Observing Time Request
MDM Observatory

Date: October 14, 2007	*Proposal number:*

TITLE: Prepare for the Moon Princess: High-Res Imaging Coordinated with *SELENE*

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Abstract of Scientific Justification:

The *SELenological & ENgineering Explorer (SELENE/Kaguya* - after the Greek Moon goddess and a legendary Japanese princess) begins operations in low lunar orbit this November, carrying the most sensitive α-particle detector ever in lunar orbit, arguably the most powerful detector to survey lunar surface outgassing, heretofore and for the next decade. The $SELENE$ ARD will detect ^{222}Rn (3.8d half-life) and its decay product ^{210}Po. Previous α detectors show ^{222}Rn (from ^{238}U decay) is released episodically, in a few locations. The short list of lunar features which most reliably show transient optical activity entirely contains all of these radon sites. Furthermore, the ^{210}Po residual signal, moonquakes, and the optical transient distribution all correlate with the boundary between mare basaltic plains and older, fractured highlands. During, before (and presumably after) $SELENE$, we will monitor the nearside Moon for optical transients using several small telescopes around the world. Our model of outgassing events sufficient to produce these optical transients shows that a region perhaps 30m across is likely to be strongly disturbed, with ejecta probably lightly scattered over several square kilometers. Since 1 arcsec at the Moon corresponds to 1.9 km, we need subarcsecond imaging to resolve the core regions without too much dilution. We propose to use "Lucky Imaging" on the 2.4-meter with a fast-read CCD imager to map large areas of the Moon likely to be active. We will exploit several photometric bands demonstrated to reveal fresh surfaces and freshly disturbed lunar regolith. This imager will provide resolution at the few-hundred km level, which should be adequate for detecting the core of these events. This will be our "before" image for the start of $SELENE$; later we will return to see if the events seen by our monitors and by the $SELENE$ ARD have changed in an "after" image.

- *Is this proposal part of a PhD thesis?* N
- *Requesting long-term status? If 'Y', please give # of semesters and nights on the next line.* N

Summary of observing runs requested for this project

Run	Telescope	Instrument, detectors, grisms, gratings, filters, camera optics, etc.
1	2.4m	Andor EMCCD (user instrument), Small Filter Wheel (Large FW O.K.)
2	2.4m	Andor EMCCD (user instrument), Small Filter Wheel (Large FW O.K.)
3		

Run	No. nights	Moon age (d)	Optimal dates	Acceptable dates
1	3	FM−3d to +6d	Feb 16 - 26	Feb - May
2	3	FM−3d to +6d	Mar 17 - 27	Mar - May
3				

- *List dates you cannot use for non-astronomical reasons on the next line.*

Scientific Justification *Try to include overall significance to astronomy.*

Despite the common lore that the Moon is inactive, it is subject to moonquakes (up to the equivalent of Richter 5), and evidently has a molten core. Periodic outgassing events, traced by radon gas, have been detected numerous times during Apollo and by *Lunar Prospector*. As shown by Crotts (2007a), these outgassing events are strongly correlated with optical Transient Lunar Phenomena (TLPs) - brightenings and obscurations that appear on the surface of the Moon, usually on the timescale of minutes.

TLPs occur so sporadically that most evidence for their existence is largely anecdotal in nature. Crotts (2007b) has shown, however, that regardless of how the roughly 1500 reports of TLPs are split according to observer characteristics e.g., location of the observer or historical period of the report, certain sites are consistently reported as origins of TLPs, in the proportions consistently of about 55% for Aristarchus, 15% for Pluto, 2% apiece for Kepler, Copernicus, Tycho, Grimaldi, and then a smattering of lesser sites. In comparison the sites where episodes of ^{222}Rn outgassing have been detected are Aristarchus (primarily), Kepler and Grimaldi (all on the lunar near side, interestingly). (Plato was not covered during Apollo due to its high latitude.) Since ^{222}Rn has a 3.8d half-life, this outgassing happens on short timescales. On longer timescales the ^{222}Rn decay product ^{210}Po records where the radon decayed, then decays itself typically after 22.7y. The polonium. like moonquakes and TLPs, tend to cluster around the boundaries between lunar maria and highlands, indicating another statistically significant correlation.

Despite this evident phenomenon, little is known about this outgassing and the nature of its relation to the optical transients. We have built the first of several robotic imaging monitors to survey the entire nearside for transients, taking several exposures per minute (compared to the typical TLP duration of about 15 minutes). Additionally, the Alpha-Ray Detector (ARD) on *SELENE* is much more sensitive than corresponding instruments on Apollo (15 and 16) and *Lunar Prospector*, and scans every location on the Moon at least once every 7d. These two instruments will be scanning the Moon and providing superlative versions of their respective data sets, simultaneously. How will we interpret these data?

We have made a model of how a high flow-rate outgassing event might evolve (Crotts & Hummels 2007), and find that a minimal "blow-out" event from a gas overpressure overcoming hydrostatic equilibrium will produce a hole in the regolith, and spread debris over several square kilometers. Can we detect such and event in another manner? To see detail on this scale (at 1.9km/arcsec), we are likely to need subarcsec resolution. We have started a sequence of images at the 3-meter Infrared Telescope Facility (IRTF), and in radar with the Greenbank/Arecibo system to perform a "before" and "after" comparison of the lunar surface during this time. There are several promising approaches that can be taken in the optical, however.

We propose to perform the "before" image in the optical for the predominant TLP/radon sites in order to correlate change in this sequence with events seen by our robotic monitors (as well as the *SELENE* ARD). We will return to perform the "after" observations when the *SELENE* mission is complete in 2009. Using Lucky Imaging we can achieve a resolution of a few hundred meters, likely to be sensitive to disturbed regolith by one of several means:

• Photometry in 0.9μm-band: fresh, iron-bearing regolith exhibits a transition at 0.9μm due to excitation of Fe^{2+} surface states. Over hundreds of thousands or millions of years, the surface will degrade due to micrometeorite and solar-wind weathering, acting as an age indicator.

• Reddening in broadband optical: over the optical the reflectance function of regoltih becomes increasingly redder with time due to particle size and structure changes, and glass formation on particle surfaces. This takes several million years.

• Polarization: scattering at phase angles between backscatter and right angles is sensitive to particle size, which can easily be changed by agitation. The timescale for restoring the surface particle distribution can be short, of order 1000 years, depending on the thickness of the dust layer involved.

Technical and Scientific Feasibility *List objects, coordinates, and magnitudes (or surface brightness, if appropriate), desired S/N, wavelength coverage and resolution. Justify the number of nights requested as well as the specific telescope, instruments, and lunar phase. Indicate the optimal detector, as well as acceptable alternates. If you've requested long-term status, justify why this is necessary for successful completion of the science.*

Why MDM? *If other optical/IR facilities are being used for this project, explain the role that MDM observations will play.*

How is it Going? *List your allocations of telescope time at MDM during the past 3 years, together with the current status of the project (cite publications where appropriate). Mark with an asterisk those allocations of time related to the current proposal. For ongoing projects, are they achieving their goals?*

$\sim$ 20 nights on the 1.3-meter and 2.4-meter M31 microlensing (some in collaboration with other investigators): data through 2001 reduced, 20 new microlensing events found, some reported and scientific meetings and now incorporated in Uglesich Ph.D thesis and ApJ publication, plus two more publications based on KPNO 4m and INT data, and the Cseresnjes et al. *HST* paper. Our MDM images are analyzed and their lightcurves are being incorporated into the larger dataset.

$\sim$ 5 nights on 2.4-meter for QSO target verification for absorption-line studies: data fully reduced and analyzed, absorption-line data being included in upcoming paper (Tytler et al. 2006) on cosmological constant Λ, plus another paper with Lidz and Hui on the value of the cosmological constant, ApJ, in press (astro-ph/0309204). About 20 of these targets have been used for follow-up observations on Keck.

3 nights 2.4-meter for lunar hyperspectral mapping: data analyzed and included in Crotts (2007), ApJ, submitted.

9 nights 2.4-meter for 2005B SDSS SN followup: the 2006 SDSS SN survey yielded almost 200 SN discoveries, and the MDM time accounted for I.D.'s for many dozens of these. The effort distinguished two SNe for our program at Columbia, but we decided not to concentrate on these (instead of 2006X). The Columbia group was identified on 6 CBRT/IAUCs concerning some 52 SNe.

Figures:

Figure 1:

Columbia observing proposal LaTeX macros v2.2.