USING THE DEEP SPACE GATEWAY TO MAP RESOURCES AND DEFEND EARTH.
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Introduction: A human-tended spaceport in cislunar space would be a valuable platform from which to conduct scientific observations supporting humankind's growth toward being a full-fledged space-faring species. The two ideas we emphasize here are (1) assessing resources for *in situ* resource utilization and (2) defending our home planet from near-Earth object (NEO) impacts.

Orbit Choice: The instrument suite we suggest can provide important scientific information from almost any orbit. However, the two science goals we focus on have different optimal orbits. Impact monitoring is best done from near the Earth-Moon L2 point because the observations would be complementary to those made from Earth. Detailed mapping of the lunar polar regions would be best accomplished from a low polar orbit. For this abstract, we focus on a near-rectilinear halo orbit.

Planetary Defense: The Deep Space Gateway (DSG) could improve planetary defense in two ways. The first is by observing new impacts on the surface of the Moon to refine our understanding of the flux of small impactors in the vicinity of the Earth. Such impacts create flashes that can be detected on the night side of the Moon using only visible wavelengths, but estimates of the energy (and thus impactor size) are improved by having follow-up infrared observations and high-resolution imaging of the crater.

The DSG could also be an important platform for characterizing NEOs, especially as they come close to Earth. The difference in viewing geometry from the DSG and Earth should assist in quickly pinning down the trajectory of the NEO and possibly help to disambiguate light curves used to calculate rotation rate. As with any space telescope, spectra collected from the DSG will not have to contend with atmospheric absorptions that block key infrared wavelength regions.

Resource Assessments: Observations from the DSG would be useful for both lunar and NEO resources. We consider hydrogen/water to be the primary resource of interest with regolith and free Fe-Ni alloy for construction as a secondary interest. In principle, observations from a DSG in low polar orbit around the Moon could complement, augment, and ultimately supplant data from robotic orbiters like LRO. Flying "next-generation" versions of the full suite of LRO instruments would be recommended in this scenario. The more challenging question, and the one we explore in this abstract, is what can be done from a range of thousands or even tens of thousands of kilometers that has not already been done by LRO and its robotic brethren.

We recommend focusing on infrared spectroscopy. The existing data sets (e.g., Kaguya Spectral Profiler, Moon Mineralogy Mapper, and DIVINER) have significant issues in the areas of greatest interest near the lunar poles. An instrument with the capacity to collect high quality spectra of the lunar polar regions would also be well suited to collect spectra of NEOs.

In addition to the classic passive remote sensing, a dedicated spectrometer on the DSG could allow repeats of the LCROSS experiment with carefully targeted impacts of spent boosters. Furthermore, human visits to the DSG are liable to produce volatile-rich waste that could be disposed by impacting the Moon. Observations of such impacts into volatile-poor parts of the Moon could provide critical calibration for using remote sensing to measure the volatiles liberated by impacts.

Required Instrumentation: Using remote sensing to characterize the lunar surface and NEOs is a mature science. We put our recommendations in three categories: threshold, baseline, and enhanced. Threshold requires resources of the same magnitude as a CubeSat. The baseline suite is comparable to a Discovery class mission and we briefly touch on potential enhancements if resources are more plentiful.

Threshold. The threshold system has two level-1 requirements: complement Earth-based tracking of (1) the number and energy of impacts on the Moon and (2) NEOs making close approaches to the Earth. While an orbit near the Earth-Moon L2 point would be optimal, useful data could be collected from any of the orbits discussed for the DSG.

A panchromatic visible imager with COTS hardware should be able to meet the requirements. Impact flashes are monitored by modest sized telescopes on Earth (<0.5 m diameter primary mirrors) [1,2] and a 6U CubeSat has been proposed to be adequate to make these measurements [3]. A standard 4Kx4K-pixel detector would allow the entire disk of the Moon to be monitored from close to L2 with better than 1 km/pixel ground sampling distance. Earth-based impact flash monitoring has used a 25 Hz image acquisition rate [1]. Meeting this same rate would require the ability to read and process, continually, at a rate of 400 Mpixels/s. This data rate is challenging to return to Earth from a CubeSat but should be straightforward from the DGS, especially after the data volume is reduced via onboard processing. A framing camera with a large FOV and short integration times has very benign pointing and stability requirements. NEO observations would have stricter pointing knowledge needs and require stacking many images to build up signal but no special modifications would be needed to the imager. Mass, volume, power, and cost should be similar to a CubeSat.

Baseline. The level-1 requirement driving the design of the baseline instrument suite is the ability to obtain robust characterization of the mineralogy and thermo-physical parameters of even dark NEOs and the lunar polar regions. This means more than the classic 0.5-3.0 micron infrared spectra. The suite must also monitor the cooling of new impact sites, measure the temperature of shadowed regions of the Moon, and provide additional constraints on the size and surface properties of NEOs. We also require compositional information from the impact flashes. The most practical solution is to have two separate imaging systems: a staring multi-band imager and a scanning hyperspectral imager.

The staring imager would be used to obtain compositional information from emissions from the impact flash. The system would be similar to the threshold camera but would have 4 or more detectors, at least two to measure the color temperature of the flash and the others viewing selected UV-NIR wavelength bands tied to at least H and O emission lines. Na, S, C and Si emissions would be also be of interest. The narrower bandpasses will require additional light gathering capacity so the instrument would need to substantially larger than the threshold imager. To view the whole disk of the Moon over a wide range of distances, the optics must be also be able to adjust focus and focal length as in a zoom lens. While the imager would generally stare at the Moon, it would interrupt such observations to track any NEO that approached the Earth. A detailed trade study is needed to choose the optimal combination of (1) a system with separate slaved zoom telescopes for each detector, (2) a single telescope with a series of wavelength selective mirrors to send the desired light to each detector, and (3) a detector with a Bayer pattern of filters over pixels and reduced spatial resolution. The MSL Mastcam could be a starting point for the design [4].

The hyperspectral imager can leverage the extensive work put into designing the HyspIRI Earth observing mission. The 0.38 to 12 micron wavelength coverage and spectral resolution of HyspIRI [5] is very well suited to lunar and NEO compositional studies. The planned optics would provide an acceptable ground sampling distance of a few km/pixel on the Moon from the Earth-Moon L2 point. The possibility of integrating HyspIRI on the ISS has been examined, so many of the issues of operating on the DSG have already been investigated. The one major difference would be that in a high halo orbit the instrument may not be able to rely on the spacecraft's orbital motion alone to sweep the push-broom sensors across the target. A scan platform may also be required to point at NEOs. Other benefits of a scan platform would be the ability to (1) use target motion compensation if the DSG makes high-speed close flybys of the Moon and (2) obtain super-resolution in multiple directions. Based on HyspIRI estimates, the hyperspectral imager is likely to have a mass of ~150kg and require ~700W of power. The HyspIRI mission was estimated to cost ~$500M but a derivative mounted on the DSG should be significantly cheaper.

Enhanced. There are numerous ways to enhance the proposed observations but the most valuable addition is likely to be radar. Radar can be used for altimetry, subsurface sounding, ice mapping in permanently shadowed regions, and classifying asteroids. However, a radar system that could provide such observations from a range of tens of thousands of km would be very large, complex, power-hungry, and expensive.

Note on Radiometric Calibration: Given that the instruments are expected to operate in space for many years, and the detectors may be swapped at various times, provisions for robust radiometric calibration must be included as part of the instrument suite. This is especially critical for the spectral observations used to infer the compositions of the Moon and NEOs. The current LANDSAT satellites are flying with onboard calibration targets that are good examples of the type of hardware and operations required to maintain accurate and precise radiometric calibration.

Note on Geometric Calibration: For precise tracking of NEOs, it is important to know the precise location of the gateway relative to Earth. A laser retroreflector attached to the DSG could prove invaluable for this. The ability to slew the hyperspectral imager introduces more sources of uncertainty in pointing knowledge. It may prove worthwhile to have metrology capability on the DSG – a capability that may prove useful for other activities such as docking of sample capsules.

Benefits of Using the DSG: These observations could be taken from any spacecraft in cislunar space. However, being on a human-tended platform means that the instruments can be upgraded in a manner similar to the Hubble Space Telescope. The baseline instrument suite is well suited for many investigations unconnected to resource assessments or planetary defense. For example, with appropriate optics, the hyperspectral imager could examine samples brought to but kept outside the DSG. Especially for asteroid samples, obtaining spectra of surfaces unaltered by the terrestrial environment may prove extremely useful.

References: [1] Ortiz, J.L., et al. (2006) *Icarus*, 184, 319-326. [2] Suggs, R.M., et al. (2014) *Icarus*, 238, 23-36. [3] Topputo, F., et al. (2017) *7th Interplanetary CubeSat Workshop*, Abstract #2017.A.2.1. [4] Malin, M.C., et al. (2017) *Earth and Space Sci*., 4, 506-539. [5] Green, R.O., et al. (2017) Global Earth Imaging Spectroscopy and Thermal Infrared Measurements (HyspIRI) Workshop, HyspIRI_overview_20171016ba.pdf.