VIRTUAL SWIRLS: HIGHLIGHTS FROM NLSI'S FIRST WORKSHOP WITHOUT WALLS. C.D. Neish[1], S. Besse[2], G. Kramer[3], W. Farrell[4], C. Pieters[5], M. Horanyi[6], Y. Pendleton[7], [1]The Johns Hopkins University Applied Physics Laboratory, Laurel, MD, 20723 (catherine.neish@jhuapl.edu), [2]The University of Maryland, College Park, MD, 20742, [3]Lunar and Planetary Institute, Houston, TX, 77058, [4]NASA Goddard Spaceflight Center, Greenbelt, MD, 20770, [5]Brown University, Providence, RI, 02912, [6]University of Colorado, Boulder, CO, 80309, [7]NASA Lunar Science Institute, Moffett Field, CA, 94035.

Introduction: Swirls are among the most puzzling features on the surface of the Moon. Their bright, looping patterns are unlike anything seen in the solar system (Figure 1). The origin of the lunar swirls has been discussed for many years, but a universally accepted explanation for their formation remains elusive [1,2,3, 4].

Current space missions are returning new views of the lunar swirls, at resolutions and wavelengths never before considered. These new data have the potential to provide tremendous new insights into swirl formation. We therefore organized an informal one day "Workshop without Walls" on lunar swirls using NASA Lunar Science Institute (NLSI) remote communications tools. The workshop was held on September 7, 2011 and was open to interested persons from all over the world. This represents NLSI's first virtual workshop, based on previously successful workshops sponsored by the NASA Astrobiology Institute (NAI).

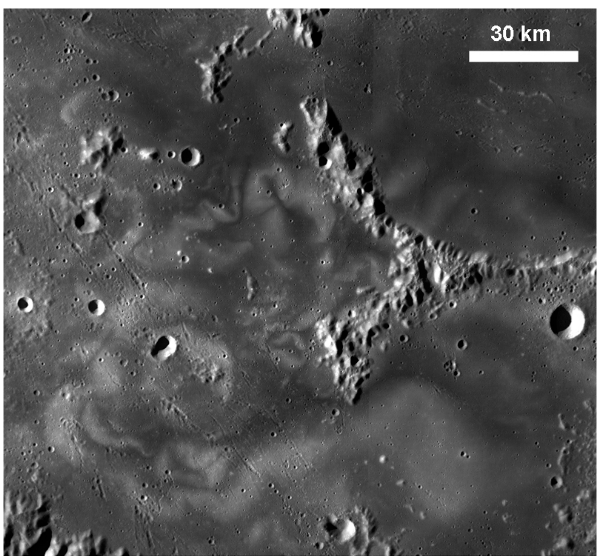

Figure 1: LROC WAC image of the swirls at Mare Ingenii (credit: NASA/GSFC/Arizona State University).

The Workshop: The purpose of the meeting was to bring together an international group of experts from various disciplines (geology, plasma physics, magnetism, remote sensing, etc.) to share their knowledge of the many processes related to lunar swirl formation. In the course of the workshop, it was hoped that we could identify new links between these processes that may explain the origin of the lunar swirls. The processes discussed during the meeting included the origin of lunar magnetic anomalies, the interaction between the solar wind and magnetic anomalies, dust transport, and space weathering. We also presented the latest data from the flotilla of international spacecraft that have been studying the Moon over the last few years. These data provide information about the swirls at wavelengths and resolutions previously unavailable to the scientific community. Complementary laboratory experiments were discussed addressing the charging and mobilization of dust on surfaces, and the interaction of plasma flows with localized magnetic fields.

The workshop featured eighteen presenters from six countries, representing eight instruments on three spacecraft (LRO, Chandrayaan-1, and Kaguya), as well as one future spacecraft (LADEE). In addition, we had over 150 registered participants from 18 countries, who actively engaged in discussions over the phone line and in the online chat window (Figure 2).

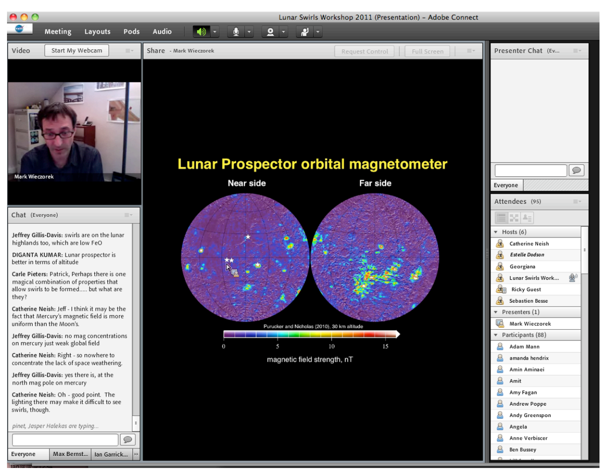

Figure 2: Mark Wieczorek discusses the origin of lunar magnetic anomalies at NLSI's first Workshop Without Walls. A chat window at lower left facilitated discussions between participants during the event.

Results: During the course of the workshop, speakers compared and contrasted the primary models for swirl formation. These include cometary impacts [1], differential space weathering [2], dust levitation

[3], and exo-ion congregation [4]. Experts in fields ranging from remote sensing to plasma physics discussed these theories in the context of new data presented from an international set of investigators. Some of the new results presented during the meeting included:

1) Data from several instruments, including the LROC NAC and Kaguya Terrain Camera (TC), demonstrated conclusively that Reiner Gamma and other swirls lack any observable topography.

2) There is no signature of the swirls in the radar data collected by Mini-RF on LRO, suggesting that the swirls are a surficial coating, less than a meter thick.

3) There is evidence of craters in LROC NAC images that have 'punched through' a thin bright layer to reveal a dark substrate beneath.

4) Data from Diviner on LRO do not indicate substantial thermal anomalies associated with the swirls, inconsistent with the presence of thick deposits of dust.

5) Laboratory experimental results indicated the generation of localized electric fields near magnetic anomalies, and the transport of charged dust near boundaries of lit and dark regions.

6) Several presentations support the idea that swirl material represents some of the most immature material on the lunar surface.

7) Data from the M^3 instrument on Chandrayaan-1 suggests that there is a decrease in OH ions on swirl compared with surrounding regions, implying that whatever process forms the swirls also controls the surficial OH.

8) Kaguya magnetometer data demonstrated that the horizontal component of the magnetic field lines up remarkably well with the surface markings of the swirls, at the 10 km scale.

Although no official consensus was reached during the meeting, much of the data presented above is consistent with an origin for the swirls linked to the interaction between the solar wind and the lunar magnetic anomalies. However, more work will be required to fully understand the origin of the lunar swirls. Some of the future research directions identified in the workshop include:

1) What is the ultimate source of the lunar magnetic anomalies?

2) What is the chronology of swirl emplacement relative to the surrounding geology? How can we use new data available on fresh, small craters to place the swirls in sequence?

3) Why are swirls visible at some magnetic anomalies, but not all magnetic anomalies?

4) What causes the unusually bright albedo characteristic of the lunar swirls? How might laboratory experiments help us to understand this process?

5) How does the magnetic signature at orbital altitudes (> 50 km) map to the detailed swirl structure at the surface?

6) What future missions (either orbital or in-situ) would be required to determine the electrical and magnetic environment at the swirls? What observations could be done from orbit, and what measurements could only be done on the surface?

It is our hope that the presentations and discussions from this workshop will encourage future collaborations between the participants, leading to a new understanding of the enigmatic lunar swirls. The workshop itself will also serve as a model for future meetings, saving time and money by eliminating the need for travel (Figure 3). This is especially important for fostering international collaboration, where travel may be prohibitive to participation.

Figure 3: NLSI Teams from the University of Colorado, Brown University, NASA Ames, and NASA Goddard (clockwise from top left) participated in the workshop using video teleconferencing (credit: E. Dodson).

References: [1] Schultz P.H. and Srnka L.J. (1980) *Nature, 284*, 22-26. [2] Hood L. and Schubert G. (1980) *Science, 208*, 49-51. [3] Garrick-Bethell I. et al. (2011) *Icarus, 212*, 480-492. [4] Keller J. et al. (2011) LPSC XLII, Abstract #1817.