Position Paper

A Long-Term Strategy for Space-Based Astronomy and Lunar Surface Observatories

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Executive Summary

The National Space Society (NSS) advocates for a long-term strategy to transition astronomical observatories into space and onto the lunar surface. As the number of satellites and other space infrastructure continues to grow, preserving Earth's dark and quiet skies becomes increasingly challenging. Establishing space-based and lunar observatories offers a powerful alternative, allowing humanity to continue groundbreaking astronomical discoveries while supporting the development of space infrastructure that provides significant economic, scientific, and national security benefits. Furthermore, developing a comprehensive long-term strategy for extensive space-based astronomy brings together both the astronomical and commercial space communities, fostering cooperation and mutual compromise. This collaborative approach ensures that both sectors work in tandem to achieve sustainable advancements in space exploration and scientific research, rather than being pitted against each other.

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Introduction

As humanity's presence in space expands, the intersection between commercial space activities and scientific research becomes increasingly significant. The proliferation of satellites and space infrastructure poses challenges to traditional ground-based astronomical observatories, necessitating a strategic shift towards space-based and lunar surface observatories. This policy paper outlines the National Space Society's (NSS) position on transitioning astronomical research to space, emphasizing collaboration, inclusivity, and sustainable growth.

The Best Place to Study Space Is in Space

The National Space Society (NSS) envisions space-based and lunar surface observatories as the future of astronomy. Earth's atmosphere has consistently hindered scientific discovery by distorting and absorbing light from celestial objects. Atmospheric turbulence causes stars to twinkle and images to blur, while certain wavelengths—such as ultraviolet, X-rays, and gamma rays—are entirely absorbed, rendering them inaccessible to ground-based telescopes.

In addition to atmospheric challenges, surface light pollution poses a growing threat to astronomical observations. Many legacy observatories built in remote locations are now compromised by the expansion of nearby cities, diminishing their effectiveness. Establishing new large-scale facilities in even more secluded areas not only significantly increases construction and operating costs but can also infringe upon the interests of indigenous communities.

Beyond these issues, it is well established that the optimal environment for conducting astronomy lies beyond Earth's surface. Space-based and lunar observatories eliminate atmospheric limitations, enabling continuous observations and providing access to the full electromagnetic spectrum. This shift not only enhances the quality and scope of astronomical research but also fosters innovation and sustainability in space exploration.

Significant investments in space-based observatories like the Hubble Space Telescope and the James Webb Space Telescope (JWST) have already demonstrated the effectiveness of conducting astronomy from space, yielding unprecedented insights into the universe. Similarly, space-based facilities for particle astronomy and planned radio and gravitational wave astronomy show the potential for more precise and comprehensive observations free from Earth-based interferences.

By moving observatories off-planet, the aim is to unlock the full potential of scientific discovery, reduce conflicts between commercial and scientific interests, and create opportunities for public involvement, including underrepresented groups, in space-based exploration.

Modern Astronomy: Ground vs. Space-Based Observatories

Modern astronomy is predominantly conducted by analyzing data streams from both ground-based and space-based telescopes. While the fundamental experience of data analysis remains consistent regardless of a telescope's location, space-based observatories offer significantly superior data quality by eliminating atmospheric distortions and terrestrial interferences. Instead of imposing restrictive measures, we advocate for a strategy that fully embraces space-based observatories, enabling both astronomical research and space development to thrive. Transitioning observatories off-planet not only enhances scientific discovery but also mitigates conflicts between commercial space activities and scientific interests. Furthermore, this shift creates broader opportunities for public engagement, including initiatives that involve underrepresented groups in space-based exploration. By democratizing access to high-quality astronomical data and fostering inclusive participation, space-based observatories can inspire a diverse range of individuals and communities, ensuring that the advancements in astronomy benefit and involve a wide spectrum of society.

The Dark and Quiet Skies Act in the Context of Space Development

Imposing Constraints on Space Development:

As the commercial space sector expands, limiting satellite operations to protect dark skies may place significant burdens on companies building satellite constellations for global communication, Earth observation, and space infrastructure. This could result in slowed innovation and additional operational costs that are not sustainable in the long run. In the worst-case scenario, such limitations could effectively prohibit numerous space development projects, stifling the growth of the commercial space industry and undermining the economic, scientific, and national security benefits it provides.

Temporary Solutions to a Growing Problem:

The **Dark and Quiet Skies Act of 2024** addresses the symptoms of an overcrowded low-Earth orbit (LEO) and geostationary orbit (GEO) but does not offer a long-term solution. As satellite traffic continues to increase, Earth-based astronomy will face growing challenges, even with mitigation measures. Ultimately, a more permanent solution—moving observatories off-planet—must be embraced.

Diverting Resources from Space Expansion:

By focusing on mitigating the impact of space activities on Earth-based observatories, the bill may inadvertently divert resources and political will from more forward-looking initiatives, such as developing space-based observatories that can coexist with and benefit from expanded space development.

Challenges in Global Compliance:

Constraining U.S.-based companies with added costs and regulations may, in the short run, alleviate some issues for ground-based astronomers. However, such constraints may not be followed by international competitors. This could result in a situation where the U.S. industry is disadvantaged or even overtaken, while ground-based astronomers continue to be affected by emissions from foreign satellites. Focusing on moving astronomy into space sidesteps this issue and has the added benefit of improving the potential for discovery.

A Long-Term Vision: Space-Based and Lunar Surface Observatories

NSS proposes that space-based and lunar surface observatories represent the future of astronomy. Earth's atmosphere has always limited scientific discovery by distorting and absorbing light from celestial objects. Atmospheric turbulence causes stars to twinkle and images to blur, while certain wavelengths—such as ultraviolet, X-rays, and gamma rays—are completely absorbed, making them inaccessible to ground-based telescopes. Cost aside, it is well known that the best place to conduct astronomy is off Earth's surface, where these limitations are eliminated, and additional benefits like continuous observation and access to the full electromagnetic spectrum are gained.

As the cost of launching into space continues to fall, space-based observatories will become more affordable and accessible. The remote sensing industry is booming with the manufacture of hundreds—and soon thousands—of optical, infrared, and multi-spectral satellite systems. The economies of scale from this manufacturing level should also directly translate into more affordable outward-looking space systems for astronomy. Additionally, space-based astronomy serves as a platform for developing international best practices, fostering collaboration and standardization among global scientific communities. Moreover, the advantages of space-based astronomy far outweigh the limitations of maintaining dark and quiet skies on Earth.

To fully realize these benefits, it is essential to explore specific types of space-based observatories that can revolutionize our understanding of the universe.

Observatories Across the Electromagnetic Spectrum

Space-based observatories operating across the electromagnetic spectrum—from radio waves to gamma rays, including optical wavelengths—are crucial for comprehensive astronomical research. Moving observatories into space offers unparalleled advantages:

- **High-Resolution Imaging:**
  Without atmospheric interference, space-based optical and infrared telescopes produce clearer, higher-resolution images. This enables detailed observations of distant galaxies, exoplanets, and star formation processes.
- **Access to All Wavelengths:**
  Telescopes in space can detect electromagnetic radiation that is absorbed or scattered by Earth's atmosphere. Observing in ultraviolet, X-ray, and gamma-ray wavelengths allows scientists to study phenomena such as black holes, neutron stars, and high-energy cosmic events that are inaccessible from the ground.

- **Radio Astronomy in Space and on the Moon:**
  While radio telescopes on Earth are limited by atmospheric interference and human-made radio noise, space-based and lunar surface radio observatories can operate without these constraints. The far side of the Moon, shielded from Earth's radio emissions, provides an unparalleled environment for radio astronomy.

- **Multi-Wavelength Observations:**
  Integrating instruments that observe multiple wavelengths simultaneously gives astronomers a complete picture of cosmic events and structures, enhancing our understanding of the universe's complexities.

Space-Based Particle Detectors

Particle detectors are essential tools for exploring high-energy astrophysical phenomena by detecting cosmic rays, neutrinos, and other subatomic particles originating from space. Ground-based particle detectors like **IceCube**, **Super-Kamiokande**, and the **Pierre Auger Observatory** have made significant contributions to our understanding of the universe. However, they face limitations due to Earth's atmosphere, which absorbs or deflects many particles before they reach the detectors. Background radiation and terrestrial interference can also obscure signals from cosmic sources.

Moving particle detectors into space or onto the lunar surface offers significant advantages:

- **Enhanced Detection Capabilities:**
  Space-based particle detectors can directly measure primary cosmic rays and high-energy particles without atmospheric interference, allowing for the detection of particles with energies that are attenuated or blocked by the atmosphere.

- **Reduced Background Noise:**
  The Moon's lack of atmosphere and magnetic field results in a cleaner environment with less background radiation, improving the sensitivity of detectors.

- **Neutrino Astronomy:**
  The detection of neutrinos—elusive particles that can pass through matter almost unhindered—is a growing field in astronomy. Space-based or lunar-based neutrino detectors could provide new insights into cosmic events like supernovae, gamma-ray bursts, and processes occurring in the cores of stars.

- **Dark Matter Research:**
  Particle detectors in space can aid in the search for dark matter particles by reducing background noise and increasing the likelihood of detecting rare interactions.

An example of successful space-based particle detection is the **Alpha Magnetic Spectrometer (AMS)** aboard the International Space Station (ISS), which has provided valuable data on cosmic rays and antimatter. Expanding such efforts to larger, more advanced detectors in space or on the Moon could significantly advance our understanding of fundamental physics and the universe.

The anticipated growth of lunar infrastructure will facilitate the deployment of particle detectors on the Moon. The stable environment and potential for larger-scale installations make the lunar surface an ideal platform for next-generation particle astronomy.

Space-Based Gravitational Wave Observatories

Gravitational wave astronomy has revolutionized our understanding of the universe, with observatories like **LIGO** detecting ripples in spacetime caused by massive cosmic events such as black hole mergers and neutron star collisions. While these Earth-based detectors are not impacted by satellite constellations or other space infrastructure, relocating gravitational wave observatories to the Moon or space offers significant advantages that can greatly enhance our ability to study the cosmos.

Space-based gravitational wave observatories can detect a wider range of frequencies, including those inaccessible from Earth due to seismic and environmental noise. This expanded capability allows for the observation of massive cosmic events and phenomena from the early universe. Lunar and space-based detectors complement ground-based observatories, offering a more complete picture of gravitational wave sources and enhancing our understanding of fundamental physics and cosmology.

The **Laser Interferometer Space Antenna (LISA)** mission, led by the European Space Agency (ESA) in collaboration with NASA, exemplifies the pioneering efforts in space-based gravitational wave detection. LISA aims to detect gravitational waves from space with unprecedented sensitivity by utilizing three spacecraft arranged in an equilateral triangle millions of kilometers apart. This configuration allows LISA to observe gravitational waves from sources that are difficult or impossible to detect with ground-based observatories, such as those originating from the early moments of the universe. The LISA mission cannot be accomplished on Earth, exemplifying the new astrophysical phenomena and insights that can only be achieved through space-based observatories. The success of missions like LISA underscores the critical role that space-based gravitational wave observatories will play in the future of astrophysics, highlighting the necessity of transitioning to off-planet observatories to fully realize the potential of gravitational wave astronomy.

The **Laser Interferometer Lunar Antenna (LILA)** is another proposed gravitational wave detector on the Moon that further exemplifies the potential of lunar-based observatories. LILA views the Moon as a stepping stone, leveraging its unique environmental benefits over Earth:

- **Significantly Less Seismic Noise:**
  The Moon experiences minimal seismic activity compared to Earth. This low-seismic environment allows for more sensitive measurements, as seismic noise is a major limiting factor for ground-based detectors.
- **Natural High-Quality Vacuum:**
  The Moon's surface provides vacuum conditions that rival the best vacuum systems on Earth. This near-perfect vacuum reduces interference from particles that can affect laser interferometry.
- **Economic Synergies:**
  An anticipated burgeoning lunar economy will facilitate easier and more affordable access to the Moon, enabling a rapid iteration approach to improving detector performance. Instruments can be developed and enhanced directly in the lunar environment.

Additionally, the **Laser Interferometer Space Antenna (LISA)** underscores the critical role that space-based gravitational wave observatories will play in the future of astrophysics, enabling the detection of gravitational waves that are otherwise inaccessible from Earth-based facilities. This mission exemplifies the new astrophysical frontiers that can only be explored through space-based instrumentation, highlighting the necessity of transitioning to off-planet observatories to fully realize the potential of gravitational wave astronomy.

This innovative method of developing and refining fundamental instruments in space will accelerate research pathways. Ultimately, while the best place to operate gravitational wave detectors might be in deep space, the advancements made possible by innovation on the Moon are crucial steps toward that goal.

Public Involvement in Space-Based Astronomy

Space-based and lunar surface observatories present new opportunities for public engagement in science and discovery:

1. **Citizen Science Programs:**
   With the growth of remote networked access to space-based observatories, the public can actively participate in data collection and analysis through citizen science initiatives. This democratizes access to space-based data and empowers individuals, including those from underrepresented and underserved communities, to contribute to real scientific discoveries.

2. **Educational Platforms:**
   Space-based observatories can create immersive educational experiences, allowing students and the general public to interact with live data feeds from telescopes in orbit or on the Moon. These programs can inspire the next generation of scientists and engineers by giving them direct access to the universe's wonders, particularly engaging underrepresented groups and fostering inclusive educational opportunities.

3. **Public Data Sharing:**
   Space-based observatories can publish real-time data on publicly accessible platforms, enabling amateur astronomers, educators, and researchers worldwide, including those from underserved communities, to explore the cosmos alongside professional scientists. This increases transparency and fosters collaboration between institutions and the public. By providing open access to high-quality astronomical data, these initiatives ensure that underrepresented and underserved communities have the opportunity to engage with cutting-edge scientific research. This inclusive approach broadens participation in astronomy, allowing a diverse range of individuals to contribute to and benefit from advancements in space-based observations.

4. **Inclusive Outreach Initiatives:**
   By partnering with organizations that focus on reaching disadvantaged and underserved communities, such as **Astronomers Without Borders (AWB)**, space-based astronomy initiatives can ensure that the benefits of astronomical advancements are accessible to all. This includes deploying amateur telescopes to underserved areas and providing resources and training to empower local enthusiasts.

5. **Active Participation in Observatory Development:**
   To further engage the amateur community, NSS proposes creating pathways for amateurs to be actively involved in the **design, building, testing, launching, and operation** of space-based astronomical instruments. This hands-on involvement transforms passive observers into active contributors, fostering a deeper connection with astronomical research and ensuring that amateur astronomers remain vital to the scientific community.

Recommendations

1. **Propose the Commercial Space Cooperation Act:**
   NSS recommends reframing the **Dark and Quiet Skies Act** into the **Commercial Space Cooperation Act**. This proposed act would allocate resources to further analyze and incorporate the aforementioned recommendations, developing a comprehensive roadmap for transitioning to predominantly space-based astronomical observatories. It aims to achieve two primary objectives: (a) mitigate impacts on surface-based astronomy in the interim where reasonably and economically feasible, and (b) continue supporting and accelerating space development to introduce valuable new capabilities globally. By fostering collaboration between the commercial space industry and the astronomical community, the act would establish a sustainable, long-term strategy for space-based astronomical observatories while simultaneously advancing the exploration and development of space. This cooperative approach not only alleviates the negative impacts of satellite constellations on astronomy but also drives innovation and economic growth within the commercial space sector.

2. **Invest in Space-Based and Lunar Astronomy:**
   Federal funding for Astronomy should prioritize space-based astronomy, including the continued strong support of existing space telescopes like Hubble and Chandra whose 2025 budgets have been selected for 10% and 40% cuts, respectively, by NASA. For the future, Federal funding should prioritize deploying numerous smaller, cost-effective space-based telescopes and lunar surface observatories rather than concentrating solely on large, multi-billion-dollar programs like the **James Webb Space Telescope (JWST)**. By deploying hundreds of these smaller instruments, we can compensate for the observational capacity lost due to orbital and surface light pollution, as well as overcome the limitations inherent in ground-based astronomy. This strategy ensures continuous astronomical research, secures the future of astronomy, and supports the burgeoning space industry. Funding for these initiatives could be partially generated through fees charged to low-Earth orbit

(LEO) satellite constellation owners/operators and other light-reflecting orbital infrastructures, known as an "albedo tax." Alternatively, satellite operators might satisfy the "albedo tax" requirement by voluntarily incorporating a suitable ratio of space-based telescopes within their satellite constellations, providing free launches for astronomical instruments, or leveraging the expansion of the trillion-dollar commercial space industry, which already contributes significant new tax revenues for allocation.

3. **Reorganize Astronomy Funding:**
   Transfer the astronomy budget from NASA to the **National Science Foundation (NSF)**, enabling the NSF to manage funding for all astrophysical endeavors—both ground-based and space-based. Currently, the division of budgets between NASA for space-based projects and NSF for ground-based astronomy creates a fragmented approach that hinders a seamless transition from Earth-based to off-planet observatories. By consolidating funding under NSF, we can ensure a more coordinated and systematic advancement of astronomical research. In this new structure, NASA could still play a crucial role by building and operating space-based instruments under contracts managed by NSF, thereby fostering collaboration and maximizing the effectiveness of our astronomical programs. This unified management approach will facilitate the deployment of numerous smaller, cost-effective space-based telescopes and lunar observatories, replacing any observational capacity lost due to orbital light pollution and enhancing the overall efficiency and impact of our astronomical research.

4. **Enhance Public Engagement through Space-Based Astronomy Initiatives:**
   Future space observatories should integrate citizen science platforms that allow the public to participate in data analysis and discovery processes. By providing open access to data from space-based telescopes, we empower amateur astronomers and enthusiasts to contribute to real scientific research, fostering a collaborative environment that transcends traditional observational limitations caused by orbital light pollution. Additionally, partnering with amateur astronomy and outreach organizations like **Astronomers Without Borders (AWB)** can extend these opportunities to underserved and disadvantaged communities, ensuring that astronomical advancements are inclusive and globally accessible.

5. **Develop Affordable, Networked Space-Based Instruments for Citizen Astronomers:**
   Federal funding and supportive policies should facilitate the creation of affordable, networked space-based astronomical instruments specifically designed for amateur astronomers. These instruments would enable continuous, day-and-night observations from space, independent of the user's location, thereby circumventing

the limitations posed by increasing orbital and surface light pollution. Additionally, a strategic approach should be implemented to equitably engage underserved populations in the **design** and **implementation** of these instruments. By democratizing access to space-based data, we can enhance both the quantity and quality of astronomical information available, ensuring that the amateur community remains a vital contributor to astronomical research.

6. **Facilitate International Partnerships for Global Space-Based Observatories:** Space-based and lunar observatories present unique opportunities for international collaboration, enabling global participation in addressing the challenges of dark and quiet skies. Partnering with international space agencies will facilitate the sharing of resources, expertise, and data, reducing costs and maximizing the scientific output of space-based astronomical projects. These collaborations ensure that the benefits of space-based astronomy are shared globally, promoting a unified approach to preserving astronomical research environments.

7. **Encourage Private Sector Involvement through Incentivized Partnerships:** The private space industry can play a key role in developing and launching space-based telescopes and instruments. NSS supports public-private partnerships to advance space-based astronomy and reduce costs through innovation. The federal government should encourage the use of commercial capabilities to launch a new generation of less mass-constrained and more affordable space astronomical observatories, leveraging the agility and efficiency of the private sector.

8. **Enhancing Lunar Astronomy through Laser Communication Standards:** Because of the Moon's lack of atmosphere, laser communication is more feasible on the Moon than on Earth. This advantage allows for expanded lunar far-side development with minimal interference to radio astronomy. We propose the promulgation of **industry standards and best practices** for laser communication networks to promote lunar economic development while preserving a radio-quiet environment. Implementing these standards will ensure that the Moon remains an optimal location for high-precision astronomical observations, facilitating both scientific advancements and economic growth in lunar infrastructure.

About the National Space Society (NSS): NSS is an independent non-profit educational membership organization dedicated to the creation of a spacefaring civilization. NSS is widely acknowledged as the preeminent citizen's voice on space, with over 50 chapters in the United States and around the world. The Society publishes *Ad Astra* magazine, an award-winning periodical chronicling the most important developments in space. To learn more, visit www.nss.org.