Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington, DC 20554

In the Matter of

Amendment of Parts 2, 15, 80, 90, 97, and 101 of the Commission's Rules Regarding Implementation of the Final Acts of the World Radiocommunication Conference (Geneva, 2012)(WRC-12), Other Allocation Issues, and Related Rule Updates	ET Docket No. 15-99
Petition for Rulemaking of Xanadoo Company and Spectrum Five LLC to Establish Rules Permitting Blanket Licensing of Two-Way Earth Stations With End-User Uplinks in the 24.75-25.05 GHz Band	IB Docket 06-123
Petition for Rulemaking of James E. Whedbee to Amend Parts 2 and 97 of the Commission's Rules to Create a Low Frequency Allocation for the Amateur Radio Service	
Petition for Rulemaking of ARRL to Amend Parts 2 and 97 of the Commission's Rules to Create a New Medium-Frequency Allocation for the Amateur Radio Service	

REPLY 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 Reply Comments in response to the Commission's April 27, 2015 Notice of Proposed Rulemaking (NPRM) in the above-captioned docket. In these Reply Comments, CORF discusses the nature of observations by the Radio Astronomy Service (RAS) and the Earth Exploration Satellite Service (EESS) at various

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

frequencies, and issues associated with shared use of such bands with active services. CORF generally supports the sharing of frequency allocations, where practical, but in enacting rules in this proceeding, protection of passive scientific observations must be addressed.

I. Introduction: The Role of Radio Astronomy and the Special Vulnerability of Passive Services to Interference.

CORF has a substantial interest in this proceeding because it represents the interests of the passive scientific users of the radio spectrum, including users of the RAS and EESS bands. RAS and EESS observers perform extremely important yet vulnerable research.

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 at the Earth's surface. Subsequent radio observations of pulsars have revolutionized our 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. Observation of the enormous energies contained in the enigmatic quasars and radio galaxies discovered by radio astronomers has led to the recognition that 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 extraordinary 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 the cosmic microwave background (CMB), the radiation left over from the original Big Bang that has now cooled to only 2.7 K above absolute zero. Later observations revealed the 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. The CMB is a unique probe for the ongoing search for gravity waves in the inflationary period of growth after the Big Bang, a particularly active topic in modern astrophysics. 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 (HF) radio propagation.

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

However, the critical science undertaken by RAS observers cannot be performed without access to interference-free spectrum. 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. Furthermore, the potential for interference increases as the bandwidth increases.

In sum, the important science performed by radio astronomers cannot be performed without access to interference-free spectrum. 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 from the information learned and the technologies developed.

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 not only for the United States, but 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, the National Science Foundation, the National Aeronautics and Space Administration (NASA), the Department of Defense (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 often be protected regionally by limiting emissions within a certain radius of a facility, this typically is not the case with EESS observations, which are satellite-based and typically global in extent.

II. Protection of Passive Scientific Observation and Specific Proposals in the NPRM.

CORF generally supports the sharing of frequency allocations, where practical. With shared use, however, comes shared responsibility to protect other users.

A. Radio Astronomy at 4800-5000 MHz.

As noted in the NPRM, RAS observation in this band is primarily of formaldehyde (H_2CO). Observation of formaldehyde is valuable in the study of interstellar clouds, and the line at 4829.66 MHz is a particularly important tracer of the more diffuse interstellar medium because it can be detected in absorption against background radio sources.[2] This frequency line is recognized as one of the lines of greatest importance to RAS.[3] Formaldehyde maser emission and absorption are found in a growing number of galaxies, including our own, and observation of the distribution of formaldehyde clouds helps scientists understand the structure of galaxies. In addition to the spectral line observations of formaldehyde, radio continuum observations at 5 GHz make use of this spectral region to detect synchrotron emission from the centers of active galaxies and quasars.

As a general matter, RAS is most vulnerable to interference from airborne transmissions, and thus the addition of an allocation for Aeronautical Mobile Telemetry (AMT) in this band is not supported by CORF.[4] However, if such an allocation is to be made, CORF generally supports the operational restrictions in footnote USXX2 proposed in paragraph 220 of the

---

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

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

4 Footnote US113 notes that RAS observations are made in this band, and states that "[e]very practical effort will be made to avoid the assignment of frequencies to stations in the fixed and mobile services" in this band. Footnote US342 notes that RAS observations are made at 4825-4835 MHz, and states that "all practical steps shall be taken to protect the [RAS] from harmful interference. Emissions from spaceborne or airborne stations can be particularly serious sources of interference to the [RAS]."

NPRM. CORF notes, though, that the provision of WRC-07 Resolution 416 that "the peak EIRP density of a telemetry transmitter antenna shall not exceed –2.2 dB(W/MHz)" exceeds the protection level in ITU-R RA.769 by 53.8 dB, and thus cannot offer adequate protection to RAS facilities within line of sight of AMT transmissions. Hence, the coordination requirement proposed in footnote USXX4 in paragraph 220 is critical for the protection of RAS. Core to the concept of USXX4 is the valid idea that the best protection of RAS facilities is to situate the observatory below the horizon (not in line of sight) to an AMT transmission. However, the distance of that horizon will vary based on the altitude of the transmitting aircraft. For flights at altitudes greater than 40,000 feet, the 200/500 kilometer coordination distances proposed in USXX4 must be correspondingly increased.[5] In addition, CORF recommends that USXX4 in the NPRM be revised to require operators to share their schedule (whereas the footnote as written only requires operators to share their schedule "as much as practicable").

B. Protecting EESS Use of the 86-92 GHz Band.

As noted in para. 247 of the NPRM, WRC-12 revised Resolution 750 to urge administrations to take all reasonable steps to ensure that unwanted emissions of fixed stations in the 81-86 GHz and 92-94 GHz bands do not exceed the recommended maximum levels contained in Table 1-2, and it revised RR 5.338A by adding the 81-86 GHz and 92-94 GHz bands to the list of band to which Resolution 750 applies. The NPRM proposes that footnote US162 replicate the WRC-12 unwanted emissions levels for the 81-86 GHz and 92-94 GHz

[5] CORF believes that a 500 kilometer radius is the minimum that can be considered for single dish telescopes, and 200 kilometer for Very Long Baseline Array (VLBA) stations. This finding is based on the following: Assuming an aircraft height of 40,000 feet (or about 12,200 meters), then using the well-known formula of R=4.12.sqrt(h) for the horizon distance, with R in km and h in meters, one arrives at an aircraft horizon distance of 455 km. To this figure must be added the horizon of the radio telescope, which depends on local terrain but will often be tens of kilometers or more. VLBA stations have a higher immunity to interference (unless received simultaneously in two separated antennas, as may be possible for the closely spaced antennas at the Pie Town and Los Alamos VLBA stations), so the less stringent distance proposed for VLBA stations is generally acceptable.

bands. CORF supports that proposal.

EESS observations in these bands are quite valuable. First, many meteorological and surface environmental data products are produced using multivariable algorithms to retrieve a set of geophysical parameters simultaneously from calibrated multichannel microwave radiometric imagery, and observations near 86-92 GHz figure prominently in that task. For example, cloud parameters, oil spills, ice, snow, and rain are routinely observed using multichannel imagery, including 86-92 GHz. These channels are also used as a reference window for temperature soundings observed near 60 and 118 GHz. In addition, passive microwave measurements near 89 GHz play an important role in the retrieval of precipitation data, particularly over land. Because of the combination of high emissivity and cloud thickness and temperature over land, signatures of convective precipitation cells are often strongest at 89 GHz. At this frequency there is high sensitivity to clouds over land, causing the upwelling brightness temperatures to be cooler rather than warmer, as observed over a relatively cold ocean background. Clouds over land exhibit much less contrast at lower microwave window frequencies (e.g., 10, 18, and 37 GHz) with the result that 89 GHz observations play an important role in determining rain rate over land.

CORF supports the unwanted emission standards proposed in footnote US162 as consistent with Resolution 750, and believes the standards are necessary to properly protect EESS observations in this band.

C. <u>Passive and Active Shared Use of Bands Above 275 GHz.</u>

As noted in para. 250 of the NPRM, Agenda Item 1.6 of WRC-12 reviewed RR 5.565 to update the spectrum use by the passive services between 275 GHz and 3000 GHz, and provided a list of frequency bands throughout the 275-1000 GHz range that have been identified for observations of spectral line emissions and spectral windows for the passive services. RR 5.565 states that "Administrations wishing to make frequencies in the 275-1000 GHz range available for active service applications are urged to take all practicable steps to protect these passive services from harmful interference until the date when the Table of Frequency Allocations is established in the above-mentioned 275-1000 GHz frequency range."

However, the NPRM states at para. 254 that "it is important to recognize that this frequency range is used and may be used more extensively in the future for experimentation with, and development of, an array of active service applications…, and that RR 5.565 should not be misconstrued as placing a 'reservation' for future passive service allocations in the U.S. Table, which would inhibit commercial development of this spectrum." Thus, the NPRM seeks comments on proposed footnote US565, which would state that "International footnote 5.565 does not establish priority of use in the United States Table of Frequency Allocations, and does not preclude or constrain the allocation of frequency bands in the range 275-3000 GHz to active services at a future date."

CORF is concerned that the text of the Commission's proposed footnote appears to be at odds with RR 5.565's explicit goal of protecting passive uses, and it urges the Commission to adopt the text of RR 5.565. Nevertheless, CORF generally supports the sharing of frequency allocations where practical, and technical factors associated with radio transmission in these high frequencies may well support shared use in many cases. CORF would welcome the opportunity to recommend criteria for protecting passive scientific applications while promoting the responsible active use of the spectrum above 275 GHz. In connection with such possible shared use in the future, the Commission should consider the following discussion pertaining to EESS and RAS.

1. Earth Exploration-Satellite Service (EESS).

The frequency spectrum above 275 GHz is rich with molecular line emission and absorption, as well as atmospheric "windows"—frequency spans free from significant emission and absorption. Observations of molecular lines are regularly used for studies of atmospheric chemistry, tracing the impacts of pollutants as they cycle through the troposphere and stratosphere. Because of the complicated nature of the chemistry and the interaction with solar radiation, it is necessary to study a large number of frequency line species. NASA's Aura-Microwave Limb Sounder tracks more than 8 line species in 12 frequency bands between 250 and 2500 GHz. It is impossible to move observations off of these lines, so special care must be taken to protect these applications. However, in contrast to the weak lines, the strong absorption lines (O_2 and H_2O) are highly opaque close to their peak, providing natural mitigation to potential RFI. For this reason, EESS applications are tolerant to emissions in these bands, creating a natural opportunity for spectrum sharing.

The use of the window channels represents a more complicated situation. These bands are typically used for studies of high resolution temperature and humidity in the stratosphere and upper troposphere. Because these bands allow observations close to the Earth's surface, they are useful for studies involving scattering, in particular by ice particles in the atmosphere. There are notable windows at 200-300 GHz, 340-360 GHz, 390-420 GHz, 630-680 GHz, and 800-870 GHz. The opacity of these windows tends to increase with frequency due to the strong water absorption lines at 325 GHz, 380 GHz, 448 GHz, 557 GHz, 621 GHz, and 752 GHz. The more opaque windows probe different altitudes in the atmosphere, when observed from above. As the observation frequency is increased, the instruments are more sensitive to smaller ice particles. However due to the increased opacity, these high-frequency observations require wider bandwidths to obtain a reasonable signal-to-noise ratio. Indeed, it is not uncommon for window channels above 320 GHz to utilize 10 GHz or more of bandwidth, which of course, makes these observations more susceptible to interference.

2. *Radio Astronomy Service (RAS).*

As is the case with EESS, the frequency spectrum above 275 GHz is rich with molecular line transitions of importance to the RAS.[6] Unlike EESS, RAS observations are limited to the atmospheric windows where it is possible to detect astronomical sources (with telescopes at high, dry sites) despite the atmospheric attenuation. The frequency ranges listed for RAS in the proposed footnote US565 are appropriate for RAS observations and correspond to these atmospheric windows. Unlike EESS, RAS only requires protection in a very limited number of sites, all in relatively remote locations. At the present time, Mauna Kea, Hawaii and Mt. Graham, Arizona are the primary sites for such observations in the United States.[7]

There are (at least) two fields of science that require observations at these frequencies. Both are relatively "young" fields, and are expected to have rapid growth in the near future. First, the spectroscopic study of the emission lines from many different molecular species allows astronomers to learn about the physical conditions (temperature, density, pressure, etc.) of molecular clouds in the Milky Way and other galaxies. For example, measurements of the abundance of trace molecular species (i.e., weak lines, which require clean, interference-free spectra to detect and measure) are critical to our understanding of the chemical pathways for forming the complex molecular species that are the origin of life here on Earth. Furthermore, the field of astrochemistry connects astronomical observations of molecular transitions with

---

[6] A number of frequency lines between 279 and 930 GHz are recognized as among the most important for RAS. *See*, *Handbook on Radio Astronomy* (ITU Radiocommunications Bureau, 2013) at page 39, Table 3.3.

[7] *See, e.g.*, http://www.eaobservatory.org/jcmt/science/ and http://mgio.arizona.edu/.

laboratory experiments to identify the numerous, and often unusual, molecular species found in molecular clouds.

Second, the submillimeter atmospheric windows provide the opportunity to observe redshifted[8] molecular transitions emitted from galaxies and quasars in the early universe. In synergy with other ground-based and space-based facilities, submillimeter telescopes will be used to detect redshifted CO transitions to measure the physical conditions (temperature and density) of molecular clouds in the early universe. These physical conditions have direct input into models of how the first stars are formed and how galaxies form and evolve. In addition, observations of the redshifted [C II] 158 micron (1.9 THz) and [O III] 88 micron (3.4 THz) lines will provide direct measures of the carbon and oxygen abundance in the early universe. The redshifted [O III] line is of particular importance for our understanding of the chemical enrichment of the early universe, which is tied to the formation of the first stars and the release of their products of nucleosynthesis into the surrounding medium. Because these lines are redshifted to lower frequencies due to the expansion of the universe, the exact frequencies at which these emission lines are detected will depend on the source. However, observations of multiple sources at a range of frequencies are required to trace the chemical enrichment history of the universe. Thus, observations throughout the atmospheric windows need to be protected from spurious emissions.

Since ground-based radio astronomy observations are not possible within frequency bands of very high atmospheric attenuation, we urge that, wherever possible, and in particular for short range applications, allocations of frequency bands to the active services be made within one

---

8 The expansion of the universe results in an apparent Doppler shift (known as redshift) that is directly related to the distance to the astronomical source. Furthermore, because of the finite travel time for light, the radio signals we detect today from distant objects are actually radio signals emitted by the source in the past. Thus, by observing distant objects, at high redshifts, astronomers are able to probe the physical conditions and properties of the early universe with light detected in the present day.

of these bands. Not only will that avoid conflicts between the active and passive services, but it will enable the maximum reuse of frequency bands by different active services without danger of mutual interference.

In sum, RAS anticipates significant growth in passive use at frequencies above 275 GHz during the next decade which is likely to yield foundational knowledge about the formation of the first structures in the universe, including the first stars, galaxies, and quasars, and will thereby address some of the most fundamental questions regarding the origin of life on Earth. Such observations should not be incompatible with responsible active use of the spectrum.

III. Conclusion.

CORF generally supports the sharing of frequency allocations, where practical. In this proceeding, while CORF is concerned about the proposed allocation of 4400-4940 MHz for AMT, it supports the proposed restrictions (modified as discussed above) on AMT operations designed to help protect RAS observations. In regards to the 86-92 GHz band, CORF supports the unwanted emission standards proposed in footnote US162 as consistent with Resolution 750, and believes the standards are necessary to properly protect EESS observations in this band. In regards to use of frequencies above 275 GHz, CORF is concerned that the text of the Commission's proposed footnote US565 appears to be at odds with RR 5.565's explicit goal of protecting passive uses, and it urges the Commission to adopt the text of RR 5.565. Nevertheless, CORF generally supports the sharing of frequency allocations where practical, such as the opaque bands at 325 GHz, 380 GHz, 448 GHz, 557 GHz, 621 GHz, and 752 GHz, and technical factors associated with radio transmission in these high frequencies may well support shared use in many (though not all) cases. CORF would welcome the opportunity to work with the Commission in developing regulations to protect passive scientific applications while promoting the responsible active use of the spectrum above 275 GHz.

Respectfully submitted,

NATIONAL ACADEMY OF SCIENCES'
COMMITTEE ON RADIO FREQUENCIES

By: Ralph J. Cicerone

Ralph J. Cicerone
President, National Academy of Sciences

Direct correspondence to:

CORF
Keck Center of the National Academies
500 Fifth St., NW, Room 954
Washington, DC 20001
(202) 334-3520

September 28 2015
Date

Appendix

Committee on Radio Frequencies

Members

Jasmeet Judge, *Chair*, University of Florida
Liese van Zee, *Vice-Chair*, Indiana University
William Blackwell, MIT Lincoln Laboratory
Todd Gaier, Jet Propulsion Laboratory
Kenneth Jezek, The Ohio State University
David Le Vine, NASA Goddard Space Flight Center
Amy Lovell, Agnes Scott College
Timothy Pearson, California Institute of Technology
Paul Siqueira, University of Massachusetts, Amherst
Gregory Taylor, University of New Mexico
Thomas Wilson, Naval Research Laboratory

Consultants

Michael Davis, SETI Institute, retired
Darrel Emerson, National Radio Astronomy Observatory, retired
Paul Feldman, Fletcher, Heald, and Hildreth