NATIONAL RADIO ASTRONOMY OBSERVATORY

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National Telecommunications and Information Agency
Department of Commerce

In the matter of

Development of a	)	Regulations.gov
National Spectrum Strategy	)	Docket NTIA–2023–0003

Comments of the
National Radio Astronomy Observatory and Green Bank Observatory

A. The AUI Observatories

NRAO (https://www.nrao.edu) was founded in 1956 with operations in Green Bank, West Virginia. It operates the Jansky Very Large Array of 27 antennas in New Mexico and the Very Long Baseline Array network of 10 antennas spread across the US from the Virgin Islands to Hawaii. NRAO also operates the National Radio Quiet Zone covering some 13,000 sq. miles with its reference point in Green Bank as described in 47 CFR 1.924 of the Federal Communication Commission rules. NRAO is the North American partner in the ALMA mm-wave observatory array of 66 antennas in Chile (https://almascience.nrao.edu).

The Green Bank Observatory https://greenbankobservatory.org/ operates the 100m Robert C. Byrd Green Bank Telescope (GBT) and other instruments on its 2,700-acre campus in Green Bank.

NRAO and GBO are operated by Associated Universities, Inc. (https://www.aui.edu) under cooperative agreements with the National Science Foundation (NSF). Their facilities in the US have been used by 6500 unique observers over the last decade and received 510 proposals for observing time in the past year. The estimated replacement cost of their major instruments is $1.3bln.

The ALMA telescope is an international collaboration, 37.5% of whose funding (from NSF) is managed by NRAO. ALMA was dedicated in 2014 with a construction cost of $1.3bln in then-current dollars. It received 1700 proposals for observing time during the 2022 call for proposals.

The AUI observatories and NRAO's share of ALMA together comprise by far the largest radio astronomy enterprise. NRAO has a 60-year history of involvement in national and international spectrum management, advocating for the protection of the radio astronomy service at home and abroad. NRAO is a frequent commenter in FCC rulemaking proceedings and is uniquely well-positioned to provide comments regarding Development of a National Spectrum Strategy.

B. History

The history of astronomy is the story of discovery of the Universe, our place in it and our understanding of the laws of Nature.

Copernicus deduced that the Earth revolved about the Sun; Galileo discovered the moons of Jupiter and realized there was a solar system of planets with their own moons centered on the Sun. Shapley showed that the Sun and its Solar System were embedded in a vast galaxy like others visible throughout the heavens and Hubble discovered that the Universe of galaxies was expanding. After the discovery of radio astronomy at Bell Labs by Karl Jansky in 1933, Wilson and Penzias (also Bell Labs scientists) discovered the origin of the Universe and its expansion in the "Big Bang". The Event Horizon Telescope recently imaged the shadow of a black hole at radio wavelengths. Optical observations of distant supernovae show that the expansion of the Universe is accelerating, that the Universe will eventually grow empty, cold and dark as stellar energy sources are exhausted, the speed of the expansion approaches the speed of light over short distances and the galaxies lose sight of each other. The Universe began in fire and ends in ice.

Although astronomy is concerned with things that are "out there," it is done here on Earth and it is not a subject of purely historical or philosophical interest. Galileo described the working of gravity and the first formulation of relativity. Newton created calculus and mechanics to describe how his new laws of gravity and motion could predict the return of Halley's comet and the orbital movement of the planets. Einstein's General Relativity explains subtle anomalies in the orbit of Mercury but it also explains why the clocks on GPS satellites run faster than their counterparts on Earth[1].

Modern technology is enabled by physical laws whose discovery was stimulated by astronomical observation.

C. The meaning of spectrum and spectrum access for radio astronomy

The spectrum rubric is increasingly identified with the radio portion of the electromagnetic spectrum, and spectrum access is identified with the provision of spectrum for use by radiocommunication systems that transmit and receive information on modulated radio waves. Spectrum access in this context is a matter of finding frequency bands that can compatibly and reliably be allocated and employed, and putting appropriate hardware in the hands of users. A good example is International Mobile Telecommunications (IMT), mobile service cell phones. Once a user has access to a handset, that user has access to the spectrum.

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[1] The orbits of satellites are determined with reference to the International Celestial Reference System incorporating precise astronomical coordinates of extragalactic radio sources determined by geodetic Very Long Baseline Interferometry conducted at NRAO's VLBA and elsewhere. The usefulness of satellite timing and navigation applications like GPS would be severely compromised without the high precision of VLBA measurements.

Spectrum and spectrum access mean something somewhat different to astronomers who do not create the signals they receive, which are only subject to the laws of Nature.

Radio astronomers cannot control the frequency at which signals are received. Radiation originating in the Milky Way remains Doppler-shifted within +/-0.1% of the frequency at which it is emitted, but cosmic signals from distant sources are Doppler-shifted by factors of 7 or more: Radiation from atomic hydrogen in the Milky Way that would be observed in the protected frequency band at 1400 – 1427 MHz appears below 200 MHz when emitted from a proto-galaxy in the early Universe. The epoch of formation of the first stars and galaxies is predicted to occur at Doppler shifts of 15 or more and would be received below the FM radio band. The discovery of the epoch of formation of the first stars will not occur unless signals can be detected in this frequency range.

Moreover, the diagnostics that radio astronomy uses to trace physical phenomena occur across a range of frequencies that cannot all be allocated to the radio astronomy service. Different cosmic environments support the presence of different mixes of ionized and neutral, hotter and colder, more nearly atomic or molecular gas, whose constituents radiate at characteristic frequencies according to their atomic structure. And the same environment is observed at different frequencies when seen at different distances. Thus, unlike users of other radio services, radio astronomers are forced by the laws of Nature to use spectrum outside allocated frequency bands. The allocated frequency bands are indispensable, but insufficient.

Finally, the means of reception – the large and sometime numerous antennas that comprise a radio telescope – must be situated where detection of cosmic signals is feasible. The atmosphere or ionosphere must be transparent to incoming radiation and the ambient electromagnetic environment must allow extraction of the cosmic signal. To this end, radio observatories are placed in remote areas with associated human and operating costs, and they are occasionally surrounded by radio quiet zones like the National Radio Quiet Zone within which interference from fixed terrestrial transmitters is coordinated away at all frequencies.

D. Existing spectrum regulatory protections for radio astronomy

For later reference, note that there are two regulatory means of protecting radio astronomy's spectrum access: Frequency allocations and a radio quiet zone. \

- About two percent of the spectrum below 86 GHz is allocated exclusively to radio astronomy and other passive services, and a somewhat higher fraction above 86 GHz. Radio astronomy has relatively little spectrum shared with active services below 76 GHz, and more above.
- The National Radio Quiet Zone limits the power flux density that fixed terrestrial transmitters within the Zone may produce at the NRQZ reference point in Green Bank. The quiet zone rules limit the emissions at all frequencies including those not allocated to radio astronomy, but emissions from airborne and spaceborne platforms are not addressed.[2]

[2] In a few instances there is mandatory coordination protecting radio astronomy in allocated bands from mobile or non-terrestrial transmitters at specific locations, see footnotes US 131 and 385 to the US frequency allocation table.

E. Radio astronomy's operating model in the evolving spectrum environment

The operational model of radio astronomy expressed in terms of spectrum access has been to find or create (ie the NRQZ) a site with a clean local electromagnetic environment that allows detection of cosmic signals arising from the sky. This model fails if a) the local environment is not clean or b) a frequency that has been rendered clean in the local environment is used from airborne or spaceborne platforms that radiate above the telescope. Interference arises when a platform-born transmitter illuminates the radio telescope with its main or sidelobe radiation patterns, and/or when the transmitter passes through the main or sidelobes of the radiation pattern of the radio telescope.

For a) it is increasingly recognized that access to modern radiocommunication technology is essential, making the ideal of a clean local environment harder to support because even remote areas used for radio astronomy are not entirely uninhabited. Communication services that could be provided with higher bandwidth over wires and fibers, preserving the electromagnetic environment, may instead be provided only by radio and from satellites.

For b), frequencies that formerly were used only by ground-based applications subject to coordination and/or remoteness are increasingly being used from airborne and/or space-borne platforms. High Altitude Platform Systems (HAPS) at 20-50 km altitude use fixed service frequency bands that previously were used only on the ground. HIBS are IMT base stations on HAPS in mobile service frequency bands, also previously used only on the ground. Mobile service allocations are increasingly being used aeronautically. Fixed service and fixed-satellite service allocations overlap. Frequency bands formerly used by either GSO or nGSO satellites are now used by both. The impending FCC action on Supplemental Coverage from Space (FCC-23-22) will see mobile phones operating as earth stations to communicate with satellites in terrestrial mobile spectrum.

For b) also note that the numbers of satellites are currently increasing by factors of 100 or more. C-band and X-band synthetic aperture radars (SAR), formerly operated in small numbers as flagship missions of national space agencies, are now operated in constellations of dozens by numerous commercial operators. These high-power radars can damage a radio astronomy receiver when they illuminate a radio observatory. Until 2019 the largest satellite constellation was the 75 space stations in low earth orbit operated by Iridium, but OneWeb currently has some 600 in orbit and SpaceX with 4400 in orbit is approved to launch the first 7500 stations of a projected constellation of 30,000. The frequencies used by these satellites have largely been accessible to radio astronomy in most of the sky, but will no longer be usable. NRAO has been coordinating with satellite operators under US 131 (see footnote 2) to lessen the severity of their impact but this addresses only a small part of the more general problem.

F. Future protection of radio astronomy

Radio astronomy is operating productively but there is an impending collision among its needs for spectrum access, deterioration of its operating model, obsolescence of the available spectrum regulatory protections, and the pace of change of radiocommunication technology and spectrum occupation. The operating model is being undercut by rapid technological advancements while construction of new astronomical facilities or renewal of old ones occurs once in a generation. The operating model is also being undercut by the spectrum regulatory actions that accommodate new technology and NRAO comments vigorously in spectrum regulatory proceedings but often without much effect.

Any system of protection for radio astronomy that is based solely on protecting the existing frequency allocations will fail because the allocations to radio astronomy comprise such a small fraction of the spectrum and pressure on the allocated bands from unwanted emissions may be irresistible. An approach based on radio quiet zones seems more suitable, but the NRQZ simultaneously fails to address most uses of the radio spectrum while extending over a geographic area that is far larger than might be needed if it were more appropriately constructed and operated with modern technology.

NRAO suggests that radio telescopes should operate in appropriately-defined geographic zones where their operation is protected (momentarily/dynamically) to the extent required by the actual observations that are being conducted. This might build on nascent efforts toward defining National Radio Dynamic Zones in trading spectrum rights and access among affected parties.

NRAO and GBO stand ready to cooperate with the responsible agencies in achieving this goal.

G. Overhaul of the spectrum regulatory regime

NRAO can cite examples in spectrum regulatory decisions where radio astronomy operations were misunderstood or misconstrued while accommodating potentially-interfering operations from active services. Conversely, NRAO finds that spectrum regulatory proceedings occur with comment periods that are far shorter than the time required to understand the impact of complicated radiocommunication systems.

The current model for regulatory proceedings is that the petitioners and other concerned parties are separate spokes on the regulatory agency's hub, lacking the ability to communicate or collaborate in reaching mutual understanding and an equitable decision. The agency's final recounting of its decision appears as a story of "he said, she said" with the agency choosing one side on an unclear basis. The system should be made more collaborative, more collegial, more comprehensive, better informed and more deliberative.

Given the overwhelming attention to the requests of active services at regulatory agencies, NRAO suggests that ombuds positions be created at spectrum regulatory bodies to ensure that the interests of science (radio astronomy and remote sensing) are adequately considered during spectrum regulatory proceedings. The United States House of Representatives Committee on Science, Space and Technology has repeatedly appealed to the FCC and the White House to provide more effective, evidence-based protection for science in spectrum regulatory proceedings[3].

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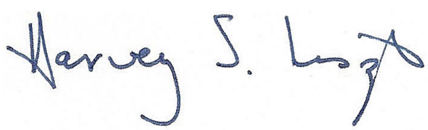
[3] https://republicans-science.house.gov/2021/8/chairwoman-johnson-and-ranking-member-lucas-call-standards-avoid-spectrum
https://republicans-science.house.gov/press-releases?label_id=AA37DF7D-B640-4A8E-9038-6F88544744A1

NRAO suggests that spectrum regulatory agencies should be more actively aware and overtly concerned with the impacts of their actions beyond the narrow remit of making and protecting radio spectrum frequency allocations. Such concerns include the natural environment as it is affected by approval of the launch of tens of thousands of radiocommunication satellites, and effects on disciplines like optical astronomy whose operations are suffering from the negative impacts of Solar light reflections from the many recently-launched satellites. On a hopeful note, recent FCC authorizations to SpaceX and Amazon have required coordination with NSF regarding and Solar light reflections by satellites and an annual report on what the satellite operator is doing to mitigate this optical light pollution. But the FCC's categorical exclusion of satellite activity from the National Environmental Policy Act should be reconsidered[4].

References regarding such spectrum regulatory-adjacent matters may be found in the proceedings of the recent "Dark And Quiet Skies for Science and Society" meetings organized by the International Astronomical Union and the UN Office of Outer Space Affairs[5].

Respectfully submitted,
National Radio Astronomy Observatory



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[4] "Satellite Licensing: FCC Should Reexamine Its Environmental Review Process for Large Constellations of Satellites" https://www.gao.gov/products/gao-23-105005

[5] Dark and Quiet Skies for Science and Society I and II:
https://www.iau.org/news/announcements/detail/ann21002/
https://www.iau.org/news/announcements/detail/ann22002/