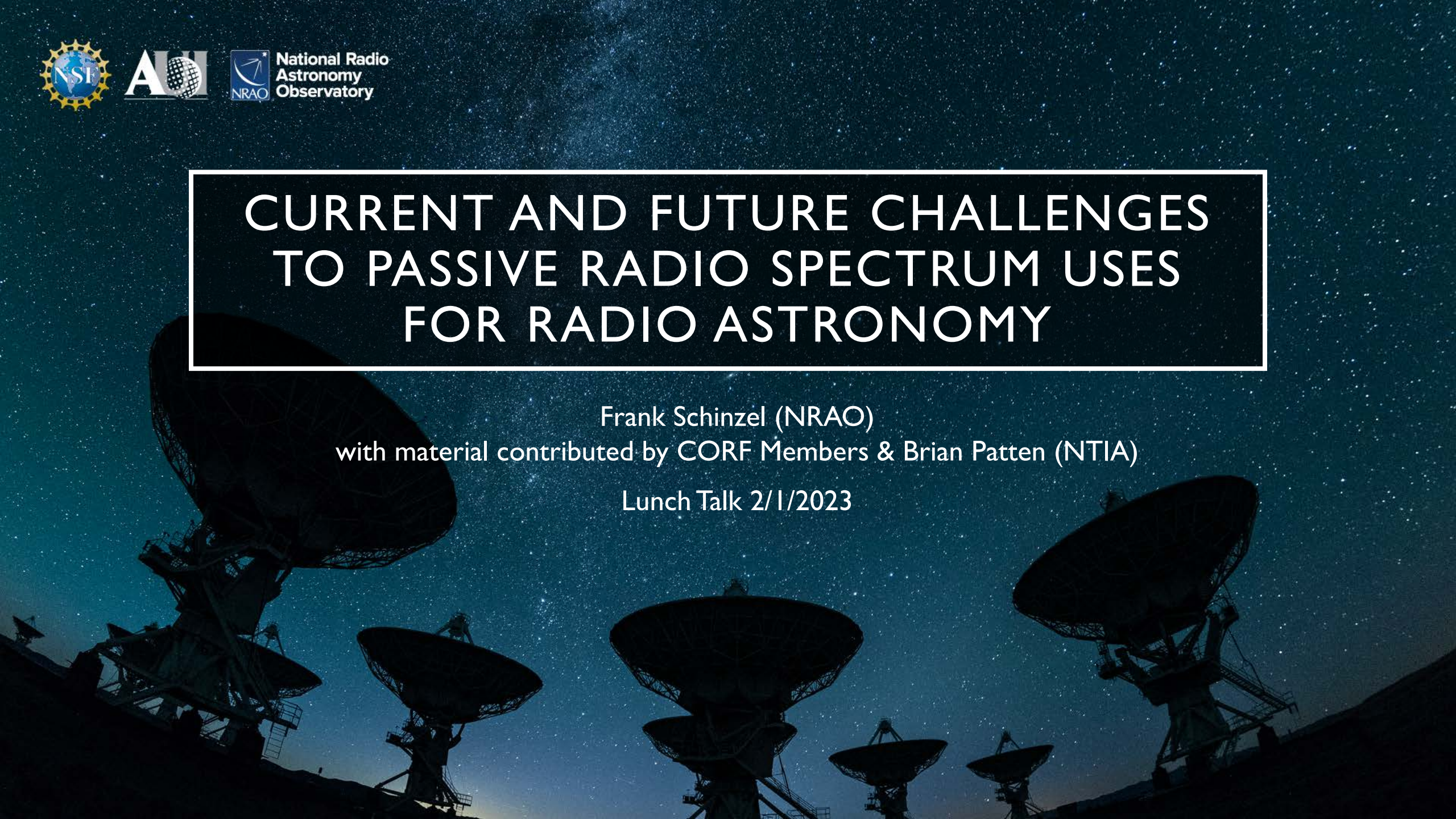


CURRENT AND FUTURE CHALLENGES TO PASSIVE RADIO SPECTRUM USES FOR RADIO ASTRONOMY

Frank Schinzel (NRAO)
with material contributed by CORF Members & Brian Patten (NTIA)

Lunch Talk 2/1/2023

Spectrum Management in a Nutshell

Spectrum Management: minimize interference and ensure efficient use of the radio spectrum

The radio spectrum is shared between commercial, governmental, and scientific users (the latter both "passive" and "active")

Access to Radio Spectrum (active and passive) are codified through radio regulations:

Internationally: International Telecommunication Union (ITU)
Domestically: Federal Communications Commission (FCC)
National Telecommunications and Information Administration (NTIA)

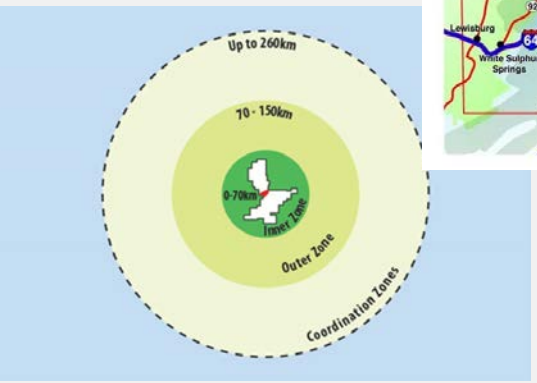
In 1959, World Administrative Radio Conference first recognized the Radio Astronomy Service (RAS), allowing for spectrum allocations and special protections.

There is an ever-increasing commercial demand for and usage of radio frequencies, driven in part by continuing advances in telecommunications technologies.

Current Protections and Tools for RAS

Coordination and Quiet Zones (excludes space applications)

e.g. National Radio Quiet Zone, PR Coordination Zone,
Australian Radio Quiet Zone



Frequency Allocations (mainly for spectral lines; <275 GHz)
and Footnotes (e.g. 5.149, 5.340, 5.565, US246)

~1% of spectrum below 50 GHz are all emissions prohibited

~8% below 100 GHz

Most of radio astronomy is performed in unprotected parts of the spectrum!

Growing danger for RAS and other passive users like Earth Exploration Satellite Services to be crowded out in most places on Earth with staggering demands for wireless services at cm and to a growing extent also at mm-wavelengths.

UNITED STATES FREQUENCY ALLOCATIONS

THE RADIO SPECTRUM

RADIO SERVICES COLOR LEGEND

- AERONAUTICAL MOBILE
- AERONAUTICAL MOBILE SATELLITE
- AERONAUTICAL RADIONAVIGATION
- AMATEUR
- AMATEUR SATELLITE
- BROADCASTING
- BROADCASTING SATELLITE
- EARTH EXPLORATION SATELLITE
- FIXED
- FIXED SATELLITE
- INTER-SATELLITE
- LAND MOBILE
- LAND MOBILE SATELLITE
- MARITIME MOBILE
- MARITIME MOBILE SATELLITE
- MARITIME RADIONAVIGATION
- METEOROLOGICAL
- METEOROLOGICAL SATELLITE
- MOBILE
- MOBILE SATELLITE
- RADIO ASTRONOMY
- RADIODETERMINATION SATELLITE
- RADIOLOCATION
- RADIOLOCATION SATELLITE
- RADIONAVIGATION
- RADIONAVIGATION SATELLITE
- SPACE OPERATION
- SPACE RESEARCH
- STANDARD FREQUENCY AND TIME SIGNAL
- STANDARD FREQUENCY AND TIME SIGNAL SATELLITE

ACTIVITY CODE

- FEDERAL EXCLUSIVE
- FEDERAL/NON-FEDERAL SHARED
- NON-FEDERAL EXCLUSIVE

ALLOCATION USAGE DESIGNATION

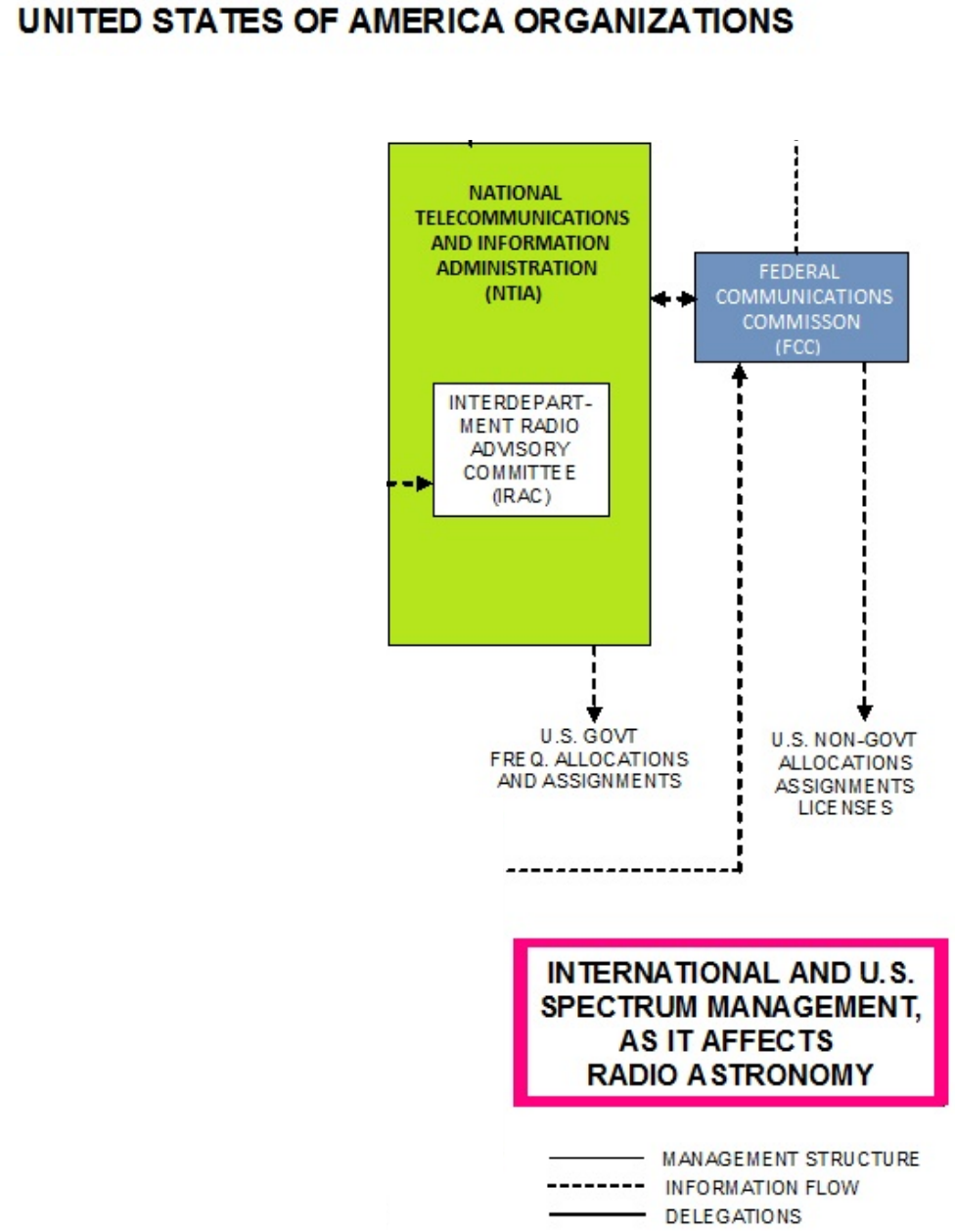
SERVICE	EXAMPLE	DESCRIPTION
Primary	FIXED	Capital Letters
Secondary	Mobile	1st Capital with lower case letters

The chart is a graphic representation of the Table of Frequency Allocations used by the FCC and NTIA. As such, it may not completely reflect all aspects of a footnote and recent changes made to the Table of Frequency Allocations. Therefore, for complete information, users should consult the Table to determine the current status of U.S. allocations.

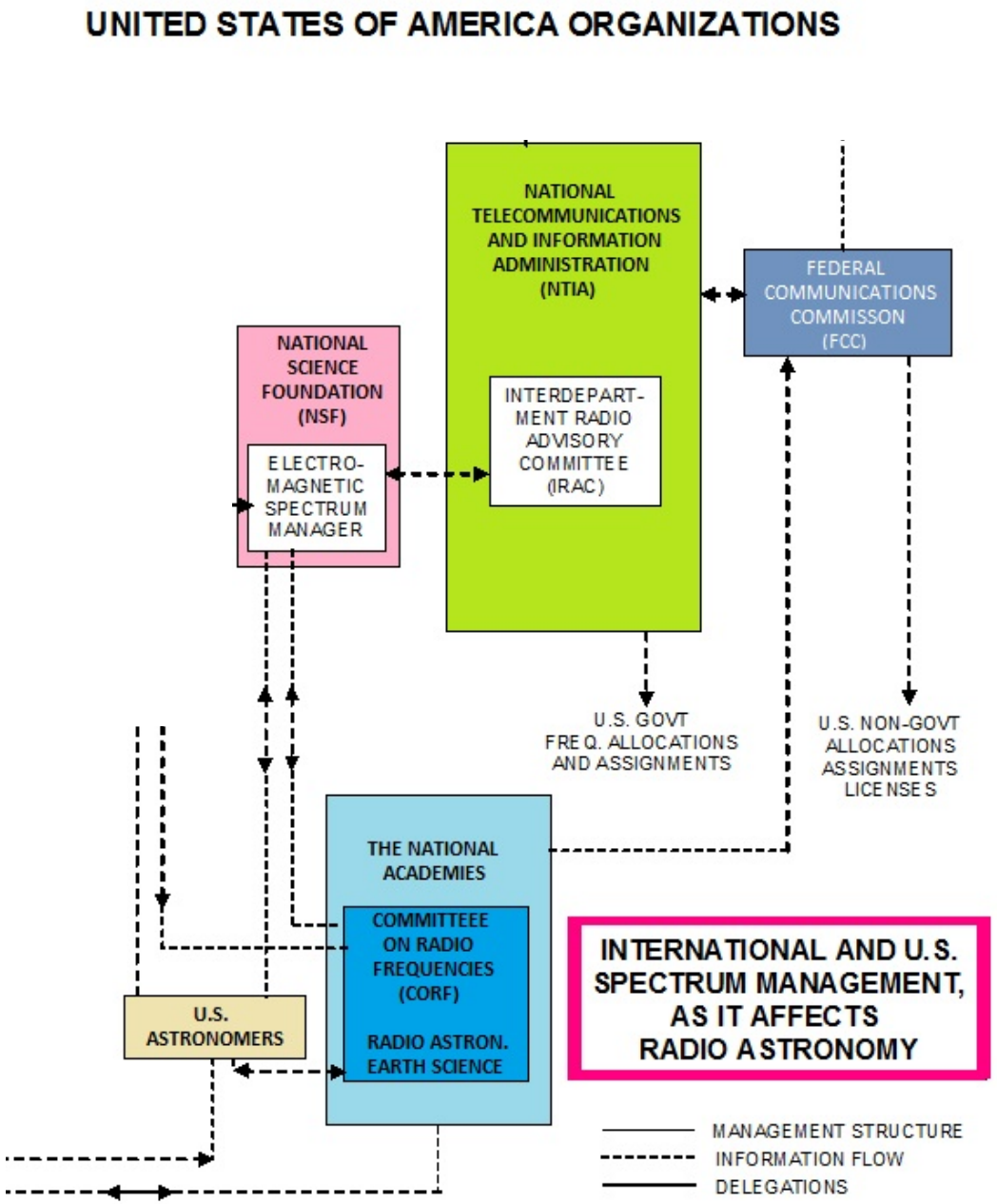
U.S. DEPARTMENT OF COMMERCE
National Telecommunications and Information Administration
Office of Spectrum Management

JANUARY 2016

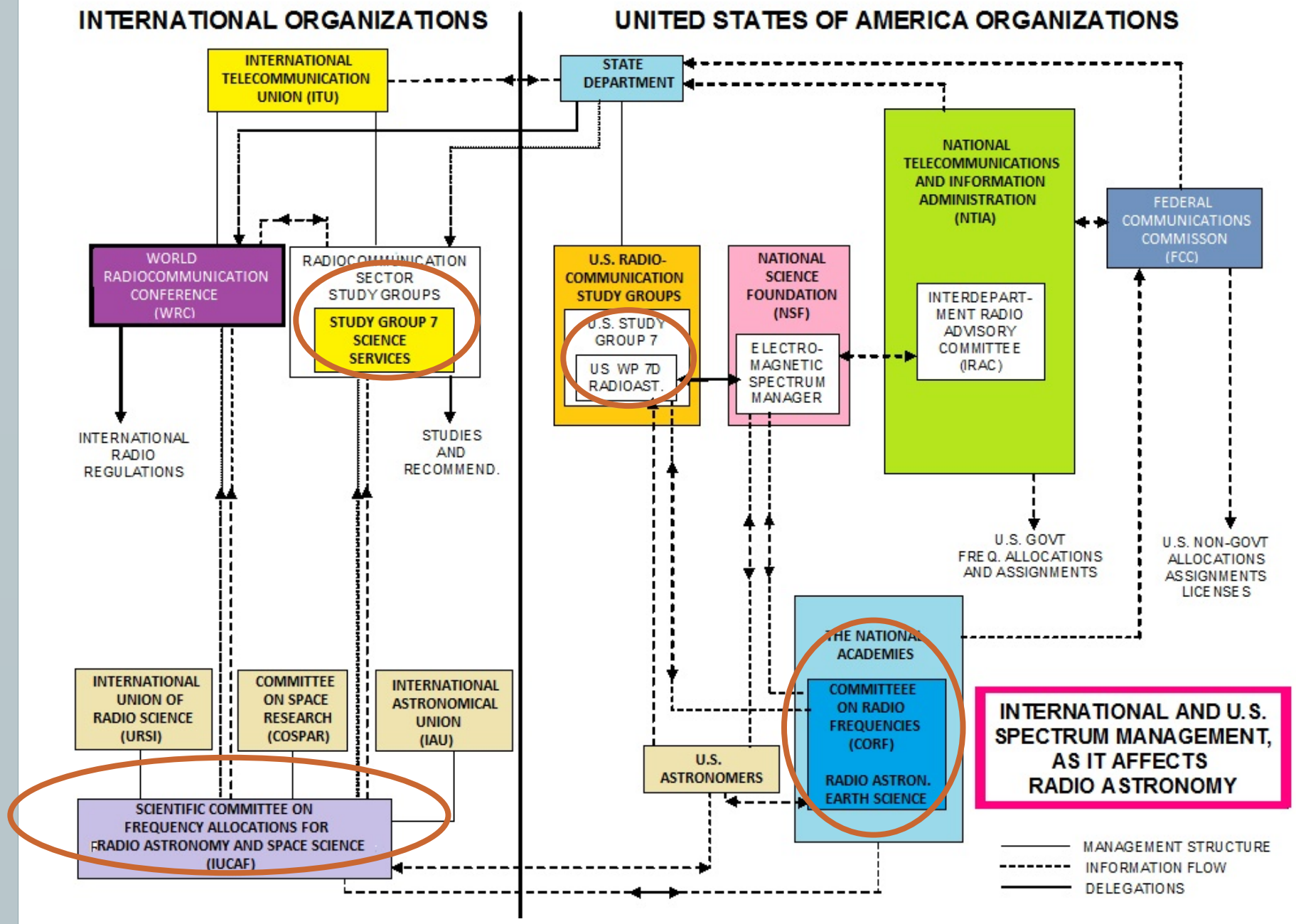
Regulatory Relationships for RAS



Regulatory Relationships for RAS



Regulatory Relationships for RAS



Committee on Radio Frequencies (CORF)

https://www.nationalacademies.org/our-work/committee-on-radio-frequencies

The National Academies of SCIENCES ENGINEERING MEDICINE

CORF considers the needs for radio frequency requirements and interference protection for scientific and engineering research, coordinates the views of the U.S. scientists, and acts as a channel for representing the interests of U.S. scientists

Membership of CORF

Committee Members

Nathaniel Livesey, NASA JPL (Chair) – EESS
Scott Paine, CfA (Vice Chair) – RAS
Nancy Baker, NRL – EESS
Laura Chomiuk, Michigan State – RAS
Dara Entekhabi (NAE), MIT – EESS
Phil Erickson, Haystack Observatory – EESS
Kelsey Johnson, U. Virginia – RAS
Christopher Kidd, GSFC/UMD – EESS
Karen Masters, Haverford – RAS
Mahta Moghaddam (NAE), USC – EESS
Frank Schinzel, NRAO – RAS

Consultants

Darrel Emerson, Ariz., retired – RAS
Tomas Gergely, NSF, retired – RAS
Paul Feldman, Esq., Fletcher, Heald and Hildreth – Legal counsel

Staff

Colleen Hartman, Director, Space, Physics, and Aeronautics
Neeraj Gorkhaly, Linda Walker

Roles of CORF

- CORF represents interests of U.S. researchers using radio frequencies: both radio astronomers and Earth scientists
- CORF coordinates the views of U.S. scientists and acts as a channel to represent their interests
- CORF recommends requirements and limits necessary to protect scientific use of the radio spectrum from interference
  - This is largely through filing comments in public proceedings of the Federal Communications Commission (FCC)
  - Comments are drafted by CORF and its legal counsel, then reviewed per standard NAS protocols and approved and signed by the NAS President
- CORF also performs specific studies, maintains a Handbook and conducts various forms of outreach to scientists and industry
- CORF is funded by NSF and NASA

Recent CORF FCC Filings

2021:

23.6 GHz: Implications of international Mobile (i.e. 5G) – June

57 GHz: New approvals for short-range devices – September

4.9 GHz: 8th FNPRM on public safety use – November

70/80/90 GHz: Airborne Internet revisit – December

2022:

Response to FCC's Notice of Inquiry on "*Promoting Efficient Use of Spectrum Through Improved Receiver Interference Immunity Performance*" – June

Latest FCC NPRMs of concern to RAS:

Expediting Initial Processing of Satellite and Earth Station Applications

Spectrum Rules and Policies for the Operation of Unmanned Aircraft Systems

Personal views on latest FCC NPRM's

Expediting Initial Processing of Satellite and Earth Station Applications

"...waiver applicants should provide a sufficient electromagnetic compatibility analysis to support a Commission finding that the intended use of the frequency assignment will not cause harmful interference to other stations operating in conformance with the ITU Radio Regulations";

guard bands, geo fencing, and stay away from primary and secondary allocations to protect radio astronomy.

Spectrum Rules and Policies for the Operation of Unmanned Aircraft Systems (i.e. drones)

Adhere to protections under Footnote US211, for VGOS sites, and e.g. NRQZ

CORF Response on "receiver standards" (June 2022)

Receivers used in the passive services have exceptionally high sensitivity and the strongest possible spectral selectivity

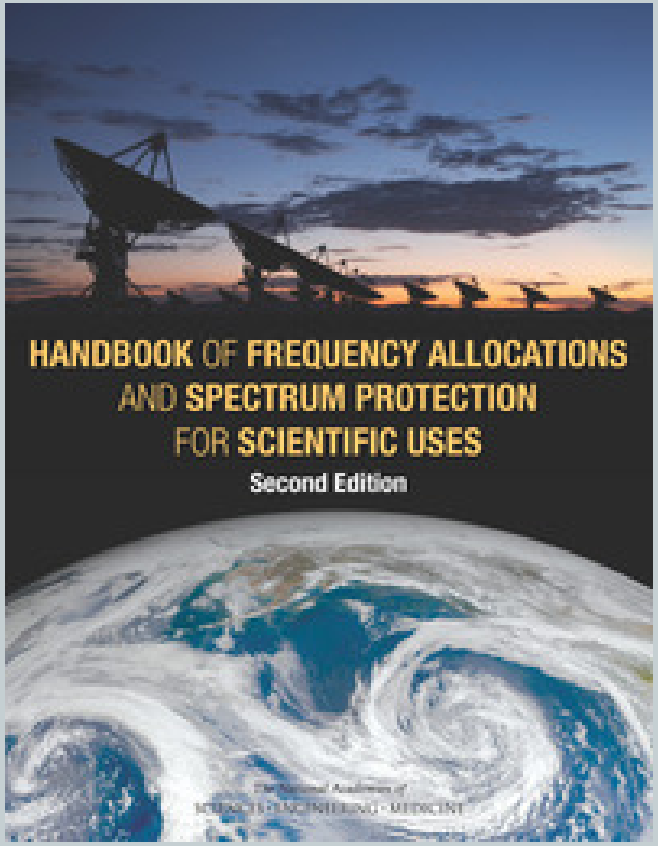
The sensitivity is driven by the need to **observe very weak signals** (and changes of such) emitted from natural sources, e.g. CMB, climate

High spectral selectivity driven need for **accurate and repeatable measurements**

As such, **receivers in the passive services already possess levels of selectivity the FCC is seeking to encourage** and would be difficult to improve upon

Accordingly, any general receiver standards designed to improve interference immunity performance in active services would likely be inappropriate and/or inapplicable to passive receivers

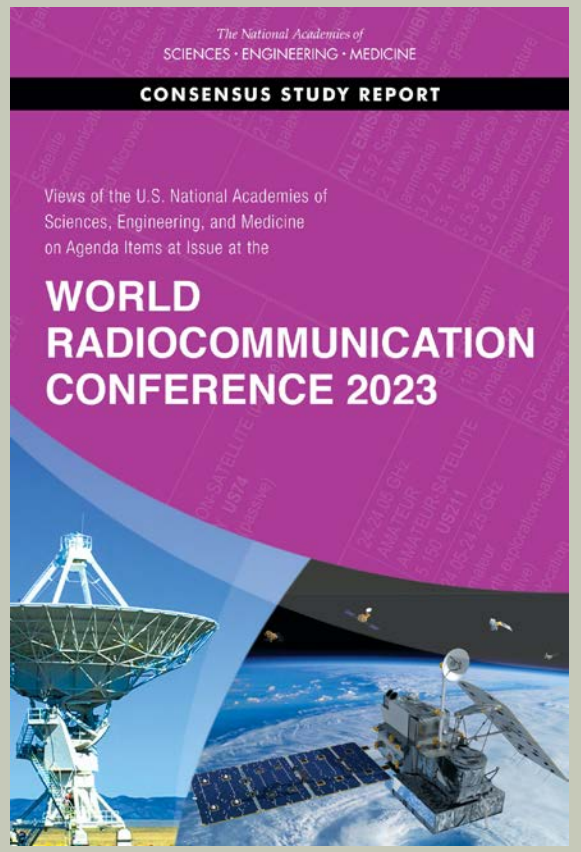
"CORF Handbook"



Comprehensive resource for scientists, engineers, and spectrum managers.

Detailed information on regulatory bodies, scientific background, spectrum allocations, and spectrum protection issues.

WRC-23 Views Report



Consensus committee report, representing input from US scientists regarding agenda items at the World Radio Conference (WRC-23), and preliminary items for the WRC-27 agenda

The International Telecommunication Union

The ITU is the leading United Nations specialized agency for information and communication technologies (ICTs)

The ITU has been around since the earliest days of electronic communications and it has evolved as an organization to match the evolution of telecommunications technologies

Following the invention of the telegraph (1837), the first public telegraph message (1844), and then short-distance *wireless* telegraphy (1854), the International Telegraph Union was founded in *1865*

Membership in the ITU

Member States – These are administrations. They have all rights and privileges. *Only member states hold the right to vote*

Sector members – Organizations, Industry, Recognized Operating Agencies, Academia, etc.

- **Sector** members, may participate in the activities of a *Sector*
- **Associate** members, may participate in a single *Study Group*
- **Academia** members, may participate in the activities of a *Study Group* through an Memorandum Of Understanding (MOU) with the General Secretariat

Structure of the ITU

- Plenipotentiary Conference (the primary governing body – *all powerful*)
- Council (acts on behalf of the Plenipotentiary Conference)
- World Conference on International Telecommunications (WCIT)
- Core Sectors (ITU-R, ITU-T, ITU-D)
  - Radiocommunication Sector (ITU–R)
  - Telecommunication Standardization Sector (ITU–T)
  - Telecommunication Development Sector (ITU–D)
- General Secretariat

The General Secretariat provides services to the membership of the Union. The General Secretariat manages the administrative and financial aspects of the Union's activities

Radiocommunication Sector (ITU-R)

The **ITU-R** ensures the rational, equitable, efficient, and economical use of the radio-frequency spectrum by all radiocommunication services, including those using geostationary-satellite or other satellite orbits. The ITU-R does its work through,

- World Radiocommunication Conferences (WRCs)
- Radio Regulations Board (RRB)
- Radiocommunication Assemblies (RAs)
- Radiocommunication Study Groups
- Radiocommunication Bureau

You often hear people talking about the work in the current or previous "cycle" or "study cycle" at the ITU. What is this "cycle"?

=> The simple answer is 4 years

At International Level (ITU-R)

WP 7C – Earth Remote Sensing (EESS)

CORF members are participating in US WP7C

Numerous NASA/NOAA representatives on US Delegation

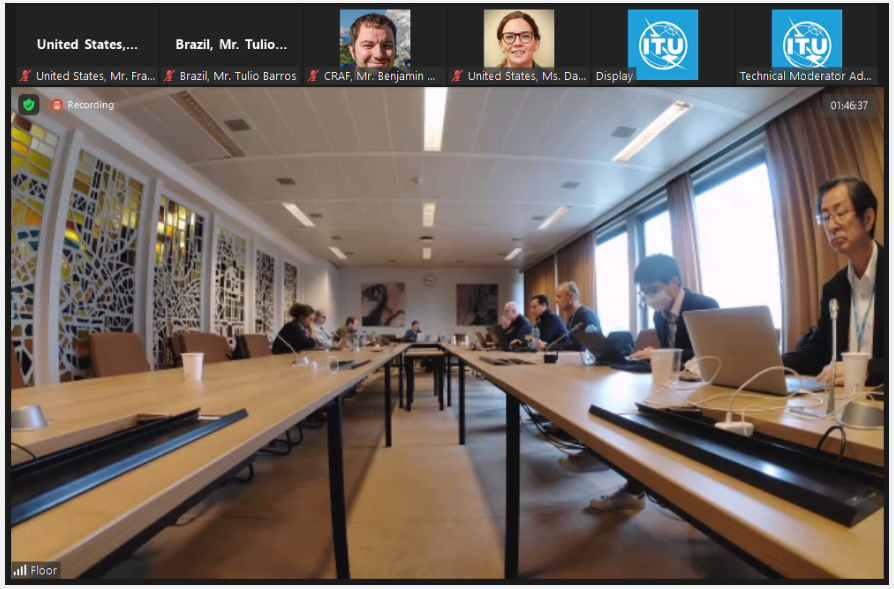
WP 7D – Radio Astronomy (RAS)

Harvey Liszt represents IUCAF as sector member.

CORF members and others in the US RA community are now participating in US WP7D and in ITU WP7D through the US prep process and delegation.

This work has been spearheaded by Liese van Zee (prior CORF chair), recognizing an imbalance within prior US delegations to ITU 7D

As a result of this activity multiple US-originated reports made their way through the 7D approval process.



October 2022 ITU WP 7D meeting in Geneva (and online at Geneva time)

WP 7D – approved reports in latest study cycle

There are 17 active ITU-R reports for radio astronomy;
5 added in November, 2022

RA.2507 Technical and operational characteristics of the existing and planned Geodetic Very Long Baseline Interferometry

RA.2508 Widely-distributed radio astronomy array systems operating above 200 GHz

RA.2509 Technical and operational characteristics of radio astronomy systems operating below 350 MHz (85 cm)

RA.2510 Technical and operational characteristics of radio astronomy systems in the 67-116 GHz (3-4 mm) range

RA.2512 Technical and operational characteristics of broadband, background-limited detectors operating in the millimeter-wave regime

Upcoming World Radio Conference & beyond

Dubai November 20 – December 15, 2023

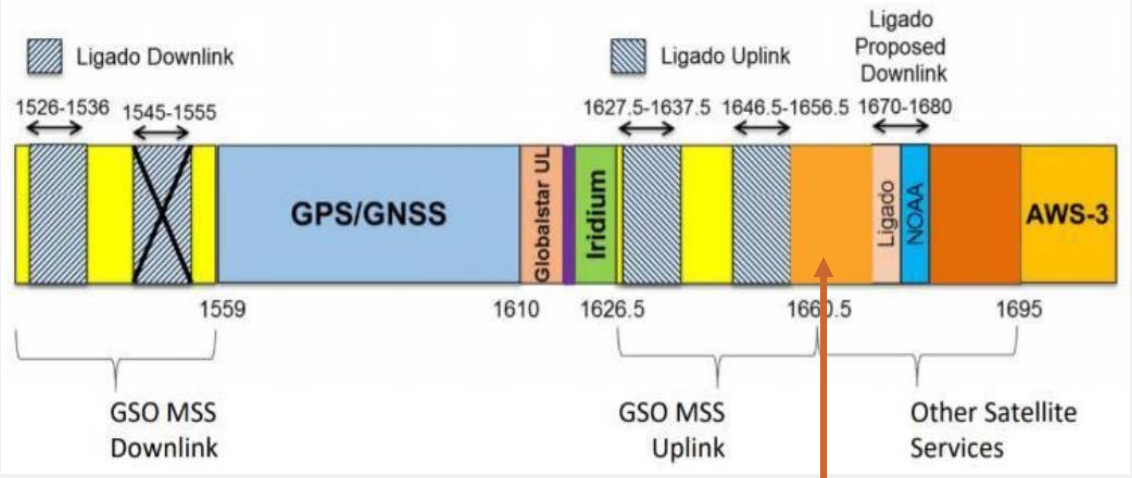
Limited representation of RAS at WRC through NSF, NTIA, IUCAF, et al.
Ensure that RAS stays on the negotiation table as interested party for the next study cycle for many agenda items. WRC outcome determines some of next study cycle for WP 7D.

Expected ongoing work in WP 7D (depends largely on community support):

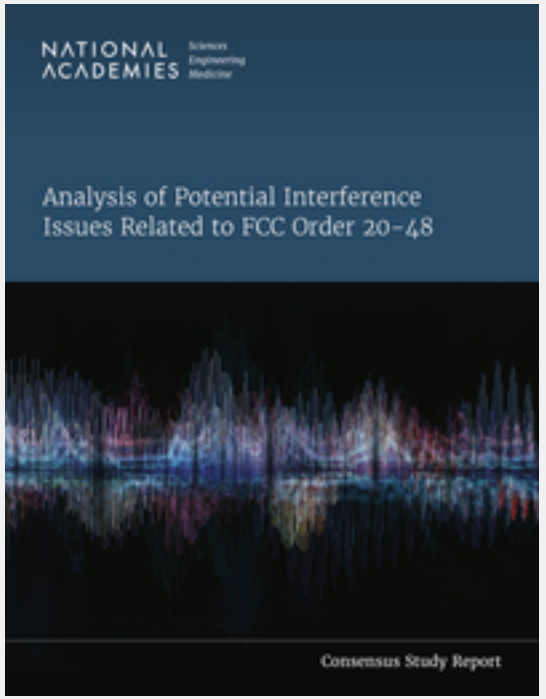
- Report on measurements of Harmonics relating to RAS
- Define criteria for impact studies of large satellite constellations
- Define criteria for impact studies at mm-wavelengths (>40 GHz)
- Further work in response to ITU-R Question 260/7 (Shielded Zone of the Moon)
- Updates to ITU-R Handbook on Radio Astronomy (10 years old)
- Updates to Report ITU-R RA.2126: "*Techniques for mitigation of RFI in radio astronomy*"
- Updating Recommendation RA.314: "*Preferred frequency bands for RA measurements*"
- Define for RR.149 bands what means "all practical steps" to protect RAS
- ...

NAS Review of FCC Order 20-48 Authorizing Operation of a Terrestrial Radio Network near GPS Frequency Bands

Study determined risk of harmful interference to deployed GPS receivers from Ligado. Primarily high precision receivers will experience significant harmful interference as authorized by the FCC.



RAS: 1660.5 – 1670 MHz co-primary status



Iridium downlinks are also prone to experience harmful interference.

The terrestrial network authorized by FCC Order 20-48 will create unacceptable harmful interference for DoD missions. The mitigation techniques and other regulatory provisions in FCC Order 20-48 are insufficient to protect national security missions.

Wireless Broadband (5G+)

FCC Next-Gen Wireless (5G+, Wifi)

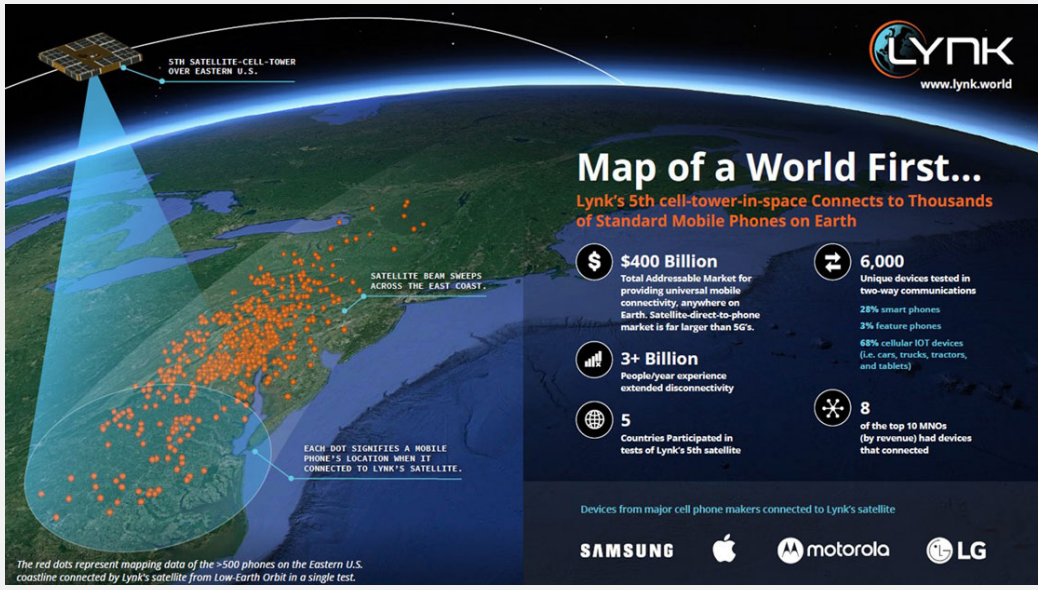
High-band: 24, 28, 37, 39, 47 GHz (5 GHz for 5G)
+ 2.75 GHz more 26/42 GHz expected
+ Reallocation of 12.7 GHz

Mid-band: 2.5, 3.5, and 3.7-4.2 GHz making >600 MHz available

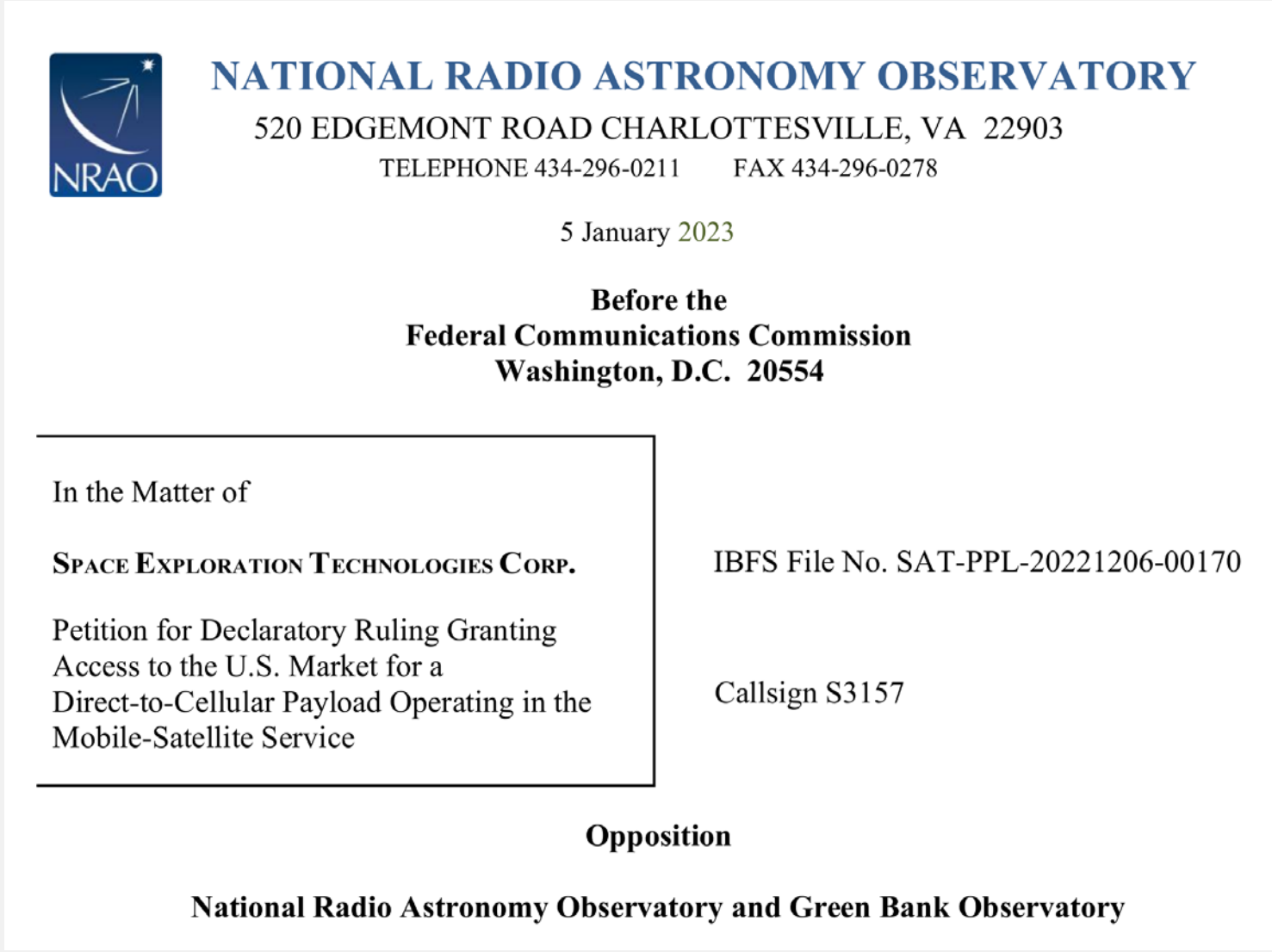
Unlicensed: next-gen Wifi and 5G 5.9 GHz, 6 GHz, and >95 GHz

Cell-towers in space

Lowering standards to accept satellite applications that do not conform to the international frequency allocations, i.e. direct-to-cell communication from satellites using spectrum neither allocated nor studied for space communication.



=> ***Setting dangerous precedents with particular adverse impacts for radio quiet zones***



NATIONAL RADIO ASTRONOMY OBSERVATORY

520 EDGEMONT ROAD CHARLOTTESVILLE, VA 22903

TELEPHONE 434-296-0211 FAX 434-296-0278

5 January 2023

Before the
Federal Communications Commission
Washington, D.C. 20554

In the Matter of

SPACE EXPLORATION TECHNOLOGIES CORP.

Petition for Declaratory Ruling Granting Access to the U.S. Market for a Direct-to-Cellular Payload Operating in the Mobile-Satellite Service

IBFS File No. SAT-PPL-20221206-00170

Callsign S3157

Opposition

National Radio Astronomy Observatory and Green Bank Observatory

Opposition filed by Harvey Liszt

SpaceX petition is in violation of radio regulations and stipulates erroneously that T-Mobile has authority to permit satellites to communicate with its mobile stations.

Similar to the Apple / Globalstar agreement: At CES2023 Qualcomm Introduced Snapdragon Satellite, The World's First Satellite-Based Solution Capable of Supporting Two-Way Messaging for Premium Smartphones and Beyond

- Qualcomm and Iridium (1610.6-1613.8 MHz) entered into an agreement to bring satellite-based connectivity to next-generation premium Android smartphones; Garmin looks forward to collaborating with support for emergency messaging.

- Snapdragon Satellite offers truly global coverage from pole to pole and can support **two-way messaging for emergency use, SMS texting, and other messaging applications** – for a variety of purposes such as emergencies or recreation in remote, rural and offshore locations.

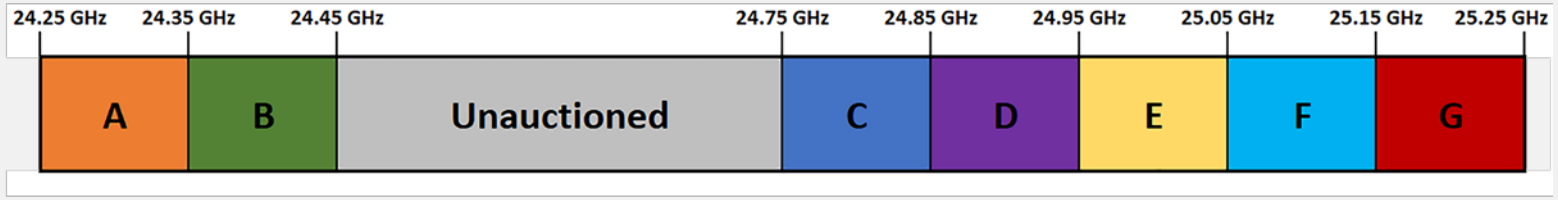
- This industry leading solution also provides the opportunity to expand emergency and two-way satellite messaging **beyond smartphones** to other devices needing global messaging capabilities.

Text adopted from original Qualcomm press release

Upper Microwave Flexible User Service (5G) at 24-25 GHz

Auctioned licenses by FCC for 5G in 2019 ($2B proceed)

RAS co-primary
23.6 – 24.0 GHz



The associated out-of-band emission limits were inconsistent with protecting 23.6–24.0 GHz EESS (column and near-surface water vapor) and RAS (NH_3) observations

The FCC urged international confirmation of such limits, but WRC-19 adopted stricter limits (though not as strict as those advocated by, for example, WMO) In 2021, the FCC requested comments on US implementation of WRC-19 limits

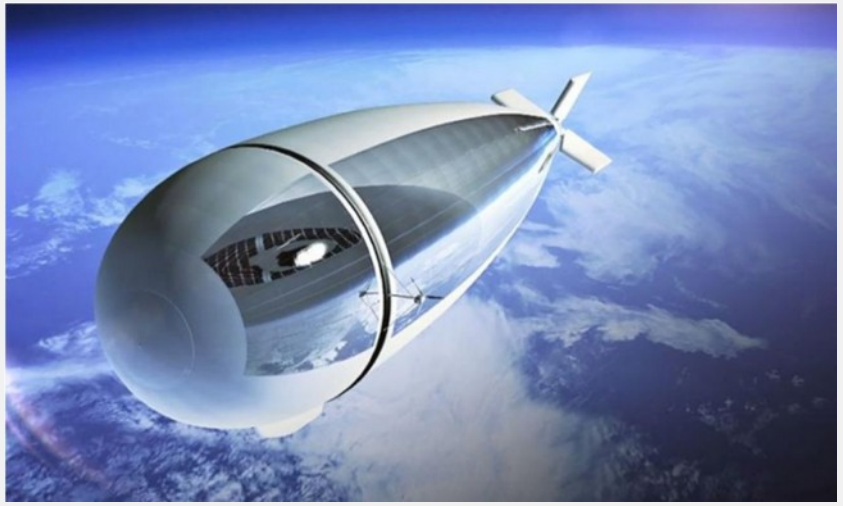
CORF responded with details on the importance of the 23.6–24.0 GHz band to Earth science and radio astronomy, urging that the WRC-19 limits be implemented as expediently as possible while arguing that they may still ultimately prove insufficient in some circumstances

In an unusual move, the NTIA submitted a response on behalf of NASA and NOAA urging speedy implementation of the limits, with strong procedures for addressing violations

High-Altitude Platform Station (HAPS)

HAPS systems can potentially be used to provide both fixed broadband connectivity for end-users and transmission links between the mobile and core networks used for backhauling traffic. Both types of HAPS applications would enable wireless broadband deployment in remote areas, including in mountainous, coastal, and desert areas.

ITU Radio Regulations (RR) define HAPS as radio stations located on an object at an altitude of 20-50 kilometers and at a specified, nominal, fixed point relative to the Earth.



Shielded Zone of the Moon (SZM)

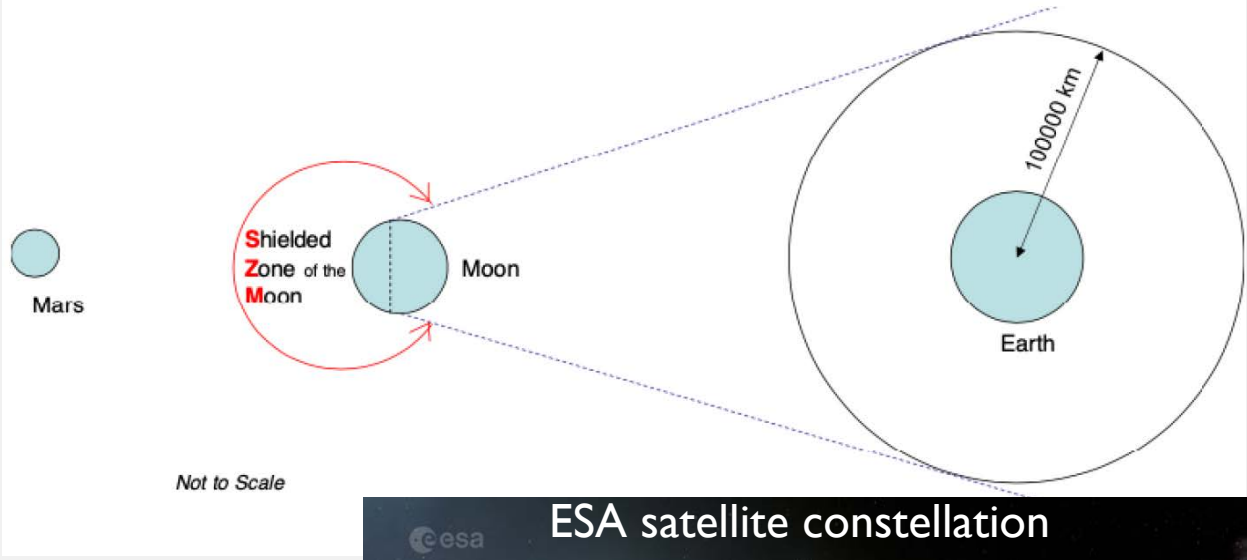
An area of the Moon's surface and an adjacent volume of space that are shielded from emissions originating from within 100,000 km of Earth's center.

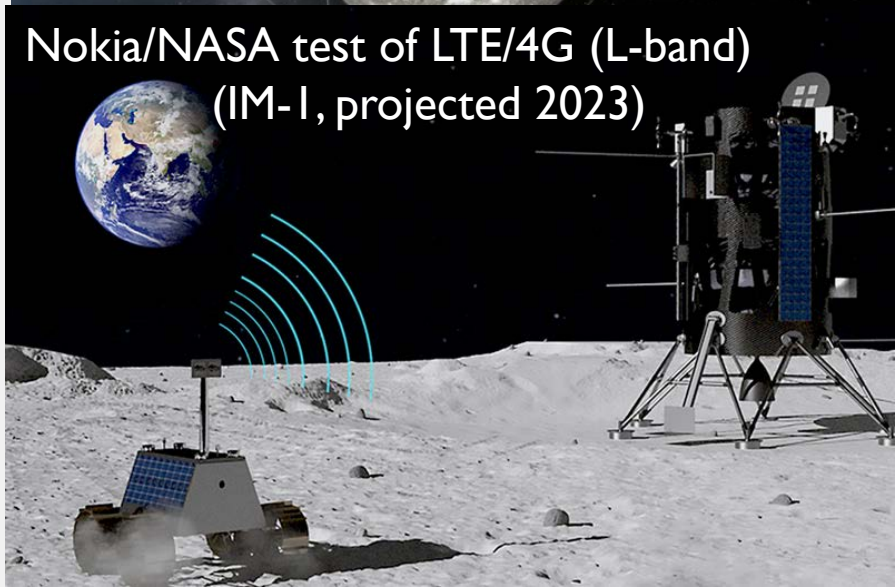
Shielded from Earth-based radio emissions and isolated from potential interference emanating from the satellites orbiting the Earth.

ITU RR afford legal protection from radio emissions in this naturally quiet zone for RAS and other passive services.

Will we be able to keep a silent lunar environment despite projections of increased human activity on the Moon?

ITU-R Question 260/7 to be studied.



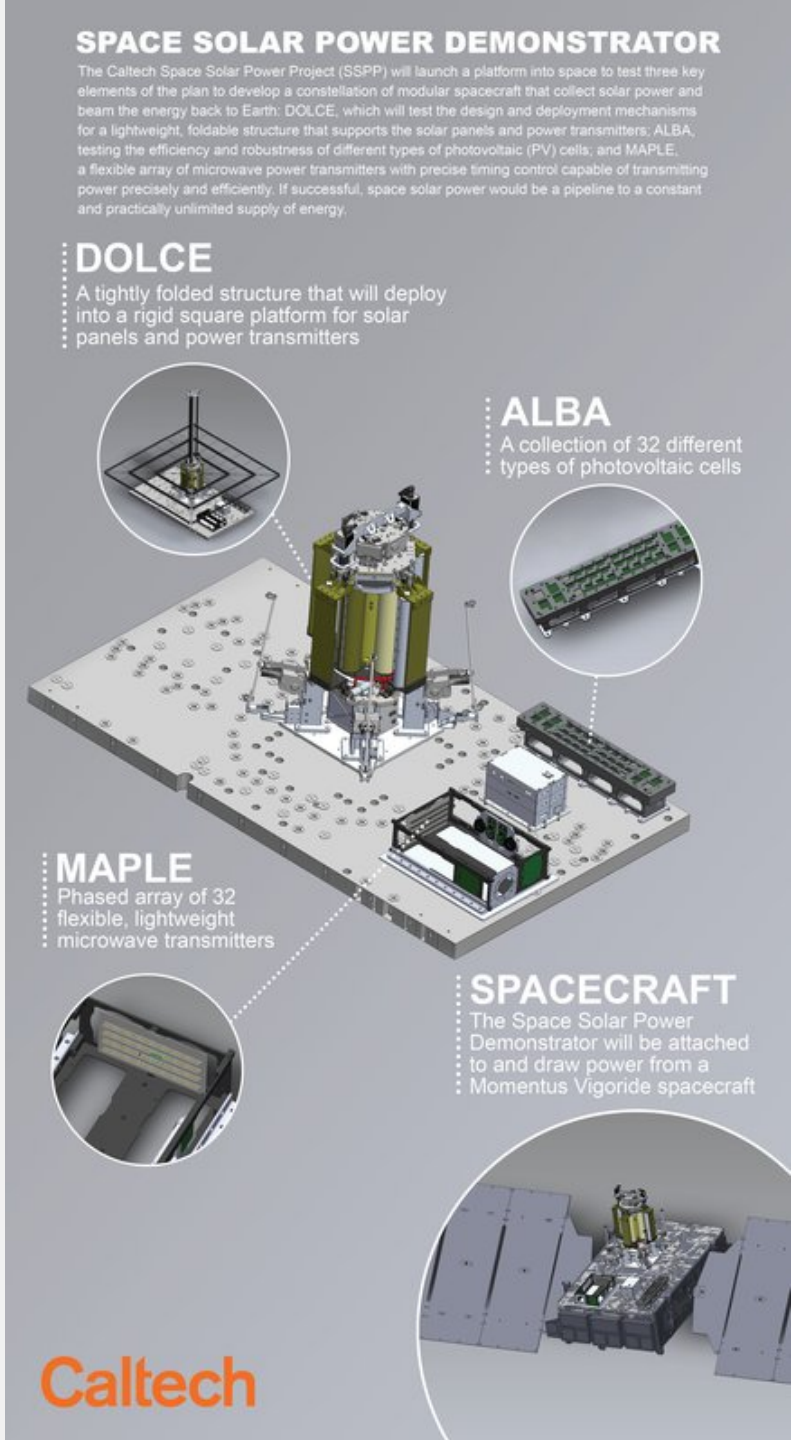


Solar Power Satellite Systems

Caltech Space Solar Power Project (https://arxiv.org/abs/2206.08373) (launched prototype January 3rd, 2023)

MAPLE (Microwave Array for Power-transfer Low-orbit Experiment) at 9.984 GHz; 38 dBm EIRP towards Earth: An array of flexible lightweight microwave power transmitters with precise timing control focusing the power selectively on two different receivers to demonstrate wireless power transmission at distance in space.

URSI White Paper on Solar Power Systems estimates of a total end-to-end efficiency of 7% for transmission at 2.45 GHz. The Caltech SSP estimates an end-to-end efficiency of 7-14%.



Other "Hot Button" Issues

Constellations with thousands of satellites

- NSF and SpaceX Astronomy Coordination Agreement

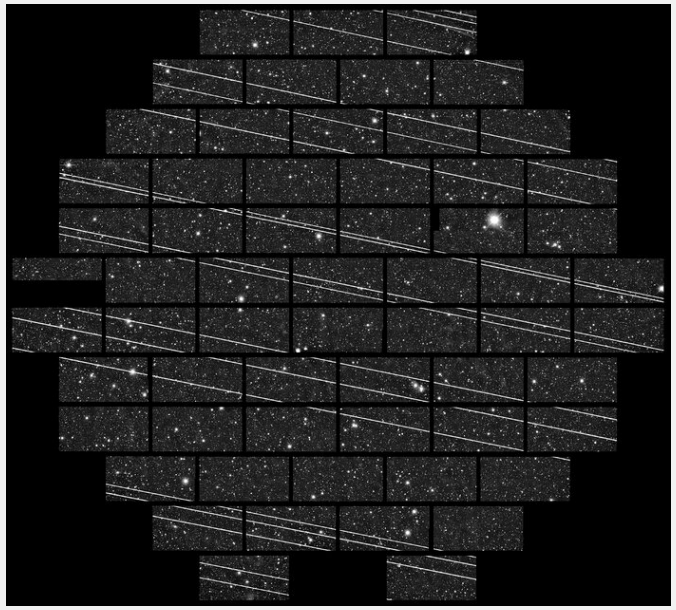
National Radio Dynamic Zone(s)

- Dynamic spectrum sharing for ngVLA?

NSF Spectrum Innovation Initiative

Spectrum Management

- Next generation of leaders



Threats to "all emissions prohibited" restrictions > 95 GHz (FCC Spectrum Horizons)

- Resisting efforts from industry to undermine/revise the "All emissions prohibited" status of all the passive bands in the region of the spectrum above 95 GHz currently having that protection
- These efforts started within the US process, but have moved to the international arena (and the FCC are full-throated in their support)

Satellite Constellations - an enormous threat to astronomy and beyond

IAU Centre for the Protection of the Dark and Quiet Sky from Satellite Constellation Interference (NOIRLab & SKAO)

NSF and SpaceX Astronomy Coordination Agreement

- 10.7-10.7 GHz coordination (2019)
- Darkening of Gen2 satellites (2022)
- Dynamic coordination with radio observatories (2022)

What about other constellations?

SpaceX (~30k), OneWeb (~50k), Kuiper (~3k), Others (~>30k)

Starlink Satellites pass overhead near Carson National Forest, New Mexico, photographed soon after launch.

Summary

Provided an overview of the spectrum management landscape relevant to RAS
(NAS CORF, ITU-R WP7D, IUCAF)

A wide range of national and international regulatory issues with the common theme being:

- ✓ The active use of the radio spectrum is growing with many desires for wireless communication and other broad-band applications at all wavelengths!
- ✓ Defending passive radio spectrum use is becoming increasingly difficult with $B's of commercial interests and more and more limitations to geographic protections
- ✓ Earth is not the limit! Commercial interests are reaching for the Moon and beyond
- ✓ Very limited resources to defend scientific uses in policy (largely volunteer activity)

- ➢ **The radio spectrum will get more crowded anywhere on Earth.**
- ➢ **There is a significant risk of raising the noise floor above the cosmic background for a substantial part of the radio spectrum over large geographic areas.**
- ➢ **Advanced dynamic spectrum sharing a solution?**

U.S. DOMESTIC PREPARATORY PROCESS