DREAM 2009-2010 Annual Report Executive Summary

While the Moon is often considered a stagnant "dead" body, it actually percolates with activity – as the recent Chandrayaan M-cubed results suggest. The surface interface is in constant interaction with its environment, acting as an obstacle to inflowing plasma and continually releasing solar-stimulated atomic neutrals. These interactions create a super-surface layering about the Moon containing (1) a plasma interaction region that includes a near-surface plasma sheath and an extended, trailing solar wind plasma wake and (2) a neutral surface boundary exosphere and exo-ionosphere that extends hundreds of miles above the surface. Apollo-era studies of these two systems revealed their presence and the tantalizing possibility of a very complicated and dynamic neutral-ion-volatile-plasma-dust environment.

Dynamic Response of the Environment At the Moon (DREAM) consists of two primary institutes and 10 expert partners embarking on an advanced study of these two seemingly separate environmental systems. DREAM's theory-modeling-data validation study focuses on advancing the knowledge base of the systems, understanding the systems' response to the variable solar drivers, finding common linkages between the two systems, and to test these modeled systems via extreme events. DREAM EPO has a primary focus on teacher and student participation in Lunar Extreme Workshops or LEWs. These LEWs will center on the lunar response to solar storms and to impacts/gas releases. Before each of the LEWs, introductory material will be placed on a dedicated web-site and webinars will occur where DREAM team members discussed LEW-specific subject matter and e-interact with the students/teachers. These now-knowledgeable students and teachers will then be active participants in the LEWs, interacting directly with the co-investigators and collaborators in viewing the first results of the models run for extreme events.

Figure ES.1 caption: The DREAM concept to understand the solar-lunar connection

The essence of DREAM is to address the fundamental question: **"How does the highly-variable solar energy and matter incident at the surface interface affect the dynamics of lunar volatiles, ionosphere, plasma, and dust?"** To answer this, DREAM has formulated 4 primary science objectives:

1. Advance understanding of the surface release and loss of the **neutral gas exosphere** over small to large spatial scales and a broad range of driver intensities.

2. Advance understanding of the enveloping **plasma interaction region** over small to large spatial scales and over a broad range of driver intensities.

3. Identify **common links** between the neutral and plasma systems and test these linkages by modeling **extreme environmental events**.

4. **Apply** this new-found environmental knowledge to guide decision-making for future missions, assess the Moon as an observational platform, and aid in human exploration.

In the first year of DREAM, a number of key advancements were made in the **understanding of the neutral gas exosphere (Objective 1)**. Some highlights of DREAM applications include the following (and are presented in greater detail in the attached progress reports): 1) In support of both DREAM and the LADEE mission, Co-I Richard Hodges is developing the LExS neutral gas code to ultimately be distributed to the entire community. Currently, the code is being applied by the LADEE NMS team to fine-tune the predicted species that should be detected by that instrument. 2) Co-I Rosemary Killen obtained time on the McMath-Pierce telescope to search for a sodium plume during the LCROSS impacts. In fact a plume was observed by this ground based telescope suggesting that about ~1 kg of sodium was released at impact. The number density of observed sodium matches almost exactly the number obtained by the LCROSS impact team. Co-I's Rosemary Killen, Dana Hurley, and Tony Colaprete are now modeling that exospheric transport of the transient sodium plume using a neutral gas Monte Carlo code and thermal information provided by LCROSS impact studies (~1000K thermal expansion). Killen's and Hurley's work are funded primarily under DREAM. It is a nice example of institute funding in the form of a larger block grant that subsequently allowed a quick response to unanticipated/unplanned events. The use of McMath-Pierce's 62 inch telescope for LCROSS observation was in fact considered by Killen well after the DREAM proposal was in place – but the available resources provide a fast response that enabled and expanded the observations (resources available in an afternoon), instead of having to write and wait on a separate LASER proposal for support. 3) Co-I Menelaos Sarantos completed a study showing that the sodium emission from the lunar surface is created primarily by photon-stimulated desorption, but also enhanced by the influx of solar wind protons. The comprehensive study examined all ground based observations to date and correlated activity with location in the magnetosphere (low ion concentration) and solar wind (high ion concentration). A clear and distinct ~2-3 times increase in Na emission rate was clearly observed upon entry into the solar win ion flow.

A number of key advancements were made in the understanding of the **plasma interaction and ionized gas flow at the Moon (Objective 2).** Some highlights include the following (and included in more detail in the attached progress reports): 1) PI William Farrell and Co-I Tim Stubbs further advanced and published a model of the solar wind expansion into lunar polar craters. The model applies both an ambipolar expansion process like that occurring in the plasma wake of the space shuttle and surface-sheath charging model to predict proton and electron flux levels at the bottom of the crater floor. The model finds that the surface should become strongly negatively charged at the leeward edge of a polar crater – that edge directly under the flow. 2) Co-I Tim Stubbs and Dave Glenar published a prediction of the dust flux, sodium neutral gas flux, and light scattering expected during the LADEE mission. The results will fine-tune the LADEE UVS observations of the horizon glow – and will aid in determining if this glow is created by gas or dust (which is a key LADEE objective). They especially found at wavelengths below 350 nm that the lunar dust scattering from smaller particles should dominate over zodiacal light- providing a unique spectral range for the detection of any lofted dust from the lunar surface. The work is funded under DREAM and provided to LADEE in support. 3) Co-I Jasper Halekas and Greg Delory have been in close contact with DREAM collaborator Prof. Yoshi Saito in support of joint Kaguya electron and ion studies. In May of 2009, Halekas and Delory visited JAXA and had a set of very successfully discussion on joint topics where DREAM could provide modeling analysis to aid in Prof. Saito's team analysis of the unique Kaguya MAP-PACE observations through the polar wake region.

During the first year, DREAM investigators designed the architecture for the "solar storm-lunar interaction model (SSLIM)" - a supermodel – that will **integrate the existing neutral, dust, and plasma models into a semi-merged system with a common event trigger (Objective 3).** Figure ES.2 shows a simplified view of SSLIM. Once a common solar storm is identified, the data sets, including solar wind plasma, UV, and solar energetic particle measurements, will be provided to the neutral Monte Carlo, exo-ionosphere, plasma, and dust model curators. The curators will then run their models under identical solar storm/extreme event conditions. The outputs will be exchanged between the curators and the models will be run again given the added cross-model inputs (like those shown in the figure). For example, we anticipate that the surface sheath E-fields will increase during a solar storm and thus increase the amount of electrostatically-lofted dust from the surface. This added environmental dust load is then incorporated into plasma hybrid simulations to understand the dust load affect on the passing solar wind plasma. In the first year, DREAM formed an 'Extreme Event Selection Committee

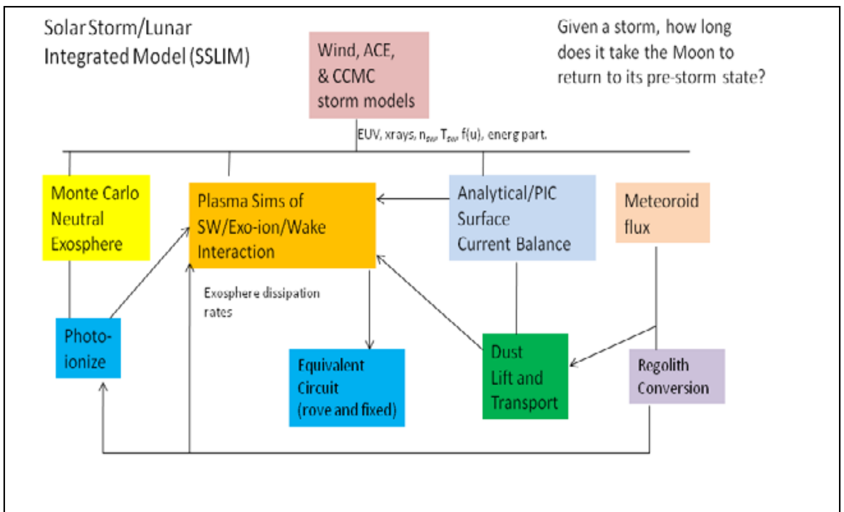

Figure ES.2 – The layout of the solar storm-lunar interaction supermodel.

(EESC)' headed by Jasper Halekas and Menelaos Sarantos that examined a large number of candidate solar storms as the event driver for SSLIM. A key criterion derived by the EESC is that the storms occur during a period of time when LP was in orbit about the Moon (to provide local plasma and surface potential measurements). Another requirement is that the storms have an increase in the abundance of heavy-mass solar wind ions for enhanced neutral and ion sputtering from the surface. The EESC found that presence of heavily massed ions tended to increase within the coronal mass ejection (CME) driver gas. The EESC thus concluded that the set of solar storms/CME passages in early May of 1998 appear to be ideal candidates for SSLIM drivers since they are very active, LP was taking measurements, and the events provide an abundance of heavy ions. The events have also been well-studied by the Heliophysics Space Weather community and thus their previous analysis will provide DREAM with valuable insights into the solar drivers.

DREAM team members applied their environmental knowledge in **support of number of ongoing missions in 2009-2010 (Objective 4),** including Kaguya, LRO, the LCROSS impacts and the upcoming LADEE mission. Tim Stubbs is supporting LRO by providing shadowing models and surface potential maps both as a DREAM Co-I and LRO Participating Scientists. The provision of both funding lines allowed Stubbs to bring on an additional early career scientist in support of the shadowing codes. Besides Killen's LCROSS telescopic observations , Colaprete is providing the LCROSS impact code as an input to DREAM model activities (the starting point for the impact supermodel being developed) and DREAM Co-I Dave Glenar is working the LCROSS team on the interpretation of UV spectrometer limb scans of lunar dust and gas horizon glow. DREAM Co-I Telana Jackson further advanced a human system equivalent circuit model to demonstrate tribo-charge buildup in roving systems – which would be of direct benefit to Exploration. As a team we continue to work with Exploration Technology Development Program's dust (ETDP-dust) lead, Mark Hyatt, on passing along our understanding of the lunar dusty-plasma environment that will affect exploration. A key message we have been sending ETDP-dust is that a human system in the polar region is electrically grounded to the plasma and not easily grounded to the highly-resistive surface. Not only does this affect dust adhesion and mitigation, but could have a profound effect on power electrical systems.

In cadence with these mission findings, DREAM investigators were simultaneously helping to **publically frame the new view of the Moon**. There is no direct metric for measuring LSI's implicit influence in publically advocating lunar science - it is an intangible – but there does indeed appear to be a substantial LSI public impact. For example, DREAM had a very strong presence at the LCROSS press conference on 13 Nov 2009 (http://www.nasa.gov/mission_pages/LCROSS/main/prelim_water_results.html), with LCROSS PI/DREAM Co-I Tony Colaprete and DREAM Deputy Team Leader Greg Delory publically presenting the new findings on water at the Moon. They described the impact of lunar water in terms of the inner solar system's past and present, but also framing it in DREAM-like terms. When considering an active lunar surface, percolating with atoms and strongly affected by the inflowing plasma , Delory was quoted: 'This is not your father's Moon' and this expression became the take-home axiom of the event. This idea was later rephrased as a title of a year ending essay on the Moon that appeared as a lead article on CNN.com on 22 Dec 2009 (http://www.cnn.com/2009/TECH/space/12/22/moon.missions/index.html). LSI's influence was thus involved in framing the newly-minted views of the Moon as derived by M-cubed and LCROSS – working with (and within) other lunar investigation team to place their exciting new findings of a possible reactive/active Moon in understandable context. NASA's LSI team members were at the right place, at the right time, framing the issues in the exactly right way.

DREAM team members also actively participated in **NASA-related mission and lunar science advocacy.** Especially in 2009, there were a number of ongoing NASA activities that required a community collective response, including the Augustine Commission on the reformulation of exploration and the Planetary Decadal study. In response, DREAM team members formed a larger NLSI Dust and Atmosphere Focus Group (D&A FG) containing ~60 members from the larger lunar community. They wrote an advocacy letter to the NASA Advisory Council on keeping the LADEE mission alive. The D&A FG also provided a white paper to the Decadal Study on the Lunar Atmosphere as an Inner Planet Extreme Atmosphere. DREAM Co-I Dana Hurley also lead the submission of white paper on lunar volatiles and DREAM Co-I Jasper Halekas authored a white paper on the impact of ARTEMIS in lunar science.

Besides advocacy, DREAM was also active in **'Supporting Other Institute Objectives (SOIO)'**. These activities included the following: 1) DREAM Participated in a number of E/PO events including Maryland Day 2009 at the University of Maryland Campus and Moonfest held at NASA/Ames. 2) Team members made over a half-dozen public presentations to large groups about DREAM-related lunar science. 3) The GSFC team worked with the Lunar and Planetary Space Academy on lunar projects for undergraduate science and engineering majors in the summer of 2009. 4) The IT team developed a DREAM webpage that describes our lunar science (http://ssed.gsfc.nasa.gov/code695/dream/index.html). 5) The IT team built a dedicated videoconferencing room in GSFC's new ESB building and regularly participate via video in LSI meetings. 6) CoI Lora Bleacher and Collaborator Noah Petro used DREAM to leverage a the Next Generation Lunar Scientist and Engineer (NGLSE). NGLSE's purpose is to engage and develop the next generation of lunar scientists and engineers, and to enable their successful involvement in current planning for the scientific exploration of the Moon. 7) The E/PO team continued to plan for the inclusion of students in the Lunar Extreme Workshops was in initiated in 2009-2010. 8) DREAM Co-Is Tim Stubbs and Dana Hurley were sponsors/leaders of a dedicated Moon session at Fall 2009 American Geophysical Union meeting.

All total in DREAM's program year #1 from 2009-2010, the team authored 6 new science papers and has initiated a large number (~10) of manuscripts slated for PY2 submission, provided ~50 talks/presentations at AGU, workshops, Lunar Science Forum, & LPSC – all of these advancing the objectives of integrating the neutral-gas-plasma environment at the Moon and providing critical and timey advocacy for NASA's lunar missions. In the second program year, we will continue to advance DREAM's goals, but also remain poised and flexible to coherently respond to the ongoing realignment of NASA's objectives.