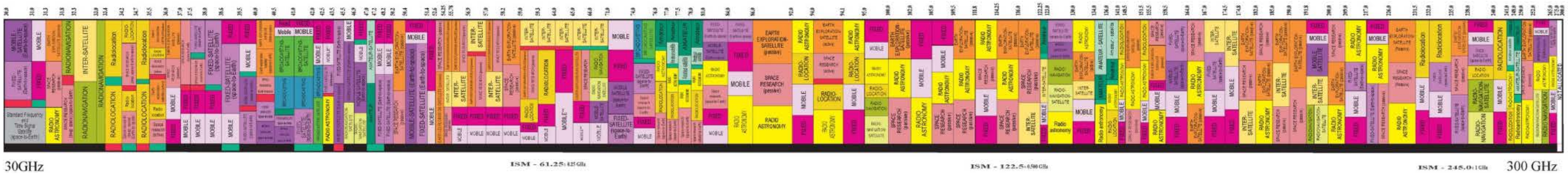
National Science Foundation

Electromagnetic Spectrum Management



May 3, 2019

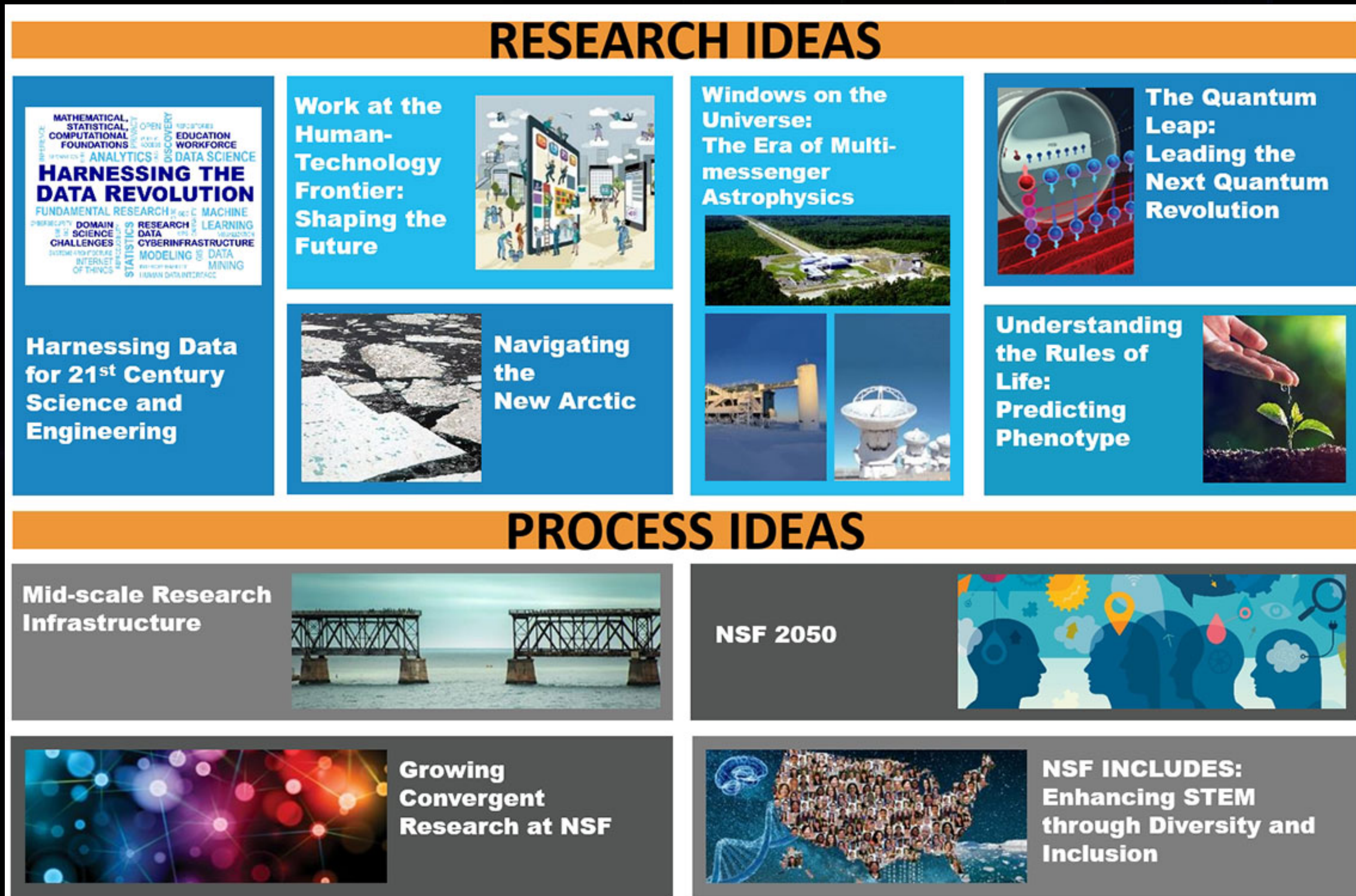
Report to the MPS Advisory Committee

B. Ashley Zauderer - *bezauder@nsf.gov*

Jonathan Williams - *jonwilli@nsf.gov*

What is "Spectrum Management" and how is it vital to enabling cutting-edge science?

NSF 10 Big Ideas for Future Investments



Big Ideas

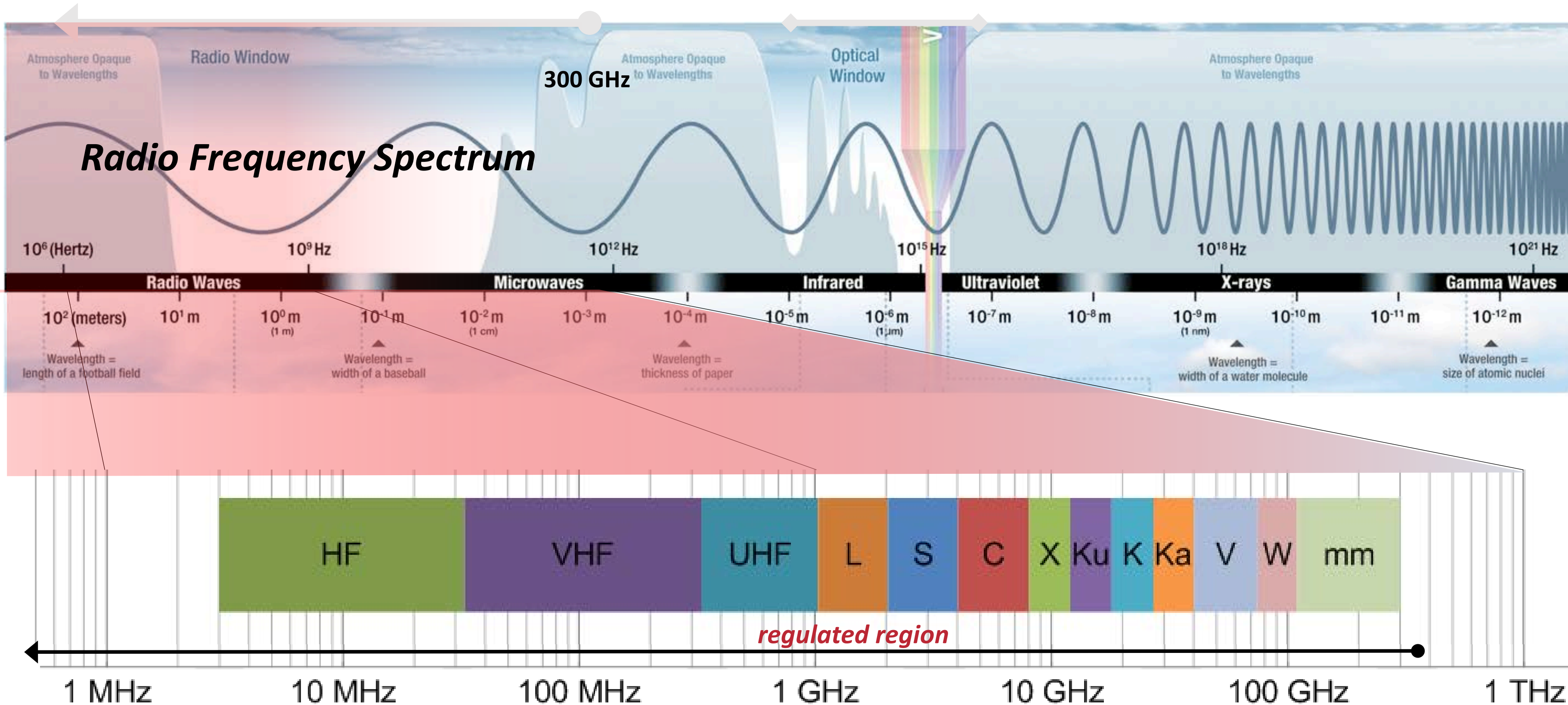
- Human Technology Frontier – most technology is connected via wireless communications (IoT, wi-fi)
- Navigating the New Arctic – data backhaul challenge requiring spectrum
- Windows on the Universe – RFI contamination of data; increasing demand for spectrum
- Rules of Life – Questions at the intersection of physics and biology
- Mid-scale research – infrastructure needed for RFI monitoring, RF-resistant receivers, a new “dynamic” sharing approach to increase spectrum access in certain locations
- Data Revolution – RFI analysis is a big data problem

Wireless communications impacts every aspect of Research

Research at NSF impacts the development of Wireless communications

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)



Terminology used with portions of the radio frequency domain

Slide Credit: NASA

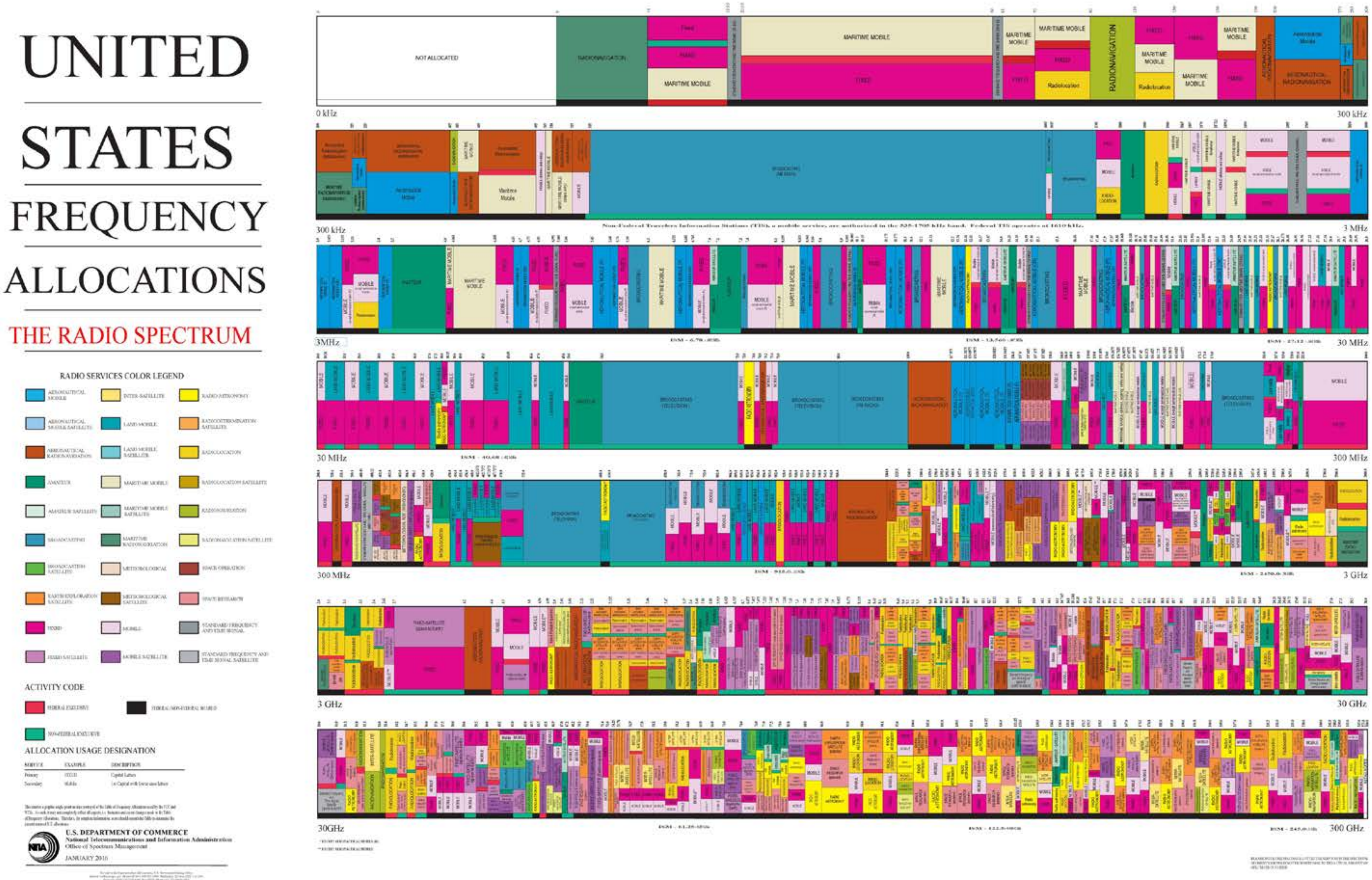
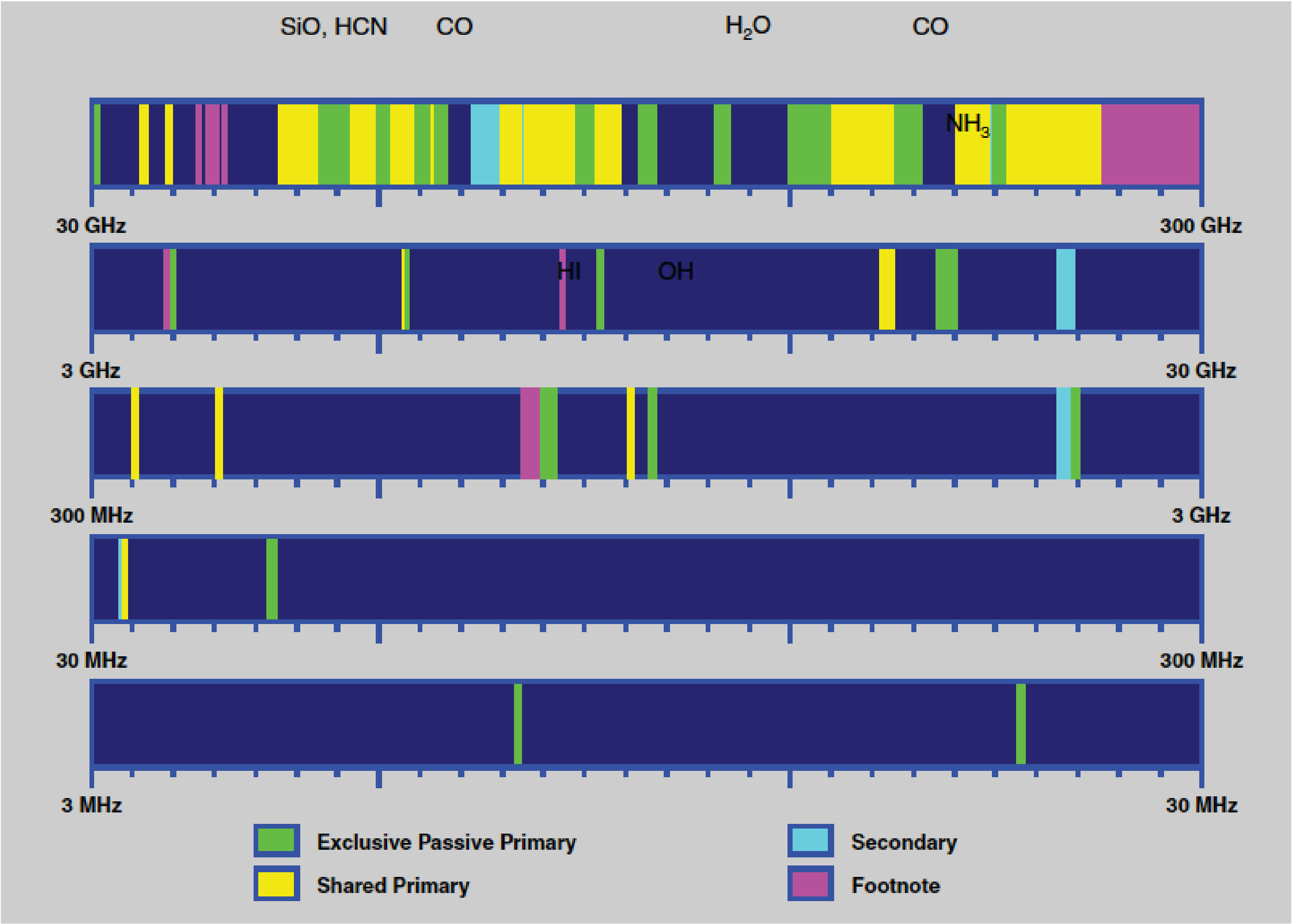


Image Credit: www.ntia.doc.gov

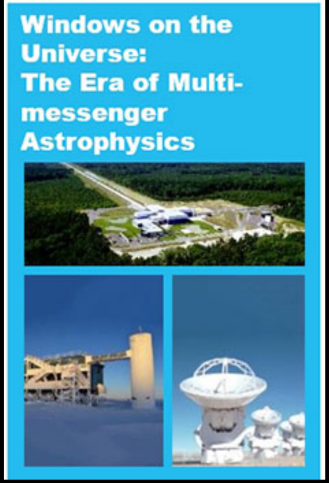
<2 % below 3 GHz is allocated to RAS as primary



Radio Astronomy Frequency Allocations in the United States

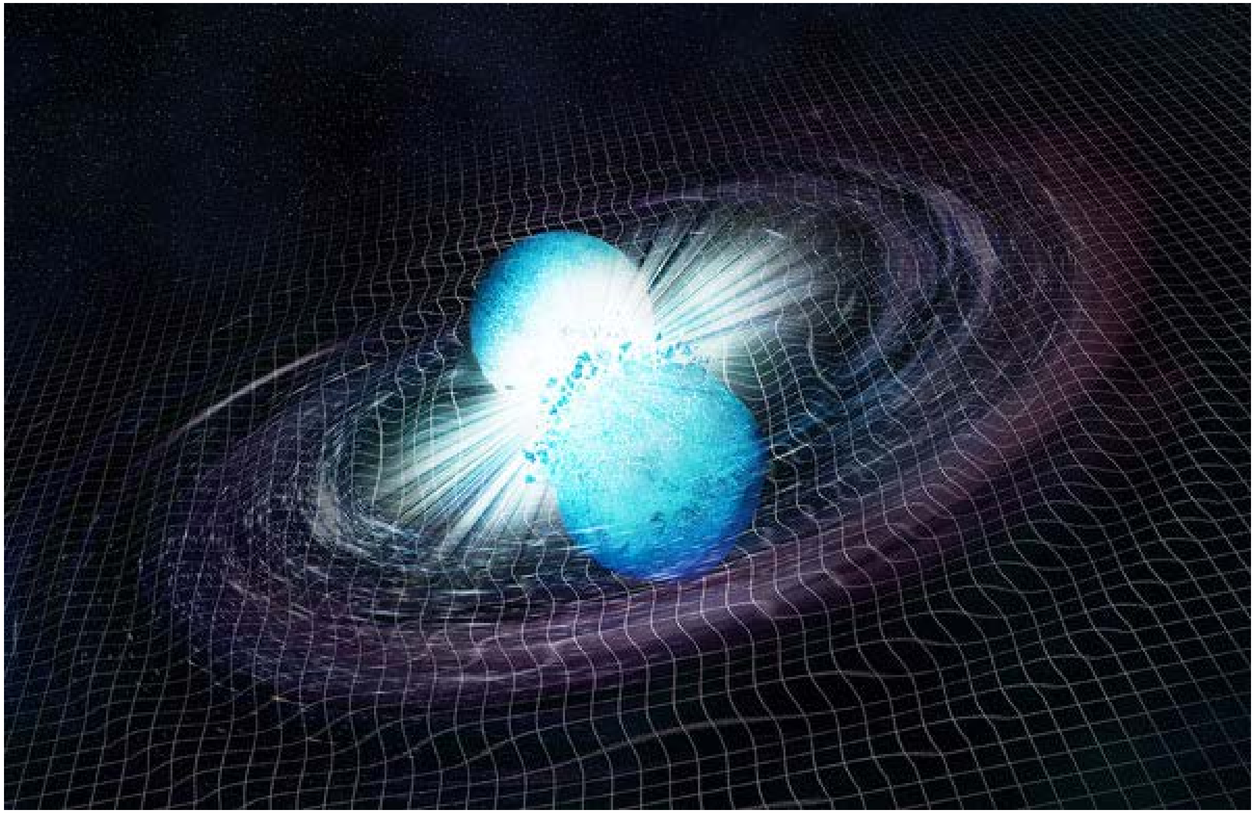
NSF 10 Big Ideas for Future Investments

NSF 10 Big Ideas for Future Investments



Multi-messenger & Time-Domain Astronomy

GW170817



Artist's illustration of the merger of two neutron stars. A new study suggests that the neutron-star merger detected in August 2017 might have produced a black hole.
NASA/CXC/M.Weiss

A radio counterpart to a neutron star merger

G. Hallinan[1,*,†], A. Corsi[2,†], K. P. Mooley[3], K. Hotokezaka[4,5], E. Nakar[6], M. M. Kasliwal[1], D. L. Kaplan[7], D. A. Frail[8], S. T. Myers[8], T. ...

+ See all authors and affiliations

Science 22 Dec 2017:
Vol. 358, Issue 6370, pp. 1579-1583
DOI: 10.1126/science.aap9855

Article Figures & Data Info & Metrics eLetters PDF

GROWTH observations of GW170817

The gravitational wave event GW170817 was caused by the merger of two neutron stars (see the Introduction by Smith). In three papers, teams associated with the GROWTH (Global Relay of Observatories Watching Transients Happen) project present their observations of the event at wavelengths from x-rays to radio waves. Evans *et al.* used space telescopes to detect GW170817 in the ultraviolet and place limits on its x-ray flux, showing that the merger generated a hot explosion known as a blue kilonova. Hallinan *et al.* describe radio emissions generated as the explosion slammed into the surrounding gas within the host galaxy. Kasliwal *et al.* present additional observations in the optical and infrared and formulate a model for the event involving a cocoon of

Why does access to the radio spectrum matter?

10 uJy at 3 GHz ~2 weeks

2 GHz BW (~1.4 GHZ after RFI excision)

<50 MHz is RAS primary

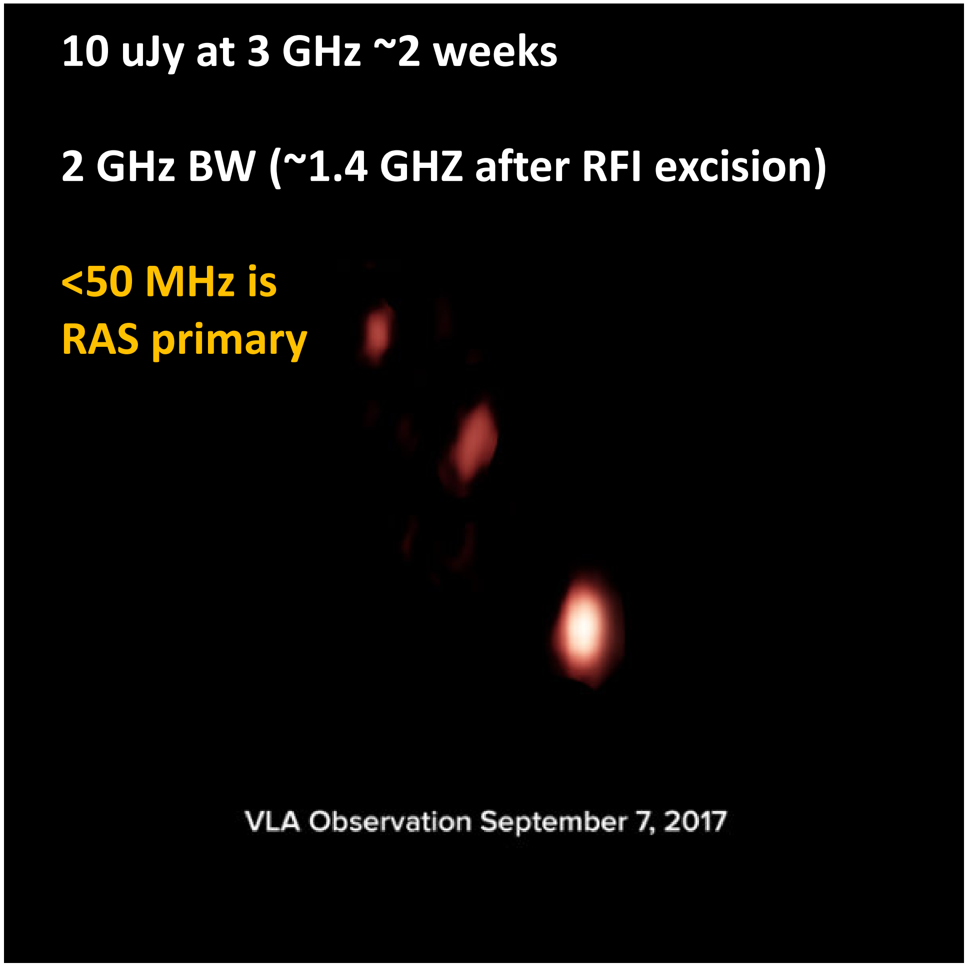
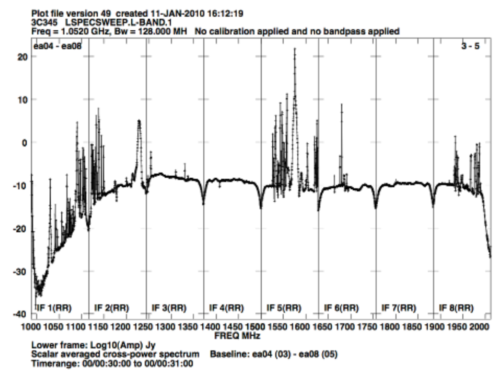
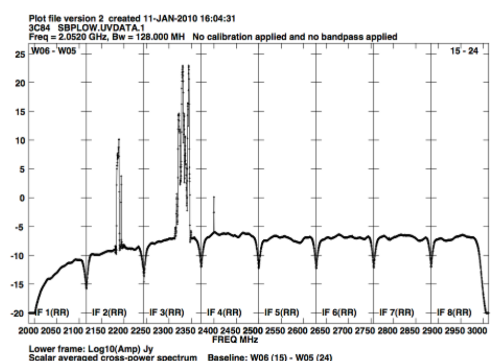


Image Credit: Hallinan et al., Science (2017)





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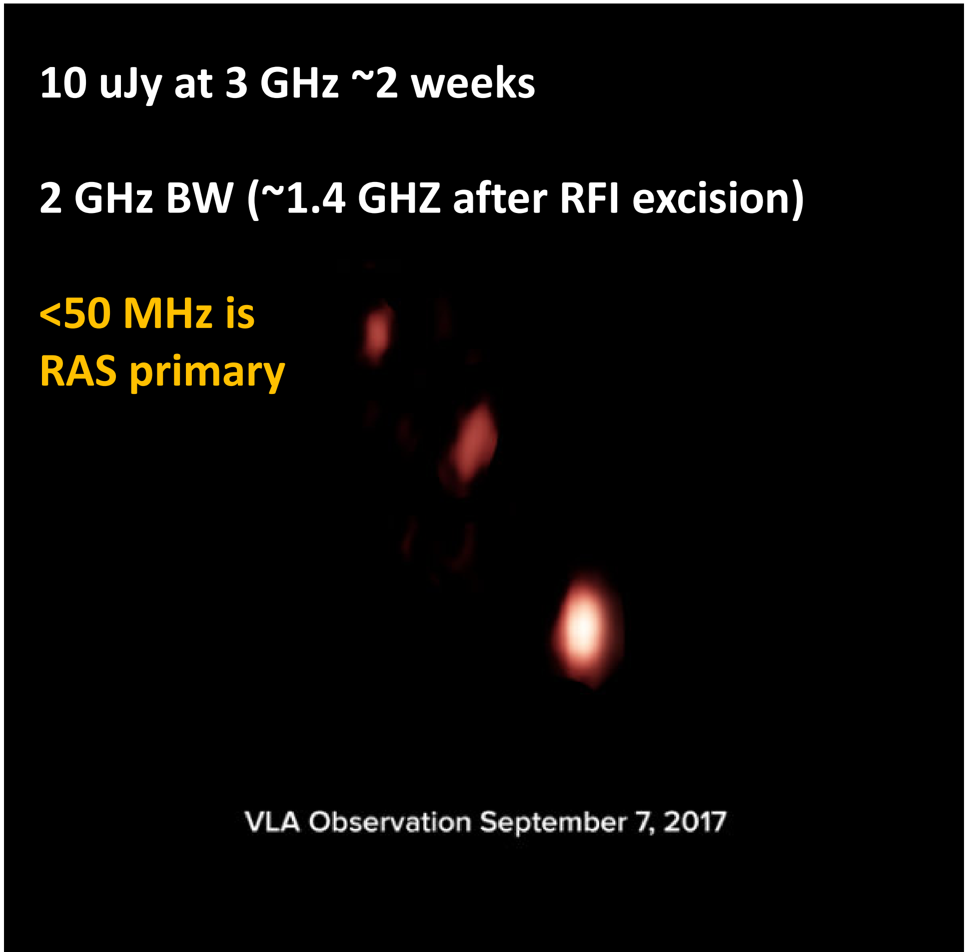
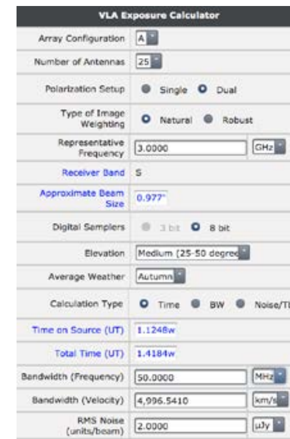


Image Credits: Hallinan et al., Science (16 Oct 2017)

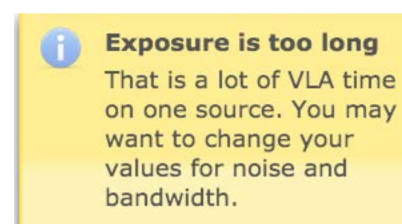
To achieve 2 uJy RMS
requires integration time on source of:



<u>2 GHz bandwidth:</u>
5.5 hours

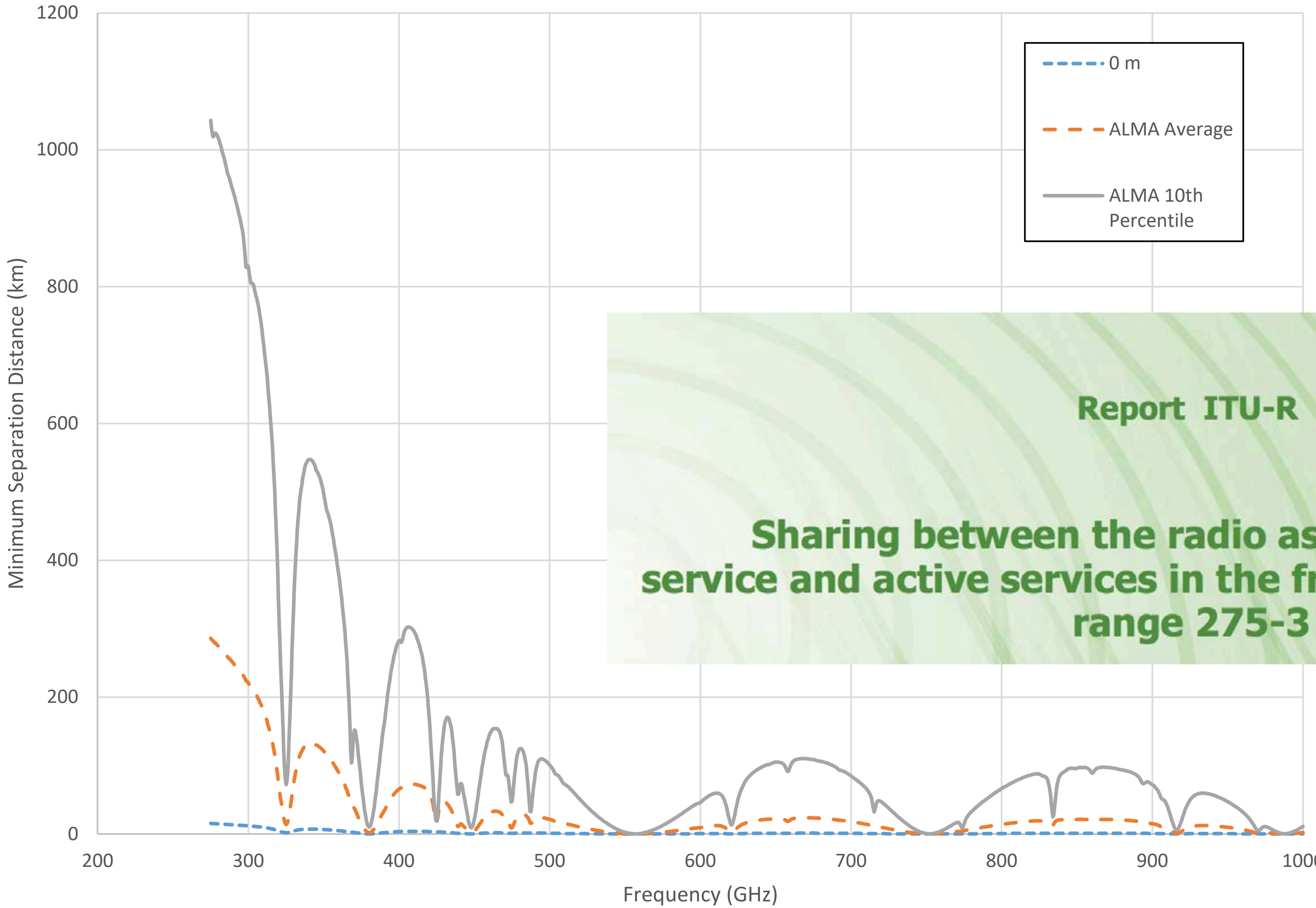
<u>1.4 GHz bandwidth:</u>
6 hours

<u>50 MHz bandwidth:</u>
185 hours (more than one week)



World Radio Conference 2019 Agenda Item 1.15: mm-wave

http://www.itu.int/pub/R-REP-RA.2189-1-2018



Report ITU-R RA.2189-1
(09/2018)

Sharing between the radio astronomy service and active services in the frequency range 275-3 000 GHz

Updated Fall 2018

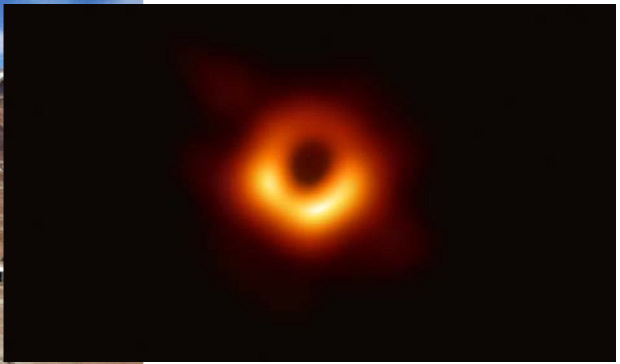
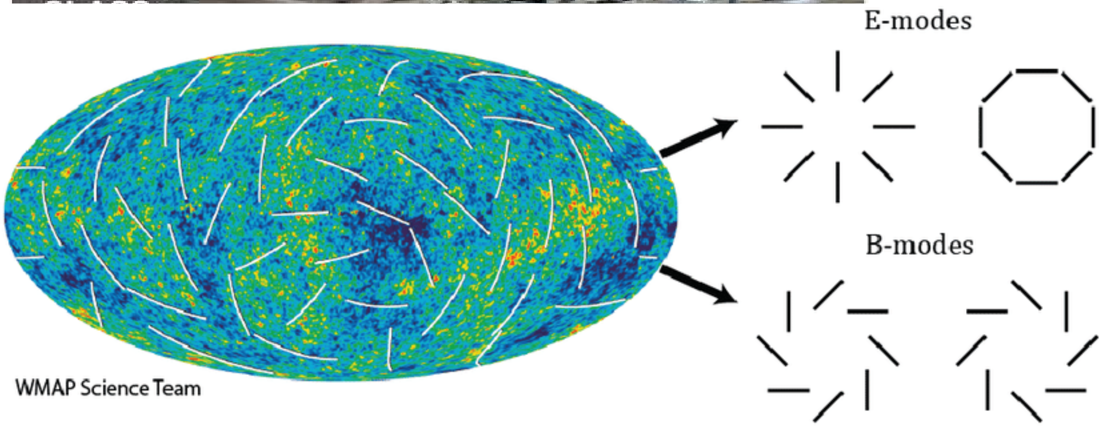


Image credit: Event Horizon Telescope Collaboration

Image credit: almaobservatory.org



Importance of EM Access

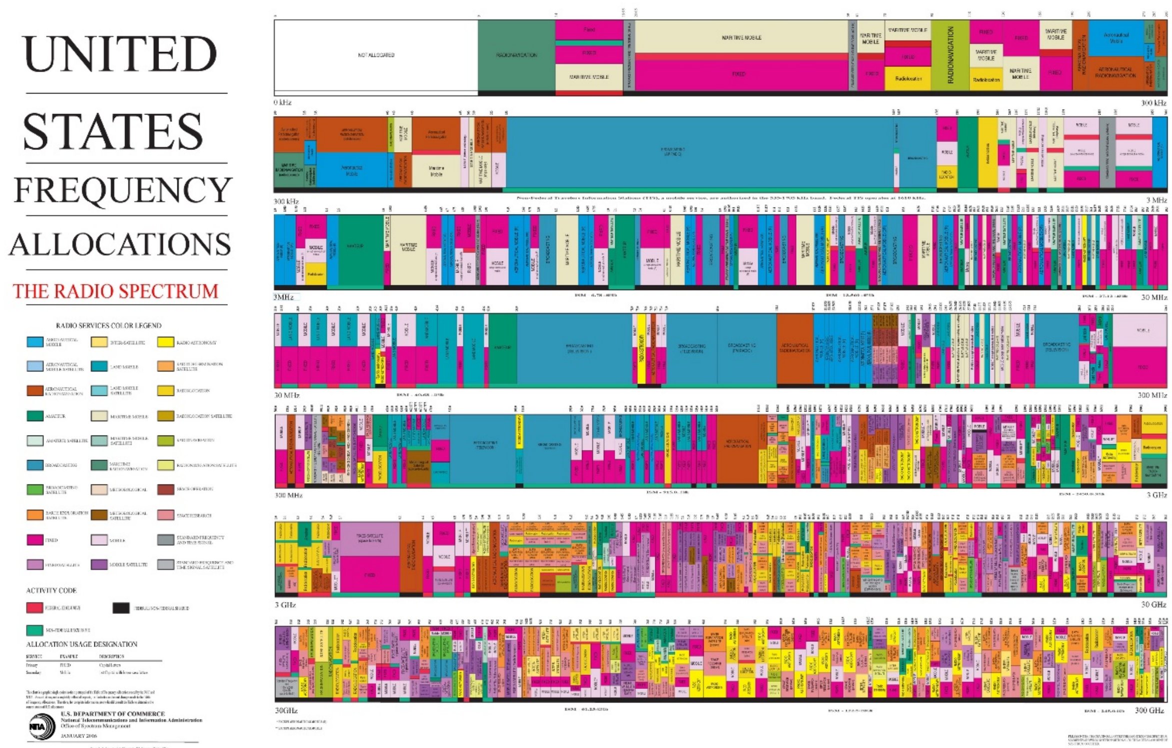
- ***Not a new issue:***
  - "*The stability and continuity associated with officially reserved segments of the spectrum are essential to radio-astronomical research.*" (Pankonin and Price, IEEE, 1981)
    - RAS allocated very little spectrum (~2% at cm $\lambda\lambda$)

  - "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)

Scientific Frequency Usage

Frequency Usage Takeaways

- **Protected frequency bands include *<u>most important identified spectral lines for studying the local universe</u>* (e.g. HI, CO, OH masers), but *<u>doppler-shifted lines</u>* 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

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

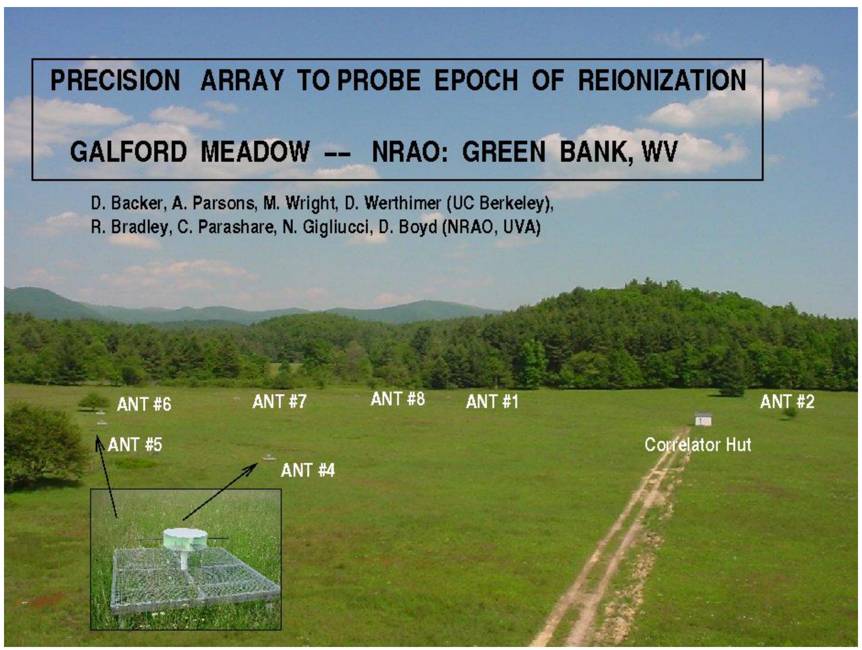


Image Credit: w.astro.berkeley.edu

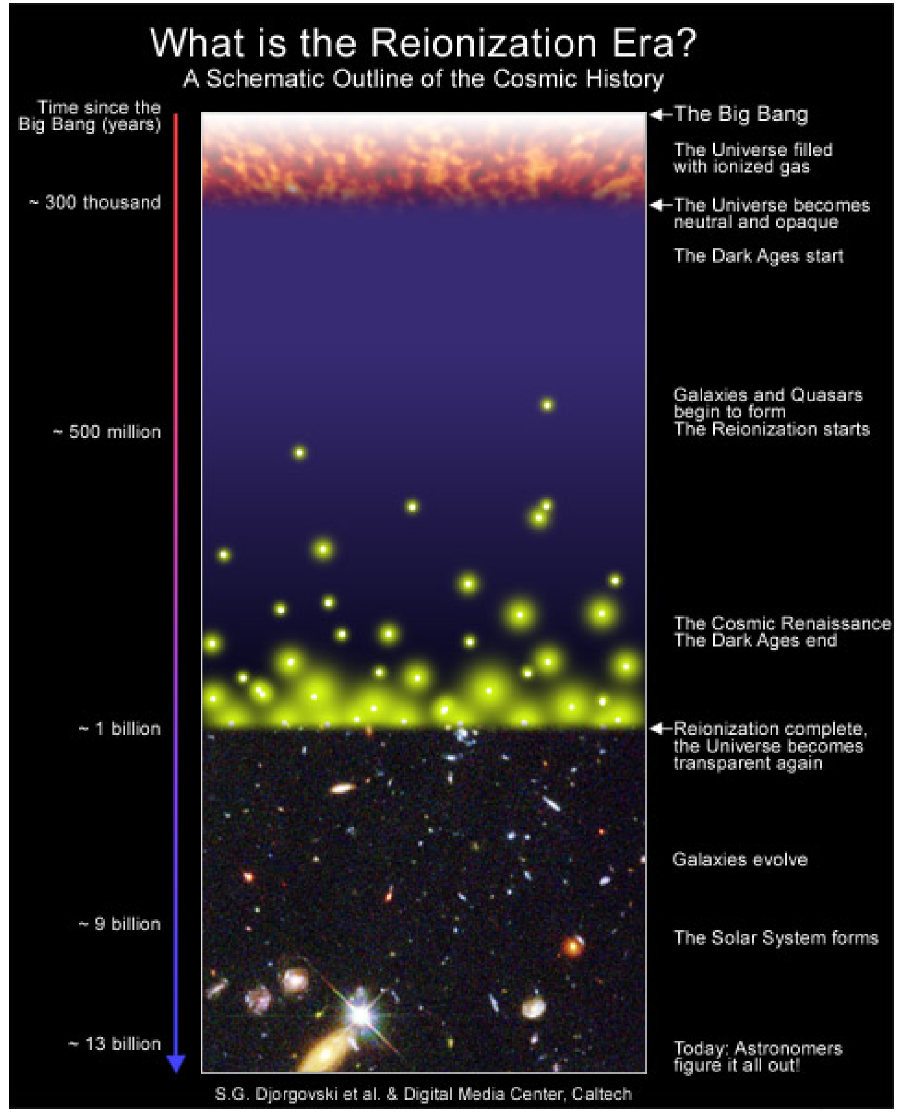


Image Credit: Djorgovski et al. (Caltech); www.haystack.mit.edu

Frequency Usage Takeaways

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- **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).**

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

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.**

Frequency Usage Takeaways

- **NRQZ (established 1958) needs updated protections from airborne transmitters; other radio telescopes need also need newly established coordination zones**

- **We need a new "National Radio Dynamic Zone" for the VLA and other facilities**

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: Green Bank Observatory

Credit: NRAO

Frequency Usage Takeaways

Image credit: NASA

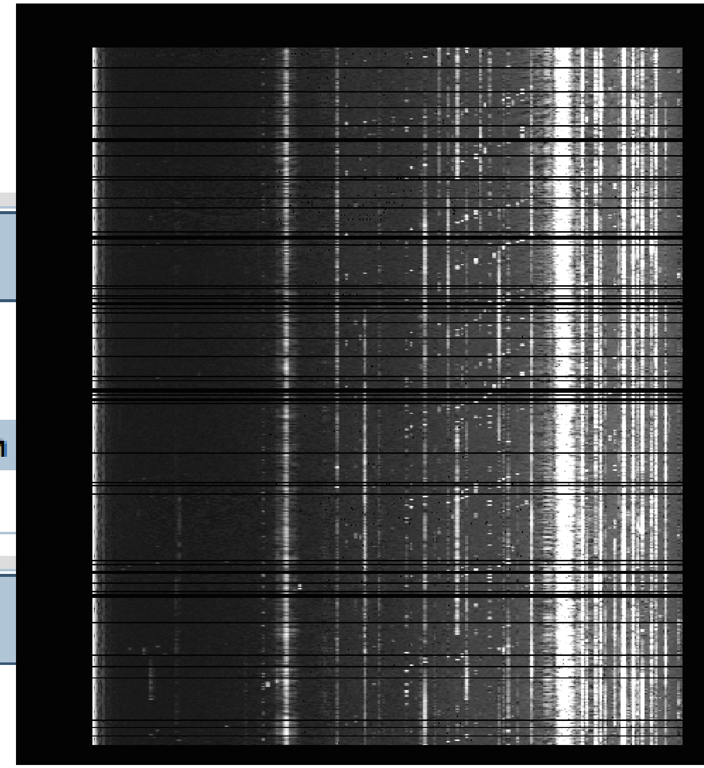
- **<u>Space observations are not "safe"</u>… for example JWST currently plans to use a Ka-band downlink (X band is saturated, not enough throughput in S-band downlinks)**

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

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

Frequency Usage Takeaways

- **Impact and Challenge is Widespread:**

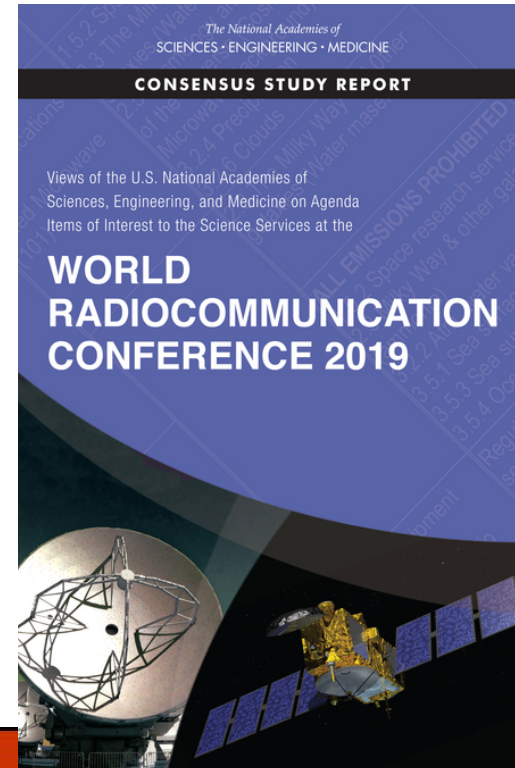
  - Impacts
    - Ground based radio astronomy
    - High energy astrophysics & Space Research (via Deep Space Network)
    - Optical astronomy (potentially via space debris and glints)
    - Space weather / solar physics
    - Big data needs
  - Challenges
    - Scientific disciplines utilize different frequencies and can be at odds with each other
    - Community largely unaware

Spectrum is an issue for the entire Scientific community, not just a small subset of radio astronomers.

Advisory Process to NSF

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

Chair: Liese van Zee, Indiana University Bloomington



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

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

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

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

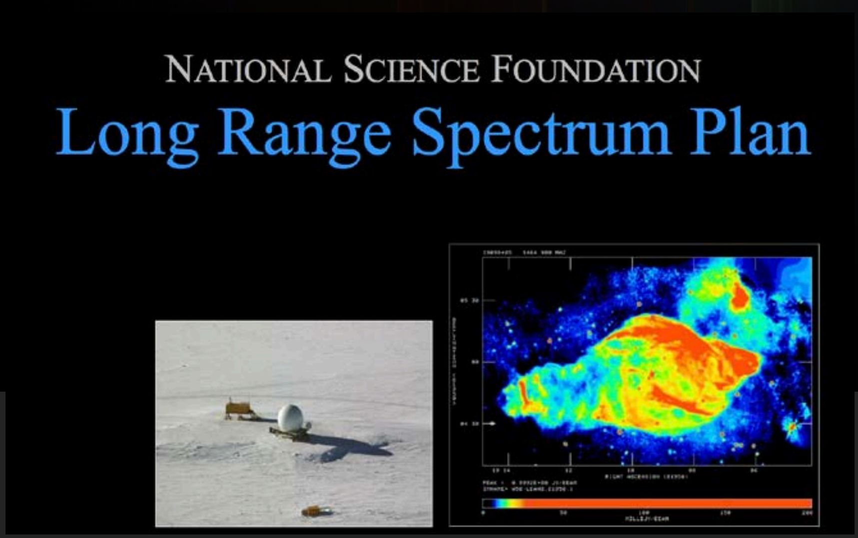
Especially heavy use by these Directorates: Physics, Astronomy, Polar Programs, Atmospspheric and Geospace Sciences, Ocean Sciences and Earth Sciences.

Usage: Passive and Active

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

NSF ESM Coordination Group

- Formed March 2018
- Include NSF input across all relevant scientific disciplines
- First Tasks:
    - Update the NSF Long Range Spectrum Plan for the next Decade – estimated June 1, 2019
    - Respond to Presidential Memo – New National Spectrum Plan



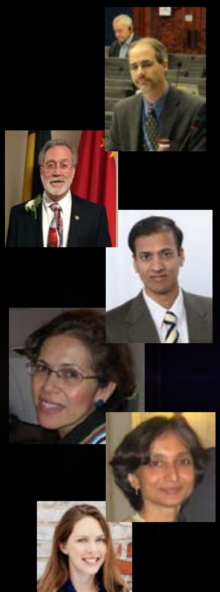

PRESIDENTIAL MEMORANDA

Presidential Memorandum on Developing a Sustainable Spectrum Strategy for America's Future

INFRASTRUCTURE & TECHNOLOGY

Issued on: October 25, 2018

NSF Coordination Group



Jonathan Williams	*Chair, Division of Astronomical Sciences*
Patrick Smith	*Office of Polar Programs*
Thyaga Nandagopal	*Division of Computing and Communications Foundations*
Carmiña Londoño	*Division of Electrical, Communications and Cyber Systems*
Mangala Sharma	*Office of International Science and Engineering*
Ashley Zauderer	*Division of Astronomical Sciences*

Jim Ulvestad — *Chief Officer for Research Facilities, Office of the Director*

NSF Goals

- **Keep protected allocations as RFI-free as possible**
    - *Emissions may be prohibited at certain frequencies, out-of-band emissions can still be problematic*

- **Utilize technology developments and advancements to increase spectrum availability, esp. in strategic geographic locations**
    - *Research in RFI excision techniques and receiver technology*
    - *"National Radio Dynamic Zone" for 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**
    - *Dynamic spectrum sharing*
    - *Costs must be considered; resources are investment in the future*

Opportunities

Mathematics, Physics and Astronomy Communities can help solve problems facing the broader society related to this limited resource

- materials research
- waveform analysis, algorithms, and big data problems
- receiver design
- RFI mitigation techniques
- cross-disciplinary intersections (e.g. biology/physics)

Educational/Broader Impact opportunity - Increased awareness of the spectrum as a finite resource

Questions and Comments

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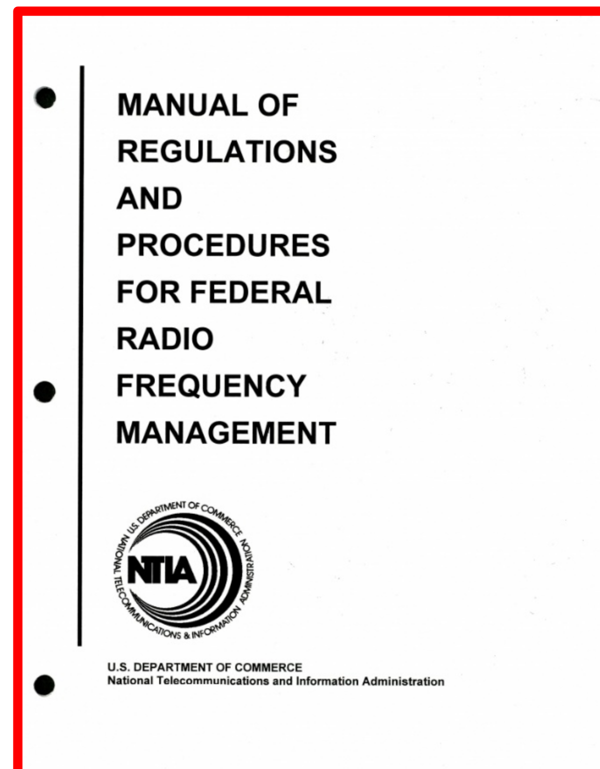
Jonathan Williams *jonwilli@nsf.gov*

Back-up Slides

What is the regulatory process?

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

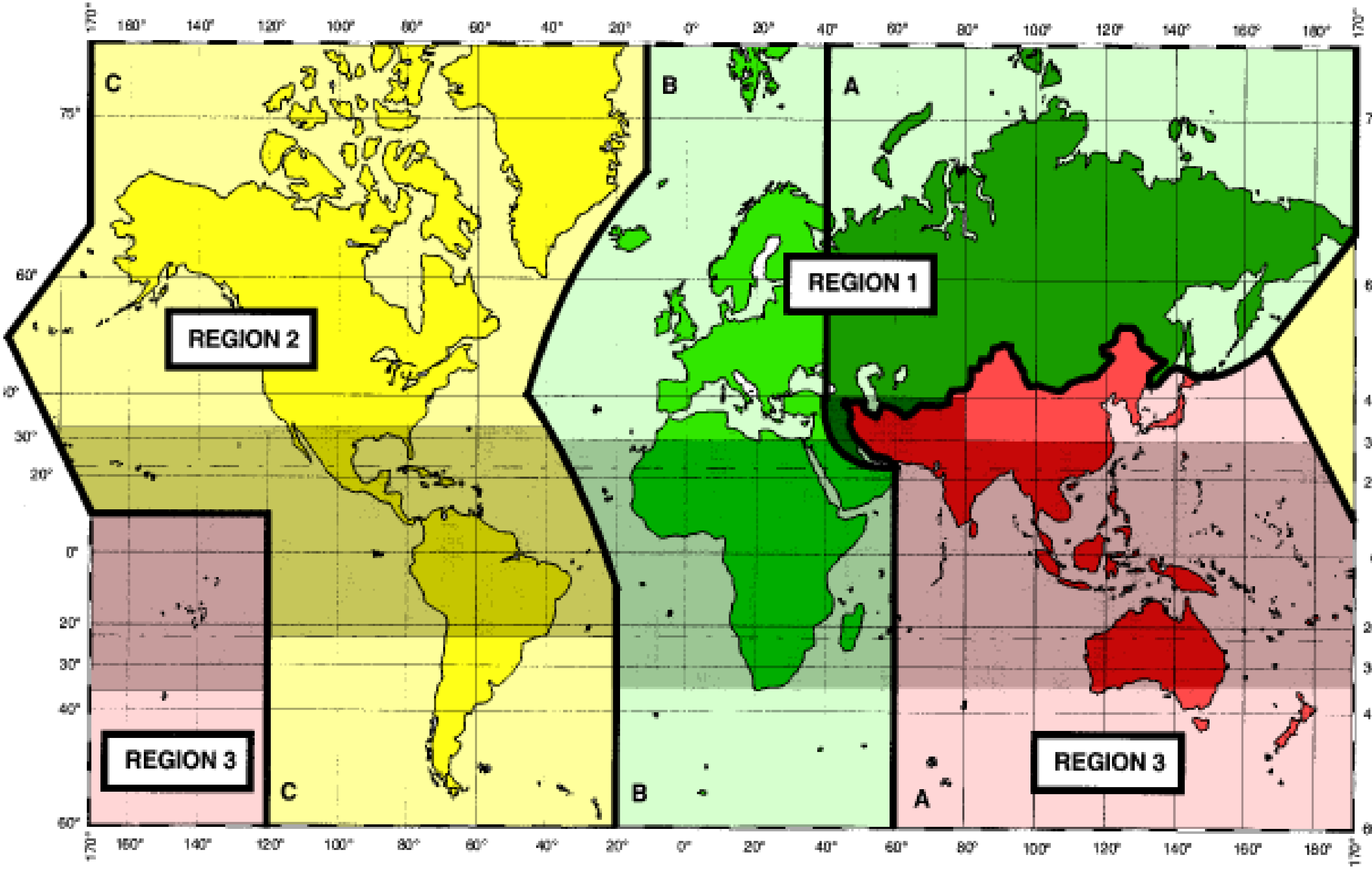


Image Credit: ITU

US Domestic Spectrum Policy

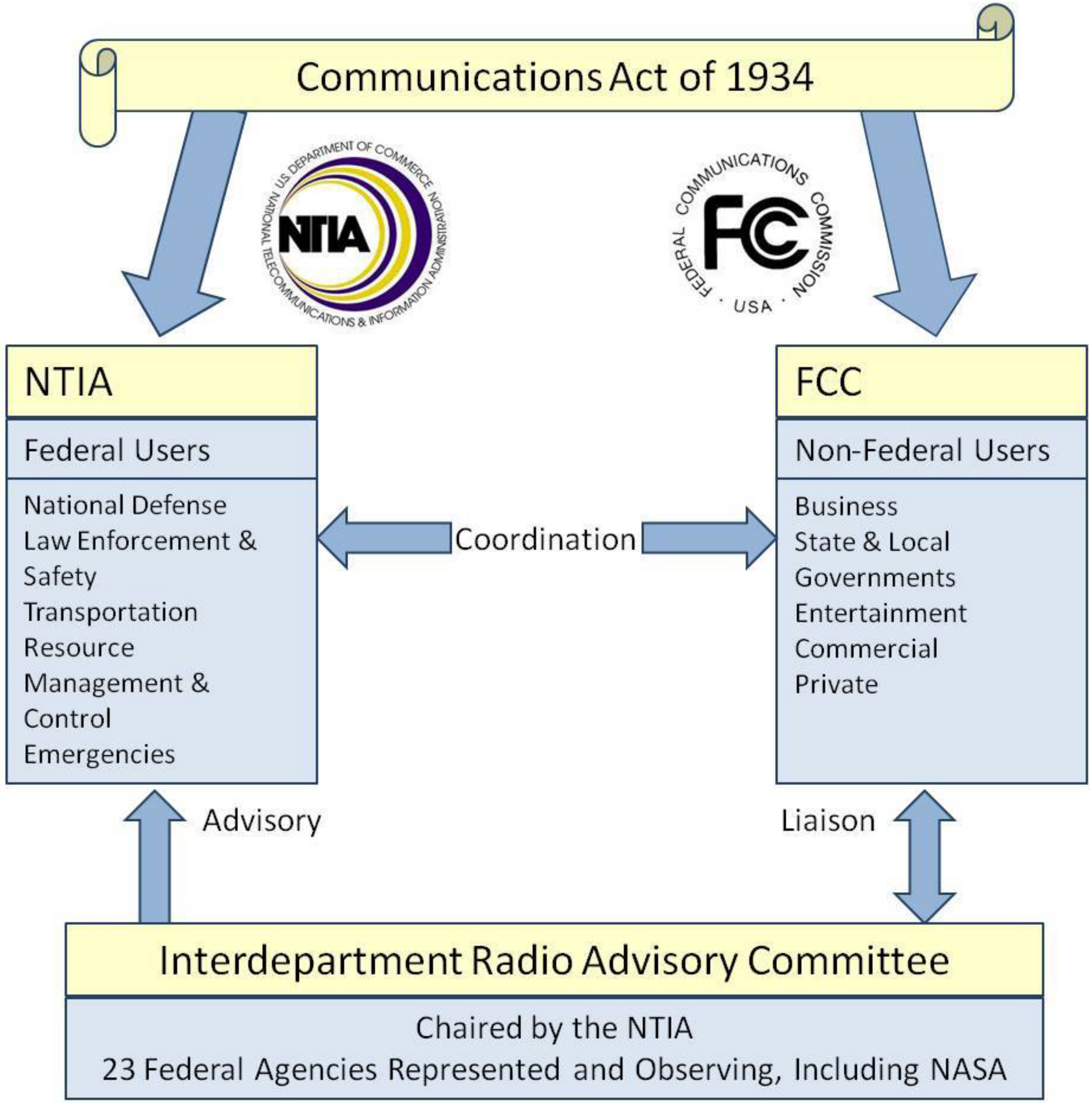
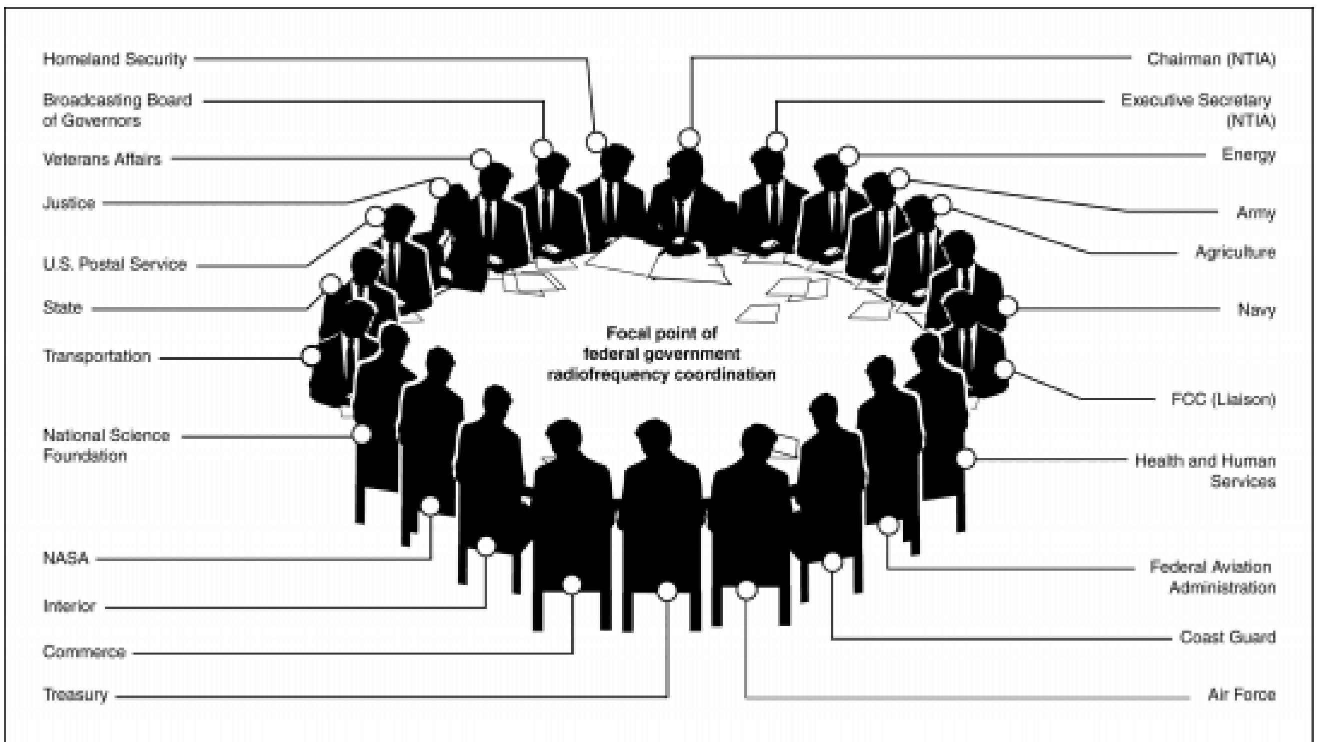


Image Credit:
www.nasa.gov
National Spectrum Management Plan

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



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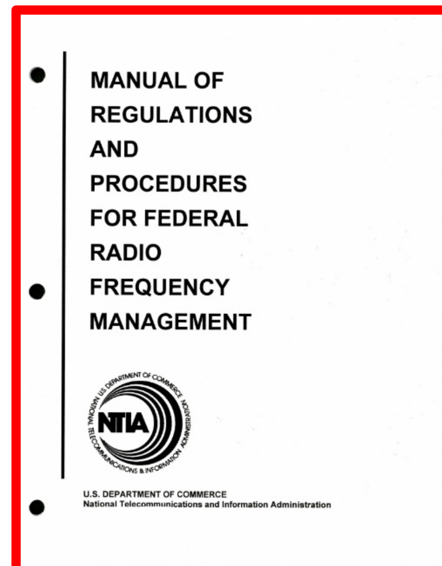
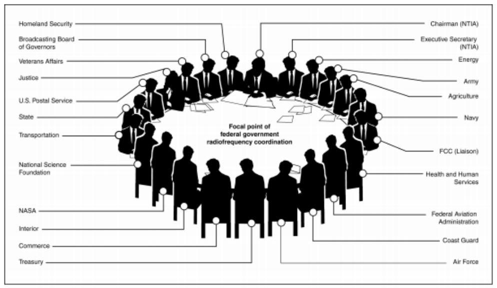


NSF's Activities

NSF ESM Unit Activities



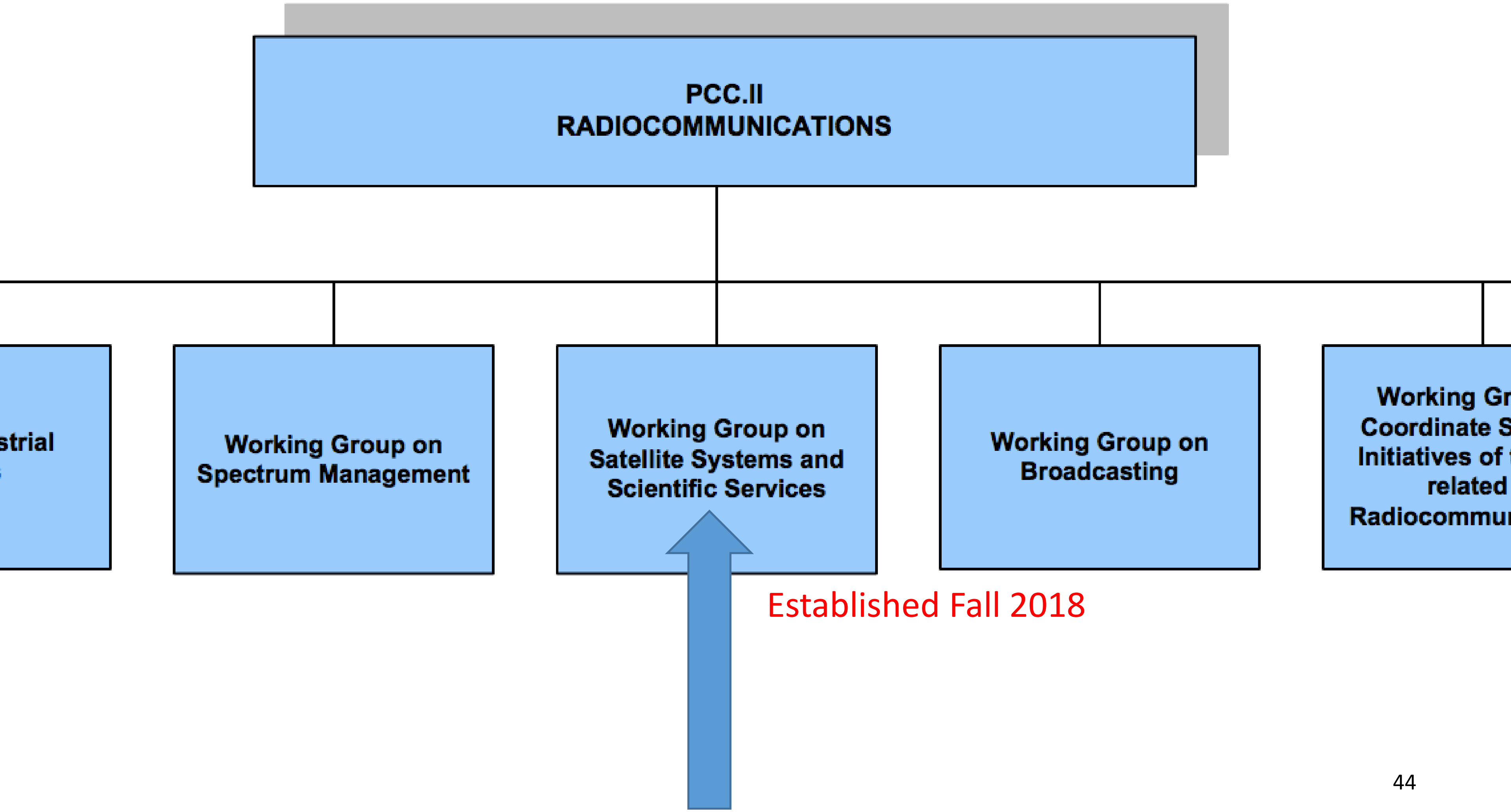
Source: NTIA.

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

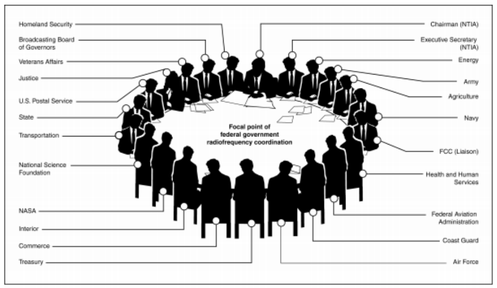
- Representation on official U.S. Delegations to the Inter-American Telecommunications Commission (CITEL) of the Organization of American States (OAS)

- Representation on official U.S. Delegations to the International Telecommunication Union's World Radiocommunication Conference (WRC 2019), including leading 7D – Radio Astronomy

OAS | CITEL


PCC.II
RADIOCOMMUNICATIONS
strial
Working Group on Spectrum Management
Working Group on Satellite Systems and Scientific Services
Working Group on Broadcasting
Working Gr
Coordinate S
Initiatives of
related
Radiocommu
Established Fall 2018

NSF ESM Unit Activities



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World Radiocommunication Conference

- Every Four years; where International Regulations are formulated; Treaty
- WRC-19 in Fall 2019

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

Important Scientific Community Input

Recent FCC Filings

- Two filings in 2017
  - Earth Stations in Motion (ESIMs) : NPRM – July 31
    - 14.47-14.50 GHz; 18.6 – 18.8 GHz
  - Mid-band Spectrum (5 – 24 GHz) : NOI – October 2
    - Includes both passive and active science allocations
- Five filings in 2018
  - Spectrum Horizons (Above 95 GHz) : NPRM – March 30
  - Google Request for Waiver of part 15 rules (60 GHz) : PN – April 20
  - 4.9 GHz : Sixth FNPRM – July 5
  - Above 24 GHz : Third FNPRM – September 7
  - ESIMs FNRPM (10.7 GHz; near 18.7 GHz) : Submitted for review
- On the horizon:
  - OOBE for Satellites
  - 6 GHz unlicensed devices
  - NGSO ESIMs

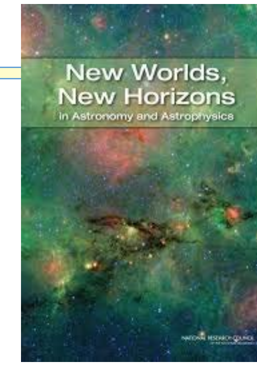
Scientific Community Input

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

- 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

Relevant Advisory Reports



I. ***New Worlds, New Horizons in Astronomy & Astrophysics*** (NRC 2010)
   - Science is impacted by spectrum management, but no specific mention outside of ESM budget

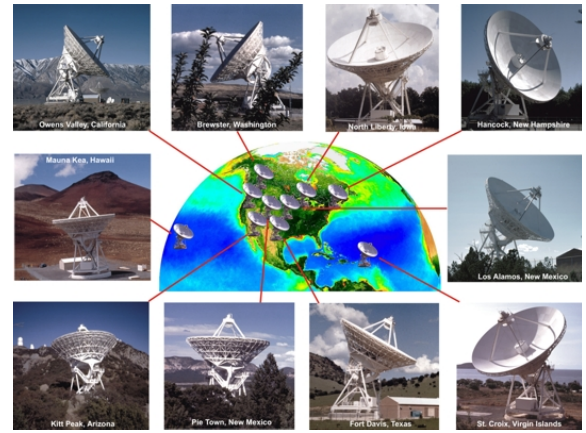
II. ***Spectrum management for Science in the 21st Century*** (NRC 2010)
   - Multiple explicit recommendations; see Summary Intro (pages 1 - 5)

NSF-funded Astronomy research relies on access to electromagnetic spectrum

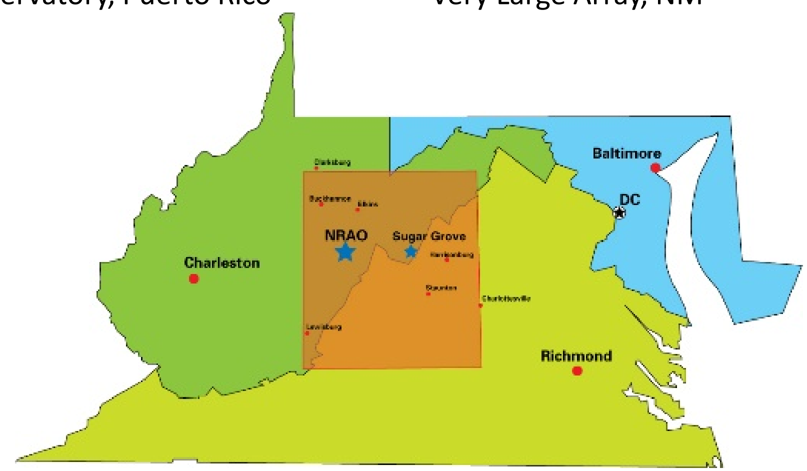
ESM resides in MPS/AST because historically spectrum usage has been focused primarily around the needs of <u>a few large facilities</u> and <u>the National Radio Quiet Zone</u>.

Arecibo Observatory, Puerto Rico

Very Large Array, NM



Very Long Baseline Array

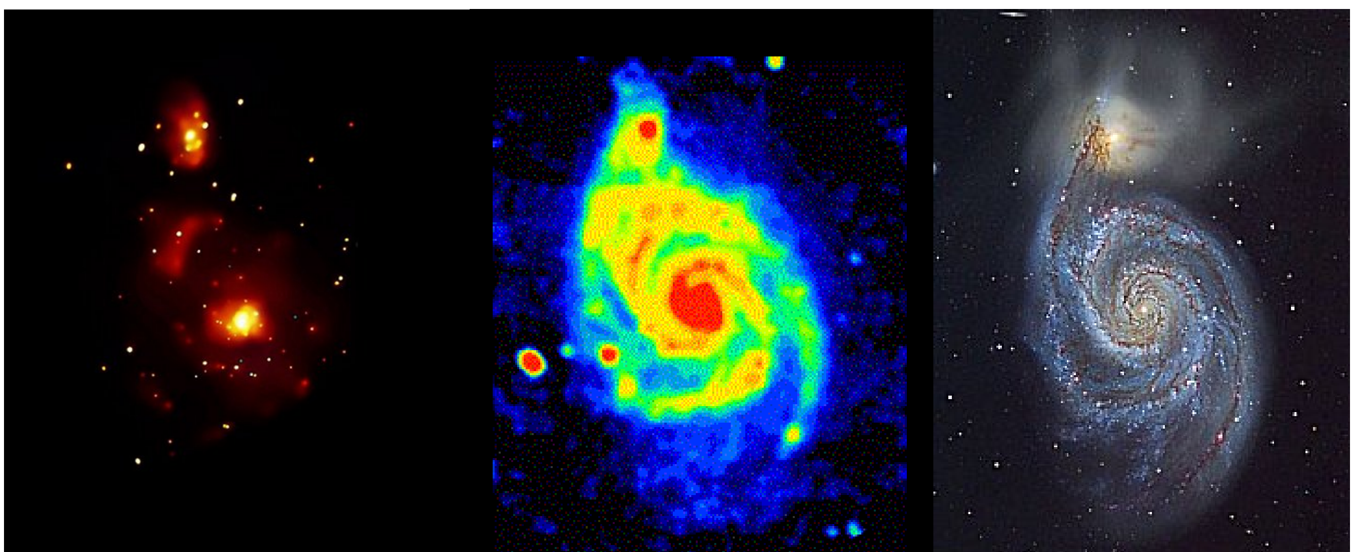


Green Bank Observatory
National Radio Quiet Zone

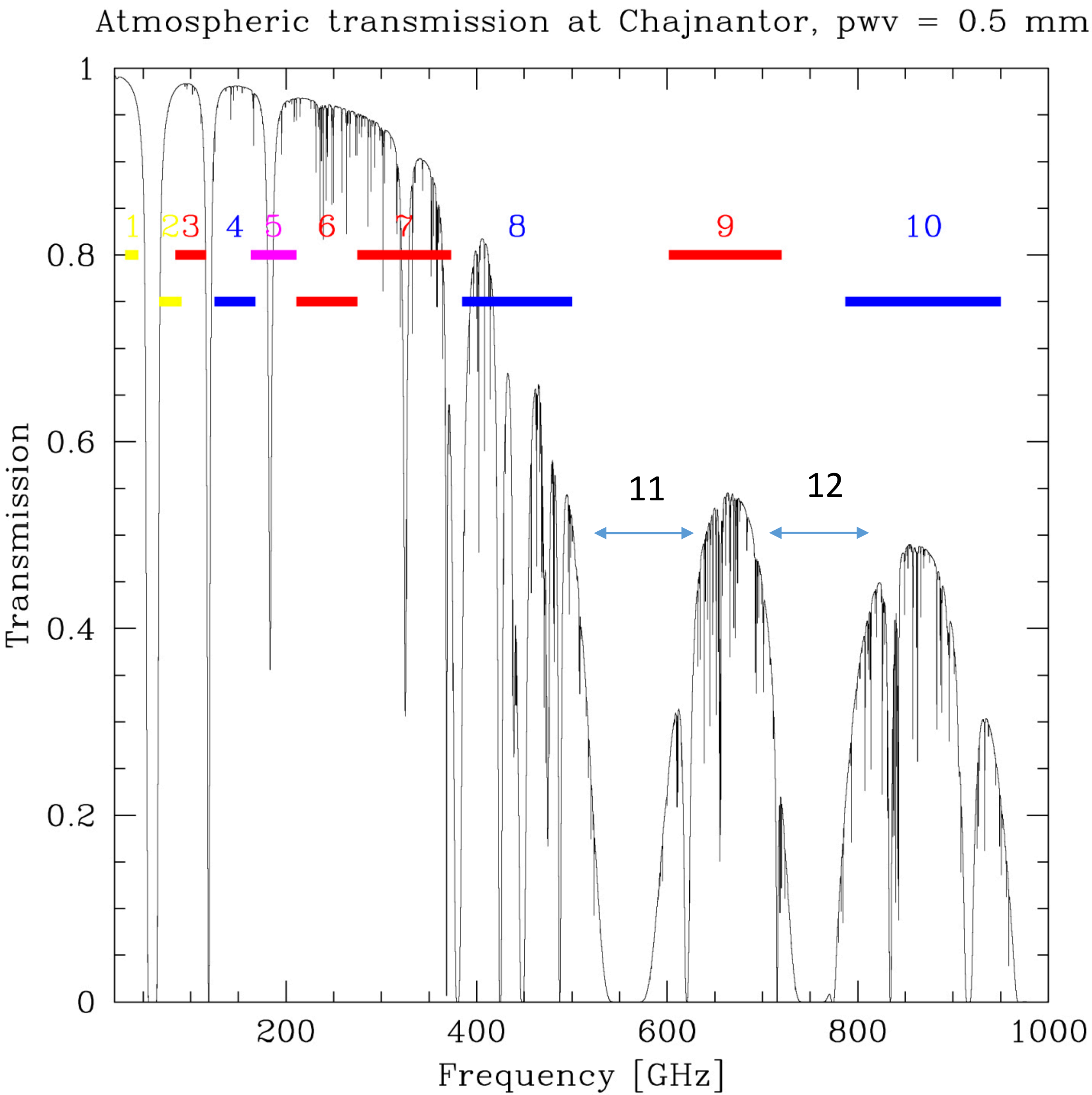
Importance of EM Access

- *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/)



Atmospheric transmission at Chajnantor, pwv = 0.5 mm
Transmission
Frequency [GHz]
1
0.8
0.6
0.4
0.2
0
200
400
600
800
1000
1
2
3
4
5
6
7
8
9
10
11
12

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

Spectrum Horizons Report and Order

I. INTRODUCTION

1. Innovators continue to push technological boundaries in wireless communications. Frequency bands once thought of as unusable are now well within the range of modern communications systems. With this First Report and Order, we take steps to provide new opportunities for innovators and experimenters to push those boundaries even further, and to develop new equipment and applications for spectrum between 95 GHz and 3 THz. These frequencies — long considered to lie at the outermost horizons of usable radio spectrum —are becoming increasingly well-suited for the development and deployment of new active communications services and applications. The rules we adopt in this First Report and Order will permit enhanced experimental licensing and unlicensed applications within this