Team Executive Summary

***The DREAM2 team led by Dr. Bill Farrell at Goddard Space Flight Center** examines the complex three-way interaction between harsh space environment, the exposed surfaces of airless bodies, and human systems near these affected surfaces. During its fourth program year the team produced over 25 papers on the space environment at airless bodies. In the area of surface interactions, the team presented a new model of the expected solar wind implanted hydrogen trapping in the lunar regolith, performed laboratory experiments in the GSFC Radiation Facility of proton implantation and hydroxyl creation in mineral samples, and modeled the solar wind weathering rate based on new ARTEMIS ion measurements. In the area of exospheric research, the team presented a generalized model of exosphere creation and simulated lunar exospheric water events from micro-meteoroid impacts with an eye toward LADEE applications. In the area of space plasma, team members examined the plasma wave turbulence found overlying lunar magnetic anomalies and examined the possible complex plasma flow around a potentially magnetized 16 Psyche asteroid. In radiation research, the team continues to monitor galactic cosmic ray flux and allowable astronaut flight days during this unusual period of weakening solar cycles and model the possible deep dielectric discharge that can occur at cold regions on airless bodies. As part of an intra-mural project, the team has published and/or presented a set of models on the space environment at Phobos, including illumination, surface charging, astronaut first contact, and the first preliminary radiation-surface model for this unusual exposed body. To enable this array of research, we continue our outstanding DREAM2 intern program – many from a Howard University-DREAM2 collaboration established in 2013. We continue to have a rich post-doc and grad student involvement at Goddard and at our expert partnering institutions. We also work in close coordination with our SSERVI partnering teams, like VORTICES, IMPACTS and REVEALS especially in the area of surface interactions and exospheric research. The expertise and topics are so intimately connected across these teams that we consider these other teams investigators as our own investigators, with many shared cross-team authorships.*

1. DREAM2 Team Project Report

DREAM2 has 4 space environmental themes in the area of space plasma interactions at airless bodies (1.1), collsionless atmospheres or exospheres formed at airless bodies (1.2), radiation environment (1.3), and surface interactions (1.4). We also have 2 derived themes: one being team intermural studies, like that recently performed on the space environment at Phobos (1.5) and the other being DREAM2's footprint into mission activities (5.0).

1.1 Plasma Environment

The DREAM2 plasma team continued its successful campaign to understand the interaction between airless body surfaces and exospheres of all scales with the space environment. Airless bodies represent arguably the most common object in our solar system and beyond, and they interact directly with the space environment, which consists in large part of plasma. Indeed, by most estimates, more than 99% of the visible matter in the universe is ionized and therefore classified as plasma. The plasma-surface and plasma-exosphere interactions that the DREAM2 plasma team studies are therefore of fundamental importance in our universe, with implications for airless bodies of all sizes both within and outside of our solar system.

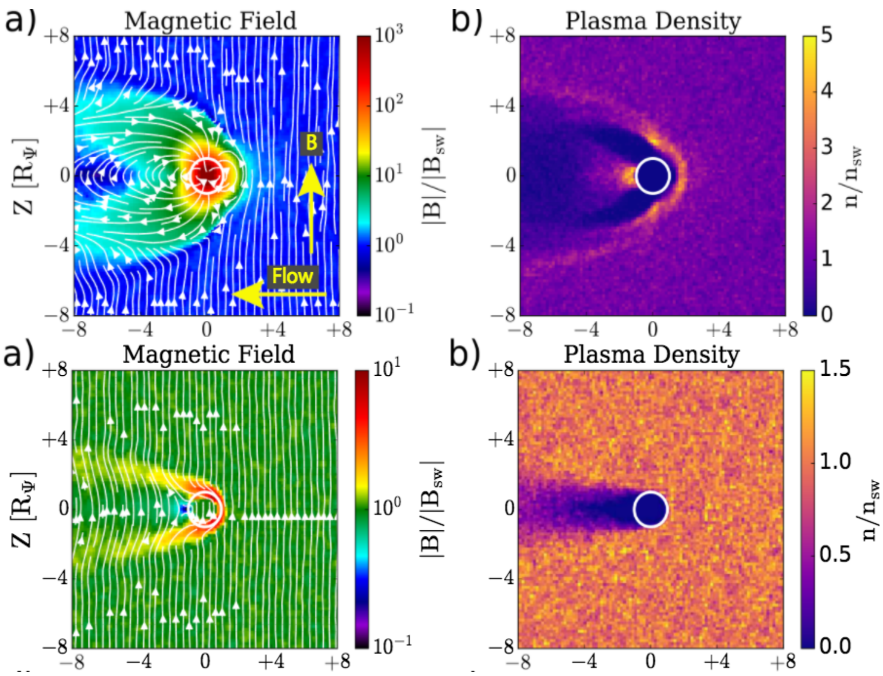


Figure 1.1.1 Predicted magnetic field and plasma density at 16 Psyche for magnetized (top) and unmagnetized (bottom) cases.

The DREAM2 plasma team conducted fundamental data analysis and theoretical investigations focused on Phobos, the Earth's Moon, and small bodies. Several studies highlighted the space environment of and potential future mission concepts for the exploration of Phobos [Farrell et al., 2017; Collier et al., 2017]. Other highlights include fundamental investigations of the physics of the interaction of the solar wind with small-scale magnetic fields at the Moon [Halekas et al., 2017] and the characteristics of the resulting low-frequency electromagnetic turbulence in the space surrounding the Moon [Howard et al., 2017]. DREAM2 plasma team members also studied solar wind and photon interactions with the lunar regolith, revealing the response of the regolith and the nearby electrostatic environment to solar ultraviolet photon flux [Harada et al., 2017], and determining the surface weathering rate of small regolith grains under solar wind bombardment [Poppe et al., 2017].

A highlight of the DREAM2 plasma team's 2017 research was the first plasma simulation of the solar wind interaction with 16 Psyche (Figure 1.1.1) [Poppe and Fatemi, 2017], in anticipation of measurements from the upcoming Psyche mission now in development. These sophisticated simulation results will be critical for interpreting Psyche magnetometer measurements and inferring not only the physics of the plasma interaction but also the internal structure and magnetization of Psyche, by differentiating the magnetic field signatures expected for the interaction between magnetized and unmagnetized obstacles.

1.2 Exospheres at Airless Bodies

Exospheres, or collisionless atmospheres, form as a direct result of space weathering of the surfaces at airless bodies. Solar radiation, space plasmas, and meteor impacts all create outgassing in the form of thermal, photonic, and electron desorption, plasma sputtering and impact vaporization. Depending upon the species released and the gravity of the body, the material can remain in the local space environment to form a surface bounded exosphere.

DREAM2 team members continues to contribute to knowledge of the lunar volatile and exosphere environment from observations, Monte Carlo models, and laboratory studies. Highlights include:

Killen et al [2017] published a generalized exosphere model determining the species mass that could be captured as a function of surface energization process and planetary body mass. Figure 1.2 shows the water (AMU=18) escape fraction as a function of airless body radius. Note that for source energy (or temperature) for thermal and impact processes at the Moon, water can mostly retained. However, for the energetic plasma sputtering process, the release of water is energetic with a substantial portion escaping the Moon. At low-gravity Phobos, surface water will not be gravitationally bound even for weak thermal release processes.

Hurley et al. [2017] published studies of the contribution of micrometeoroids to the inventory of surface water in the Moon's exosphere and on the surface to compare with LADEE results.

Killen et al continues to observe the lunar sodium exosphere remotely using their coronagraph situated at the Winer Obervatory in Sonoita, Arizona. They reported on the results at the NASA Lunar Science forum, the annual DPS meeting and at the AGU, and feature the new observation of possible north/south asymmetries in the lunar sodium exosphere.

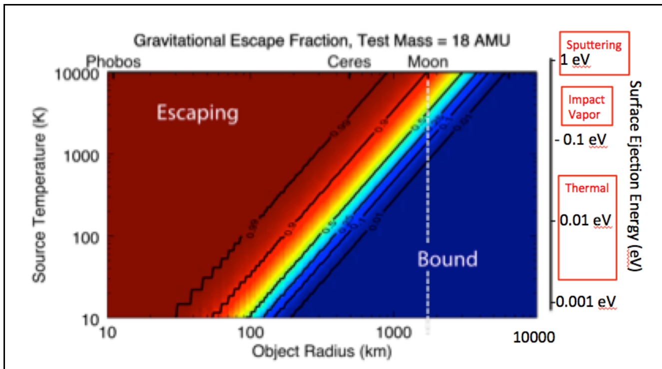


Figure 1.2.1 – Gravitational escape fraction for water as a function of airless body size [Killen et al., 2017]

McLain and Keller continue to perform laboratory studies of gas sorption on regolith material at low temperatures to simulate the effects in lunar polar and nightside regions. Within their specialized chamber, a layer of molecules can be laid out onto a regolith bed (including small 'smokes' and Apollo soil samples). The temperature is allowed to rise via a laser heating system. The desorption of carbon dioxide, methane and argon to Apollo soil samples has been examined.

Killen and David Williams are continuing a study of the lunar exosphere using the recently archived LACE data from Apollo 17. In addition, Killen is collaborating with Prabal Saxena, Avi Mandell and Noah Petro on examining moderate volatile loss through lunar history. Collier has phase A funding for PRISM, a Phobos Regolith Ion Sample Mission with Killen, Stubbs and Farrell supporting the effort.

1.3 Radiation Environment and Humans

The DREAM2 radiation team continued to explore how energetic charged particles affect the surface of the Moon and of Phobos. While plasmas interact with the surface of airless bodies, galactic cosmic rays (GCRS) from outside the Solar System and solar energetic particles (SEPs) from solar flares and coronal mass ejections can penetrate down to ~1 m. Not only can they modify regolith at depth, but they also enable us to probe the regolith. We highlight some work below, but other ongoing work ranges from inferring the past heliospheric conditions to how the radiation is modulated throughout the heliosphere [Rahmanifard et al., 2017; Quinn et al., 2017; Schwadron et al., 2017a; Schwadron et al., 2017b; Winslow et al., submitted to *Astrophys. J.*]

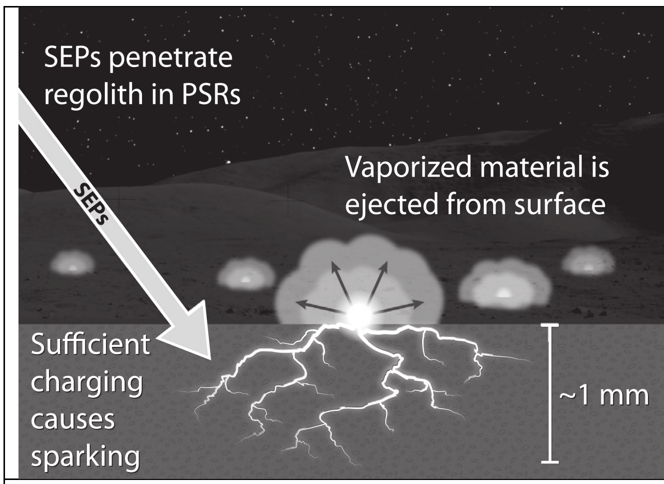


Fig. 1.3.1. (Top) Cartoon showing how SEPs can penetrate the soil in lunar PSRs and cause dielectric breakdown.

One highlight of this year's work continued previous investigations of how SEPs can cause dielectric breakdown in the top ~1 mm of soil within the Moon's permanently shadowed regions (PSRs) [Jordan et al., 2017]. A sufficiently large SEP event could deposit enough charged particles to increase the subsurface electric field to the point of dielectric breakdown (top of Fig. 1.3.1). Because breakdown vaporizes and melts material, it might weather soil in a way similar to meteoroid impacts. By comparing energy budgets, team members predicted that dielectric breakdown weathering is as important in PSRs as meteoroid impacts, affecting 10-25% of the regolith. They also extrapolated this work to Mars's satellite Phobos [Jordan et al., accepted in *Adv. Space Res.*]. If the electrical properties of its regolith are similar to the Moon's, then breakdown weathering may also be important there.

Another highlight is that the radiation team has begun to leverage a process generated by GCRs to help determine whether, as suggested by other studies, hydrogen varies diurnally on the lunar surface [Schwadron et al., 2017]. When GCRs collide with nuclei in the regolith, they release neutrons and "albedo protons." Unlike neutrons, which are suppressed when they encounter a layer of hydrogen, albedo protons are enhanced: some of the neutrons collide with the hydrogen (i.e., protons) and eject those protons. Since they originate at a depth of ~1-10 cm, albedo protons are a critical link between the reflectance data (surface) and the neutron data (~50 cm depth). Using the Cosmic Ray Telescope for the Effects of Radiation (CRaTER) on the Lunar Reconnaissance Orbiter (LRO), team members have detected diurnal variation in the albedo protons which may, in part, be due to diurnally varying hydrogenation. The team has developed new analysis and observational techniques to continue this exploration.

1.4 Surface Interactions

The harsh space environment including impactors, energetic plasma, and radiation creates damage within the regolith-rich surfaces at airless bodies. In PY 4, DREAM2 team members further examined the surface response to this environment. We highlight some of the activity below, but do not list all the ongoing work. See the attached bibliography that identified further activity.

Team members Farrell, Hurley, McLain and Zimmerman, along with DREAM2 intern Esposito, published a model of solar wind hydrogen implantation and expected surface hydroxylation (Fig.1.4.1). The model predicted the amount of retained hydrogen at the Moon as a function of solar zenith angle including the effects of H atom diffusion in damaged, irradiated silica surfaces. While a set of remote sensing IR observations have observed this OH in lunar regolith, to date there has not been a comprehensive solar wind-OH model to place these observations in context. The model predicts a lunation variation in OH content that was more recently confirmed in the IR observations. The model also predicts a reduction in OH formation in magnetic anomalies due to the reduced energy and flux of the incoming solar wind protons. The reduction in energy makes the implantations occur at a shallow depth – which allows a quick diffusion out of the surface. The lack of OH in magnetic anomalies via remote sensed IR has also been reported.

Poppe et al. merged ARTEMIS time-averaged solar wind proton and He ion energy distributions with ion transport models of lunar-like material. They demonstrated the high energy tail of the solar wind energy distribution could create amorphousization (crystal lattice destruction) at relativelylarge 100-200 nm depths. Such deep damage had been reported previously from electron transmission studies of Apollo sample. In essence, they linked the plasma observations to the grain damaged found in lunar samples.

McLain, Loffeler and Hudson continue their laboratory investigation of proton implantation and associated hydroxylation using the unique Goddard Radiation Facility. In PY4, they completed and tested the DREAM2 beam line and have made preliminary implantation results finding H becoming trapped in fused silica to form OH when irradiated for ~24 hours in a 1 keV proton beam. In PY5, we will then irradiate and damage the surface using a 1 MeV Argon beam to determine the effect on retention of the lower energy implanted H atoms. This two-beam experiment is a unique contribution to understanding the ability of oxide-rich regolith to act as a sort of catalyzing surface to create more complex chemical products like OH, water, and methane.

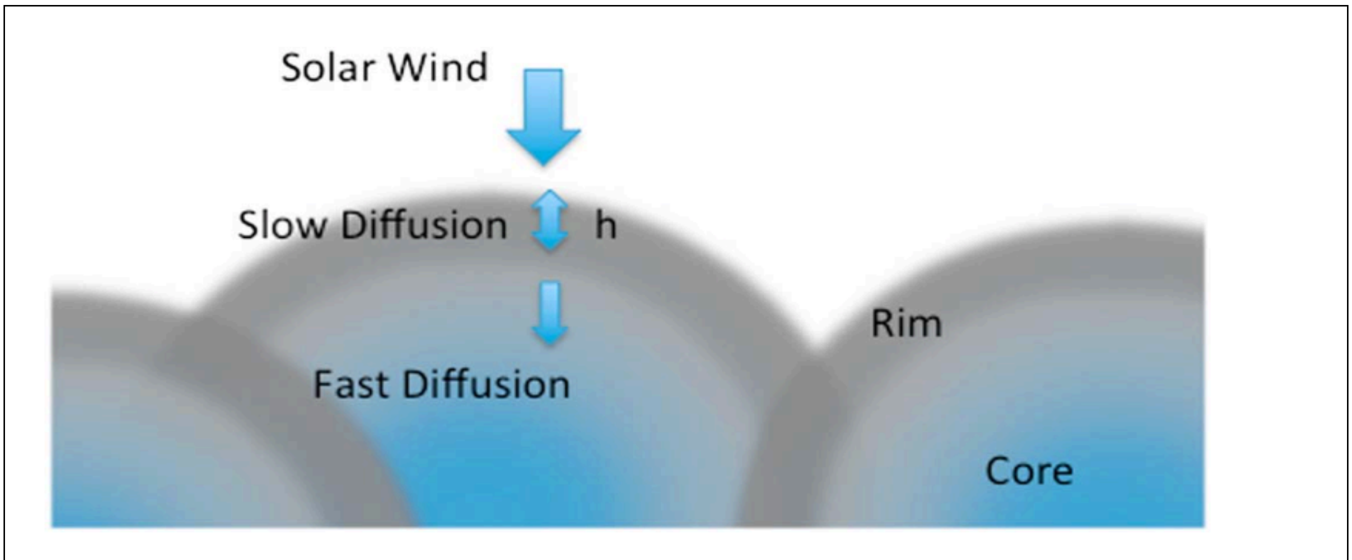


Figure 1.4.1: An illustration of the region of hydrogen 'slow' diffusion given solar wind protons as a source [Farrell et al., 2017]

DREAM2 team member Marshall has been investigating how particulate materials respond to transport forces, abrasion, tribocharging, and cohesion in airless or near-airless solar system environments with relevance to understanding fundamental physical processes as well as the response of solar system body surfaces to contacts with astronauts or mechanical objects. He currently examining the requirements for grain lifting from airless bodies including adhesion effects.

Team members Stubbs and Glenar are currently modeling the radiated power at lunar polar regions from sunlight reflected from the Earth (i.e., Earthshine). They have developed a visible and IR model of the Earth reflectance and will consider how this Earth shine will illuminate polar craters using LOLA topo maps along with the Moon' orbital orientation. This work is in support of the Lunar Prospector Mission,

1.5 Progress on the Space Environment at Phobos Study

During PY4 the team continued to extend their work on the space environment at Phobos. In PY4 DREAM2 team members published a set of papers to the 'Science and Exploration of Small Bodies' special issue of the journal 'Advances in Space Research'. Presentations were also made at LPSC, NESF, and DPS (Figure 1.5.1). In the summer of 2017, we also issued a press release on the possible surface charging at Phobos (https://www.nasa.gov/press-release/goddard/2017/mars-electric-moons) and shortly thereafter made a presentation at NASA HQ on the space environment at this enigmatic body.

The current list of papers from the DREAM2 Phobos study include:

-Poppe et al 2016: Phobos neutral and ion torus, JGR [published]

-Farrell et al. 2017: Hydroxylation at the Moon and Phobos, JGR [published]

-Killen et al. 2017: General Scaling of Exospheres, ASR/SB [published]

-Hartzell et al. 2017: Cohesive regolith on human explorers, ASR/SB [in press]

-Farrell et al. 2017: Electrical environment at Phobos, ASR/SB [in press]

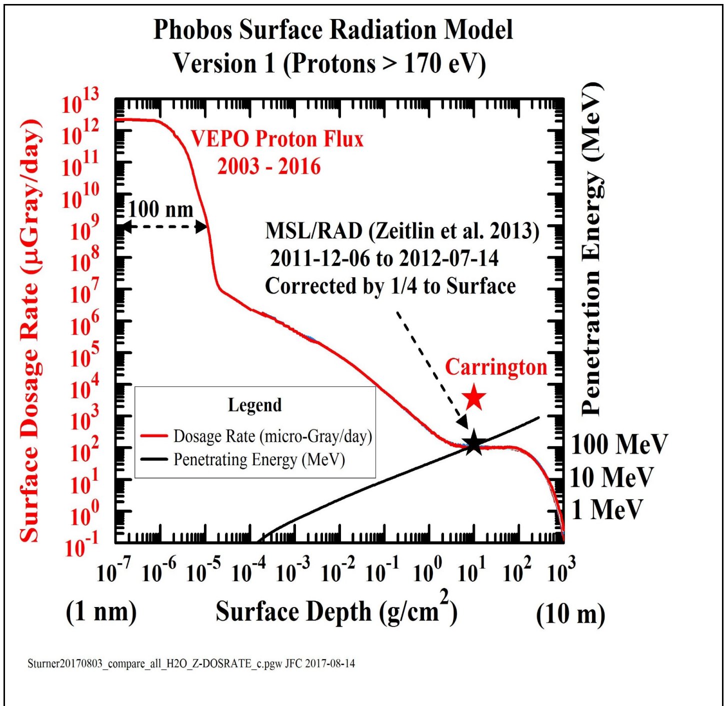
-Jordan et al., 2017: Dielectric breakdown at Phobos, ASR/SB, [in press]

-Collier et al., 2017: Smallsat mission to Phobos, to be submitted in ASR/SB [completed manuscript]

Extended Abstracts

-Hurley et al, Impact Gardening at Phobos, 3rd P/D Workshop

-Stubbs et al., Solar illumination at Phobos, LPSC 2017



1.5.1: A model of the Phobos radiation-surface interaction presented by Cooper et al. (2017) at the AAS/DPS meeting this past fall 2017. Most of the influx of radiation (170 MeV protons) is attenuated in the first few meters of regolith.

1.6 Conclusions and RP

The next topic for a DREAM2 Intramural study is the lunar environment expected to be encountered during the Resource Prospector (RP) mission. We initiated the study in PY4 and will continue the work in PY5. Specifically, we have created models of RP rover wheel charging that would be useful to determine rover speeds in low plasma PSR regions. If the wheel moves over the surface too fast, excess tribo-charging could occur in PSR regions with low plasma influx. Prim and Hurley are also examining the effect the landing craft exhaust plume will have on the local volatile environment. During the Chang'e – 3 landing, over 100 kg of water was dumped onto the surface from the exhaust plume– in some locations possibly creating in excess of a monolayer of water. This water was found to desorb and migrate over the surface. A similar exhaust plume from the RP lander could place a layer of volatiles adjacent to the survey site, which would also desorb and migrate poleward to contaminate the regions examined by RP. DREAM2 model can predict the impact of this process. Stubbs and Glenar are creating a model of Earthshine into regions where RP will examine. Jordan and Stubbs also have made some preliminary calculations of the possibly of active electrical events from radiation-induced deep dielectric discharge during solar energetic particle events and CME passes during the RP mission. RPs NIRVSS system may have to potential to directly observe the discharge event.

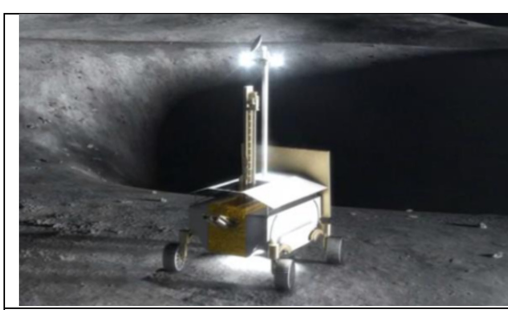


Figure 1.6.1 : An illustation of the RP lander

There were many 10's of DREAM2 scientific and outreach activities occurring during PY4, and we highlight a few of these herein. We continue to make great strides in understand the space environment's effect on the surfaces of airless bodies, and the three-way interaction between the surface response, environmental drivers, and human systems that contribute to the complexity of the environment-surface interactions. As we note in the RP study, RP is sent to prospect for resources, but RP's own effect on the fragile environment may impact the prospecting process. DREAM2 is poised to examine and assist the RP team in evaluating these lander-surface-environmental effects.

2 DREAM2 Inter-team and International Collaborations.

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

REVEALS: DREAM2 PI Farrell is part of the REVEALS Science Advisory Board and the team works together on modeling and lab efforts regarding solar wind implantation and surface hydroxylation at the Moon and other airless bodies. The two teams recently proposed to share an NPP position via a SSERVI-Central slot. We are currently working on a Long Duration Exposure Platform (LDEP) to be placed on the Deep Space Gateway to examine the effects of solar wind and impact weathering on a set of surfaces.

NESS: DREAM2 and NESS share collaborators in understanding and assessing the space environmental effects on a sophisticated and sensitive radio astronomy system. We currently supported NESS colleagues on assessing the lunar dust and electrostatic environment, and how to better-ground the radio system,

TREX DREAM2 team members Hurley and Farrell are working with TREX lead Hendrix on the UV signature of surface water at the Moon. REVEALS team members are also involved.

VORTICES: Strong collaborating work on solar wind/airless body interactions, volatile interactions, and Orion/asteroid interactions and lunar pits. Strongest collaborations with individuals Zimmerman, Hurley, Prem, & 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 architect, design and build future exploration-oriented field instrumentation for astronaut use.

IMPACT: 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 IMPACT modelers on magnetic anomaly studies.

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

<u>International Partners</u>

Japan: DREAM2 team members work closely with Dr. Y. Saito, the Kaguya plasma and mag PI, at the Institute of Space and Astronautical Science, on lunar plasma interactions. Prof. Halekas took a sabbatical from his then-position 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. Many DREAM2 and Kaguya plasma team members are working together on a New View of the Moon 2 chapter on 'Dust, Atmosphere, and Plasma 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 in 2012-2013. DREAM2 coi Shahab Fatemi relocated from UCB to Kiruna and is working closely with DREAM2 team members in modeling of the plasma environment at asteroids, like 16 Psyche. We continue to team with our Kiruna partners in our cubesat proposals, like the SIMPLEX HALO proposal lead by Collier.

3. Public Engagement (including EPO) Report

3.1 Undergraduate Internship Program

Summer 2017 marked a fourth successful DREAM2 Undergraduate Internship Program. Team members at GSFC (W. Farrell, R. Killen, M. Sarantos, M. Collier, T. Stubbs, J. Cooper, L. Bleacher) hosted eight students, including seven from DREAM2 Co-I institution, Howard University. 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.

Funding for five of the students was leveraged through a NASA Minority University Research and Education Project (MUREP) funding award to Howard University. The project pairs Howard students with GSFC mentors and engages them in cutting-edge Earth and Space Science research throughout their undergraduate tenure. The project takes a multi-faceted approach, with each year of the program specifically tailored to each student's strengths and addressing their weaknesses, so that they experience a wide array of enriching research and professional development activities that help them grow both academically and professionally. During the academic year, the students are at Howard taking a full load of courses towards satisfying their degree requirements and engaging in research with their GSFC mentors via regular telecons, e-mail exchanges, video chats and at least one visit per semester to GSFC for an in-person meeting with their mentor. The students extend their research with full-time summer internships at GSFC, culminating in a Capstone Project and Senior Thesis. As a result, these Early Opportunities Program students, who have undergone rigorous training in the Earth and Space Sciences, are expected to be well prepared to enter the NASA workforce.

3.2 DREAM2Explore Educator Professional Development Workshop

The DREAM2 Education and Public Engagement Team also led the third annual DREAM2Explore Educator Professional Development Workshop, which took place from June 26-July 1st, 2017. Fifteen 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, A. Jordan, J. Cook, R. Killen, M. Loeffler. FINESSE PI Jen Heldmann participated as well. 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 National Air and Space Museum.

A survey was issued at the workshop's conclusion to gauge its success. 100% of DREAM2Explore participants strongly agree that: The workshop allowed them to acquire a new understanding of planetary science and exploration that will be valuable in working with their students in the future, and they acquired activities while at the workshop that they will use 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." "These workshops are very valuable. The knowledge will be passed on. It is hard to tell how many lives will be touched by what we learned this week."*

4. Student / Early Career Participation

Undergraduate Students

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 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
Sirak Fessehaye
Jamil Johnson
Grace Kenlaw
John Clark
Trey Jean-Baptiste

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 participants are listed:

Keenan Hunt-Stone (Howard)
Iman Ahmed (Howard)
Edward Williams (UMD)

Graduate Students

Heidi Fuqua, UCB, Lunar Plasma Interactions
Colin Joyce, UNH, Radiation studies
Stephanie Howard, Iowa, Solar wind plasma disturbances at the Moon
Fatemeh Rahmanifard, UNH, Radiation
Philip Quinn, UNH, Radiation

Postdoctoral Fellows

Charles Lue, Iowa, Space Plasma and ARTEMIS
Jeff Walker, Iowa, Space plasma and dust
Rika Winslow, UNH, Radiation studies
Orenthal Tucker, GSFC, Hydrogen Cycle and Exopsheres
Dov Rhodes, GSFC, Charging on human systems (arrives in April)

New Faculty Members

Menelaos Sarantos, NASA Civil Service, GSFC, Exospheres

5. Mission Involvement

Shown are DREAM2 team member roles on current and planned missions. (PSD= NASA's Planetary Science Division, HSD= NASA's Heliophysics Science Division, AES=NASA's Advanced Exploration Systems Division)

PI, Co-I, and Guest Investigator roles (* = DREAM2 collaborator):

1. PSD/Lunar Reconnaissance Orbiter/Petro*/Project Scientist
2. PSD/Lunar Reconnaissance Orbiter/ Keller/Deputy Project Scientist
3. PSD/Lunar Reconnaissance Orbiter/Schwadron/CRaTER PI
4. PSD/Lunar Reconnaissance Orbiter/Spence/CRaTER Co-I and former PI
5. PSD/Lunar Reconnaissance Orbiter/Hurley/LAMP Co-I
6. PSD/ Lunar Reconnaissance Orbiter/Elphic/Diviner Co-I
7. PSD/Lunar Reconnaissance Orbiter/Stubbs/Participating Scientist
8. PSD/LADEE/Elphic/Project Scientist
9. PSD/LADEE/Delory/Deputy Project Scientist
10. PSD/LADEE/Colaprete/UVS PI
11. PSD/LADEE/Hodges/NMS Co-i
12. PSD/LADEE/Stubbs/Guest Investigator
13. PSD/LADEE/Glenar/Guest Investigator (named on the Stubbs GI proposal)
14. PSD/LADEE/Hurley/Guest Investigator
15. PSD/LADEE/Halekas/Guest Investigator
16. PSD/LADEE//Poppe/Guest Investigator (named on Halekas GI proposal)
17. PSD/LADEE/Sarantos/Guest Investigator
18. PSD/OSIRIS REx/Marshall/Co-I and former lead of Regolith Working Group
19. PSD/OSIRIS REx/Nuth*/Deputy Proj Sci
20. PSD/OSIRIS REx/Lim*/Co-i
21. PSD/OSIRIS REx/Hartzell*/Participating Scientist
22. PSD/Phoenix/Marshall/MECA Co-I
23. PSD/MAVEN/Delory/Co-i
24. PSD/MAVEN/Halekas/Co-I and lead build of ion spectrometer
25. PSD/MESSENGER/Killen/Co-i
26. PSD/Curiosity/L. Bleacher/Communications
27. PSD/Cassini/Farrell/RPWS Co-i
28. AES/Resource Prospector/Colaprete/NIRVSS lead
29. AES/Resource Prospector/Elphic/NSS lead
30. AES/Lunar IceCube/Clark/Science PI
31. HSD/ARTEMIS/Halekas/Deputy PI
32. HSD/ARTEMIS/Delory/Co-i
33. HSD/WIND/Collier/Deputy PI
34. HSD/WIND/Farrell/WAVES and MFI Co-i
35. HSD/Parker Solar Probe/Farrell/Co-i
36. HSD/Parker Solar Probe/Schwadron/Co-I
37. HSD/IBEX/Schwadron/Co-I
38. HSD&ESA/Solar Orbiter/Collier/co-I Heavy Ion Sensor (GSFC lead)
39. HSD&ESA/SMILE/Collier/Co-I
40. HSD/CuPID cubesat/Collier/Co-I and instrument lead
41. ESA/BepiColumbo/Killen/Coi
42. ISRO/Chandrayaan-1/Holmstorm*/Co-i
43. JAXA/Kaguya/Saito*/PI
44. JAXA/MMX/Elphic/MEGANE Co-I
45. KARI/KPLO/Elphic/MEGANE Co-I
46. DoD (Space Test Program)/FASTSAT/Collier/Co-I and instrument lead
47. DoD (Space Test Program)/USAF DSX/Farrell/Co-I and Search coil build lead

Mission-recognized supporting roles includes:

46. PSD/Lunar Reconnaissance Orbiter/Glenar/LAMP data analysis
47. PSD/ Lunar Reconnaissance Orbiter/Prem/Diviner and Mini-RF data analysis
48. PSD/ Lunar Reconnaissance Orbiter/Wilson/CRaTER data analysis
49. PSD/ Lunar Reconnaissance Orbiter/Jordan/ CRaTER data analysis
50. PSD/LADEE/Marshall/UVS instrument calibration
51. PSD/Cassini/Cooper/CAPS team member, data analysis
52. PSD/Cassini/Hurley/Enceladus modeling
53. HSD/ARTEMIS/Poppe/plasma data analysis
54. HSD/ARTEMIS/Fatemi/plasma data analysis & modeling