PROCEEDINGS OF SCIENCE

The Importance of Space Sustainability for the Continuity of Scientific Services

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Space sustainability has become a critical issue as the increasing number of orbital objects poses significant risks to space-based services, scientific research, and technological progress. Key challenges include space debris, radio frequency interference (RFI), and orbital congestion, which jeopardize essential scientific activities such as Earth observation, meteorology, and radio astronomy. International organizations, including the United Nations (UN), the International Telecommunication Union (ITU), and the Committee on the Peaceful Uses of Outer Space (COPUOS), have developed frameworks to address these challenges through debris mitigation, spectrum management, and collaborative guidelines.

This paper explores the historical evolution and current challenges of space sustainability, emphasizing the importance of international cooperation in implementing sustainable practices. Initiatives such as the ITU's Best Practices Handbook, the COPUOS 2018 Guidelines, and the Dark and Quiet Skies (DQS) project highlight global efforts to preserve orbital and spectral resources. Advancing Space Situational Awareness (SSA) capabilities, fostering international collaboration, and strengthening regulatory frameworks are identified as key priorities to ensure the long-term usability of outer space and the continuity of vital scientific services.

Radio Frequency Interference Conference (RFI2024)
14-18 October 2024
Bariloche, Argentina

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ISSN 1824-8039 . Published by SISSA Medialab.

https://pos.sissa.it/

1. Introduction

The launch of Sputnik I in 1957 marked the start of the Space Age, driving scientific and technological progress. However, this growth has brought sustainability challenges, such as space debris and collision risks, which threaten critical scientific services like Earth observation and radio astronomy. International organizations, including the United Nations (UN) and the International Telecommunication Union (ITU), have developed international frameworks for sustainable space governance. This paper examines the importance of global cooperation to ensure space sustainability and the preservation of scientific services.

2. History of Space Sustainability

Efforts to regulate space activities began with the 1961 UN Registry of Objects [1] and the 1963 Declaration of Legal Principles [2], which promoted peaceful exploration. The 1967 Outer Space Treaty [3] further consolidated these principles, establishing guidelines for responsible use of outer space.

Growing concerns about space debris emerged in the late 20th century, driven by the Kessler Syndrome [4], which warned of cascading collisions. This led to initiatives such as NASA's Orbital Debris Program and ESA's Space Debris Office. Notable milestones include the 2007 UN Resolution 62/217 [5], which highlighted equitable access to space, and the 2018 Committee on the Peaceful Uses of Outer Space (COPUOS) Long-term Sustainability Guidelines [6], emphasizing debris mitigation and transparent orbital data-sharing frameworks. These developments underscore the evolving nature of global governance in addressing sustainability challenges.

3. Current Challenges in Space Sustainability

Space sustainability faces complex challenges that require international coordination. Key issues include the rapid increase in orbital objects, congestion, debris, radio frequency interference (RFI), and the preservation of dark and quiet skies.

3.1 Growing Number of Objects Launched into Space

By 2023, 17,489 objects had been launched into space, with a sharp increase driven by megaconstellations since 2019 [7]. The past five years saw launches nearly matching the total of the previous 62 years, highlighting the unprecedented acceleration in orbital occupation.

Projections from Gebrim and Bakaus [8] indicate that this number could surpass 105,000 by 2035, the urgency of sustainable orbital management. The rise of satellite constellations [9] for internet services exacerbates collision risks and pressures finite resources, such as radio-frequency spectrum and orbital slots. Equitable and sustainable management of these resources is critical to ensuring the safety and success of future space missions.

3.2 Orbital Congestion and Space Debris

Low Earth Orbit (LEO) and Medium Earth Orbit (MEO) face increasing congestion due to megaconstellations, with limited regulatory oversight. The 2021 European Space Agency (ESA) report estimated over 130 million debris fragments larger than 1 mm in orbit [7]. While Active Debris Removal (ADR) programs and responsible satellite design are being developed, stricter regulations are needed, particularly in LEO and MEO.

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The Inter-Agency Space Debris Coordination Committee (IADC) Space Debris Mitigation Guidelines [10], supported by UNOOSA, outline non-binding principles for reducing orbital congestion, such as the timely removal of defunct satellites at the end of their operational life. However, the implementation of these guidelines remains inconsistent, as they lack enforcement mechanisms.

Geostationary Orbit (GEO), in contrast, benefits from the ITU's Radio Regulations (RR) [11], which ensure interference prevention and equitable slot allocation. Expanding such rigorous governance to LEO and MEO is essential to address higher risks in these regions. Enhanced cooperation and stricter regulations are vital to mitigate orbital congestion and ensure sustainable use of orbital resources.

3.3 Radio Frequency Interference (RFI)

RFI disrupts critical services such as navigation, meteorology, climate monitoring, communication, defense systems, and space operations. The increasing density of satellites in shared orbits heightens the risk of RFI, making spectrum management essential for sustainable space activities.

International collaboration through regulation and agreements is key to mitigating RFI and ensuring equitable spectrum use, especially for developing countries. The ITU plays a crucial role, with its RR ensuring stations operate without causing harmful interference to other services.

As satellite megaconstellations grow, the risk of aggregated signal interference increases. Stricter spectrum-sharing policies, adherence to ITU regulations, and enhanced international cooperation are essential to manage RFI in increasingly congested orbital regions.

3.4 Dark and Quiet Skies (DQS)

The DQS Global Outreach Project [12], led by the International Astronomical Union (IAU) and supported by UN Office for Outer Space Affairs (UNOOSA), addresses the impacts of Artificial Light at Night (ALAN), satellite trails, and RFI from satellite constellations on astronomy and cultural heritage. To mitigate these challenges, DQS promotes regulatory frameworks, public awareness, and technical guidelines.

Global efforts to protect dark and quiet skies reflect growing recognition of their importance for preserving scientific research and cultural heritage. Initiatives like DQS exemplify the need for international collaboration to align space activities with sustainability principles.

3.5 Space Situational Awareness (SSA)

Space Situational Awareness (SSA) involves detecting, tracking, and predicting the movement of satellites, debris, and near-Earth objects to ensure the safety and sustainability of space operations. It requires adherence to COPUOS guidelines, ITU regulations, and transparent data-sharing to mitigate collision risks and enhance operational safety. Additionally, SSA supports environmental monitoring, disaster response, and sustainable development while addressing challenges like radio frequency interference (RFI) and light pollution, which impact space communications and astronomy.

Advancing SSA depends on international collaboration, technical capacity-building, and the adoption of modern technologies. Through global seminars, training programs, and standardized guidelines, stakeholders can align efforts to achieve sustainability goals and safeguard the long-term usability of space for scientific, commercial, and societal benefits.

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4. Space Sustainability and the Future of Scientific Services

Space sustainability is crucial for the continuity of scientific services such as Earth observation, meteorology, and radio astronomy. These services rely on an interference-free and debris-free environment to operate effectively. However, challenges like the growth of mega-constellations, space debris, and radio frequency interference (RFI) jeopardize their performance. Addressing these issues demands strong regulations, international cooperation, and technological innovation.

4.1 Scientific Services at Risk

Earth Observation: Satellites play a vital role in environmental monitoring, climate tracking, and disaster response. Space debris and RFI pose significant risks, threatening the accuracy and availability of critical data.

Meteorology: Weather and space weather monitoring depend on satellites to forecast storms, predict solar activity, and mitigate infrastructure risks. Disruptions from debris or RFI could undermine these essential functions.

Radio Astronomy: Observatories rely on interference-free environments to detect faint cosmic signals. Increasing satellite deployments heighten RFI risks, requiring mitigation measures like Radio Quiet Zones (RQZs) and international regulations..

4.2 Ensuring Long-term Usability

To safeguard these services, it is vital to maintain a sustainable space environment through stricter debris mitigation measures, improved RFI management, and enhanced international collaboration. Regulatory frameworks, such as ITU spectrum guidelines and COPUOS sustainability practices, play a key role in ensuring the safe operation of satellites for scientific and societal benefit.

5. International Initiatives

Global efforts to ensure space sustainability are driven by key organizations such as the ITU and COPUOS. These institutions promote sustainable practices through regulatory guidelines, technical recommendations, and initiatives aimed at orbital resource management, debris mitigation, and international collaboration.

The ITU, through Resolutions PP-219 [13] and ITU-R 74 [14], established the Space Sustainability Gateway [15] to consolidate resources for responsible Non-Geostationary Orbit (NGSO) operations. It is also developing a Handbook on Best Practices for NGSO Sustainability [16] and advancing recommendations for the safe disposal of satellites to minimize orbital risks.

COPUOS oversees the Working Group on the Long-term Sustainability of Outer Space Activities (WG-LTS) [17], which revises its guidelines to address emerging challenges such as megaconstellations. At its 67th session in 2024, COPUOS incorporated Dark and Quiet Skies (DQS) [18] into its agenda to mitigate satellite impacts on astronomy.

These initiatives demonstrate the international community's commitment to preserving orbital and spectral resources for future generations.

6. Conclusions

Space sustainability is a critical concern affecting the safety and longevity of space-based services, as well as the future of scientific research and technological advancements. The growing

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number of orbital objects, coupled with challenges such as space debris, RFI, and orbital congestion, underscores the need for coordinated action at national and international levels.

Global efforts, including the ITU's Best Practices Handbook, the revision of the COPUOS 2018 Guidelines, and the DQS initiatives, demonstrate the international community's commitment to maintaining space as a safe and accessible domain for future generations.

Sustained vigilance is essential to prevent the degradation of the space environment. Key priorities include promoting sustainable practices, advancing SSA capabilities, and fostering international collaboration to ensure the continuity of scientific services.

References

[1] UNOOSA, "United Nations Register of Objects Launched into Outer Space." Available: https://www.unoosa.org/oosa/en/spaceobjectregister/index.html.

[2] UN, "Declaration of Legal Principles Governing the Activities of States in the Exploration and Use of Outer Space," Res. 1962 (XVIII), Dec. 1963.

[3] UN, "Outer Space Treaty," Jan. 1967.

[4] D. J. Kessler and B. G. Cour-Palais, "Collision Frequency of Artificial Satellites: The Creation of a Debris Belt," J. Geophys. Res., vol. 83, no. A6, pp. 2637–2646, Jun. 1978.

[5] UN, "International cooperation in the peaceful uses of outer space," Res. 62/217, Dec. 2007.

[6] UNOOSA, "Guidelines for the Long-term Sustainability of Outer Space Activities," 2018.

[7] E. Mathieu and M. Roser (2022) - "Space Exploration and Satellites" Published online at OurWorldinData.org: https://ourworldindata.org/space-exploration-satellites.

[8] R. C. Gebrim and T. A. Bakaus, "Do Sputnik à era das grandes constelações de satélites: os desafios em se garantir a sustentabilidade espacial de longo prazo," in Proc. SBrT, 2024.

[9] SPACE.com, "Over 1 million satellites could be headed to Earth orbit, and scientists are worried," 2023. Available: https://www.space.com/million-satellites-congest-low-earth-orbit-study-shows.

[10] IADC, "IADC Space Debris Mitigation Guidelines," Rev. 3, 2020.

[11] ITU, "Radio Regulations," 2024. Available: https://www.itu.int/en/ITU-R/space.

[12] IAU, "Dark Skies Awareness." Available: https://www.darkskiesawareness.org.

[13] ITU, "Resolution 219: Sustainability of the radio-frequency spectrum," ITU PP Conference, 2022.

[14] ITU, "Resolution ITU-R 74: Sustainable use of the radio-frequency spectrum," 2023.

[15] ITU, "Space Sustainability Gateway." Available: https://www.itu.int/space-sustainability/.

[16] ITU, "Draft Handbook on Best Practices for NGSO Sustainability," Annex 16, WP 4A, Oct. 2024.

[17] UNOOSA, Working Groups. Available: https://www.unoosa.org/oosa/en/ourwork/copuos/working-groups.html.

[18] UNOOSA, "Report of the Committee on the Peaceful Uses of Outer Space, Sixty-seventh session," 2024.

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