GEOPHYSICAL TILTMETER FOR MEASURING TIDAL DISTORTION OF THE MOON. James H. Roberts, Ralph D. Lorenz, *Johns Hopkins University Applied Physics Laboratory, Laurel, MD 20723 (James.Roberts@jhuapl.edu).*

A ground-based lunar network offers the prospect of making a novel geophysical measurement that provides information on the rigidity of the lunar interior. This measurement is simply one of the tilt of the ground (or equivalently, the changing orientation of the local gravitational vector to the surface) which can be made with quite simple and robust instrumentation [1] which complements other proposed measurements.

In essence, the horizontal component of the changing tidal acceleration on a satellite in an elliptical orbit is expressed in a tilt of the local gravity relative to an inertial frame. A lander on a perfectly rigid satellite would measure this changing tilt. However, if the surface of the satellite itself distorts in phase in response to the changing tide, then the tilt measured on the surface is reduced (see figure 1).

The tilt measurement effectively measures the difference between surface deformation (characterized by the tidal Love number h_2), and the equipotential. The tilt sensed on the surface is greatest for a high rigidity, such that the planet does not deform to follow the changing equipotential. An in-situ measurement of the lander tilt in this way is strongly complementary to orbital measurements, such as laser altimetry and Doppler tracking that measure the Love numbers separately [3,4], and are most sensitive when the body is fluid. Figure 2 shows the amplitude of the expected tidal tilts on the Moon (relative to the tilt measured at perigee) for different values of h_2 [2]. h_2 is a function of the satellite's rigidity (for a purely fluid planet, $h_2 = 2.5$ and the tilt is zero). However, the expected tilts for even a rather weak interior ($h_2 = 0.25$) are well above the expected measurement resolution of a few nrad. The tidal tilt history shown in figure 2 is perfectly analytical, and corresponds to a uniform crust responding with no phase lag. In reality, there may be some phase lag which could be detected through an asymmetry of the curve [2].

Instrumentation and Requirements: A tiltmeter is an intrinsically simple instrument. A variety of sensing techniques is possible. For a lander application a simple pendulum sensor may be better. Modern optical or capacitive position sensing techniques can be used - the best approach to use should be considered taking the lander environment into account. Preventing large temperature changes nearby is important to avoid thermally-induced tilts via differential expansion.

A star tracker telescope can be rigidly mounted to a pendulum style tiltmeter. The star tracker measures the orientation of the system with respect to the celestial sphere to a few μrad accuracy, and measures the Moon's rotation state. A tiltmeter on a lander needs to incorporate a leveling mechanism to set the pendulum measurment within 1°, but the star-tracker obviates the need for precision alignment. The system can also be used to measure thermal distortion in the ground, discriminating thermal expansion from tidal forcing at the same period.

A pendulum tilt meter acts as a long-period seismometer and thus can augment or replace other seismic instrumentation. For a pendulum a few tens of cm in length, the angular resolution acheivable corresponds to ∼10 nrad, amply sensitive to detect teleseismic events. Data over two tidal periods (60 days) would be desirable to reliably characterize the tidal cycle. For that measurement, only a few tens of measurements, at 2 axes x 24 bits each - say 5000 bits total - is adequate. Measuring seismic activity obviously demands a larger dataset, perhaps exploiting event-driven sampling and data compression.

The mass of the pendulum structure and position sensors can be quite small (<1 kg). The leveling mechanism may entail ∼0.3 kg, and the star-tracker and imager may add another 2 kg. However, these values depend strongly on the impact decelerations expected on the lander and on the range of angles that the leveling mechanism must accommodate. A nominal total on the order of 9 W is ample for continuous operation, although the instrument can be operated at a low (10%) duty cycle if this is considered prohibitive.

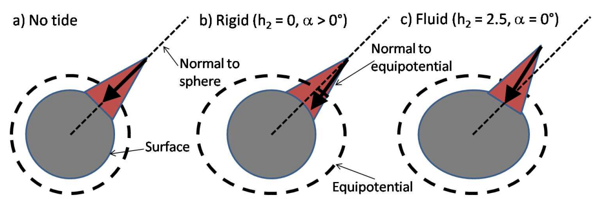

Figure 1: Tiltmeter (red) sitting on a tide-free (a), and tidally excited rigid (b) and fluid (c) bodies. The pendulum (bold arrow) is always normal to the equipotential surface.

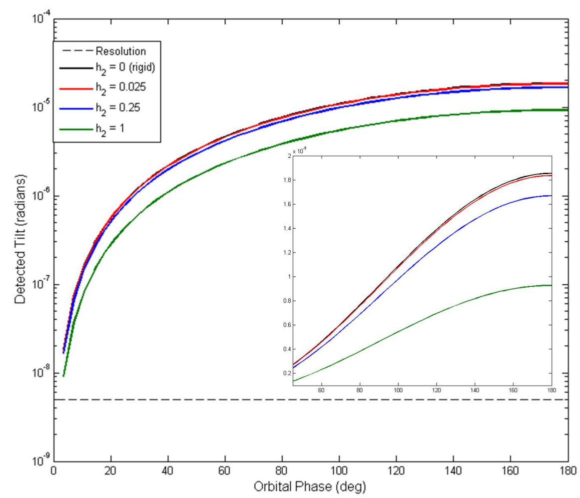

Figure 2: Tidal tilt as a function of orbital phase.

References: [1] Lorenz, R. D. (2009) *International Workshop on Europa Lander: Science Goals and Experiments*, 45. [2] Roberts, J. H. and R. D. Lorenz (2010) *Ground-based Geophysics on the Moon*, 3031. [3] Wahr, J. et al. (2006) *JGR, 111*, E12005. [4] Wu, X. et al. (2000) *GRL, 28*, 2245-2248.