SPACE SCIENCE WITH UVIS TELESCOPES ON THE LUNAR SURFACE. J. A. Morse[1], [1]ASTRONETX PBC, 867 Boylston St Suite 500, Boston, MA 02116; jamorse@astronetx.com

Introduction: As NASA and commercial exploration activities and capabilities are established, the lunar surface will become more accessible for hosting modest space science payloads during the next decade. The lunar surface is a stable platform from which to conduct observational investigations of the cosmos. For some experiments it may even hold unique near-term advantages, particularly from polar locations.

We envision a number of modest aperture remote sensing ultraviolet-visible (UVIS) telescope facilities capable of impactful science investigations from the lunar surface. Such payloads can be affixed to lunar landers or transported by humans or rovers some distance away from the landing site. For example, UVIS wide-field, diffraction-limited imaging and spectrophotometry supporting time domain astronomy and large survey science are possible within ESPA-class payload masses, volumes and development budgets. More complex facilities could support coronagraphic imaging of exoplanets and optical interferometry as capabilities and access evolve. Many logistical issues – especially power, communications and dust mitigation – need to be studied in the context of location, capabilities and infrastructure accompanying the anticipated future human presence.

Stable Platform: Achieving precision pointing stability in order to take full advantage of the theoretical resolution limits offered by smallsat optical systems (25-50 cm diameter apertures) is highly challenging. Pointing stability is a key enabler for sub-arcsecond, diffraction-limited imaging, high precision (spectro-)photometry and other types of measurements that can impact a wide range of scientific fields including the study of exoplanets, stellar structure, accretion disks and outflows, stellar ejecta and supernovae, star forming galaxies and active galactic nuclei. Past Explorer missions have produced datasets with ~5” spatial resolution in part due to the difficulty and cost of achieving precision pointing stability over scientifically meaningful exposure times (minutes to hours). Earth observing smallsats now regularly achieve diffraction-limited imaging performance, mainly because the typical exposure times are short, 0.1s to a few seconds in duration — and with the consequence (and opportunity) that industry is now mass-producing visible/near-IR optical systems capable of diffraction-limited performance at much lower cost than 5-10 years ago. The challenge is to create the stable conditions necessary to take advantage of the quarter-arcsecond resolution that the optical systems can deliver.

For free-flying small satellites in low-Earth orbit (LEO) or other orbital environments, precision pointing could be achieved by a highly capable spacecraft bus or in two stages, combining a spacecraft bus capable of few-arcseconds rms coarse pointing and a fast steering mechanism in the opto-mechanical system (such as a fold mirror or detector mount), fed by an error signal. This performance generally is only accomplished on larger missions such as the Hubble Space Telescope, Spitzer Space Telescope, Kepler observatory, and James Webb Space Telescope. However, fine pointing control of ~5 milli-arcseconds (mas) rms has now been demonstrated for brief times on a sounding rocket payload [1], and the Asteria cubesat has achieved better than 500 mas rms performance observing bright stars [2].

Another way to solve the problem for small payloads is to place the smallsat on the lunar surface, where only the fine guiding capability is needed – i.e., use the moon as the coarse pointing bus and replace the spacecraft bus reaction wheels with the lunar equivalent of a clock drive.

Mission Concepts: Ultraviolet imaging and spectroscopy of astrophysical targets from the lunar surface was demonstrated by the Far-Ultraviolet Camera/Spectrograph deployed during Apollo 16 (Carruthers 1973 [3]). (Carruthers even remarks on “the great potential of the lunar surface as a base for astronomical observations.”) More recently, China’s Chang’e 3 mission hosted UV instrumentation, including a Lunar Ultraviolet Telescope (LUT) that operated for over 18 months [4].

ESPA-class payloads for UVIS imaging and spectroscopy from the moon would have masses from 30-100 kg, depending on the aperture size and instrument configuration. More complex optical systems such as a coronagraph with active wavefront control would be on the heavier end of the range. A stand or mount with alt-az steering capability and fine guiding may double that mass. We note that a 45-50 cm diameter telescope can resolve the habitable zones of our nearest Sun-like stellar neighbors, α Centauri A & B [5]. Placement on the lunar surface below 45° S latitude allows stable, continuous viewing of α Centauri throughout the year. (A ~1-meter class aperture could explore a number of other nearby systems.)

Later in the decade the lunar surface could serve as a platform for initial optical interferometry demonstrations while free-flying station-keeping and metrology techniques are developed for missions like LISA. An optical interferometer working in vacuum and with the stability of the lunar surface could resolve magnetic processes in the universe, such as structures and flows on stellar surfaces, protostellar accretion columns, and other energetic disk/wind systems such as AGN. Such a facility might use a sparse array of 30-50 cm diameter telescopes located at 100 m to 1 km distances from a central beam combiner, proceeding in phases beginning with a linear array and accumulating apertures over time. Such a concept may be a practical path towards realizing many of the science goals of the Stellar Imager Vision Mission [6]. Astronaut-assisted deployment across baselines that could not be realized on a single spacecraft would be enabling for such an array, though placement and alignment procedures would need to be studied.

Lunar surface considerations: It is time to update our perspectives on lunar surface-based telescopic facilities since those presented in the 2007 National Academy report on *The Scientific Context for Exploration of the Moon* [7]. Scientific, technical and programmatic developments have evolved during this decade that make certain implementations more plausible and affordable than previously thought. Nevertheless, despite some advantages the lunar surface may hold for certain scientific investigations – and notwithstanding the technical challenges of achieving continuous, long-duration observatory operations – there are environmental conditions on the lunar surface at a south polar location that are not present in other orbital environments. Besides limiting the view of the sky to 2π steradians, the three most obvious ones are gravity, the sunlit vista, and lunar dust.

Lunar gravity, though only one-sixth that on Earth, may ultimately limit the size of any telescopic apertures that are deployed on the moon, particularly for monolithic architectures. While structural behavior can be modeled for one-sixth G performance, similar to modeling for zero G performance, lander capacity (mass, volume) is likely to limit the aperture size of what can be sent to the surface. Launch loads will be more severe, but surviving landing needs to be integrated into payload design and testing. We do not foresee significant gravity-related issues with smallsat scale telescopes either for landing or surface operations, but future apertures of 0.5-1 meter or larger may require more elaborate designs and test plans. Some lunar lander providers envision enabling landing several metric tons on the lunar surface, so the future may allow for lunar telescopes beyond ESPA class, including possibly astronaut-assembled or deployed structures on the surface.

The lunar landscape in sunlight is a source of stray light. Especially for wide-field imaging applications, the sunlit vista will need to be avoided by lunar surface telescopes through appropriate baffling and exclusion angles. In principle, mitigating this should be similar to dealing with the bright Earth in LEO, as well as following ground-based telescope protocols.

The moon has a tenuous dusty exosphere that has been observed in various ways, including by the Lunar Dust Experiment aboard NASA's LADEE mission (e.g., [8]). A persistent cloud of ballistic dust surrounds the moon, fed by micrometeoroid impacts on the lunar surface. Close to the surface the estimated densities are low enough that they would not impact a smallsat scale experiment operating for a limited time. However, over time the settling of dust on optical surfaces may impede their long-term throughput and affect precision optical measurements and interferometric instruments. Analysis suggests that over several decades, lunar dust has accumulated on exposed optical surfaces of the lunar retroreflectors left by the Apollo astronauts [9]. But the Chang'e 3 LUT UV photometric stability demonstrates that over small mission lifespans of a few years, this is not overly deleterious. It is normal practice for ground-based telescopes and space telescopes being launched to adopt dust mitigation protocols. Lunar surface UVIS telescope concepts will need to incorporate a dust mitigation strategy such as aperture covers (like Hubble, Spitzer, Kepler), baffling, defining sun, Earth and surface avoidance angles, and perhaps even consider an optical surface cleaning procedure.

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