National Science Foundation

Electromagnetic Spectrum Management

USTTI
September 19, 2019

National Science Foundation
Agency Overview

I seem to have been only like a boy playing on the seashore, and diverting myself in now and then finding a smoother pebble or a prettier shell than ordinary, whilst the great ocean of truth lay all undiscovered before me.

- Isaac Newton

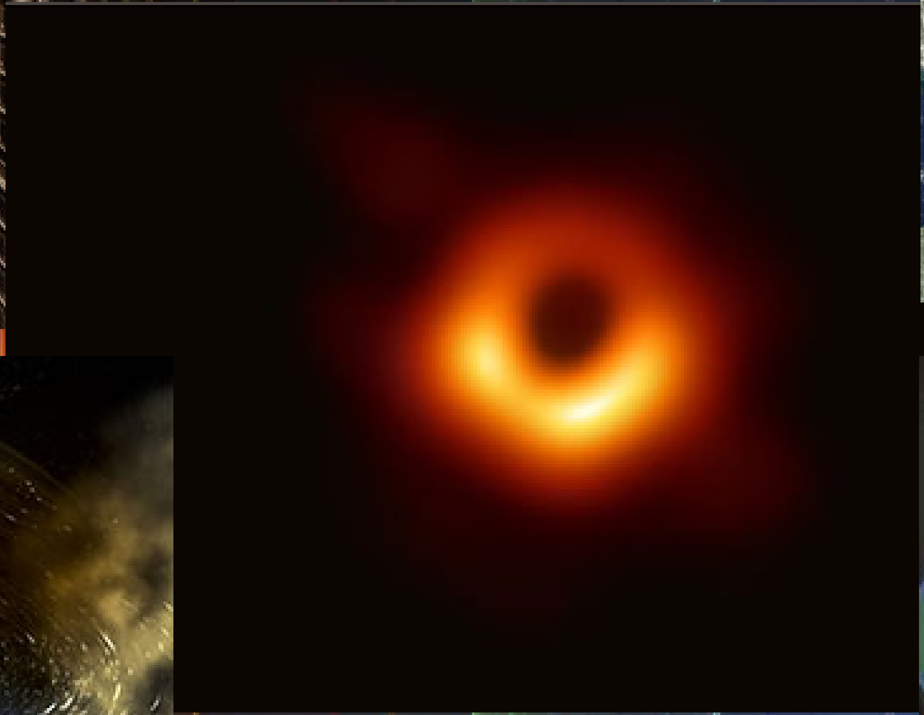
Image Credit: NRAO/AUI

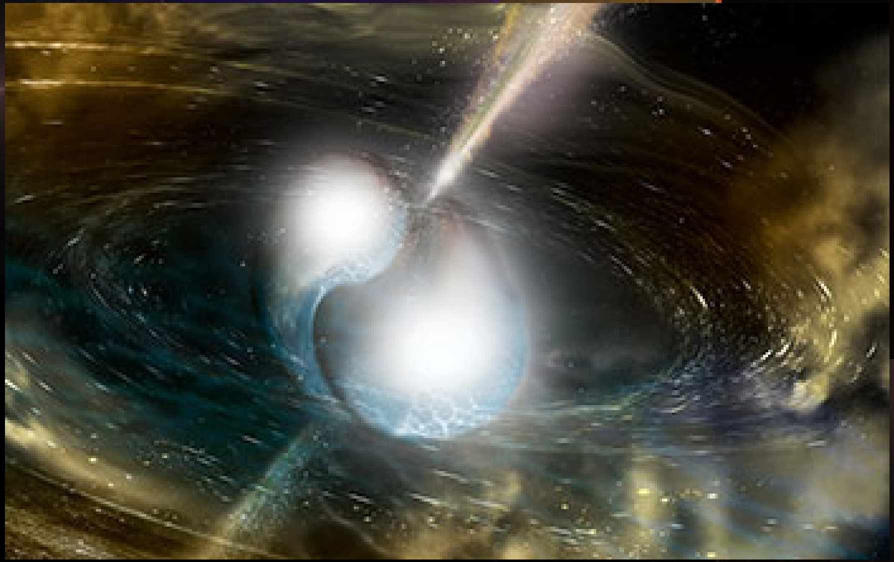
National Science Foundation - Agency Overview

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

- 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*





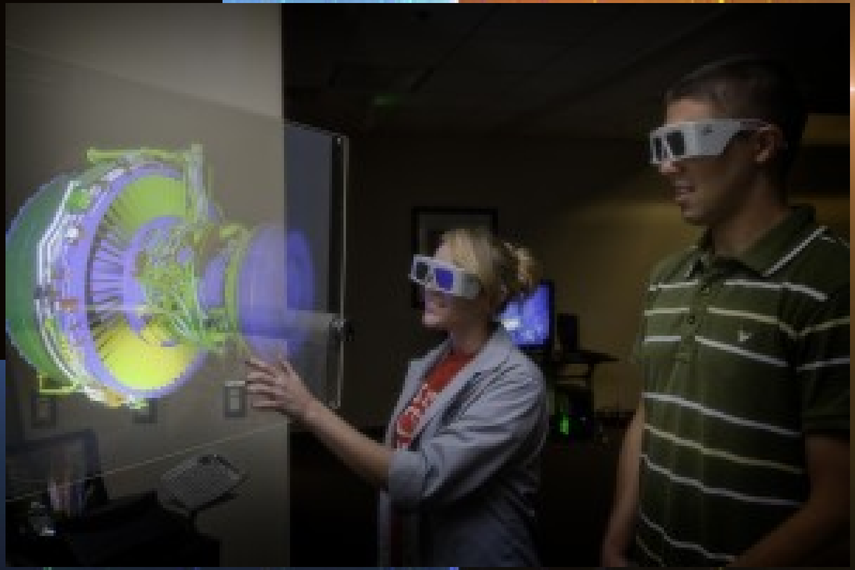
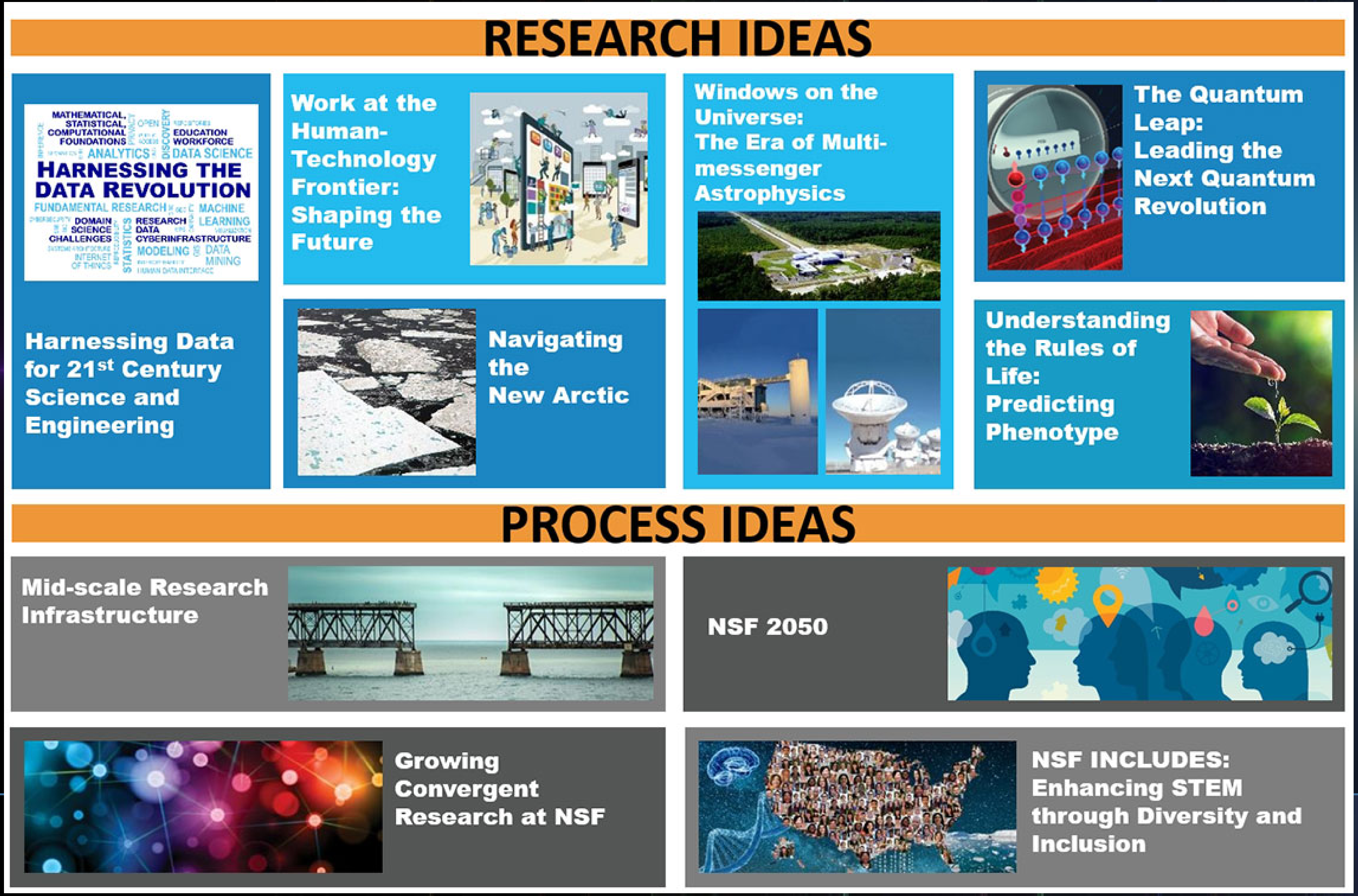


Image Credits: TACC, Event Horizon Telescope collaboration et al., National Science Foundation/LIGO/Sonoma State University/A. Simonnet, NASA

NSF 10 Big Ideas for Future Investment



Scientific Progress

- NSF has funded 236 Nobel Laureates
- Funding amounts exceed U.S. $8 billion/year
- International collaborations – LIGO, OISE
- Karl G. Jansky Very Large Array – leading scientific instrument
- Greenbank observatory
- ALMA
- Many more facilities

National Science Foundation
Spectrum Management Activities

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, 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 Coordination Group on Electromagnetic Spectrum Management

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

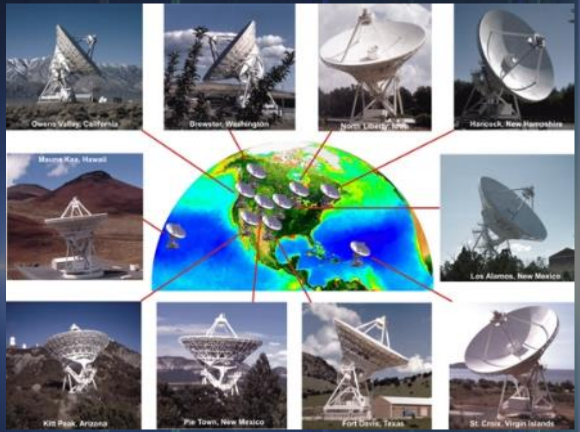
Chief Officer for Research Facilities,
Office of the Director

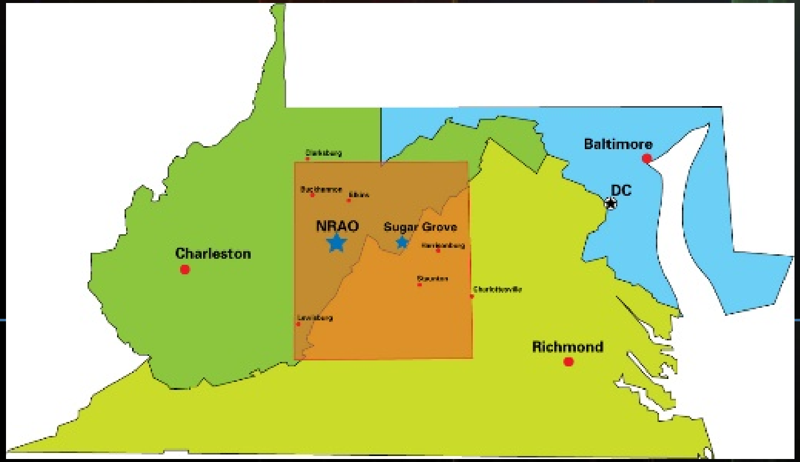
Astronomy research critically relies on access to the electromagnetic spectrum

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

Astronomy research critically relies on access to the electromagnetic spectrum

Radio Astronomy is a worldwide endeavor, and access to spectrum requires international collaboration.

Image credit: the Square Kilometer Array Organization (SKA Organization)

Astronomy research critically relies on access to the electromagnetic spectrum

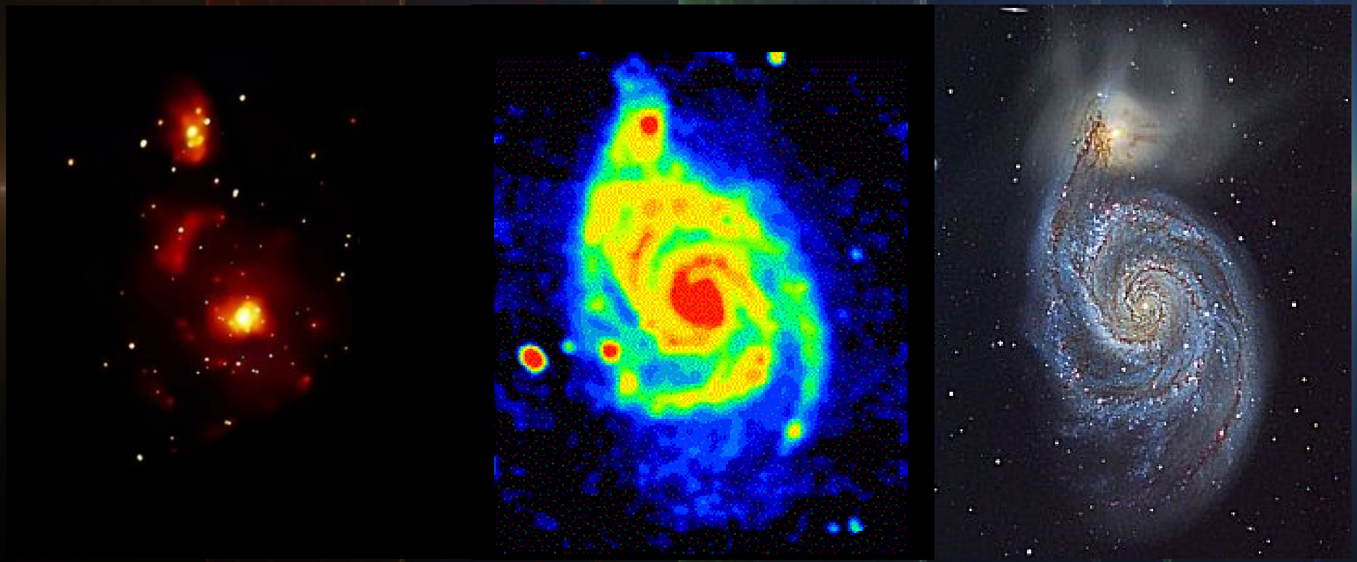
Radio Astronomy is a worldwide endeavor, and access to spectrum requires international collaboration.

Ghana Astronomy Radio Observatory

(Image via SIRO360)

Importance of EM Access

AST sciences are <u>fundamentally dependent on the detection of light across the full EM spectrum</u> (AAAC report, March 2017)



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

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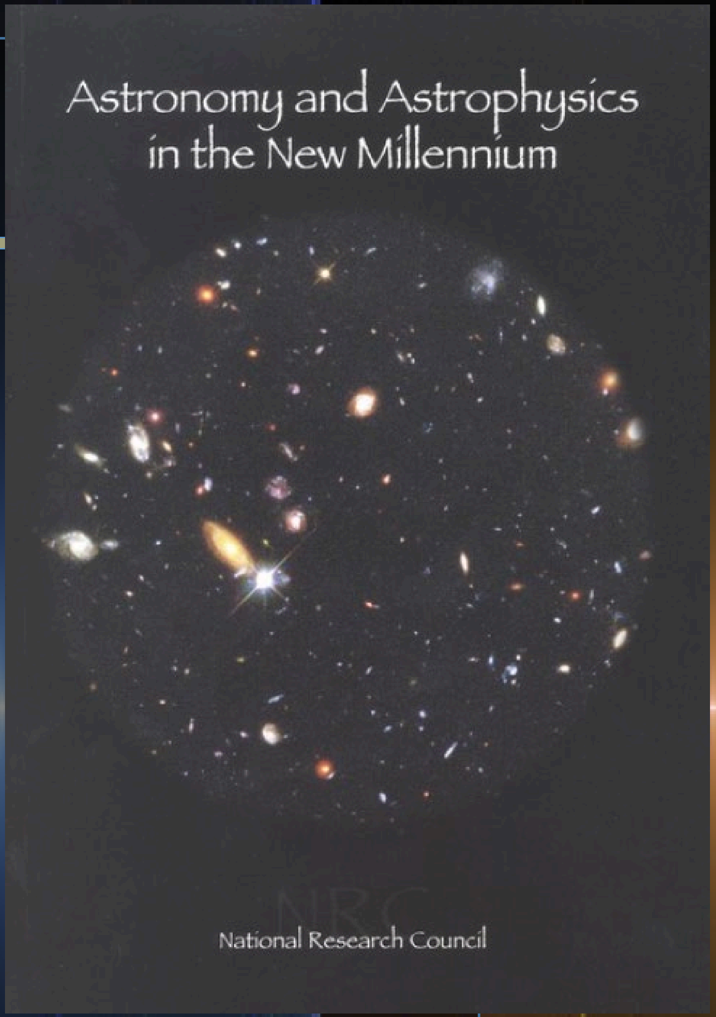
Challenges & Opportunities

An Increasing Challenge…

"*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,
Astronomy & Astrophysics in the New Millennium



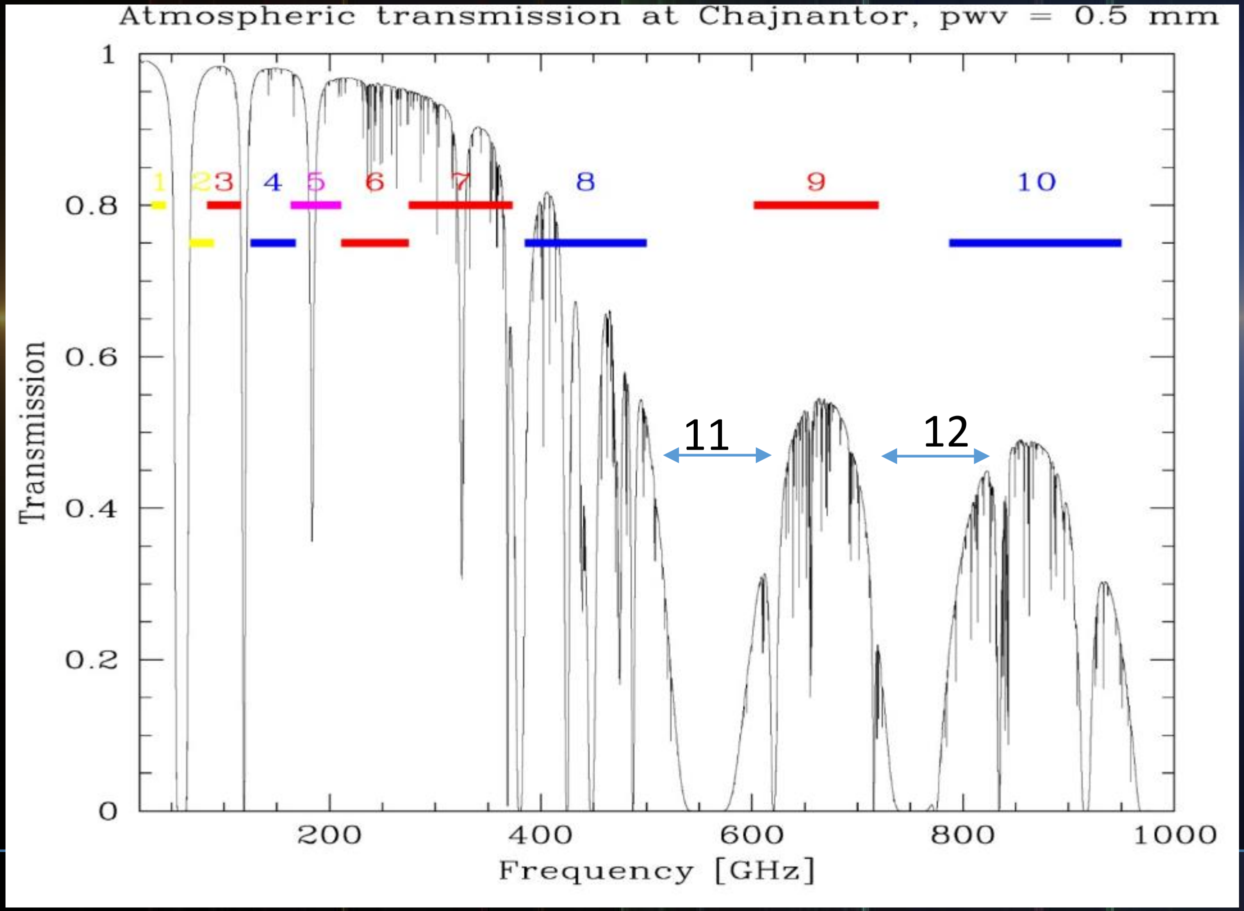
Specific Challenges

- ***Emitters in motion; esp. continuous emission***
- ***Out-of-band and Harmonic emissions***
- ***Limited resources*** e.g. for RFI reporting; increasing interest of the astronomy community
- ***Scientific disciplines utilize different frequencies*** (e.g. radio astronomy vs. earth sensing, GPS, polar) – and can be at odds with each other
- **Protections are no longer sufficient - even the National Radio Quiet Zone!**

Specific Challenges, continued

- 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

Science uses of the spectrum go where the physics leads



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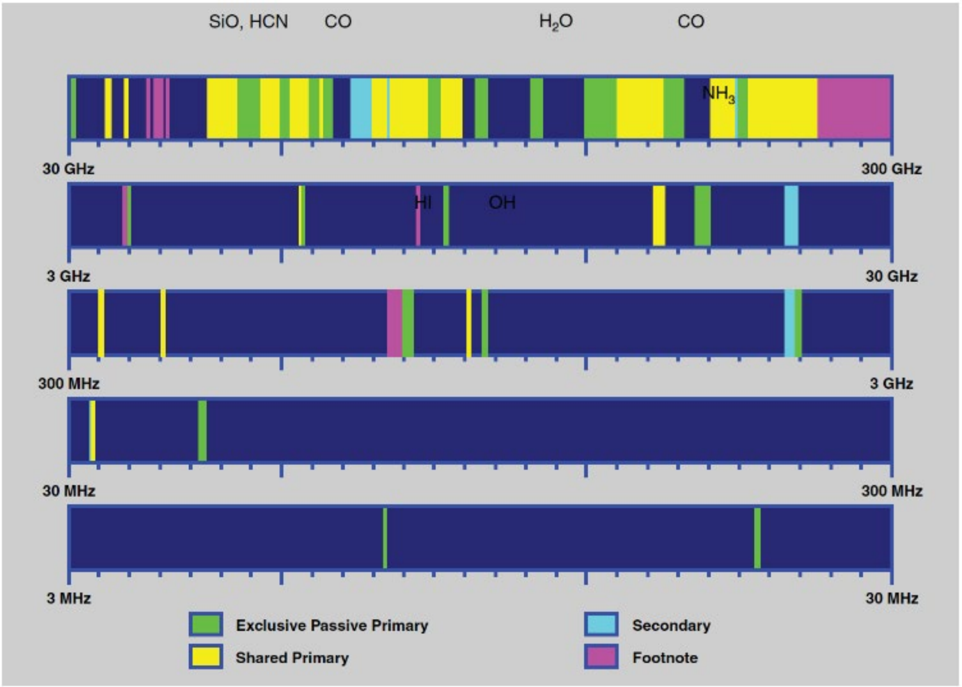
Takeaways

Physics & Astronomy 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.



Radio Astronomy Frequency Allocations in the United States

Image Credit: Andy Clegg, Spectrum Management for the 21st Century

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

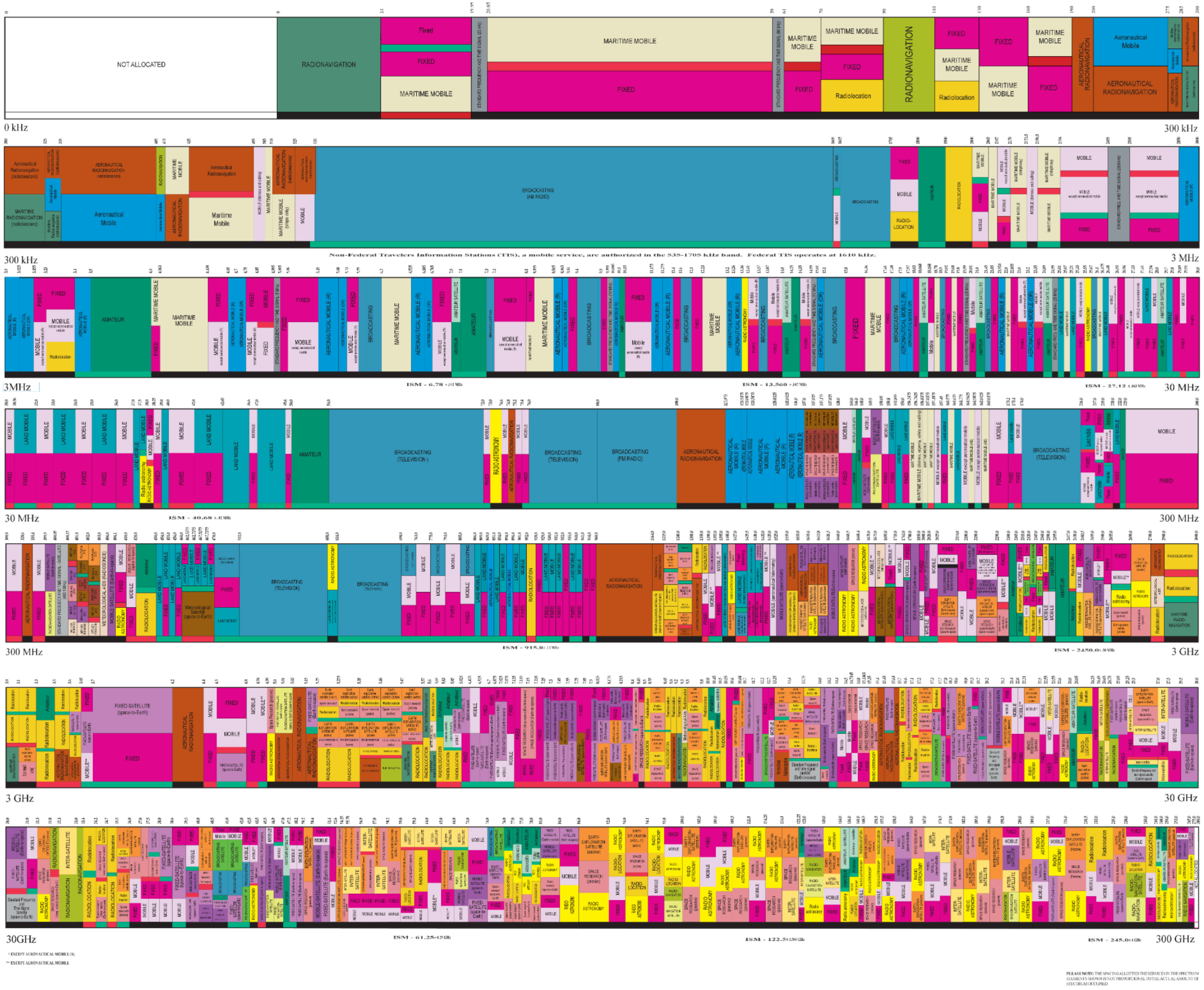
ALLOCATION USAGE DESIGNATION

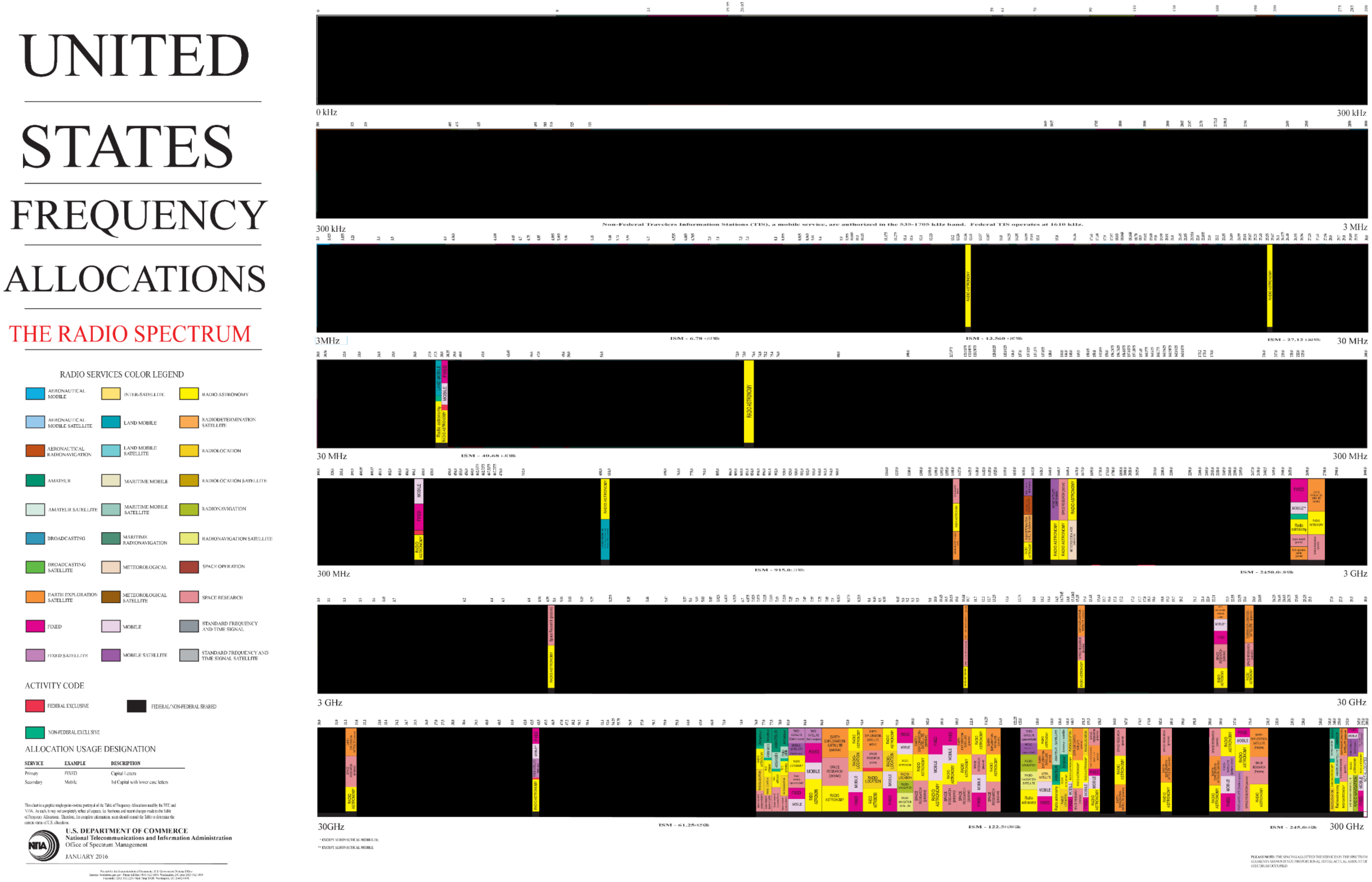
SERVICE	EXAMPLE	DESCRIPTION
Primary	FIXED	Capital Letters
Secondary	Mobile	1st Capital with lower case letters

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





UNITED
STATES
FREQUENCY
ALLOCATIONS
THE RADIO SPECTRUM
RADIO SERVICES COLOR LEGEND
AERONAUTICAL MOBILE
INTER-SATELLITE
RADIO ASTRONOMY
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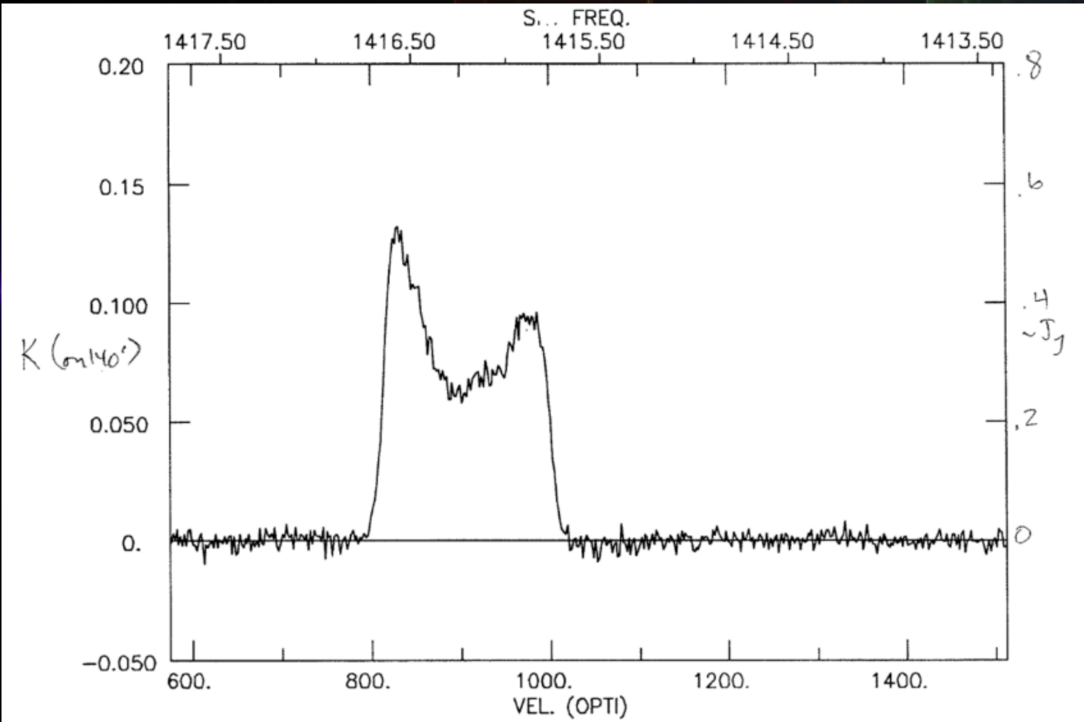
FEDERAL/NON-FEDERAL SHARED
NON-FEDERAL EXCLUSIVE
ALLOCATION USAGE DESIGNATION
SERVICE
EXAMPLE
DESCRIPTION
Primary
FIXED
Capital Letters
Secondary
Mobile
1st Capital with lower case letters
U.S. DEPARTMENT OF COMMERCE
National Telecommunications and Information Administration
Office of Spectrum Management
JANUARY 2016
0 kHz
300 kHz
300 kHz
3 MHz
Non-Federal Travelers Information Stations (TIS), a mobile service, are authorized in the 535-1705 kHz band. Federal TIS operates at 1610 kHz.
3MHz
30 MHz
30 MHz
300 MHz
300 MHz
3 GHz
3 GHz
30 GHz
30GHz
300 GHz
RADIO ASTRONOMY

Scientifically valuable signals may be doppler-shifted outside allocated bands



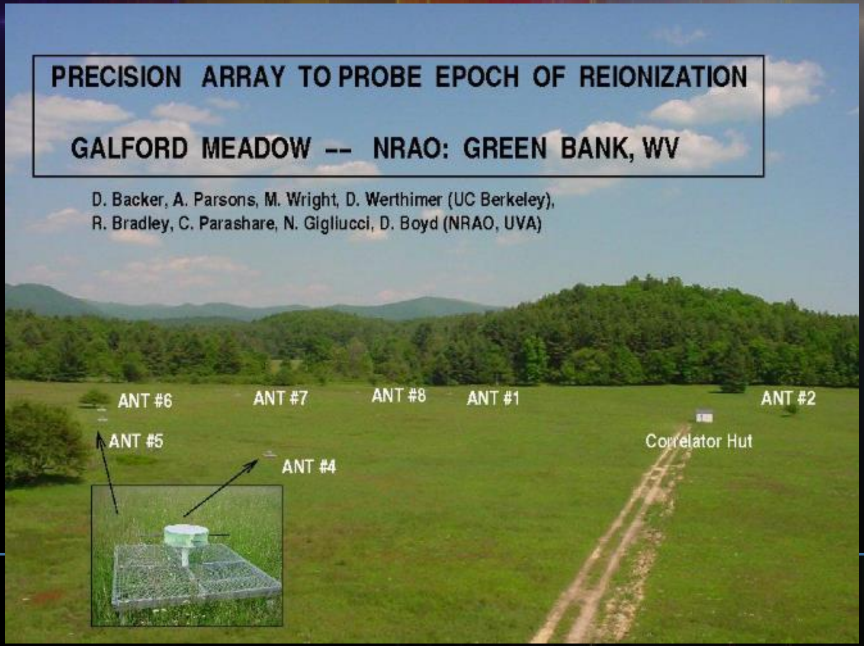
This integrated HI spectrum of UGC 11707 obtained with the 140-foot telescope (beamwidth ≈ 20 arcmin) shows the typical two-horned profile of a spiral galaxy.

Epoch of Reionization

HI: 21 cm -> 1.5 m

Freq ~ 1420 MHz -> 200 MHz

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



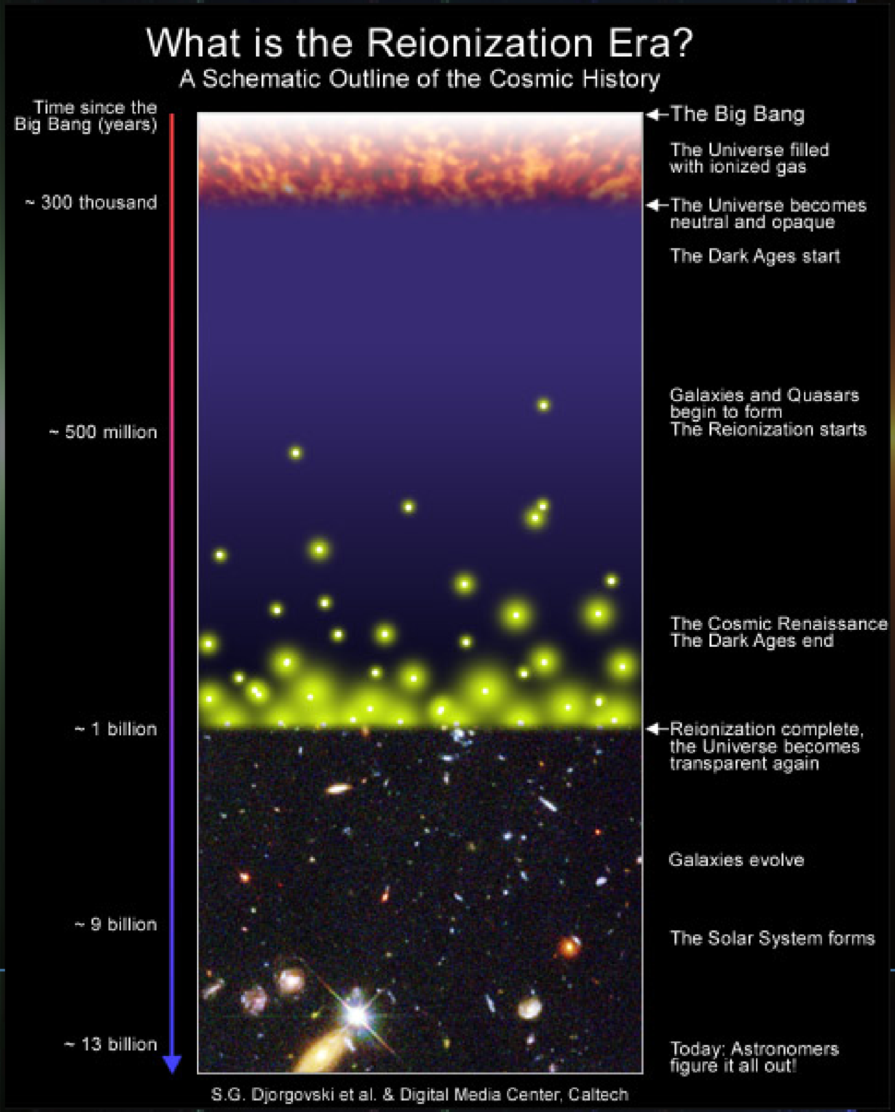
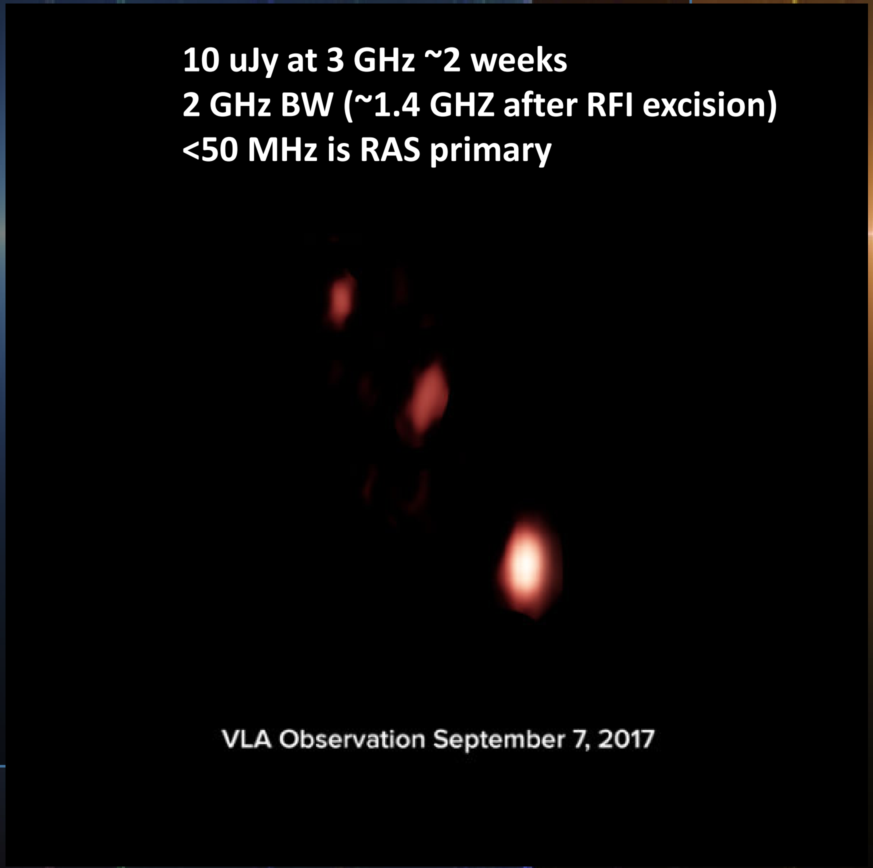


Image Credit: Djorgovski et al. (Caltech); www.haystack.mit.edu

Physics & Astronomy Frequency Usage Takeaways

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 <u>continuum emission</u> (thermal, non-thermal).



Physics & Astronomy Frequency Usage Takeaways

- **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.**

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 (10-50 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)

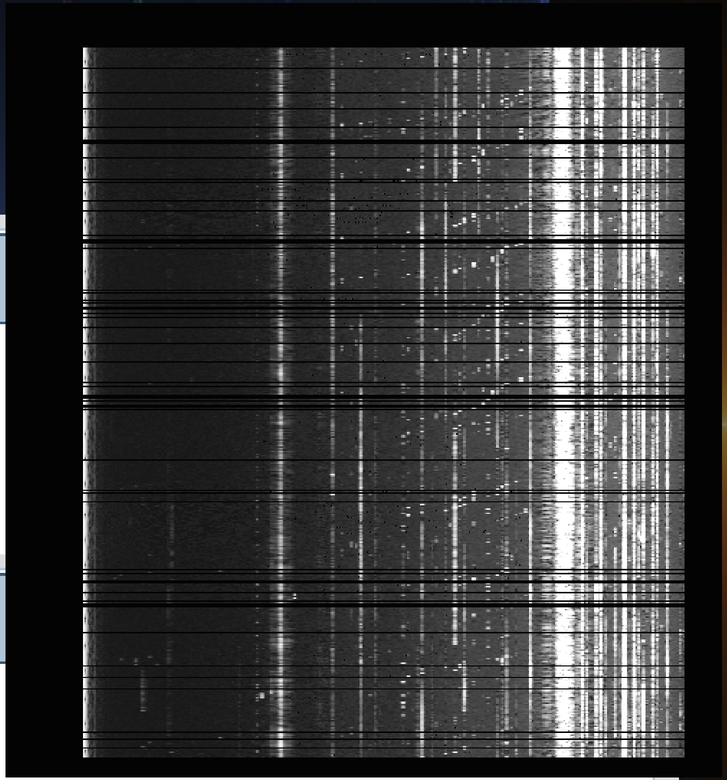
by Emmanuel Momjian — last modified Jul 07, 2011

Frequency (MHz)	Description	Origin	Classification	Spectrum
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

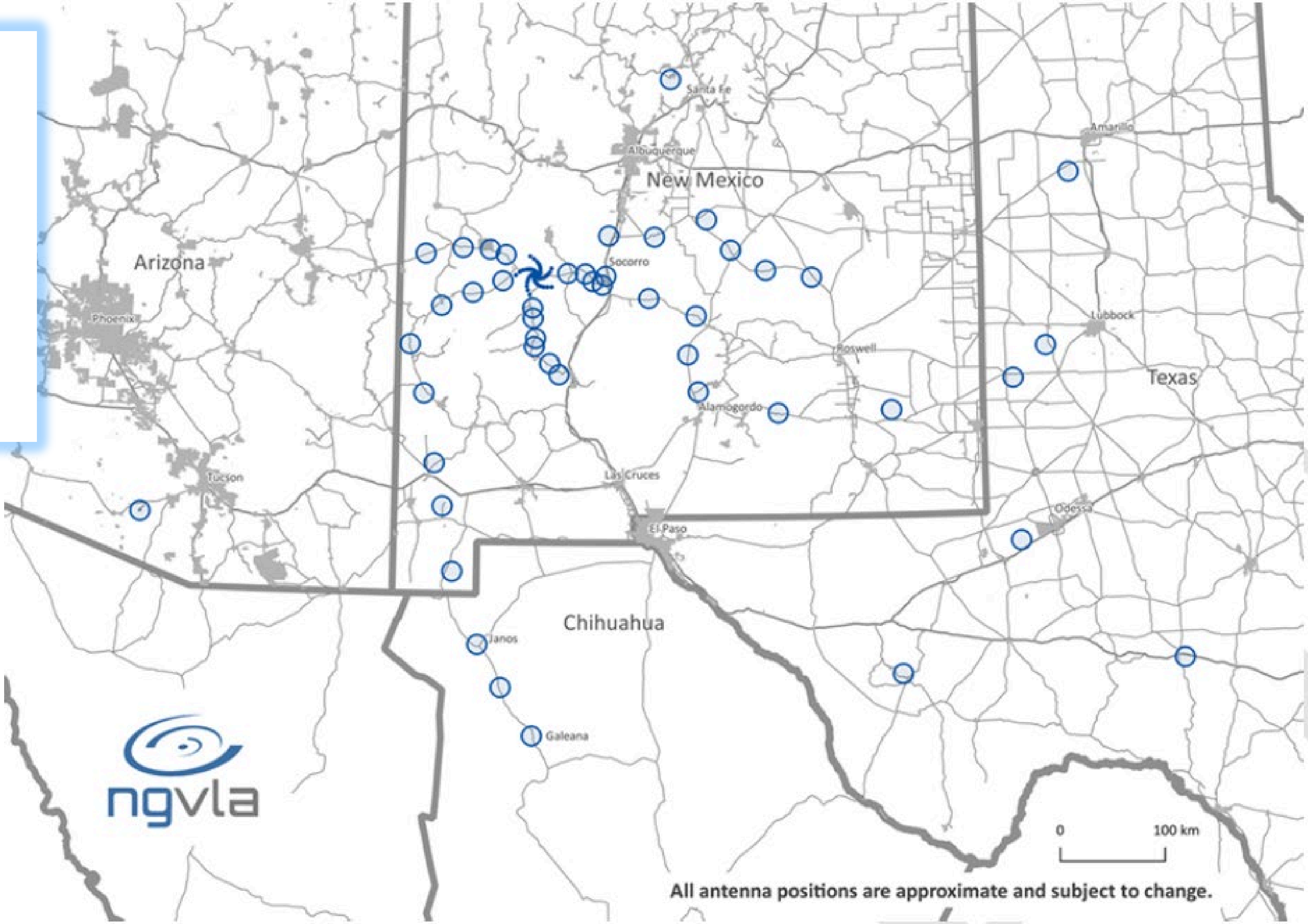


Figure 1. ngVLA Array Configuration Rev. B (Spiral-214). Antenna positions are still notional, but are representative for performance quantification.

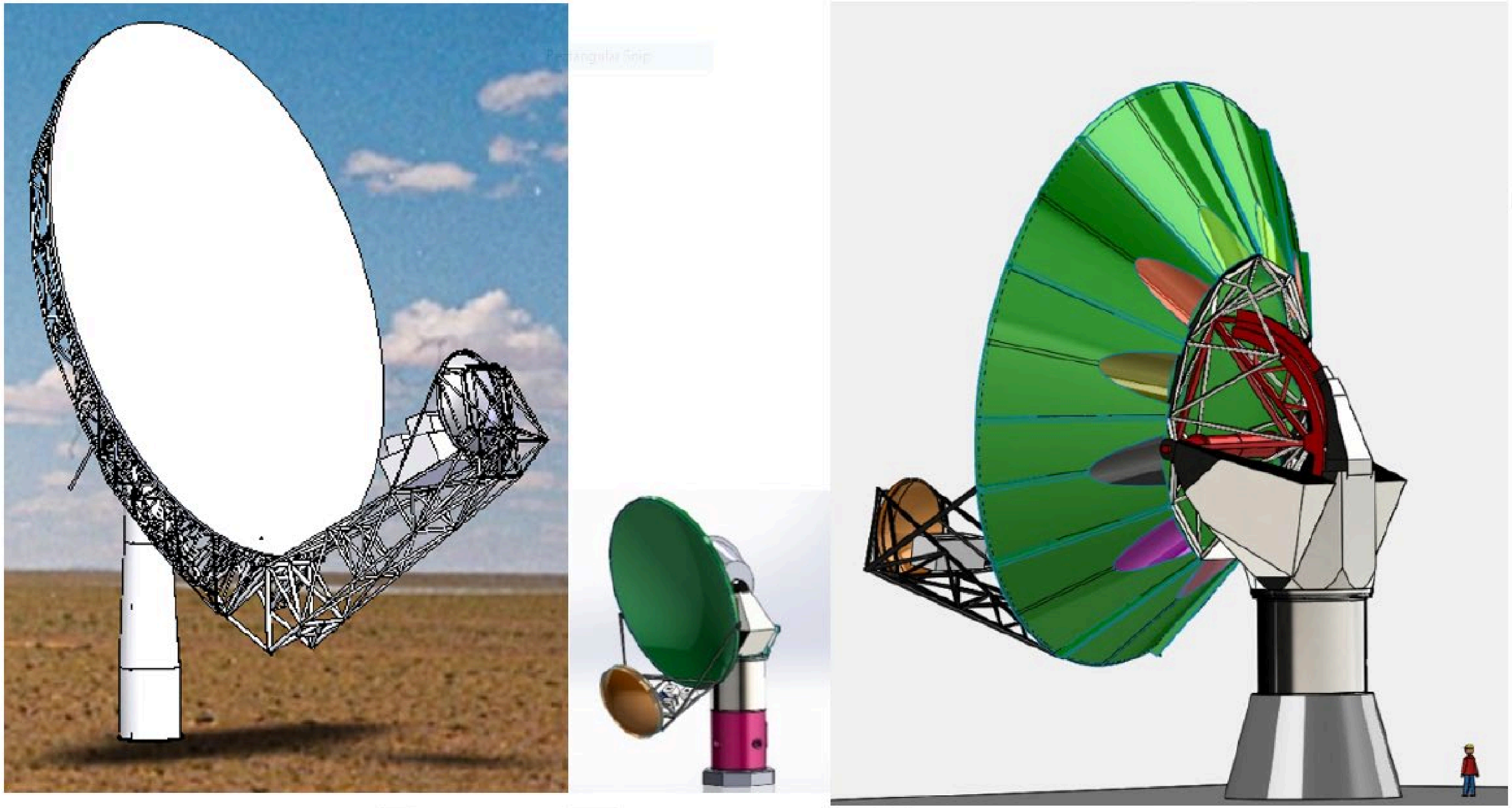


Figure 3. Left: ngVLA 18 m antenna reference design concept prepared by GDMS. Center: 6 m short spacing array antenna concept prepared by NRCC. Right: ngVLA 18 m antenna composite design concept prepared by NRCC.

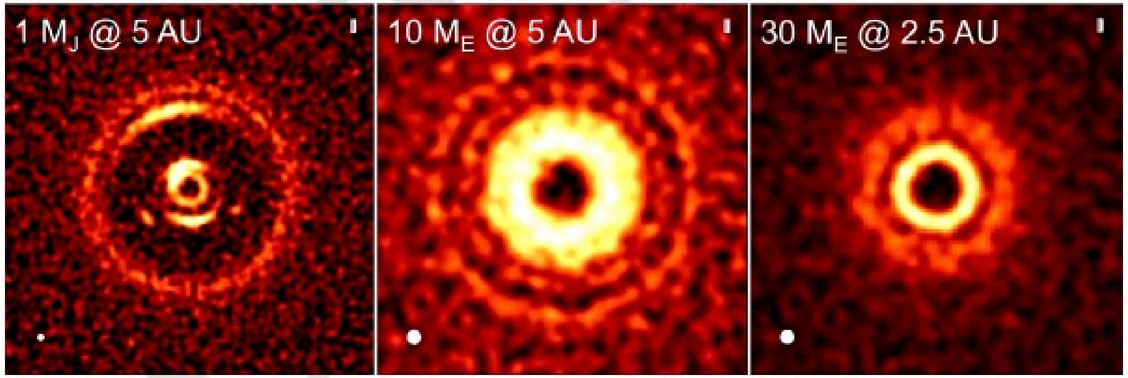


Figure 1. Simulated ngVLA observations of protoplanetary disk continuum emission perturbed by a Jupiter mass planet at 5 AU (left), a 10 Earth mass planet at 5 AU (center), and a 30 Earth mass planet at 2.5 AU (right). The ngVLA observations at 100 GHz were simulated with 5 mas angular resolution and 0.5 μJy/bm rms (Ricci et al. 2018).

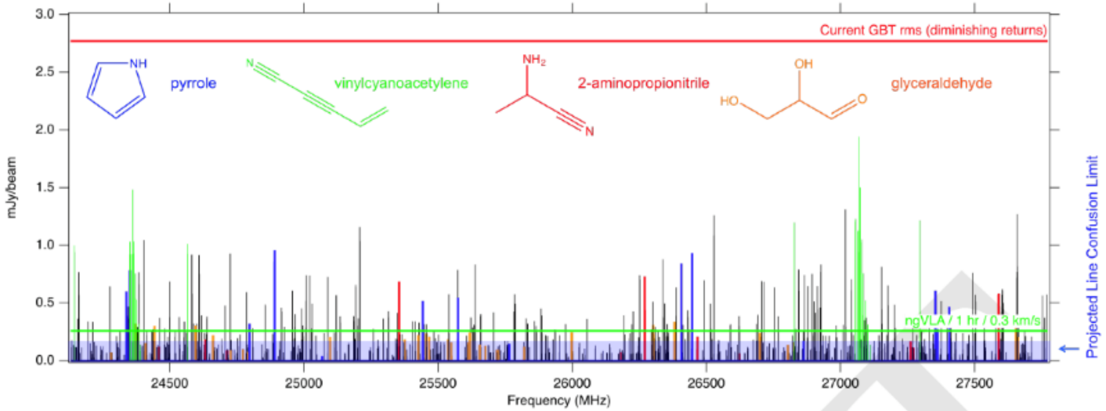


Figure 2. A conservative simulation of 30 as-yet-undetected complex interstellar molecules (black) likely to be observed by the ngVLA above the confusion limit around hot cores with typical sizes of $\sim 1 - 4''$. Key molecules are highlighted in color. (Credit: B. McGuire)

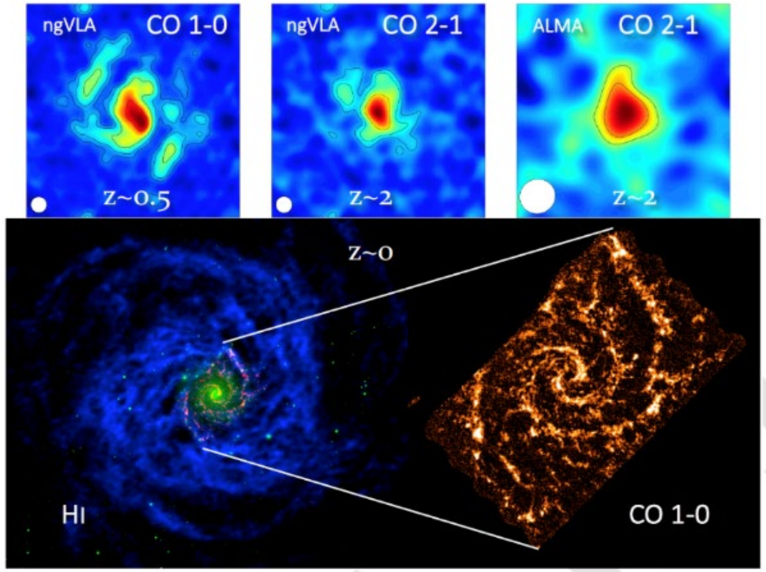


Figure 3. *Top Panels:* Simulations based on M 51 with molecular mass scaled by 1.4× (z = 0.5) and 3.5× (z = 2) to match the lowest molecular mass galaxies observable by ALMA and the NOEMA (Carilli & Shao 2017). The synthesized beam shown in the bottom left corner is (left to right) θ_s = 0.″19, 0.″20, and 0.″43 corresponding to linear scales L = 1.2, 1.7, and 3.7 kpc, respectively. Integration times are 30 hr. *Bottom Panels:* The spiral galaxy M 74 illustrating the CO molecular disk imaged by ALMA (red; Schinnerer in prep.), the stellar disk at 4.5 μm imaged by *Spitzer* (green; Kennicutt et al. 2003), and the atomic disk imaged in HI by the VLA (blue; Walter et al. 2008), showing the gas phases to which the ngVLA will be sensitive. *Right Panel:* The CO $J = 2 \rightarrow 1$ map at 1″ resolution.

Deep-Space Spacecraft Telemetry with ngVLA

Table 2. Frequency Bands for Deep-Space Spacecraft Telemetry

Name	Telemetry (Downlink) (space-Earth) (GHz)
S band	2.29–2.30
X band	8.40–8.45
Ka band	31.8–32.3

Conclusions

- **Keep protected RAS allocations as RFI-free as possible**
  - *Guard bands for other services*

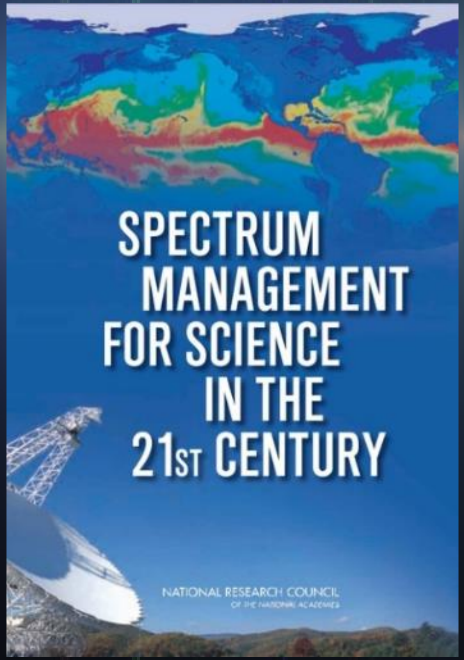
- **Utilize technology developments and advancements to increase spectrum availability for physics and astronomy in strategic geographic locations**
  - *“National Radio Dynamic Zone” for enhanced ESM protections*
  - *Work with us to pilot a win-win for science and commercial interests*

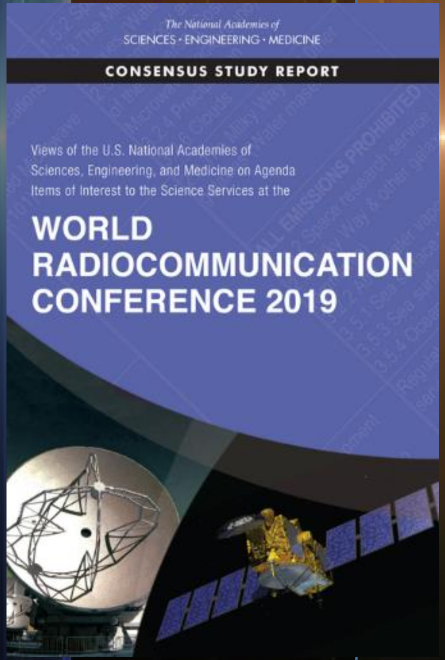
- **Research leads the way to technologies we all use**
  - *Research in RFI excision techniques and receiver technology*
  - *e.g. GPS, Wi-fi*

- **Educational opportunity - Increased awareness of the spectrum as a finite, but renewable resource**
  - *Department of Interior / Educational Awareness program at the National Parks*

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





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BOARD ON PHYSICS AND ASTRONOMY
Division on Engineering and Physical Sciences

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