Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington, DC 20554

In the Matter of Expanding the Economic and Innovative Opportunities of Spectrum Through Incentive Auctions	)))))	Docket No. 12-268

**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), hereby submits its Comments in response to the Commission's October 2, 2012, Notice of Proposed Rulemaking in the above-captioned docket (NPRM). In these Comments, CORF discusses the nature of observations by the Radio Astronomy Service (RAS) in the 608-614 MHz band (i.e., Channel 37) and the remainder of the television band (TV Band). CORF urges the Commission to maintain a protected band for RAS observation of red-shifted hydrogen and other astrophysical phenomena, either at Channel 37 or in another TV Band channel (such as TV Channel 4). CORF has significant concerns about the Commission's proposal to allow operation of unlicensed "white space" devices on Channel 37, but if such devices are allowed to operate on Channel 37 (or on another channel allocated to the RAS), then the Commission should protect certain RAS facilities by prohibiting operation of white space devices in areas surrounding those RAS facilities. Last, it is essential that the Commission be mindful of out-of-band emission rules for wireless broadband downlinks in any channel allocated next to a channel allocated to the RAS.

I. Introduction: The Role of Radio Astronomy, the Unique Vulnerability of Passive Services to Interference, and the Importance of Observations in the TV Band.

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 bands. RAS 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 the gravitational field on 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, may contain a supermassive black hole at their center, 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 have discovered 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 discovered the weak temperature fluctuations in the CMB of only one-thousandth of a percent: these are 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 (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 weak, distant in-band man-made emissions can preclude RAS use.

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.

Of particular concern in this proceeding is protection of RAS observations in the TV Band, including at 608-614 MHz (TV Channel 37). This band is one of the preferred RAS bands for continuum observations.[1] Observations in the TV Band are important for studying the interstellar medium, pulsars, and the Sun. Important observations are made of the neutral hydrogen line (rest frequency of 1420 MHz) shifted in frequency by the Doppler effect (red-shifted) into this band. Such observations are used to investigate interstellar matter and the evolution of galaxies, including unique new initiatives to study the large-scale structure of the universe via the so-called baryonic acoustic oscillation (BAO) effect. In regard to the interstellar medium, the TV Band has great importance in observations of thermal and non-thermal diffuse radiation in our own Milky Way Galaxy. Such observations give information on the high-energy cosmic-ray particles in our galaxy and their distribution, and also on the hot ionized plasma in the disk of our galaxy.

Observations in the TV Band are very important for the study of pulsars, which

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1 *See*, ITU Handbook On Radio Astronomy (Geneva, 1995) at page 11, Table 1.

are highly condensed neutron stars that rotate with a period as short as a millisecond. Pulsars are commonly the remains of supernova outbursts, and the discovery and study of such objects in the past two decades have opened up a major new chapter in the physics of highly condensed matter, and have contributed immensely to our understanding of black holes and the final state in stellar evolution. Observations of binary pulsars by radio astronomers have verified the existence of gravitational radiation at the level predicted by Einstein's general theory of relativity.

Important observations in the TV Band are also made of radio-frequency outbursts from our Sun which precede bursts of high-energy particles that interact with Earth's atmosphere and can cause severe interruptions in radio communications and power systems, as well as having dangerous effects on aircraft flying at altitudes above 15,000 meters. Study of these solar bursts can enable prediction of failures in radio communications. In addition, knowledge regarding high-energy solar bursts is essential for successful space exploration, both manned and unmanned.

II. The Commission Should Retain a Protected Channel for the RAS in the TV Band, Either at Channel 37, or in the VHF Band.

As set forth above, radio astronomers have made and will continue to make observations in the TV Band, particularly of red-shifted hydrogen, to advance important scientific investigations. Currently, observations in the United States[2] at 608-614 MHz

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2 In response to the Commission's question in paragraph 204 of the NPRM, it is CORF's understanding that the Dominion Radio Astrophysical Observatory in Penticton, British Columbia, currently observes at 608-614 MHz. CORF recommends that the United States consult with the Canadian administration prior to authorizing any new allocation for wireless services on Channel 37 in the United States.

are made at the Robert C. Byrd Green Bank Telescope (GBT),[3] as well as at the Very Long Baseline Array (VLBA).[4] In response to questions raised in paragraphs 206 and 207 of the NPRM, CORF notes the following:

For radio astronomy observations a single contiguous band of at least 6 MHz is highly preferable to multiple small, noncontiguous bands. The reason is that sensitivity is improved with bandwidth, but only in the absence of systematic issues (spectral curvature of sources, etc.) that arise if the bandwidth is not contiguous.

CORF asserts that there would be benefits for multiple stakeholders if the current allocation of Channel 37 were maintained solely for the RAS and the Wireless Medical Telemetry Service (WMTS). The WMTS and the RAS both need strong protection from interference and have been good spectral neighbors for each other. In addition, retaining the existing allocation would eliminate the need to reimburse expenses associated with refitting RAS receivers (as well as WMTS equipment).

The NPRM raises the possibility of a protected allocation in the TV Band other than Channel 37. Although it would be possible to perform the same radio astronomy research on Channel 32 (pursuant to the proposal in paragraph 207 of the NPRM), there would be costs associated with refitting RAS receivers. Alternatively, however, there are strong scientific reasons for allocating a VHF channel to the RAS. With recent advances in technology, use of such a channel would facilitate detection of highly (Doppler) red-shifted hydrogen heated by the first stars, galaxies, and black holes.

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3 The GBT is part of the National Radio Astronomy Observatory in West Virginia.

4 In addition, there is a long history of observation at 608-614 MHz at the Arecibo Observatory (AO), the world's largest single-dish telescope. The AO may observe at 608-614 MHz and other portions of the TV Band in the near future.

Such observations could measure the thermal and ionization history of the early universe and provide invaluable information about how our universe was formed and how it evolved. Astronomical theory suggests that the most interesting frequency range for investigating this cosmic dawn is in the lower VHF channels, between 40 MHz and 100 MHz. Related experiments are currently being conducted in the United States at the Long Wavelength Array Radio Observatory in New Mexico (LWA1).[5] In addition, the California Institute of Technology is constructing a Long Wavelength Array station at the site of the Owens Valley Radio Observatory, where similar observations will be performed.[6]

Consistent with this approach, the Commission could consider allocating TV Channel 4 (66-72 MHz) to the RAS. When combined with the existing RAS allocation at 73-74.6 MHz, this allocation would provide 7.6 MHz of nearly[7] contiguous bandwidth. The scientific uses of this new RAS band would include all of those listed above for Channel 37, but would also include the study of the cosmic dawn via red-shifted neutral hydrogen.

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[5] The LWA1 (Long Wavelength Array Station 1) is a compact array radio telescope operating in the 10-88 MHz band, collocated with the Very Large Array Radio Observatory (VLA) in central New Mexico. The LWA1 currently consists of 260 dual-polarization active dipole antennas in a 100 meter x 110 meter elliptical footprint. Each dipole is individually digitized and then formed into 4 beams using a delay-and-sum technique. The participating institutions in the LWA1 include the University of New Mexico, the Naval Research Laboratory, Virginia Tech, the Los Alamos National Laboratory, and the Jet Propulsion Laboratory. Support for operations and continuing development of the LWA1 is provided by the National Science Foundation.

[6] A related and equally important area of study is that of the Epoch of Reionization (EoR). The EoR refers to the period in the history of the universe during which the predominantly neutral intergalactic medium was ionized by the emergence of the first luminous sources. Reionization was complete about 1 billion years after the big bang. Astronomical theory suggests that evidence of the EoR requires observation of red-shifted hydrogen at frequencies between 50 and 200 MHz. *See, e.g.*, http://www.haystack.mit.edu/ast/science/epoch/index.html (last accessed November 26, 2012).

[7] The 72-73 MHz portion of this band is not allocated to the RAS. If the Commission moves the RAS allocation from Channel 37 to Channel 4, then it should consider reallocation of the 72-73 MHz band to make the RAS co-primary or primary.

In summary, there would be benefits for multiple stakeholders to maintaining the current allocation of Channel 37 solely for the RAS and the WMTS. However, if the Commission determines that it will clear Channel 37 for wireless broadband use, there also would be substantial benefits to radio astronomy in moving the RAS allocation to the VHF Band, especially to Channel 4. Such a reallocation would require reimbursement of expenses at the VLBA and GBT. In addition, any such reallocation would require a level of protection for the new channel similar to that currently provided to the RAS at Channel 37. These protections would include no allocation to any licensed services in the RAS channel, or alternatively, rigorous exclusion/coordination zones. Furthermore, protection from interference from wireless microphones and "white space" devices would be equally important.[8]

III. Protection of the RAS from Interference from White Space Devices.

No matter which channel is allocated to the RAS in the TV Band, RAS facilities will need protection from interference from white space or TV Band devices (TVBDs).

In enacting rules for TVBDs, the Commission has properly recognized the need to protect RAS observations at Channel 37. Section 15.707(a) of the Commission's rules prohibits operation of such devices on Channel 37. In addition, pursuant to

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[8] The protection criteria for the RAS set forth in ITU-R RA.769-2 is −196 dBW/m^2 at 73 MHz. Assuming that unlicensed wireless microphones operate at 50 mW into a low-gain antenna (i.e., assuming 50 mW EIRP), then interference would be caused to radio astronomy observations at this frequency at a distance up to 350 kilometers, even without a line of sight between the microphone and the observatory. Thus, if the Commission were to allocate a low VHF channel to the RAS, protection from interference from wireless microphones would be necessary. Protection could be provided either by requiring a 350 kilometer exclusion zone, or by reducing the permitted power for microphones in the channel allocated to the RAS to 12 mW. CORF notes that if wireless microphones operated in a quiet

Section 15.712(h), operation of such devices on any channel is prohibited within 2.4 kilometers of certain radio astronomy observatories. Furthermore, out-of-band emissions into Channel 37 are particularly limited, pursuant to Section 15.709(c)(4).

Nevertheless, CORF recognizes the importance of sharing spectrum resources among services, where practical. Accordingly, CORF does not oppose the proposed operation of TVBDs on Channel 37 (or whichever channel is ultimately allocated to the RAS in the TV Band), subject to the establishment of appropriate RAS protection areas.[9]

To avoid interference from TVBDs operating on Channel 37, exclusion zones of up to 350 kilometers from the RAS facilities (as specified in Section 15.712(h) of the Commission's rules) are necessary. For example, a line-of-sight transmitter of 100 mW effective isotropic radiated power (EIRP) at this distance is received with a power flux density (pfd) of -132 dBW/m^2, which is 53 dB above the RA-769 interference threshold of -185 dBW/m^2, for a 6 MHz bandwidth. While an exclusion zone of 350 kilometers is needed to guarantee that all TVBDs are below the horizon (not the line of sight) to observatories, smaller exclusion zones based on propagation model contours could allow these devices at closer distances if they are fixed at known locations and coordinated with the observatory, or are mobile and are able to estimate their location and access a database to determine if they may operate at that location and if so at what power. Since typical 2-edge diffraction loss exceeds 53 dB, zones well below 350

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environment they could use lower power levels, which would have the added benefit of extending their battery life.

[9] CORF assumes that WMTS devices would also have to be protected from interference from TVBDs, if Channel 37 remains allocated to the WMTS.

kilometers will suffice for many RAS facilities. If we assume that for non-line-of-sight multipath propagation the typical path loss increases with the fourth power of distance beyond 300 meters, the exclusion zone radius is reduced to 200 kilometers for mobile devices of 40 mW EIRP.

In addition to exclusion zones around certain RAS observatories for operation of TVBDs on Channel 37, it will also be necessary to maintain the remainder of the protections of Channel 37 in the current Part 15 rules for TVBDs: the Section 15.712(h) prohibition of operation of such devices on any channel within 2.4 kilometers of certain radio astronomy observatories, the specific limits on out-of-band emissions into Channel 37 in Section 15.709(c)(4), and the limitation on TVBD operation on the first available channel above and the first channel below TV Channel 37, as set forth in Section 15.707(a).[10]

IV. Protection of the RAS from Out-of-Band Emissions from Licensed Wireless Operations.

Under one of the band plans set forth in the NPRM, Channel 36 (and other channels) would be allocated for broadband wireless downlinks. *See* NPRM at para. 136. If this allocation were to occur, and the RAS allocation remains at Channel 37, there could be a significant risk of out-of-band interference from the wireless downlinks into RAS observations at Channel 37, in the absence of an appropriate out-of-band

10 The provisions of these rules may need to be modified if applied to an RAS allocation in the UHF channels.

emission standard.[11]

At a distance of 350 kilometers, which is the largest distance at which a line-of-sight path is still a possibility, a broadband downlink tower within the line of sight of an RAS facility would need to ensure that its out-of-band emissions into the Channel 37 Radio Astronomy band below −63 dBW EIRP fall below the RA-769 interference threshold of -185 dBW/m^2, for a 6 MHz bandwidth. This upper limit requires that a 1 watt transmitter into a 0 dBi antenna have an additional 20 dB suppression of the out-of-band emissions over the proposed $43 + 10*\log_{10}(P)$, where P is defined as the transmitter power in watts. A propagation model combined with the antenna pattern would be required to determine if a specific location within 350 kilometers is acceptable given a specified limit of $43 + 10*\log_{10}(P)$.[12]

V. Conclusion.

CORF urges the Commission to maintain a protected band for RAS observation of red-shifted hydrogen, either at Channel 37, or in a VHF TV Band channel. There would be benefits for multiple stakeholders to maintaining the current allocation of Channel 37 solely for the RAS and the WMTS. However, if the Commission determines that it will clear Channel 37 for wireless broadband use, there also would be substantial benefits to radio astronomy from moving the RAS allocation to the VHF Band, especially

[11] More generally, the Commission should make sure that 600 MHz licensees are aware of the Quiet Zone and the notification requirements of Section 1.924 of the Commission's rules.

[12] For VLBA sites a 1 watt transmitter into a 21 dBi antenna within the line of sight at 350 kilometers exceeds the RA-769 interference threshold of −212 $dBW/m^2/Hz$ for a 6 MHz bandwidth unless the out-of-band emissions are below the limit of $43 + 10*\log_{10}(P)$.

to Channel 4. CORF has significant concerns about the Commission's proposal to allow operation of unlicensed TVBDs on Channel 37, but if such devices are allowed to operate on Channel 37 (or another channel allocated to the RAS), then the Commission should protect certain RAS facilities by prohibiting operation of devices in areas surrounding those RAS facilities. Last, it is essential that the Commission be mindful of out-of-band emission rules for wireless broadband downlinks in any channel allocated next to a channel allocated to the RAS.

Respectfully submitted,

NATIONAL ACADEMY OF SCIENCES'
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January 25, 2013

Appendix A

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