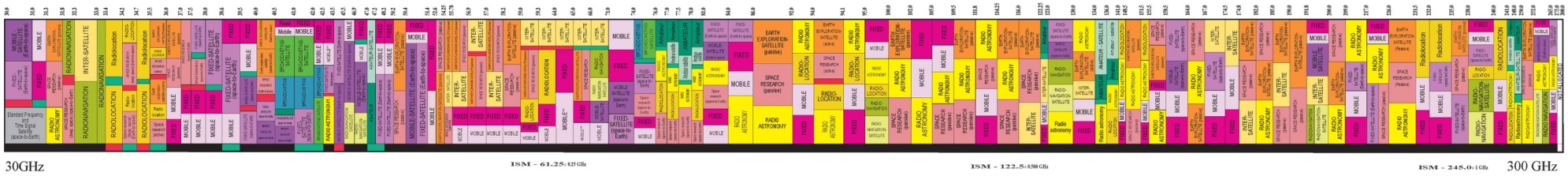
# National Science Foundation

## Electromagnetic Spectrum Management
## Division of Astronomical Sciences




January 25, 2018

Report to the Astronomy and Astrophysics Advisory Committee (AAAC)

# ESMU Contacts at NSF: esm@nsf.gov

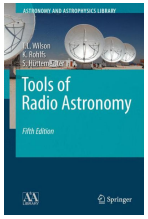
**Glen Langston** — **Frequency Assignments, FAS rep**

**Joe Pesce** — **Arecibo Observatory**

**Pat Smith** — **Polar Research Support**

**Jonathan Williams** — **All areas**

**Tom Wilson** — **All areas, Retired**




**Ashley Zauderer** — **All areas**

# What is Spectrum Management and Why is it Vital to Enabling Cutting-Edge Science?

# Outline

I. Overview of NSF Spectrum Usage

II. Spectrum Allocations and Regulations

III. NSF ESM Activities

IV. Review of AAAC Findings and Recommendations

V. Conclusions

# I. Overview of NSF Spectrum Usage

# NSF-funded research relies on access to electromagnetic spectrum (all Divisions)

NSF funds a wide variety of programs
that *require usage of the radio spectrum* across Divisions:

- Geosciences
- Biological Sciences
- Computer and Information Science and Engineering
- Engineering
- Mathematical and Physical Sciences

Especially heavy use by these Directorates: Physics, Astronomy, Polar Programs, Atmospsheric and Geospace Sciences, Ocean Sciences and Earth Sciences.

Usage: Passive and Active

Research utilizes

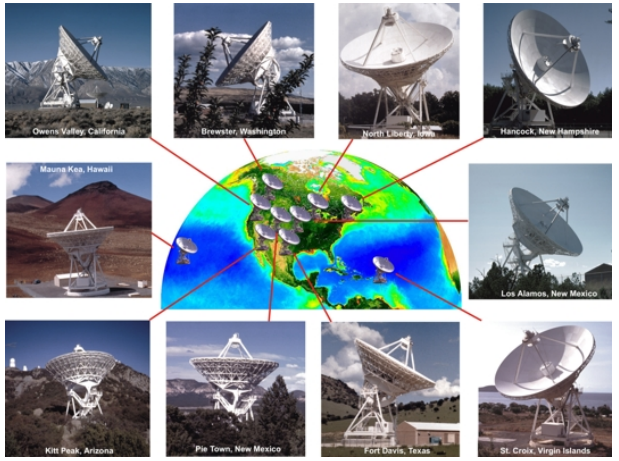
- commercially marketed instruments and communications devices/services
- original design instrumentation

# NSF-funded Astronomy research relies on access to electromagnetic spectrum

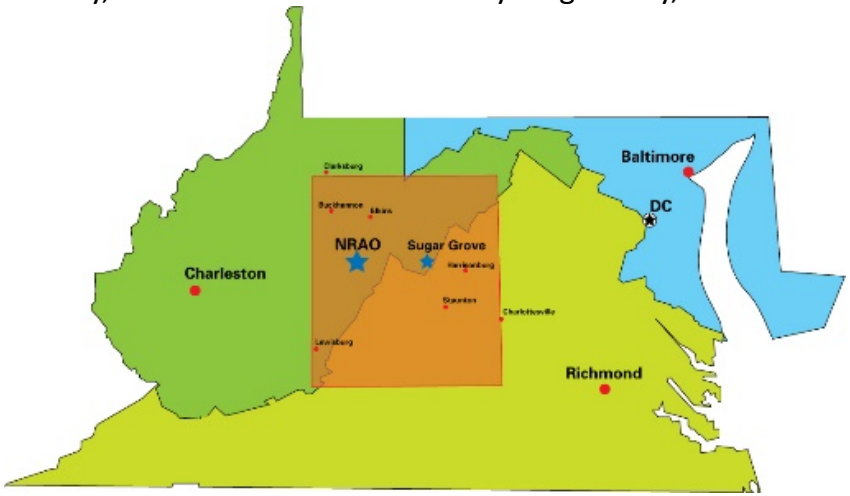
ESM resides in MPS/AST because historically spectrum usage has been focused primarily around the needs of a few large facilities and the National Radio Quiet Zone.

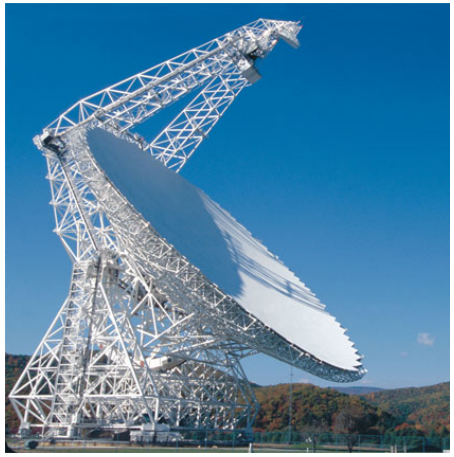
Arecibo Observatory, Puerto Rico

Very Large Array, NM




Very Long Baseline Array



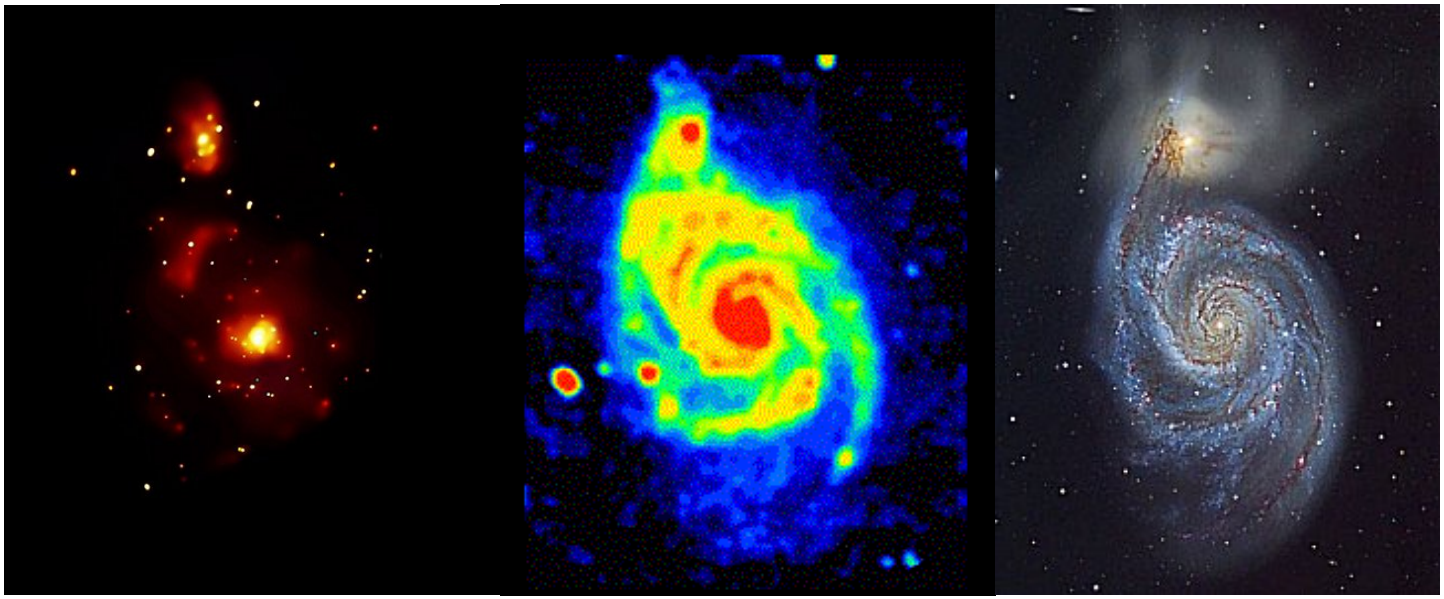



Green Bank Observatory
National Radio Quiet Zone

# Importance of EM Access

*- AST sciences are fundamentally dependent on the detection of light across the full EM spectrum (AAAC report, March 2017)*

- "The observations exploited the large collecting area of the GBT and the power of a recently developed high-speed digital signal processor. In general, such measurements *depend critically on access to wide swaths of the electromagnetic spectrum free of interference.*" (p. 10, AAAC report 2010 - 2011)



M51 in X-ray, radio, and visible light (Image Credit: http://coolcosmos.ipac.caltech.edu/)

# UNITED STATES FREQUENCY ALLOCATIONS

## THE RADIO SPECTRUM


This chart is a graphic single-point-in-time portrayal of the Table of Frequency Allocations used by the FCC and NTIA. As such, it may not completely reflect all aspects, i.e. footnotes 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

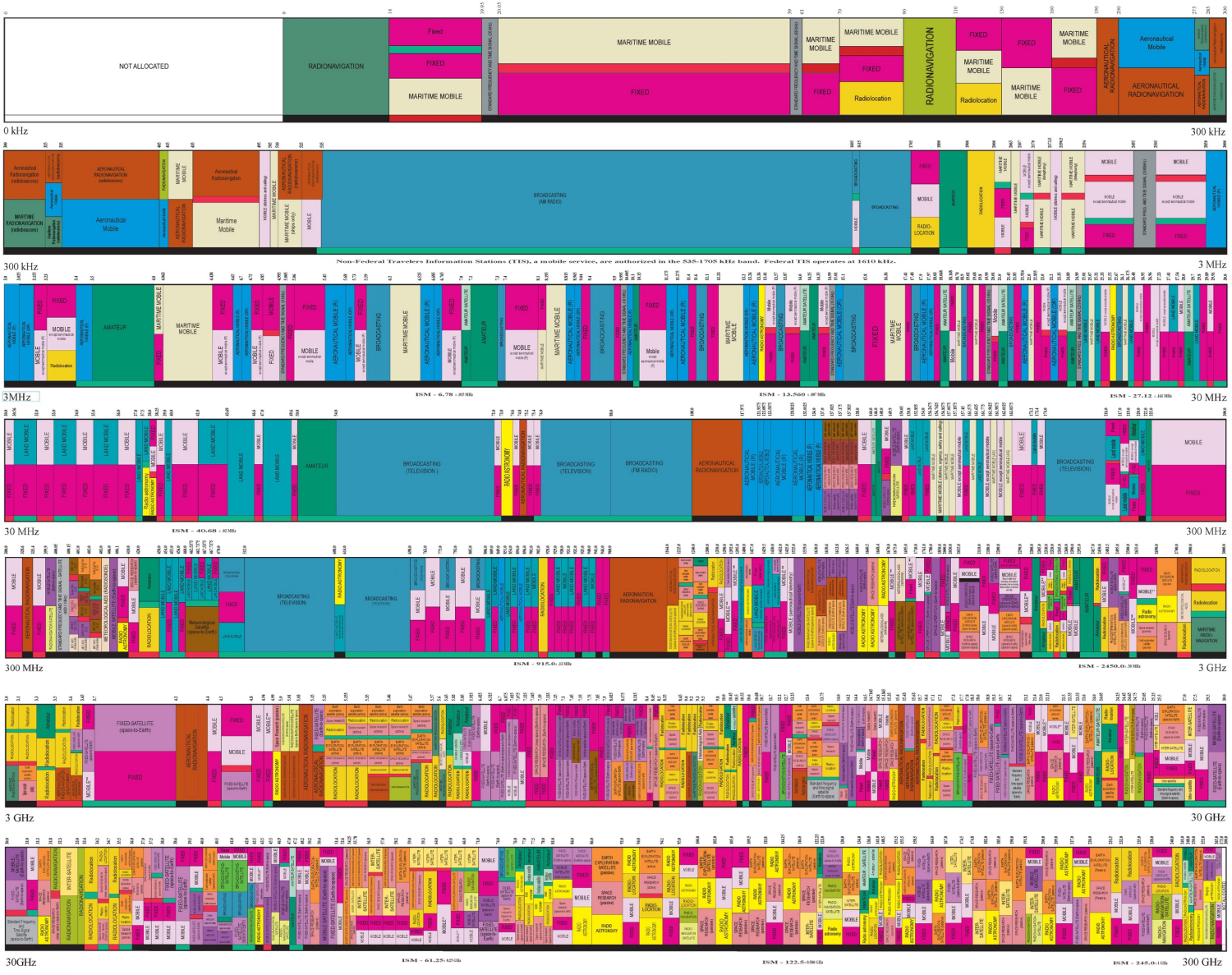



Image Credit: www.ntia.doc.gov

# AST Frequency Usage Takeaways

- **Protected frequency bands include most important identified spectral lines for studying the local universe (e.g. HI, CO, OH masers), but doppler-shifted lines from sources further away in the Universe fall into non-protected bands. Frequencies used for observation are often non-interchangeable, and much observation is done opportunistically.**

# Epoch of Reionization

HI: 21 cm -> 1.5 m

Freq ~ 1420 MHz -> 200 MHz

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

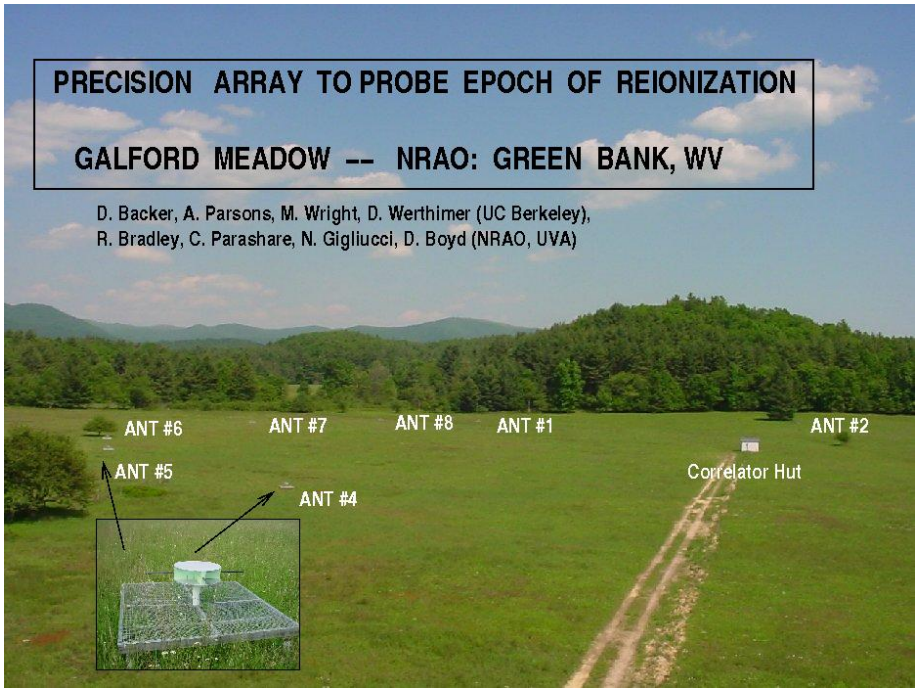



Image Credit: w.astro.berkeley.edu

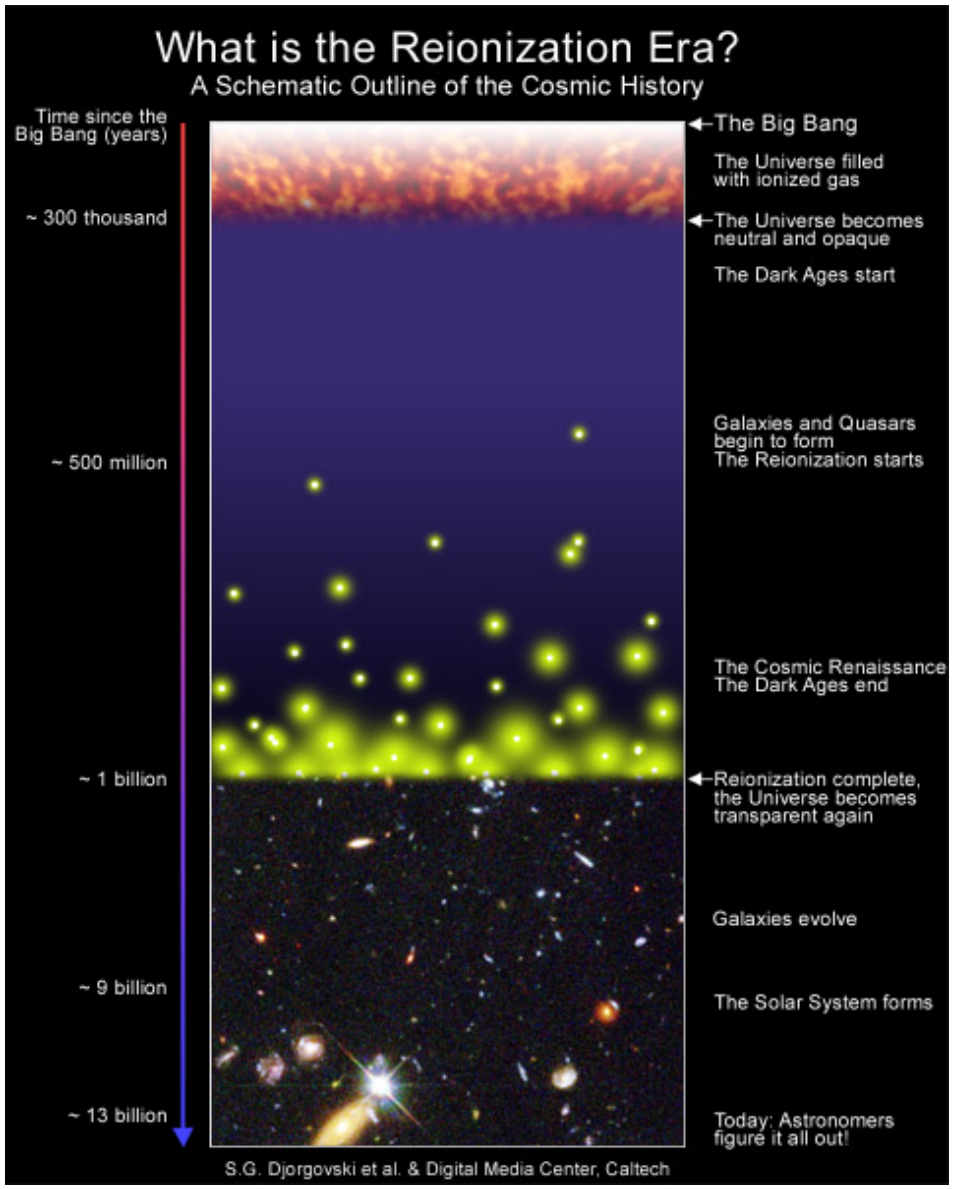


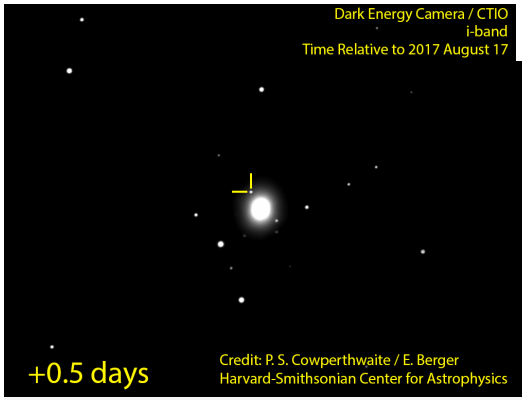

Image Credit: Djorgovski et al. (Caltech); www.haystack.mit.edu

# AST Frequency Usage Takeaways

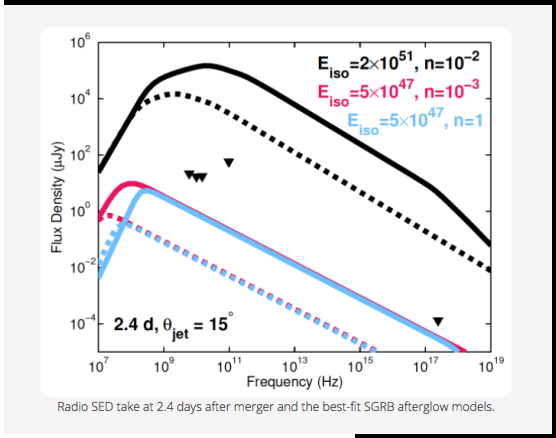
- **Protected frequency bands include most important identified spectral lines for studying the local universe (e.g. HI, CO, OH masers), but doppler-shifted lines from sources further away in the Universe fall into non-protected bands. Frequencies used for observation are often non-interchangeable, and much observation is done opportunistically.**

- **It is imperative that the increasing demands for spectrum take into consideration the challenges to scientific progress and NSF appreciates efforts to coordinate and to limit out-of-band emissions; Astronomy observations also include continuum emission (thermal, non-thermal).**

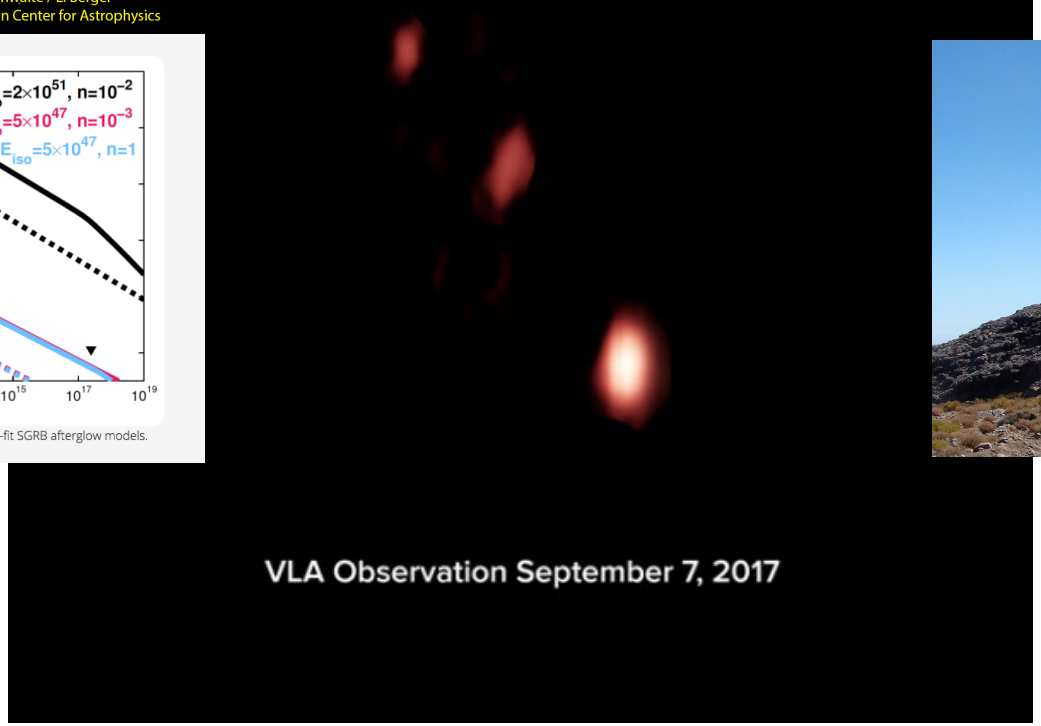
# Multi-messenger & Time-Domain Astronomy




**10 uJy at 3 GHz ~2 weeks**
**2 GHz BW (~1.4 GHZ after RFI excision)**
**<50 MHz is RAS primary**



Radio SED take at 2.4 days after merger and the best-fit SGRB afterglow models.



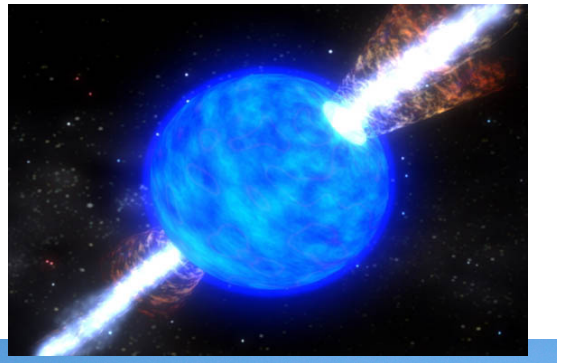



Image credits: NASA
www.lsst.org

Image Credits: Hallinan et al., Science (16 Oct 2017)

# AST Frequency Usage Takeaways

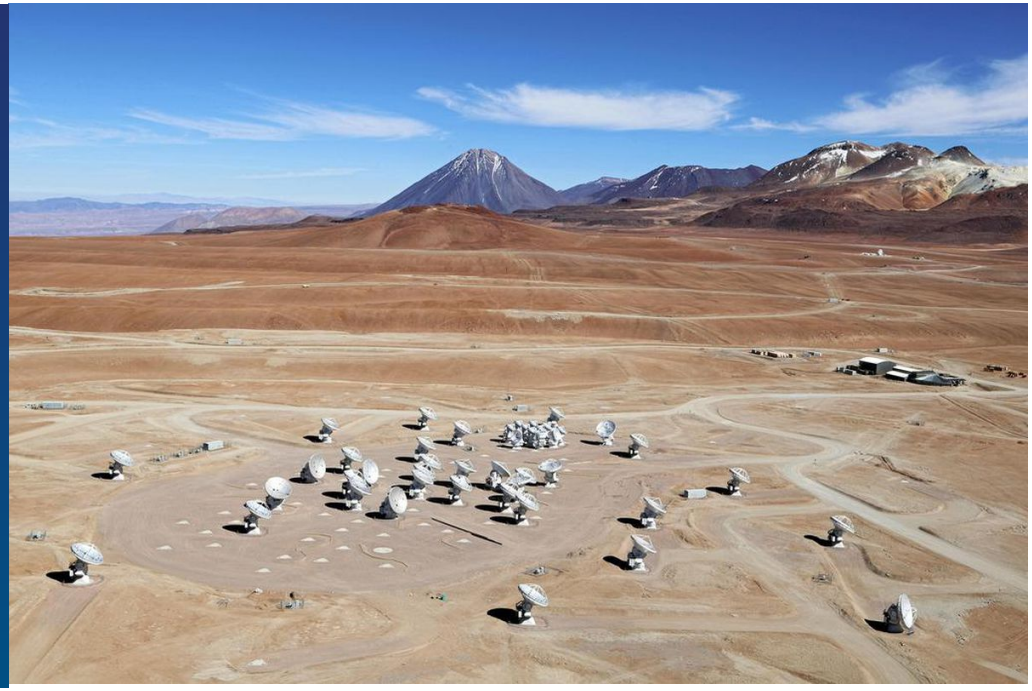


Image credit: almaobservatory.org

- **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.**

# Importance of EM Access

- ***Not a new issue:***
  - "*The stability and continuity associated with officially reserved segments of the spectrum are essential to radio-astronomical research.*" (Pankonin and Price, IEEE, 1981)
    - RAS allocated very little spectrum (~2% at cm λλ)

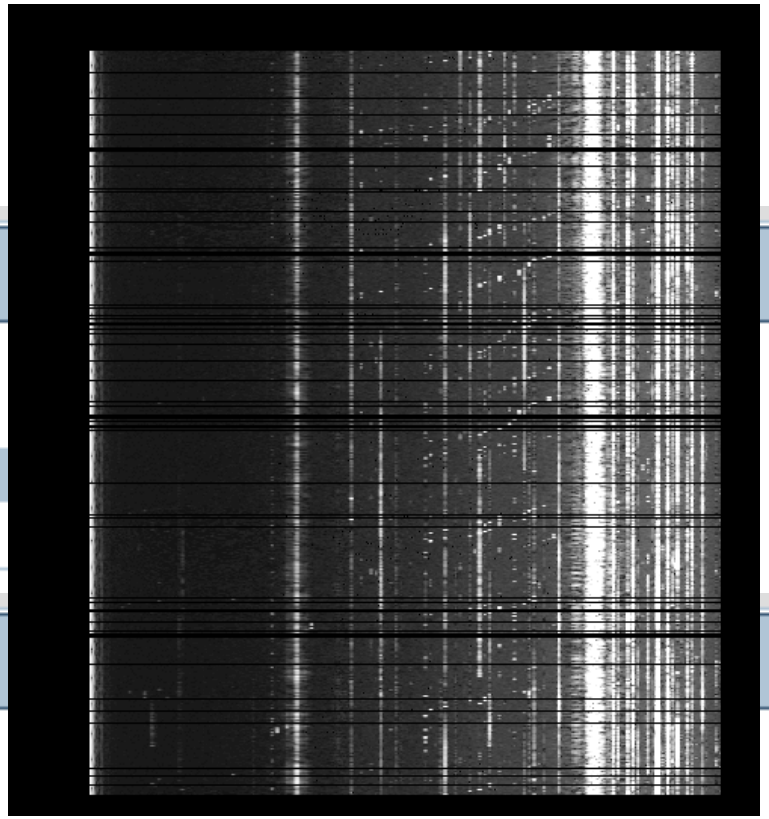
  - "The past two decades have seen a huge increase in the number of end users of already-popular applications, such as cell phones and the Global Positioning System, and an enormous variety of new applications continue to be introduced. *The result has been significant contamination of much of the frequency space with unpredictable and broadband emissions from an array of communication devices.* Although many applications of the radio spectrum provide a clear benefit for society, concern is growing about protecting observing conditions for radio astronomy, a uniquely powerful tool for studying the universe." (NAS 2001 Decadal Report)

| Table 1: Overall EVLA Performance Goals | | | |
|---|---|---|---|
| Parameter | VLA | EVLA | Factor |
| Continuum Sensitivity (1-σ, 9 hr) | 10 μJy | 1 μJy | 10 |
| Maximum BW in each polarization | 0.1 GHz | 8 GHz | 80 |
| | | | |
| Log (Frequency Coverage over 1–50 GHz) | 22% | 100% | 5 |

Table and Image Credit: NRAO

# *What is coming…*

- Constellations of thousands of satellites (20-50 GHz regime) such that from any location you would always “see” at least one, preferably (in mind of satellite providers) up to 3 or 4 satellites
- Mobile telecommunications
- High Altitude Platform Systems



## RFI at K-Band (18-26.5 GHz)

by Emmanuel Momjian — last modified Jul 07, 2011

| Frequency (MHz) | Description | Origin | Classification |
|---|---|---|---|
| 17800-20200 | Satellite downlink | Clarke Belt | continuous |

## RFI at Ka-Band (26.5-40 GHz)

by Emmanuel Momjian — last modified Mar 15, 2013 by Heidi Medlin

| Frequency (MHz) | Description | Origin | Classification | Spectrum |
|---|---|---|---|---|
| 29500-30000 | local Wildblue VSAT | Local residences | Intermittent | |
| 34875 | Internal (June 2 to Oct. 8, 2010) | Antenna EA10 | Continuous | plot |
| 36286 | Internal (June 2 to Oct. 8, 2010) | Antenna EA10 | Continuous | plot |

https://science.nrao.edu/facilities/vla/observing/RFI

# II. Spectrum Allocation & Coordination

# UNITED STATES FREQUENCY ALLOCATIONS

## THE RADIO SPECTRUM

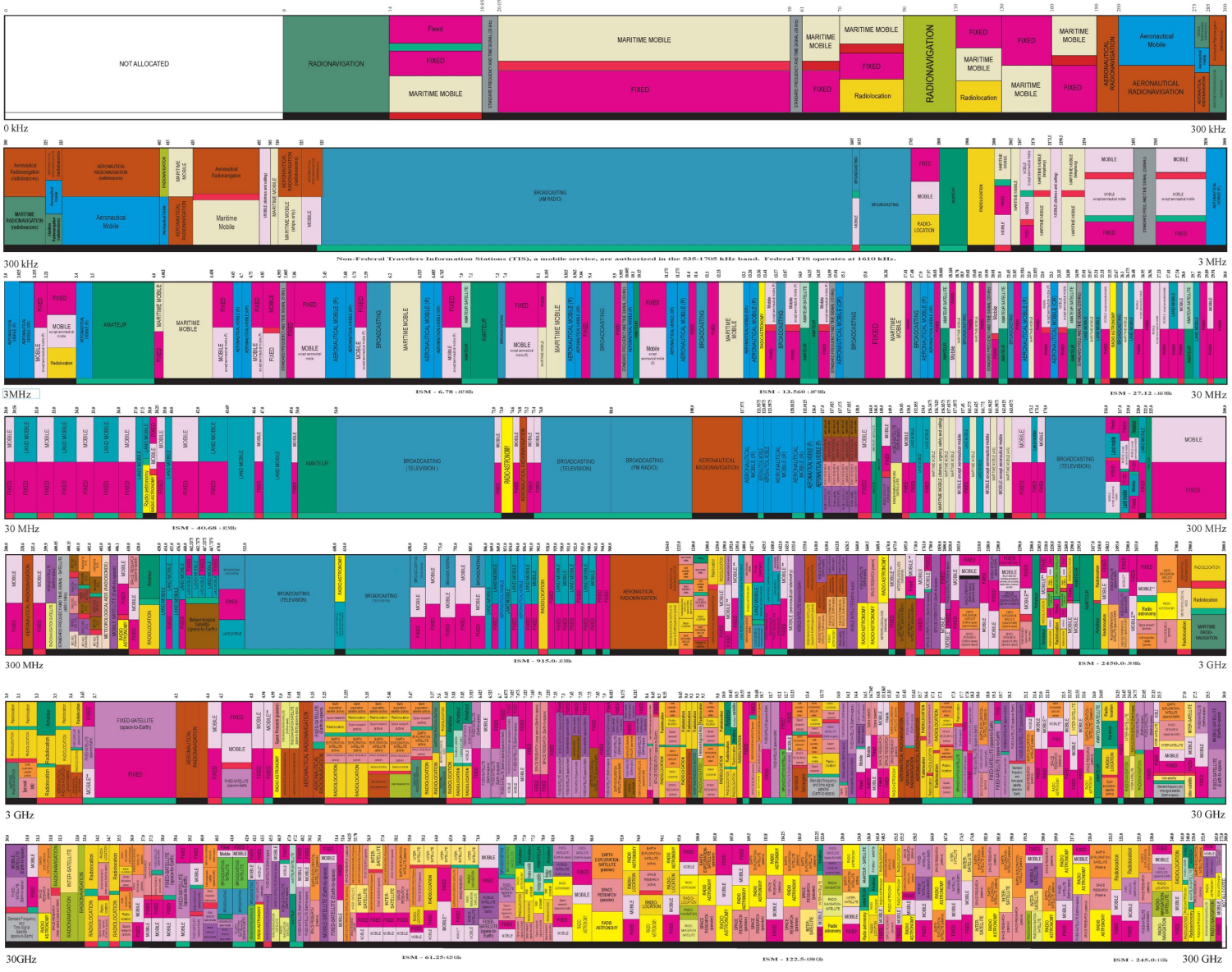
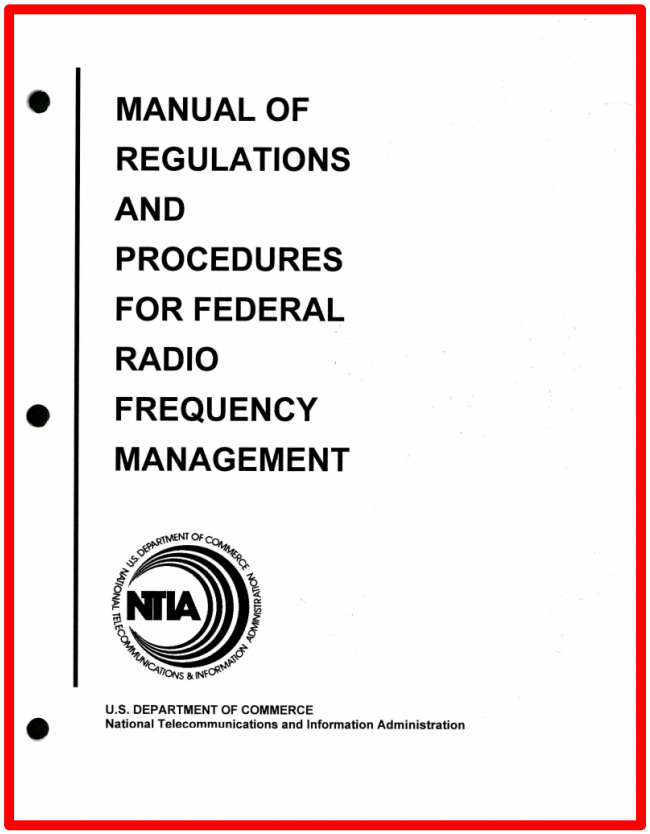




Image Credit: www.ntia.doc.gov

# Allocations and Coordination

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

# ITU-R regions

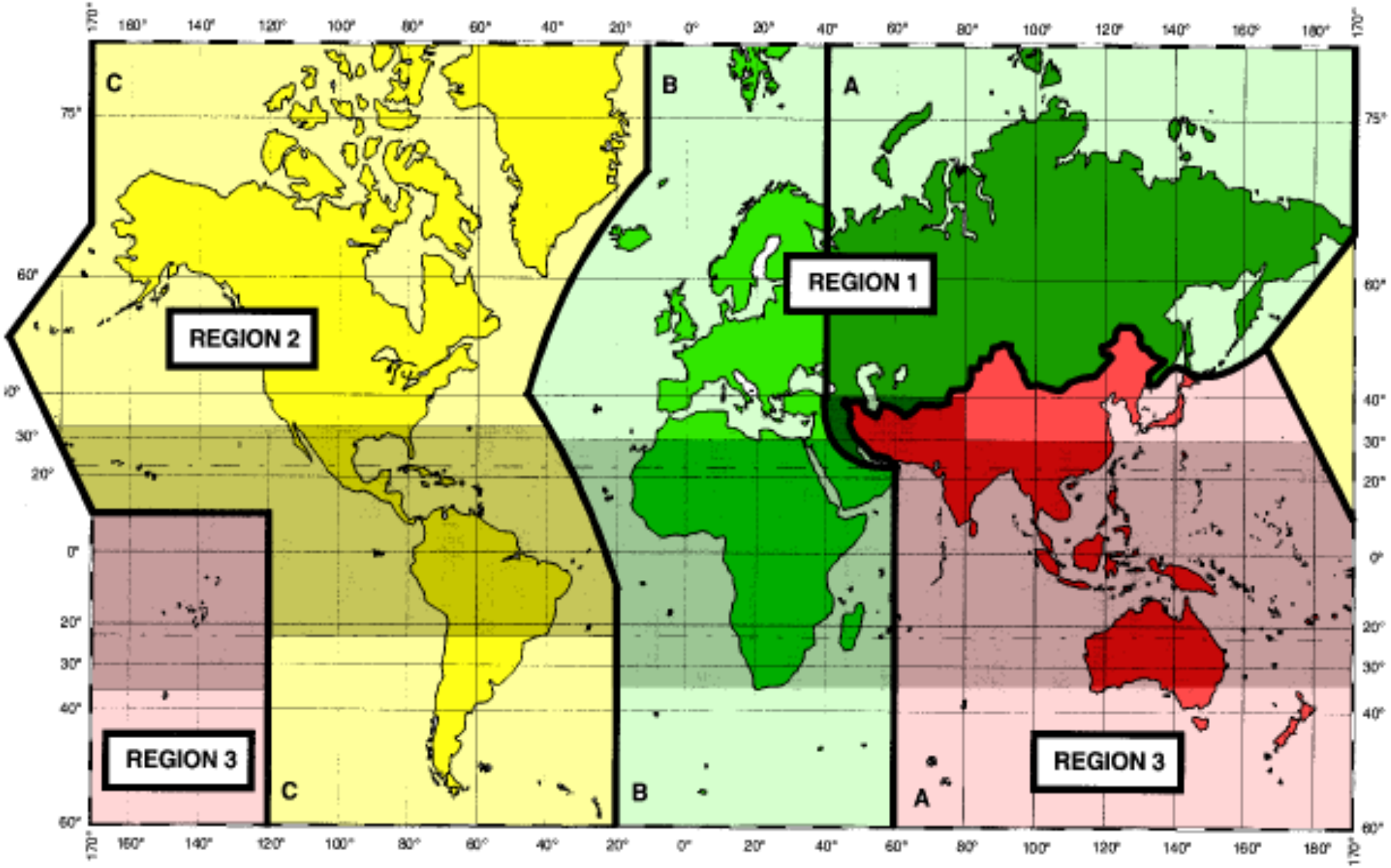
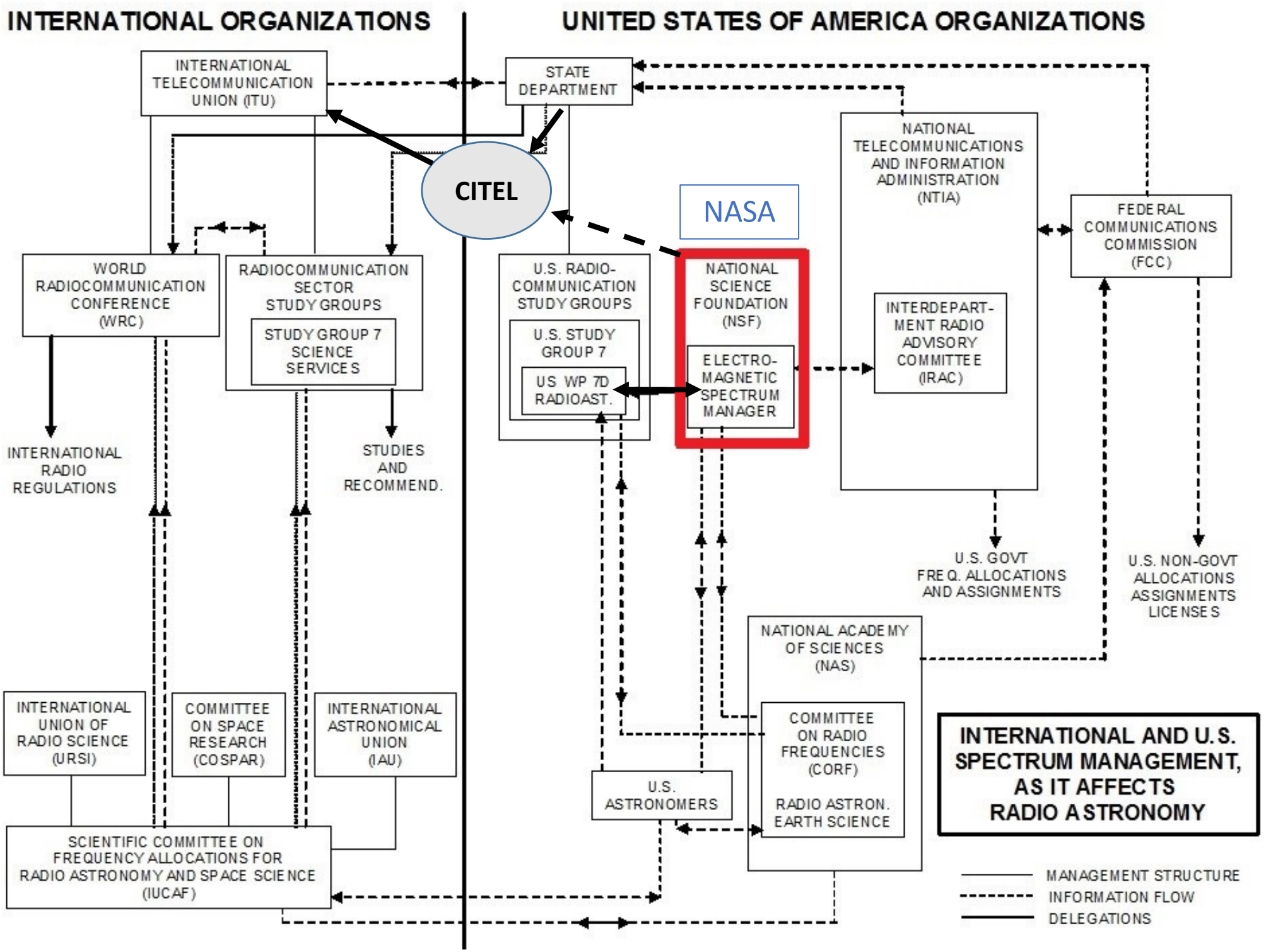



Image Credit: ITU


INTERNATIONAL ORGANIZATIONS
UNITED STATES OF AMERICA ORGANIZATIONS
INTERNATIONAL TELECOMMUNICATION UNION (ITU)
STATE DEPARTMENT
CITEL
NASA
NATIONAL TELECOMMUNICATIONS AND INFORMATION ADMINISTRATION (NTIA)
FEDERAL COMMUNICATIONS COMMISSION (FCC)
WORLD RADIOCOMMUNICATION CONFERENCE (WRC)
RADIOCOMMUNICATION SECTOR STUDY GROUPS
STUDY GROUP 7 SCIENCE SERVICES
U.S. RADIO-COMMUNICATION STUDY GROUPS
U.S. STUDY GROUP 7
US WP 7D RADIOAST.
NATIONAL SCIENCE FOUNDATION (NSF)
ELECTRO-MAGNETIC SPECTRUM MANAGER
INTERDEPART-MENT RADIO ADVISORY COMMITTEE (IRAC)
INTERNATIONAL RADIO REGULATIONS
STUDIES AND RECOMMEND.
U.S. GOVT FREQ. ALLOCATIONS AND ASSIGNMENTS
U.S. NON-GOVT ALLOCATIONS ASSIGNMENTS LICENSES
NATIONAL ACADEMY OF SCIENCES (NAS)
INTERNATIONAL UNION OF RADIO SCIENCE (URSI)
COMMITTEE ON SPACE RESEARCH (COSPAR)
INTERNATIONAL ASTRONOMICAL UNION (IAU)
COMMITTEE ON RADIO FREQUENCIES (CORF)
RADIO ASTRON. EARTH SCIENCE
U.S. ASTRONOMERS
SCIENTIFIC COMMITTEE ON FREQUENCY ALLOCATIONS FOR RADIO ASTRONOMY AND SPACE SCIENCE (IUCAF)
INTERNATIONAL AND U.S. SPECTRUM MANAGEMENT, AS IT AFFECTS RADIO ASTRONOMY
MANAGEMENT STRUCTURE
INFORMATION FLOW
DELEGATIONS

# Astronomical Input to formulating NSF's position

- CORF – Committee on Radio Frequencies, National Academies
  - Chair: Liese van Zee
- IUCAF – International Committee working in field of spectrum management on behalf of passive radio sciences (set up in 1960 by URSI, IAU and COSPAR; http://www.iucaf.org/)
  - IUCAF Secretariat: Harvey Liszt
- CRAF – European Science Foundation's Committee on Radio Astronomy Frequencies, 22 member countries (https://www.craf.eu)
  - Chairman: W. van Driel; Frequency Manager: Talayeh Hezareh
- Spectrum Managers at Telescopes and/or their Managing Organizations

  NRAO: Harvey Liszt

  Very Large Array: Dan Mertely

  Arecibo: Angel Vazquez

  Green Bank: Paulette Woody
- Astronomers and Telescope Staff

# NSF's Input to Policy

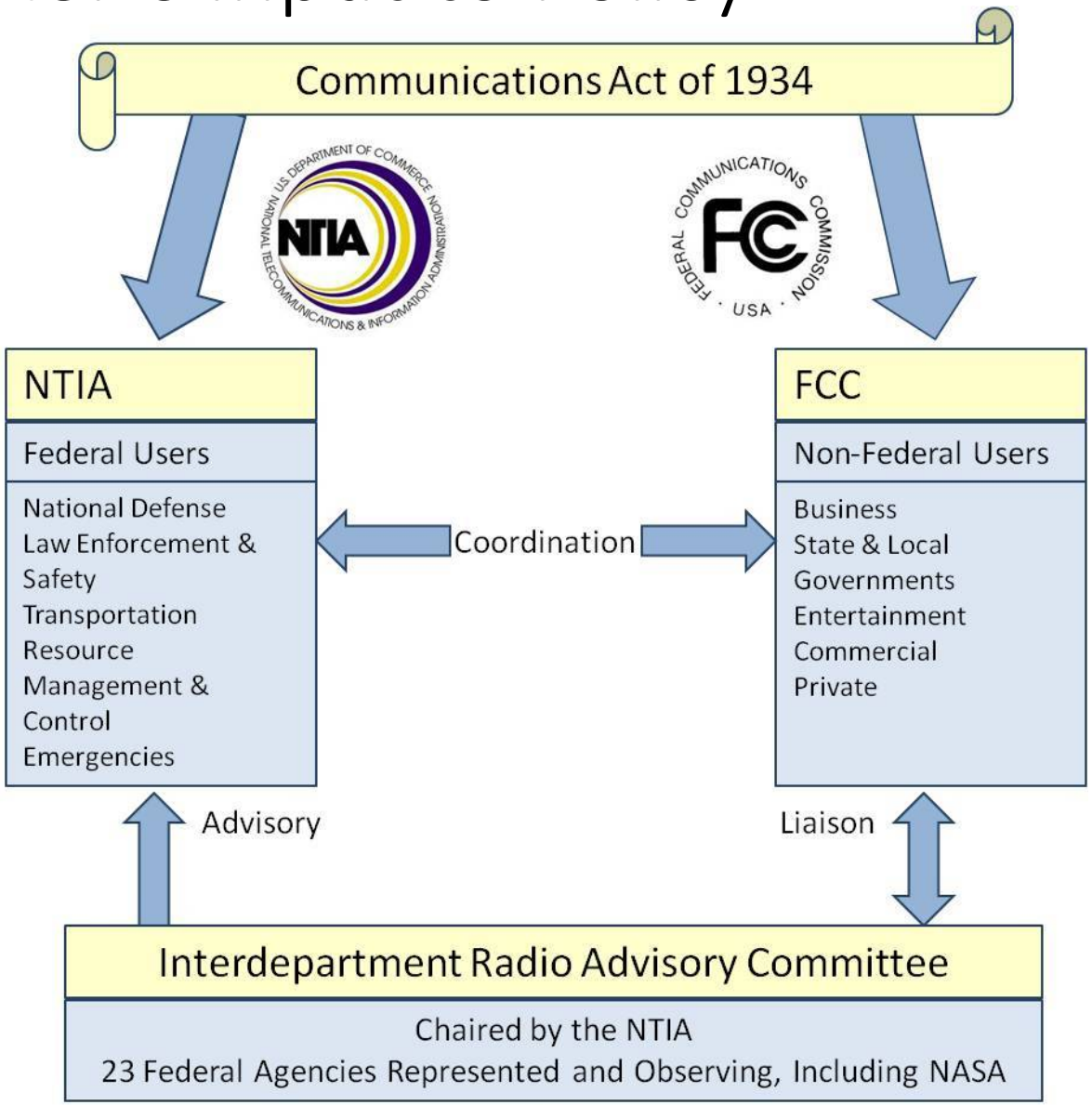
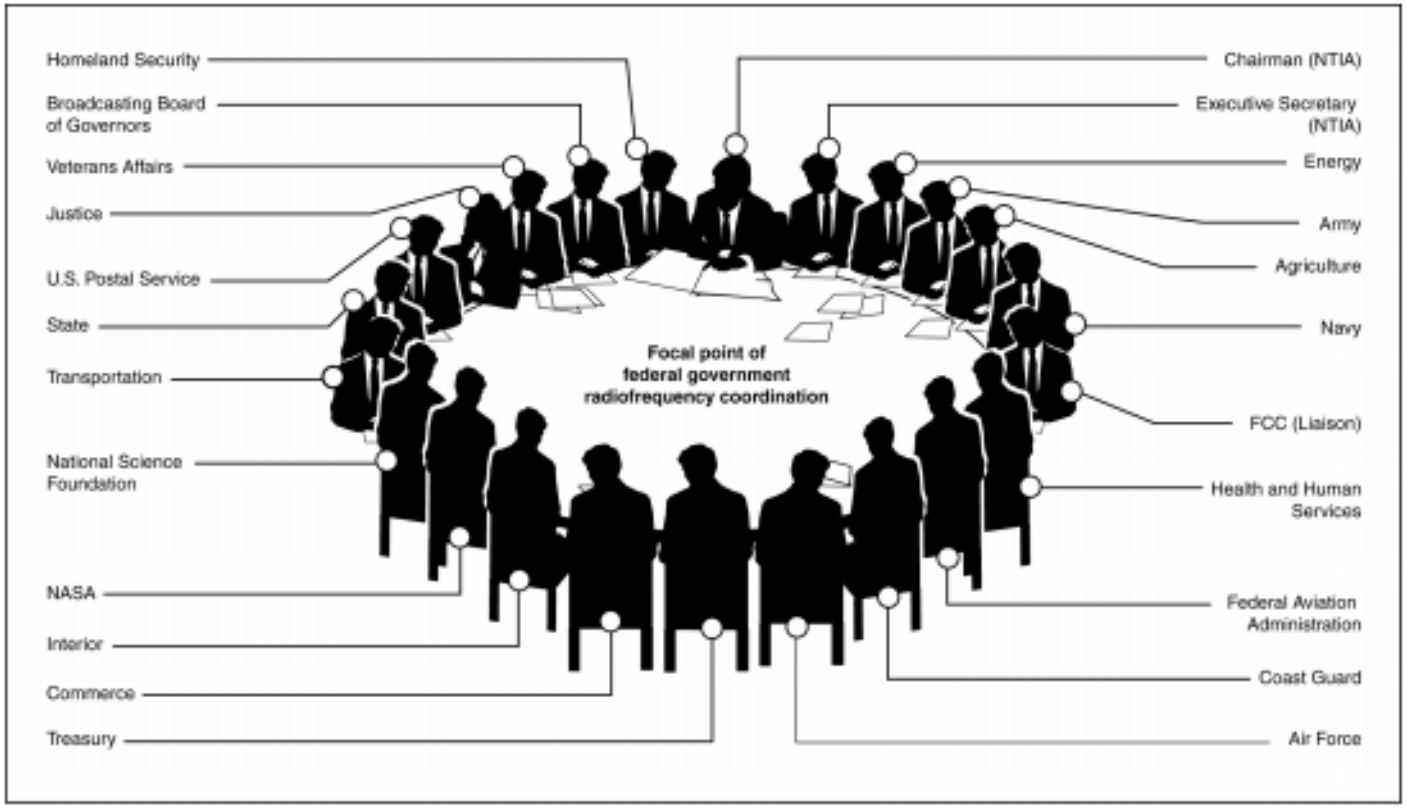


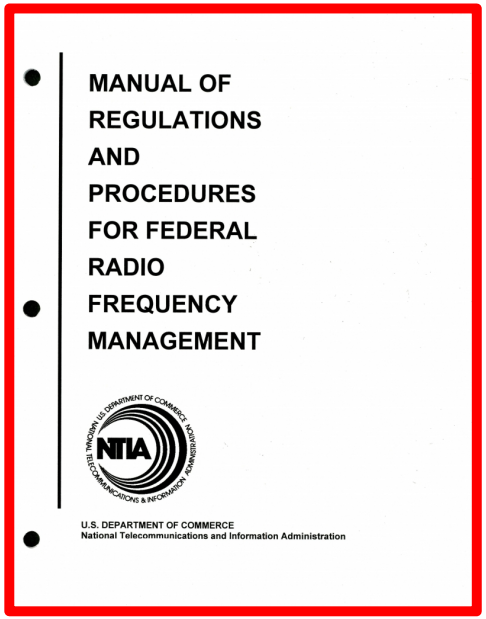

Image Credit:
www.nasa.gov
National Spectrum Management Plan

# Interdepartment Radio Advisory Committee

- FAS - Frequency Assignment Subcommittee
- SPS - Spectrum Planning Subcommittee
- RCS - Radio Conference Subcommittee
- SSS - Space Systems Subcommittee
- TSC - Technical Subcommittee
- EPS - Emergency Planning Subcommittee
- PPSG – Policy and Plans Steering Group
- Ad Hocs: US-Mexico, US-Canada, NTIA manual modernization




Source: NTIA.



# World Radiocommunication Conference


- Every Four years; where International Regulations are formulated; Treaty

- 2015 World Radiocommunication Conference (WRC-15) in Geneva, 2-27 Nov.
  - Over 160 International Telecommunication Union members participated in treaty-based modifications to the ITU Radio Regulations
- Technical preparatory work done in the ITU Radiocommunication Sector Study Groups (ITU-R)
- Conference Preparatory Meeting (CPM) report contained approaches (Methods) for satisfying each agenda item (technical basis upon which Administration proposals are made)
- US Regulators oversee conference preparations by Federal Government (NTIA) and private sector (FCC)
- U.S. Delegation to WRC-15 lead by Ambassador Decker Anstrom (Former Chairman of the Weather Channel companies)

# Radiocommunication Study Groups

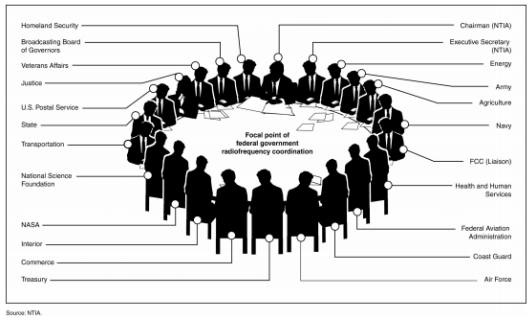
- www.itu.int/en/ITU-R/study-groups

- SG 1: Spectrum Management
- SG 3: Radiowave Propagation
- SG 4: Satellite Services
- SG 5: Terrestrial Services
- SG 6: Broadcasting Services
- SG 7: Science Services
  - Working Party 7A – Time signals and frequency standards
  - Working Party 7B – Space Radiocommunication applications
  - Working Party 7C – Remote sensing systems
  - Working Party 7D – Radio astronomy

Bi-annual meetings in Geneva for all Study Groups and Working Parties, monthly national preparatory meetings leading up to International meetings

# III. NSF ESM Unit Activities

# NSF ESM Unit Activities



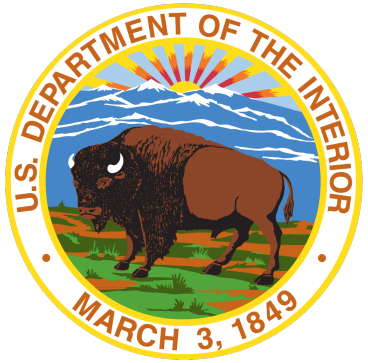

- Represent NSF as a Federal Agency to the National Telecommunications and Information Administration
  - 10 subcommittees including
    - IRAC
    - FAS (NRQZ coordination)

- 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

# NSF ESM Unit Activities


- At NSF – Coordination with other Directorates and Divisions with spectrum needs, manage spectrum related grants portfolio (CORF, Enhancing Access to the Radio Spectrum Solicitation; EARS)


- Coordinate with other US Agencies

Federal Communications Commission

- Interface with commercial interests to advocate for their taking "practicable" steps to not cause interference to passive services

# Advisory Process to NSF

- NSF and NASA co-fund the Committee on Radio Frequencies (CORF) of the National Academy of Sciences, Engineering and Medicine

Free pdf downloads available:
https://www.nap.edu


The National Academies of | SCIENCES ENGINEERING MEDICINE

BOARD ON PHYSICS AND ASTRONOMY
Division on Engineering and Physical Sciences

# *Views of the U.S. National Academies of Sciences, Engineering, and Medicine on Agenda Items of Interest to the Science Services at the World Radiocommunication Conference 2019*

- Report to articulate the views of the U.S. science community on specific WRC-19 Agenda Items related to the Radio Astronomy Services and the Earth Exploration-Satellite Services (Chair Dr. Jasmeet Judge, University of Florida)

- Recommendations given on 11 agenda items for WRC-19, and one for WRC-23
    - Power Limits for Earth Stations
    - Earth Stations in Motion (ESIM)
    - Non-GSO FSS Satellite Systems at 37 – 50 GHz
    - Spectrum Needs for non-GSO Satellites
    - Global Maritime Distress Safety Systems
    - Autonomous Maritime Radio Devices
    - Maritime Mobile-Satellite Allocations
    - Future Development of International Mobile Telecommunications
    - High-Altitude Platform Systems (HAPS)
    - 275 – 450 GHz
    - Wireless Access between 5150 and 5925 MHz
    - Radar Sounders at 45 MHz

# Advisory Process to NSF

- NSF Advisory panels (e.g. Astronomy & Astrophysics Advisory Committee)
- Scientific community (i.e. proposals for original and creative research)
- Intra-agency (at NSF) and Inter-agency (Federal) coordination and information sharing

# IV. March 2017 AAAC Report

# 2016-2017 AAAC Report
# Spectral Protection and Management

- Astronomical sciences are fundamentally dependent on the detection of light across the full range of the electromagnetic spectrum (EMS). The process through which portions of the EMS are protected or allocated for specific uses is understandably subject to a variety of scientific, economic, and security concerns and a large number of stakeholders whose interests need to be addressed. Both the NSF and NASA have staff assigned to spectrum management, and the National Academies sponsor the "Committee on Radio Frequencies" (CORF). As commercial needs for access to the EMS increase (including more than a dozen new frequency requests from commercial interests to be considered at the 2019 ITU meeting), we are concerned whether the available NASA and NSF resources will be adequate to advocate for the protection of astronomical requirements on wavelength allocation. Without clean access to these wavelengths, the ability of astronomers to obtain fundamental knowledge about the universe would be profoundly impaired.

p. 10, Section 4.2

# 2016-2017 AAAC Report
# Spectral Protection and Management

- Finding: Increasing demand from scientific, commercial, and security interests for access to the same regions of the electromagnetic spectrum as those needed for astronomical research pose a challenge for managing spectrum access and ensuring astronomical research continues to be viable in necessary regions of the EMS.
- Recommendation: The agencies should consider coordinating their separate efforts on advising on the use and protection of the electromagnetic spectrum to better protect access to the electromagnetic spectrum for astronomical and astrophysical research.

p. 10, Section 4.2


# V. Conclusions

# FY2018 Goals

- **NSF Presence and Awareness**
- **Keep Protected RAS allocations as RFI-free as possible**
  - *emissions may be prohibited at certain frequencies, out-of-band emissions can still be problematic*
- **Make coordination of the varied needs/uses of spectrum for researchers across the NSF a priority**
- **Continued and increased coordination between NSF and other federal agencies and entities with activities in the science services, esp. NASA**
- **Increased awareness of the spectrum as a finite resource**
  - *e.g. educational outreach*
- **Technology developments and advancements to facilitate sharing, RFI excision**
- **Facilitate the best science at NSF**

# ESM Challenges

- Demand for use of the spectrum is unrelenting (~20 GHz, >95 GHz); emitters in motion esp. problematic (constellations, 5G, car radars)
- Threats to passive use of the spectrum can come from unexpected directions
- Resources for technical analysis; increasing interest of the astronomy community (e.g. ‘broader impact’)
- Different scientific disciplines care about different frequencies

# Questions?

**esm@nsf.gov**

# National Science Foundation

## Mission

"To ***promote*** the ***progress of science***;
to ***advance*** the ***national health, prosperity, and welfare***;
and to ***secure*** the ***national defense…***"

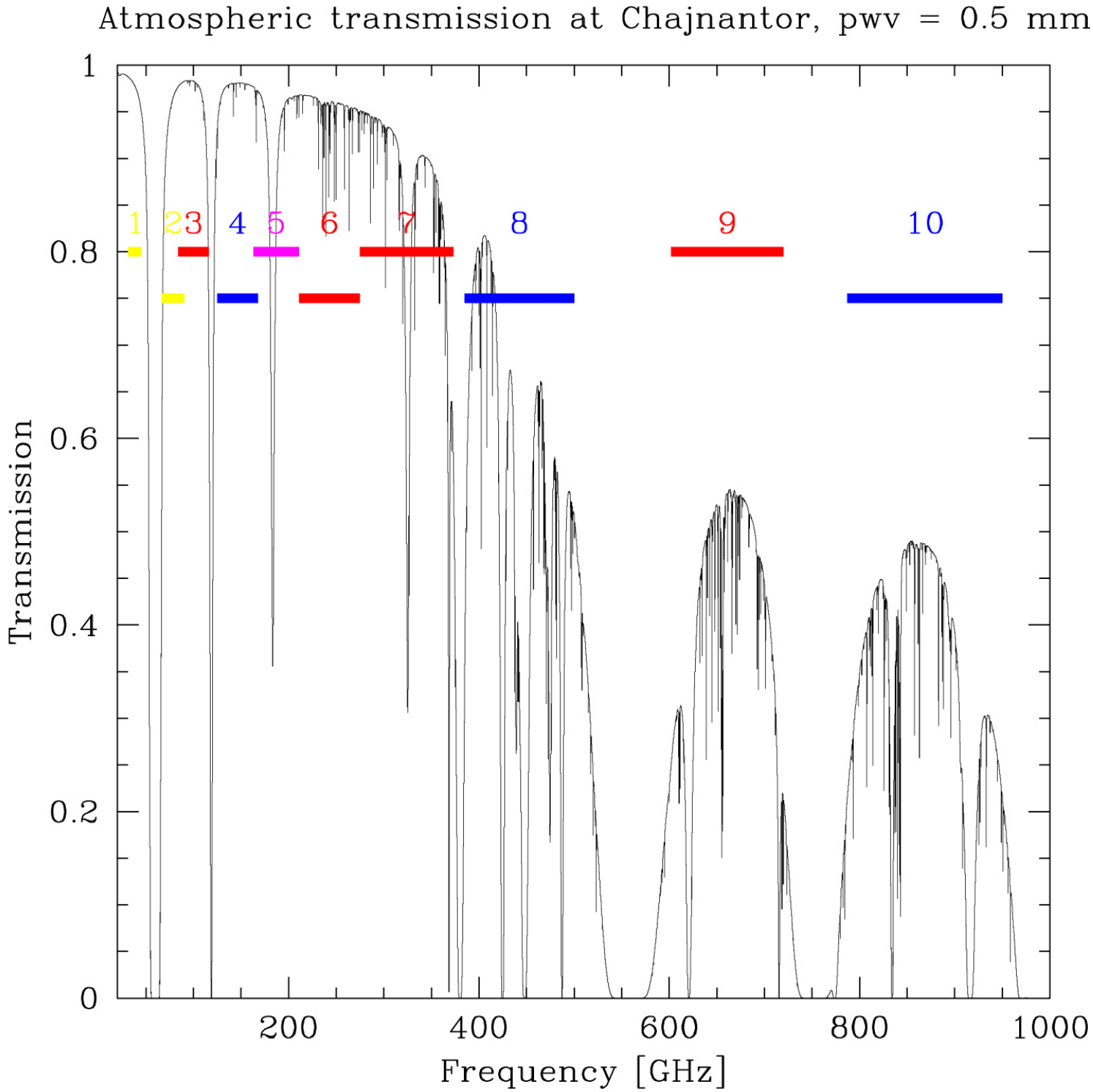
*- National Science Foundation Act of 1950*

## Vision and Goals

"…a Nation that ***creates*** and ***exploits new concepts*** in science and engineering
and provides ***global leadership in research and education***"

*- NSF's Strategic Plan for 2014 - 2018*

# Thank you


Atmospheric transmission at Chajnantor, pwv = 0.5 mm
Transmission
Frequency [GHz]
0
0.2
0.4
0.6
0.8
1
200
400
600
800
1000
1
2
3
4
5
6
7
8
9
10

# Policy challenges

- Constellations of satellites
- High Altitude Platform Systems
- 5G
- Car radars
- Commercial technologies in mm, sub-mm and THz regimes
  - E.g. atmospheric attenuation does not take care of all THz transmissions

- Many recommendations/reports are outdated; requires man-power to carefully redo and time to shepherd thru National and International Committee processes