LUNAR TETHERED RESOURCE EXPLORER (LUNAR T-REx): IDENTIFYING RESOURCES ON THE MOON USING TETHERED SMALLSATS.

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Introduction: On Earth, economically viable mineralization associated with large impact craters can often be identified by its magnetic signatures [1,2]. The magnetic field from these features decays with the inverse of distance, such that identification requires low altitude measurements. On the Moon, many of the large Nectarian-aged impact features have prominent magnetic features associated with their central peak regions [3]. It is possible that the signatures of economic mineralization could be identified at the Moon with low altitude (<20 km) in situ magnetic field measurements.

Tethered Architecture: However, low altitude lunar orbits (<50 km) tend to be unstable, such that without regular orbit maintenance maneuvers they last only a few weeks before impacting the Moon [4]. A mission surveying lunar magnetic fields would require at least a few months, if not more than a year. The fuel mass burden for maintaining a low altitude orbit is prohibitive, especially for SmallSats.

The Lunar Tethered Resource Explorer (Lunar T-REx) team is studying the possibility of using two SmallSat/CubeSat buses connected by a tether that is many kilometers in length, such that they orbit in a gravity gradient formation (see Figure 1). The main advantages over a more conventional mission architecture are that low altitude measurements can be achieved with a much longer mission lifetime.

Payload and Measurements: The primary payload on each spacecraft would be a mini-magnetometer deployed on a stacer boom. The dual-point (high and low altitude) measurements would enable a more accurate determination of the lunar magnetic fields. Also included would be nadir-facing, mini-cameras to image surface features for more accurate registration (lower spacecraft), and monitoring tether deployment and dynamics (upper spacecraft).

In addition to identifying the magnetic signatures of potential resources, the measurements would address science objectives identified in the 2014 NASA Science Plan, Planetary Decadal Survey, as well as Strategic Knowledge Gaps (SKGs).

Leveraging: Lunar T-REx builds upon the findings of the Bi-sat Observations of the Atmosphere above Swirls (BOLAS) concept study funded by the Planetary Science Deep Space SmallSat Studies (PSDS3) program [6,7]. The primary BOLAS target was the Gerasimovich crustal magnetic field and

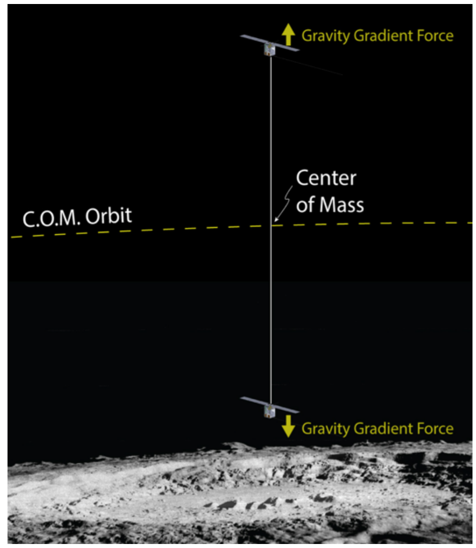

Figure 1: A tethered lunar CubeSat mission.

swirls. BOLAS consisted of two EPSA-class SmallSats connected by a 25 km tether with the formation center-of-mass in a "frozen" orbit, which was stable for at least a year and had a 30° inclination. At closest approach, the lower spacecraft (BOLAS-L) was only 2 km from the surface, and regularly surveyed Gerasimovich at altitudes <12 km.

In turn, BOLAS leveraged on-going experience from the Lunar IceCube mission being developed for EM-1 (PI B. Malphrus), as well as heritage from tethered missions that had flown in low Earth orbit [8].

The BOLAS concept was shown to be feasible, with the next steps being: (i) maturation of the tether deployment system for a lunar application, (ii) assessment of tether survivability against dust impacts in lunar orbit, and (iii) development of an attitude control system (ACS) model that could account for tether forces. These modest investments would advance the "game-changing" technology required for realizing tethered missions to the Moon with a wide variety of applications.

References: [1] Purucker & Clark (2011), *Geomagnetic Observations & Models*. [2] Purucker & Whaler (2015), *Treatise of Geophysics*. [3] Wieczorek et al. (2018), *NVM-2*. [4] Collier et al. (2016), *Acta Astron*. [5] Cosmo & Lorenzini (1997) *Tethers in Space Handbook*. [6] Stubbs et al. (2018), *LPSC*, #2394. [7] Stubbs et al. (2018), *BOLAS Final Report*. [8] Hoyt et al. (2007), *AIAA/SCC07-VII-8*.