USING THE LUNAR SURFACE AS A PLATFORM FOR ASTRONOMY. W. D. Cochran[1], A. L. Cochran[1], F. P. Mills[1,2,3] and K.-L. Jessup[4]. [1]Center for Planetary Systems Habitability and McDonald Observatory, The University of Texas, Austin, TX USA, [2]Fenner School of Environment & Society, Australian National University, Canberra, ACT, Australia, [3]Space Science Institute, Boulder CO, USA, [4]Southwest Research Institute, Boulder CO, USA .

Introduction: The NASA Artemis III mission to the Lunar south polar region offers an unprecedented opportunity to open a new doorway for exploration of the entire Universe. The Lunar surface is capable of providing an outstanding platform for conducting cutting-edge astronomical research that is impossible from Earth's surface and much more difficult and expensive from spacecraft. The concept has long been discussed [1] and debated [2]. The Moon offers the obvious advantage of being outside of Earth's atmosphere, allowing astronomical observations from the Moon to be conducted at ultraviolet (UV) and infrared (IR) wavelengths that do not penetrate Earth's atmosphere. Telescopes will be able to operate at their diffraction limit, unfettered by atmospheric turbulence and smearing ("seeing"). The Lunar surface, with its 0.166 g gravity and very low seismic noise, provides an extremely stable platform for operation of delicate instruments without the significant engineering challenges of spacecraft implementation. The slow synchronous rotation of the Moon allows extended continuous observations of any available astronomical target. Lunar-based astronomical observations do *not* require the active participation and engagement of an astronaut. The short light-travel-time from Earth to Moon means that any Lunar-based observatory could easily be operated remotely from Earth, either in real-time or via a robotic queue.

We advocate that *every* Lunar exploration mission should include at least one autonomous astronomy payload that can be deployed on the Lunar surface by the astronauts. These payloads would then continue astronomical data acquisition for an extended period of time after the astronauts have departed. The data sets acquired would truly be unique and would be obtained at significantly lower cost than from dedicated spacecraft missions. Below we give several examples of the astronomical observation techniques that would particularly benefit from a Lunar-surface environment, and for each technique we give an example application to a pressing astronomical problem. Our list is not intended to be comprehensive, but rather to suggest the extremely wide array of possible uses of Lunar-based astronomical observatories.

Ultraviolet Observations: UV imaging, spectroscopy, or imaging spectroscopy from a Lunar platform could access wavelengths below 300nm blocked by the Earth's atmosphere, track sub-hourly temporal variations over the course of a day that cannot be observed at the necessary cadence from Earth orbit, provide comparable or better spectral/spatial resolutions as many spacecraft instruments, and monitor interannual to decadal changes that exceed most space mission lifetimes.

Example Application: Venus is a critical endmember for understanding terrestrial and extrasolar planets. Its climate system comprises complex, but poorly understood, links among radiation, multi-scale dynamics, microphysics, and chemistry. For example, ~50% of the solar energy absorbed by Venus is absorbed in its upper cloud layer by an unidentified absorber at 250-500 nm (e.g., [3],[4],[5]) which has been observationally linked to SO_2. In turn, SO_2-H_2O-H_2SO_4 chemistry controls the 30-km thick global sulfuric acid clouds that are a key part of Venus' extreme atmospheric greenhouse. The photochemical lifetime of SO_2 at the equatorial cloud top is ~ 20 minutes, and a factor of 10 and larger variations in SO_2 cloud top abundances have been observed on time scales from a few hours to a decade (e.g., [6],[7]). Figure 1 shows an HST/STIS UV spectrum of SO_2 absorption bands at two different locations on the Venus disk taken on 27 January 2011 [5]. SO_2 increased on this day with increasing latitude, a reversal of the customary gradient,

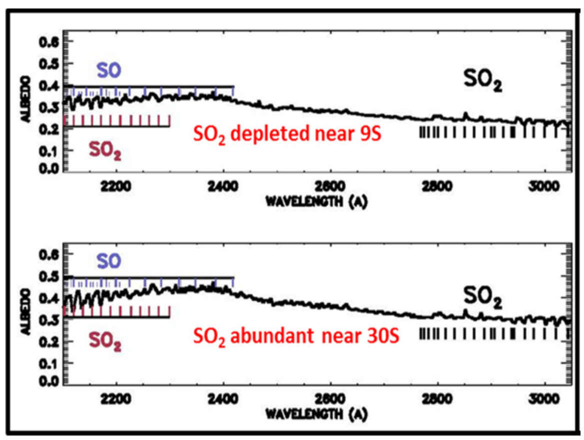

Figure 1: HST/STIS spectrum of two locations on the Venus disk taken 27 January 2011. These spectra show significant differences in the SO_2 absorption bands.

which was observed one week earlier [5]. This is consistent with a proposed intermittent weakening of the equator-to-pole circulation [7]. HST data suggest local and global circulation may depend on the underlying terrain and local solar time [5], but HST's degraded gyroscopes mean it can no longer be used to observe Venus. Imaging spectroscopy that can identify and track temporal and spatial variations of SO_2, SO, H_2O, and the unidentified absorber can quantify links among these species and cloud and albedo variations and help elucidate the poorly known links among radiation, chemistry, and dynamics that control Venus' climate. These studies also allow us to investigate the question "is there any component of Venus' current chemical/radiative/dynamical state that suggests/ requires a link to biological activity?" [8]

Infrared Observations: The lack of Lunar atmosphere also provides an excellent environment for astronomical observations in infrared spectral windows that are obscured by Earth's atmospheric constituents. NASA's recognition of the importance of IR observations from above the atmosphere motivated the building of the *Spitzer Space Telescope*, the *James Webb Space Telescope,* as well as a large number of smaller spacecraft and instruments for the *Hubble Space Telescope*. The Lunar South Pole offers the opportunity to deploy an infrared telescope in a manner where it could be shielded from time-variable heating by the Sun, either inside a crater or with a light-weight ring solar shield around it. Cooling for the telescope and instrument package can be provided by simple radiative coolers looking to deep space. Power would be provided by an array of solar panels placed outside the solar shield that could track the sun around the horizon. Adequate batteries would be required to power the telescope during the Lunar night.

Example Application: Comets represent some of the least altered bodies left over from the formation of the Solar System. As such, they are probes of conditions in the solar nebula. Because they formed in the middle of the disk, they probe a region of the disk that cannot be seen easily in proto-stellar disks. One of the dominant ices in comets is CO_2, a molecule that cannot be studied in comets from Earth due to Earth's atmosphere. Understanding what percentage of the ices are represented by this volatile molecule is important to our understanding of disk conditions. CO_2 has only been measured in comets in the past by spacecraft such as AKARI. In addition to CO_2, many other parent species have transitions in the IR, including H_2O, and thus a Lunar observatory will enable a better understanding of the nucleus ices.

Diffraction-Limited Imaging: The lack of atmosphere will allow telescopes to image astronomical objects at their full diffraction limit of 1.2 λ/D, without needing to resort to technically challenging and expensive extreme adaptive optics systems required for Earth-based observations. The lack of any Lunar atmosphere also means that the background sky will be much darker than as observed from Earth. These two effects will allow extremely high contrast imaging of astronomical targets.

Example Application: A major challenge for exoplanet studies is to image an Earth-like exoplanet, and then to obtain the spectrum of the planet. We now know that the very nearest stars to our Sun do indeed harbor Earth-sized exoplanets. Such observations will need to be carried out in the mid-infrared region, where the planet brightness is thermal emission and the star-planet contrast is about 10^6, as opposed to the optical region where the planet reflects starlight and the contrast is 10^{10}. The 7-20 μm spectral region contains rotation-vibration bands of H_20, H_2SO_4, CH_4, O_3 and CO_2, allowing significant chemical characterization of the atmosphere of the planet, thus enabling astronomers to search for biosignatures in the spectrum indicating the possible presence of life beyond Earth. This combination of Lunar diffraction-limited imaging to isolate the planet-light from the star-light, and a powerful infrared spectrograph could achieve this truly landmark result.

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