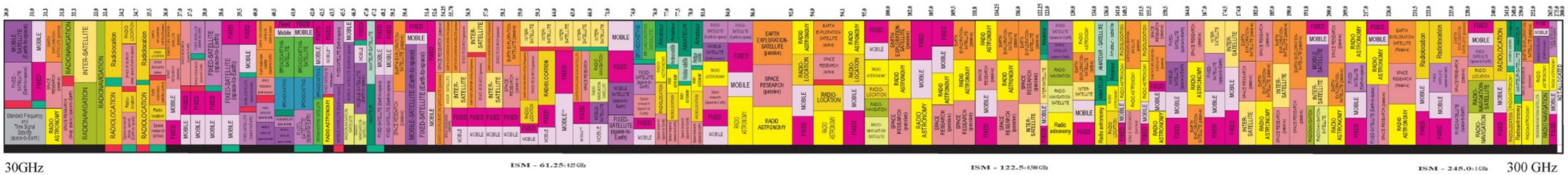
National Science Foundation

Electromagnetic Spectrum Management



National Academy of Sciences

Steering Committee of the Decadal Survey on Astronomy & Astrophysics

Radio-Frequency Interference Meeting

June 9, 2020

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

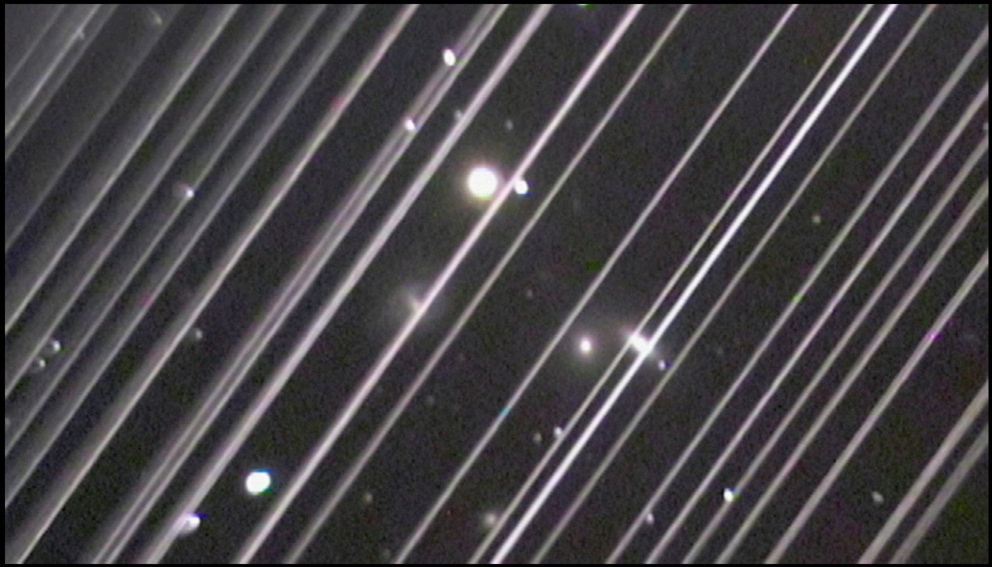
Jonathan Williams - *jonwilli@nsf.gov*

2020:
A decade with
new opportunities

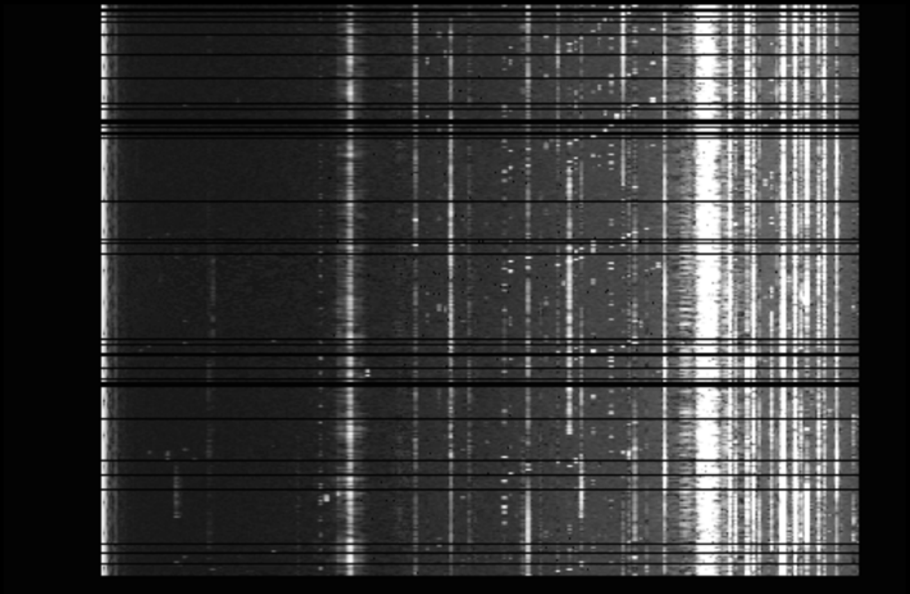
Credit: LSST

Credit: almaobservatory.org

2020:
A decade with
new opportunities
and
new challenges



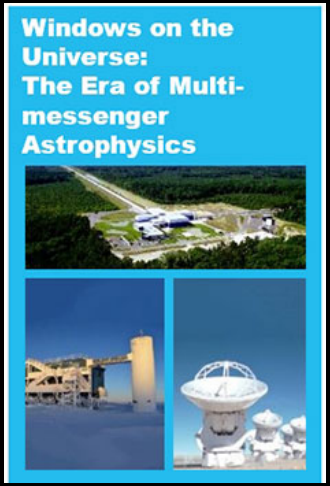
optical interference



radio interference

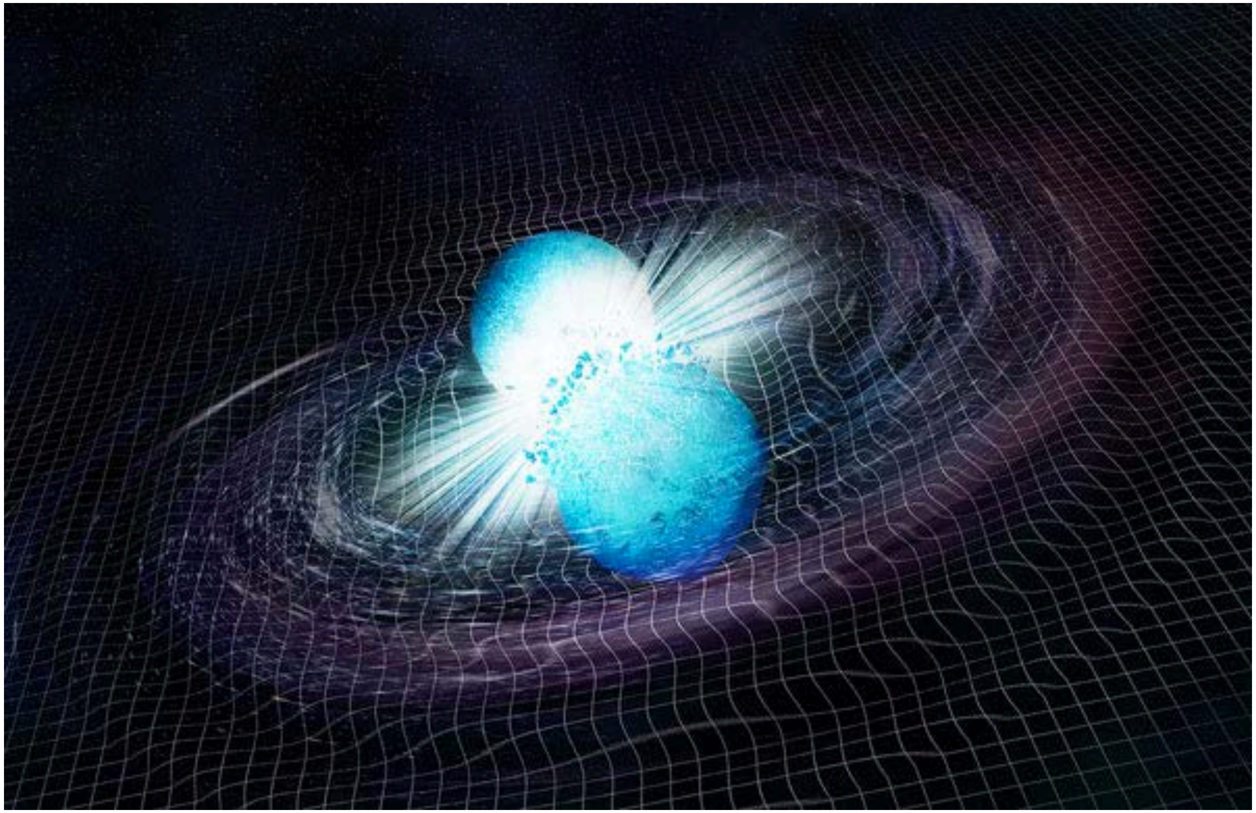
NSF 10 Big Ideas for Future Investments

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

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?

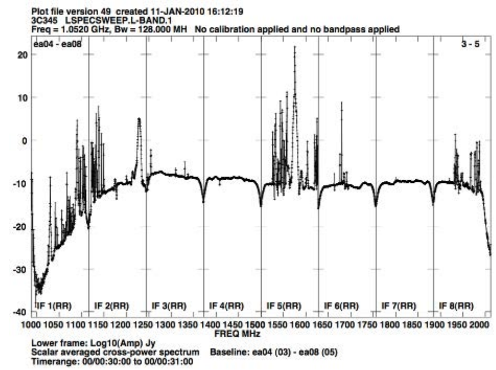
10 uJy at 3 GHz ~2 weeks

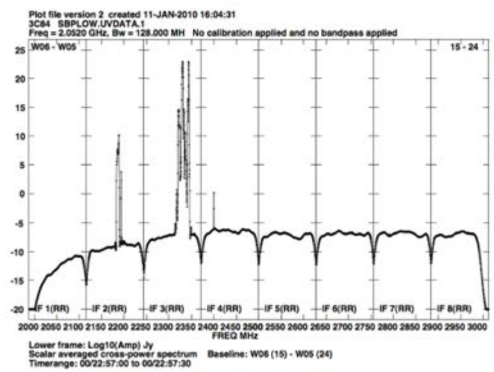
2 GHz BW (~1.4 GHZ after RFI excision)

<50 MHz is
RAS primary

VLA Observation September 7, 2017

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





Why does access to the radio spectrum matter?

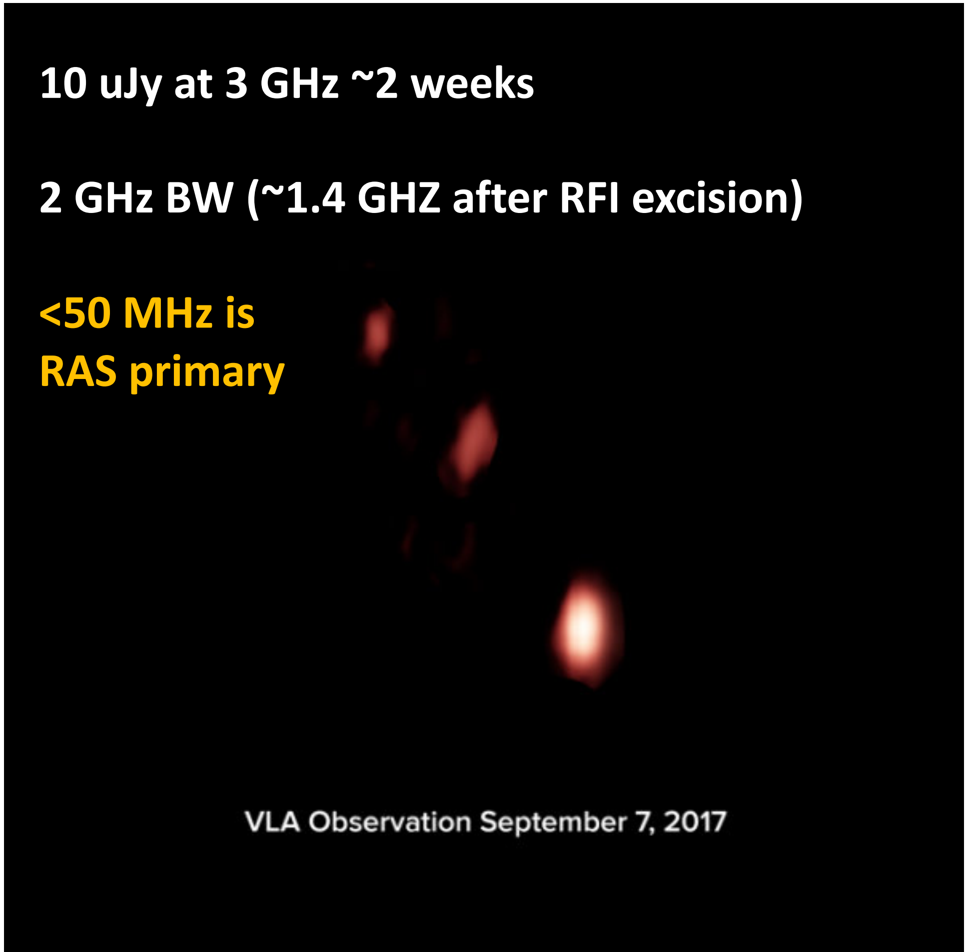
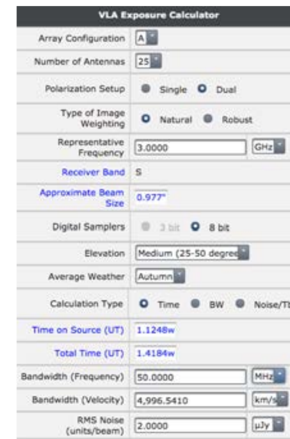


Image Credits: Hallinan et al., Science (16 Oct 2017)

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

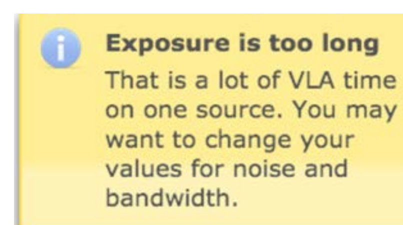


VLA Exposure Calculator	
Array Configuration	A
Number of Antennas	25
Polarization Setup	Single / Dual
Type of Image Weighting	Natural / Robust
Representative Frequency	3.0000 GHz
Receiver Band	S
Approximate Beam Size	0.977"
Digital Samplers	3 bit / 8 bit
Elevation	Medium (25-50 degre
Average Weather	Autumn
Calculation Type	Time / BW / Noise/Tb
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 µJy

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

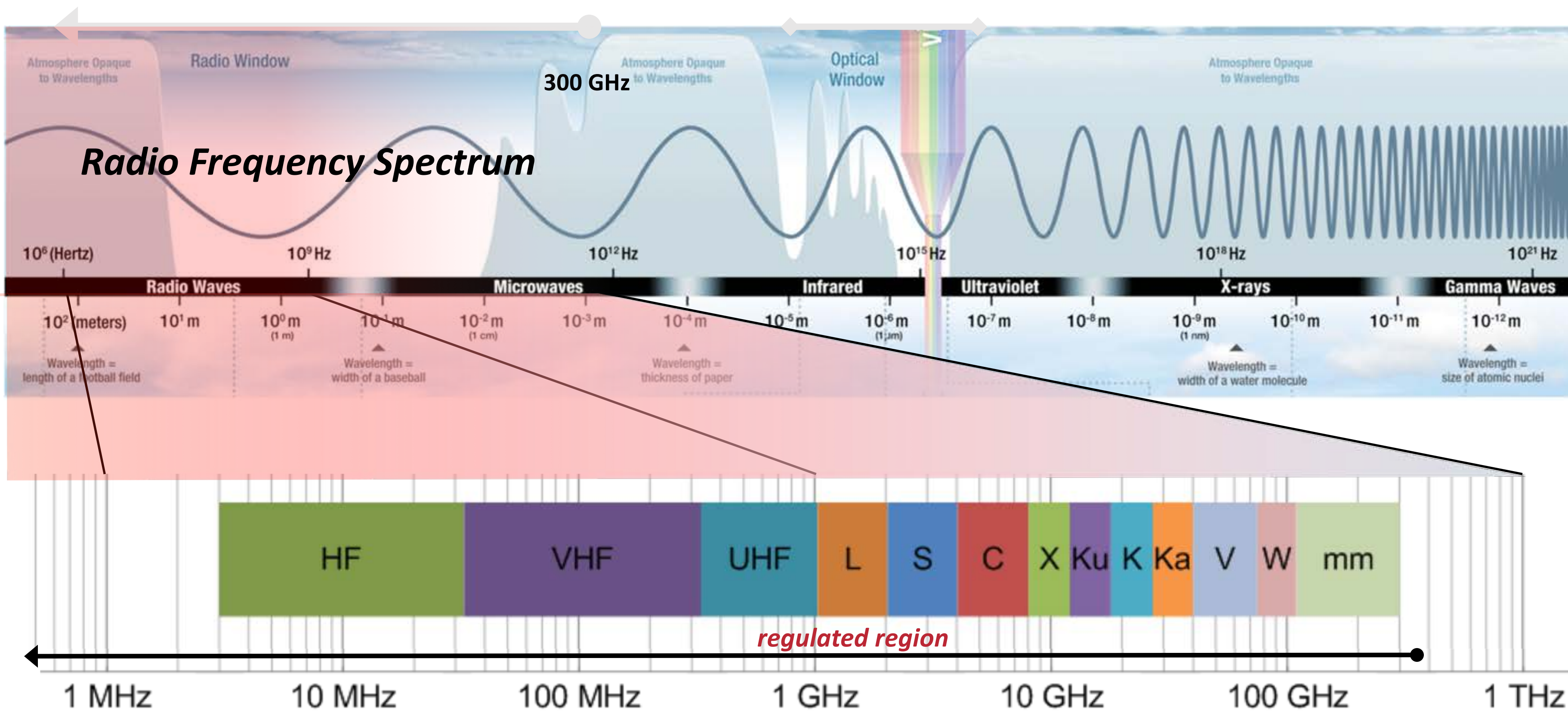
<u>1.4 GHz bandwidth:</u>
6 hours

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



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

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.**

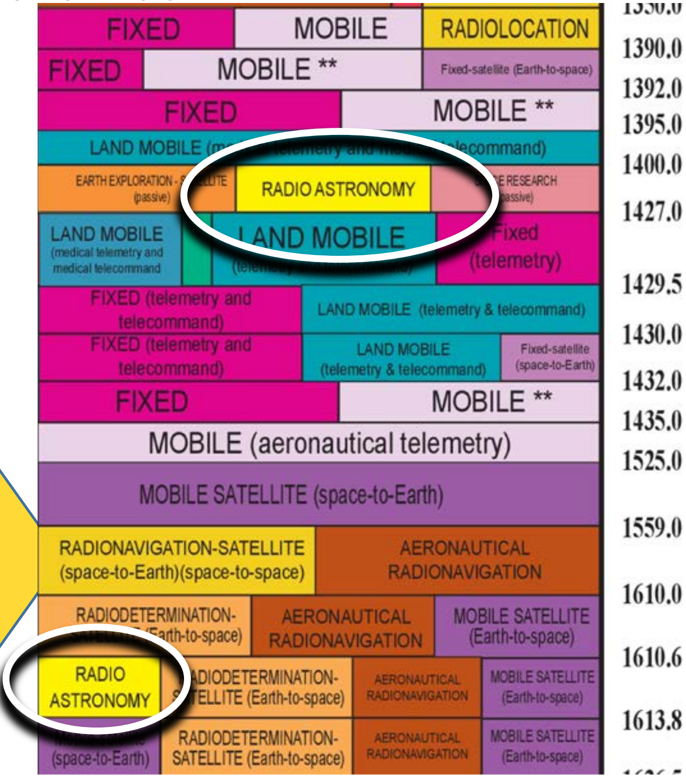


Image credits: <u>https://techcrunch.com/2016/02/05/new-air-force-satellites-launched-to-improve-gps/</u> (L), NTIA (R)

Epoch of Reionization

HI: 21 cm -> 1.5 m

Freq ~ 1420 MHz -> 200 MHz

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

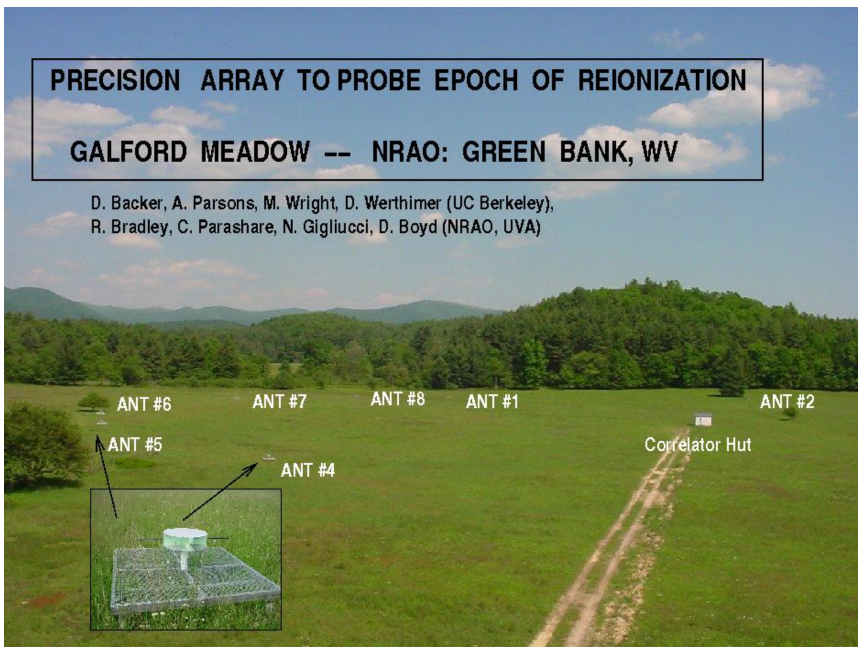


Image Credit: w.astro.berkeley.edu

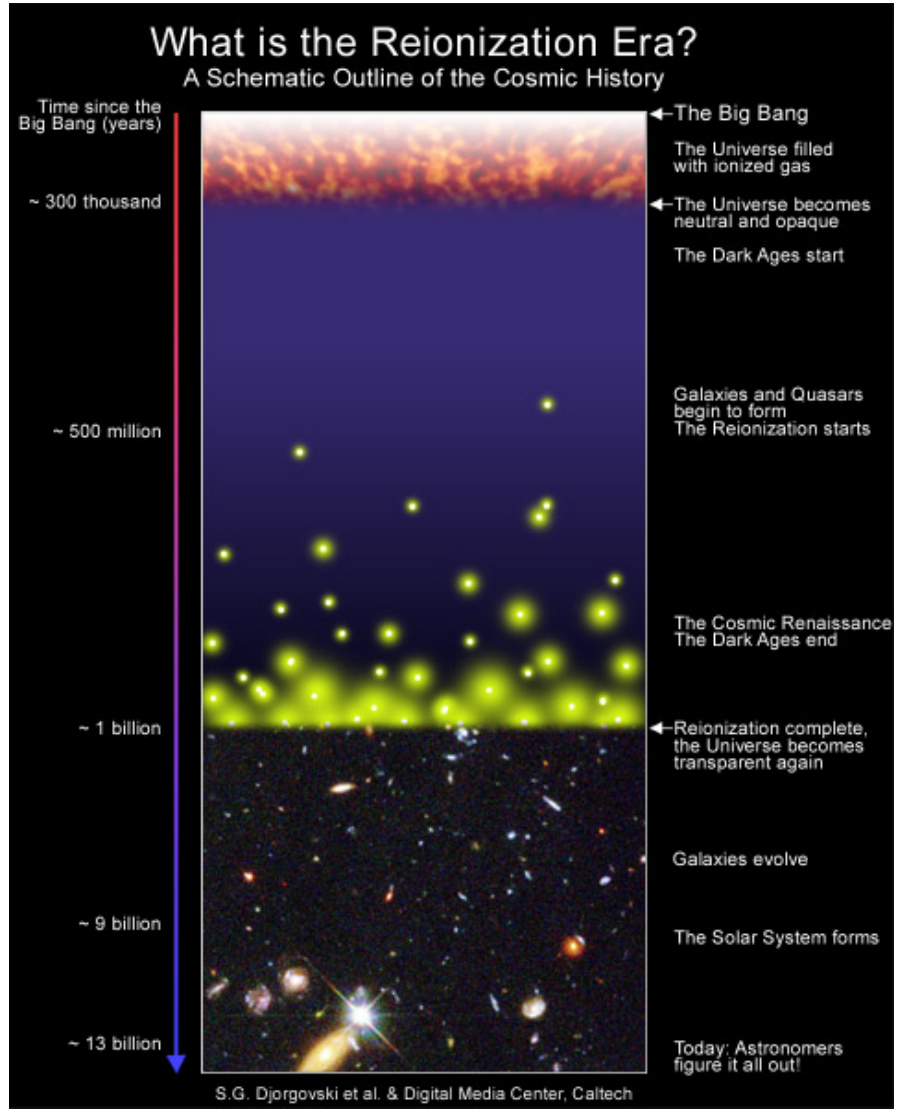
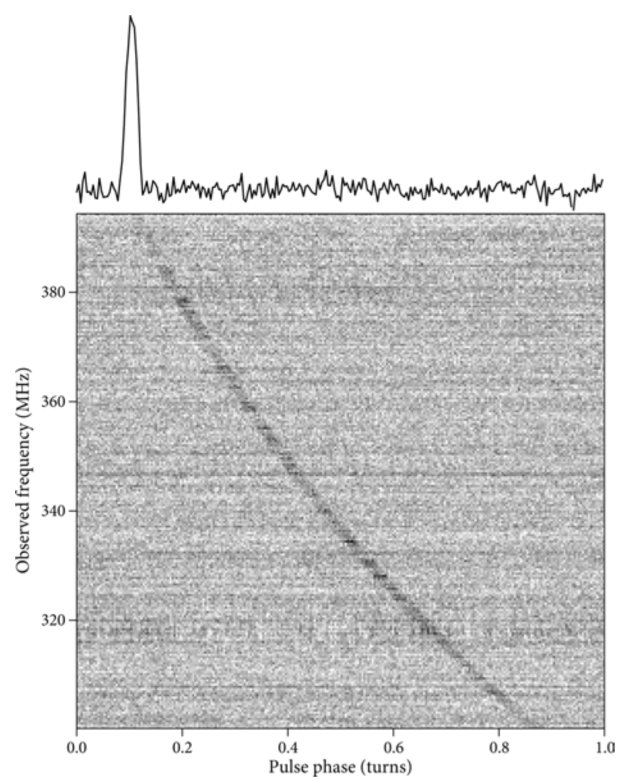


Image Credit: Djorgovski et al. (Caltech); www.haystack.mit.edu

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 continuum emission (thermal, non-thermal).**



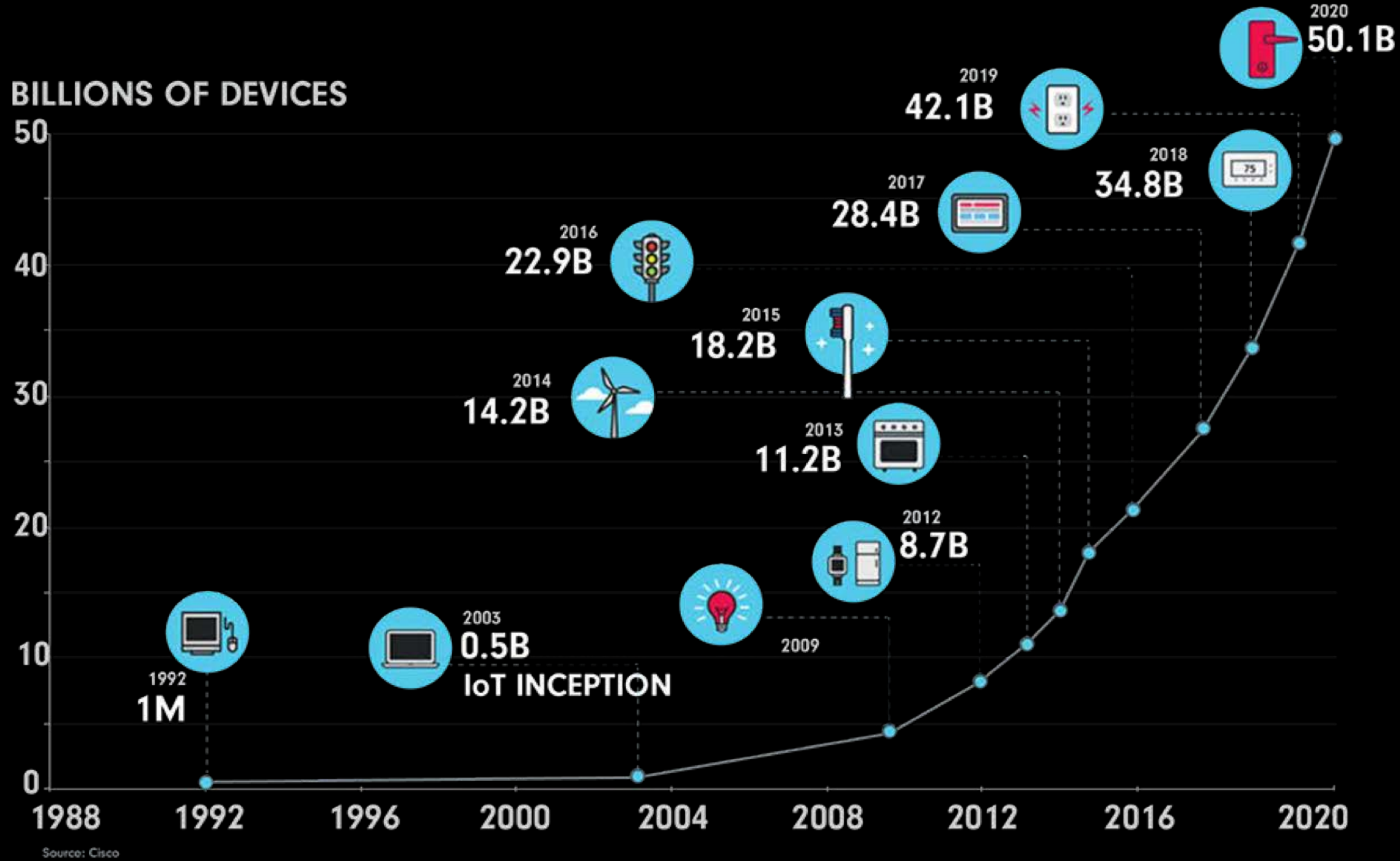
https://www.cv.nrao.edu/~sransom/web/Ch6.html

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

At the same time there are large improvements in radio astronomy capabilities…

Table and Image Credit: NRAO

Demand for spectrum is unrelenting



Frequency Usage Takeaways

ALMA

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 “quiet” dynamic coordination zones**

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 (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

Changes in Satellite Constellations

2020
~6,000 satellites

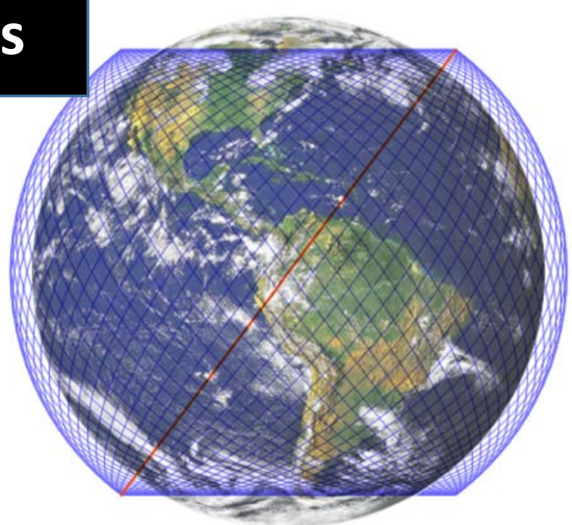
2030
10,000+ satellites

2040
40,000+ satellites

- Numbers of satellites is increasing;
  -factor of 10 over the next 20 years

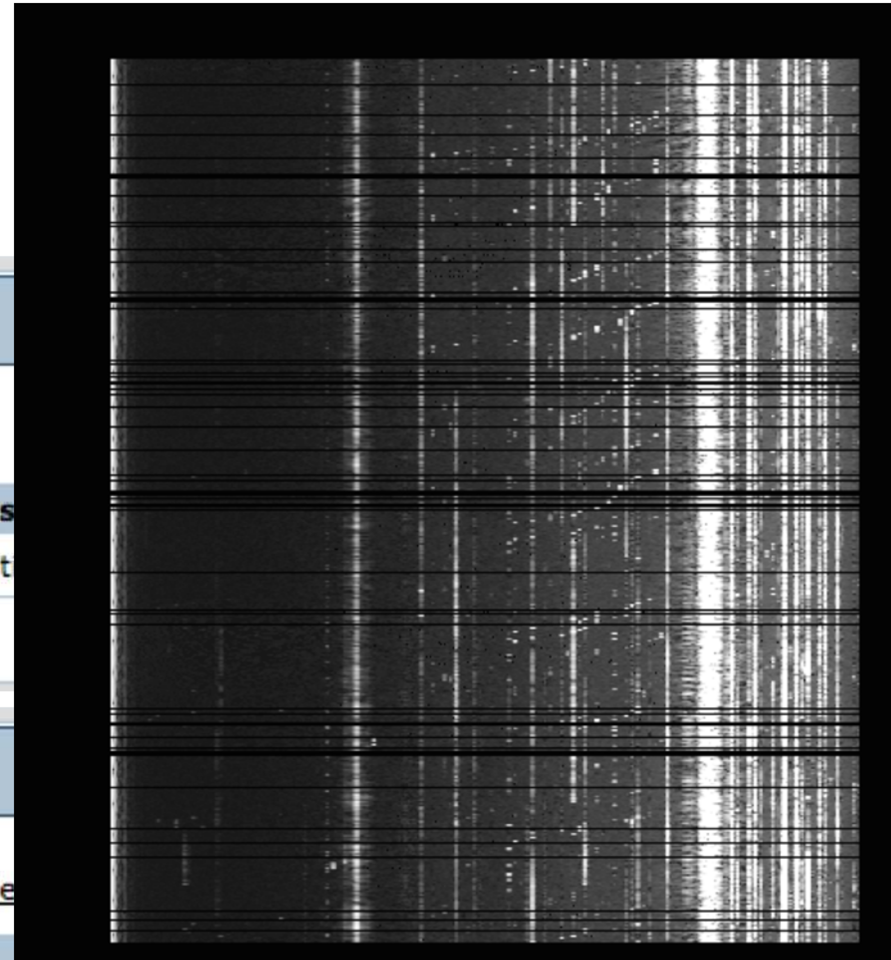
- Type of orbit is changing;
  -GSO -> NGSO constellations in LEO; 500 – 1200 km
  -Closer, brighter

- Radio frequencies utilized is increasing;
  -problem for radio astronomy



Images: Wikipedia SpaceX entry

What is coming…



RFI at K-Band (18-26.5 GHz)

by Emmanuel Momjian — last modified Jul 07, 2011

Frequency (MHz)	Description	Origin	Clas
17800-20200	Satellite downlink	Clarke Belt	cont

RFI at Ka-Band (26.5-40 GHz)

by Emmanuel Momjian — last modified Mar 15, 2013 by He

Frequency (MHz)	Description			
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

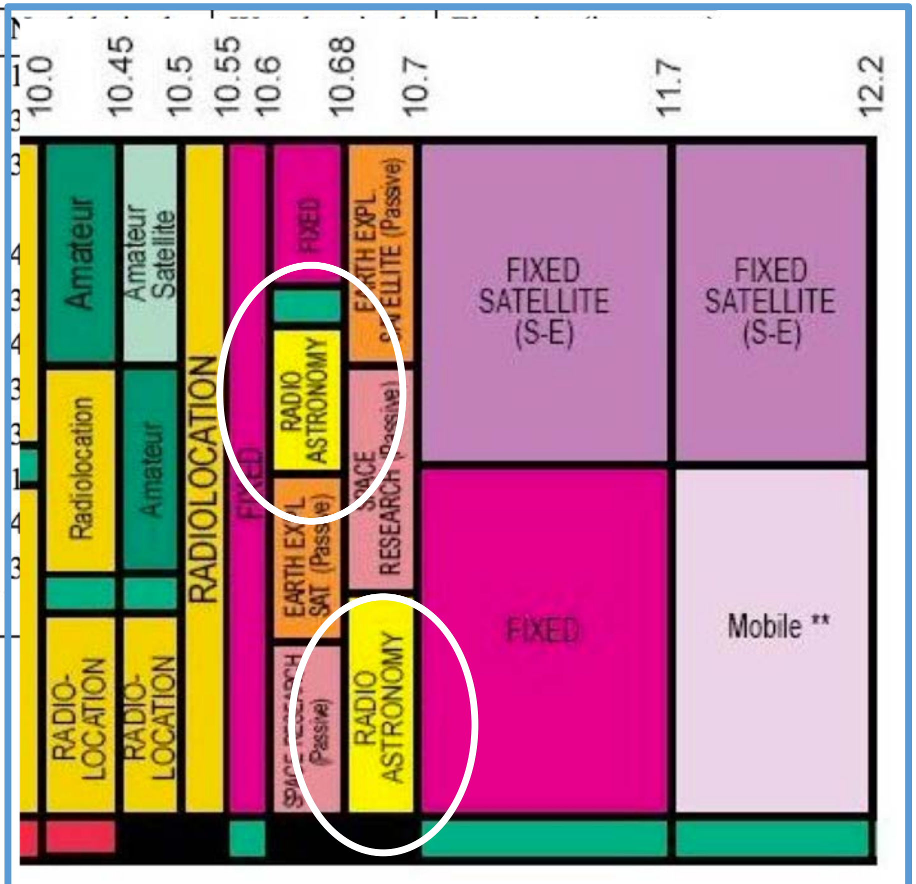
https://science.nrao.edu/facilities/vla/observing/RFI

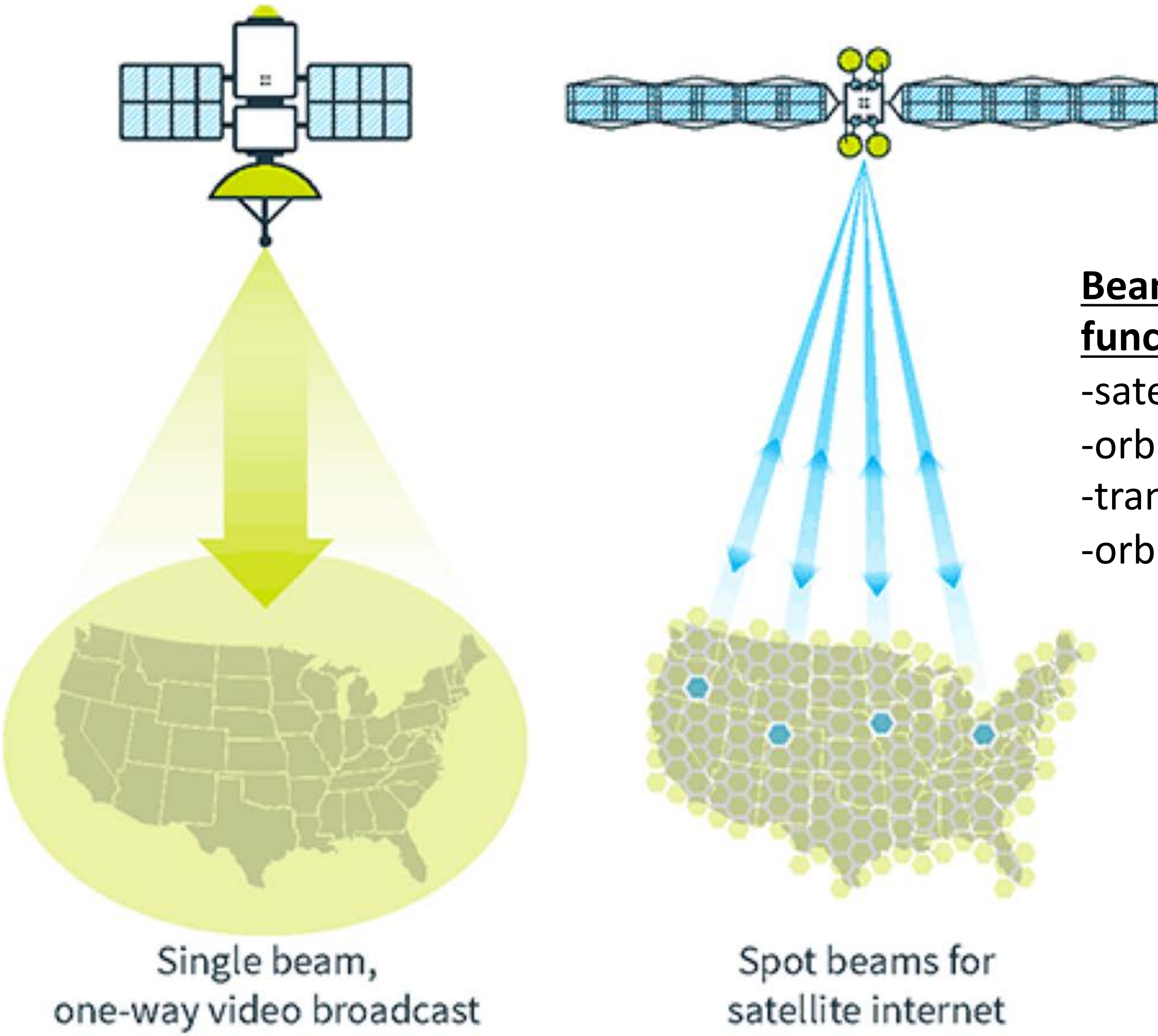
Radio Astronomy protections at 10.6 GHz

US131 In the band 10.7-11.7 GHz, non-geostationary satellite orbit licensees in the fixed-satellite service (space-to-Earth), prior to commencing operations, shall coordinate with the following radio astronomy observatories to achieve a mutually acceptable agreement regarding the protection of the radio telescope facilities operating in the band 10.6-10.7 GHz:

Observatory
Arecibo Observatory, PR....................
Green Bank Telescope (GBT), WV..............
Very Large Array (VLA), Socorro, NM.........
Very Long Baseline Array (VLBA) Stations:
Brewster, WA................................
Fort Davis, TX..............................
Hancock, NH.................................
Kitt Peak, AZ...............................
Los Alamos, NM..............................
Mauna Kea, HI...............................
North Liberty, IA...........................
Owens Valley, CA............................

United States (US) Footnotes





<u>Beam footprint is a function of:</u>

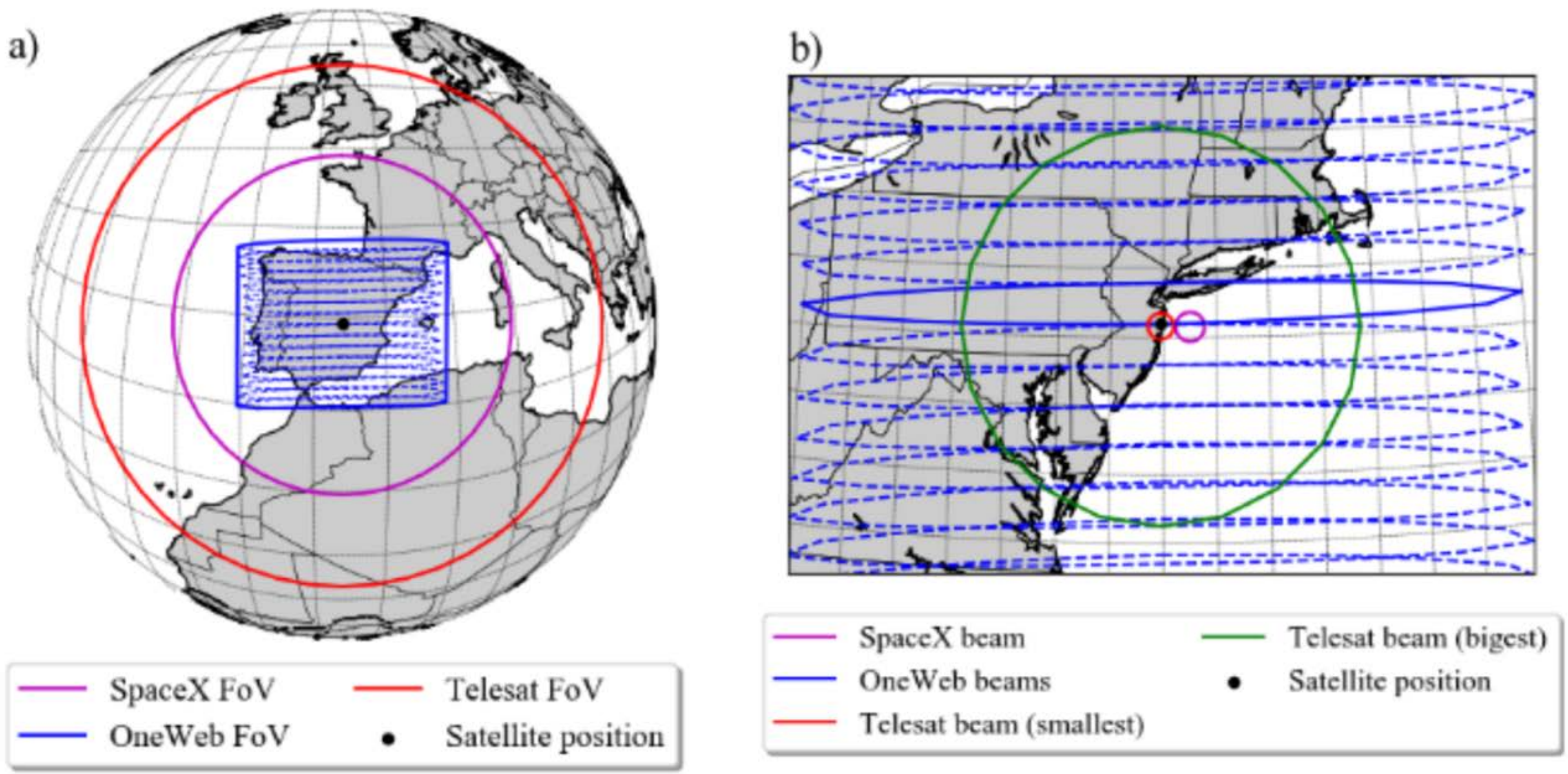
-satellite design

-orbit altitude

-transmitting frequency

-orbital parameters

https://corpblog.viasat.com/how-it-works-the-technology-behind-satellite-internet/



- Figures from presentation by Portillo et al.; see http://www.mit.edu/~portillo/files/Comparison-LEO-IAC-2018-slides.pdf

Data loss is expected even in protected band

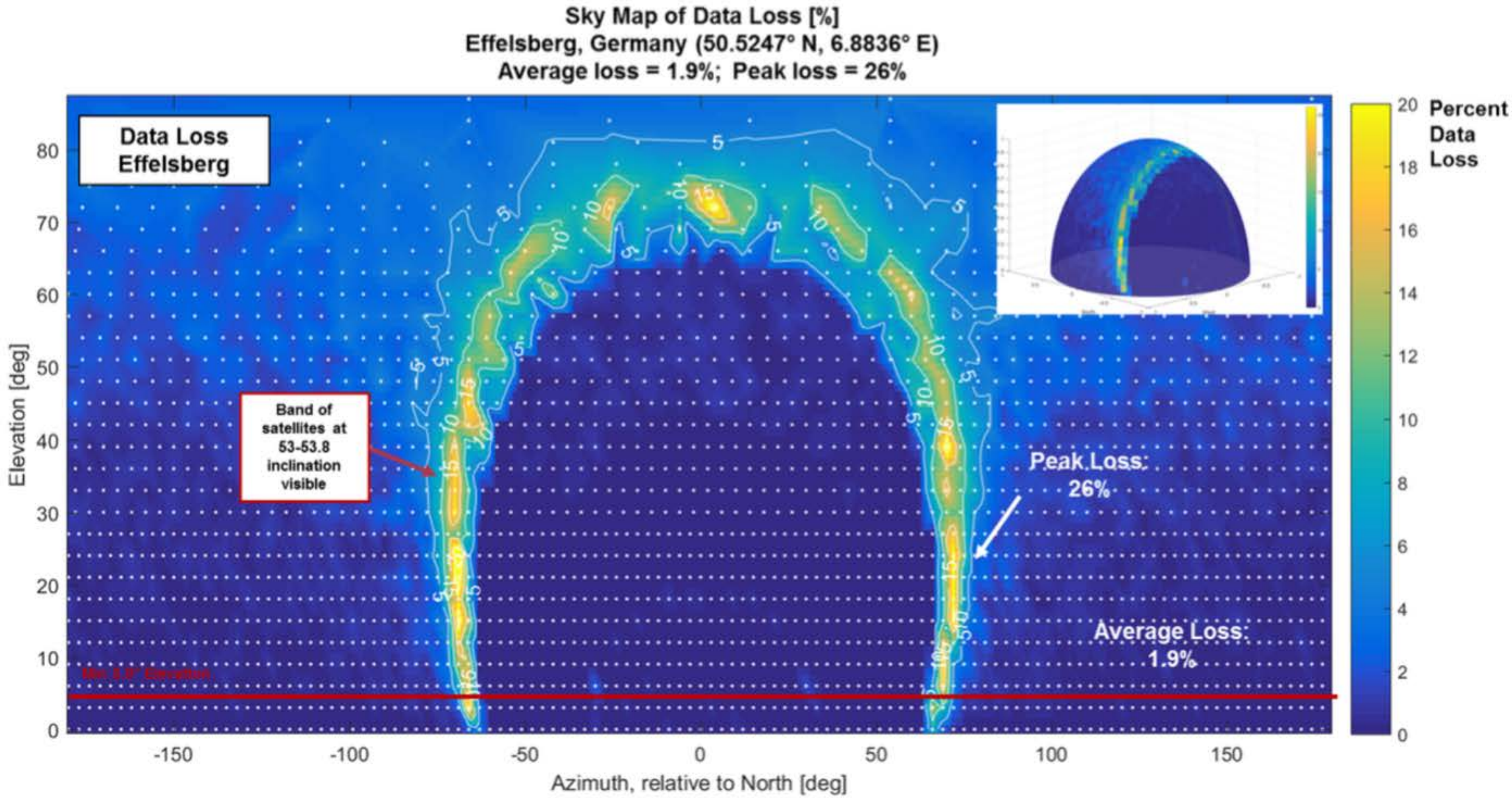
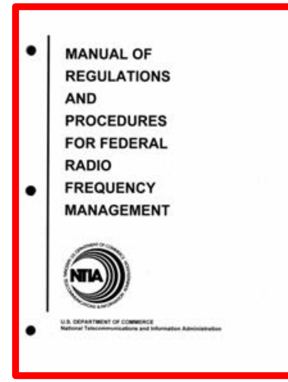


Figure 64: Effelsberg – Sky Map of Percent Data Loss

NSF ESM Unit Activities

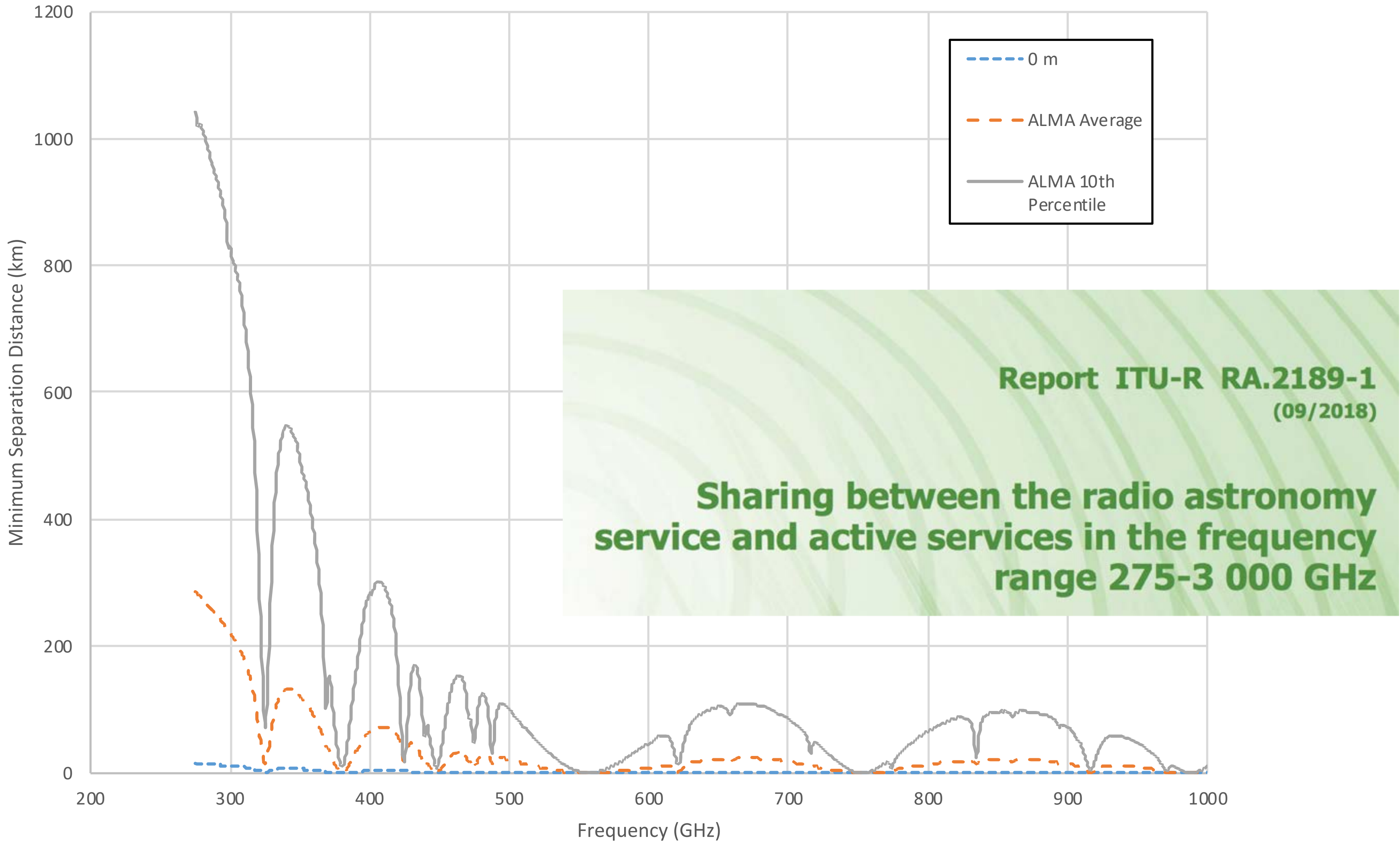
- **Represent NSF Domestically** –to the National Telecommunications and Information Administration (NTIA); coordinate with the FCC, commercial companies, and other Federal Agencies



- **Represent NSF Internationally** – serve on U.S. Delegations to the international preparatory meetings leading to World Radiocommunication Conference

Agenda Item 1.15: >275 GHz

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



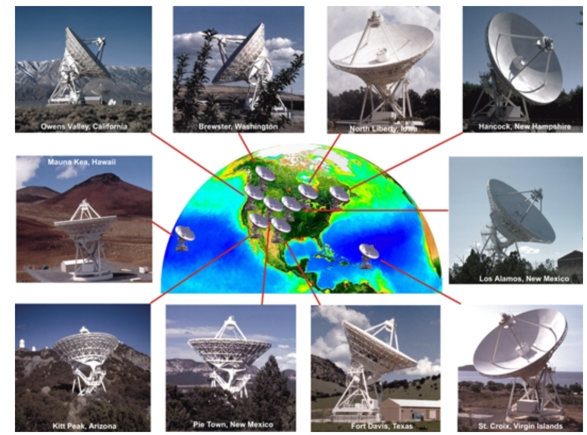
Updated Fall 2018

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

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:

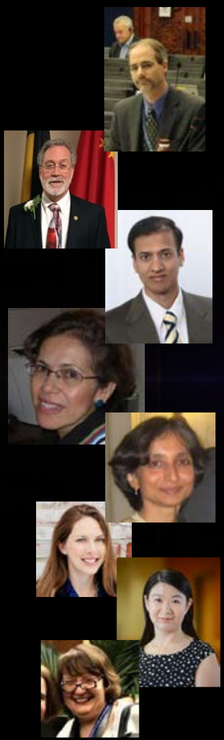
- Geosciences
- Biological Sciences
- Computer and Information Science and Engineering
- Engineering
- Mathematical and Physical Sciences

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

Usage: Passive and Active

NSF ESM Coordination Group

- *Formed March 2018*
- *Includes NSF input across all Directorates*



Jonathan Williams	*Chair, MPS/AST, ESM Unit*
Patrick Smith	*GEO/OPP*
Thyaga Nandagopal	*CISE/CCF*
Carmiña Londoño	*ENG/ECCS*
Mangala Sharma	*GEO/AGS*
Ashley Zauderer	*MPS/AST, ESM Unit*
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Also Contributing:

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Jenshan Lin (ENG)

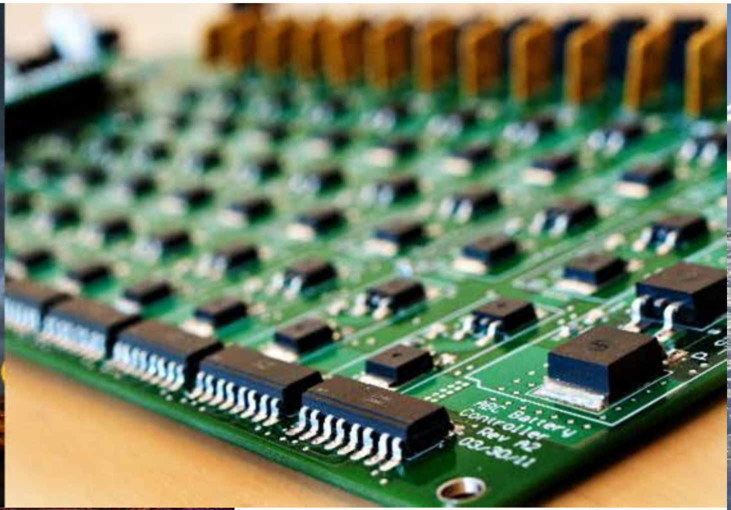
Alex Sprintson (CISE)

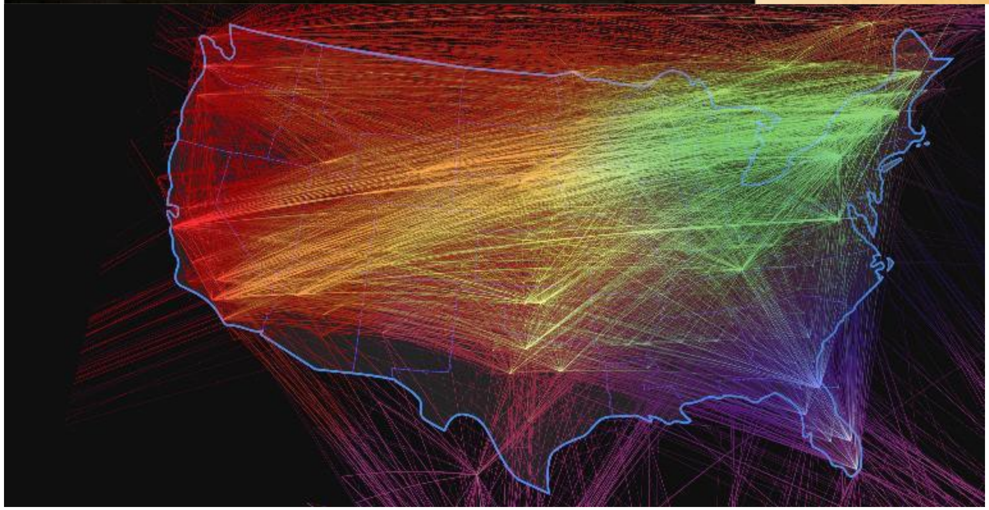
Mohammod Ali (ENG)

Larry Goldberg (CISE)

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

NSF's Spectrum Innovation Initiative

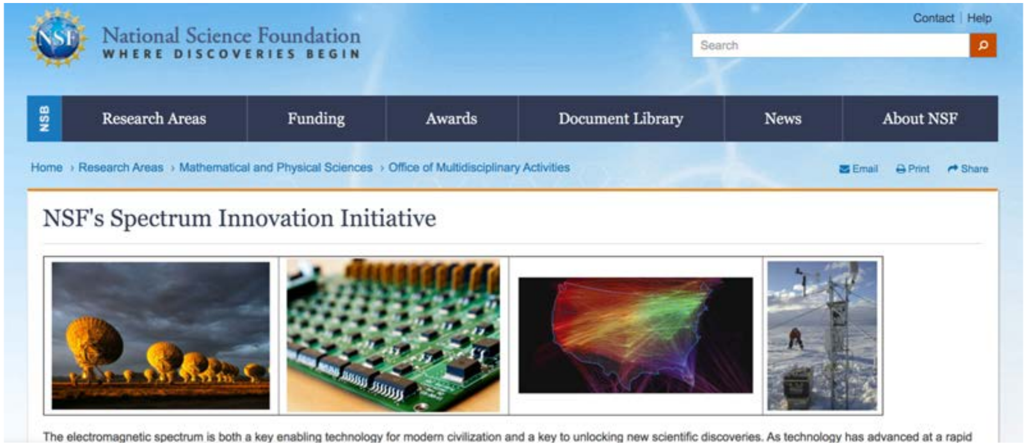





Cross-Directorate, housed in MPS Office of Multidisciplinary Affairs (OMA)
via the stewardship model under leadership of Sean L. Jones, AD, MPS

Spectrum Innovation Initiative

- National Radio Dynamic Zones
- National Center for Wireless Spectrum Research
- Research Integrative Activities
- Education and Workforce Development



https://nsf.gov/mps/oma/spectrum_innovation_initiative.jsp

NSF Goals: Innovate and Secure

- **Keep protected scientific <u>allocations</u> 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 <u>increase</u> spectrum availability, esp. in strategic geographic locations**
  - *Research in advanced wireless, RFI excision techniques and receiver technology*
  - *"National Radio Dynamic Zone" for enhanced ESM geographical protections*

- **<u>Coordination</u> – internal at NSF and external stakeholders**
  - *Spectrum sharing*
  - *Costs must be considered; resources are investment in the future*

Conclusions

Physics and Astronomy Scientific Communities need to be aware of the spectrum environment and regulations:

- **New technical concepts and scientific cases should demonstrate awareness of spectrum challenges**
- **R&D is needed**
  - **receiver design**
  - **RFI mitigation techniques**
  - **Dynamic quiet zones**
- **Regulatory change takes time (e.g. for new allocations)**

Questions and Comments

esm@nsf.gov

Credit: Sophia Dagnello, NRAO/AUI/NSF; NASA, STScI

Thank you!