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

In the Matter of	)	
	)	
Use of Spectrum Bands Above 24 GHz For Mobile Radio Services	)	GN Docket No. 14-177
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	)	
Petition for Rulemaking of the Fixed Wireless Communications Coalition to Create Service Rules for the 42-43.5 GHz Band	)	RM-11664
	)	

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

The National Academy of Sciences, through the National Research Council's Committee on Radio Frequencies (hereinafter, CORF[1]), hereby submits its comments in response to the Commission's October 17, 2014, *Notice of Inquiry* (NOI) in the above-captioned dockets. In these Comments, CORF discusses the importance of passive observations by users of the Radio Astronomy Service (RAS) and the Earth Exploration Satellite Service (EESS) in the frequency bands discussed in the *NOI*, and protection of such observations. CORF generally supports the sharing of frequency allocations where practical, but if the Commission moves this proceeding to a rulemaking, protection of passive scientific observation must be addressed.

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

I. Introduction: The Role of Radio Astronomy and Earth Remote Sensing, and the Unique Vulnerability of Passive Services to Interference.

CORF has a substantial interest in this proceeding, as it represents the interests of the passive scientific users of the radio spectrum, including users of the RAS and EESS bands. These users perform extremely important, yet vulnerable, research. Furthermore, extensive experience in operating instruments above 24 GHz makes this community well suited to comment on technical matters in this frequency range.

As the Commission has also long recognized, radio astronomy is a vitally important tool used by scientists to study our 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 only experimental evidence so far 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. 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 galaxies, including our own Milky Way, probably 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 astronomy measurements led to the discovery of cosmic microwave background (CMB), the radiation left over from the original Big Bang, which has now cooled to only 2.7 K above absolute zero. Later observations revealed weak temperature fluctuations in the CMB of only one-thousandth of a percent—signatures of tiny density fluctuations in the early universe that were the seeds of the stars and galaxies we know today. Within our own solar system, radio astronomy observations of the Sun have been used for more than half a century to aid in the prediction of terrestrial high-frequency radio propagation.

Since 1974, eight scientists, six of whom are American, have received the Nobel Prize in physics for their work in radio astronomy.

The critical science 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 man-made emissions are weak and distant.

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 aspects of the global atmosphere, land, and oceans. For certain applications, satellite-based microwave remote sensing represents the only practical method of obtaining atmospheric and surface data for the entire planet. EESS data have contributed substantially to the study of meteorology, atmospheric chemistry, climatology, and oceanography. Currently, instruments operating in the EESS bands provide regular and reliable quantitative atmospheric, oceanic, and land measurements to support a broad variety of scientific, commercial, and government (civil and military) data users. U.S. EESS satellites represent billions of dollars in investment and provide data for major governmental users, including the National Oceanic and Atmospheric Administration (NOAA), the National Science Foundation, the National Aeronautics and Space Administration (NASA), the Department of Defense (DoD, especially the U.S. Navy), 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. These agencies use EESS data on issues impacting hundreds of billions of dollars in the U.S. economy.

As a general technical note applicable to all proposed new frequency allocations, care must be taken in assessment of the impact on incumbent EESS bands. While RAS bands can be protected regionally by limiting emissions within a certain radius of a facility, this is not the case with EESS observations, which are typically satellite-based and global in extent. The only technique available to protect these observations is time sharing of the band; e.g., dynamic scheduling to accommodate frequent passes overhead. This is of particular interest given the choice of frequencies proposed by the Commission. In the case of three of the selected bands (31.0-31.3, 37.0-38.6, and 81-86 GHz), mobile communications are proposed immediately adjacent to passive remote sensing bands, with no guard band protection. This is critically important because the incumbent users of these bands designed and developed EESS missions without the expectation of mobile communications in such close spectral proximity. Indeed, most incumbent passive users at 31.5 and 37 GHz operate in a direct detection (homodyne) mode. Until such time that current satellites can be replaced with satellites with filtering suited to the new spectral environment, we recommend protection of these vital orbital assets through provision of adequate guard bands.

In direct detection, band definition is achieved with filters which are limited by the properties of the materials used in the filter itself. For a given material, the bandwidth of a filter is proportional to the central frequency, so the width of the necessary guard bands to suppress emissions to a desired level also increases in proportion to the frequency. In other words, proportionally larger guard bandwidths are needed as the frequency increases. It is impossible to reject a signal 10 MHz away from a band edge at these higher frequencies, so guard bandwidths must be scaled in frequency to accommodate this physical limitation. Furthermore, for the same reasons, it is likely that mobile devices with limited size and cost will not be able to adequately filter their out-of-band (OOB) emissions to meet the stringent requirements of these passive bands.

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 loss arising from impaired weather and climate forecasting.

II. Passive Use and Protection of Specific Frequency Bands.

The FCC suggests a set of bands for specific consideration, and these are discussed below. The *NOI* also sought comments on other proposed frequencies for use in the 24 GHz range.

A. 24 GHz Bands

The band 23.6-24.0 GHz is protected by Radio Regulation 5.340 (no transmissions are permitted) and is close to the lower edge of the frequencies under consideration. The protected band is intended to cover a water vapor absorption line which is unique in the atmosphere in that it is not opaque at sea level. This band is extremely important for forecasting the weather and is used operationally by many nations. Any use of frequencies below 24.25 GHz should include measures to protect the 23.6-24.0 GHz EESS band.

B. LMDS Band (27.5-28.35 GHz, 29.1-29.25 GHz, and 31-31.3 GHz)

The primary band of interest to RAS and EESS passive applications in the LMDS band is the 31-31.3 GHz band. There is a primary RAS and EESS (passive) allocation from 31.3-31.8 GHz, in which all emissions are prohibited (ITU RR 5.340) and no station shall be authorized to transmit (Footnote US 246).

For EESS, this band is used by a variety of satellites for weather forecasting. Data products obtained from this band include cloud liquid water and integrated water vapor, both key to initializing global weather forecast models. The typical 3 dB band edge is only 10 MHz from the proposed band, and the instrument filter rejection is limited. A single 1 W isotropic radiator at 31.3 GHz results in an equivalent thermal signal of 30 K and would need to be rejected at >20 dB to not be seen by NASA/NOAA's Advanced Technology Microwave Sounder (ATMS), for example.[2] Similarly, for mobile applications, 1,000 devices operating in that band would need to be rejected by >50 dB.

For RAS, this is a vitally important band for continuum measurements, because it lies near the minimum in atmospheric absorption in this part of the spectrum. Combined with measurements in other bands at approximately octave intervals, such measurements provide information on the broad spectrum of astronomical radio sources, such as supernovae, pulsars, radio galaxies, and quasars. The detrimental interference level for this band is -228 dBW/m^2/Hz, averaged across the full 500 MHz width of the band (ITU-R RA.769, Table 1), and as such careful filtering will be required.

C. <u>37/42 GHz Bands (37.0-38.6 GHz, 42.0-42.5 GHz)</u>

As noted in paragraph 67 of the *NOI,* there is a primary allocation to the RAS in the adjacent 42.5-43.5 GHz band. Frequency lines at 42.519, 42.821, 43.122, and 43.424 GHz (for observations of silicon monoxide) are among those of greatest importance to radio astronomy.[3] This band is important for detection of strong silicon monoxide maser emissions from stars and star-forming regions. Measurements of these masers yield important information on stellar temperature, density, wind

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[2] The ATMS instrument is the next-generation cross-track microwave sounder providing atmospheric temperature and moisture measurements for operational weather and climate applications. ATMS is a key instrument that collects microwave radiation measurements from the Earth's atmosphere and surface all day and all night, even through clouds. ATMS currently flies on the Suomi NPP satellite mission and will fly on the JPSS-1 and JPSS-2 satellite missions. *See,* http://www.jpss.noaa.gov/atms.html.

velocities, and other parameters. The 42.5-43.5 GHz band is also one of the preferred RAS bands for continuum observations.[4] The detrimental levels for continuum and spectral line radio astronomy observations are -227 dBW/m^2/Hz and -210 dBW/m^2/Hz, respectively, for the average across the full 1 GHz band and the peak level in any single 500 kHz channel (ITU-R RA.769, Tables 1 and 2, respectively). Careful studies will be required to determine whether mobile and/or fixed point-to-point services in the 42 GHz band can be consistent with protection of the RAS in the 42.5-43.5 GHz band.

In addition to the comments received by NASA through the National Telecommunications and Information Administration regarding space research (*NOI* at para. 66), there is an important primary EESS allocation at 36-37 GHz that is used by many agencies. As described earlier, many of these sensors operate in direct detection mode and their ability to reject OOB emissions is limited by basic physics. These instruments include the NASA Global Precipitation Measurement Mission's Microwave Imager, NASA Tropical Rainfall Measuring Mission's Microwave Imager, DoD Special Sensor Microwave/Imager and WindSat instruments, and the JAXA Global Change Observation Mission-Water 1's Advanced Microwave Scanning Radiometer 2.[5] The purpose of these instruments is to provide data on ocean winds, cloud liquid water, precipitation, terrestrial snow, sea ice cover, and sea surface temperature.[6] The data are assimilated into global circulation models and directly affect the quality of weather forecasting. The proposed bands offer no protection for these instruments because the

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3 *See, Handbook on Radio Astronomy* (ITU Radiocommunications Bureau, 2013) at page 37, Table 3.2.

4 *Id. at* page 35, Table 3.1.

5 While the GCOM-W1 is not a U.S. satellite, its measurements are and will continue to be used heavily by U.S. agencies (e.g. NOAA, NASA).

band definitions line up precisely with the allocated bands. Furthermore, with lower orbits, and larger receiver antennas, these instruments are far more susceptible to terrestrial interference than the ATMS described in the last section. OOB rejection levels need to be increased by 16 dB over the ATMS levels specified in the previous section to >36 dB and >66 dB rejection for a single mobile device and 1,000 mobile devices, respectively. It would therefore be prudent to include guard bands designed to match the incumbent users' filter response in order to preserve these expensive and important assets. Alternatively, dynamical allocation of frequencies could be mandated to avoid interfering with the satellite receptors when they are overhead, as determined by ephemerides and instrument beam pattern.

D. 70/80 GHz Bands (71-76 GHz, 81-86 GHz)

There are primary allocations to RAS at 76.0-77.5 GHz and 78.0-94 GHz. The 86-92 GHz band is an allocation in which all emissions are prohibited (ITU 5.340) and no station shall be authorized to transmit (US 246). The detrimental levels for continuum and spectral line radio astronomy observations are -228 dBW/m^2/Hz and -208 dBW/m^2/Hz, respectively, for the average across the full 6 GHz band and the peak level in any single 1 MHz channel (ITU-R RA.769, Tables 1 and 2, respectively). Dynamic access control may be required to avoid interference to radio astronomy sites.

These bands are used very extensively for a wide range of continuum and spectral line observing. The U.S. radio astronomy community has been a leader in millimeter wavelength research, with the initial discovery of a very wide range of complex molecules in space. The understanding of star formation and evolution is

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6 *See,* http://www.nasa.gov/mission_pages/GPM/spacecraft/; http://pmm.nasa.gov/node/161;

critically dependent on millimeter wave observations. Highly redshifted galaxies can be detected over the full range of the RAS allocations. It is essential that the protection presently available remain in place.

The 86-92 GHz band is also a primary allocation to EESS. This band is used by the satellite instruments described in the previous sections. The primary data product is precipitation (from cloud ice scattering), and it is widely used to provide real-time imagery for weather forecasting (such as NOAA's NexRad system).[7] The band usage tends to be quite broad in order to reduce the effect of the higher receiver noise at these frequencies. As such, this band is also highly susceptible to OOB emissions and, being at a higher frequency and having a large bandwidth, would require even more guard banding.

For radio astronomy, because there is relatively little absorption from atmospheric O_2 and H_2O, these bands constitute some of the most important high-frequency ranges for both continuum and line observations[8] of celestial objects.

III. Conclusion.

Observations at the frequency bands discussed herein are critical for scientific research. CORF generally supports the sharing of frequency allocations where practical, but if the Commission moves this proceeding to a rulemaking, protection of passive scientific observation must be addressed.

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http://podaac.jpl.nasa.gov/SSMI; and http://mirs.nesdis.noaa.gov/windsat.php.

[7] *See,* http://www.srh.noaa.gov/srh/sod/radar/radinfo/radinfo.html.

Respectfully submitted,

NATIONAL ACADEMY OF SCIENCES'
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[8] *See*, Handbook on Radio Astronomy, *supra* note 3, at Tables 3.1 and 3.2.

Appendix

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