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Space and sustainable development

Protection of Astronomy and Science on the Moon

Submitted by the International Astronomical Union, International Academy of Astronautics, Secure World Foundation, and For All Moonkind

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Summary

The Moon offers unique opportunities for major observational discoveries in astronomical science. While cheaper launches to the Moon and the development of lunar infrastructure can enable these opportunities, many planned and potential activities are, in some instances, incompatible with the critical need for these scientific facilities to be free from noise, contamination and interference.

Building upon the foundational principles of the Outer Space Treaty[1], dedicated processes are needed to preserve the freedom of scientific investigation of the Moon, especially in unexplored areas and sites of exceptional scientific importance to assure successful and sustainable scientific uses of the Moon and its orbital environment.

This paper defines the terms of the problem for the consideration and awareness by the Committee.

I. Introduction and Background

1. The International Astronomical Union (IAU) was founded in 1919. Its mission is to promote and safeguard the science of astronomy in all its aspects, including research, communication, education and development, through international cooperation. Its individual members are professional astronomers from all over the world, at the Ph.D. level and beyond, who are active in professional research, education and outreach in astronomy. The IAU has a total membership of 12761. The IAU has been an observer at the Committee on the Peaceful Uses of Outer Space since 1995.

2. The IAU Working Group on Astronomy on the Moon was established in 2023, and is chaired by Dr. Richard Green from the University of Arizona, with Dr. Martin Elvis of the Harvard Smithsonian Center for Astrophysics, and Christopher Johnson, Director of Legal Affairs and Space Law at the Secure World Foundation serving as co-chairs. The Working Group is constituted as part of the IAU standing Commission C.B7 for Protection of Existing and Potential Observatory Sites.

3. The IAU Working Group on Astronomy on the Moon has the following Terms of Reference:

(a) Develop scientific information and policy recommendations to support those working, in particular at ITU-R, to protect the ability to make radio astronomical observations unique to the Shielded Zone of the Moon;

(b) Lead and collaborate on identifying, prioritizing and developing policy to protect sites of extreme scientific value for other astronomy-related observational facilities (e.g., infrared telescopes, gravitational wave detection arrays);

(c) Inform policy makers and agencies about cis-lunar astronomy needs and immediate threats;

(d) Support the IAU in their efforts at the United Nations Committee on the Peaceful Uses of Outer Space and other bodies to promote an international policy for multiple uses of the Moon that includes lunar astronomical site designation and management.

4. This paper is specific to the astronomical needs for utilization of the Moon. The entities that submitted the present Conference room paper note many previous presentations to the Committee on the Peaceful Uses of Outer Space from, e.g., the Moon Village Association GEGSLA (A/AC.105/C.2/2023/CRP.31), towards

[1] Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies. Adopted by the General Assembly in its resolution 2222 (XXI), opened for signature on 27 January 1967, entered into force on 10 October 1967.

developing a plan for sustainable use of the Moon. The needs of astronomy add an additional dimension, broadly consistent with any scientific policy framework to be developed.

II. Astronomy and Science Opportunities on the Moon

5. The lunar surface is the best platform in the inner Solar System to conduct a variety of unique scientific and astronomical activities. These include cosmology, planetary sciences, and fundamental physics investigations.

A. Cosmology: Probing the Cosmic Dark Ages

6. Ultra-low frequency radio observations in the shielded zone on the far side of the Moon probe the original building blocks of the galaxies—myriads of clouds of pristine hydrogen, which would be detected as absorbing shadows against the cosmic microwave background as early as three million years after the Big Bang. Subtle distortions in the spectral shape of the Cosmic Microwave Background radiation in the far infrared probe the early growth of gravitationally induced structures. Mapping the elusive fluctuation signal from the Dark Ages of the Universe before any stars or galaxies were formed would herald a new era of ultraprecision cosmology, opening the possibility of discovering new physics and providing a unique probe of inflationary cosmology.

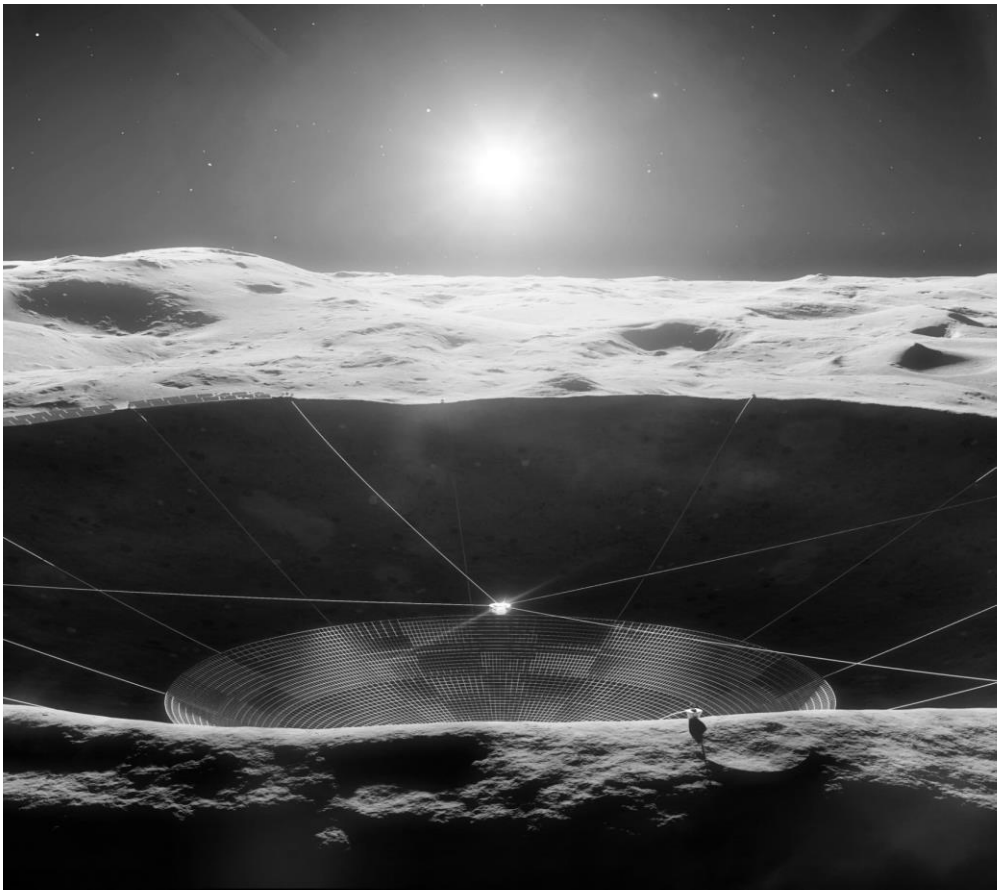
B. Planetary Sciences: Characterizing Planets in Other Solar Systems

7. From near the Moon’s poles, long periods of continuous viewing enable the monitoring of the atmospheres of exoplanets as they transition through day and night around their host stars. The sharp resolution achieved by a numerous array of large telescopes can enable searches for biosignatures in the atmospheres of Earth-like planets. Exoplanet magnetic fields, potentially vital to shielding life from harmful radiation and preventing planetary atmospheric loss, can also be detected and monitored.

C. Fundamental Physics: New Frontiers in Gravitational Wave Astronomy

8. Gravitational waves propagate through the Universe from the mergers of extremely dense objects like white dwarfs, neutron stars, and black holes. Detectors on the Moon would be sensitive to lower frequencies than those on Earth and higher than those on the planned LISA mission, allowing the exploration of mergers of intermediate-mass and seed black holes, as well as white dwarfs, throughout much of the Universe. Frequent detections with identifications of the sources can test Einstein’s Theory of Relativity.

III. Observational Techniques and Special Sites



An artist's impression of the Lunar Crater Radio Telescope (LCRT) as it would appear on the Moon. (NASA; www.nasa.gov/solar-system/lunar-crater-radio-telescope-illuminating-the-cosmic-dark-ages/)

A. The Shielded Zone of the Moon (SZM): A Lunar Farside Radio Quiet Zone

9. The far side of the Moon always faces away from Earth and is thus the only truly radio-quiet location in the inner Solar System, as it is shielded by the Moon itself from radio-frequency interference coming from powerful Earth-based transmitters. Article 22.22 of the ITU-R Radio Regulations provides comprehensive protection for radio astronomy in the SZM. This protection includes the sensitive detection of ultra-low-frequency radio signals, by placing large arrays of simple antennas on the far side of the Moon. This also enables the Search for Extraterrestrial Intelligence (SETI) to conduct more sensitive searches in the radio frequency spectrum than can be done on Earth. In analogy to the giant Earth-based radio telescopes Arecibo and FAST, a large aperture telescope could be deployed in a lunar crater, as illustrated above. In the long term, this research demands highly specific sites. The physics of the Dark Ages of the Universe tells us that eventually we will want to build an array of antennae spanning from 50 to 200 km, for which there are few sites on the far side. Those would need to be designated for scientific use and protected against Unintended Electromagnetic Radiation (UEMR), from sources such as unshielded electronic circuits in satellites and rovers. The ITU-R is considering whether to regulate UEMR in the context of radio communications; a comprehensive approach to preserving the radio-quiet nature of the shielded zone at low frequencies will be required.

B. Infrared Telescopes

10. A large-aperture single-mirror telescope or multi-telescope array operating in the infrared would have sensitivity and image resolution substantially higher than that of the James Webb Space Telescope, extending the latter's entire scientific domain. To suppress the thermal noise that would swamp the faint cosmic signals, the telescope and instruments must operate under very cold conditions. On the Moon, the permanently shadowed regions (PSRs) on crater floors have been shielded from direct illumination by the Sun for some 4 billion years, making them extremely cold, ~ -250C (~25 K), similar to the JWST or colder. These sites provide the stable cooling crucial to the functioning of these devices without complex mechanical solutions. However, many of these craters are also attractive for extraction of frozen water ice, an activity incompatible with the low dust, low noise environment required for telescope operation.

C. Gravitational-wave detection

11. The Moon is intrinsically much more seismically quiet than the Earth and has a natural (near-) vacuum. With its permanently shadowed regions, it also offers deployment sites at cold temperature and enhanced thermal stability. These features would enable lunar gravitational-wave detectors proposed in the form of long-baseline laser interferometers or using the Moon itself as an antenna for gravitational waves. Such detectors would be susceptible to the slightest environmental disturbances, and strong excess noise generated by nearby landings and launches or by heavy equipment for exploration or mining would be incompatible with these sensitive observations.

D. Sites of Exceptional Scientific Importance (SESIs)

12. The Moon presents some of the most promising sites for a next generation of high-performance instruments, protected from radio interference, wind buffeting, gravitational sag, and other constraints imposed by the terrestrial environment. Broadly, there are two classes of lunar SESIs for astronomy: the radio-quiet farside sites and the cold traps. The mountainous farside has only a few locations that are smooth and large enough to accommodate arrays of antennae spanning up to 200 km. Permanently shadowed regions (PSRs) also known as "cold traps" can passively cool infrared and X-ray telescopes without energy-expensive chillers. Only a dozen or two cold traps sustain temperatures below 25 K and most are small, about 1 km in diameter, therefore insufficient for some detector arrays. Sites of dedicated crater rims for alternate gravitational wave detection or sites for infrared telescopes with artificial shadowing near the poles may be more available, but all SESIs would require active coordination and management to be sufficiently free of interference to achieve successful mission outcomes. The astronomical community will identify and prioritise sites by developing a science traceability matrix for each major program, in which the site properties are those uniquely suited to successful achievement of the scientific requirements. The entities that submitted the present Conference room paper note that the scientific problems of sampling pristine materials that encode the history of the solar system as well as of the formation, evolution and bombardment history of the Moon will lead to a requirements-based identification and prioritisation of complementary sites through a similar process.

IV. Policy and Regulatory Needs to Protect Science and Astronomy on the Moon

13. The ability to make use of the freedom of scientific investigation on the Moon, in particular, the unique advantages of the Moon as an astronomical observing platform, will depend on the development of internationally accepted methods to communicate, signal intentions between actors, foster coordination and safety, pay due regard to the interests of relevant users and stakeholders, and avoid contamination and harmful interference.

14. Some of the most important and pioneering scientific missions on the Moon can take place only in specific locations and under specific conditions, and can take place only if they are protected from contamination and interference—even from other legitimate and peaceful uses. For this reason, it would be advisable to designate, manage, and protect specific sites in order to avoid any potentially harmful interference.

15. Such a process of transparent and internationally accepted coordination and protection for scientific investigation is needed by the time the current phase of governmental and non-governmental demonstrations and prototyping of launch, delivery, and deployment is complete.

16. The IAU will work with other organizations with complementary interests to inform the Committee's thinking and planning on this complex issue.

17. The entities that submitted the present Conference room paper welcome recent proposals for focused exchanges between States members of the Committee on the Peaceful Uses of Outer Space on the usefulness of an international mechanism to consult on lunar activities, like the one suggested by the Delegation of Romania, as those organizations firmly believe that international consultations can be instrumental in advancing much needed progress on this issue.