Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington, D.C. 20554

In the Matter of	)	
	)	
Modernizing Spectrum Sharing for Satellite Broadband	)	SB Docket 25-157
	)	
Revision of the Commission's Rules to Establish More Efficient Spectrum Sharing between NGSO and GSO Satellite Systems	)	RM-11990 (Terminated)

**COMMENTS OF THE
NATIONAL ACADEMY OF SCIENCES'
COMMITTEE ON RADIO FREQUENCIES**

The National Academy of Sciences, through its Committee on Radio Frequencies (hereinafter, CORF)[1], hereby submits its comments in response to the Commission's *Notice of Proposed Rulemaking* (NPRM), released on April 29, 2025, in the above-captioned dockets. In these comments, CORF addresses the significant potential impact on radio astronomy observations from proposals to promote a more efficient framework for sharing spectrum between non-geostationary orbit (NGSO) and geostationary orbit (GSO) satellite systems, and provides suggestions for protecting radio astronomy observations. Any change in the sharing regime between NGSO and GSO satellite systems will likely result in further increase in either the number of satellites in currently operating NGSO constellations, or in new entrant NGSO systems in the bands of interest to the Radio Astronomy Service (RAS). Either of these results has the potential to significantly increase the already serious radio frequency

[1] See the Appendix for the membership of the Committee on Radio Frequencies.

interference (RFI) challenges for ground-based radio astronomy observatories. To mitigate this result, CORF urges the Commission to consider mandating enhanced coordination between NGSO operators and impacted RAS observatories as described below. In addition, the Commission must ensure that power flux density (PFD) limits in the RAS bands refer to <u>aggregate emissions</u> that include multiple satellite operators (GSO as well as NGSO), since it is aggregate emissions that impact the ability of RAS facilities to carry out observations.

I. Background – The Importance and Vulnerability of Radio Astronomy.

CORF has a substantial interest in this proceeding because it represents the interests of the users of the passive scientific bands of the radio spectrum, specifically in this proceeding, users of the RAS bands.

As the Commission has long recognized, radio astronomy is a vitally important tool used by scientists to study the universe. It was through the use of radio astronomy that scientists discovered the first planets outside the solar system, circling a distant pulsar. The Nobel Prize-winning discovery of pulsars by radio astronomers led to the recognition of a widespread population of rapidly spinning neutron stars with surface gravitational fields up to 100 billion times stronger than that on Earth. Radio observations of pulsars have revolutionized understanding of the physics of neutron stars and have resulted in the first experimental evidence for gravitational radiation, which was recognized with the awarding of another Nobel Prize. More recently, pulsars have been used as a tool to measure the gravitational wave background in the universe. Radio astronomy has also enabled the discovery of organic matter and prebiotic molecules outside the solar system, leading to new insights into the potential existence of life elsewhere in the Milky Way Galaxy. Radio spectroscopy and broadband continuum observations have identified and characterized the birth sites of stars in the Milky Way, the processes by which stars slowly die, and the complex distribution and evolution of other galaxies in the universe. The enormous energies contained in the enigmatic quasars and radio galaxies discovered by radio astronomers have led to the recognition that most galaxies, including the Milky Way, contain supermassive black holes at their centers, a phenomenon that appears to be crucial to the creation and evolution of galaxies. Indeed, the first image of the shadow of a super massive black hole, in the M87 galaxy, was obtained by an array of radio telescopes,[2] followed more recently by similar observations toward the black hole at the center of the Milky Way Galaxy.[3] Such synchronized observations using radio telescopes spaced far apart across multiple continents around the world (i.e., with very long baseline interferometry, or VLBI) give extraordinarily high angular resolution, far superior to that which can be obtained using the largest optical telescopes on the ground or in space.

The critical scientific research undertaken by the RAS, however, cannot be performed without access to interference-free spectral bands at protected or remote geographic locations. Notably, the emissions that radio astronomers study are extremely weak—a radio telescope receives less than 1 percent of one-billionth of one-

[2] *See*, The Event Horizon Collaboration, 2019, The Astrophysical Journal Letters, 875, L1. https://doi.org/10.3847/2041-8213/ab0ec7. *See also* https://www.washingtonpost.com/opinions/2019/04/12/black-hole-photo-was-no-big-surprise-scientists-heres-why-its-still-big-deal/; https://www.washingtonpost.com/science/2019/04/10/see-black-hole-first-time-images-event-horizon-telescope; and https://www.nytimes.com/2019/04/10/science/black-hole-picture.html.

[3] *See,* The Event Horizon Collaboration, 2022, The Astrophysical Journal Letters, 930, L2. https://doi.org/10.3847/2041-8213/ac6674.

billionth of a watt from a typical cosmic object. Because radio telescope receivers are designed to detect these remarkably weak cosmic signals, they are particularly vulnerable to even very weak emissions as interference. Human-made interference into RAS bands may come from in-band, spurious, and out-of-band emissions (OOBE) from either licensed or unlicensed users of neighboring bands, or can come from emissions in other bands that also contain harmonic signals in the RAS bands. Even if these human-made emissions are weak and distant they can impact a RAS receiver.

Of particular importance in this proceeding is the impact upon radio astronomy of changes to satellite sharing rules in the 10.7-12.7 GHz band, adjacent to a RAS band. The RAS has a primary allocation[4] from 10.6-10.7 GHz, and the 10.68-10.70 GHz portion of the band is additionally protected domestically by footnote US246, and by RR No. 5.340 worldwide. Pursuant to US246, "[n]o station shall be authorized to transmit" at 10.68-10.7 GHz, and pursuant to RR 5.340, "[a]ll emissions are prohibited" at 10.68-10.7 GHz. *See* 47 CFR § 2.106, US246. In addition, in footnote US211, applicants for airborne or space station assignments at 10.7-11.7 GHz, among other frequency bands, are urged to take all practicable steps to protect radio astronomy observations in the adjacent bands from harmful interference. See 47 CFR § 2.106, US211; *see also* 47

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[4] While the Commission's inquiry in this proceeding appears to be limited to the RAS, CORF notes that the Earth Exploration Satellite Service (passive) also has adjacent primary or co-primary allocations at 10.60-10.68, 10.68-10.70 (subject to Footnotes 5.340 and US246), and 18.6-18.8 GHz. These bands, which could be subject to increased Earth-reflected OOBE under the proposed rule changes, are among a suite of channels used by multichannel passive microwave radiometers to sense Earth properties, including water vapor, cloud liquid water, rain rate, soil moisture, sea surface salinity and temperature, land surface roughness and wind-driven sea-surface roughness, and vegetation. The use of multiple channels enables the contributions of these different parameters to be disentangled through their overlapping but distinct spectral emission signatures. Thus, interference in a single band hampers interpretation of signals in other bands and reduces the information yield from the complete multi-band observing system.

CFR § 2.106, US131 (requiring prior coordination with specific RAS sites).

The 10.6-10.7 GHz band is a preferred band for RAS continuum observations. Modern radio astronomical receivers and signal-processing systems normally observe a wider bandwidth than the given allocation—for example, the X-band receiver on the National Science Foundation (NSF) Green Bank Telescope (GBT) covers 8-12 GHz continuously. The RAS allocated band in this is an interference-free sub-band with protected data quality. X-band observations target energetic non-thermal sources such as synchrotron emission from supernova remnants (SNR) and active galactic nuclei (AGN; emission from the region around the supermassive black hole in the center of a galaxy). Observing the continuum spectrum of these objects across multiple widely spaced bands is necessary to provide insight into their otherwise unresolved structure, for instance by locating the spectral break associated with synchrotron self-absorption. X-band observations are also suitable for detecting free-free thermal emission from clouds of ionized atomic hydrogen in the interstellar medium, known as HII regions, or from material surrounding an SNR or AGN. Observations at these frequencies provide some of the best angular resolutions using VLBI to study quasars (a bright type of AGN). Continuous monitoring of a set of quasars distributed across the sky is used as a reference for co-ordinate systems for geodesy. This technique enables scientists to measure the shape, gravitational field, and orientation in space of Earth, all of which is essential for accurate navigation. In addition, these objects produce surprisingly large amounts of energy for their size and have been found to vary in intensity with periods of weeks and months. Monitoring the intensity and spatial distribution of the flux density emitted from these enigmatic objects is critical to understanding the structures of quasars and the fundamental physics that can produce such events. In the same frequency range, monitoring the radio continuum emission of the Sun provides insight into the nature and evolution of coronal magnetic fields. Such monitoring observations are time-sensitive and cannot be repeated at a later time if observations are corrupted by interference, since the emitting feature will have changed.

II. Protection of Radio Astronomy

At paragraph 32 of the NPRM, the Commission notes the "extensive recent record of successful coordination and cooperation between radio astronomy systems and satellite systems," and asks whether any additional considerations with respect to NGSO Fixed Satellite Service (FSS) operation would be necessary to protect radio astronomy operations, beyond the existing PFD limits. The NPRM also seeks comment on how any changes to the NGSO-GSO sharing regime would affect co-frequency or adjacent-band radio astronomy operations, and how the Commission would ensure that successful coordination continues. CORF offers the following comments.[5]

A. Potential Impact on RAS of Changing the NGSO-GSO Sharing Regime

The typical brightness of radio emissions from astronomical objects is dwarfed by the operational PFD from both NGSO and GSO transmitters, and with the drastically increasing number of satellites placed in orbit in recent years, RAS facilities are operating in an increasingly difficult and radio loud environment. The construction of RAS facilities, which represent significant investment in scientific excellence in the

[5] While CORF's present comments address a U.S. rulemaking proceeding, the Commission notes in paragraph 14 of the NPRM that the proposed studies towards changes of the Commission's rules mirror similar studies at the ITU, and could facilitate changes in international rules. CORF encourages the Commission to consider the broader international impact of its actions in this proceeding.

United States, has typically been planned for remote areas with low population density, which, along with the help of topographical shielding, reduces human-made RFI. In some geographic locations, local or federal protections exist to create a more radio quiet environment even outside of allocated RAS bands. A few examples of such initiatives are the National Radio Quiet Zone (NRQZ), the Puerto Rico Coordination Zone (PRCZ), and the NSF Spectrum Innovation Initiative - National Radio Dynamics Zone (SII-NRDZ). The NRDZ is a recent concept study exploring a unifying and dynamic spectrum sharing framework for active and passive spectrum users.[6] The advent of large low Earth orbit (LEO) constellations poses a significant challenge to established modes of protection for RAS observatories. Current regulatory protection of radio quiet zones is not designed to address satellite transmissions, and the de facto protection once enjoyed by observatories in remote locations can no longer be assured.

Although RAS facilities have protected access to very limited spectrum allocations for dedicated passive observations, many of their receivers have been built with a wider spectral range of operation to take advantage of opportunistic passive observing in spectrum allocated to active services; for example, to increase continuum sensitivity (which increases as the square root of bandwidth) or to access spectral line emission at frequencies outside RAS allocations. Many scientific investigations, including some which have led to recent cutting-edge discoveries in astrophysics and cosmology, would be significantly limited, or even impossible, without this opportunistic observing enabled by the location of radio telescopes far from any terrestrial transmitters using the active service allocations. The relatively quiet ground-based radio

[6] *See* https://info.nrao.edu/do/spectrum-management/national-radio-dynamic-zone-nrdz.

environments in which these facilities have intentionally been sited have already been compromised by artificial radio emissions from NGSO and GSO satellites overhead. Any change in the sharing regime between NGSO and GSO satellite systems has the potential to result in further increases, in either the number of satellites in NGSO constellations currently operating, or in new entrant NGSO systems in the bands of interest to RAS. Either of these outcomes has the potential to significantly increase the already serious RFI challenges for ground-based radio astronomy. As discussed further below, CORF asks the Commission to make sure that any revisions made as a result of this proceeding do not result in increased interference from OOBE into bands where RAS has protections, including 10.6-10.7 GHz.

B. Coordination Between NGSO Operators and the RAS

As noted above, at paragraph 32 of the NPRM, the Commission asks "how should the Commission ensure that successful coordination continue?" In response, CORF notes that Footnote US131 states that "[i]n the band 10.7-11.7 GHz, non-geostationary satellite orbit licensees in the fixed-satellite service (space-to-Earth), prior to commencing operations, shall coordinate with the radio astronomy observatories listed in table 12 to this paragraph (c)(131) to achieve a mutually acceptable agreement regarding the protection of the radio telescope facilities operating in the band 10.6-10.7 GHz". Since 2019, under the coordination agreement between NSF and the Space Exploration Technologies Corp. (SpaceX), the National Radio Astronomy Observatory (NRAO) has been collaborating closely with SpaceX's Starlink engineering team to conduct coordinated and uncoordinated experiments to evaluate the impact of Starlink downlinks at 10.7-12.7 GHz on the NSF Very Large Array (VLA) and on the GBT. The coordinated experiments consist of scheduling radio telescope observation sessions at prearranged sky positions and frequency ranges. NRAO communicates operational parameters of the telescopes with Starlink, in response to which the Starlink system can adjust its downlink properties. This type of test allows for evaluation of potential in-band and out-of-band interference from different operational scenarios for both satellite and telescope systems. In addition, NRAO has been conducting uncoordinated observations to randomly assess the potential OOBE and aggregate impact from Starlink downlinks.

These coordination efforts have helped NRAO and SpaceX to develop two possible spectrum coexistence schemes. The first, Zone Avoidance (ZA), provides RAS sites with protection from downlink RFI caused by the majority of satellite passages. Starlink satellites, equipped with phased array antennas, are able to direct their downlink beams to avoid illuminating the geographical regions where radio telescopes are located. A second scheme, called Telescope Boresight Avoidance (TBA), is used for the small fraction of satellite passes that occur close to the telescope boresight direction and is described in detail below.

A near-boresight encounter with an actively transmitting satellite is an event with the potential to saturate, damage, or even destroy sensitive RAS receiver elements such as frontend (FE) analog electronics. Emission from NGSO satellites can drive the telescope FE electronics into non-linear operation, resulting in gain compression, increased electronic noise, or generation of intermodulation products, which can corrupt the clean data channels in the RAS spectrum (both protected and unprotected bands). Moreover, backend electronics may similarly be driven into compression or saturation, with similar effects. In a near-boresight encounter, even satellite antenna sidelobe emissions can produce these effects. To protect against this, SpaceX and NRAO have developed a TBA protocol that involves Starlink satellites either directing their beams away from the telescope’s boresight or even momentarily disabling the downlink entirely for satellite passes extremely close to boresight. Such instances may have been rare when only a small number of NGSO satellites were operational, but they are becoming increasingly likely to occur as the number of satellites in orbit increases. Hence, where technically possible, CORF supports adopting a real-time framework for mutual awareness similar to that already developed between SpaceX and NRAO as a core element for achieving successful coordination between relevant RAS facilities and other satellite operators.

The NRAO and SpaceX coordination efforts have led to the joint development of the Operational Data Sharing (ODS) system that allows radio telescopes to automatically inform a satellite constellation system of their current observing sky positions and frequency ranges in real time through an authenticated Application Programming Interface (API). This information allows satellites to plan and take avoidance measures such as directing downlink emission away from the telescope's main beam, or disabling the downlink momentarily depending on the degree of angular separation. The coordination methods developed by SpaceX and NRAO are currently in use by both NRAO and a number of non-NRAO RAS facilities, including Hat Creek Radio Observatory (HCRO), MIT Haystack Observatory, Owens Valley Radio Observatory (OVRO), and the Australian Commonwealth Scientific and Industrial Research Organization (CSIRO) Australia Telescope National Facility (ATNF).

Meanwhile, NSF is also working toward finalizing coordination agreements between NRAO and other NGSO operators including Amazon Kuiper and AST SpaceMobile.

While ZA and ODS/TBA represent a considerable success in coordination between some NGSO operators and facilities operated by the NRAO, to date, it is mostly done on a "best efforts" basis. Due to technical limitations, not all NGSO systems are capable of adopting dynamic avoidance techniques. CORF recommends that the Commission make the ODS and ZA/TBA methods, or similar technical coordination with RAS facilities, part of the conditions for licensing of new NGSO satellite systems. Doing so would require developers of new NSGO satellite systems to include the requisite technical capabilities. Finally, CORF notes that ongoing successful coordination with any system will require continuous monitoring and data verification.

C. Additional Considerations for Protection of RAS – Aggregate Emissions

In paragraph 32 of the NPRM, the Commission asks, "Would any additional considerations with respect to NGSO FSS operation be necessary to protect radio astronomy operations, beyond the existing PFD limits?" The answer is "yes." PFD limits in the RAS bands need to refer to <u>aggregate emissions</u>,[7] from both the NGSO and GSO systems of all relevant satellite operators. The ever-increasing number of satellites launched in NGSO constellations means that the radio sky is becoming noisier. The

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[7] ITU Recommendation RA.1513 states that 2% data loss is acceptable from a given system and 5% data loss is acceptable from <u>all</u> systems operating in a frequency band allocated to RAS on a primary basis. *See also, e.g., Amendment of Parts 2 and 25 of the Commission's Rules to Enable GSO Fixed-Satellite Service (Space-to-Earth) Operations in the 17.3-17.8 GHz Band, to Modernize Certain Rules Applicable to 17/24 GHz BSS Space Stations, and to Establish Off-Axis Uplink Power Limits for Extended Ka-Band FSS Operations,* Report and Order, FCC 22-63 (Aug. 3, 2022) at paras. 26 and 35. Regarding calculation of the aggregate impact from multiple operators, s*ee, e.g., In the Matter of Space X Services, Inc. and Kepler Communications, Inc.,* DA 22-695 (June 30, 2022) at para. 34.

aggregate impact on RAS facilities needs to be evaluated through both numerical simulations and coordinated testing starting at an early stage of new satellite design. The accuracy of numerical simulations could be increased significantly with more information about detailed antenna radiation patterns of the satellites (beyond the generic Effective Isotropic Radiated Power (EIRP) mask typically available in public filings).

III. Conclusion

The proposed changes in the sharing regime between NGSO and GSO satellite systems appear to be designed to facilitate further increases in either the number of satellites in currently operating NGSO constellations, or in new NGSO systems operating in the bands of interest to the RAS. Either of these results has the potential to significantly increase the already serious RFI challenges for ground-based radio astronomy. To mitigate this result, CORF urges the Commission to consider mandating enhanced coordination between NGSO operators and impacted RAS observatories as described above. In addition, the Commission needs to ensure that PFD limits in the RAS bands refer to <u>aggregate emissions</u> that include multiple satellite operators of <u>both</u> NGSO and GSO systems.

Respectfully submitted,

NATIONAL ACADEMY OF SCIENCES'
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