



Electromagnetic Spectrum Management Division of Astronomical Sciences



Report to the Astronomy and Astrophysics Advisory Committee (AAAC)



The 2020s:
A decade with
new opportunities



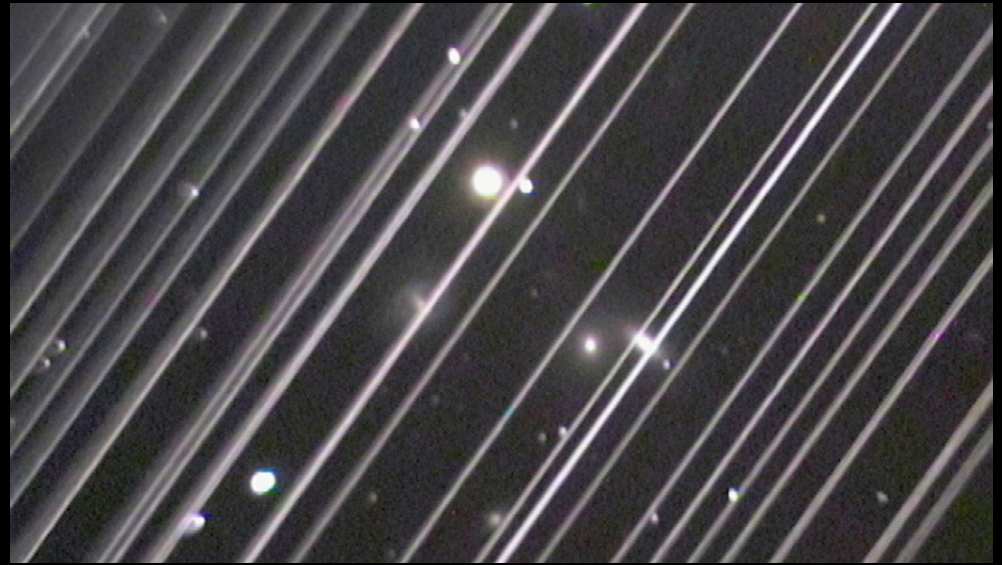
Credit: LSST



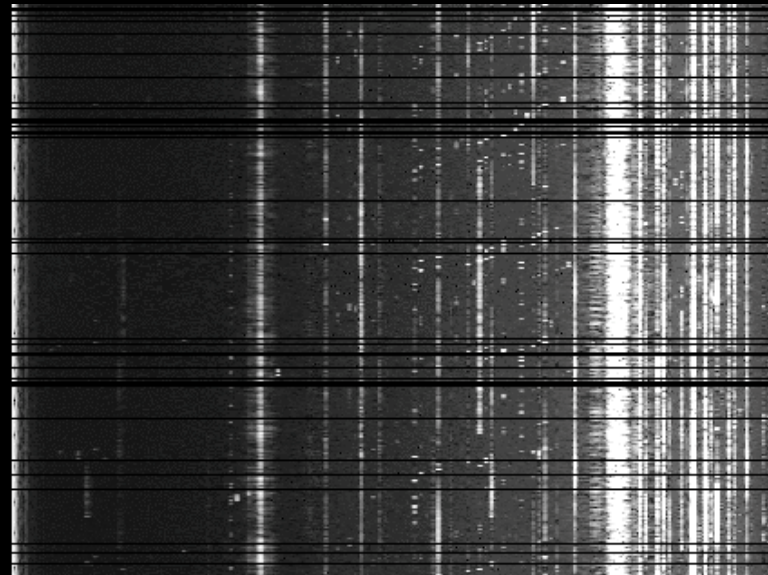
Credit: almaobservatory.org



The 2020s:
A decade with
new opportunities
and
new challenges



optical interference



radio interference



AAAC 2018 report

Report of the Astronomy and Astrophysics
Advisory Committee

March 15, 2018



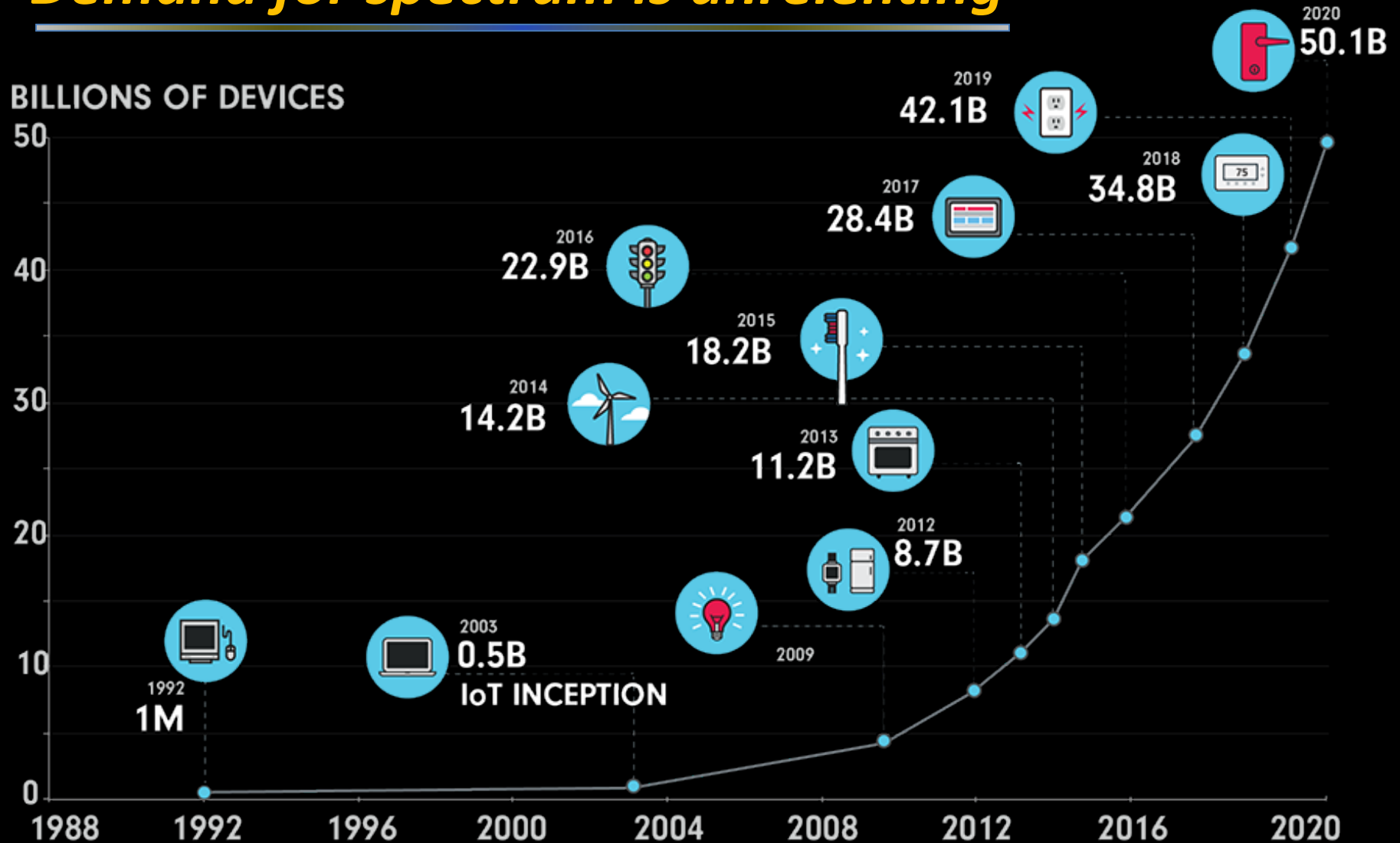
Image credit: Robin Dienel courtesy of the Carnegie Institution of Science.

...the original protected frequency regions have been eroded both from external challenges, as well as significant out-of-band emission from competing sources and harmonics overlapping with key astronomical lines.

The original protected frequencies do not include emission lines that have become increasingly important as astrophysical diagnostics since the 1970's, nor do the protected frequencies encompass known lines that are redshifted out of the protected bands.

Demand for spectrum is unrelenting

BILLIONS OF DEVICES



Source: Cisco



2019 AAAC report

Finding (12): Competing interests continue to provide a severe and unrelenting threat to astronomers' ability to detect electromagnetic signals from space. Without clean access to these wavelengths, the ability of astronomers to obtain fundamental knowledge about the universe is profoundly impaired. This is particularly important as time-variable astronomy gains visibility (for example in detecting gravitational wave counterparts or other multi-messenger astronomy activities). Mobile and transient noise sources form a large and growing threat.

Finding (13): The resources currently available to the NSF and NASA are not sufficient to protect essential astronomical wavelengths in an arena of competing commercial interests with deep financial support and professional lobbyists.

Report of the Astronomy and Astrophysics
Advisory Committee

April 26, 2019

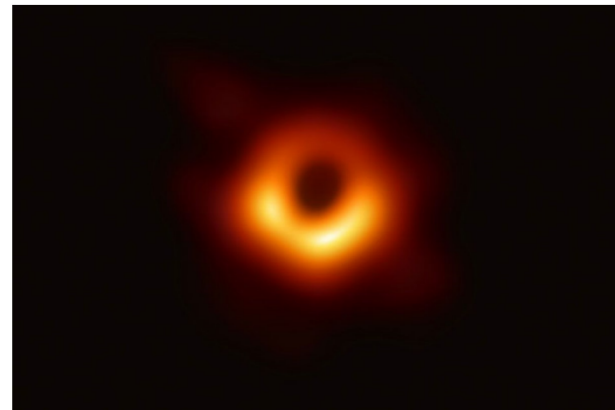


Image credit: Event Horizon Telescope Collaboration



Epoch of Reionization

HI: 21 cm -> 1.5 m

Freq ~ 1420 MHz -> 200 MHz

$$1 + z = \frac{f_{\text{emit}}}{f_{\text{obsv}}}$$

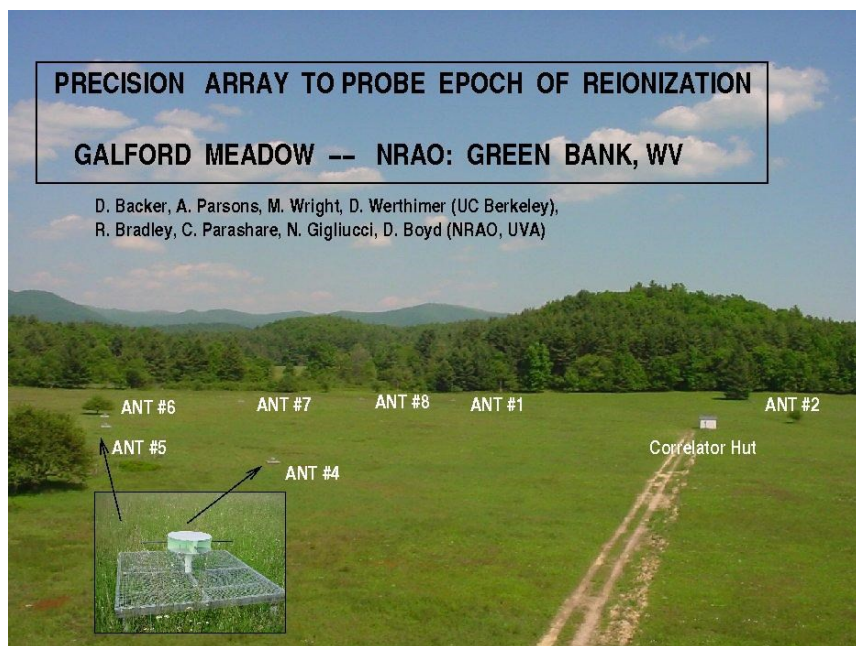


Image Credit: w.astro.berkeley.edu

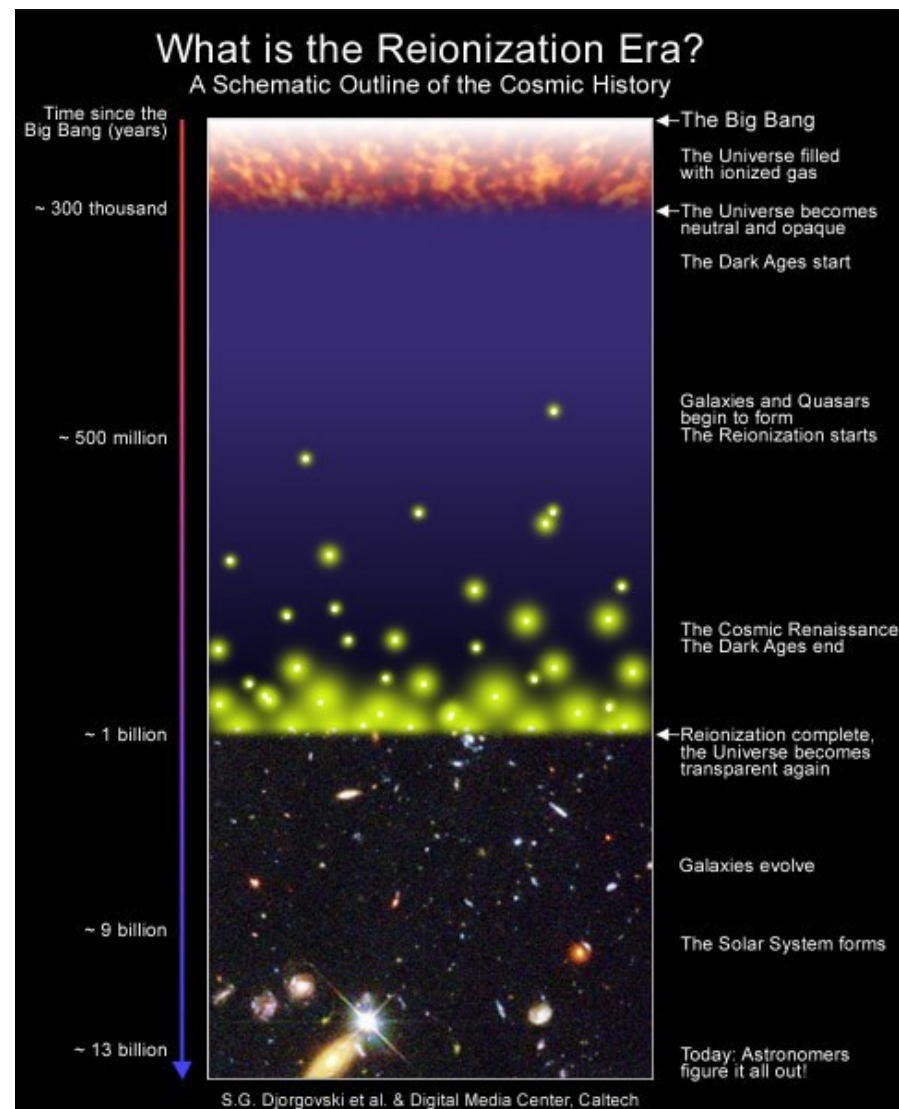


Image Credit: Djorgovski et al. (Caltech); www.haystack.mit.edu



UNITED STATES FREQUENCY ALLOCATIONS

THE RADIO SPECTRUM

RADIO SERVICES COLOR LEGEND

NON-FEDERAL ACTUAL MOBILE	FEDERAL MOBILE	RADIO ASTRONOMY
NON-FEDERAL ACTUAL MOBILE SATELLITE	LAND MOBILE	EXPERIMENTATION MOBILE SATELLITE
NON-FEDERAL ACTUAL MOBILE SATELLITE	LAND MOBILE SATELLITE	RADIO EDUCATION
NAVSTAR	NAVSTAR MOBILE	NAVSTAR MOBILE SATELLITE
NAVSTAR SATELLITE	NAVSTAR MOBILE SATELLITE	NAVSTAR MOBILE SATELLITE
BROADCASTING	BROADCASTING	BROADCASTING SATELLITE
BROADCASTING SATELLITE	METEOROLOGICAL	SPACE OPERATION
NAVSTAR MOBILE SATELLITE	METEOROLOGICAL SATELLITE	SPACE RESEARCH
FIXED	MOBILE	STANDARD FREQUENCY AND TIME SIGNAL
FIXED SATELLITE	MOBILE SATELLITE	STANDARD FREQUENCY AND TIME SIGNAL SATELLITE

ACTIVITY CODE

FEDERAL EXCLUSIVE	FEDERAL/CONFIDENTIAL
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FOR FEDERAL EXCLUSIVE

ALLOCATION USAGE DESIGNATION

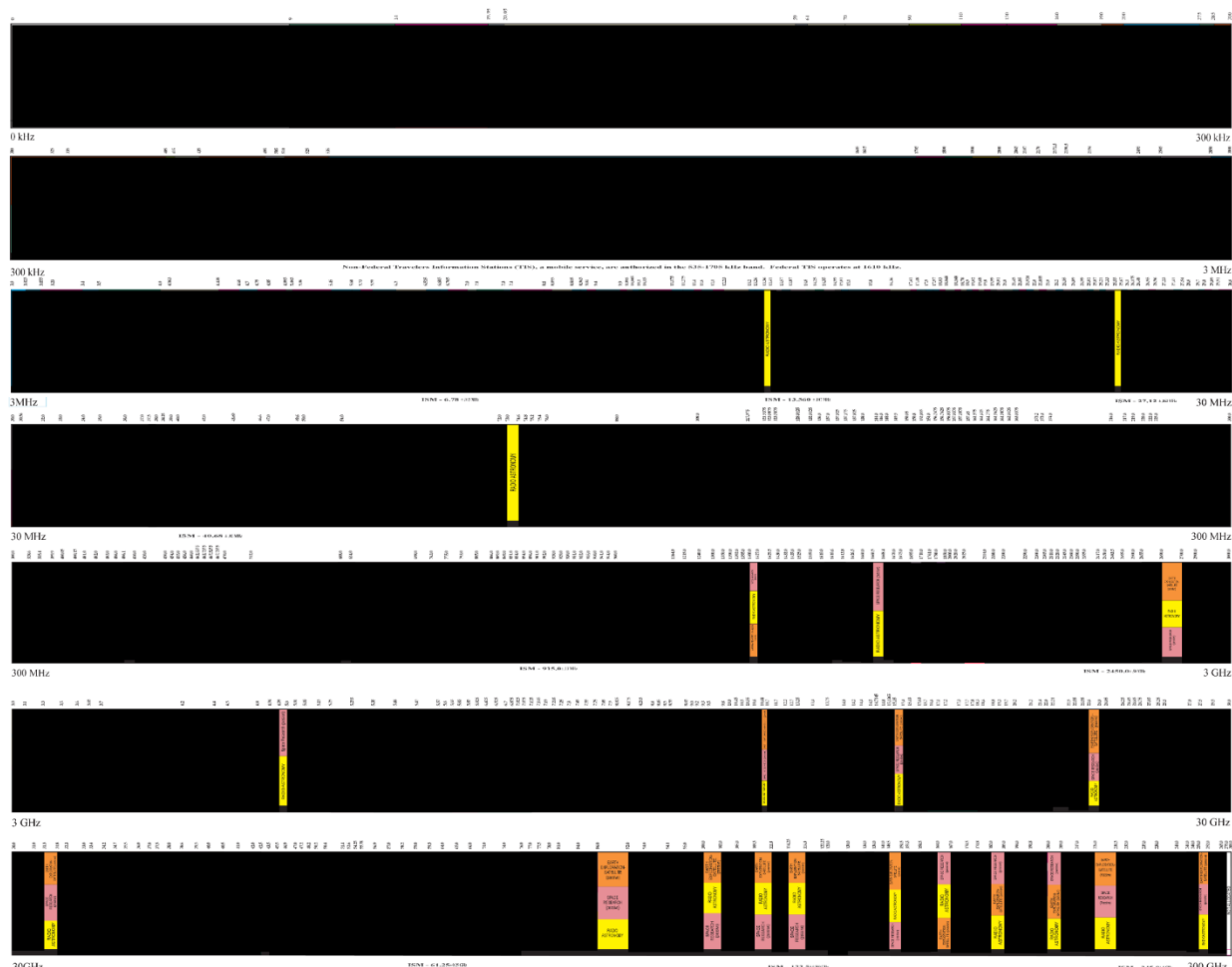
SERVICE	EXAMPLE	DESCRIPTION
Private	Private	Private
Mobile	Mobile	Mobile

This chart is a graphic representation of the United States Frequency Allocation Table (USFAT) and is not a legal document. It is intended for informational purposes only and should not be used as a basis for legal action.

U.S. DEPARTMENT OF COMMERCE
National Telecommunications and Information Administration
Office of Spectrum Management
JANUARY 2016

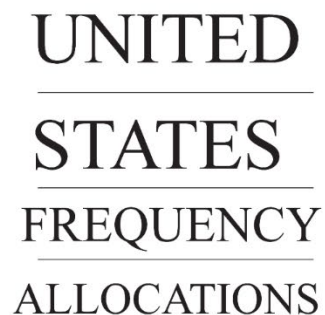


Revised from the previous version of the USFAT, 2014, by the Office of Spectrum Management, U.S. Department of Commerce, National Telecommunications and Information Administration, Office of Spectrum Management.



300 kHz
30 MHz
300 MHz
3 GHz
30 GHz
300 GHz

Revised from the previous version of the USFAT, 2014, by the Office of Spectrum Management, U.S. Department of Commerce, National Telecommunications and Information Administration, Office of Spectrum Management.



RADIO SERVICES COLOR LEGEND

 AIRBORNE POLICE	 POLICE	 RADIO BROADCAST
 AIRBORNE POLICE SATELLITE	 LAND MOBILE	 AIRBORNE TERMINAL SATELLITE
 AIRBORNE POLICE SATELLITE	 LAND MOBILE SATELLITE	 RADIO MOBILE
 AIRBORNE POLICE SATELLITE	 LAND MOBILE SATELLITE	 RADIO MOBILE SATELLITE
 AIRBORNE POLICE SATELLITE	 LAND MOBILE SATELLITE	 RADIO MOBILE SATELLITE
 AIRBORNE POLICE SATELLITE	 LAND MOBILE SATELLITE	 RADIO MOBILE SATELLITE
 AIRBORNE POLICE SATELLITE	 LAND MOBILE SATELLITE	 RADIO MOBILE SATELLITE
 AIRBORNE POLICE SATELLITE	 LAND MOBILE SATELLITE	 RADIO MOBILE SATELLITE
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 AIRBORNE POLICE SATELLITE	 LAND MOBILE SATELLITE	 RADIO MOBILE SATELLITE
 AIRBORNE POLICE SATELLITE	 LAND MOBILE SATELLITE	 RADIO MOBILE SATELLITE
 AIRBORNE POLICE SATELLITE	 LAND MOBILE SATELLITE	 RADIO MOBILE SATELLITE
 AIRBORNE POLICE SATELLITE	 LAND MOBILE SATELLITE	 RADIO MOBILE SATELLITE

 FEDERAL EXCLUSIVE FEDERAL/NONFEDERAL QUAD

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

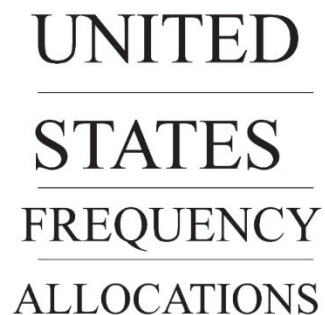
This chart is a graphic representation of the portion of the Table of Frequency Allocations used by the FCC and NTIA. As such, it is not a complete table of spectrum use. For a complete and more detailed version of the Table of Frequency Allocations, therefore, for complete information, you should consult the Table of Frequency Allocations.



The authors thank the members of Government of F. J. Government, Portugal, CITEC, University of Coimbra, for their support. This work was supported by the Portuguese Government, through the FCT, under the project PTDC/AGR/1010/2001.



PLEASE NOTE: THE ONLINE CATALOGUE IS AVAILABLE FOR THE PRESENT
 15 MONTHS UNTIL 15 NOVEMBER 2008. ALL INFORMATION
 IS SUBJECT TO CHANGE.



RADIO SERVICES COLOR LEGEND



ALLOCATION USAGE DESIGNATION

This chart is a graphic representation of the portion of the Table of Frequency Allocations used by the FCC and NTIA. It only shows the frequencies which are used by the business and marine service within the table.

This chart is a graphic representation of the portion of the Table of Frequency Allocations used by the FCC and NTIA. In each block are accurately noted all names, in English and where known, in the table.



For details, see the corresponding official report: <http://www.gov.hk/eng/pe/pe.htm>

PLEASE NOTE THE SPACING ALLOTTED FOR THE CONNECTIONS IN THE WIRE FROM
CLOSURE TO GROUND IT IS ONLY FROM FEDERAL TELEGRAPHIC & CABLE CO. ADDRESS OF
SPC 000000000000

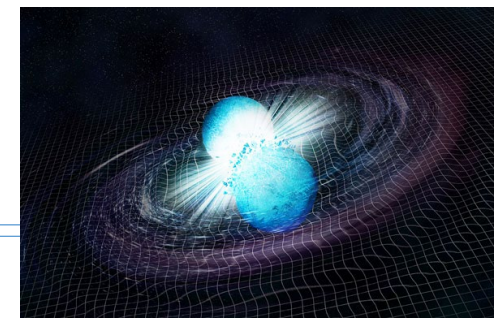


Epoch of Reionization





Importance of EM Access



10 μ Jy at 3 GHz \sim 2 weeks

2 GHz BW (\sim 1.4 GHz after RFI excision)

<50 MHz is
RAS primary



VLA Observation September 7, 2017

GW170817

To achieve 2 μ Jy RMS
requires integration time on source of:

2 GHz bandwidth:

5.5 hours

1.4 GHz bandwidth:

6 hours

50 MHz bandwidth:

185 hours (more than one week)

VLA Exposure Calculator	
Array Configuration	A
Number of Antennas	25
Polarization Setup	<input type="radio"/> Single <input checked="" type="radio"/> Dual
Type of Image Weighting	<input checked="" type="radio"/> Natural <input type="radio"/> Robust
Representative Frequency	3.0000 GHz
Receiver Band	S
Approximate Beam Size	0.977"
Digital Samplers	<input type="radio"/> 3 bit <input checked="" type="radio"/> 8 bit
Elevation	Medium (25-50 degrees)
Average Weather	Autumn
Calculation Type	<input checked="" type="radio"/> Time <input type="radio"/> BW <input type="radio"/> Noise/To
Time on Source (UT)	1.1248w
Total Time (UT)	1.4184w
Bandwidth (Frequency)	50.0000 MHz
Bandwidth (Velocity)	4,996.5410 km/s
RMS Noise (units/beam)	2.0000 μ Jy



Exposure is too long

That is a lot of VLA time on one source. You may want to change your values for noise and bandwidth.



NSF-funded Astronomy research relies on access to electromagnetic spectrum

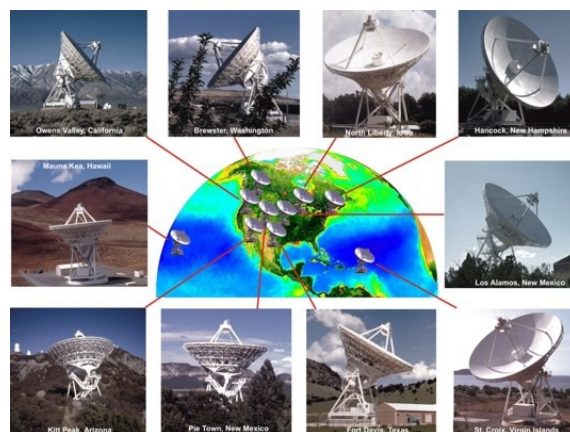
ESM resides in MPS/AST because historically spectrum usage has been focused primarily around the needs of a few large facilities and the National Radio Quiet Zone.



Arecibo Observatory, Puerto Rico



Very Large Array, NM



Very Long Baseline Array



Green Bank Observatory
National Radio Quiet Zone



Domestic and International Impact



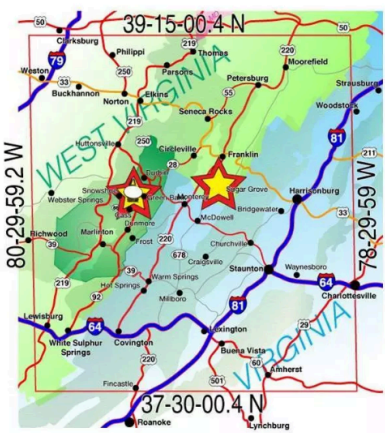
Image credit: almaobservatory.org

- The United States has significant scientific assets / large facilities outside of its national borders.
- Observatories tend to be in geographically remote sites, but radio emission from moving emitters: car radars, satellites and high altitude delivery systems will be an increasing challenge.



National Radio Quiet Zone

- NRQZ (established 1958) **needs updated protections** from airborne transmitters; other radio telescopes need also need newly established coordination zones.
- We need **new quiet/coordination zones** for coordinating access to wider bandwidths for the VLA, Arecibo, VLBA, ALMA and other facilities



Credit: Green Bank Observatory

Description

The National Radio Quiet Zone (NRQZ) was established by the Federal Communications Commission (FCC) in [Docket No. 11745](#) (November 19, 1958) and by the Interdepartment Radio Advisory Committee (IRAC) in Document 3867/2 (March 26, 1958) to minimize possible harmful interference to the National Radio Astronomy Observatory (NRAO) in Green Bank, WV and the radio receiving facilities for the United States Navy in Sugar Grove, WV. The NRQZ is bounded by NAD-83 meridians of longitude at 78d 29m 59.0s W and 80d 29m 59.2s W and latitudes of 37d 30m 0.4s N and 39d 15m 0.4s N, and encloses a land area of approximately 13,000 square miles near the state border between Virginia and West Virginia.



Credit: NRAO



2019 AAAC report

Recommendation (14): Given their common interests in access to the spectrum, NASA and NSF should enhance their collaboration with each other and with other groups, including international agencies and commercial interests, to protect the accessibility of essential astronomical wavelengths to researchers.

Recommendation (15): Efforts, ideally coordinated with all three agencies, should be made to increase awareness of spectrum management issues among astronomers, the general public, and government agencies. Possible agents for meeting this recommendation might include the NSF-funded national facilities for operations at radio and optical wavelengths. Efforts to engage and coordinate with other international agencies should continue.

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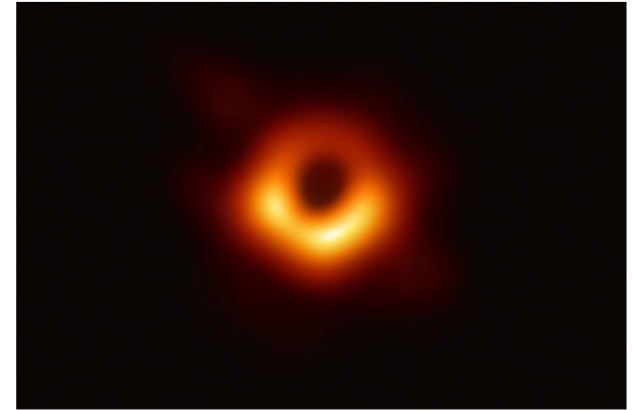



Image credit: Event Horizon Telescope Collaboration



ESM Office Actions

- I. Outreach - Presented at the AAS 235th meeting***
- II. Ongoing regular meetings with NASA and NOAA***
- III. Represented U.S. scientific interests at the World Radio Conference 2019, beginning WRC-23 prep cycle***
- IV. Stepping into a role to consider the optical impacts from satellites as well as the radio impacts***
- V. NSF-wide Coordination Group***



National Science Foundation

Are you losing DATA to **RFI**?

The radio spectrum is regulated, and radio astronomical observations are protected by law.

A regulatory framework governs the use of the radio spectrum on domestic and international scales. NSF works at both levels.


UNITED STATES FREQUENCY ALLOCATION CHART

Frequency bands are allocated to radio/communication services. That includes radio astronomy. Some of the most important bands are set aside for astronomical use. Others are shared. NSF facilitates both, and helps to protect astronomy from interference.

NSF seeks to protect and innovate on spectrum issues.

We work with regulators, federal agencies, companies, scientists, and national/international organizations to protect the spectrum interests of NSF research.

NSF is the primary voice for the spectrum needs of ground-based radio astronomy in the United States. In helping to protect spectrum set aside or used by radio astronomy, NSF works to defend the interests of individual astronomers and billion-dollar facilities alike.



National Science Foundation

World Radiocommunication Conference



Many users share the radio spectrum. Worldwide, the use of the spectrum is coordinated by the International Telecommunication Union, and updated at World Radiocommunication Conferences every four years.



Issues on the agenda of each Conference are set by the previous Conference. Four years of technical studies in sub-groups culminate in changes to the International Radio Regulations (a treaty between 193 member nations). There are many radio services, most of which transmit radio energy and which may interfere with radio astronomical observations. Satellites, high-altitude platforms, cellphones, and car radars are just some of the challenges.



Compared with most radio receivers, radio astronomy systems are phenomenally sensitive. That makes them especially susceptible to interference, and in need of both technical and regulatory protection.

Over 2000 delegates from around the world attend each Conference, representing countries, companies, and organizations. In four weeks, they complete their work.

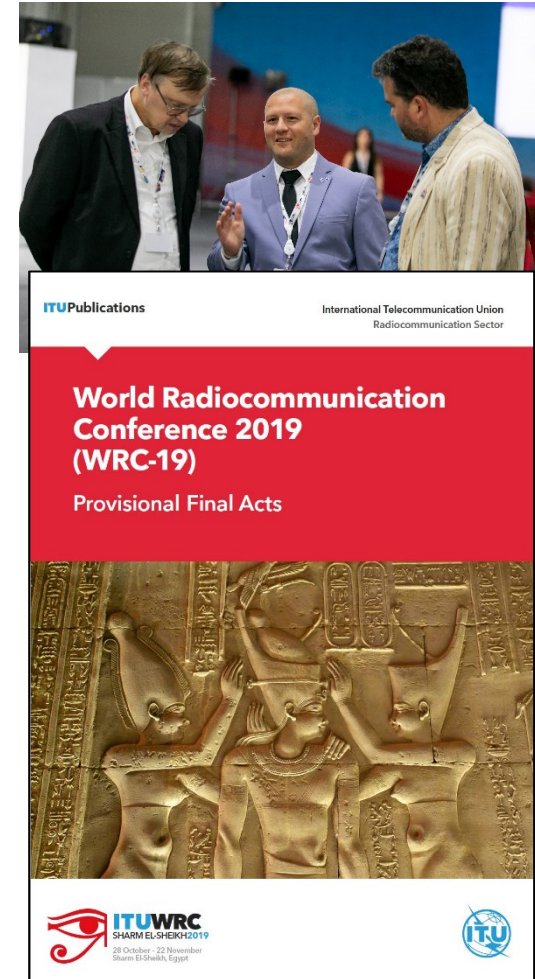




World Radiocommunication Conference



- Treaty conference convened every four years
- Just completed; held in Egypt, Oct-Nov, 2019



*The National
Academies of*

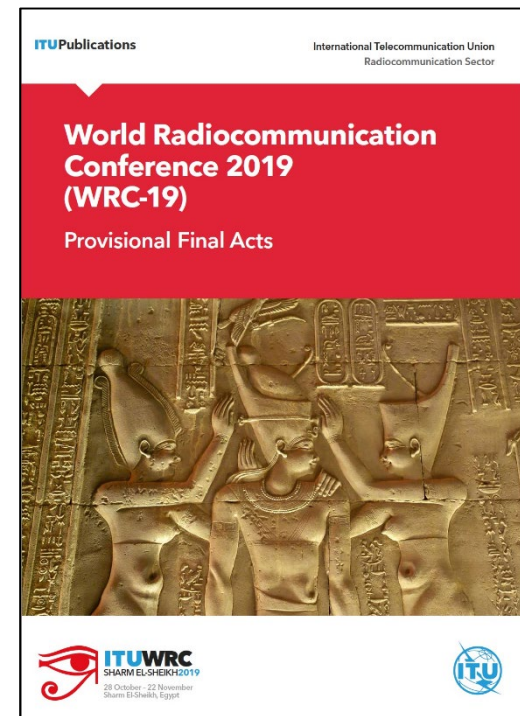
SCIENCES
ENGINEERING
MEDICINE

BOARD ON PHYSICS AND ASTRONOMY
Division on Engineering and Physical Sciences



World Radiocommunication Conference

- **Astronomy outcomes at WRC-19:**
 - 275 – 450 GHz protections for RAS from FSS/LMR
 - Protection of 1610-1613 MHz
 - Language for development of a recommendation for protection of RAS sites from 5G (especially at 24 and 42 GHz)
 - RAS protections from HAPS (coordination distances required)
 - Still ambiguous how RAS limits are treated from out-of-band emissions from nearby services





World Radiocommunication Conference

Key WRC-2019 Outcomes

- IMT (Mobile Broadband)
 - Identification in 24.25-27.25 GHz, 37-43.5 GHz
 - In-band and adjacent to radio astronomy frequencies
 - Further ITU documentation for protection to be developed
 - Modifications to numerous country footnotes adding IMT identification
- High-altitude platforms
 - Identification in 21.4-22 GHz, 24.25-25.24 GHz, 31-31.3 GHz, 38-39.5 GHz
 - Significant protections for radio astronomy (more strict than Recommendation ITU-R RA.739-2)
- 275-450 GHz terrestrial operation
 - 275-296 GHz, 306-313 GHz, 318-333 GHz and 356-450 GHz identified for land-mobile and fixed service applications
 - Means to protect radio astronomy assets indicated as necessary



World Radiocommunication Conference

Key WRC-2019 Outcomes

- GMDSS identification for Iridium system (1616-1626 MHz)
 - Out of band interference from Iridium system into OH maser band (1610-1613 MHz) noted for more than two decades
 - Significant discussion at WRC-19 revolved around resolving ongoing interference situation
- End result:
 - GMDSS operation allowed in frequency band 1621.35-1626 GHz
 - Restrictions on out-of-band emissions greatly strengthened
 - Radio astronomy limits incorporated into the radio regulations for emissions into the OH maser band
 - Several loopholes in compliance were fixed



World Radiocommunication Conference

WRC-23 Agenda

- The most challenging issues from a radio astronomy perspective were redirected to the WRC-27 agenda
- Issues of interest on WRC-23 agenda:
 - IMT (Mobile Broadband) in 3300-3400 MHz, 3600-3800 MHz, 6425-7 025 MHz, 7025-7125 MHz and 10.0-10.5 GHz
 - Use of high-altitude platforms for provision of IMT services in 694-960 MHz, 1710-1885 MHz, 2500-2690 MHz
 - Sub-orbital vehicles (frequencies to be determined; of interest to NASA)
 - More GMDSS
 - Upgrade of SRS allocation in 14.8-15.35 GHz
 - Review of frequency allocations for EESS (passive) in the frequency range 231.5-252 GHz
 - Space weather sensors

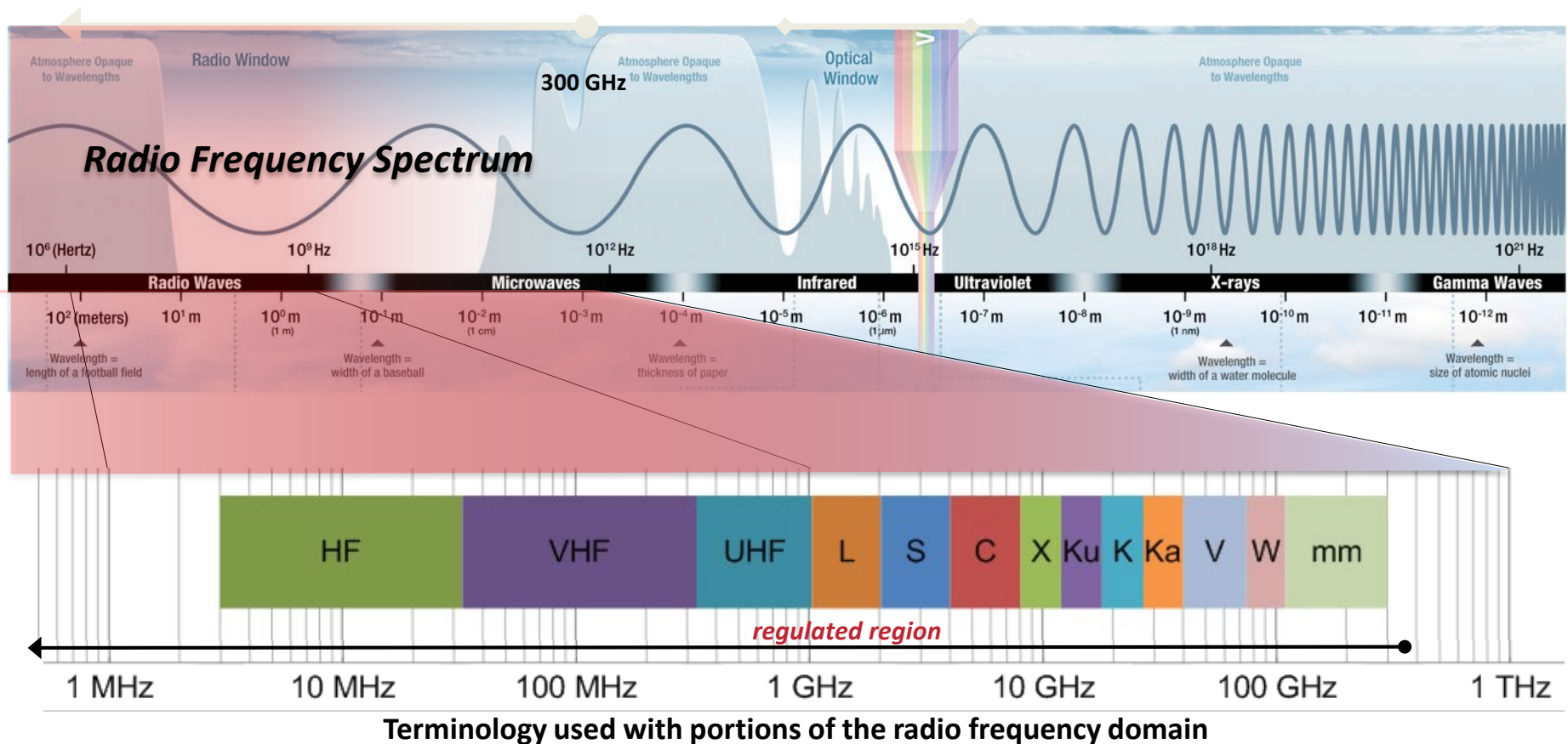


World Radiocommunication Conference WRC-27 Agenda

- Approaching cautiously; these issues may never be studied
- Items of concern:
 - New allocations and identifications to the radiolocation service in 275-700 GHz
 - ESIMs in 37.5-39.5 GHz (space-to-Earth), 40.5-42.5 GHz (space-to-Earth), 47.2-50.2 GHz (Earth-to-space) and 50.4-51.4 GHz (Earth-to-space)
 - Fixed satellite service allocations in 43.5-45.5 GHz, 71-76 GHz, 81-86 GHz
 - Space-to-space inter-satellite links in 1525-1544 MHz, 1545-1559 MHz, 1610-1645.5, 1646.5-1660.5 MHz, and 2483.5-2500 MHz
 - IMT studies in 1300-1350 MHz

Scientists use the entire spectrum but only 8.3 kHz to 275 GHz is regulated:

- **Radio Frequency Spectrum:** frequency region of the EM Spectrum that is managed via international and national laws and regulations
- Limited regulations in the near-infrared and optical region (e.g., laser coordination & safety standards)



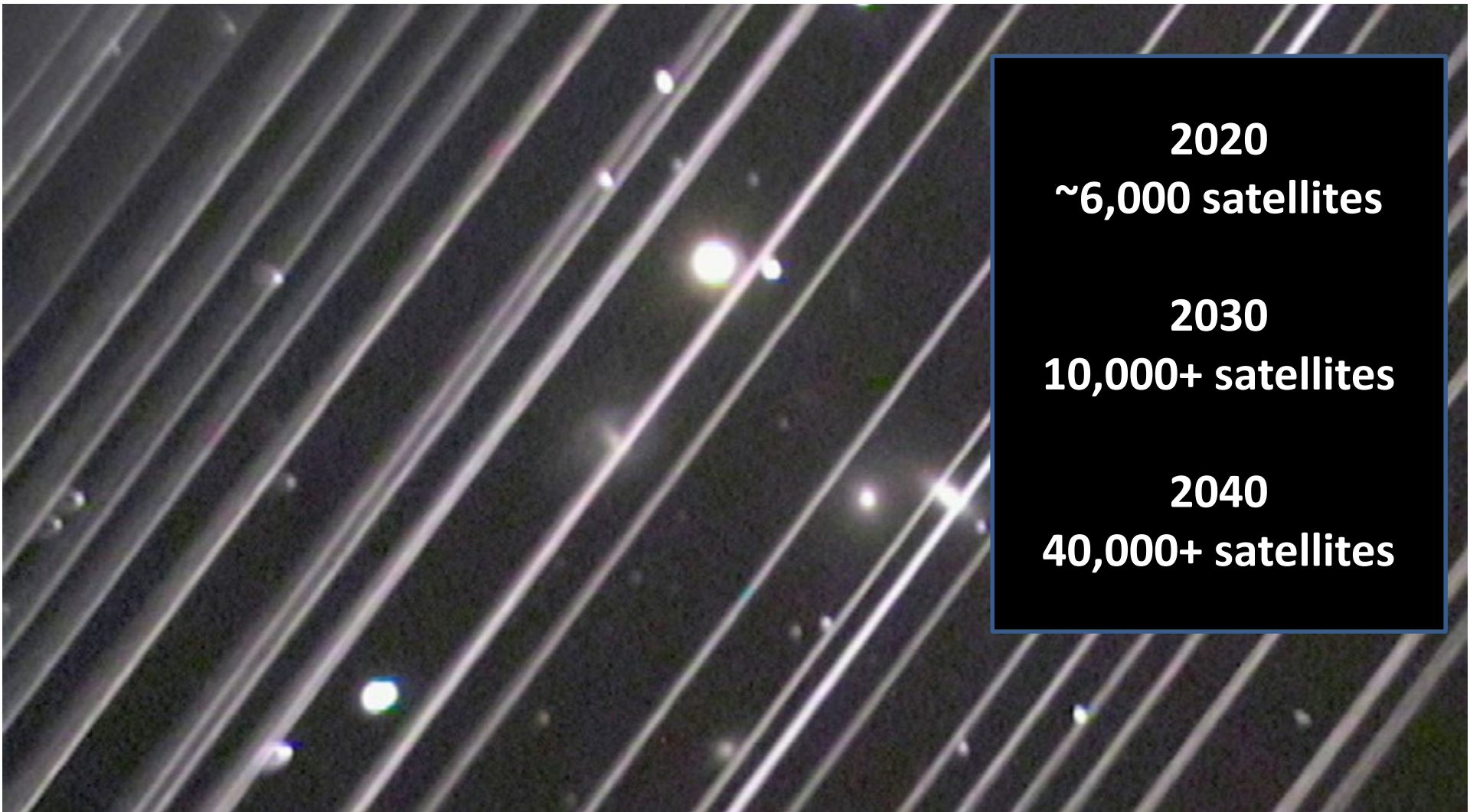
What is coming?

- Constellations of thousands of NGSO satellites (10-50+ GHz transmitters) such that from any location you would always “see” at least one and up to 3 or 4 satellites or more!
- Mobile telecommunications (5G, IMT)
- High altitude platform systems



Credit: Univer





2020
~6,000 satellites

2030
10,000+ satellites

2040
40,000+ satellites

Optical image of NGC 5353/4 galaxy group (25 May 2019)

Image Credit: Victoria Girgis / Lowell Observatory

<https://www.iau.org/public/images/detail/ann19035a/>





Summary

- **Keep protected allocations as RFI-free as possible**
 - *Emissions may be prohibited at certain frequencies, out-of-band emissions can still be problematic*
 - *New challenges above the regulated regime (above 275 GHz, into optical)*
- **Utilize technology developments and advancements to increase spectrum availability, esp. in strategic geographic locations**
 - *Research in RFI excision techniques and receiver technology*
 - *Astronomy needs enhanced ESM geographical protections*
 - *a new coordinated quiet zone for the upcoming decade (VLA has no quiet zone, NRQZ in WV does not protect from airborne emitters)*
- **Coordination – internal at NSF and external stakeholders**
 - *Spectrum sharing*
 - *Costs must be considered; resources required for dynamic sharing*
- **Educational opportunity - Increased awareness of the spectrum as a finite resource**

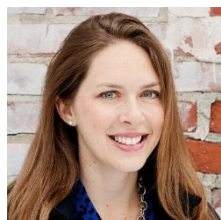


Questions?



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Thank you



NSF Coordination Group on Electromagnetic Spectrum Management



Jim Ulvestad

**Chief Officer for Research Facilities,
Office of the Director**



Jonathan Williams

Coordination Group Chairman

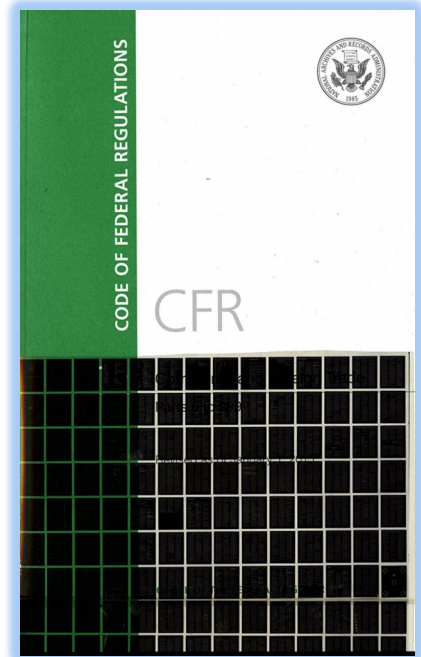
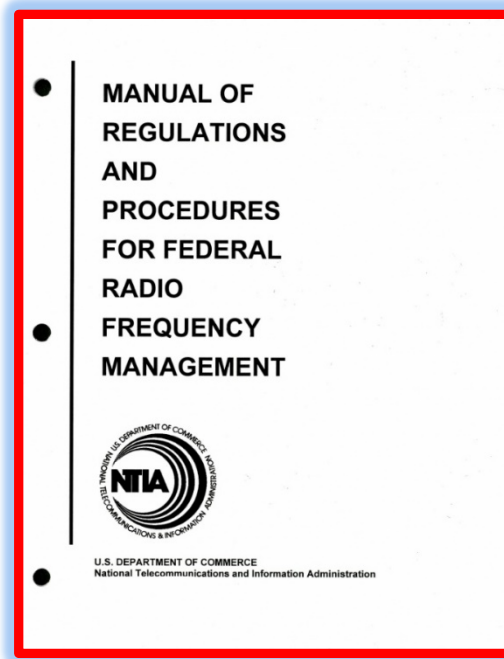
NSF Coordination Group includes representation from

- Mathematical and Physical Sciences
- Geosciences
- Computer and Information Science and Engineering
- Engineering
- Biological Sciences
- Social and Behavioral Sciences
- Education and Human Resources
- Office of the General Counsel
- Office of International Science and Engineering



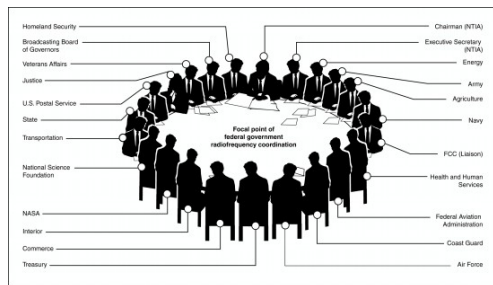
Allocations and Coordination

- Radio Regulations:
 - (1) International (ITU-R Radio Regulations; www.itu.int)
 - (2) Regional (bilateral agreements)
 - (3) National (USA: NTIA - www.ntia.doc.gov; FCC - www.fcc.gov)





NSF ESM Unit Activities



- Represent NSF as a Federal Agency to the National Telecommunications and Information Administration
 - 10 subcommittees including
 - IRAC
 - FAS (NRQZ coordination)
- Representation on official U.S. Delegations to the Inter-American Telecommunications Commission (CITEL) of the Organization of American States (OAS)
- Representation on official U.S. Delegations to the International Telecommunication Union's World Radiocommunication Conference (WRC 2019), including leading 7D – Radio Astronomy

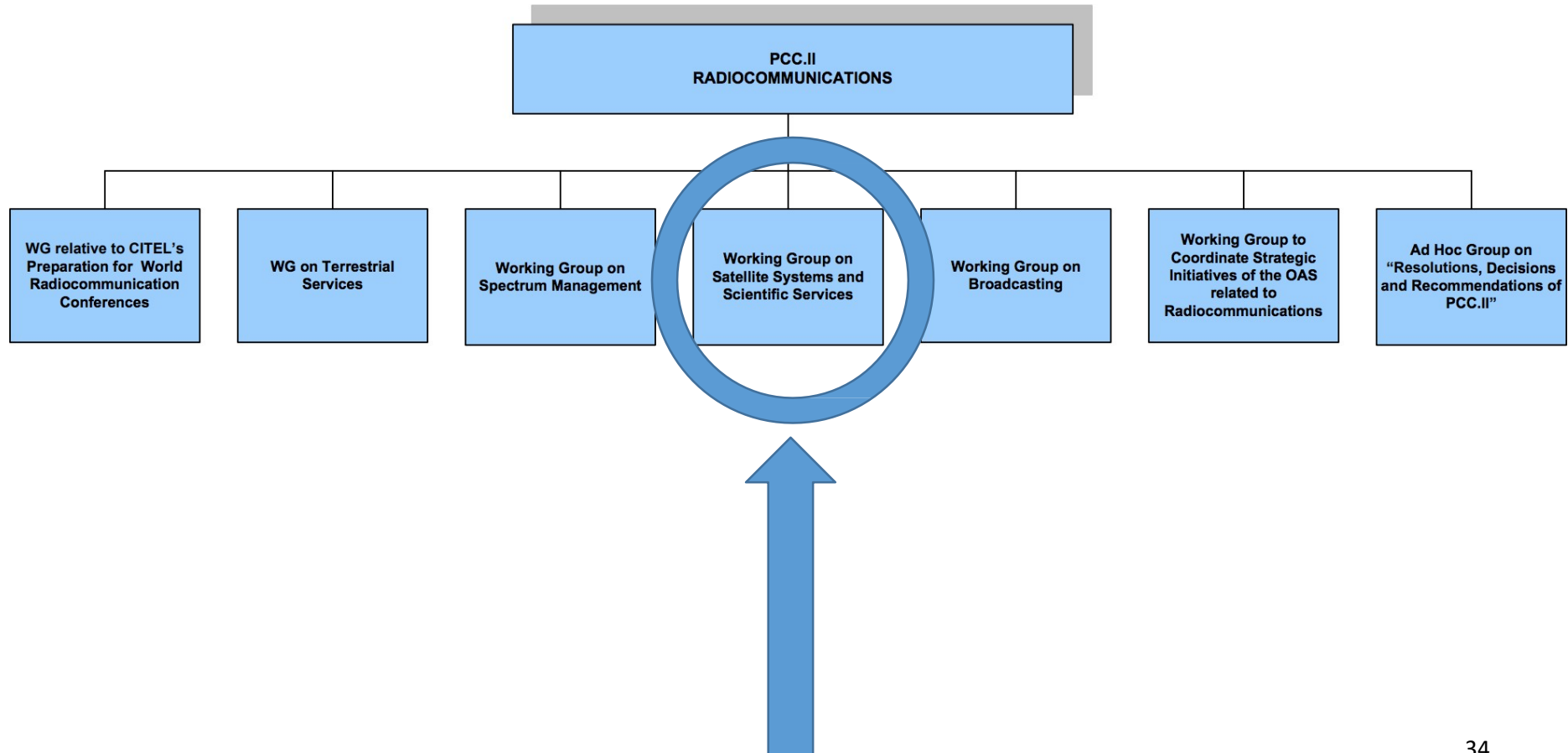


OAS | CITEL



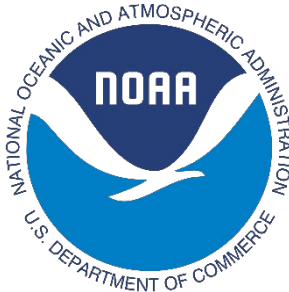


OAS | CITEL





NSF ESM Unit Activities



Federal
Communications
Commission

- At NSF – Coordination with other Directorates and Divisions with spectrum needs, and manage spectrum related grants portfolio, including the National Academies of Sciences Committee on Radio Frequencies (CORF)
- Coordinate with other US Agencies, especially science agencies
- Interface with commercial interests to advocate for their taking “practicable” steps to not cause interference to passive services

JWST plans to use the Ka-band downlink...

Name:	Ka-Band Transmitter
Frequency:	25.9 GHz
Emission Designators:	56M0G1D, 28M0G1D, 14M0G1D
Service Directions:	<ul style="list-style-type: none">• Space to Earth• Deep Space
Radio Services:	<ul style="list-style-type: none">• Space Research
Station Classes:	<ul style="list-style-type: none">• EH - Space Research (Space)
Earth Stations:	<ul style="list-style-type: none">• Canberra (AUS)• Goldstone (CA)• Robledo de Chavela (E) (Madrid)
Asset Type:	Emitter
DBIU:	03/30/2021