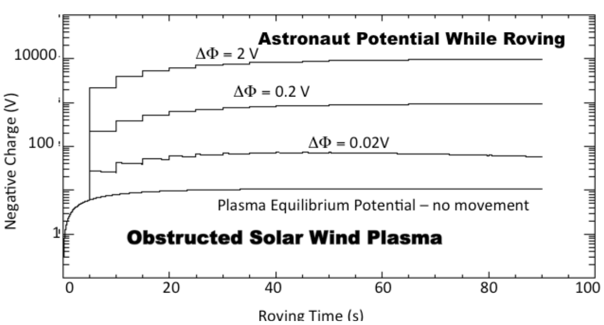

Figure 6. Astronaut charging vs time in shadowed region of Stickney Crater for various work function differences

A key finding was the exposed surfaces at Phobos will become charged in the solar wind (Figure 5), and this surface potential will intensify during a passing solar storm, especially in shadowed regions of the moon. An astronaut in a shadowed region (like Stickney Crater when Phobos is on the Martian dayside) will also charge strongly negative as they rove due to regolith-boot contact electrification effects which have been modeled by DREAM2 team members. The intensity of boot charging depends strongly on the difference in work function between materials in contact (see Figure 6, with largest potentials associated with largest material work function differences).

Summary

DREAM2 had another successful year. At any given instant, there are nearly 30 ongoing activities many using the > 24 models, 8 data sets and 4 labs at DREAM2's access. However, the strength of such a center is the ability to organize members and their assets into larger intramural efforts that go well beyond efforts that are possible via tactical awards – like was done for the systematic study of the space environment at Phobos. Entirely new findings regarding moon charging, hydroxylation, impact gardening, radiation environment have been discovered during the DREAM2 intramural activity, leading to a set of new papers to be released shortly.

In the next program year, we anticipate to perform organized environmental studies of the locations being considered for the Resource Prospector traversals – providing critical science support of that HEOMD effort.

2. DREAM2 Inter-team and International 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, 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. DREAM2 modelers working with IMPACTS modelers on magnetic anomalie studies.

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.

CLSE: DREAM2 exospheric modeler Hurley examined the possible evolution and deposition of the gas release from vent regions in Schrodinger crater – a target for a sample return mission designed by CLSE team members.

<u>International Partners</u>

Japan: DREAM2 team members work closely with Dr. Y. Saito, the Kagyua plasma and mag PI, at the Institute of Space and Astronautical Science, on lunar plasma interactions. Prof. Halekas took a sabbatical from his then-postion at UCB in the late 2000's (as part of NLSI) to enhance the relationship – which continues to be very fruitful. The teams are currently working together to integrate the ARTEMIS, Lunar Prospector MAG/ER, and Kaguya plasma data sets. Kaguya co-I M. Nishino makes regular visits to UC Berkeley to discuss the plasma and exosphere interactions at the Moon.

Sweden: DREAM2 team members continue close interactions with investigators at the Swedish Institute of Space Physics in Kiruna Sweden. DREAM2 co-I Mike Collier took a 3-month NASA fellowship (sabbatical) to study with Mats Holmstrom, Stas Barabash, and Martin Wieser in Kiruna. DREAM2 UCB postdoc, Shahab Fatemi, was a student in Kiruna who was advised by Mats Holmstrom and now working with Poppe and Delory - all part of the exchange of talent between the Kiruna group and DREAM2. We continue to team with our Kiruna partners in our cubesat proposals, like the SIMPLEX HALO proposal lead by Collier.

UK: The DREAM2 team at UCB is interacting with Rosetta scientist Tom Nordheim on understanding the plasma interactions at a cometary body.

3. DREAM2 Public Engagement Report

Undergraduate Internship Program

Summer 2016 marked a third successful DREAM2 Undergraduate Internship Program. Team members at GSFC (R. Killen, M. Sarantos, M. Collier, T. Stubbs, R. Hudson, M. Loeffler) hosted five students, including one from DREAM2 partner, Howard University (see Section 4). Students gained experience in both doing and communicating science by participating in DREAM2 team meetings and by preparing and delivering poster and oral presentations attended by the greater GSFC community. Their families were also invited to attend the oral presentations.

Two students presented their research at the 2016 Exploration Science Forum. One student continued their DREAM2 research into the academic year. Two students plan to return to GSFC in summer 2017 for a second DREAM2 internship.

Feedback gleaned from a survey issued at the end of the internship indicated that 100% of the participants agreed to strongly agreed that, as a result of their participation in a DREAM2 internship, they have a better understanding of the practice of science, a better understanding of the different types of NASA careers available to them, and they are more interested in a science, technology, engineering, or math job.

DREAM2Explore Educator Professional Development Workshop

The DREAM2 Education and Public Engagement Team also led the second annual DREAM2Explore Educator Professional Development Workshop, which took place from July 11-15th, 2016. Twenty-one science teachers from around the country, grades 6-9, participated. DREAM2Explore was an in-depth week of hands-on activities, discussions, presentations by DREAM2 team members and other GSFC subject matter experts, tours, and networking opportunities. Content focused on SSERVI target bodies – Earth's Moon, Near Earth Asteroids, and the moons of Mars, – including formation and evolution, the space environment, NASA's current plans to explore these objects, and NASA's "Journey to Mars". Participating DREAM2 team members included B. Farrell, J. Bleacher, D. Hurley, J. Cook, and J. Nuth. Tours included GSFC integration and testing facilities, a behind-the-scenes visit to the meteorite collection at the Smithsonian's National Museum of Natural History, and a tour of the Lunar Reconnaissance Orbiter Camera exhibit, *A New Moon Rises*, at the National Air and Space Museum.

A survey was issued at the workshop's conclusion to gauge its success. 100% of the participants agreed that they acquired activities that they will use with their students. 91% agreed that they feel confident in implementing the activities, and that they acquired a new understanding of planetary science and exploration that will be valuable when working with their students. Participant quotes included the following: *"It exceeded my expectations. I am far more confident to facilitate the learning experience for my students." "This will literally change how I teach and what my students will learn!"*

Public Engagement

The DREAM2 team supported GSFC's annual International Observe the Moon Night event on October 8^{th}. Over 374 members of the public attended.

4. DREAM2 Student/Early Career Participation

The PI institution, GSFC, is a government laboratory and thus does not have direct access to students. However, DREAM2 E/PO Lead Lora Bleacher has leveraged NASA internship programs to enable early career STEM undergraduates at Howard University and other academic institutions to work at the GSFC facility. This approach has been wildly successful: it allows access and participation of DREAM2 and STEM activities to a great number of students. Our academic partners also have been extending the pipeline with graduate and post-doc personnel. These early-career activities and particpents are listed herein.

GSFC 2016 Undergraduate Summer Interns funded by the DREAM2 E/PO budget
Anastasia Newheart, St. Marys (Mentor: Mike Collier)
Keenan Hunt-Stone, Howard Univ. (Mentor: Tim Stubbs)
Alexandra Cramer, College of William and Mary, (Mentor: Menelaos Sarantos)
Cassandra Hatcher, Oregon State (Mentor: Rosemary Killen)
Katarina Yocum, Kutztown University (Mentor: Reggie Hudson)

GSFC 2016 Year-around undergraduate interns from Howard University
DREAM2 co-i Prabhakar Misra at Howard University won a separate NASA award to fund a number of undergraduates for a 4-year internship with the DREAM2 and others at GSFC. The Award is "NASA Early Opportunities Program for Underrepresented Minorities in Earth and Space Sciences" (PI: P. Misra, Howard University; Co-PIs: D. Venable, Howard University; B. Meeson, NASA Goddard; S. Hoban, UMBC; & B. Demoz, UMBC; 8/1/16-7/31/19). The HU students are:

Skylar Grammas (Mentor: William Farrell/GSFC Code 695)
John Henry Clark (Mentor: John Cooper/GSFC Code 672)
Sirak Fessehaye (Mentor: Timothy Stubbs/GSFC Code 695)
Nikolas Rassoules (Mentor: Michael Collier/GSFC Code 695)
Zahraa Lopez (Mentor: Rosemary Killen/GSFC Code 695)

Graduate Students
Heidi Fuqua, UC Berkeley
Colin Joyce, U. New Hampshire

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

5. Publications (Calendar Year 2016 only)

Poppe, A. R., S. M. Curry, and S. Fatemi (2016), The Phobos neutral and ionized torus, J. Geophys. Res. Planets, 121, DOI: 10.1002/2105JE004948. **SSERVI-2016-003.**

Collier, M. R., R. R. Vondrak, R. P. Hoyt, M. A. Mesarch, W. M. Farrell, J. W. Keller, P. E. Clark, N. E. Petro, and K.-J. Hwang (2016), Tethered lunar subsatellites for multi-point and low altitude measurements, Acta Astronautica., 128, 464-472 **SSERVI-2016-004.**

Farrell, W. M., D. H. Hurley, M. J. Poston, M. I. Zimmerman, T. M. Orlando, C. A. Hibbitts, and R. M. Killen (2016), The Gas-Surface Interaction of a Human-Occupied Spacecraft with a Near Earth Object, Adv. Space Res., 58, 1648-1653. **SSERVI-2016-037.**

Joyce, C. J., Schwadron, N. A., Townsend, L. W., Mewaldt, R. A., Cohen, C. M. S., Rosenvinge, T. T., Case, A. W., Spence, H. E., Wilson, J. K., Gorby, M., Quinn, M., and Zeitlin, C. J. (2015), Analysis of the potential radiation hazard of the 23 July 2012 SEP event observed by STEREO A using the EMMREM model and LRO/CRaTER, Space Weather, 13, 560. **SSERVI-2016-038.**

Hodges, R.R. and P.R. Mahaffy (2016), Synodic and semiannual oscillations of Argon-40 in the lunar exosphere, Geophys. Res. Lett. 43, doi:10.1002/2015GL067293. **SSERVI-2016-039.**

Zimmerman, MI, W. M. Farrell, C. M. Hartzell, X. Wang, and M. Horanyi (2016), Grain-scale supercharging and breakdown on airless regolith, J. Geophys. Res.- Planets, 121, . doi: 10.1002/2016JE005049 **SSERVI-2016-093**

Hodges, R. R. (2016), Methane in the lunar exosphere: Implications for solar wind carbon escape, Geophys. Res. Lett., 43, doi:10.1002/2016GL068994., **SSERVI-2016-094**

Halekas, J. S., A. R. Poppe, W. M. Farrell, and J. P. McFadden (2016), Structure and composition of the distant lunar exosphere: Constraints from ARTEMIS observations of ion acceleration in time-varying fields, J. Geophys. Res. – Planets, 121, 1102-1115. **SSERVI-2016-095.**

Wooden, D. H. , A. M. Cook, A. Colaprete, D. A. Glenar, T. J. Stubbs, M. Shirley (2016), Evidence for a dynamic dust cloud enveloping the Moon, Nature Geoscience, 9, 665-668 **SSERVI-2016-142.**

Fatemi, S., A. R. Poppe, G. T. Delory, W. M. Farrell (2016), AMITIS: a 3D GPU-based Hybrid-PIC Model for space and plasma physics, J. of Physics Conf. Proc., in press, **SSERVI-2016-143.**

Farrell, W. M. D. M. Hurley, V. J. Esposito, J. L. McLain, and M. I. Zimmerman (2016), The statistical mechanics of solar wind hydroxylation at the Moon, within lunar magnetic anomalies, and at Phobos, J. Geophys. Res. Planets, in press, doi: 10.1002/2016JE005168 **SSERVI-2016-144.**

Jordan, A. P., T. J. Stubbs, J. K. Wilson, P. O. Hayne, N. A. Schwadron, H. E. Spence, and N. R. Izenberg (2016), How dielectric breakdown contributes to the global weathering of regolith on the Moon, Icarus, submitted. **SSERVI-2016-155.**

Collier, M. R., A. Newheart, A. R. Poppe, H. K. Hills, W. M. Farrell (2016), Stairstep particle flux spectra on the lunar surface: Evidence for nonmonotonic potentials, , Geophys. Res. Lett., 43, doi:10.1002/2016GL071457. **SSERVI-2016-156.**

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Poppe, A. R., M. O. Fillingim, J. S. Halekas, J. Raeder, and V.Angelopoulos (2016), ARTEMIS observations of terrestrial ionospheric molecular ion outflow at the Moon, Geophys. Res. Lett., 43, 6749–6758, doi:10.1002/2016GL069715. **SSERVI-2016-151.**

Colaprete, A., M. Sarantos, D. H. Wooden, T. J. Stubbs, A. M. Cook, M. Shirley (2016), How surface composition and meteoroid impacts mediate sodium and potassium in the lunar exosphere. Science, 351, 249-252. **SSERVI-2016-152**

Grava, C., K. D. Retherford, D. M. Hurley, P. D. Feldman, G. R Gladstone, T. K. Greathouse, J. C. Cook, S. A. Stern, W. R. Pryor, J. S. Halekas, D. E. Kaufmann (2016). Lunar Exospheric Helium Observations of LRO/LAMP Coordinated with ARTEMIS, *Icarus 273*, 36-44. **SSERVI-2016-153**

Hendrix, A. R., T. K. Greathouse, K. D. Retherford, K. E. Mandt, G. R. Gladstone, D. E. Kaufmann, D. M. Hurley, P. D. Feldman, W. R. Pryor, S. A. Stern, and J. T. S. Cahill (2016), Lunar Swirls: Far-UV Characteristics, *Icarus 273*, 68-74. **SSERVI-2016-183**

Hurley, D. M., J. C. Cook, M. Benna, J. S. Halekas, P. D. Feldman, K. D. Retherford, R. R. Hodges, C. Grava, P. Mahaffy, G. R. Gladstone, T. Greathouse, D. E. Kaufmann, R. C. Elphic, and S. A. Stern (2016), Understanding Temporal and Spatial Variability of the Lunar Helium Atmosphere Using Simultaneous Observations from LRO, LADEE, and ARTEMIS, *Icarus 273*, 45-52. **SSERVI-2016-111**

Joyce, C. J., Schwadron, N. A., Townsend, L. W., deWet, W. C., Wilson, J. K., Spence, H. E., Tobiska, W. K., Shelton-Mur, K., Yarborough, A., Harvey, J., Herbst, A., Koske-Phillips, A., Molina, F., Omondi, S., Reid, C., Reid, D., Shultz, J., Stephenson, B., McDevitt, M., and Phillips, T. (2016) Atmospheric radiation modeling of galactic cosmic rays using LRO/CRaTER and the EMMREM model with comparisons to balloon and airline based measurements, Space Weather, 14, 659, **SSERVI-2016-184**

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Nathan A. Schwadron, John Cooper, Mihir Desai, Cooper Downs, Matt Gorby, Andrew Jordan, Colin J. Joyce, Kamen Kozarev, Jon Linker, Zoran Mik´ıc, Pete Riley, Harlan Spence, Tibor T¨or¨ok, Larry Townsend, Jody Wilson, and Cary Zeitlin (2017), Particle radiation sources, propagation and interactions in deep space, at Earth, the Moon, Mars, and beyond, submitted to Sp. Sci. Rev, **SSERVI-2016-182**