LUNAR SWIRL IMPACTORS: A LOW-COST MISSION TO STUDY LUNAR SWIRLS, MAGNETISM, WATER, SPACE WEATHERING, DUST, AND PLASMA PHYSICS. I. Garrick-Bethell[1], R. Lin[2], H. Sanchez[3], and D. Hemingway[1]. [1]University of California, Santa Cruz (igarrick@ucsc.edu), [2]University of California, Berkeley. [3]NASA Ames Research Center.

Introduction: Lunar swirls are one of the most enigmatic geologic features in the solar system. Swirls are sinuous high-albedo features correlated with strong crustal magnetic fields (Fig. 1). Swirls are at the intersection of many disciplines, including the origins of lunar magnetism, space weathering, space plasma physics, dust lofting, and most recently, surface hydroxyl formation [1]. Therefore, a mission to swirls would benefit many in the planetary science community.

NASA Ames Research Center, UC Berkeley, and UC Santa Cruz have been designing a low-cost, low-mass mission to swirls that uses cubesat technology. Below we outline how this mission can cost-effectively make first of a kind measurements and inform a number of important problems in lunar science.

Multidisciplinary science at lunar swirls

Swirl formation: The two leading models for swirl formation are the solar wind deflection model [2], and the dust transport model [3]. Under the solar wind deflection model, the brightness of swirls is explained by the local magnetic field deflecting the solar wind (a darkening agent) from portions of the surface. Under the dust transport model, the brightness of swirls is explained by the accumulation of fine, bright dust, due to weak plasma-produced electric fields operating on charged dust lofted during terminator crossings. Measurements of the solar wind flux very near the surface, at bright and dark areas, would determine if the solar wind model is correct. Measurements of lofted dust very near the surface would help determine if dust lofting can contribute to swirl formation.

Lunar magnetism: The origin of lunar magnetism is still unknown, with interpretations suggesting either impact-produced plasma processes [4] or an ancient dynamo [5]. If crustal magnetic anomalies formed in a dynamo field, they should be homogenously magnetized with minimal short-wavelength variability in direction near the surface, except at the scale of small craters. Presently, magnetic field measurements at anomalies have only been taken above ~16 km in altitude, at best. Measurements of the magnetic field near the surface would help determine the strength and coherence of the underlying crustal magnetization, and thereby its formation mechanism. Such measurements would also help explain how the solar wind direction and flux is altered near the surface.

Lunar water: The M3 instrument on Chandrayaan has revealed that high lunar latitudes have higher abundances of hydroxyl molecules [6]. More recently, M3 data were used to show that lunar swirls have relatively low hydroxyl abundances relative to their surroundings [1]. Therefore, swirls are a natural laboratory for understanding water formation on the Moon, and likely on silicate bodies in general. Determining the swirl formation mechanism and quantifying the relevant processes should help elucidate how hydroxyl molecules and water form on the Moon's surface.

Space weathering: A long-standing question in space weathering is the relative importance of micrometeoroid impacts compared to the solar wind [7]. Under the solar wind deflection model for swirl formation, solar wind weathering at swirls is reduced, and the surface is kept brighter. However, because micrometeoroids are undeflected by the magnetic field and reach the surface, swirls may also be a natural laboratory for unraveling and quantifying the relative contributions of these two darkening agents. Improved knowledge of these processes would have applications to the spectral study of asteroids and Mercury.

Lunar dust: Dust lofting during terminator crossings has been inferred from a variety of measurements since the Surveyor missions [8], and may also be important in asteroid geology [9]. However, the amount of dust lofted above the lunar surface, if any, is not fully known. Measurements of the dust flux very near the surface, in particular during terminator crossings, would help constrain how much dust is lofted each day, and possibly the mechanisms behind dust lofting.

Plasma physics: The interaction of the solar wind with weak magnetic anomalies on the Moon presents interesting plasma physics phenomena, such as the development of a mini-magnetosphere [10]. The scale size of the magnetic anomalies ranges from below to above the solar wind proton gyrodiameter; thus, across the transition from kinetic to fluid behavior.

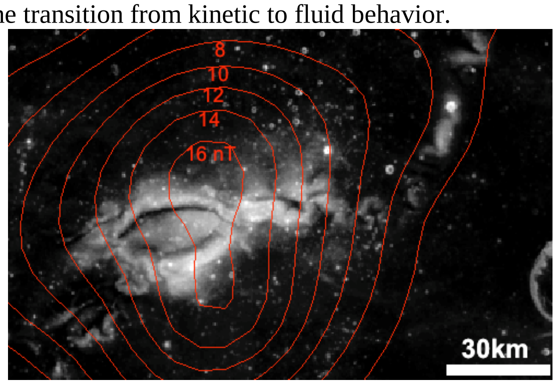

Fig. 1 – Reiner gamma swirl (Clementine 750 nm reflectance) and magnetic field contours at 18 km (Lunar Prospector).

A low-cost mission to lunar swirls

Mission objectives and concept: A mission to swirls that measures very near the surface:

1) Magnetic field strength and direction,
2) Solar wind flux and direction, and
3) Dust density,

would answer the key science questions above. A spacecraft on a very low-angle impact trajectory into the heart of a swirl could perform the necessary measurements at low altitude (Fig. 2), and transmit data in real-time to an orbiting spacecraft, up until the time of impact. Because many of the measurements can be made at high frequency, data from <50 m above the surface is possible, even though the spacecraft is traveling at >2 km/s. After impact, the probe's mission is over, but several probes can be launched to provide multiple transects at one swirl, or at several swirls.

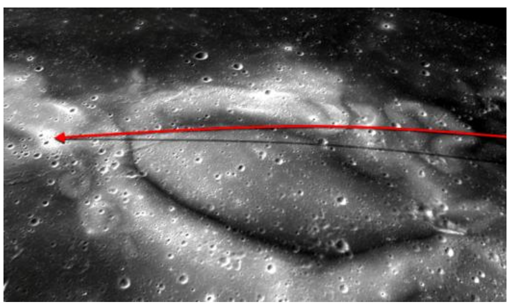

Fig. 2 – Low-angle impact trajectory over Reiner gamma swirl.

Spacecraft and payload: Ames has designed a small mother ship (<200 kg, Fig. 4) capable of orbiting the Moon and releasing two 3u cubesats on impact trajectories. Each of these cubesats is based on the CINEMA spacecraft (Fig. 3), an NSF-funded project built by UC Berkeley and Kyung Hee University (South Korea), and launching in June 2012. The CINEMA spacecraft carries two magnetometers (one inboard and one on a 0.9 m boom) and a particle detector (STEIN). Berkeley is currently designing a modified STEIN particle detector to measure the solar wind flux and direction at high cadence. In addition, Berkeley is designing a very high sensitivity dust detector.

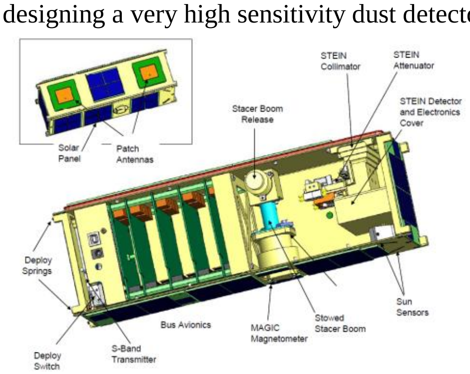

Fig. 3 – The NSF-funded 3u CINEMA cubesat, the basis of the impact probe, scheduled to launch in June 2012.

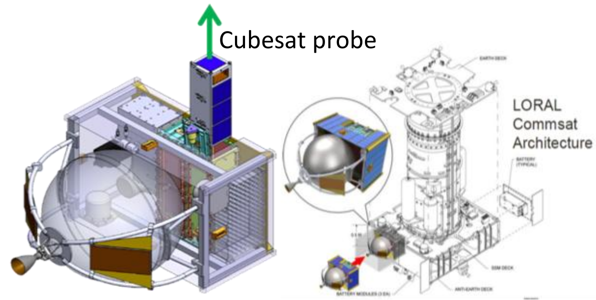

Fig. 4 – Left: Mother ship releasing a 3u cubesat probe. Right: Mothership piggybacking on a LORAL commsat launch.

Trajectory: Launching the spacecraft as a secondary payload greatly reduces the cost of the mission. Therefore, the trajectory to the Moon has been designed based on a drop-off in GTO by a commercial satellite launch (Fig. 5). Once at the Moon, the mother ship enters a highly elliptical orbit, and then conducts a burn to establish an impact trajectory. Then, the mother ship releases the probe, and performs a second burn to reestablish a stable orbit. The mothership flies over the impact site, collects data from the probe, and relays it to Earth. The total mission Δv is 1500 m/s.

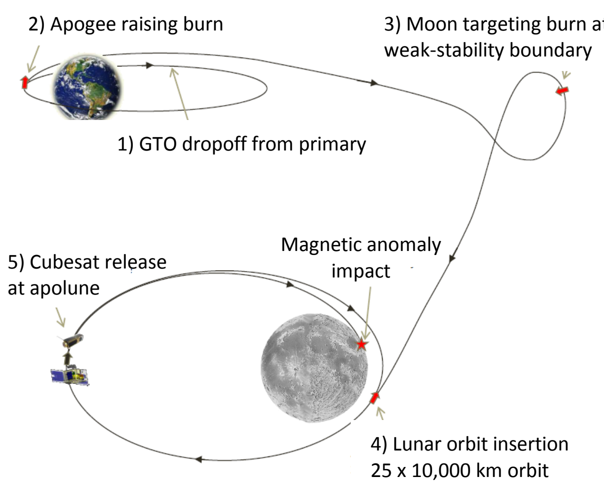

Fig. 5 – Spacecraft and probe trajectory to the Moon.

Conclusions: An impactor mission to lunar swirls could be accomplished for very low cost, while returning science that would benefit many planetary science disciplines. The mission would also demonstrate the first use of cubesats beyond low Earth orbit.

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