Moon-Based Radio Telescope on The Dark Side of The Moon

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Abstract: Lunar Radio Telescope Concept

A Radio Telescope on the dark side of the Moon would aid in the search for other extraterrestrial life in the Galaxy or Universe. This construction would take multiple launches to position all the pieces for it in the correct locations. I got the Idea from Paul Hunt from Hunt Utilities Group LLC located in Pine River, Minnesota. HUG for short has done research on reusable energy such as solar panels both for electricity, water heating, and geothermal storage of the sun's heat below the ground of buildings. They also study sustainable energy efficient housing, organic gardening, hydroponics with gray water systems, and were a cold fusion proving ground trying to prove others' designs for Nikole to Copper fusion. Paul proposed that we use a 1000-mile spread of the surface of the moon on the dark side, but I believe a large crater like the one in South America or China would also work. Just instead being built onto the surface of the moon to aid the current infrastructure of satellites such as James Web, Hubble, etc. This would also aid the ground radio telescopes with less interference from our Earth-based satellites that hog the night sky with radio signals. Because Artemis is already going to stay on the moon currently, this could be a later supplemental mission project with autonomous systems for minimal human factor repairs or set up after the initial setup time and cost. All feedback on this subject would be great. Why would this technology benefit humanity as a whole species? What would we discover in the far reaches of space, Space bearing civilizations, or more emptiness? Could this be a multi-country mission or project to split the enormous costs that would be associated with it?

I. Introduction

Space exploration has long captivated humanity's imagination, driving scientific discovery and technological innovation. Among the myriad endeavors to unlock the mysteries of the cosmos, the deployment of telescopes in space has played a pivotal role in expanding our understanding of the universe. A space-based low-frequency radio instrument promises to unlock the virtually unexplored Ultra-Low Wavelength (ULW) domain, offering a wealth of scientific opportunities akin to the groundbreaking discoveries made in other wavelength domains. Such an instrument would complement existing radio, optical, infrared, sub-millimeter, high-frequency X-ray, or gamma-ray instrumentation, shedding light on processes occurring at the lowest energies and largest physical scales. Scientific investigations enabled by a space-based ULW radio instrument encompass a diverse range of topics, including the study of solar activity and space weather, which provide crucial insights into the effects of solar flares and bursts on Earth and beyond (Jester and Falcke, 2009; Zarka et al., 2017). Additionally, probing the magnetospheric emission from massive planets like Jupiter and Saturn yields valuable information about their spin periods (Zarka et al., 2017). Other significant science cases involve studying large-scale structures such as galaxy clusters and radio galaxies and detecting Jupiter-like flares and Crab-like pulses from extragalactic sources.

One of the most anticipated scientific advancements lies in exploring the very early universe during a period known as the cosmological Dark Ages. The Dark Ages span the time between the epoch of recombination when the universe became transparent. The cosmic microwave background was emitted, and the epoch of reionization (EoR) marked the onset of the first stars reionizing neutral hydrogen. The global Dark Ages signal, characterized by the redshifted 21-cm line absorption feature, is expected to peak around 30-40 MHz, albeit weak, approximately six orders of magnitude below the foreground signal (Jester and Falcke, 2009).

Jester and Falcke (2009) demonstrate that with a single antenna strategically positioned on the Moon, under low Radio Frequency Interference (RFI) conditions and stable temperature and gain, the global signal can be detected at a 5σ level with one year of integration. However, greater sensitivity and a larger collecting area are imperative to resolve variations in hydrogen distribution at arc-minute or even arc-second scale resolutions. It has been suggested that up to 10^5 individual antenna elements, corresponding to an area of 0.5 km^2, are required to achieve a 10' spatial resolution (Loeb and Zaldarriaga, 2009). Thus, in addition to requiring a low-RFI, low-temperature, and stable gain environment, a ULW radio interferometer aimed at detecting minute variations in the mass distribution of the Dark Ages and the EoR must possess a substantial collecting area, on the order of square kilometers. Optimal locations for such an array include the far side of the Moon, perpetually dark craters at the lunar poles, or space-based solutions such as a Sun-leading or trailing orbit, the Sun-Earth L2 point, or Lunar orbit.

From Earth-based observatories to orbiting satellites, telescopes have peered into the depths of space, revealing celestial phenomena across the electromagnetic spectrum. With its unique vantage point shielded from Earth's radio interference and offering a stable platform for observation, the lunar far side presents an unparalleled opportunity for astronomical research. A radio telescope positioned on the far side of the Moon offers significant advantages over those located on Earth or in Earth's orbit. Firstly, it enables observations at wavelengths greater than 10 meters, corresponding to frequencies below 30 megahertz (MHz), which have remained largely unexplored by humans due to reflection by Earth's ionosphere((Jester, 2009); (Rajan, 2016); (Bentum, 2018)). Secondly, the Moon is a natural barrier, shielding the lunar surface telescope from radio interferences originating from Earth, the ionosphere, Earth-orbiting satellites, and the Sun's radio emissions during the lunar night. This paper explores the design considerations, challenges, and potential benefits of developing telescopes for the far side of the Moon. We delve into the scientific objectives driving such endeavors, the technological requirements for lunar observatories, and the innovative approaches to realize this vision. Astronomers aim to revolutionize our understanding of fundamental astrophysical processes and cosmic evolution by harnessing the lunar environment and leveraging advancements in space exploration technology.

Frank Drake (1988) initially proposed the idea of a substantial radio observatory utilizing a reflector placed within a lunar crater. However, these early proposals envisioned constructing support structures extending from the crater floor to sustain the primary reflector, akin to the design of the 300-

meter diameter Arecibo telescope (Giovanelli, 2005) and the 500-meter diameter FAST observatory (Nan, 2006). Nevertheless, the Arecibo telescope and the FAST observatory are situated on Earth's surface, subject to various disruptive forces absent on the lunar terrain. Several historical concepts for lunar telescope missions, including the Apollo-era proposal ((Burns, 1990)), the Very Low-Frequency Array (VLFA) ((Barrow, 1997)), the Radio Observatory for Lunar Sortie Science (ROLSS) ((Lazio, 2011)), the Dark Ages Lunar Interferometer (DALI) ((Lazio T. J., 2009)), and the Arecibo-type telescope ((Drake, 1988)), have suggested transporting the entire radio telescope from Earth to the Moon. The distance between the Moon and Earth is approximately 384,300 km, while the Lagrangian L2 point lies further away at approximately 64,700 km from the Moon. In 1974, the lunar orbiter Radio-Astronomy Explorer-2 (RAE-2) satellite utilized a 37-meter dipole antenna to map non-thermal galactic emissions in the frequency range of 25 kHz to 13 MHz ((Alexander, 1974)). Other single-satellite lunar-orbiting proposals include the Lunar Observer Radio Astronomy Experiment (LORAE) ((Burns J. O., 2005)) and the Dark Ages Radio Explorer (DARE) ((Burns J. O., 2011)). Additionally, various multi-satellite missions have been suggested for deployment at the L2 point, such as the Astronomical Low-Frequency Array (ALFA) ((Jones, 1998)), the Formation-flying sub-Ionospheric Radio Astronomy Science and Technology (FIRST) ((Bergman J. E., 2009)), and the Orbiting Low-Frequency Antennas for Radio Astronomy (OLFAR) ((Budianu, 2015)).

According to the International Telecommunication Union (ITU), most Earth-orbiting satellites are located within 100,000 km of Earth. Therefore, the actual radio-quiet zone where the Moon shields radio noise from Earth and Earth-orbiting satellites extends only 6,733 km from the center of the Moon, considering the Moon's radius of 1,737 km. Even with a conservative estimate of 50,000 km from Earth, where many geostationary and lower-altitude satellites reside, the radio-quiet zone extends just 13,831 km from the center of the Moon. The analysis presented in the past demonstrates that proposed lunar satellite missions at the L2 point will not be shielded from radio interference originating from Earth-orbiting satellites. Consequently, these missions have collected areas with orders of magnitude smaller than LCRT and experience poorer signal-to-noise ratios (SNR) due to partial or no lunar shielding from Earth's radio noise. Consequently, an alternative approach for a large radio reflector on the Moon may be conceived, eliminating the need for support structures connecting the reflector to the crater floor and instead suspending it directly from the crater walls. Such an approach facilitates a lightweight and deployable design for the proposed radio reflector.

Several international teams, including those from the Netherlands, France, Sweden, the UK, the USA, and China, have proposed initiatives and conducted feasibility studies for space-based radio interferometers ((Saks, 2010); (Cecconi, 2018); (Bergman, 2009)). Bentum, in 2020, said that these initiatives aim to leverage advancements in small spacecraft technology and swarm analysis to realize the vision of a space-borne radio observatory capable of imaging the sky at ultra-low frequencies. The prospect of establishing kilometer-scale craters on the far side of the Moon as sites for large radio telescopes holds immense significance for future astronomical endeavors. These craters present a unique opportunity to observe the universe at wavelengths and frequencies beyond the capabilities of conventional Earth-based or orbital approaches, ranging from greater than 10 meters to less than 30 megahertz (MHz) (Bentum M. J., 2020). The NASA mission of constructing a Lunar Crater Radio Telescope (LCRT) on the far side offers several distinct advantages, including isolation from Earth's ionosphere, orbiting satellites, and solar interference, as well as uninterrupted periods of dark and cold sky viewing during lunar nights.

The LCRT concept introduces a novel antenna architecture leveraging the natural terrain geometry of kilometer-scale impact craters. This innovative design enables astronomers to delve into the "dark ages" of the early universe, exploring wavelengths and frequencies previously unattainable due to atmospheric noise and attenuation challenges on Earth. The LCRT antenna comprises a 1-kilometer diameter wire mesh reflector and an overhead receiver suspended from the rim of a lunar crater, allowing for unprecedented observations (Arya, 2023).

However, realizing the LCRT concept faces significant challenges, particularly concerning deployment strategies. Proposed as a fully robotic assembly and operation, the deployment of LCRT necessitates careful consideration of factors such as deployment time, energy requirements, system complexity, and overall cost-effectiveness. While prior concepts have explored deployable structures on the lunar surface for radio astronomy applications, LCRT represents a pioneering endeavor to push the boundaries of astronomical observation capabilities. The Lunar Crater Radio Telescope (LCRT) aims to address two key scientific objectives:

Exploring the Cosmic Dawn: LCRT seeks to investigate the Cosmic Dawn epoch, a pivotal period in the universe's evolution. As stated in the Astrophysics roadmap, LCRT is designed to explore "these epochs," referring to the Cosmic Dawn, which was identified as one of the key science objectives ((Kouveliotou, 2014)). This epoch involves the transition from a neutral to an ionized state in the intergalactic medium, signifying the emergence of the first stars and galaxies. LCRT endeavors to achieve this by observing the highly redshifted hyperfine transition of neutral hydrogen (HI), providing unique insights into the state of the intergalactic medium and large-scale structures during this critical phase ((Blandford, 2010), (Furlanetto, 2006), (Pritchard, 2012)).

Detection of Extrasolar Planetary Magnetic Fields: LCRT also aims to detect and study the magnetic fields of extrasolar planets. According to the paper, LCRT endeavors to observe "radio emission at 22 MHz from Jupiter," which is indicative of its planetary-scale magnetic field ((Burke, 1955)). This approach offers a remote sensing method to understand the interior properties of planets, potentially contributing to assessments of habitability. The paper highlights the significance of such detections, noting that knowledge of extrasolar planetary magnetic fields may be essential for understanding habitability and planetary dynamics ((Lazio T. J., 2018)).

In comparison to alternative approaches, such as orbiting assets or surface-deployed arrays, LCRT offers distinct advantages in terms of noise reduction, observation during lunar nights, and a larger collection area. While previous concepts have utilized mobile rovers or tethered deployment methods, LCRT seeks to advance these approaches further, drawing inspiration from recent advancements in extreme-terrain robotics for in-situ antenna deployment within lunar craters. (Hallinan, 2020)

Brief History: Background on Radio Telescopes and Their Role in Astronomy Radio Telescopes can be used for a variety of scientific research operations from studying background cosmic radiation to gravity waves. The scientific advancements from the first detection of shortwave radio interference in 1932 by Karl Jansky helped discover why and where the interference was coming from. With his turntable makeshift design, he discovered not only thunderstorms causing interference in the distance but also interference coming from the center of our own Milky Way Galaxy. (Britannica) (NRAO, 2022)

The WOW signal was a strong signal detected on August 15, 1977, by the Big Ear telescope in Ohio, USA. This signal lasted 72 seconds at a frequency of 1420 MHz123 which happens to be the same frequency of cosmic neutral hydrogen. This is a strong narrow-band frequency and has left astronomers stump. The Frequency has not been repeated and could be a possible attempt at extraterrestrial communication, we may never know. (Britannica) (NRAO, 2022)

II. Fundamentals of Radio Telescopes

A. Definition and Functionality

A radio telescope is an astronomical instrument consisting of a radio receiver and an antenna system that is used to detect radio-frequency radiation between wavelengths of about 10 meters (30 megahertz [MHz]) and 1 mm (300 gigahertz [GHz]) emitted by extraterrestrial sources. (Source Britannica). The LCRT study phase 1 and phase 2 were focused on analyzing the frequencies between 10-50 meters wavelength which would study the background of the universe's Dark Ages before the modern day galaxies. The Science and Space communities have a lot of studies on the beginning of the known universe and the observable universe but are missing a huge chunk of time. (Hall, 2020)

B. Types of Telescopes (Ground-based vs. Space-based)

Radio telescopes, essential tools in our cosmic exploration, allow us to peer into the universe beyond what our eyes can perceive. In this paper, we delve into the advantages and trade-offs between space-based and ground-based radio telescopes, shedding light on their unique capabilities and limitations. By understanding these two approaches, astronomers can make informed decisions based on their research objectives.

Ground-based Radio Telescopes offer more data capture but lack detailed quality images due to atmospheric turbulent interference. They are cheaper to manufacture than space-based operational satellites. They can be maintained easier also than the later version.

Space-based telescopes can capture very detailed quality sections of the sky, but come at a high cost to be able to develop telescopes or satellites that can use their correct technology for the next 15 to 50 years.

Therefore both Ground-based and Space-based Telescopes tend to work together in astronomy to provide both aspects that benefit the two types of Radio Telescopes. One benefit of this type of telescope is these frequency ranges can penetrate dust clouds throughout the cosmos. (Kellermann, 2020)

C. Importance of Radio Frequency Observations

Radio Telescopes help monitor the cosmos for frequencies that can penetrate the dust clouds that some other frequencies are unable to transfer through. Satellites can observe a wide range of Frequencies to observe multiple aspects of the observable universe. Pulsars can be observed along with other areas throughout the galaxy, cosmos, and universe because the frequency range can penetrate cosmic dust clouds.

III. Advantages of Space-based Radio Telescopes

A. Overview of Space-based Observations

Here are some of the current operating satellites that have benefited humanity in the Space-Based fleet.

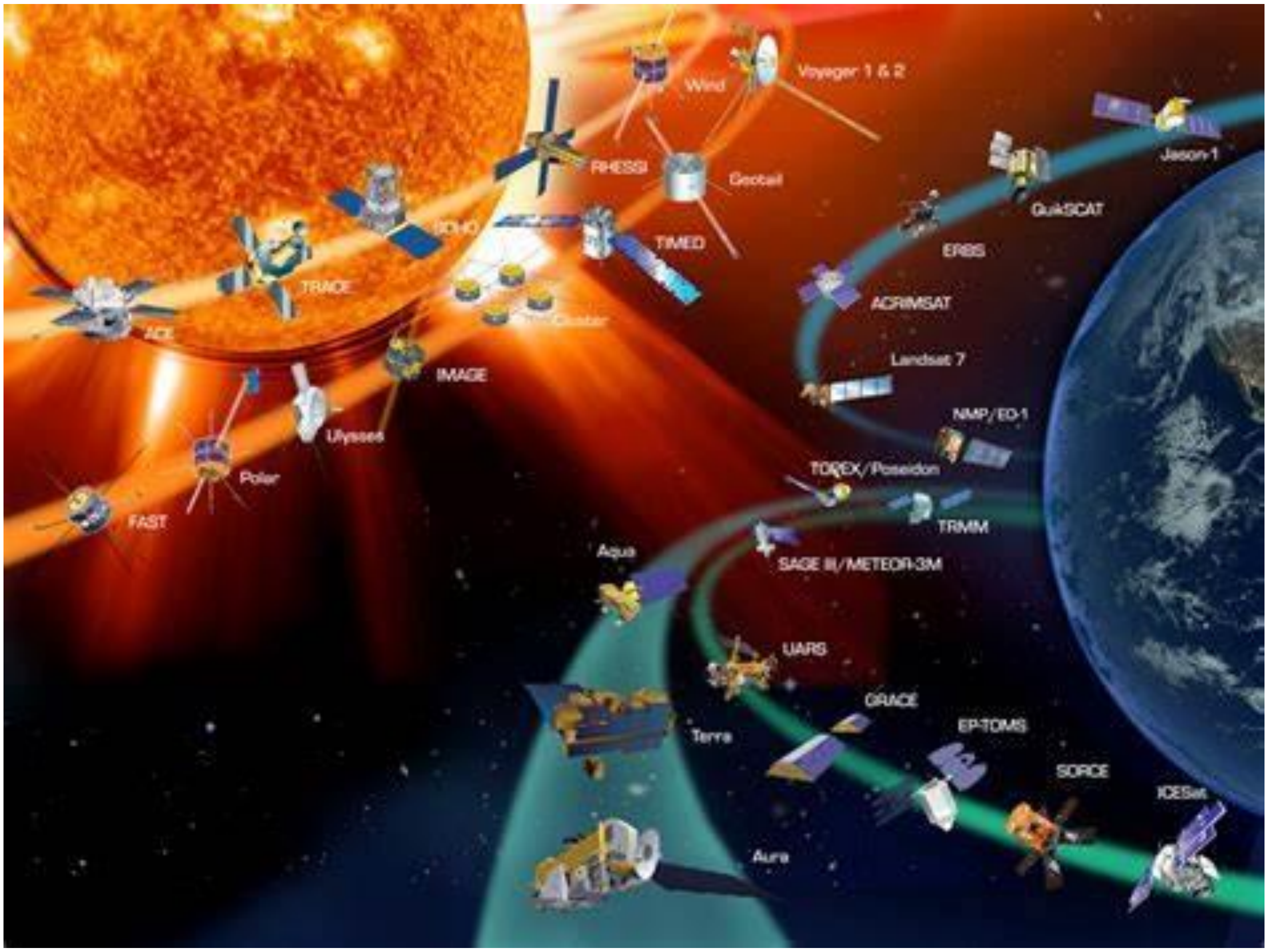

Figure I. (infohow., 2024)

B. Elimination of Atmospheric Interference

The pros as discussed in section II.B. is that this will eliminate most not all of the atmospheric interference which actually prevents studying the range of Frequencies the LCRT will study on Earth. This is because Earth's ionosphere bounces the frequencies at that range and a good signal can not be established. This will also eliminate the human-made radio frequencies that have to be modulated and compensated for. Overall this LCRT mission would aid most of the Space-based operations and help understand the little-known dark ages of the universe. The science and educational benefits alone are priceless.

C. Extended Observation Windows

The telescope would primarily operate during the Lunar night and would need to be positioned to avoid most of the Milky Way galaxy frequency hot zones as possible. So typically it could operate over 8 hours per day, the design could possibly use solar being the dark side has half of the rotation. The preferred operation would be remote with a data dump in a nearby space station such as Gateway or a Lunar operation outpost possibly on the South Pole with Artemis

D. Access to Different Wavelengths

By utilizing a range of wave length, humans can study a range of the sky. Here's a visual.

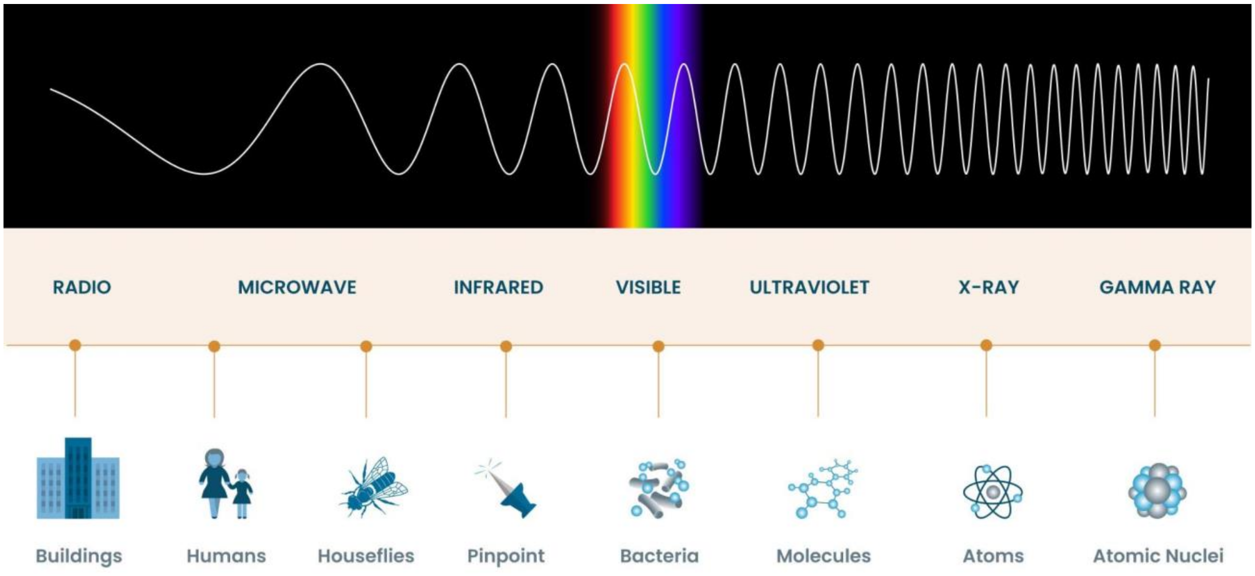

Figure II. (NASA, 2019) The Hubble webpage

E. Technical Aspects of Moon-Based Radio Telescope Construction

Technical aspects include landing on the moon inside a crater and then deploying a complicated origami mesh reflector network and a receive, which currently looks like it will be done through harpoon-like cables instead of the small rover cable grabbing crawling unit that LCRT originally proposed.

F. Feasibility of Building on the Moon's Surface

Large Structures in the short-term future would be too costly and would outweigh the benefits of building them; that's why (LCRT) is a great design to get observations without radio signal interference coming from Earth. The science if done with a Mesh single or double lander with a single launch vehicle would greatly benefit all of humanity for generations to come. The pros would be an extensive study of the universe's dark ages utilizing the 10 to 50 meter range. The cons would be the risk of deploying a multi-point precious system that would be similar to deploying the James Webb Telescope in risk though with 1⁄6 the gravity instead of a microgravity environment like Webb.

G. Comparison of Different Moon Locations (e.g., 1000-mile spread vs. Large Crater)

With the new Lunar Reconison satellites there is more evidence about the craters on all sides of the moon and there are no shortages of sites that are suitable for a 1 to 5 kilometer crater for the LCRT concepts that were already proposed.

Description	***LCRT Concept 1***	***LCRT Concept 2***
Range of diameters	$1 - 5$km	$5 - 50$km
Number of craters	$\approx$ 3000 craters [15]	$\approx$ 2000 craters [15]
Angular resolution $\lambda = 5$m $\lambda = 100$m	For 2km diameter $(\theta \approx \frac{1.22\lambda}{\text{Diameter}})$ $\theta = 10'$ $\theta = 3.5^\circ$	For 20km diameter, 2km rim height $\theta = 1' - 10'$ $\theta = 0.35^\circ - 3.5^\circ$

Figure III.

H. Integration with Existing Moon Missions, Such as Artemis

The Lunar Radio Telescope could be integrated into future large scale space missions such as Artemis or even SpaceX's Starship plans for the Moon and Mars. This could be a smaller scale part of the permanent stay on the moon or even be launched in a ride share with Starship. Starship can carry about

150 tons to orbit, thus could have a shared use until lunar orbit where parts separate out. Utilizing current Lunar plans would be the optimal plan to incorporate this telescope. Sharing cost and data with other countries and agencies is also possible through cooperation efforts. (NASA)

lV. Key Space-based Radio Telescopes

A. Hubble Space Telescope

- **Overview and Capabilities**

The Hubble Space Telescope was launched on April 24, 1990, and its journey was originally rough. During its development, Hubble suffered multiple delays from technical issues to the Challenger incident. When it finally made it to space at 380 miles above the Earth the operators finally realized that the main mirror was ground wrong resulting in aberrations in the images. Thus, The engineers and scientists at NASA had to work on another mission to replace this mirror that wasn’t really designed to be taken apart in space. After all these tiring delaying and technical challenges, Hubble was finally ready to benefit humanity in the observable universe. Over the years Hubble has continued to amaze generations of astronomers, scientists, and the global civilian population all together. The Hubble has outlived its expected life expectancy and even now NASA is seeing if someone can upgrade Hubble and refuel or boost its orbit to extend its life a little longer. (NASA, 2019)

- **Contributions to Radio Astronomy**

During Hubble's amazing missions in space, it has brought back magnificent images that have awed all people of Earth in amazement. These images can make humans feel as if they are a spec of sand in comparison to the immensity of the cosmos. This has brought greater understanding to moons around Jupiter, Saturn, Neptune, and Uranus through the search to understand the origins of the universe or even the solar system that Earth resides in. The Hubble has also taken breathtaking images of the Orion Nebula, The Crab Nebula and so much more that a ground-based telescope would never be able to complete due to atmospheric interference. This Interference restricts many ground-based operations globally. (NASA, 2019)

B. James Webb Space Telescope

- **Introduction and Objectives**

The JWST, launched on December 25, 2021, is the most powerful space telescope ever built. It aims to explore the cosmos in unprecedented ways, surpassing the capabilities of the Hubble Space Telescope. Named after James E. Webb, an early NASA administrator, JWST has several key objectives such as Ancient Objects. JWST will observe some of the oldest and faintest objects in the universe, including the first galaxies formed. During its mission, it will help understand the early Cosmic History. It will study every phase of cosmic history, from the Big Bang to galaxy, star, and planet formation. JWST will also help understand the Solar Systems and Exoplanets. JWST will investigate solar systems that could support life, including Earth-like planets. JWST will assist in understanding our origins by examining our own solar system's evolution, JWST contributes to our understanding of human origins. Operating nearly 1 million miles from Earth, JWST's sunshield keeps it cool for precise infrared observations. Its debut images include distant galaxies, exoplanets, and dying stars, inspiring awe and deepening our cosmic knowledge.

V. Scientific Discoveries Enabled by Space-based Radio Telescopes

The Cosmic Microwave Background is the furthest detectable radiation which is visible with humanity's most sensitive instruments. The Cosmic Microwave Background(CMB) was discovered on May 20, 1964 by a group of American radio astronomers, Robert Wilson and Arno Penzias. Later on March 21, 2013, high precision data confirmed the original detection of the CMB using NASA's Microwave Anisotropy Probe(WMAP), the Planck observatory predecessor(Griswold, 2010). This probe was launched into an orbit into the L2 Sun-Earth Lagrange point.

The detection of Pulsars and Quasars has played a critical role in the understanding of the universe and has been achievable through the use of space-based developments in radio astronomy and instrumentation. The first detection of a pulsar was made in 1967 when astronomy graduate student

Jocelyn Bell noticed a “strange bit of a scruff” coming from her radio telescope. This scruff was later determined to be a pulsar in 1968(ApsPhysics, 2026).

Space-based radio telescopes have played a critical role in understanding galaxy formation and evolution, which has played an important role in understanding the universe. Radio telescopes allow astronomers to view longer, lower-energy wavelengths. Data collected by radio telescopes in orbit have included data on stellar formation rate, the distribution of matter, and galactic mergers and other such interactions. This data has better allows us to develop more sophisticated models of the universe.

Radio telescopes in space or on celestial bodies with minimal atmospheric interference have less noise within the radio signals, allowing for better detection of extraterrestrial signals. This can be in the form of natural and artificial signals which would improve with improvement of space based radio telescope instrumentation. Furthermore, positioning a radio telescope on the moon allows for continuous monitoring of the sky and minimal interference from scattering and satellites. Furthermore, reducing atmospheric interference improves telescope sensitivity and resolution.

Continued advancements in space based radio telescopes will lead to further breakthrough in astronomy and astrophysics. These innovations will allow for a better understanding of the universe and humanity’s place within the universe. Furthermore, deploying radio telescopes on minimal-atmospheric celestial bodies will serve as a new utilization of the technology and allow for more potential discoveries through modification of the utilization of the underlying technologies and instruments.

VI. Technological Advancements in Space-based Radio Telescopes

A. Innovations in Telescope Design

The LCRT that has previously been design has multiple sophisticated designs in both Phase 1 and Phase 2. In Phase 1 they were planning to utilize a lander and rover system to retrieve the cables from the crater lander to then be brought up to the crater edge and grounded. Then, they would slowly tension the cables and unfold the mesh dish that was designed to be a 1 km mesh dish. During Phase to the team designed a harpoon cable system that would launch from the crater lander and the special Grabble would grab the Lunar regolith. Then the Mesh system this time consisting of a 350 meter mesh dish would deploy. Both system have their own risks and liabilities that could lead to critical failure and only partial mission successes.

B. Data Processing and Analysis Tools (Gateway or a Lunar Base Data catch)

Proposal to use either Gateway or the Lunar ground outpost as a data dump to then filter through to transmit relevant information back to Earth and its satellite constellations for the use of science and technology innovation. Utilizing this data dumb as a resource would conserve weight for the Radio Telescope to be landed and set up in a crater on the dark side of the moon.

C. Extended lifetime operations and Scalability/expandability to other craters or celestial bodies

20 year to 50 year life without Human repairs or operating by itself with limited Human interaction on the surface would be the optimal situation. Having a design that would operate for multiple decades, not just months would make it easier to expand the total array on the dark side of the moon and into other craters around other celestial bodies. This makes scalability and expandability more realistic for future space-based operations with multiple options including other countries assisting in the design and funding of the projects.

VII. Technological Benefits for Humanity

It is important to consider the technological benefits for humanity as a whole when considering the development of novel instrumentation. An associated benefit of the development of a lunar radio telescope on the Moon is the advancements in space technology; primary in-situ resource utilization(ISRU). As a radio telescope on an extraplanetary body would be of considerable size; the extraction, manufacturing, refining, and transportation of resources would have to take place on the lunar surface. Utilizing ISRU on the lunar surface will allow for a reduction in logistical lead times and operational costs. This would lead to the development of novel technologies to improve several aspects of ISRU.

The first aspect of ISRU which would result in an advancement are instruments which serve to extract raw resources from the lunar surface. Innovations on regolith-based volatiles acquisition technologies will be necessary to extract vast deposits of volatiles and fuels at scale.

The second aspect of ISRU which would result in advancement of space technologies are regolith-based volatile resource processing refinery technologies. These technologies are needed to maximize the utilization of harvested resources by appropriating the key compositions needed for manufacturing of the lunar radio telescope through a multi-step process of metal fabrication.

The third aspect of ISRU which would advance notably is lunar-based resource transportation systems. Lunar-based resource transportation systems are critical to transporting raw and processed materials from their respective waypoints in the lunar logistical chain. Private companies and agencies, like NASA, are currently working on the development of foundational technologies to eventually support industrial grade transportation of resources. One such project is the NASA Volatiles Investigating Polar Exploration Rover(VIPER) Moon Rover which is set to launch in late 2024. The VIPER Moon Rover is a small autonomous resource extraction rover which serves as a foundational mission for large scale autonomous lunar-resource hauling vehicles.

The development of autonomous systems to reduce human intervention in the development process is critical for the development of large scale structures on the lunar surface and cislunar bodies. The development of autonomous systems is important to reduce the time and labor burden on human subjects on the lunar surface to allow for time allocation toward primary science objectives and external aspects such as maintaining muscle composition and mental health. Furthermore, autonomous systems perform tasks with a higher degree of consistency, with accuracy tending to have a positive correlation with the enhancement of these technologies.

The usage of autonomous systems can be applied throughout all areas in the development cycle; from raw resource extraction to fabrication of the telescope.

VIII. Economic Considerations and Collaborative Opportunities

A. Cost Analysis of Moon-Based Radio Telescope(compare launch services assume we are not building the rocket)

Assuming this is a command and control autonomous landing and control system based on Intuitive Machines launch costing a mix of $238 million with $110 million coming from NASA directly. The total cost of the Lunar Radio Telescope should be in the range of $600 million to $2.2 Billion with a lifetime operational cost of over $200 million. Assuming Blue Origin’s New Glen and SpaceX’s Starship drive the cost to Lunar entry down in their competition. (Sharp, 2024) (SLIM) (NASA)

B. Comparison chart: Cost for a Lunar Lander/Rover to Assembly and Deploy the Lunar Radio Telescope Concept (LRTC)

	Japan SLIM Lander	Intuitive Odysseus	Apollo era average	Lunar Telescope est.
Lander Weight(kg)	700 kg (load with fuel)	1,908 kg	16,375 kg Average	1800-1900 kg Estimated
Estimate cost to launch	$120 Million (2024)	$268 Million (2024)	$49 Billion for all Lunar Modules with inflation adjustment	$600 million to $ 2 Billion (Complexity reasons)

Figure IV. (Sharp, 2024) (SLIM) (NASA)

C. Launch provider comparison based on x weight to the Lunar Surface

Blue Origin's New Glenn spacecraft is a viable heavy-lift option with a 7-meter fair that has a reusable first stage. It is currently in development and should launch before the end of 2024. (Hedlund, 2023)

SpaceX's Starship is another viable option with its 9-meter fairing. This is still in the development stage and hasn't had a fully successful flight yet. Though they are ramping up production, this could add to rapid usability like The Falcon 9s and Falcon heavies. The Falcon could also be used to rapidly deploy large payloads into multiple trajectories. (Hedlund, 2023)

The Vulcan Centaur rocket being developed by the ULA might be viable also depending on the weight that is needed to get to the Lunar surface. (NASA)

The Space Launch System uses proven technology that can lift an impressive amount of tonnage to the Lunar Surface. This has been launched once and is using proven technology. The cons are it is a single launch system, so has a very high cost to launch. Though Artemis is utilizing many of these to start the Gateway mission and Lunar base. (NASA)

D. Possibility of Multi-Country Collaboration and Potential Partnerships with Existing Space Agencies

The use of multiple countries and Space Agencies that would benefit from the overall science of these observations could be split to help reduce the overall cost to a single country. Jaxa, ESA, CSA, and many other agencies could help develop the components and/or just help front the cost for the benefit of humanity. The collaboration will assist humans in becoming multi-planetary.

IX. Public Engagement and Awareness

It is important to communicate the significance of the Moon-Based Radio Telescope to the public as it outlines several benefits. The first benefit of communicating the project to the general public is to develop sustainable interest in the development of the project. By leveraging the sustained awareness and support of the project, opportunities for partnerships, grants, and additional sources of funding may be more attainable which will assist in the development cycle of the telescope.

Another benefit of communicating the significance of the project to the general public is to inspire future iterations and innovations of Lunar-Based Radio Telescope technologies which will allow for better data collection, scientific integration, and a more thorough understanding of our universe and place within it. This will allow for the future opportunity for higher education internships and co-ops from people who were previously inspired by the original version of the Moon-Based Radio Telescope

Generating interest, and more importantly support, is the cornerstone of the development of scientific projects from ideation to production and utilization in academic and enterprise environments. A multi-stage engagement plan will need to be formulated to make sure the project achieves all desired milestones within the appropriate deadlines. These milestone include: generating initial interest with limited physical and financial resources, developing key partnerships with an advisory board with resources and research attained through the first milestone, generating interest with industry leaders and attaining the resources deemed appropriate to begin the full-scale development cycle of constant iterations of the Moon-Based Radio Telescope to be utilized in a development and production environment.

This multi-staged process reduces early potential dismissals of the research and technology, allows for ideation and research timelines to be developed, and an engagement cycle which positively correlates with the transition to the development and production cycles. Furthermore, by allowing a significant time for preliminary research and small-scale testing of key technologies, the confidence of grantees is likely to be elevated due to a higher confidence that the proposal is: (i) a new technology deemed appropriate for a grant - demonstrated through scientific understanding of the state-of-the-art(SOA) and the scientific principles for the output of the project , (ii) a new technology which is of the public interest - demonstrated through the first state in the engagement cycle, and (iii) a technology which is likely to be executed - demonstrated through development of a key programmatics roadmap.

These justifications for likely proposal acceptance can be achieved with minimal resources and funding. This is why it is important to dedicate a significant amount of upfront time to project requirements before attempting to fabricate the telescope and dealing with potential issues of developing, funding, or public interest; making it unlikely for the project to succeed.

Educational opportunities and outreach will allow for the longevity of the interest and development of the current SOA and future technologies to be sustained. An educational opportunity campaign may consist of a multi-step education and outreach program. During preliminary stages of the project, before development of large-scale-prototypes and production models, there will be a higher emphasis on communicating the need of the technologies and the future benefits and/or innovations which the technology could yield. This is to prioritize development of communication strategies highlighting the need for the technology, this is to better attain grants to begin development.

During development of the telescope, the educational outreach campaign will pivot to focus on the science behind the technology and how it will eventually be utilized in a production environment. The audience target will likely those in high school and university as understanding the science of the technology requires fundamental understanding of basic physics and astronomy. Additional programs will be developed to target younger audiences to primarily inspire them to pursue careers in science, technology, engineering, and math(STEM).

During the later stages of development and post development, educational opportunities and outreach will adjust to focus on new technologies and innovations to the Moon-Based Radio Telescope and beyond. This will be done to open the door to future opportunities for funding and workforce development. Workforce development can be included in the educational opportunities and outreach program as there likely exists resources to onboard new talent for internships and careers working to innovate on future technologies of the Moon-Based Radio telescope.

X. Conclusion

A. Summary of the Proposal

In conclusion, the Lunar base Radio Telescope has the potential to benefit humanity greatly by helping us research the dark ages of the universe. The frequency window of ≤30 MHz opens a new realm of interesting science cases and yet remains one of the last unexplored frequency regimes in astronomy. The benefits of this project seem to outweigh the costs, especially in the current space race.

Though this idea has been considered before, such as by NASA in the 1960s, it was ruled out due to the high weight and complexity needed at the time. However, with today's technology, remote operation of the telescope would be possible once it is placed and fully operational. This would require experts in various fields to work together to make it happen. A data dump in the Gateway or Lunar settlement could be utilized to store and analyze the data collected by this marvelous telescope. In conclusion this Lunar base Radio Telescope could benefit the whole of humanity in the research about the dark ages of the universe. The benefits seem to outweigh the cost in the current space race. These designs have been brought up multiple times in history going back to the 1960s when NASA considered it and ruled it out over the sheer weight and complexity needed in the early Space Race. The Telescope could be operated remotely once it is placed and fully operational with the utilization of a data dump in the Gateway or Lunar settlement. This would not be an easy feat even in today's technology and would require a sophisticated group of technological experts to be able to pull this marvel off.

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