Protection of Astronomy and Science on the Moon

Richard Green

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Good morning; my name is Richard Green; I'm an Astronomer at the University of Arizona, and I'm speaking with you today on behalf of the International Astronomical Union (the IAU) about **Protection of Astronomy and Science on the Moon.** The IAU has recently established a Working Group on Astronomy on the Moon as part of its Commission on Site Protection. I serve as its Chair; true expertise comes from my co-Directors, **Dr. Martin Elvis** from the Harvard-Smithsonian Center for Astrophysics, who spoke to the STSC last year about lunar issues, and **Christopher Johnson** from the Secure World Foundation.

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The focus of this talk is that the Moon provides a platform for astronomical observations that is unique in the Inner Solar System. The observations that cannot be done with comparable sensitivity on Earth or in orbit are low-frequency radio, mid- to far-infrared, and mid-frequency gravitational wave detections. We recognize that the prospect of locating astronomical observatories on the Moon is the result of competitive lower launch costs and the development of infrastructure there for other purposes. However, many of the commercial and national exploration activities motivating the competitive development are incompatible with the scientific need to be free of noise and interference. A process for the allocation and protection of sites is needed for successful multiple uses of the Moon.

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The scientific problem that prompted the earliest thinking about using the Moon as a quiet observing platform and has the most mature concepts is that of **Probing the Cosmic Dark Ages.** This is pure observational cosmology. As the hot Big Bang cooled, the soup of cosmic plasma became a sea of neutral atomic gas, but in the period when the Universe was 3 to more than 100 million years old, stars and galaxies had not yet formed. With no sources of luminous energy, those were the Cosmic Dark Ages.

Yet at that early time, small variances in the density of the gas would form the seeds of structures that would grow under the force of gravity. Myriads of clouds of pristine hydrogen were forming the building blocks of primordial galaxies. The cooled radiation from the Big Bang, the Cosmic Microwave Background, also pervaded space, and these nascent clouds of hydrogen were forming absorbing shadows against that background.

Investigating how the early development of density fluctuations and the growth of cosmic structure unfolds can move ahead in two ways. The hydrogen atom is detected through a characteristic radio spectral signature; the absorption would be highly redshifted and detected at very low radio frequencies. That faint signal is essentially undetectable from the ground because of the Earth's auroral emissions and man-made interference. The Cosmic Microwave Background has a distinct temperature at each cosmic epoch as the Universe expands and the radiation cools. Departures from a single temperature at these early epochs would signal the growth of cosmic structure, possibly in unexpected ways. That signature would be measured in the far infrared, for which the Earth's atmosphere is opaque.

Detection of these signatures would create a new era of ultraprecision cosmology, revealing the currently hidden details of the earliest formation of structure, and opening the possibility of discovering new physics.

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The UN, through the ITU, has long recognized the unique nature of the far side of the Moon as being the solar system's radio-quiet zone, shielded from the low-frequency radio radiation from the Earth's aurorae and man-made interference. That hemisphere is the obvious place to build the radio telescope array to make these exciting discoveries. To achieve the part-in-a-million sensitivity and the high angular resolution for characterizing the absorbing structures, ultimately such a large array in both number of antennas and dimension would extend for over 100 km. Martin Elvis and colleagues have shown that there are only 3 sites on the far side with sufficiently smooth terrain over a large area to accommodate such an array.

There are current issues in maintaining the protection of the shielded zone. Interfering radiation at low frequencies does not come from communications radio transmitters; it comes from noisy electronics from unshielded motors and circuits. Such noise has recently been detected by a ground-based radio telescope from orbiting communications satellites. Although the ITU could regulate stray radiation, rare sites would still need to be allocated for a specific scientific use and then protected from interference.

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The Moon provides a unique platform for c**haracterizing exoplanets** in the myriads of solar systems around other stars. The ultimate goal is to find a planet with an atmosphere that has been chemically transformed by extraterrestrial life. The spectrum of a planet's atmosphere is rich with molecules in the infrared and the most information is retrieved by observing a planet all the way through its day-night cycle. The challenge is that an Earth-sized planet in the habitable zone of stellar warmth is millions of times fainter than its host star and very close in angle. An extended array of large infrared telescopes will ultimately be required to get sufficient sensitivity and angular resolution for such observations.

The Moon affords long periods of uninterrupted viewing (~two weeks, compared to a single Earth night), and near the poles, the viewing can be continuous. The vacuum allows light beams to be combined from separated telescopes as though they were a single mirror, and the absence of the atmospheric turbulence found on Earth allows achieving the very high contrast to observe a faint planet right next to its host star.

A related problem is understanding how planets that are potential sites of extraterrestrial life can shield their surfaces from the damaging radiation from stellar flares. Such a shield is provided by a planet's magnetic field: the large low-frequency radio array for cosmology will also have the sensitivity to monitor and measure the auroral activity from exoplanetary magnetic fields and stellar flares from their hosts.

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A truly sensitive infrared telescope must be cooled so that the thermal noise does not swamp the very faint cosmic signal. The topology of the Moon provides a unique option for such natural cryogenic cooling in **Polar Cold Traps.** These are Permanently Shadowed Regions (PSRs) that are so cold that they have retained volatiles for billions of years. Lunar surveys have shown that these PSRs might contain a billion tonnes of water. The oldest traps have temperatures as low as 25 Kelvin, and are a few kilometres in scale.

Not surprisingly, the extraction of water in situ is considered the key to lunar industry and settlement. However, mining activities could loft lunar dust and create seismic disturbances that would be incompatible with the clean and quiet environment essential for the effective operation of an infrared telescope array.

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New Frontiers in Gravitational Waves

Einstein's Theory of General Relativity predicted that gravitational waves propagate through the Universe from the mergers of extremely dense objects like white dwarfs, neutron stars and black holes. The motivators and leader of the LIGO project won the Nobel Prize for the successful detection of the passage of gravitational waves from such merger events, requiring the sensitivity to measure the stretching and contraction of the Earth's surface at the level of 1/20th the diameter of a proton. The first identified detection came a couple of years later with the merger of a pair of neutron stars in a nearby galaxy.

Gravitational Wave detectors on the Moon would be sensitive to lower frequencies than those on Earth, because the Moon is seismically quieter and has fewer man-made disturbances. Going to lower frequencies would enable the detection of mergers of intermediate-mass black holes (between star-sized and the million to billion solar mass monsters in the centers of galaxies). It would be sensitive to the mergers of seed black holes at early cosmic times, the precursors to the supermassive black holes powering quasars, as well as those of white dwarfs throughout much of the Universe.

Frequent detections with identifications of the sources can test Einstein's Theory of Relativity. Another advantage to providing a gravitational wave detector on the Moon is that the triangulation with the ones on the Earth will provide accurate positions to make those identifications to understand the environment and nature of the sources.

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The LIGO/Virgo/KAGRA method of **Gravitational Wave Detection** uses a similar method of combining light beams as that for the array of infrared telescopes, called interferometry. An alternate approach is an array of cryogenically cooled seismometers, best located in a PSR crater. There are only a few 50 kilometre-scale cold traps that would be appropriate.

For both techniques seismic disturbances are incompatible: activities such as landing and launch or mining would need to be substantially separated. For interferometry, the additional restriction is minimal contamination from lofted lunar dust.

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The existence of sites of unique, fragile, scientific value on the Moon leads us to identify the **Policy and Regulatory Needs to Protect Science and Astronomy on the Moon:**

1. The ability to utilize the unique advantages of science on the Moon, including astronomy, will depend on the development of internationally accepted methods to communicate, signal intentions between actors, foster coordination and due regard between relevant users and stakeholders, avoid harmful interference, and in allocating and protecting specific sites from interfering activities.
2. In short, some of the most important and pioneering scientific missions on the Moon can only take place in specific locations and under specific conditions and can only take place if they are protected from interference—even from other peaceful uses.

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3. Such a process of transparent and internationally-accepted coordination and protection for science is needed by the time the current phase of governmental and non-governmental demonstrations and prototyping of launch, delivery, and deployment is complete.
4. The IAU will work with other organizations with complementary interests to encourage COPUOS's thinking and planning on this complex issue.