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

In the Matter of	)	
	)	
Expanding Flexible Use in Mid-Band Spectrum Between 3.7 and 24 GHz	)	GN Docket No. 17-183
	)	

**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 August 3, 2017, *Notice of Inquiry* (NOI) in the above-captioned docket. In these comments, CORF reminds commenters regarding frequency bands protected for scientific use in the 5-24 GHz range. Attachment A to these Comments provides a list of these bands, along with a brief summary of the scientific use of each band. CORF generally supports the sharing or "flexible use" of frequency allocations where practical, but protection of scientific observations, as discussed herein, must be addressed.

I. The Role of Radio Astronomy and Earth Remote Sensing, Scientific Observation at 5-24 GHz, and the Unique Vulnerability of Scientific Services to Interference.

CORF has a substantial interest in this proceeding, because it represents the interests of scientific users of the radio spectrum, including users of the Radio Astronomy Service (RAS) and Earth Exploration-Satellite Service (EESS) bands. These users perform extremely important, yet vulnerable, research.

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

A. 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 discovery of pulsars by radio astronomers has led to the recognition of a widespread galactic population of rapidly spinning neutron stars with gravitational fields at their surface up to 100 billion times stronger than on Earth's surface. 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. Radio astronomy has also enabled the discovery of organic matter and prebiotic molecules outside our solar system, leading to new insights into the potential existence of life elsewhere in our galaxy, the Milky Way. Ongoing searches for polarized radio emission from extra-solar planets could reveal the presence of cosmic-ray shielding planetary magnetic fields, a likely prerequisite for life. Radio spectroscopy and broadband continuum observations have identified and characterized the birth sites of stars in the galaxy, 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 our own Milky Way, contain supermassive black holes at their centers, a phenomenon that appears to be crucial to the creation and evolution of galaxies. 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.

Radio astronomers typically make observations of both specific *spectral lines* and of a *continuum* of frequencies. Such observations at 5-24 GHz are described below.

Continuum observations consider the broad variations of naturally occurring celestial emissions within a large frequency range. Individual measurements are made with broadband receivers that are sensitive to interference over a wide range of frequencies. The 5-24 GHz frequency range includes some of the primary bands for continuum observations of astrophysical processes and objects. In particular, the frequencies between 5-16 GHz (including the RAS allocations of 4990-5000 MHz, 10.6-10.7 GHz, and 15.35-15.40 GHz) are used for a wide variety of studies of star formation (both within the Milky Way Galaxy and in other galaxies), active galactic nuclei (AGN), and of the Sun, to name just a few.

Galaxies in general, but particularly those with active star formation, emit in the radio continuum over this full range. Near 5 GHz, non-thermal synchrotron emission from hot, magnetized interstellar gas and supernova remnants often dominates the emission. In the 10-20 GHz range, thermal-free emission, an important diagnostic of the amount of star formation occurring in a galaxy, takes over. And at the centers of these galaxies, the AGN and their jets emit synchrotron emission at almost all of these frequencies, depending on the exact objects in question. The radio emission of galaxies and AGN are some of the most common observations made with modern interferometers like the Very Large Array (VLA) and the Very Long Baseline Array (VLBA).

Continuum observations in the 5-24 GHz range also allow observations of pulsars and the peculiarities of their emission processes (particularly with the Green Bank Telescope (GBT) and Arecibo Observatory) and observations of Faraday rotation from polarized. distant radio galaxies (particularly with the Owens Valley Radio Observatory (OVRO) and the MIT Haystack Observatory), which enable astronomers to trace out the cosmic magnetic field. Finally, continuum observations at 5 and 10 GHz of distant radio galaxies or AGN are crucial for geodesy measurements that tie terrestrial and celestial coordinate systems.

Radio continuum observations of the Sun from 1-18 GHz provide insight into the nature and evolution of coronal magnetic fields and the temperature and density of non-thermal electrons in active regions. The slowly varying component of solar radio emission has been found to provide one of the best indicators of the variation of solar activity over the Sun's 22-year cycle. The Owens Valley Solar Array monitors solar emission within the 2.5-18 GHz frequency range.

Radio astronomy observation of *spectral lines* is an important diagnostic of the physical properties of astronomical sources in the radio part of the electromagnetic spectrum. Current research based on spectral lines in the radio spectrum, 5-24 GHz in particular, has been very important for understanding the chemical cycles in dense interstellar media known as molecular clouds and of how stars are formed in them. Perhaps the most important set of spectral lines for the study of how stars form are from ammonia, a set of which is protected by the 23.6-24.0 GHz allocation. This particular molecule is only excited in regions of relatively high density. It has recently been discovered that it traces long filaments of gas in molecular clouds created by supersonic shock waves. Stars and clusters of stars form at the intersections of these filaments. The details of how gas at enhanced density at these intersections undergoes gravitational collapse to form stars is being investigated intensively with these ammonia transitions. High-resolution images from instruments such as the VLA, which can determine the precise spatial-velocity structure of the clouds, are leading to important advances in the precise mechanisms responsible for the formation of stars.

Closely related to study of star formation is the observation of spectral lines to understand the chemical processes inside molecular clouds. Radio astronomy provides a unique way to study the generation of highly complex molecules, including prebiotic molecules, in these clouds. The reason for this is that spectral lines from heavy molecules, such as long carbon chain molecules, tend to concentrate in the radio portion of the spectrum. The largest molecule detected so far has 13 component atoms of hydrogen, carbon, and nitrogen. Observations of methanol at 6650-6675.2 MHz and formaldehyde at 14.47-14.5 GHz provide measures of the physical parameters of molecular clouds, including density and temperature.

The 22.2 GHz emission line from water is another important spectral line because it facilitates a laser-like amplification process known as a maser. The unanticipated discovery of powerful beacons of maser emission in the 22.2 GHz line has made it a remarkable probe of the material orbiting black holes at the centers of distant galaxies. Indeed, measurement of the location and Doppler shifts of water masers in distant galaxies now provides the most accurate method available for determining the masses of these black holes.

The critical scientific research undertaken by RAS observers, however, cannot be performed without access to interference-free bands. 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 emissions, spurious, and out-of-band emissions from licensed and unlicensed users of neighboring bands, and emissions that produce harmonic signals in the RAS bands, even if those human-made emissions are weak and distant.

B. Earth Remote Sensing

The Commission has also long recognized that satellite-based Earth remote sensing, including sensing by users of the EESS bands, is a critical and uniquely valuable resource for monitoring Earth and its environment. Satellite-based microwave remote sensing presents a global perspective and, in many cases, is the only practical method of obtaining atmospheric and surface data for the entire planet. Instruments operating in the EESS bands provide data that is important to human welfare and security and includes support for scientific research, commercial endeavors, and government operations in areas such as meteorology, atmospheric chemistry, climatology, oceanography, agriculture, and disaster management. Examples are measurement of parameters—such as ocean surface temperature, wind velocity, salinity, and precipitation rate over the ocean—needed to understand ocean circulation and the associated global distribution of heat. They include monitoring soil moisture—a parameter needed for agriculture and drought assessment, weather prediction (heat exchange with the atmosphere), and defense (planning military deployment). Passive sensors provide temperature and humidity profiles of the atmosphere, information to monitor changes in the polar ice cover, and information needed in assessing hazards such as hurricanes, wildfires, and drought. Indeed, the ability to produce improved weather forecasts is due in part to the high-quality data that comes from satellite-borne passive sensors that observe the entire planet in a consistent and timely manner. Users of this data include the National Oceanic and Atmospheric Administration (NOAA), the National Science Foundation, the National Aeronautics and Space Administration (NASA), the Department of Defense, the Department of Agriculture, the U.S. Geological Survey, the Agency for International Development, the Federal Emergency Management Agency, and the U.S. Forest Service. Much of this data is also available free to anyone anywhere in the world.

Passive instruments in space are particularly vulnerable to human-made emissions because they rely on very small signals emitted naturally from Earth's surface and atmosphere. This is especially a concern for EESS (passive) because sensors in space monitor globally and view large swaths of the surface at one time. In this sense, the issue for EESS (passive) differs from that of RAS, which generally involves receivers at fixed locations that often can be protected with regionally specific restrictions.

EESS (active) is also an important tool for monitoring the environment and is also sensitive to interference. For example, radio frequency interference (RFI) has been detected in C-band scatterometer and synthetic aperture radar (SAR) data, and there is concern that the aggregate interference introduced by the proliferation of radio local access networks (RLANs) will exceed the interference maximum defined in ITU-R RS.1166-4.[2] As with EESS (passive), EESS (active) cannot be protected by regionally specific restrictions, but may be coordinated with time-specific restrictions based on satellite ephemerides.

Remote sensing scientists make both passive and active observations in both the lower and upper portions of 5-24 GHz for the specific purposes and using specific instruments, as set forth below.

The EESS bands in the frequency range of 4-16 GHz are used for a number of EESS applications, including observations of soil moisture, sea surface temperature, sea surface height, sea ice, snow, and precipitation (see Figure 1). Measurement of these geophysical parameters is critically important for weather prediction, climate monitoring, and understanding changes in the global water cycle. Among the primary concerns for remote sensing in the 4-16 GHz frequency range is the 10.6-10.7 GHz EESS (passive) allocation as well as the EESS (passive) bands near 7 GHz (6425-7075 MHz, 6650-6675.2 MHz, and 7075-7250 MHz). Currently, the Advanced Microwave Scanning Radiometer (AMSR-2) measures emission in a 350 MHz bandwidth at 6.925 GHz and a 100 MHz bandwidth at 10.65 GHz. The Navy's WindSat radiometer also measures emission in a 125 MHz bandwidth at 6.8 GHz and a 300 MHz bandwidth at 10.7 GHz. In this frequency range, the passive microwave response to sea surface temperature is strongest; this frequency range is also used for monitoring soil moisture. International Footnote 5.458 urges "Administrations [to] bear in mind the needs of Earth exploration-satellite (passive) and space research (passive) services in their future

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[2] National Academies of Sciences, Engineering, and Medicine, *A Strategy for Active Remote Sensing Amid Increased Demand for Radio Spectrum*, The National Academies Press, Washington, D.C., 2015,

planning" of the 6.4-7.25 GHz frequency range. Indeed, actions affecting this frequency range should be considered carefully so its use by EESS (passive) is preserved.

There are also a number of *active* applications of EESS in the 5-24 GHz frequency range, including RapidScat on the International Space Station that operates at 13.4 GHz and the Global Precipitation Measurement (GPM) Dual Precipitation Radar (DPR) that operates at 13.6 GHz, which have been used by NASA for ocean wind sensing and precipitation measurements, respectively. These sensors are used operationally in weather and storm prediction. Interference degrades the measurement accuracy, resulting in loss of coverage and adversely impacting forecasting capability. Other examples of active applications in this frequency range are spaceborne synthetic aperture radars (SARs) such as RADARSAT2 (5.355-5.455 GHz) and TerraSAR-X (9.05-10.05 GHz).

At higher frequencies, EESS (passive) observation of the hydrologic cycle is critical to the dynamical and thermodynamical functioning of the global climate system and to its impacts on human society. The distributions of water vapor, cloud liquid water, and cloud ice in the atmosphere and the evolution of these distributions with time determine to a great extent the radiation characteristics of clouds, with consequent large impacts on the radiation balance of the atmosphere. Column integrated abundance of water vapor is retrieved using frequencies near 18.7, 22.235, and 23.8 GHz, usually using dual-polarized (horizontal and vertical) observations that are scanned at a near-constant angle of incidence. Examples of instruments making such observations are the Global Precipitation Measurements (GPM) Microwave Imager (GMI), the Special Sensor Microwave/Imager (SSM/I), the Special Sensor Microwave/Imager Sounder

(SSMIS), WindSat, and ASMR-2. These measurements are of major use for meteorological research and forecasting and for astronomical and military applications. Radiowave propagation delays due to atmospheric water vapor can also be derived from radiometric measurements in the spectral region near 22 GHz.

Observations of the cryosphere are necessary to predict future variability in Earth's ice cover, and its interaction with other Earth systems must be made on commensurate spatial and temporal scales. Airborne and spaceborne radio-frequency technologies play a key role in acquiring data necessary to understand the important physical processes and Earth system interactions that govern the cryosphere. For example, the SSM/I instrument of the DMSP (19.35 GHz) and the AMSR-2 (18.7 GHz) provide useful, frequent measurement of ice sheet surface melt and contribute to many measurements involving sea ice concentration, snow cover, wet/dry snow, and dry snow water equivalent.

In sum, the important science performed by radio astronomers and Earth remote sensing scientists cannot be performed without access to interference-free bands. Loss of such access constitutes a loss for the scientific and cultural heritage of all people, as well as a loss of the practical applications enabled by this access, which can include financial and human loss arising from impaired weather forecasting and climate monitoring. CORF generally supports the sharing and flexible use of frequency allocations where practical, but protection of passive scientific observations, as discussed herein, must be addressed.

II. Specific Scientific Bands Subject to Protection.

The NOI seeks information on possible flexible uses of a number of frequency bands. Of particular interest to scientific users of the spectrum is the 6.425-7.125 GHz band (NOI at para. 36). When the Commission considers additional flexible uses of that frequency range, it should keep in mind the importance of protecting EESS and RAS observations.

As noted above and in Attachment A hereto, 6425-7075 MHz and 7075-7250 MHz are important frequencies for remote sensing-EESS (passive). Observations at these frequencies are subject to protection under Footnote 5.458, which states that "[i]n the band 6425-7075 MHz, passive microwave sensor measurements are carried out over the oceans. In the band 7075-7250 MHz, passive microwave sensor measurements are carried out. Administrations should bear in mind the needs of the Earth exploration-satellite (passive) and space research (passive) services in their future planning of the bands 6425-7025 MHz and 7075-7250 MHz." This NOI is precisely the sort of "future planning" for spectrum use referred to in that footnote. Future uses of Earth exploration-satellite (passive) and space research (passive) services in the bands 6425-7025 MHz and 7075-7250 MHz may include observations over the oceans, as well as over land masses.

Similarly, the 6650-6675 MHz band is important to the RAS for observation of methanol. This band is protected by Footnote US342, which states that "all practicable steps shall be taken to protect the radio astronomy service from harmful interference" in this band.[3] CORF urges the Commission to protect RAS observations in this band when considering flexible uses.

Paragraph 37 of the NOI seeks comments on flexible use in other bands between 3.7 and 24 GHz. As discussed above and in Attachment A hereto, there are many bands protected for scientific use between 4.990 and 24 GHz. In some cases, the protection comes from the primary or co-primary status of the scientific service. In other cases, the protection comes from footnotes. Of particular importance is Footnote 5.340, which states that "all emissions are prohibited" in numerous bands, including 10.68-10.70, 15.35-15.40, and 23.6-24.0 GHz.[4] Additionally, Footnote US342 requires the Commission to take all practicable steps to protect the RAS from harmful interference at the following bands:

4950-4990 MHz

6650-6675.2 MHz

14.47-14.5 GHz

22.01-22.21 GHz

22.21-22.5 GHz

22.81-22.86 GHz

23.07-23.12 GHz

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[3] In addition, Footnote 5.458A states that "[i]n making assignments in the band 6700-7075 MHz to space stations of the fixed-satellite service, administrations are urged to take all practicable steps to protect spectral line observations of the radio astronomy service in the band 6650-6675.2 MHz from harmful interference from unwanted emissions." While this footnote is intended to protect RAS observatories from satellite space stations, it should be noted that the other currently allocated uses of these bands (Fixed and Fixed Satellite Earth stations) are relatively easy to coordinate with for RAS observatories, but that the potential uses of the 5.925-7.125 GHz band that are envisioned in the NOI may require further protection of RAS observatories, for example, through protection zones.

[4] The exceptions provided in Footnote 5.340 are not applicable in this matter, as they reference Footnotes 5.483 and 5.511 (allocations in countries outside of the Americas).

Accordingly, CORF urges the Commission to take into account the existing protections in the Table of Allocations for scientific use of the spectrum when considering additional flexible uses between 5 and 24 GHz.

III. Conclusion.

CORF generally supports the sharing and flexible use of frequency allocations where practical, but protection of scientific observations, as discussed herein, must be addressed.

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

Appendix

Committee on Radio Frequencies

Members

Liese van Zee, Indiana University, *Chair*
William Blackwell, MIT Lincoln Laboratory
Sandra L. Cruz-Pol, University of Puerto Rico - Mayaguez
Namir Kassim, Naval Research Laboratory
David Le Vine, NASA Goddard Space Flight Center
Amy Lovell, Agnes Scott College
James M. Moran, Harvard-Smithsonian Center for Astrophysics
Scott Ransom, National Radio Astronomy Observatory
Paul Siqueira, University of Massachusetts, Amherst

Consultants

Darrel Emerson, retired
Tomas E. Gergely, retired

Attachment A

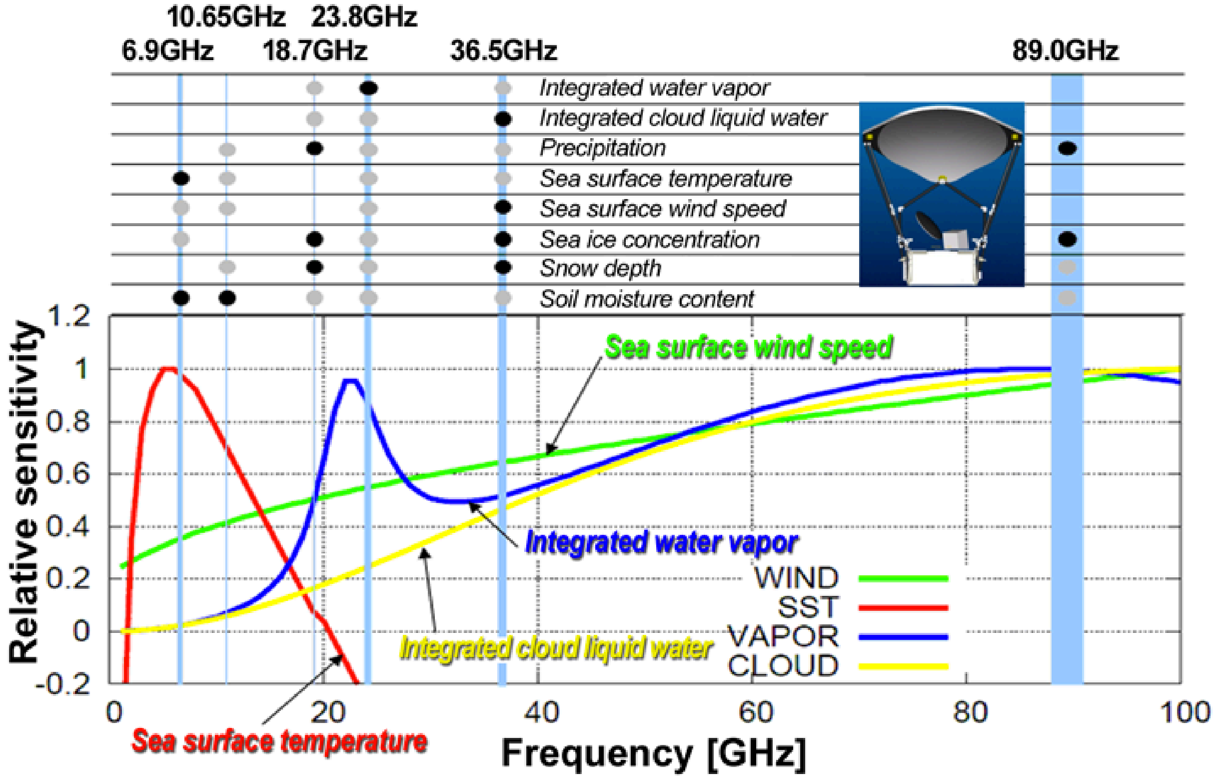

FIGURE 1 Schematic illustrating the relative sensitivity to brightness temperature changes (normalized by maximum) for oceanic geophysical parameters as a function of frequency. As illustrated here for the AMSR-2 receivers, EESS (passive) frequency bands are selected to enable measurements near the peak intensity of naturally occurring line and continuum emission from Earth's land, water, and atmosphere. Specifically, measurements at 6.9 GHz and 10.65 GHz are critical for determination of sea surface temperature and soil moisture content. Measurements at 18.7, 22.235, and 23.8 GHz are critical for determination of precipitation, integrated water vapor, sea ice concentration, and snow depth. SOURCE: Japan Aerospace Exploration Agency, "AMSR2 Channel Specification and Products," http://suzaku.eorc.jaxa.jp/GCOM_W/w_amsr2/w_amsr2_wave.html.

TABLE 1 EESS and RAS Passive Allocations 5-24 GHz

Frequency Range	Protection Status	Radio Astronomy Service Scientific Use	Earth Exploration-Satellite Service Scientific Use	RAS Threshold Interference Levels dB(W/(m^2 Hz))	EESS Interference Criteria (dBW) and (Percentage)
4990-5000 MHz	RAS co-Primary	Milky Way and other galaxies; active galaxies; cosmology		-241 (continuum)	
6425-7075 MHz and 7075-7250 MHz	RR 5.458 (over oceans)		Clouds; freeze/thaw; precipitation; soil moisture; surface water; sea surface temperature; sea surface winds		-166 dBW and 0.1%
6650-6675.2 MHz	RR 5.149 and 5.458A	Methanol			
10.6-10.68 GHz	EESS (passive) RAS co-Primary RR 5.149	Milky Way and other galaxies; active galaxies; cosmology	Precipitation; clouds; freeze/thaw	-240 (continuum)	-166 dBW and 0.1%
10.68-10.70 GHz	EESS (passive) RAS SRS (passive) co-Primary RR 5.340	The Sun; Milky Way and other galaxies; active galaxies; cosmology	Precipitation; clouds; freeze/thaw; sea surface temperature; sea surface winds	-240 (continuum)	-166 dBW and 0.1%
14.47-14.5 GHz	RAS secondary RR 5.149	Formaldehyde		-221 (line)	
15.35-15.40 GHz	EESS (passive) RAS SRS (passive) co-Primary RR 5.340	The Sun; Milky Way and other galaxies; active galaxies; cosmology	Atmospheric water vapor; rain	-233 (continuum)	-169 dBW and 0.1%
18.6-18.8 GHz	EESS (passive) co-Primary		Atmospheric water vapor; precipitation; clouds; freeze/thaw; sea ice; snow; sea surface temperature; sea surface winds; ocean topography		-163 dBW and 0.1%
21.2-21.4 GHz	EESS (passive) co-Primary	Extragalactic water masers	Atmospheric water vapor; integrated precipitable water		-169 dBW and 0.1 Percent
22.01-22.21 GHz	RR 5.149	Water masers		-231 (continuum) -216 (line)	
22.21-22.5 GHz	EESS (passive) RAS co-Primary RR 5.149	Water masers	Atmospheric water vapor; integrated precipitable water	-231 (continuum) -216 (line)	-169 dBW and 0.1%

Frequency Range	Protection Status	Radio Astronomy Service Scientific Use	Earth Exploration-Satellite Service Scientific Use	RAS Threshold Interference Levels dB(W/(m^2 Hz))	EESS Interference Criteria (dBW) and (Percentage)
22.81-22.86 GHz and 23.07-23.12 GHz	RR 5.149	Water masers; cosmic microwave background	Precipitation; clouds	-231 (continuum) -216 (line)	
23.6-24.0 GHz	EESS (passive) RAS SRS (passive) co-Primary RR 5.340	Ammonia	Atmospheric water vapor; sea surface temperature; sea surface winds; ocean topography	-233 (continuum) -215 (line)	-166 dBW and 0.01%

NOTE: Only 2.5% of the 5-24 GHz frequency range is protected by international footnote 5.340, which states “All emissions are prohibited in the following bands.” International footnote 5.149 states “In making assignments to stations of other services to which the bands … are allocated, administrations are urged to take all practicable steps to protect the radio astronomy service from harmful interference. Emissions from spaceborne or airborne stations can be particularly serious sources of interference to the radio astronomy service.” Of particular concern for both RAS and EESS is out-of-band emission (OOBE) spilling into the 5.340 protected passive bands.

The broad science categories listed above include radio astronomy observations of thermal and non-thermal radio continuum emission of celestial objects for which observations at multiple frequencies are critical to elucidate their physical properties and evolution. RAS allocations for continuum observations are spaced at approximately octave intervals. For radio astronomy observations of spectral lines, the radio frequencies are dictated by the laws of quantum mechanics and Doppler shifts that arise from the expansion of the Universe and kinematic motions of the gas. Remote sensing observations of the naturally occurring radio continuum and line emission from the Earth include a broad range of applications, including measurements of the physical properties of the land, ocean, and atmosphere. More details about the scientific results derived from RAS and EESS observations are available in National Academies of Sciences, Engineering, and Medicine, *Handbook of Frequency Allocations and Spectrum Protection for Scientific Uses*, Second Edition, The National Academies Press, Washington, D.C., 2015.

The RAS threshold interference levels are quoted from Table 1 (continuum) and Table 2 (spectral line) of ITU RA.769 for the spectral pdf needed to produce a power level ΔP_H in the receiving system with an isotropic receiving antenna. The EESS interference criteria are quoted from Table 2 of ITU RS.2017 for maximum interference level (dBW) and percentage of area or time permissible interference level may be exceeded, where for a 0.01% level, the measurement area is a square on the Earth of 2,000,000 km^2 and for a 0.1% level the measurement area is a square on the Earth of 10,000,000 km^2.

TABLE 2 EESS and RAS Active Allocations 5-24 GHz

Frequency Range	Status	Science Applications
5250-5255 MHz and 5255-5350 MHz	EESS (active) co-Primary	Freeze/thaw; surface water; ocean topography; surface dynamics and deformation; agriculture
5350-5460 MHz	EESS (active) co-Primary	Surface water; glacier and ice sheet; sea ice; river and lake ice; surface dynamics and deformation; agriculture
5460-5470 MHz and 5470-5570 MHz	EESS (active) co-Primary	Surface water; surface dynamics and deformation; agriculture
8550-8650 MHz	EESS (active) RADIOLOCATION SRS (active)	Terrestrial carbon-vegetation elevation; radar astronomy
9.3-9.5 GHz and 9.5-9.8 GHz and 9.8-9.9 GHz	EESS (active) co-Primary	Terrestrial carbon-vegetation elevation
9.975-10.025 GHz	RR 5.479	MetSat weather radars
13.25-13.40 GHz	EESS (active) co-Primary	Freeze/thaw; surface water; solid Earth
13.40-13.75 GHz	EESS (active) co-Primary	Precipitation; clouds; freeze/thaw; surface water; glacier and ice sheets; sea ice; ocean topography; solid Earth
13.75-14.0 GHz	EESS (active) secondary	Surface water
17.2-17.3 GHz	EESS (active) co-Primary	Solid Earth; biosphere; vegetation; snow