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

In the Matter of	)	
	)	
Single Network Future: Supplemental Coverage from Space	)	GN Docket No. 23-65
	)	
	)	
Space Innovation	)	IB Docket No. 22-271

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 March 17, 2023, in the above-captioned dockets. CORF appreciates the Commission's seeking ways to protect vulnerable radio astronomy observations if it chooses to implement a new regulatory framework for Supplemental Coverage from Space ("SCS"). In these Comments, CORF discusses the need for such protection and discusses proposals for protection of critical scientific research. Measures to protect bands allocated to the Radio Astronomy Service (RAS) are considered. Moreover, the proposed SCS would introduce fundamental change in the de facto radio frequency interference (RFI) environment that supports broadband RAS observations driving leading-edge science. For this reason, CORF recommends the adoption of rules for negotiated avoidance of transmissions

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

affecting certain RAS observatories to enable this science to continue advancing even as space-based active use grows.

I. The Importance and Vulnerability of Radio Astronomy.

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 has 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. Subsequent 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. Radio astronomy has also enabled the discovery of organic matter and prebiotic molecules outside of the Earth's 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 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 a super massive black hole, in the M87 galaxy, and its shadow was obtained by an array of radio telescopes,[2] followed, most recently, by observations of the black hole at the center of the Milky Way Galaxy.[3] Synchronized observations using widely spaced radio telescopes around the world 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 RAS observers, however, cannot be performed without access to interference-free spectral bands as well as protected and remote geographic locations. Notably, the emissions that radio astronomers receive are extremely weak—a radio telescope receives less than 1 percent of one-billionth of one-billionth of a watt (10^{-20} W) from a typical cosmic object. Because radio astronomy receivers are designed to pick up such remarkably weak signals, radio observatories are particularly vulnerable to interference from in-band, spurious, and out-of-band emissions (OOBE) from licensed and unlicensed users of neighboring bands and from emissions that produce harmonic signals in the RAS bands—even if those human-made emissions are weak and distant.

As stated in Footnote US342, "emissions from spaceborne or airborne stations can be particularly serious sources of interference to the radio astronomy service." This

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[2] *See*, The Event Horizon Collaboration et al., 2019, "First M87 Event Horizon Telescope Results. I. The Shadow of the Supermassive Black Hole," *Astrophysical Journal Letters* 875: L1, https://doi.org/10.3847/2041-8213/ab0ec7. *See also* J. Green, 2019, "The Black Hole Photo Was No Big Surprise to Scientists. Here's Why It's Still a Big Deal," Opinion, *Washington Post*, April 12, https://www.washingtonpost.com/opinions/2019/04/12/black-hole-photo-was-no-big-surprise-scientists-heres-why-its-still-big-deal/; S. Kaplan and J. Achenbach, 2019, "See a Black Hole for the First Time in a Historic Image from the Event Horizon Telescope," *Washington Post*, April 10, https://www.washingtonpost.com/science/2019/04/10/see-black-hole-first-time-images-event-horizon-telescope/; and D. Overbye, 2019, "Darkness Visible, Finally: Astronomers Capture First Ever Image of a Black Hole," *New York Times*, April 10, https://www.nytimes.com/2019/04/10/science/black-hole-picture.html.

[3] *See* The Event Horizon Collaboration et al., 2022, "First Sagittarius A* Event Horizon Telescope Results. I. The Shadow of the Supermassive Black Hole in the Center of the Milky Way," *Astrophysical Journal Letters* 930: L2, https://doi.org/10.3847/2041-8213/ac6674.

applies even more so to the huge constellations of low Earth orbit ("LEO"), non-geosynchronous orbit ("NGSO") satellites recently approved by the Commission, as well as those to come. For example, 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. A recent Government Accountability Office (GAO) technology assessment noted that

> Transmission effects from satellites are not a new problem for radio astronomy, and astronomers have been able to mitigate those effects to some degree. However, as the number of satellites in LEO increases significantly, satellite transmissions may increasingly challenge radio astronomy's ability to detect faint cosmic signals. . . . As the number of satellites rapidly increases in LEO, there is an increased probability that there could be a satellite in the path of a radio telescope antenna no matter where it points in the sky.[4]

This final point holds true because unwanted emissions can couple at a high level via the near sidelobes (including feed spillover) of a RAS antenna, which can extend to several degrees from the axis of the narrow primary beam. Recent technical advances, including array receivers supporting multiple beams on the sky and wide-field interferometers, which are composed of many electrically small antennas with wide primary beamwidths, further increase the likelihood of receiving unwanted emissions from space-borne transmitters.

A. Impact on Protected RAS Bands.

In considering the various "flexible use" bands proposed for SCS operations in the NPRM, CORF notes that the 600 MHz band presents the most immediate concern

[4] See Section 3.3.1 in U.S. Government Accountability Office, 2022, *Large Constellations of Satellites: Mitigating Environmental and Other Effects*, GAO-22-105166, Washington, DC, September.

for radio astronomy. As noted in paragraph 34 of the NPRM, the RAS has a co-primary allocation at 608-614 MHz (TV Channel 37). This band was originally allocated to the RAS to provide appropriate spectral sampling of the spectral energy distribution of astronomical sources. For example, continuum (broadband) observations at 600 MHz are used to study the interstellar medium, pulsars, and the Sun. In addition, observations in this band are a critical resource for two important areas of astrophysics: (1) observations in cosmologically distant sources of the 1420 MHz neutral hydrogen line, shifted downwards into this band by the red shift associated with cosmic expansion (similar to the Doppler shift of a receding transmitter), are a critical probe of state of the universe at a time 4.7 billion years after the Big Bang when the universe was only one third of its current age, near the peak star-forming epoch in cosmic history[5] and (2) pulsar timing measurements that can be made with extraordinary precision in this band and are expected to yield detections of black hole mergers, which cause ripples in the space-time fabric of the universe. Such observations are used to investigate interstellar matter and the evolution of galaxies. In regard to the interstellar medium, the 600 MHz band is used to investigate the thermal and non-thermal diffuse radiation in the Milky Way. Important observations give information on the high-energy cosmic-ray particles produced by the Sun and in the Milky Way, with great importance to, for example, space communications and space exploration, as well as ground-based communications and power infrastructure.[6]

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[5] A. Chakraborty and N. Roy, 2023, "Detection of HI 21 cm Emission from a Strongly Lensed Galaxy at z ~ 1.3.," *Monthly Notices of the Royal Astronomical Society* 519:4074.

[6] Observations in the 600 MHz band are made of radio-frequency outbursts from the Sun that precede, and thus provide early warning of, bursts of high-energy particles that interact with Earth's atmosphere. These particle bursts can cause severe interruptions in radio communications and power systems and have dangerous effects on aircraft flying at altitudes above 15,000 m. Study of these solar particle bursts and their radio-frequency signatures can enable prediction of failures in radio communications. In

A matter of great concern in the context of this NPRM is harmonic emissions into the 1420-1427 MHz RAS primary band. This band, which contains the neutral hydrogen line noted above, is extremely important for RAS observations within our own galaxy and the local cosmic neighborhood, and it also doubles as a key remote sensing band in the Earth Exploration Satellite Service ("EESS") for observations of soil moisture, surface water, snow, sea ice, and ocean salinity. Unless carefully regulated, second harmonic emissions from ubiquitous satellite transmitters servicing the lower 700 MHz cellular band could have a devastating impact, especially on RAS observations. For this reason, in response to paragraph 123 of the NPRM, CORF urges the Commission to adopt rules that ensure that <u>aggregate</u> harmonic emissions falling in RAS primary bands are at a level that ensures that surface spectral power flux densities meet the RAS interference criteria set out in Recommendation ITU-R RA.769[7] and that emissions reflected off Earth's surface and toward orbiting EESS (passive) sensors do not exceed the thresholds listed in ITU-R RS.2017.

B. <u>The Broader Impact on the RAS</u>.

addition, knowledge regarding high-energy solar bursts is essential for safe and successful space operations, including manned and unmanned space exploration.

[7] Satellite applications should be required to account for aggregate emissions from multiple transmitters within their own constellations (both those proposed and any already approved) as well as from other pending proposals and active operations in the same band. *See, e.g.,* Federal Communications Commission (FCC), 2022. "*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, August 3, paras. 26 and 35. Regarding calculation of the aggregate impact from multiple operators, s*ee, e.g.,* FCC, 2022, "*In the Matter of Space X Services, Inc. and Kepler Communications, Inc.,*" DA 22-695, June 30, para. 34.

The RAS frequency allocations are vital for protecting observations of the most important spectral emission lines of atoms and molecules in the Milky Way and nearby galaxies, and they provide windows for tracing out the spectral dependence of a wide variety of astrophysical phenomena with continuous emission spectra. However, a broad class of astronomical observations are simply impossible without access to unprotected bands, either opportunistically (typically taking advantage of remote location) or through coordination with active use. For example, as noted above, the 600 MHz RAS band provides access to the redshifted 1420 MHz neutral hydrogen line at an important epoch in cosmic history, but to trace the history of matter across all of cosmic time requires access to all redshifts, and hence the broader radio spectrum. Furthermore, wide bandwidths are routinely used by radio astronomers to increase the sensitivity of continuum observations or to improve the quality of aperture synthesis images. The technologies that enable radio astronomers to cost-effectively build instrumentation capable of processing ever-wider spectral bandwidths parallel those driving revolutionary changes in telecommunications and have opened new windows on the universe.

The value of and need for the ability to survey the sky across wide bandwidths at the UHF frequencies involved in this NPRM is exemplified by the discovery, in 2007, of fast radio bursts (FRBs)—extremely luminous bursts of radio energy on millisecond time scales detected at frequencies ranging from hundreds of megahertz to a few gigahertz.[8] Since then, hundreds of FRBs have been detected, typically as isolated events,

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[8] D.R. Lorimer et al., 2007, "A Bright Millisecond Radio Burst of Extragalactic Origin," *Science* 318: 777.

although repetition is observed in some sources.[9] The physics of FRBs is not yet fully understood but is thought to involve non-thermal emission from highly magnetized sources such as a neutron stars. Propagation effects on pulse arrival time and polarization as a function of frequency offer further clues into FRB sources and their local environments. As more detections accumulate, it is reasonable to expect that FRBs will come to be well understood. Then, much as the discovery of pulsars has come to serve our understanding of gravitation and general relativity, FRBs will themselves become a tool for further discovery—for example, as unique probes for study of the content of the intergalactic medium.

FRBs are an example of a phenomenon that could only have been discovered and can only be further studied using wide spectral bandwidths extending well beyond the protected RAS bands, with instruments that cover a wide field of view on the sky. Although the signal processing and data analysis techniques that enable FRBs to be detected can at present cope with the relatively quiet spectral environment at observatories in remote locations, these observatories would be blinded by ubiquitous overhead transmissions across the UHF band directed into their field of view. Moreover, because FRBs occur irregularly in time, spatial avoidance rather than temporal coordination with active users is the most effective way to enable this and other time-domain astrophysics to continue advancing.

Major investments in radio astronomy that are planned or already under way will depend on continued broadband access to a quiet sky. For example, in the United

[9] E. Petroff et al., 2022, "Fast Radio Bursts at the Dawn of the 2020s," *Astronomy and Astrophysics Review* 30: 2.

States, the Next-Generation Very Large Array (ngVLA),[10] identified as a priority large program by the Astro2020 Decadal Survey,[11] and the Deep Synoptic Array-2000 (DSA-2000),[12] an ambitious project also recognized therein, will both operate in the UHF bands considered in this NPRM. The current RFI environment has been an important factor in selecting sites for these projects. Similar projects are under way internationally, often with U.S. participation.

In sum, radio astronomers perform important and valuable scientific research with receivers that are extremely vulnerable to interference, particularly from space-based transmissions. Adoption of the SCS proposal would significantly increase the risk and likelihood of such interference unless protective measures are taken, such as those detailed below.

II. If the Commission Adopts SCS, It Should Implement Specific Protections for Radio Astronomy.

Historically, protection of passive scientific radio services has emphasized spectral protection via frequency allocations, augmented by geographical protections such as the radio quiet zones defined in 47 CFR § 1.924; footnotes US113, US131, US 161, and US385 in the table of frequency allocations; and 47 CFR § 2.106. The use of heretofore terrestrial-only allocations for space-based use, as proposed in this NPRM, is part of a larger trend towards space-based telecommunications that will drive a need for

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[10] *See* National Radio Astronomy Observatory, "Next Generation Very Large Array," https://ngvla.nrao.edu, accessed March 27, 2023.
[11] National Academies of Sciences, Engineering, and Medicine, 2021, *Pathways to Discovery in Astronomy and Astrophysics for the 2020s*, Washington, DC: The National Academies Press, https://doi.org/10.17226/26141.
[12] *See* the Deep Synoptic Array website at https://www.deepsynoptic.org, accessed March 27, 2023.

greater emphasis on spatial in addition to spectral protections. Anticipating this, in paragraph 123 of the NPRM the Commission notes the following:

> The novel aspects of our [SCS] proposal introduce new spectrum management challenges that warrant consideration, including the introduction of satellite downlinks and the continuing need to protect radio astronomy and other services that may be susceptible to signals emanating from the sky. . . . These spectrum management tools do not exist (e.g., terrain) or are complicated (e.g., coordination and angle of arrival) in the case of satellite operations.

CORF appreciates the Commission's recognition of the potential for harmful interference from SCS into radio astronomy observations, not only in the NPRM, but in a recent and applicable order authorizing Lynk Global Inc. to engage in direct satellite-to-cellphone transmissions outside of the United States.[13] CORF also appreciates the Commission's seeking comments on ways to protect radio astronomy in this NPRM. If the Commission adopts a proposed SCS regulatory regime, it must include specific protections for radio astronomy in those regulations.

Paragraph 125 of the NPRM notes that Section 1.924 of the Commission's rules currently does not address satellite downlink operations, and thus seeks comments in paragraph 126 whether Section 1.924 should accordingly be updated. CORF strongly recommends that Section 1.924 be revised to specifically address satellite-to-cellphone

[13] "We recognize that protection from interference is essential to the advancement of radio astronomy and associated measurements." ("Lynk Global, Inc., Application to Deploy and Operate Space Stations Filed Under the FCC Streamlined Small Space Station Authorization Process, 47 CFR § 25.122," IBFS File No. SAT-LOA-20210511-00064 Call Sign S3087, Order and Authorization, DA 22-969 at para. 22 (IB Sept. 16, 2022) (*Lynk Order*), citing ITU-R RA.769-2.

operations,[14] including both uplinks and downlinks.[15] It is a historical anomaly that the rule has not previously been modified to address the more limited operations of the 1.6/2.4 GHz Mobile Satellite Service ("MSS"), but the proposed SCS could radically increase the likelihood of interference to radio astronomy observations, due to the substantially higher number of ordinary cellphones that would be able to engage in SCS, compared with the limited number of 1.6 GHz MSS handsets.

Paragraph 126 of the NPRM seeks comments on whether protections for the RAS the Commission mandated in the recent *Lynk Order* should be applied to the SCS. CORF recommends doing so. Specifically, the Commission conditioned the grant of the Lynk authorization on "Lynk avoiding space-to-Earth transmissions into Radio Quiet Zones throughout the frequency range authorized in this grant and on a global basis consistent with protection measures necessary for individual Radio Quiet Zones."[16] This provides a recent and directly applicable precedent for modifying Section 1.924 of the Commission's rules to apply to SCS.[17]

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14 *Cf.* National Telecommunications and Information Administration, 2019, *Report to Congress on Activities on Ensuring Spectrum Access for Radio Astronomy (FY 2018 and FY 2019),* September 17, p. 3, https://www.ntia.gov/report/2019/ntia-activities-ensuring-spectrum-access-radio-astronomy-fy-2018-and-fy-2019, recommending "[a]dding geographical protections from airborne transmitters to the NRQZ, where the Green Bank, West Virginia, Observatory resides. Established by the FCC and the IRAC in 1958 to minimize harmful interference to sensitive radio astronomy telescopes and to facilities operated by other government agencies, the NRQZ has served its purpose for over 60 years. However, the rules set forth in 1958 are no longer adequate to protect the Green Bank Telescope, which resides in the NRQZ, from airborne transmissions, such as airplanes, satellites, and unmanned aerial vehicles. The U.S. scientific community will need updated rules for the NRQZ that consider the modern progress of technology. Where possible, airborne transmissions should be minimized or coordinated."

15 A revised rule should also address satellite telemetry, tracking, and command (TT&C) operations, where applicable, as well as any "ancillary terrestrial components" of SCS service.

16 *Lynk Order* at para. 25.

17 While requiring compliance with Quiet Zone requirements generally, the *Lynk Order* did not specifically require Lynk to comply with Section 1.924 because the order did not authorize transmissions into the United States.

Paragraph 34 of the NPRM states that “radio astronomy operations exist immediately below the 600 MHz band on TV channel 37 (608-614 MHz) and could be susceptible to interference from satellite downlink operations unless the SCS operator fully coordinates with the geographically distributed radio astronomy operations.” CORF notes, however, that the amendment to 47 CFR § 25.202 proposed in the NPRM would adopt the OOBE limits of 47 CFR § 22.917, which only require that OOBE be at a level 43 + 10 log(P) dB below the transmitted power P (W) in a 100 KHz bandwidth. Assuming a 100 km diameter spot beam at the surface, the corresponding spectral power flux density would be -192 dB(W/(m^2Hz)), exceeding the continuum interference threshold of -253 dB(W/(m^2Hz)) in Table 1 of ITU-R Recommendation RA.769 by approximately 60 dB. Accordingly, it will be necessary for the Commission to adopt more stringent limits, consistent with paragraph 24 of the *Lynk Order*. Similarly, as noted above, aggregate harmonic emissions into the critical RAS primary band from 1420-1427 MHz should be limited to levels that comply with ITU-R Recommendation RA.769, and CORF recommends that appropriate limits be added to the proposed amendments to 47 CFR § 25.202.

Beyond these measures to improve protection of radio quiet zones and to address concerns about OOBE and harmonic emission into RAS primary bands, CORF also recommends the adoption of SCS rules that would mandate negotiated avoidance of harmful emissions into certain existing and planned major observatories that depend, in order to carry out their scientific missions, on the ability to conduct broadband observations in the bands that are the subject of this NPRM.[18] In particular, the

[18] In arguing here for the need for spatial protection in the form of negotiated avoidance, we do not intend to diminish the importance of continued spectral protection in the form of protected bands. Indeed,

observatories currently listed in footnote US385 observe in these bands, as will the future ngVLA and DSA-2000 observatories mentioned above. By "negotiated avoidance," CORF means a bilateral effort between a RAS observatory and SCS provider to develop practical limits on the SCS system operation to avoid harmful interference to astronomical observations. While conceptually similar to the use of a geographical avoidance zone to prevent interference from terrestrial transmitters, negotiated avoidance for SCS would involve taking account of more complex factors particular to satellite operations, including geofencing of spot beam pointing as a function of beam elevation and direction. Other possible means of avoidance include dynamic control of transmitted power or spectral occupancy, and temporal measures such as time-domain multiplexing or scheduling. However, as noted above, spatial avoidance is the most effective means protecting the scientific effectiveness and return on investment of RAS facilities.

The specific operational limits or other mitigations needed for negotiated avoidance to succeed will depend on detailed technical characteristics of a given satellite system supporting SCS as well as those of the affected RAS observatory. Development of practicable avoidance measures might start with initial trial avoidance parameters, which would be refined iteratively by the SCS provider and RAS observatory, a process which would likely involve sharing of satellite ephemeris and activity data to facilitate attribution of harmful interference, followed by negotiation of

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observations of scientific targets in the local universe depend critically on the bands allocated to the Radio Astronomy Service for protection from harmful interference. In addition, small teaching telescopes at colleges and universities make use of the 1400-1427 MHz band specifically.

operational adjustments by the SCS provider or measures by the RAS observatory to achieve the greatest practicable reduction of the interference.

CORF recognizes that one of the important drivers of the Commission's SCS proposal is to improve the availability of emergency communications in remote areas, with potential impact on safety of life. Here, the goal of the negotiated avoidance process should be to maintain the greatest practicable emergency coverage, perhaps even at or near the observatory site, with the minimum spectral resources needed for a handset to join the network and initiate an emergency call.[19]

CORF notes that the technical capabilities that would support negotiated avoidance would also serve to address other concerns raised in the NPRM. Indeed, as discussed in NRM paragraph 44, concern over control of co-channel geographically adjacent market interference motivates the limitation of this NPRM to considering licensing SCS within entire Geographically Independent Areas (GIAs) only. However, paragraph 113 notes that "[s]ome satellite operators have indicated that their satellites can produce narrow spot beams that focus signal energy on small unserved areas of terrestrial markets, without otherwise impinging on the terrestrial licensee's operations." Indeed, the extended SCS scenarios discussed in Section III.D of the NPRM would depend on this capability—for example, the concept of protection zones for active incumbents explored in paragraph 139—and it is natural to extend this framework to include protection of RAS facilities through negotiated avoidance, the key difference

[19] CORF recognizes that wireless calls may be made in cases of emergency. Accordingly, in the negotiated avoidance process, calls to "911," other three-digit emergency numbers, and a list of 10-digit phone numbers for police and fire agencies in specific localities, could be excluded from limits on transmissions to and from wireless phones.

being that RAS observatories, being more sensitive, would require larger avoidance margins.

III. Conclusion.

CORF appreciates the Commission's seeking ways to protect vulnerable radio astronomy observations if it chooses to implement a new regulatory framework for SCS. By fundamentally changing the RFI environment experienced by RAS observatories in heretofore remote locations, SCS could severely curtail the ability of the RAS to perform broadband surveys and targeted observations that are driving leading-edge science now, and that are the basis of major projects currently in planning. For this reason, if the Commission adopts a proposed SCS regulatory regime, it should include specific protections for radio astronomy in those regulations, as discussed above.

Respectfully submitted,

NATIONAL ACADEMY OF SCIENCES'
COMMITTEE ON RADIO FREQUENCIES

By: Marcia McNutt
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Marcia McNutt
President, National Academy of Sciences

Direct correspondence to:

CORF
Keck Center of the National Academies
of Sciences, Engineering, and Medicine
500 Fifth Street, NW, Keck 954
Washington, D.C. 20001
(202) 334-3520

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Appendix: Committee on Radio Frequencies

Members

Nathaniel J. Livesey, Jet Propulsion Laboratory, California Institute of Technology, Chair

Scott Paine, Center for Astrophysics | Harvard & Smithsonian, Vice Chair

Nancy L. Baker, Naval Research Laboratory

Laura B. Chomiuk, Michigan State University

Dara Entekhabi, Massachusetts Institute of Technology

Philip J. Erickson, Haystack Observatory, Massachusetts Institute of Technology

Kelsey E. Johnson, University of Virginia

Christopher Kidd, University of Maryland and NASA Goddard Space Flight Center

Karen L. Masters, Haverford College

Mahta Moghaddam, University of Southern California

Frank Schinzel, National Radio Astronomy Observatory

Consultants

Darrel Emerson

Tomas E. Gergely

Staff

Neeraj P. Gorkhaly, Responsible Staff Officer