Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington, DC 20554

In the Matter of	)	
	)	
Amendment of the Commission's Rules to Promote Aviation Safety	)	WT Docket No. 19-140
	)	
WiMAX Forum Petition to Adopt Service Rules for the Aeronautical Mobile Airport Communications System (AeroMACS)	)	RM-11793
	)	
Petition of Sierra Nevada Corporation for Amendment of the Commission's Rules to Allow for Enhanced Flight Vision System Radar under Part 87	)	RM-11799
	)	
Petition of Aviation Spectrum Resources, Inc. for Amendment of Sections 87173(b) and 87.263(1) of the FCC's Rules to Allow Use of the Lower 136 MHz Band by Aeronautical Enroute Stations	)	RM-11818
	)	
Petition of Airports Council International-North America Regarding Aeronautical Utility Mobile Stations	)	RM-11832

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 June 6, 2019, *Notice of Proposed Rulemaking* (*NPRM*) in the above-captioned docket. In these Comments, CORF discusses the nature of observations by the Radio Astronomy Service (RAS) in the 92-95.5 GHz band, most of which is allocated on a primary basis to the RAS. Due to the

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

high potential for radio interference from airborne radar systems in standard atmospheric conditions, CORF does not support the designation of Radionavigation as a co-primary allocation (as opposed to a secondary allocation) in this frequency range. However, CORF notes that radio astronomy facilities are unlikely to be in operation in this frequency band during times of high wind, fog, heavy precipitation, and high atmospheric opacity, and thus recommends that, should the proposed rules be enacted, use of airborne radars must be limited to times when the atmospheric opacity at the relevant radio astronomy site is greater than at least 1.2 dB/km at 92-95.5 GHz. CORF generally supports the sharing of spectrum, where practical, but in enacting the rules in this proceedings, the protection of passive scientific observations must be addressed.

I. The Role of Radio Astronomy, the Importance of Observations at 92-95.5 GHz, and the Special Vulnerability of Passive Services to Interference.

CORF has a substantial interest in this proceedings, as it represents the interests of scientific users of the radio spectrum, including users of the RAS, in this frequency band. These users perform extremely important, yet vulnerable, research.

As the Commission has 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 Nobel Prize–winning discovery of pulsars by radio astronomers has led to the recognition of a widespread 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, which was recognized with the awarding of another Nobel Prize. 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 the Milky Way galaxy. Radio spectroscopy and broadband continuum observations have identified and characterized the birth sites of stars in the Milky Way, the processes by which stars slowly die, and the complex distribution and evolution of galaxies in the universe. The enormous energies contained in the enigmatic quasars and radio galaxies discovered by radio astronomers have led to the recognition that most galaxies, including 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.

At issue in this proceedings is the 92-95.5 GHz band. This band is a subset of a wide frequency range allocated on a co-primary basis to RAS in the 3-mm atmospheric window (Figure 1), which is used for observations of continuum and spectral line emission from cosmic sources due to the relative atmospheric transparency in this spectral region. Indeed, the 92-95.5 GHz band is included in one of the bands preferred for continuum observations. See *Handbook on Radio Astronomy* (ITU Radiocommunications Bureau, 2013) at page 35, Table 3.1. Furthermore, as noted in previous CORF filings regarding this frequency band,[2] the molecular spectral lines at millimeter wavelengths are among the most important for studies of interstellar clouds that are the precursors to the formation of stars and planets. One example of such a spectral line is diazenylium (N_2H^+) at 93.174 GHz. *Id* at page 37, Table 3.2.

[2] CORF filing on Allocations and Service Rules for the 71-76, 81-86, and 92-95 GHz Bands, WT Docket No. 02-146, Dec 18, 2002, https://ecfsapi.fcc.gov/file/6513399916.pdf.

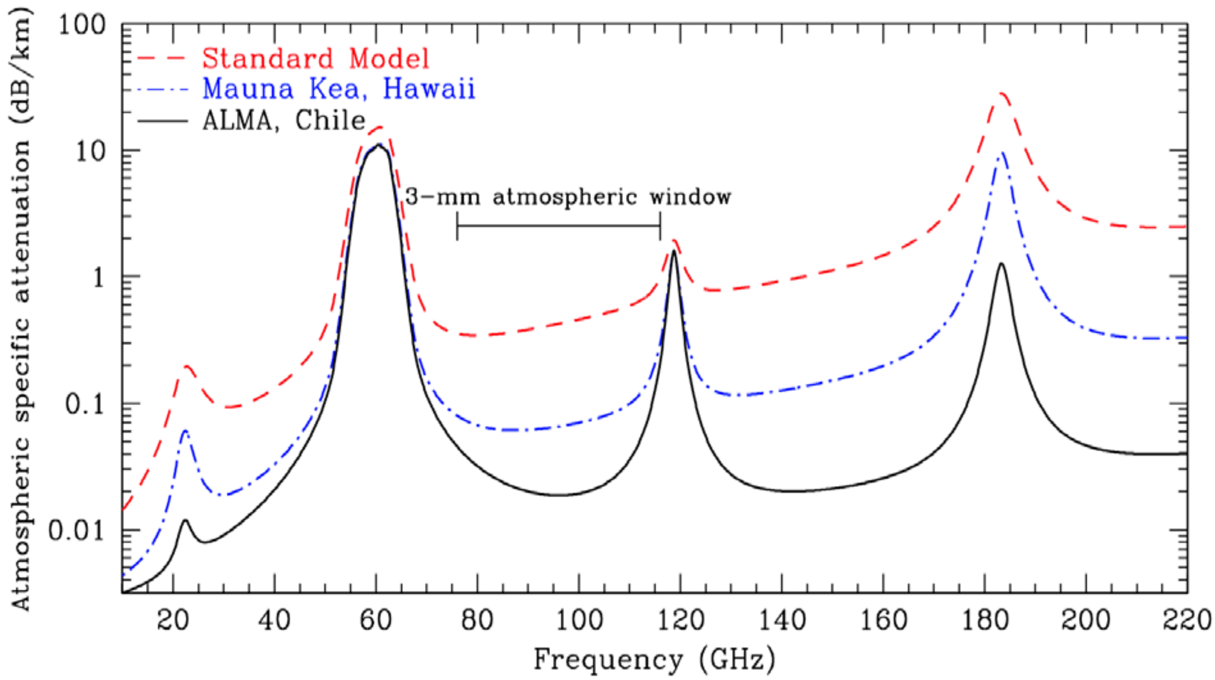

FIGURE 1 Nestled between the oxygen band complexes at 60 and 118 GHz, the 3-mm atmospheric window is a region of relatively good transparency, particularly at the high, dry sites selected for most millimeter-wave radio telescopes, such as Mauna Kea, Hawaii, and the Atacama desert in Chile, the location of the Atacama Large Millimeter/sub-millimeter Array (ALMA), for which the United States is a major partner. The attenuation curves shown here are based on the ITU-R P.676-11 formulation of specific attenuation from atmospheric gases. At 94 GHz, the standard atmosphere model has an attenuation of 0.4 dB/km. On a typical night at Mauna Kea, the atmospheric attenuation is substantially less than this (0.06 dB/km for the conditions at 10 UT on March 5, 2018), and the top 10% conditions at ALMA are even more transparent. Given the favorable atmospheric transparency and the scientific value derived from observations of the wealth of molecular lines that emit in this spectral region, the Radio Astronomy Service is allocated co-primary status in the *US Table of Frequency Allocations*[3] throughout most of the 3-mm atmospheric window.

In addition, due to the expansion of the universe, spectral lines that are emitted at short wavelengths are shifted to longer wavelengths ("redshifted") so the observed frequency of such a line from a cosmic source may be significantly lower than the emitted frequency. The magnitude of this shift is proportional to the distance, and the greatest sensitivity to the most distant objects

[3] See https://transition.fcc.gov/oet/spectrum/table/fcctable.pdf.

occurs at the frequency where the intrinsically brightest lines appear. As it happens, many of the spectral lines of particular importance for studies of distant galaxies are those of carbon monoxide, with a range of isotopes, for which the rest frequencies (i.e., without redshift) lie in the range of 109-116 GHz. However, redshifts due to the expansion of the universe bring these lines into the frequency range at issue in this proceedings for many distant galaxies. Indeed, modern instruments on millimeter radio telescopes are designed to conduct observations of the entire 3-mm atmospheric window to measure the spectral lines from distant galaxies in order to study the evolution of galaxies over cosmic time.

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, including emissions that produce harmonic signals in the RAS bands, even if those human-made emissions are weak and distant.

II. Protection of Radio Astronomy at 92-95.5 GHz and Specific Proposals in the NPRM.

In paragraph 12 of the *NPRM*, the Commission seeks comments on the assertions by Sierra Nevada Corporation that “the Enhanced Flight Vision System product would be able to co-exist successfully with other users in this band because: (1) the device will be used only under adverse conditions and operate at low power, low altitude, and for short duration; (2)

transmissions in the 92-95.5 GHz band are characterized by severe propagation losses; and (3) currently there are very few users of the band." As delineated in more detail below, each of these assertions is problematic. In addition, RAS is an incumbent user of this band with regulations that require coordination within specified distances of designated radio astronomy observatories (US Footnote 161). It is unclear from the provided material on the docket how such coordination would take place for aircraft in the process of approach and landing at an airport within these coordination zones.

A. The Radio Astronomy Service Is an Incumbent User of 92 – 95.5 GHz.

At the present time, four single-dish radio astronomy sites in the United States are equipped with receivers that operate at 92-95.5 GHz: The Arizona Radio Observatory 12m telescope at Kitt Peak, Arizona, the Green Bank Telescope (GBT) at Green Bank, West Virginia, Haystack Observatory at Westford, Massachusetts, and the Caltech Observatory at Owens Valley, California. In addition, the majority of the 10 stations of the Very Long Baseline Array (VLBA) operate in this frequency band. In the future, the Next Generation Very Large Array (ngVLA),[4] an extension of the Very Large Array (VLA), will be designed to observe in this frequency band as well. All of the existing sites, and others that observe in the harmonics of the relevant bands, are listed in Footnote US 161 and are designated as locations for which coordination between other services and RAS is required. As RAS is an incumbent user of this band, there is significant concern that designation of additional co-primary services, such as aeronautical radionavigation, could interfere with passive (receive-only) use. Indeed, as noted in

[4] The ngVLA is currently being developed by the National Radio Astronomy Observatory (NRAO). This new facility will be able to observe up to 116 GHz. The current ngVLA design is centered at the location of the current VLA on the Plains of San Agustin, New Mexico, and includes more than 200 dishes to be located in New Mexico, Texas, and Mexico. See http://ngvla.nrao.edu/page/about.

the FCC's original Report & Order for 92-94 GHz and 94.1-95 GHz (para 25),[5] "radio astronomers must observe radio waves of cosmic origin at frequencies over which they have no control. We understand that due to the extremely low levels of the signals to be observed, sharing a frequency band with other services which operate at thousands of times higher levels poses a unique challenge. We agree that adequate protection methods must exist for the RAS to operate." CORF appreciates the Commission's continued recognition of the importance to protect RAS and the prior designation of co-primary services that are compatible with radio astronomy observations in this frequency band. CORF does not recommend modifying the Federal Table of Allocations to include co-primary services that are likely to produce radio frequency interference into RAS receivers under standard atmospheric conditions, as this would be inconsistent with past decisions by the Commission.

B. Coordination Zones to Protect the Radio Astronomy Service at 92-95.5 GHz Are Between 25 km to 150 km.

As millimeter-wave radio telescopes are designed to detect faint cosmic sources, they are extremely vulnerable to human-made emissions, even in regions of the radio spectrum where there is significant atmospheric attenuation. At 92-95.5 GHz, the ITU-R RA.769 emission limit that is harmful to radio astronomy observations is −228 dB((W/(m^2 Hz)) for continuum observations and −208 dB((W/(m^2 Hz)) for spectral line observations. To protect radio astronomy observatories from unwanted emissions, US Footnote 161 designates coordination zones for each millimeter-wave radio astronomy site. For single-dish radio telescopes, the coordination zone is for applicable services within 150 km of the radio astronomy observatory, while a 25 km coordination zone is designated for the 10 sites of the VLBA.

[5] *Allocation and Service Rules for the 71-76 GHz, 81-86 GHz, and 92-95 GHz Bands*, Report and Order, 18 FCC Rcd. 23318, 23338 (2003).

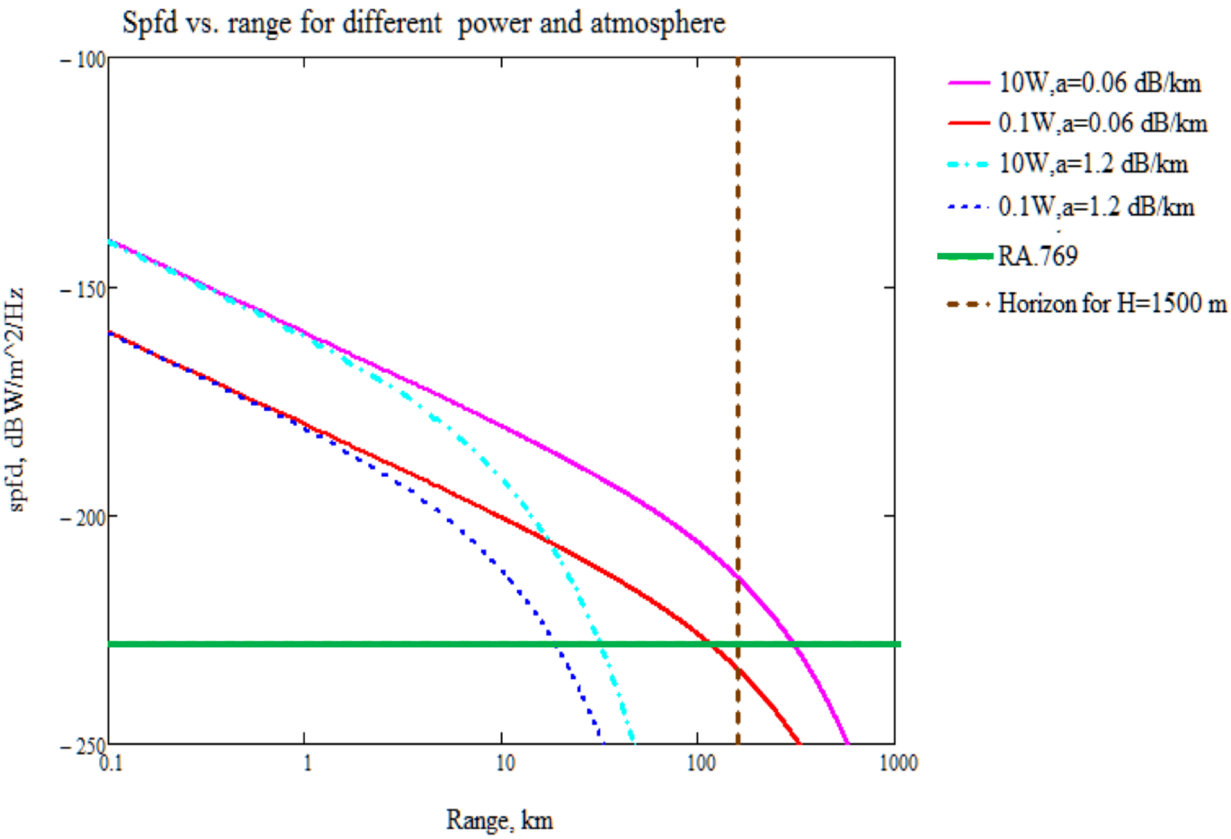

FIGURE 2 Illustration of the sensitivity of radio astronomy observatories at 94 GHz to human-made emissions. Under atmospheric conditions common to sites of millimeter radio telescopes (a = 0.06 dB/km), separation distances of over 100 km are required between radio astronomy observatories and transmitting devices. US Footnote 161 designates coordination zones of 150 km around each single-dish millimeter-wave radio astronomy observatory within the United States. While these sites do experience times of higher atmospheric attenuation, even an example of the atmospheric attenuation from a hot and humid day (a = 1.2 dB/km) still requires separation distances of several tens of kilometers due to the sensitivity of radio telescopes designed to detect faint cosmic sources. For reference, the standard atmosphere model (a = 0.4 dB/km) falls between these two examples.

As an illustration of the need for such large coordination zones, even in a region of the radio spectrum with significant atmospheric attenuation, Figure 2 shows the spectral power flux density (spfd) for two examples of atmospheric attenuation (0.06 and 1.2 dB/km) and power level of an emitting device (0.1 W and 10 W).[6] As expected, atmospheric attenuation is significant at 94 GHz, but the emission still exceeds the ITU-R RA.769 levels beyond the horizon distance for atmospheric conditions associated with the high, dry sites selected for most millimeter-wave radio telescopes and at distances of tens of kilometers under the typical atmospheric conditions experienced at many sites on a humid summer day, for example in Washington, D.C.

Thus, while the Sierra Nevada Corporation's assertion that "transmissions in the 92-95.5 GHz band are characterized by severe propagation losses" has relative merit, the coordination zones listed in US 161 are still relevant for this proceedings. In particular, relevant major commercial airports include Tucson International (TUS) and Boston Logan (BOS) within the coordination zones of the Kitt Peak 12m telescope and Haystack Observatory, respectively. A more complete listing of airports within the coordination zones of all radio astronomy observatory sites listed in US 161 is provided in Appendix B. Neither Sierra Nevada Corporation's *Petition for Rulemaking* nor this *NPRM* provide a clear plan for how aircraft approaching or landing at airports within the coordination zones listed in US 161 should coordinate with the radio astronomy facilities[7] before using Enhanced Flight Vision System (EFVS) products at 94 GHz. Such a plan must be in place before use of airborne radars at 94 GHz is authorized, as airborne transmissions at this frequency as aircraft approach nearby

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[6] In the absence of technical details regarding the proposed airborne radars at 94 GHz, this calculation assumes a steady stream of aircraft emitting with a bandwidth of 3 GHz (92.5-95.5 GHz), which is diluted into the radio astronomy receiver's 8 GHz IF bandwidth and is detected within the 2000 s integration time of ITU-R RA.769. The bandwidth considerations reduce the *effective* total transmitted power for comparison with the ITU-R RA.769. threshold levels. This calculation also includes an assumption that the radio telescope receives the radar emission in the telescope's 0 dBi sidelobe, not the main beam, and that the transmitter has an antenna gain of 0 dBi, corresponding to an average sidelobe response of the transmitter antenna. Note that this means that the transmitter will be causing radio frequency interference whenever it is activated, not just when the main beam of the transmitter points towards the radio astronomy observatory. See Appendix F of *Handbook of Frequency Allocations and Spectrum Protection for Scientific Uses, Second Edition* (2015, National Academies Press) for a detailed explanation of the 0 dBi assumption for calculations of potential radio interference to RAS facilities.

[7] CORF recommends that coordination be arranged through the Electromagnetic Spectrum Management Unit of the National Science Foundation, esm@nsf.gov.

airports are likely to interfere with radio astronomy observations except in the most extreme atmospheric conditions. However, CORF notes that one possible example of a coordination plan is to restrict use of EFVS products at 94 GHz to only the most extreme atmospheric conditions.

Finally, as noted at paragraph 12 in the *NPRM*, Footnote US 342, which applies to nearly all of this frequency range, requires that all practicable steps be taken to protect the RAS from harmful interference and correctly notes that "[e]missions from spaceborne or airborne stations can be particularly serious sources of interference to the radio astronomy service." At the minimum, before new services are allocated co-primary status for frequency bands protected by US 342, there should be evidence on the record that the new applications, under the conditions proposed, are compatible with the other primary services. In this instance, no such studies have been performed.

C. Special Vulnerability of Radio Astronomy to Airborne Emitters.

As the Commission has long recognized, the RAS is particularly vulnerable to airborne and space-borne emitters since radio telescopes cannot use geographical shielding to mitigate emission from high-altitude sources. Indeed, as noted by Sierra Nevada Corporation in their *Petition for Rulemaking*, Part 15 devices operating at 92-95.5 GHz are restricted to indoor use and are prohibited from airborne uses (page 14). Such restrictions on locations of use enable effective sharing of spectrum between RAS and other services.[8] However, almost by their very definition, radars mounted on aircraft are not compatible with RAS in standard operating conditions. In their *Petition for Rulemaking*, Sierra Nevada Corporation indicate that EFVS are designed to be low-altitude, short range systems (page 9) and that for rotorcraft the EFVS "likely

[8] As noted in *Allocation and Service Rules for the 71-76 GHz, 81-86 GHz, and 92-95 GHz Bands*, Report and Order, 18 FCC Rcd. 23318, 23338 (2003), para 38: "The Commission found that this prohibition on airborne and spaceborne use is necessary to protect in-band RAS observations."

would be used no more than 1,000 feet from the ground for a duration of approximately 30-60 seconds.” (page10). These heights eliminate the protective geographic shielding afforded some radio astronomy sites.

In addition, while the current proposed use of 94 GHz airborne radars is under poor weather conditions, it should also be noted that it is common for technological advances to result in applications under conditions that were not originally envisioned. For example, while CORF is not an expert in aviation software, one extrapolation of the current technology under development for EFVS products is the potential of their use not only during poor weather conditions but also as part of an auto-pilot system, just as car-based radars are now being deployed as part of a self-driving car revolution. Thus, without specific regulations in place to limit the conditions under which airborne radars may be employed, an allocation of co-primary status for Radionavigation in these frequency bands could result in normalizing use of airborne radars, even at times of atmospheric transparency. If such a change is made to the Federal Table of Allocations, CORF urges the Commission to include specific requirements in Part 87 to limit the atmospheric conditions when airborne radars may be used and to require any future modifications of those conditions be posted for public comment.

D. Harmonics from 94 GHz Radars Are Potential Sources of Interference at 185-191 GHz.

While the primary consideration for the proposed use of airborne radars at 94 GHz is the potential source of interference from direct in-band emissions, additional points of concern are the harmonics that may be emitted at 185-191 GHz, if not properly filtered. The 183-191 GHz frequency band is allocated to the Earth Exploration Satellite Service (EESS) (passive) on a co-primary basis; furthermore, 190-191.8 GHz is protected by US Footnote 246, which states that no station shall be authorized to transmit in the specified bands. These frequencies are used to measure atmospheric moisture by using passive radiometric observations on or near the 183.31 GHz H_2O line (by, e.g., the Advanced Microwave Sounding Unit-B, Advanced Technology Microwave Sounder, Global Precipitation Measurement Microwave Imager, and Microwave Humidity Sounder). Observations near the 183-GHz line are particularly important, because recent work to assimilate these measurements into numerical weather prediction models has shown profound improvements in forecast accuracy in cloud- and rain-impacted atmospheres. While the EFVS radars are expected to be pointed toward the Earth, the reflected signal may be detected by the EESS passive sensing instruments, which have very wide fields-of-view and are, therefore, subject to interference from multiple airports at any given time. Thus, any implementation of airborne radars at 94 GHz must include significant attention to reduction of out-of-band emissions, with particular consideration of the harmonic frequencies.

E. While Airborne Radars at 94 GHz Are Incompatible with the Radio Astronomy Service Under Standard Atmospheric Conditions, Coordination May Be Possible During Times of Extremely High Atmospheric Opacity.

As illustrated in Figure 2 above, millimeter-wave radio telescopes are extremely vulnerable to human-made radio interference, and therefore require large coordination zones to ensure compatibility between services. However, to protect their sensitive equipment, most radio telescope facilities do not operate when the weather conditions are unfavorable, including times of high wind, blowing dust, fog, and precipitation. Similarly, RAS operations are often curtailed during times of high atmospheric opacity, as severe atmospheric attenuation reduces the feasibility of observations of faint cosmic sources. Thus, in these extreme conditions, i.e., when radio astronomy facilities are unlikely to be collecting data, it would be possible for other services to operate without causing interference to RAS observations.

As stated in paragraph 9 of the *NPRM*, Enhanced Flight Vision Systems are "airborne systems that supplement instrument landing systems in limited visibility environments (such as fog, haze, smoke, sand, and precipitation)." As a general context, these are weather conditions that are also problematic for radio astronomy observations. It should also be noted, however, that local weather conditions at a nearby airport may be substantially different than those at the millimeter-wave radio telescope. For example, the high-altitude radio astronomy site at the top of Mauna Kea, Hawaii, may have excellent atmospheric conditions, while the low-lying Hilo airport may be overcast with precipitation. These localized atmospheric conditions are also common in the Southwest where, for example, radio frequency interference may be received at Kitt Peak, Arizona, from planes on approach and landing at Tucson International Airport. Thus, a local measurement of the atmospheric attenuation may not be sufficient to give a realistic estimate of the average atmospheric attenuation over the total path to the observatory. Consideration of atmospheric restrictions for when EFVS may be operated should therefore consider not only the environment at the airport, but also at the nearby observatory site.

However, as also noted by Moog, Inc.,[9] neither the *NPRM* nor the *Petition for Rulemaking* by Sierra Nevada Corporation provide sufficient technical details to evaluate compatibility between services. A full compatibility study requires information regarding the operational parameters of the radar (power, scan pattern, etc.) and the atmospheric conditions under which it would be permitted to operate. Despite this lack of technical detail, based on the analysis above, CORF estimates that an atmospheric attenuation of at least 1.2 dB/km is necessary to protect Haystack Observatory from a steady stream of 10 W airborne radars approaching the Manchester Airport (with a distance between MHT and Haystack of only 35 km,

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[9] Letter of Moog, Inc., May 28, 2019, WT Docket No. 19-140, https://ecfsapi.fcc.gov/file/105290442130539/FCC%20letter%2028_05_2019.pdf.

this is one of the closest major commercial airports to one of the radio astronomy sites listed in US 161). However, it should also be noted that there are at least 483 registered airports, airfields, heliports, balloonports, glideports, stolports, and ultralight landing facilities within the 150 km coordination zone for Haystack Observatory, which could result in aggregate interference at the observatory site from multiple planes at multiple airports. If permission is granted to operate airborne radars, a more complete analysis using the actual technical parameters and expected flight density should be completed to determine the appropriate operating conditions. Furthermore, as noted above, these operating limitations must be included in the Part 87 rules and should not be modified without further consultation.

III. Conclusion

CORF generally supports the shared use of spectrum, where practical. CORF acknowledges the statements made regarding the potential benefits of the radar uses proposed in this proceedings. Nevertheless, in light of the primary allocations to RAS and in the general use-cases in which radars could cause interference to radio astronomy observations in the 92-95.5 GHz band, protection of radio astronomy must be addressed in this proceedings. Specifically, in a general use-case under typical atmospheric conditions, RAS and Radionavigation are not compatible services. Exceptions, where use of airborne radars is limited to times of extremely high atmospheric attenuation, may be made, but consideration of RAS vulnerabilities must be taken into account and the Federal Table of Allocations should not be modified for a co-primary service for such limited use cases. In addition, specific plans must be designated to enable coordination between use of EFVS products at 94 GHz during approach and landing at airports located within the coordination zones of the radio astronomy observatories listed in US 161.

Respectfully submitted,

NATIONAL ACADEMY OF SCIENCES'
COMMITTEE ON RADIO FREQUENCIES

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Appendix A

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Appendix B

Distances Between Radio Astronomy Observatories and Nearby Airports

US Footnote 161 requires coordination between services within either 25 km (VLBA stations) or 150 km (single-dish facilities) of the following radio astronomy observatories. Distances between these radio astronomy observatories and all airports within the coordination zone have been calculated using point distance in ArcMap 10-6.

A. Telescope Sites with Coordination Distances of 150 km

Kitt Peak, AZ. Arizona Radio Observatory 12 m telescope located at latitude = 31:57:12, longitude = −111:36:53, elevation = 1,914 m. A total of at least 65 airports, airfields, heliports, balloonports, glideports, stolports, and ultralight landing facilities are located within 150 km of Kitt Peak. The larger facilities are listed below; major commercial or military airports are shown in boldface font.

Airport	Latitude	Longitude	Elevation (m)	Distance (km)
Sells Airfield (E78)	31.932583	−111.894250	734	27
Ryan Field (RYN)	32.142222	−111.174583	737	47
Marana Regional (AVQ)	32.409556	−111.218389	619	63
Tucson International Airport (TUS)	32.116084	−110.941015	806	66
Pinal Airpark (MZJ)	32.509833	−111.325333	577	68
Davis Monthan Air Force Base (DMA)	32.166364	−110.883170	824	73
Nogales International Airport (OLS)	31.417722	−110.847889	1205	94
Casa Grande Municipal (CGZ)	32.954889	−111.766833	446	112
Sierra Vista Municipal (FHU)	31.588472	−110.344389	1438	127

Gila Bend Air Force Base Aux (GXF)	32.887847	−112.719610	269	147
Chandler Municipal Airport (CHD)	33.269111	−111.811111	379	147

Owens Valley, CA. Caltech Telescope located at latitude = 37:13:54, longitude = −118:17:36, elevation = 1,222 m. A total of at least 56 airports, airfields, heliports, balloonports, glideports, stolports, and ultralight landing facilities are located within 150 km of Owens Valley. The larger facilities are listed below; major commercial or military airports are shown in boldface font.

Airport	Latitude	Longitude	Elevation (m)	Distance (km)
Bishop (BIH)	37.373111	−118.363611	1257	16
Mammoth Yosemite (MMH)	37.624056	−118.838750	2175	65
Stovepipe Wells (L09)	36.603833	−117.159222	8	122
Fresno Yosemite International (FAT)	36.776556	−119.718833	102	136
Beatty (BTY)	36.861139	−116.786389	966	140
Tonopah (TPH)	38.060194	−117.086806	1655	140
Visalia Municipal (VIS)	36.318639	−119.392861	90	141

Westford, MA. Haystack Observatory located at latitude = 42:37:24, longitude = −71:29:18, elevation = 131 m. A total of at least 483 airports, airfields, heliports, balloonports, glideports, stolports, and ultralight landing facilities are located within 150 km of Haystack Observatory. The larger facilities are listed below; major commercial or military airports are shown in boldface font.

Airport	Latitude	Longitude	Elevation (m)	Distance (km)
Boire Field (ASH)	42.7824134	−71.514094	61	18
Minute Man Airfield (6B6)	42.460640	−71.517832	82	18
Fitchburg Municipal (FIT)	42.554111	−71.758972	106	23

Laurence G. Hanscom Field (BED)	42.469944	−71.289000	40	24
Lawrence Municipal (LWM)	42.717086	−71.123556	45	32
Manchester (MHT)	42.932806	−71.435750	81	35
Gardner Municipal (GDM)	42.549889	−72.016028	291	44
Jaffrey Airport – Silver Ranch (AFN)	42.805134	−72.003022	317	47
Beverly Regional (BVY)	42.584139	−70.916139	33	47
General Edward Lawrence Logan International Airport (BOS)	42.362944	−71.006389	6	49
Worcester Regional (ORH)	42.267139	−71.875611	308	51
Norwood Memorial (OWD)	42.190528	−71.172944	15	55
Plum Island (2B2)	42.795361	−70.839444	3.4	56
Concord Municipal (CON)	43.202722	−71.502278	104	64
Orange Municipal (ORE)	42.570000	−72.288500	169	66
Dillant-Hopkins (EEN)	42.898389	−72.270778	149	71
Southbridge Municipal (3B0)	42.101111	−72.038833	213	74
Portsmouth International At Pease (PSM)	43.077944	−70.823278	31	74
Turners Falls (0B5)	42.591611	−72.523000	109	85
Skyhaven (DAW)	43.284235	−70.929550	98	86
Toutant (C44)	41.955694	−72.054361	235	88
Marshfield Municipal–George Harlow Field (GHG)	42.097499	−70.673020	3	89
Taunton Municipal–King Field (TAN)	41.874467	−71.016316	13	92
Danielson (LZD)	41.819750	−71.900972	72	96
Northhampton (7B2)	42.328010	−72.611240	37	98

Westover ARB/Metro (CEF)	42.194015	−72.534784	74	98
Theodore Francis Green State, Providence (PVD)	41.722333	−71.427722	16	100
Plymouth Municipal (PYM)	41.908617	−70.727685	45	101
Laconia Municipal (LCI)	43.573042	−71.417842	166	106
Sanford Seacoast Regional (SFM)	43.393806	−70.708000	74	106
Claremont Municipal (CNH)	43.370504	−72.368207	166	110
Windham (IJD)	41.744028	−72.180222	75	113
Westfield-Barnes Regional (BAF)	42.157944	−72.715861	82	113
New Bedford Regional (EWB)	41.676566	−70.957836	24	114
Quonset State (OQU)	41.597139	−71.412139	6	114
Harness State (Springfield) (VSF)	43.343722	−72.517278	176	116
Deerfield Valley Regional (4V8)	42.927136	−72.865654	595	117
Provincetown Municipal (PVC)	42.072278	−70.220722	2	121
Newport State (UUU)	41.532440	−71.281544	52	122
Bradley International (BDL)	41.939139	−72.683361	53	124
Richmond (08R)	41.489500	−71.620639	40	126
Moultonboro (5M3)	43.767457	−71.387626	176	127
Lebanon Municipal (LEB)	43.626111	−72.304194	184	130
Plymouth Municipal (1P1)	43.778254	−71.753850	154	130
Cape Cod CGAS (FMH)	41.659139	−70.522806	40	133
Hartford-Brainard (HFD)	41.736722	−72.649444	6	137
Harriman-and-West (AQW)	42.696254	−73.170553	199	138
Westerly State (WST)	41.349633	−71.803417	25	144

Barnstable Municipal-Boardman/Polando Field (HYA)	41.669333	−70.280361	16.5	145
William H Morse State (DDH)	42.891194	−73.246083	252	146
Portland International Jetport (PWM)	43.645644	−70.308616	23.1	148
Pittsfield Municipal (PSF)	42.427620	−73.290840	362	149

Green Bank, WV. Robert C Byrd Telescope located at latitude = 38:25:59, longitude = −79:50:23, elevation = 807 m. A total of at least 169 airports, airfields, heliports, balloonports, glideports, stolports, and ultralight landing facilities are located within 150 km of Green Bank. The larger facilities are listed below; major commercial or military airports are shown in boldface font.

Airport	Latitude	Longitude	Elevation (m)	Distance (km)
Elkins-Randolph Co-Jennings Randolph Field (EKN)	38.889444	−79.857139	606	51
Bridgewater Air Park (VBW)	38.366738	−78.960334	355	77
Greenbrier Valley (LWB)	37.858307	−80.399482	702	80
Shenandoah Valley Regional (SHD)	38.263833	−78.896444	366	84
Summersville (SXL)	38.231639	−80.870806	555	92
North Central West Virginia (CKB)	39.297655	−80.227532	373	102
Luray Caverns (LUA)	38.666710	−78.500835	275	119
Roanoke-Blacksburg Regional/Woodrum Field (ROA)	37.325472	−79.975417	358	124
Charlottesville-Albemarle (CHO)	38.139639	−78.452333	195	125
Raleigh Co Memorial (BKW)	37.787333	−81.124167	763	133
Morgantown Municipal-Walter L Bill Hart Field (MGW)	39.643595	−79.917547	379	135

Lynchburg Regional/Preston Glenn Field (LYH)	37.325389	−79.201222	286	135
Boggs Field (USW)	38.823806	−81.348833	283	138
Virginia Tech/Montgomery Exec (BCB)	37.207639	−80.407833	650	145
Front Royal-Warren Co (FRR)	38.917538	−78.253383	214	148
Gordonsville Municipal (GVE)	38.155996	−78.165780	138	149

Mt. Graham, AZ. Henrich Hertz Submillimeter Observatory located at latitude = 32:42:06, longitude = −109:53:28, elevation = 3,186 m. The SMT does not currently have a receiver that operates at 92-95 GHz, but it has the capability to do so in the future. A total of at least 72 airports, airfields, heliports, balloonports, glideports, stolports, and ultralight landing facilities are located within 150 km of Mt. Graham. The larger facilities are listed below; major commercial or military airports are shown in boldface font.

Airport	Latitude	Longitude	Elevation (m)	Distance (km)
Safford Regional (SAD)	32.853333	−109.635083	969	29
Greenlee Co (CFT)	32.957039	−109.211162	1158	70
Davis Monthan Air Force Base (DMA)	32.166364	−110.883170	824	111
Tucson International Airport (TUS)	32.116068	−110.941015	806	118
Lordsburg Municipal (LSB)	32.333464	−108.691739	1304	120
Marana Regional (AVQ)	32.409556	−111.218389	619	129
Sierra Vista Municipal (FHU)	31.588472	−110.344389	1438	131
Ryan Field (RYN)	32.142222	−111.174583	737	136
Pinal Airpark (MZJ)	32.509833	−111.325333	577	136
Bisbee Douglas International (DUG)	31.468944	−109.603750	1265	139

Mauna Kea, HI. James Clerk Maxwell Telescope (JCMT) located at latitude = 19:49:33, longitude = −155:28:47, elevation = 4,092 m. The JCMT does not currently have a receiver that operates at 92-95 GHz, but it has the capability to do so in the future. A total of at least 15 airports, airfields, heliports, balloonports, glideports, stolports, and ultralight landing facilities are located within 150 km of Mauna Kea. The larger facilities are listed below; major commercial or military airports are shown in boldface font.

Airport	Latitude	Longitude	Elevation (m)	Distance (km)
Bradshaw Army Airfield (BSF)	19.760013	−155.553766	1887	11
Waimea-Kohala (MUE)	20.001327	−155.668107	814	28
Hilo International (ITO)	19.720263	−155.048470	12	49
Mountain View Airstrip (HI23)	19.547526	−155.108338	457	51
Elison Onizuka Kona International At Keahole (KOA)	19.738766	−156.045631	14	63
Upolu Airport (UPP)	20.265194	−155.859944	29	64
Hana Airport (HNM)	20.795637	−156.014438	24	122
Kahului (OGG)	20.898653	−156.430454	16	158

Socorro, NM. The Very Large Array (VLA), with the center located at latitude = 34:04:44, longitude = −107:37:06, elevation = 2,115 m. The VLA does not currently have receivers that operate at 92-95 GHz, but there are plans to do so in the future as part of the Next Generation VLA (ngVLA). A total of at least 41 airports, airfields, heliports, balloonports, glideports, stolports, and ultralight landing facilities are located within 150 km of the center of the VLA. The larger facilities are listed below; major commercial or military airports are shown in boldface font.

Airport	Latitude	Longitude	Elevation (m)	Distance (km)
Socorro Municipal (ONM)	34.022472	−106.903139	1486	66
Belen Regional (BRG)	34.645862	−106.836340	1585	95
Truth Or Consequences Municipal (TCS)	33.235361	−107.269889	1482	99

Grants-Milan Municipal (GNT)	35.167278	−107.902056	1992	124
Albuquerque International Sunport (ABQ)	35.038932	−106.608262	1632	141

B. Telescope Sites with Coordination Distances of 25 km

Kitt Peak, AZ. VLBA located at latitude = 31.57:22.70, longitude = −111:36:44.72 elevation = 1,902 m. There are no major airports located within 25 km of the Kitt Peak VLBA station.

Owens Valley, CA. VLBA located at latitude= 37:13:53.95, longitude= −118:16:37.37, elevation= 1196 m.

Airport	Latitude	Longitude	Elevation (m)	Distance (km)
Bishop (BIH)	37.373111	−118.363611	1257	17

Mauna Kea, HI. VLBA located at latitude = 19:48:04.97, longitude = −155:27:19.81, elevation = 3,763 m.

Airport	Latitude	Longitude	Elevation (m)	Distance (km)
Bradshaw Army Airfield (BSF)	19.760013	−155.553766	1887	12

North Liberty, IA. VLBA located at latitude = 41:46:17.13 longitude = −91:34:26.88, elevation = 222 m.

Airport	Latitude	Longitude	Elevation (m)	Distance (km)
Picayune (IA16)	41.708349	−91.500169	244	9
Green Castle (IA24)	41.755011	−91.727674	229	13
Iowa City (IOW)	41.639778	−91.548139	208	15

The Eastern Iowa (CID)	41.884688	−91.710799	265	17
Rich Field (06IA)	41.841394	−91.834344	268	23
Amana (C11)	41.793583	−91.864772	217	24

Fort Davis, TX. VLBA located at latitude = 30:38:06.11, longitude = −103:56:41.34, elevation = 1,606 m. There are no major airports located within 25 km of the Fort Davis VLBA station.

Pie Town, NM. VLBA located at latitude = 34:18:03.61, longitude = −108:07:09.06, elevation = 2,365 m.

Airport	Latitude	Longitude	Elevation (m)	Distance (km)
Poco Loco (NM66)	34.415183	−108.077000	2262	13
Dream Catcher Ranch (25NM)	34.476944	−108.031111	2210	21

Los Alamos, NM. VLBA located at latitude = 35:46:30.45, longitude = −106:14:44.15, elevation = 1,962 m. The Los Alamos station of the VLBA is currently equipped with a 3 mm-band receiver that only operates below 90 GHz.

Airport	Latitude	Longitude	Elevation (m)	Distance (km)
Los Alamos (LAM)	35.879686	−106.268686	2186	12
Santa Fe (SAF)	35.617111	−106.089417	1935	22

Brewster, WA. VLBA located at latitude = 48:07:52.42, longitude = −119:40:59.80, elevation = 250 m. The Brewster station of the VLBA is currently equipped with a 3 mm-band receiver that only operates below 90 GHz.

Airport	Latitude	Longitude	Elevation (m)	Distance (km)
Anderson Field (S97)	48.104868	−119.720613	280	4

Hancock, NH. VLBA located at latitude = 42:56:00.99, longitude = −71:59:11.69, elevation = 296 m. The Hancock station of the VLBA does not currently have a 3 mm-band receiver.

Airport	Latitude	Longitude	Elevation (m)	Distance (km)
Jaffrey Airport-Silver Ranch (AFN)	42.805134	−72.003022	317	14
Hawthorne-Feather Airpark (8B1)	43.061278	−71.905361	183	16
Windswept (23NH)	43.130278	−72.015000	393	22
Dillant-Hopkins (EEN)	42.898389	−72.270778	149	23

Saint Croix, VI. VLBA located at latitude = 17:45:23.68, longitude = −64:35:01.07, elevation = −15 m. The Saint Croix station of the VLBA does not currently have a 3 mm-band receiver.

Airport	Latitude	Longitude	Elevation (m)	Distance (km)
Christiansted Harbor-Seaplane Base (VI32)	17.747195	−64.704864	0	14
Henry E Rohlsen International Airport (STX)	17.701504	−64.801943	23	25