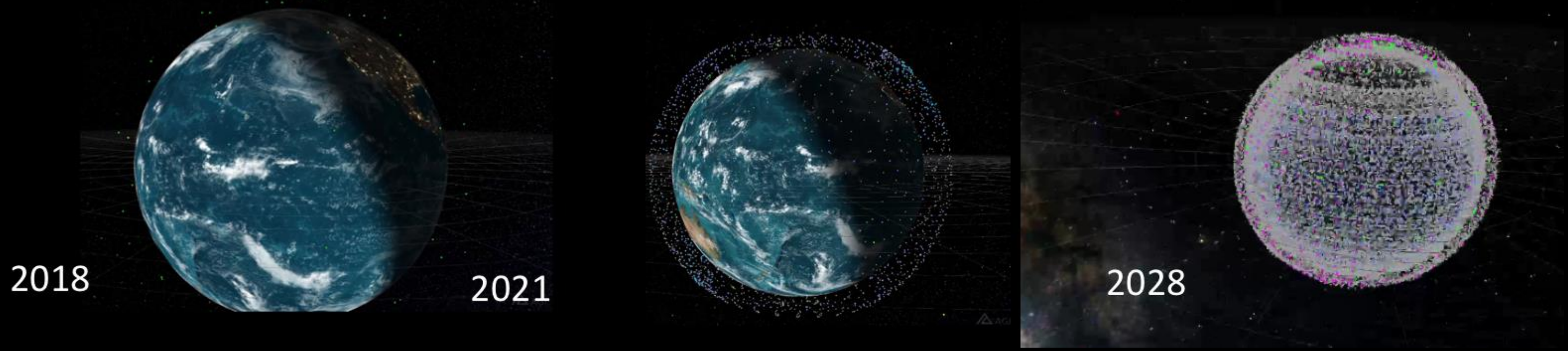
Satellite Constellations Update:
Impacts to U.S. Ground-based Astronomical Facilities

AAAC

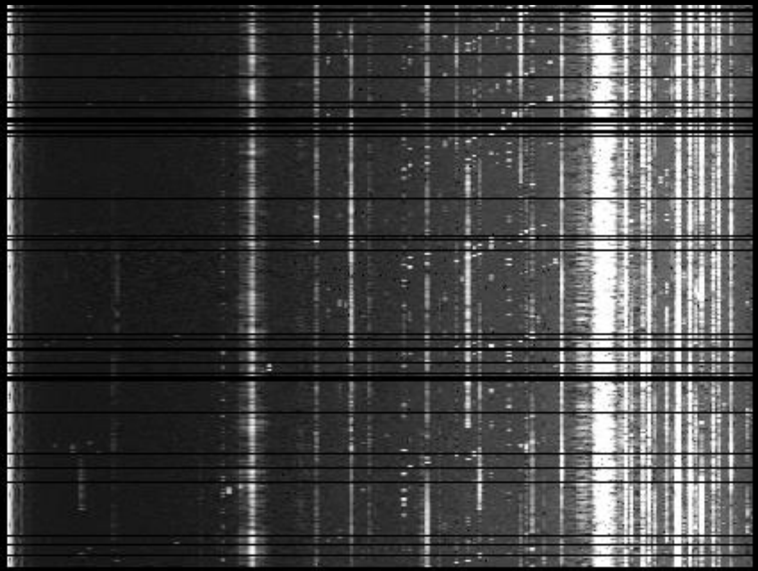
September 27, 2022

Ashley VanderLey
Senior Advisor for Facilities
Division of Astronomical Sciences

Key issue: Constellations of satellites in low Earth orbit – proposed population exceeding 50,000 in coming decade



optical interference



radio interference

Siting telescopes in remote locations is no longer sufficient for protection.

Images: Screen shots from animations based on applications filed with the ITU and the U.S. FCC. Credit: SSC.

Access to Wireless Communications

- Broadband internet and reliable mobile access is ***critical for equity***
  - GSMA reports ~66% of the world's population has a mobile
  - Internet/social media – a great avenue for collaboration, sharing science broadly, participation in discovery
- Increase in usage of wireless devices presents a challenge to sensitive astronomical research which requires ***dark and quiet skies***
  - radio observations
  - optical/infrared

Broadband plans should consider entire ecosystem

Credit: Christina S. Murrey, College of Education, University of Texas at Austin

SPACEX

SpaceX Falcon 9 over the Jersey Shore Saturday night, Sept. 24, 2022. (Credit: Astronomy photographer Chris Bakley; nj.com)

SpaceX Falcon 9 Launch
September 24, 2022

Visible Across the
North Central PA Region

CAPE CANAVERAL

Northcentral PA .com


AST
SpaceMobile
Globe

NSF activities related to new satellite constellations

Optical and Infrared

- NSF-funded workshops: NOIRLab + AAS
  - SATCON1&2 – July 2020, 2021
- **Optical laser guide star coordination**
- NSF's NOIRLab working closely with satellite operators / **co-founder of IAU CPS**
- NSF/Satellite Industry Association joint technical presentation for the USA to UN Committee on the Peaceful Uses of Outer Space (COPUOS) / **Agenda Item at COPUOS STSC 2022**

Radio Frequency

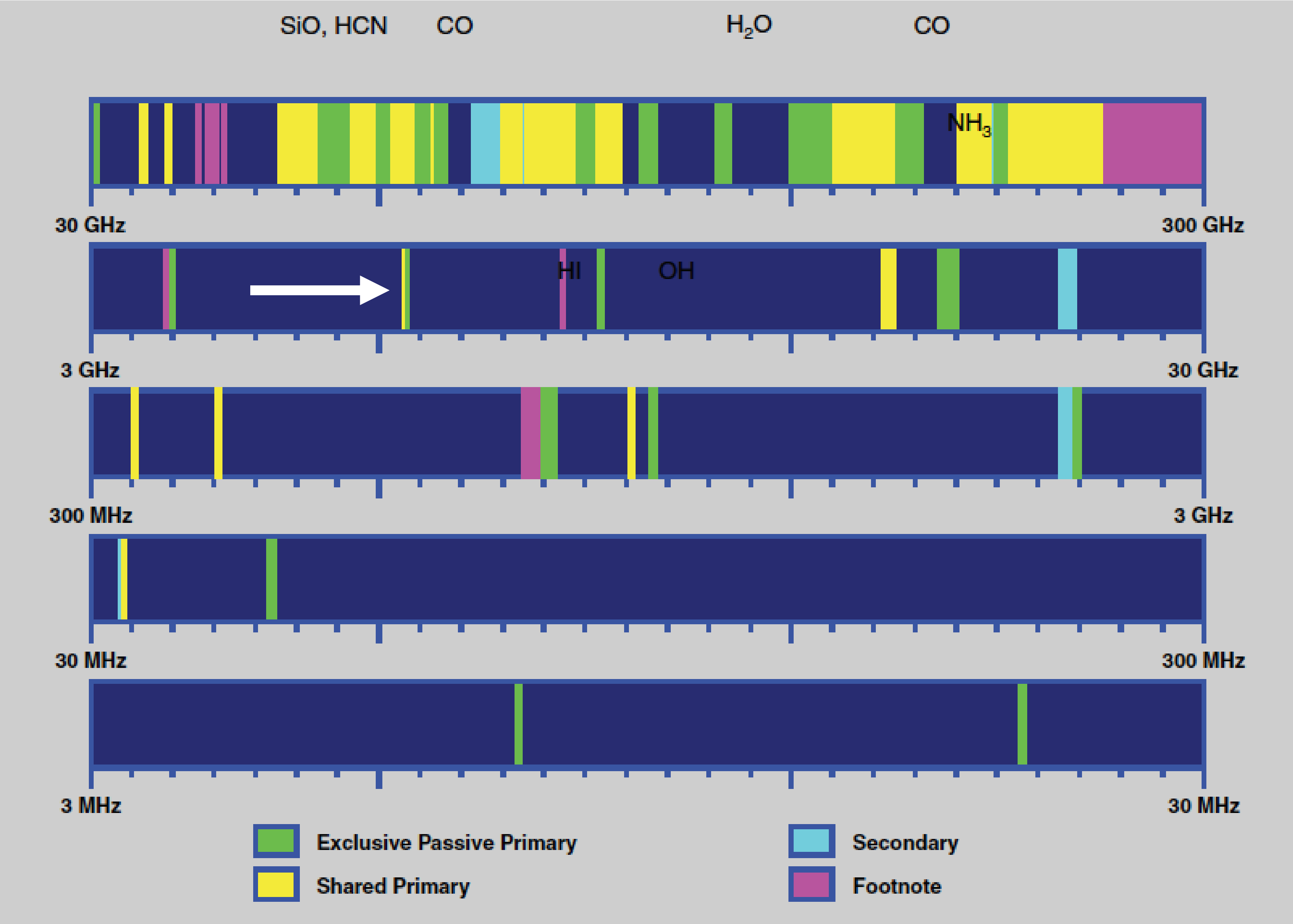
- **Spectrum coordination agreements**
  - SpaceX (signed 2019, updated 2022)
    - **Being updated** (new & modified FCC license)
  - **Other US-licensed operators to come**
- R&D on satellite interference mitigation/coexistence
  - **Spectrum Innovation Initiative** (e.g., NRDZ funding at NRAO) / MOA with NTIA and FCC
  - **SWIFT program (e.g., SWIFT-SAT)**

- NSF-supported JASON study (July 2021)
  - Optical impacts on NSF/Rubin Observatory
  - Mitigation opportunities
  - Good practices for satellite vendors
- Analytic study of radio interference, including
  - Single-dish telescopes
  - Interferometers
  - Cosmic Microwave Background-Stage 4

SATCON1: https://aas.org/satellite-constellations-1-workshop-report SATCON2: https://aas.org/satellite-constellations-2-workshop
NSF/SIA briefing to UN COPUOS: https://www.unoosa.org/oosa/en/ourwork/copuos/technical-presentations.html
JASON study: https://www.nsf.gov/news/special_reports/jasonreportconstellations/

2022 Updates

- Coordination Agreements (satisfying US131)
  - SpaceX (2019, updated 2022); OneWeb and others (in process)
  - New concerning very large and bright satellites / coordination not required
- COPUOS STSC 2022: single issue agenda item for 2023
- Research awards: SWIFT-SAT (22-571) and SII-NRDZ (22-579)
- Laser Optical Guide Star Coordination
- NIST workshop (Summer 2022): Commercial Space and Astronomy Partnering in Best Practices and Guidelines for Brightness Mitigation
- Office of Space Commerce: Open Architecture Data Repository
- Support to FFRDCs (NRAO, NOIRLab with IAU CPS)



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

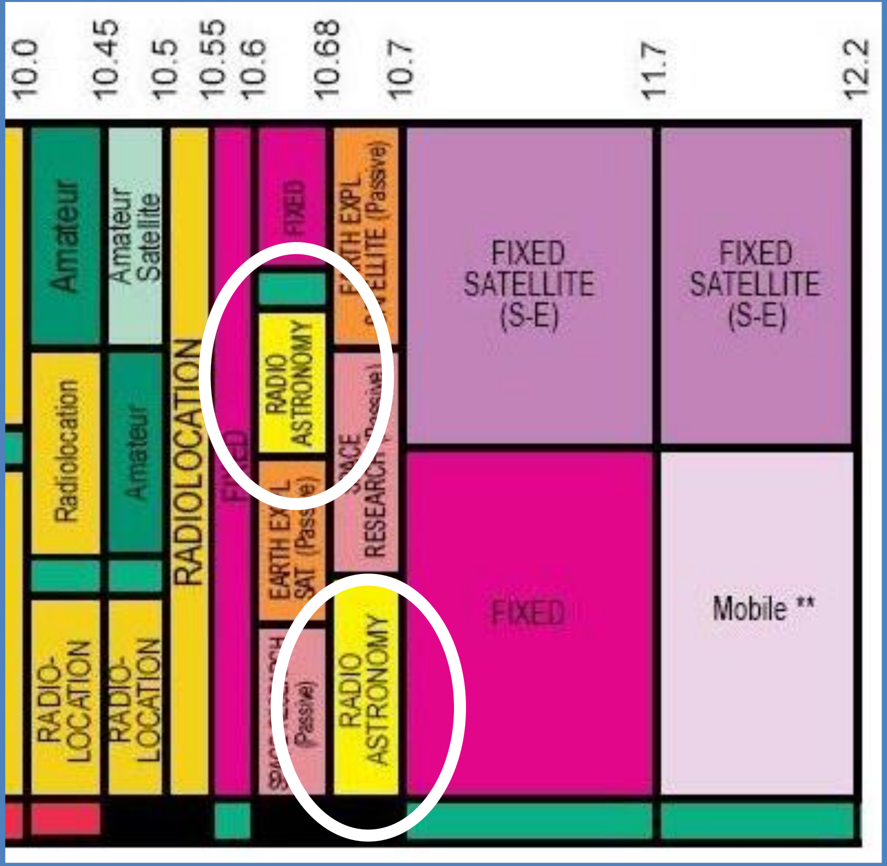
Radio Astronomy Frequency Allocations in the United States

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



Statement on NSF and SpaceX Radio Spectrum Coordination Agreement

June 4, 2019

In late May, SpaceX launched its first 60 Starlink satellites into orbit. SpaceX plans to launch a much larger satellite … into low-Earth orbit with the goal of providing terrestrial internet service. The operation of these satellites … neighbor some radio astronomy assets in the 10.6 - 10.7 GHz band. SpaceX coordinated with NS… observatories regarding potential interference from their use of the radio spectrum. After … finalized a coordination agreement to ensure the company's Starlink satellite … astronomy protection standards, limiting interference in this radio astronomy ban… …inue to explore methods to further protect radio astronomy. Together we ar… …rship between commercial and public endeavors that allows important scien… …communication.

-NSF-

Required Coordination Agreement is very helpful to begin a dialogue

Data loss is expected even in protected band

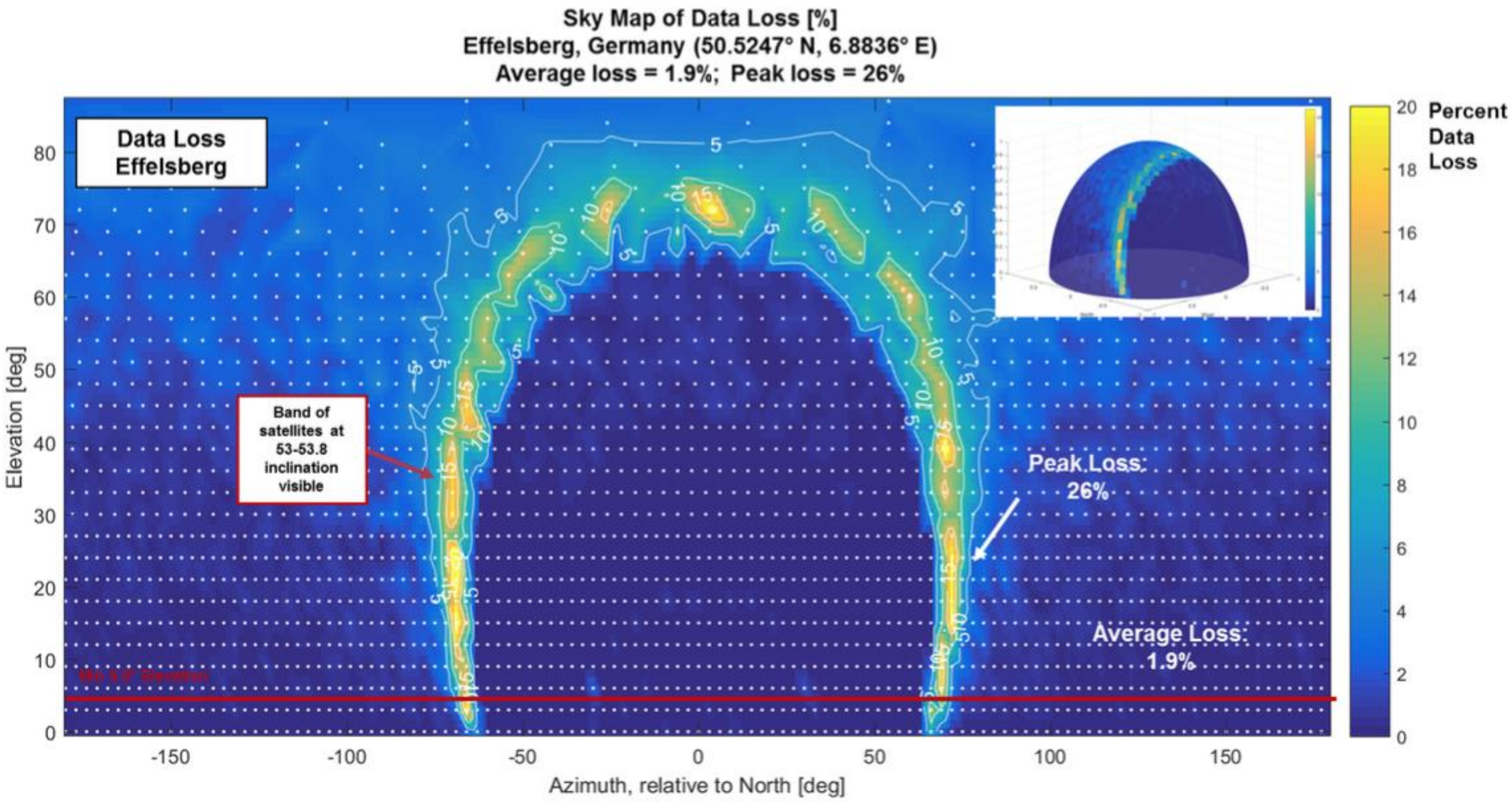


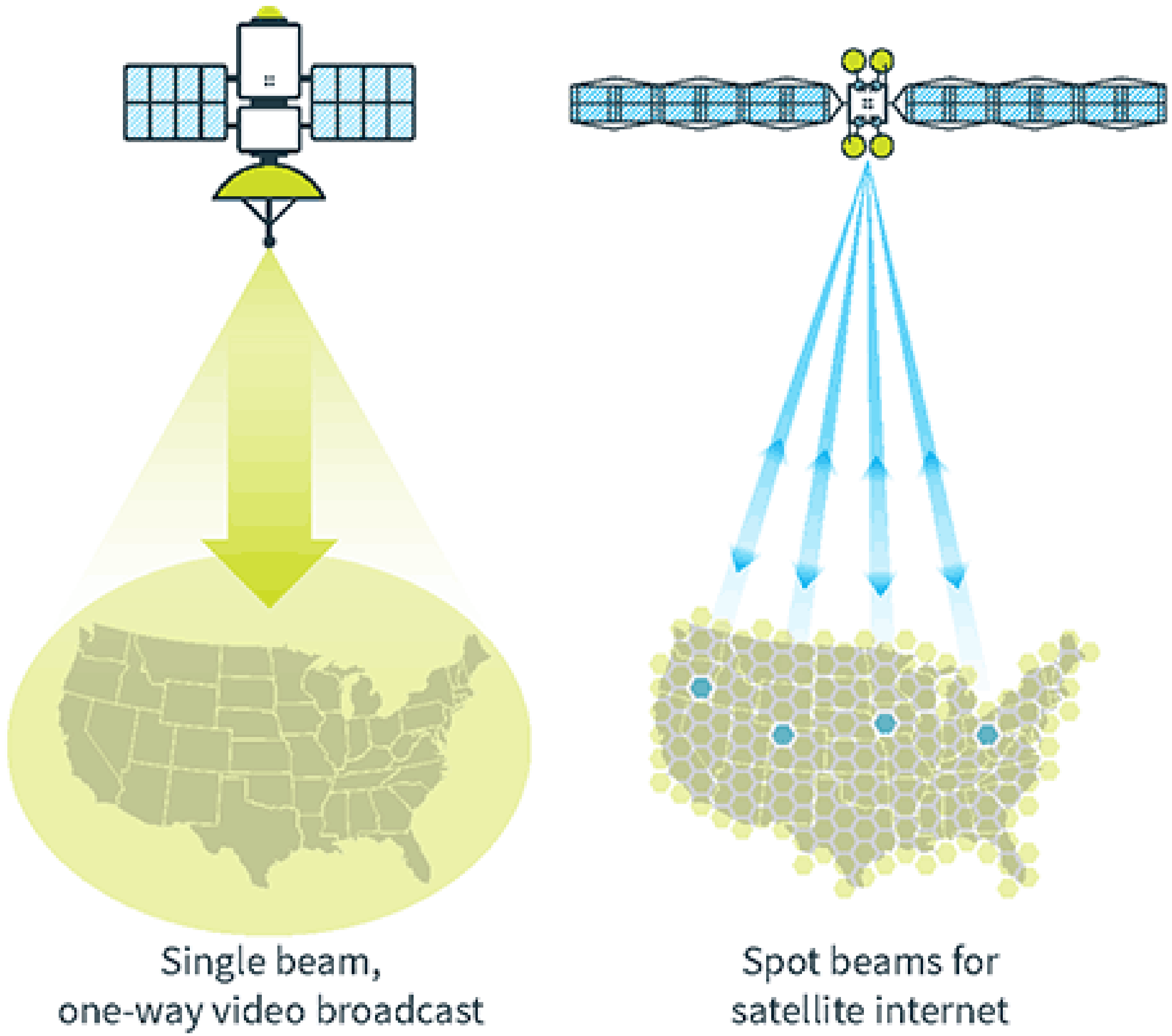
Figure 64: Effelsberg – Sky Map of Percent Data Loss

Some Characteristics of NGSO Systems to Consider:

-type of orbit, LEO, MEO, HEO etc.;
-orbit altitude;
-orbit inclination (to the equatorial plane);
-number of planes;
-number of satellites per plane;
-satellite size;
-satellite shape and design;
-aggregate impact of multiple NGS systems;
-reflectivity of material;
-whether satellite can re-orient real-time;
-earth station location and minimum elevation.

Modified from SE40 ECC report 271

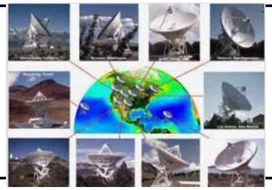
Mitigation Opportunities



<u>Beam footprint is a function of:</u>
-satellite design
-orbit altitude
-transmitting frequency
-orbital parameters

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

Radio Astronomy Existing Protections

Site	Type of protection	Summary	Shortfall	Map
Green Bank Observatory **(in National Radio Quiet Zone)**	Geographic (47 CFR § 1.924) US113 US131 US161 US385 Allocations	Required coordination for all land and mobile transmitters	Limited protection from airborne transmitters including satellites	
Very Large Array	US113 US117 US131 US161 US385 Allocations	Controls observatory property only; limited protections at some frequencies	Limited geographic protections via footnote in certain bands	
Arecibo Observatory **(in Puerto Rico Coordination Zone)**	Geographic (47 CFR § 95.42) US113 US131 US385 Allocations	Fixed/base stations in frequencies below 15 GHz must coordinate, some coordination with air traffic	Limited protection from airborne transmitters including satellites	
Very Long Baseline Array (10 sites)	US131 US161 US385 Allocations	Controls observatory property only; limited protections at some frequencies	Limited geographic protections via footnote in certain bands.	

Required Coordination by Geographic Location

- National Radio Quiet Zone
- Puerto Rico Coordination Zone

Coordination by Frequency

- 10.6 – 10.7 GHz (US131)
- 2655 – 2690 MHz (urged to; US385)
- 81 – 86 GHz, 92 – 94 GHz, 94.1 – 95 GHz (US161)

Every "practicable" effort

- 4825 - 4835 MHz (US113)
- 14.47 – 14.5 GHz (US113)
- 1350 – 1400 MHz(US385)
- 4950 – 4990 MHz (US385)

How do we do radio astronomy for the next decade and beyond?

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

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: Green Bank Observatory

Credit: NRAO

NSF 2022 Solicitation overview (22-579)

Solicitation text and other information

- Links at SII home page: https://nsf.gov/mps/oma/spectrum_innovation_initiative.jsp

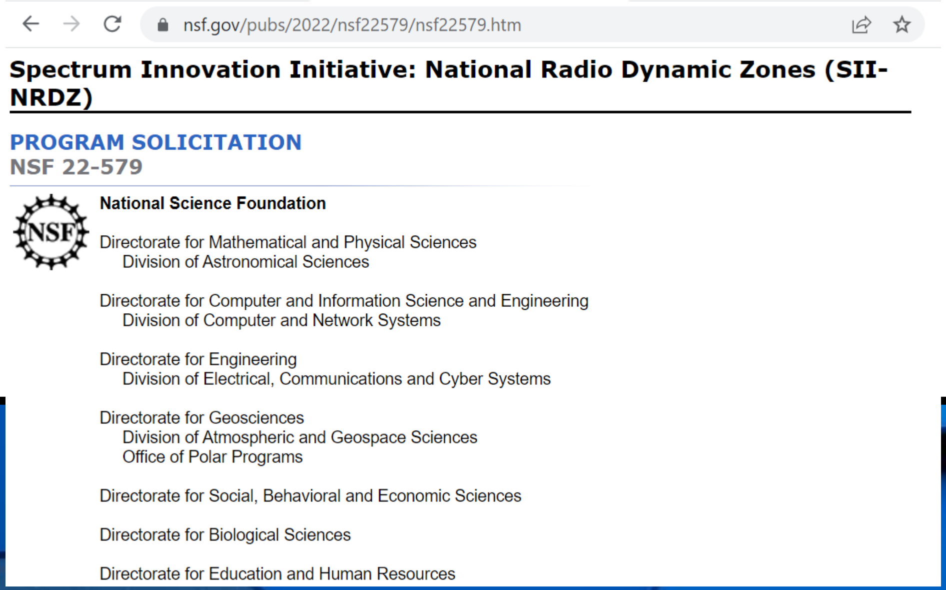
Anticipate 8-12 awards

- Approximately 6-10 grants for SII-NRDZ Studies, up to $2,000,000
- Approximately 2 cooperative agreements for Engineering and Execution Lead Phase 1, up to $500,000

Total anticipated funding: $10,000,000

Proposals due June 21, 2022

Projects launched by October 1, 2022



nsf.gov/pubs/2022/nsf22579/nsf22579.htm

Spectrum Innovation Initiative: National Radio Dynamic Zones (SII-NRDZ)

PROGRAM SOLICITATION
NSF 22-579

National Science Foundation

Directorate for Mathematical and Physical Sciences
Division of Astronomical Sciences

Directorate for Computer and Information Science and Engineering
Division of Computer and Network Systems

Directorate for Engineering
Division of Electrical, Communications and Cyber Systems

Directorate for Geosciences
Division of Atmospheric and Geospace Sciences
Office of Polar Programs

Directorate for Social, Behavioral and Economic Sciences

Directorate for Biological Sciences

Directorate for Education and Human Resources

ITU-R WP 7D (Radio Astronomy) US inputs

Number	Document Title
USWP7D_22_23-14_CMB	Updates to Working Document Toward a Preliminary Draft New Report ITU-R RA.CMB: Technical and Operational Characteristics of Broadband, Background-Limited **Bolometers Operating in the mm Wave Regime**
USWP7D_22_23-15_SZM_Q	Updates to Preliminary Draft New Question ITU-R XXX/7: **Radio astronomy in the shielded zone of the Moon**
USWP7D_22_23-18_350MHz	Updates to Preliminary Draft New Report ITU-R RA.[350MHz]: Technical and operational characteristics of **radio astronomy systems operating below 350 MHz**
USWP7D_22_23-19_3-4mm	Updates to Working Document towards a Preliminary Draft New Report ITU-R RA.[67-116GHz]: Technical and operational characteristics of radio astronomy systems and sharing feasibility in the **3-4 mm band (67-116 GHz)**
USWP7D_22_23-20_EHT	Updates to the Preliminary Draft New Report: Technical and Operational Characteristics of **Widely-Distributed Array Systems Operating Above 200 GHz**

Radio Astronomy Takeaways

-Updated geographic protections would help (NRQZ, NRDZ)

-Domestic: Required coordination helps to start technical conversations
-International: Participation in ITU-R critical

--Avoidance of main beam illumination of key radio astronomy sites is helpful, when practicable (depends on frequency, footprint)

-Technical solutions to be explored: frequency/time duplexing, minimizing sidelobes, etc.

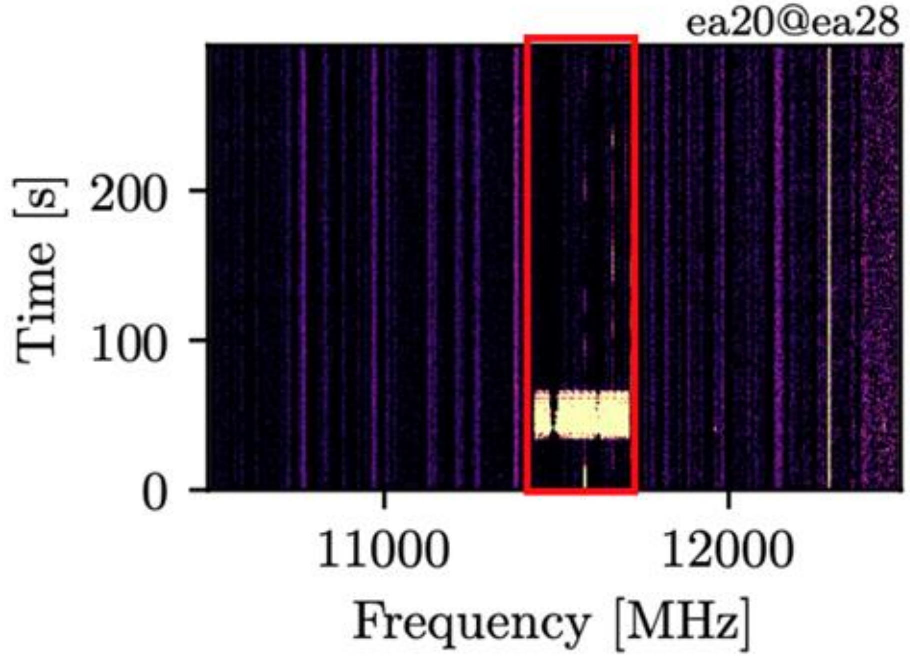
Coordinated StarLink User Terminal Testing at NRAO/AUI Sites

as presented at URSI 2022

Chris De Pree (NRAO)

Collaborators:
Albulet, Mihai (SpaceX)
Armentrout, Will (GBO)
Baummer, Robert (SpaceX)
Beasley, Anthony (NRAO)
Brisken, Walter (NRAO)
Knox, Doug (SpaceX)
Minter, Toney (GBO)
Rau, Urvashi (NRAO)
Selina, Rob (NRAO)
Svoboda, Brian (NRAO)

The Tests and Results



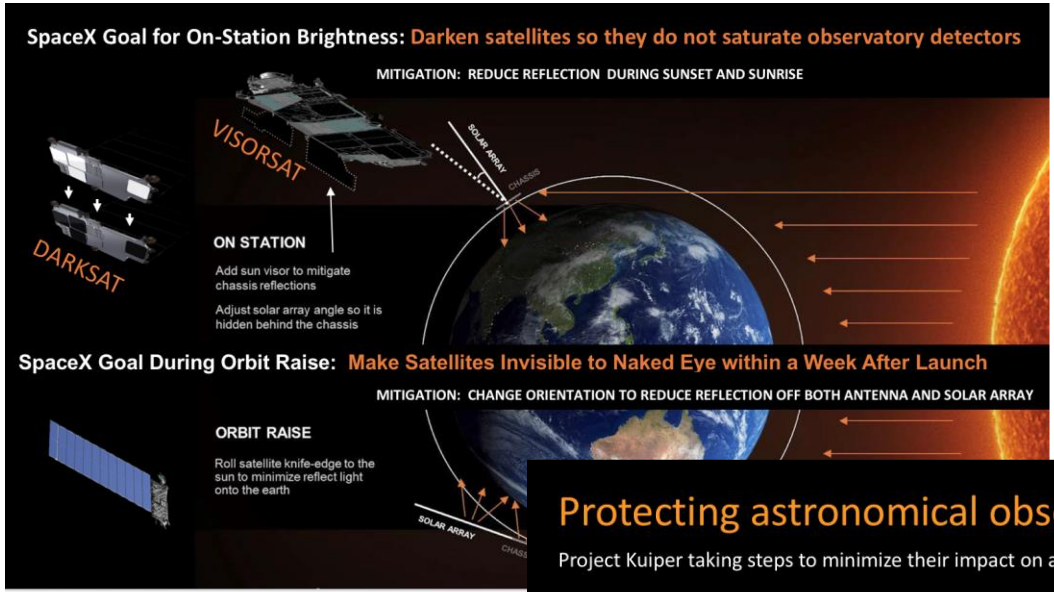
- General Experimental Design/Setup
- VLA, Phase I (September 2021)
- VLA, Phase II (October 2021)
- GBT (February 2022)
- VLA, Alamo Pilot Study (Ongoing, started March 2022)
- Next steps, Frequency Multiplexing (Ongoing, started May 2022)

COPUOS STSC 2022

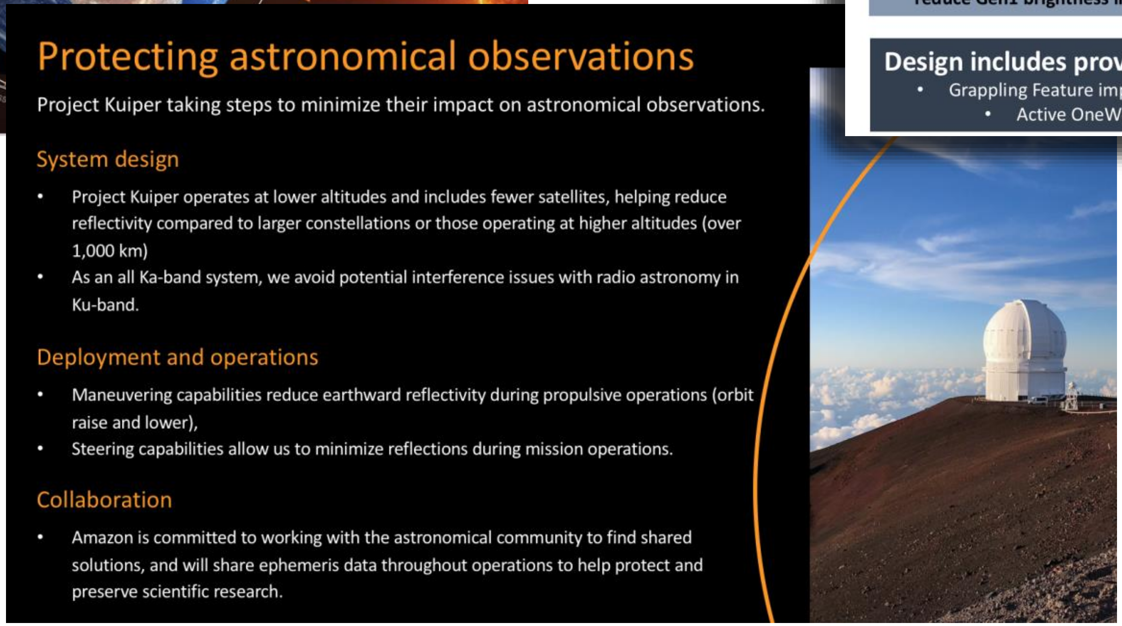
"The U.S. delegation encourages ongoing efforts of all interested nations, satellite operators, the scientific community, and others ***to evaluate both the extent of the challenge and means to address them*** with the new generation of large constellations of satellites. ***We endorse the set of best practice guidelines produced by the Industry Working Group and their voluntary inclusion into satellite design and development. We also endorse the recommendations on the many steps astronomers can take to mitigate the impact."***

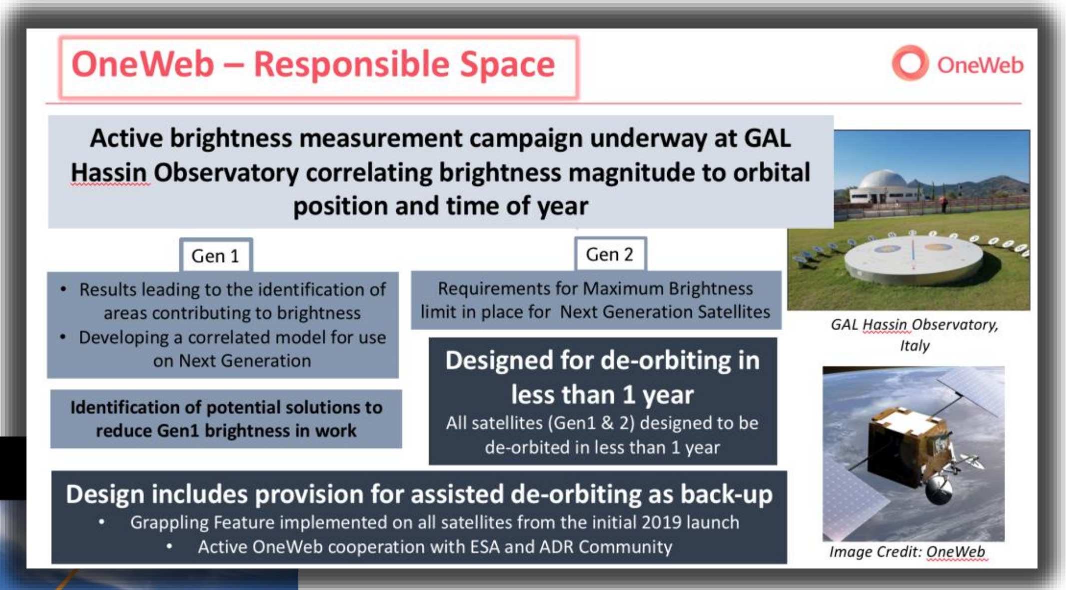
https://vienna.usmission.gov/2022-copuos-stsc-dark-and-quiet-skies/

US Examples from Industry



SpaceX Starlink





OneWeb

Amazon Kuiper

Best Practice Optical Guidance: Continued Collaboration

Satellite Operators

- Visible brightness as seen from the ground (7th magnitude)
- Orbits at ~600 km or lower
- High-accuracy locations (ephemerides)
- Orbit raising/deorbit considerations

Astronomers

- Algorithms/observations: schedulers to avoid passage through planned observational pointings
- Research on aggregate impact

See page 244: https://www.iau.org/news/announcements/detail/ann22002/

NSF's NOIRLab: co-host of CPS with SKAO

https://cps.iau.org/about/

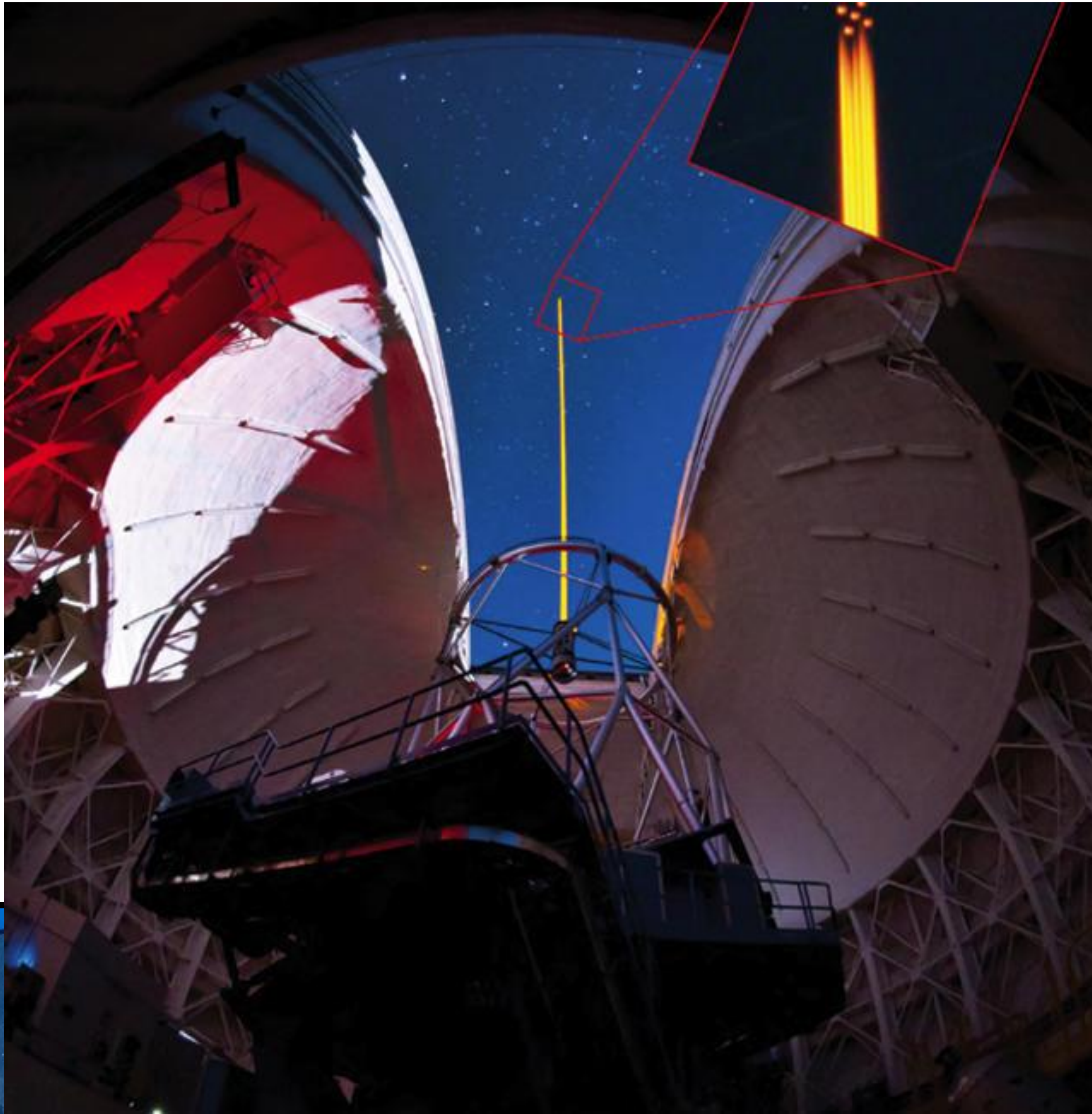
Home | About CPS | Background | SatHub | I&T Hub | CE Hub | Policy Hub | Past activities | Further Reading | Search

Our mission is to protect the dark sky

The International Astronomical Union (IAU) is deeply concerned about the increasing number of launched and planned satellite constellations in mainly low Earth orbits. The IAU embraces the principle of a dark and radio-quiet sky, not only as essential to advancing our understanding of the Universe of which we are a part, but also for the cultural heritage of all humanity and for the protection of nocturnal wildlife.

The IAU Centre for the Protection of the Dark and Quiet Sky from Satellite Constellation Interference (CPS) coordinates collaborative multidisciplinary international efforts with institutions and individuals and works across multiple geographic areas to help mitigate the negative impact of satellite constellations on ground-based optical and radio astronomy observations as well as on humanity's enjoyment of the night sky.

Gemini South laser guide stars



Continue to support R&D, coordination and communication with satellite operators and related industry, modeling and observational measurements of impact to determine and implement best mitigations

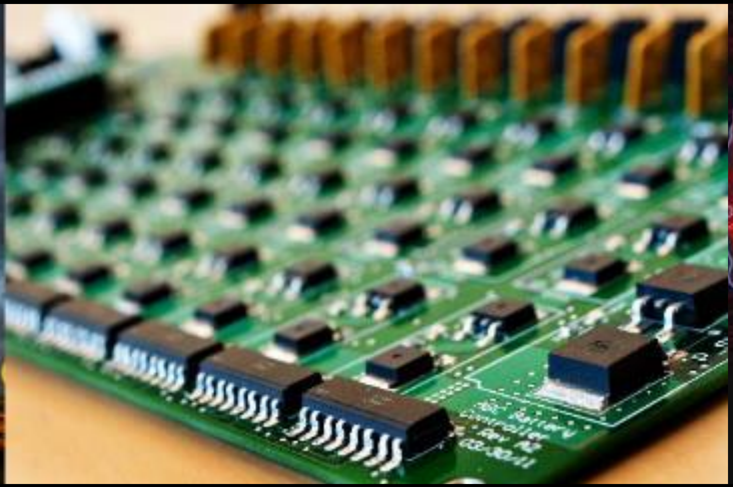
bevander@nsf.gov

NSF ESM Unit:

esm@nsf.gov

NSF’s Spectrum Innovation Initiative

Cross-Directorate, housed in MPS Office of Multidisciplinary Affairs (OMA)

I. National Radio Dynamic Zone

II. National Center for Wireless Spectrum Research

III. Spectrum Research Integrative Activities

IV. Education and Workforce Development

Partnership and Collaboration: NSF, FCC and NTIA

- Memorandum of Agreement announced Feb 2021

- FCC and NTIA staff will
  - provide subject matter expertise to NSF
  - help align NSF’s investments with U.S. spectrum regulatory and policy objectives, principles, and strategies

- Key research areas include
  - spectrum flexibility and agility
  - near real-time spectrum awareness
  - improved spectrum efficiency and effectiveness through secure and autonomous spectrum decision-making

- Establish the first National Center for Wireless Spectrum Research

FCC NEWS from the Federal Communications Commission

Media Contact:
Will Wiquist, (202) 418-0509
will.wiquist@fcc.gov

For Immediate Release

FCC JOINS FEDERAL PARTNERS IN SPECTRUM INNOVATION COOPERATION AGREEMENT

FCC, NTIA, and NSF Sign Agreement to Support NSF Spectrum Innovation Initiative

WASHINGTON, February 1, 2021—The Federal Communications Commission today announced it has entered into an agreement with the National Science Foundation and the National Telecommunications and Information Administration to support NSF’s Spectrum Innovation Initiative. NSF launched the initiative last year to seek innovative advancements in research and development on the biggest challenges facing the United States due to increased demand for electromagnetic spectrum access.

“This Memorandum of Agreement between the National Science Foundation, the National Telecommunications and Information Administration, and the Federal Communications Commission is one step toward revitalizing the interagency coordination process so that it once again is able to produce results for American consumers and the economy,” said FCC Acting Chairwoman Jessica Rosenworcel. “Better coordination between these agencies ultimately means more spectrum and n
build the 5G future.”

“Spectrum is the backbone
investments in spectrum res
Administrator. “Engaging w
impact, cutting-edge researc

“NSF’s Spectrum Innovatio
limited radio spectrum resou

National Telecommunications and Information Administration
United States Department of Commerce

Home » Blog

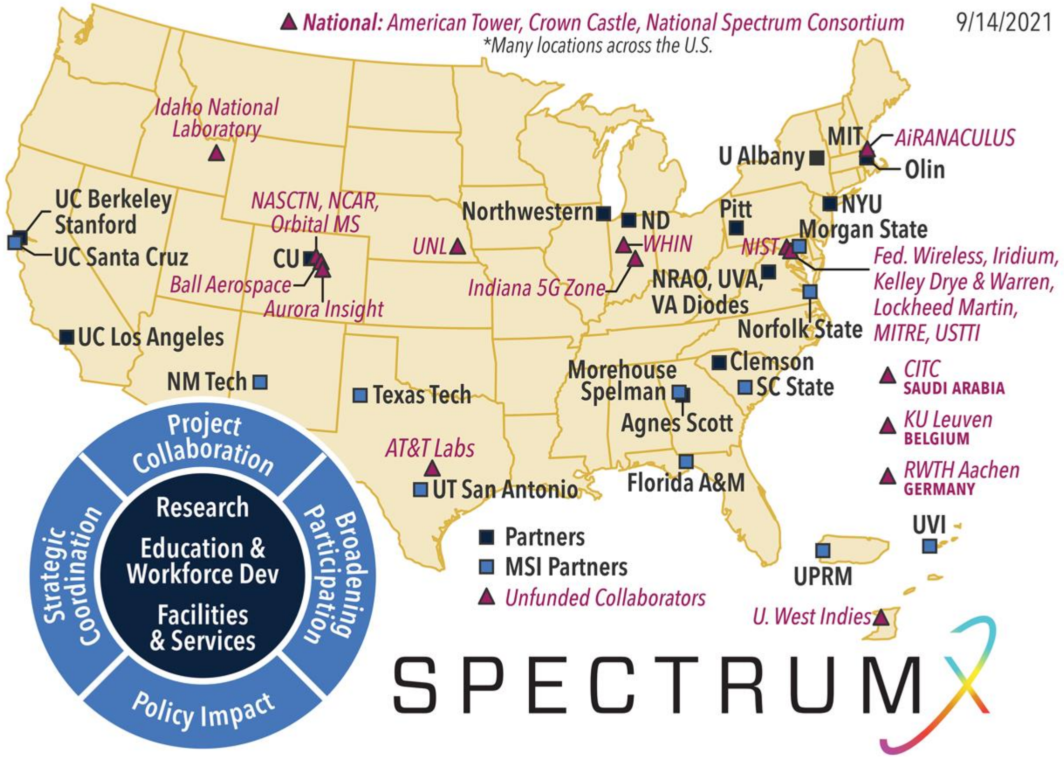
NTIA, FCC Experts Will Support the National Science Foundation’s Spectrum Innovation Initiative

March 01, 2021 by NTIA

entered into an agreement

SpectrumX: An NSF Spectrum Innovation Center (September 2021)

- The first national center focused on the transformation of radio spectrum management
  - Research, Collaboration and Workforce
- Maximize the benefits of the radio spectrum for society – Center has a strong focus on passive services, including radio astronomy
- A partnership on multiple levels
  - Created by NSF under MOA with NTIA, FCC
  - Participants: 29 institutions (12 minority serving)
    - led by University of Notre Dame
    - grow into a hub for all stakeholders
  - Expertise: convergence across field boundaries
    - communications, passive science, sensing, radio technology, policy/economics, data science, control systems
- Federal investment $25m over 5 years



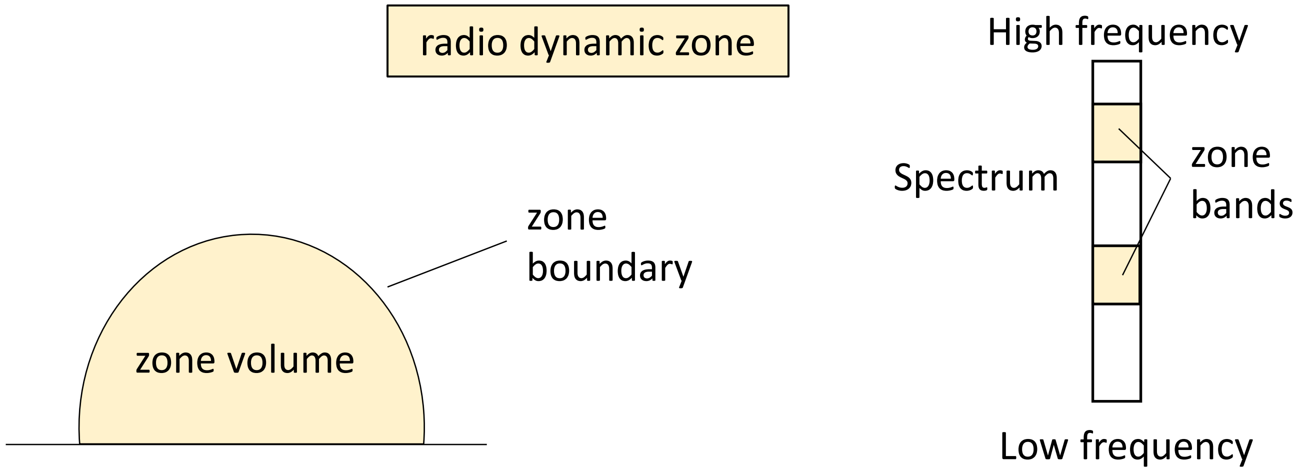
SpectrumX site: https://www.spectrumx.org

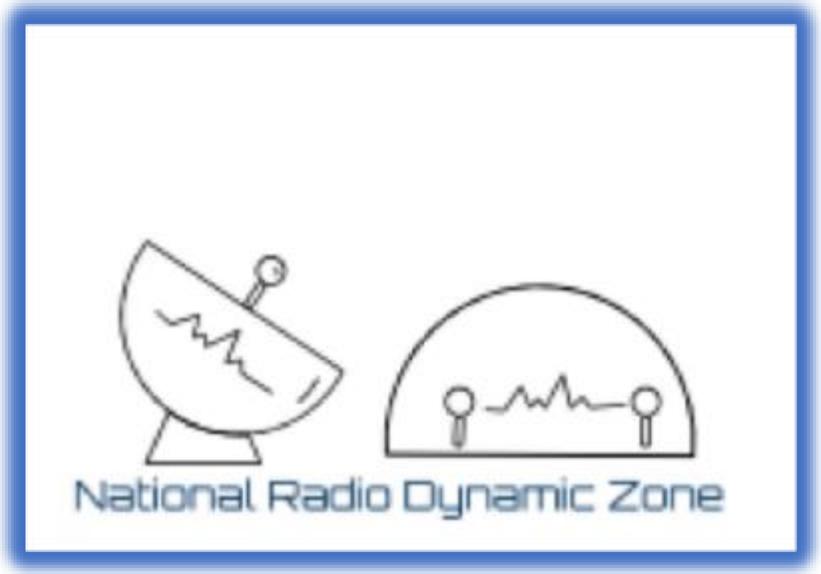
Radio dynamic zone

An area or volume

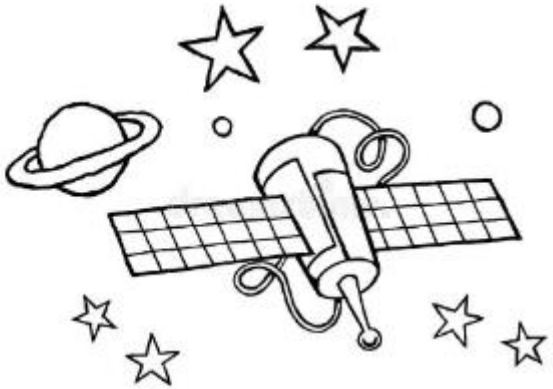
with ***automatic*** spectrum management mechanisms

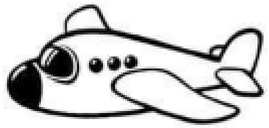
that control electromagnetic energy entering, escaping, or occupying the zone

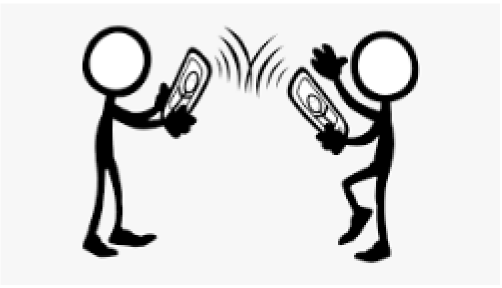


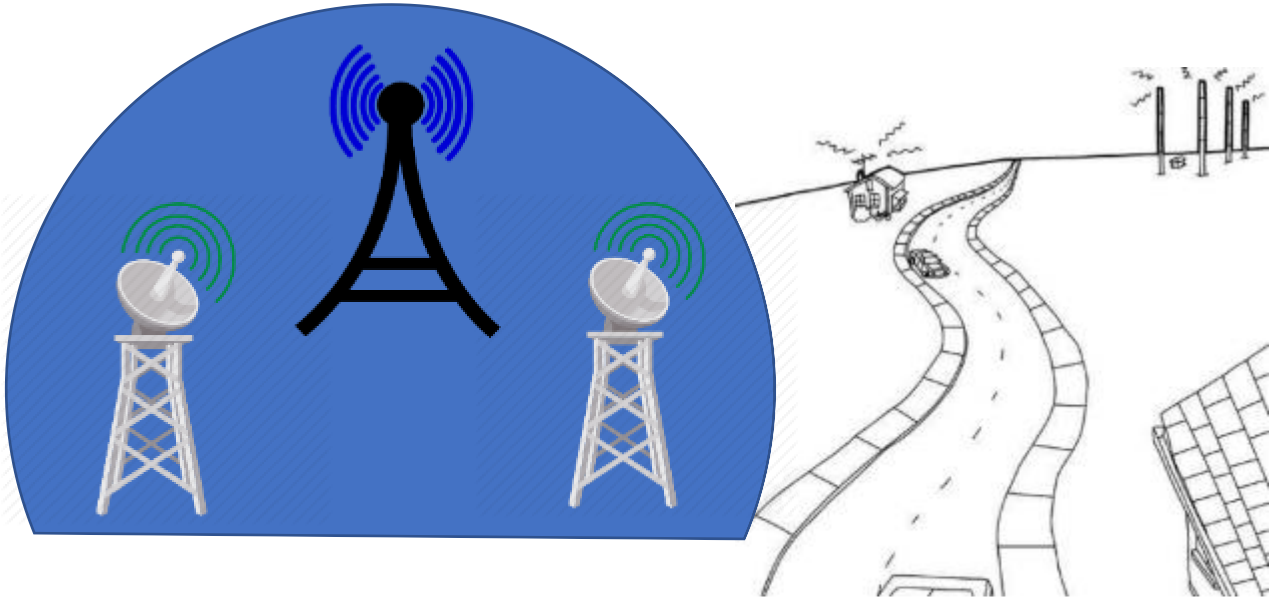


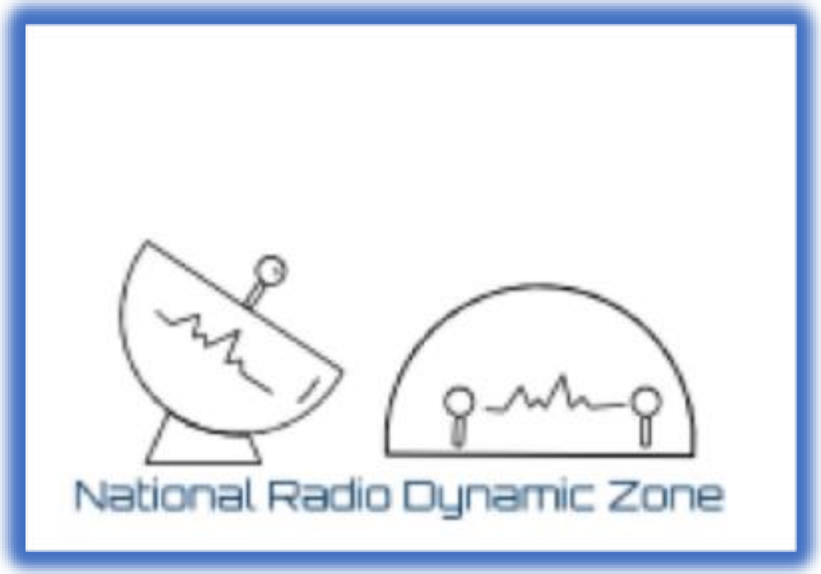
Wireless testing “in” the zone does not interfere with users of spectrum outside



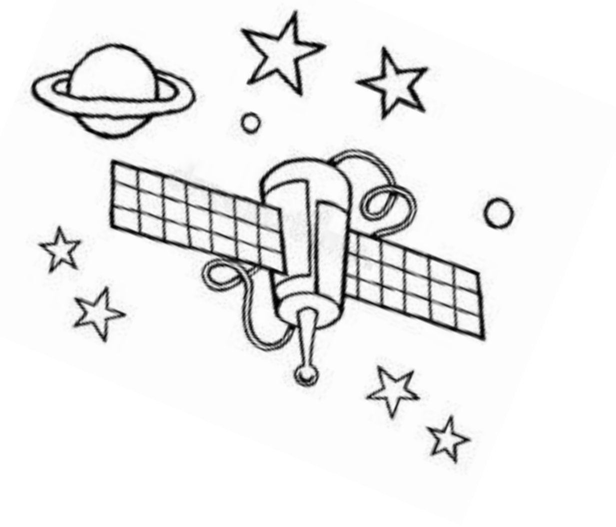


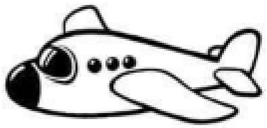


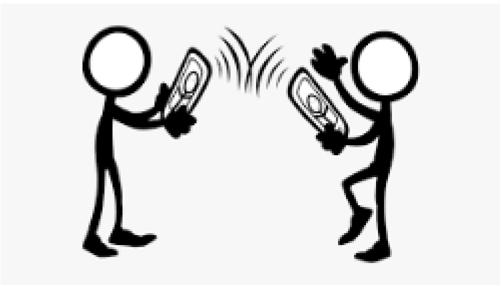


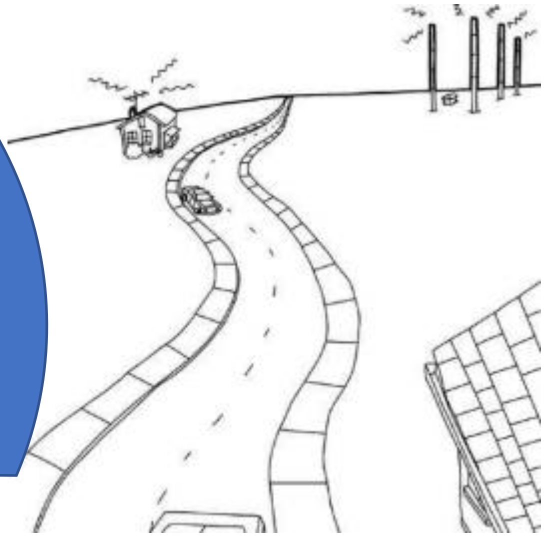


Spectrum users “outside” the zone do not interfere with passive users in the zone









Spectrum Innovation Initiative: National Radio Dynamic Zones (SII-NRDZ)

Goal	Advance the use of dynamic spectrum sharing
Method	Extended field trials of radio dynamic zones
Vision	Radio dynamic zones enhancing spectrum access for multiple facilities and applications

NSF 2022 Solicitation overview (22-579)

Solicitation text and other information

- Links at SII home page: https://nsf.gov/mps/oma/spectrum_innovation_initiative.jsp

Anticipate 8-12 awards

- Approximately 6-10 grants for SII-NRDZ Studies, up to $2,000,000
- Approximately 2 cooperative agreements for Engineering and Execution Lead Phase 1, up to $500,000

Total anticipated funding: $10,000,000

Proposals due June 21, 2022

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nsf.gov/pubs/2022/nsf22579/nsf22579.htm

Spectrum Innovation Initiative: National Radio Dynamic Zones (SII-NRDZ)

PROGRAM SOLICITATION
NSF 22-579

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Division of Atmospheric and Geospace Sciences
Office of Polar Programs

Directorate for Social, Behavioral and Economic Sciences

Directorate for Biological Sciences

Directorate for Education and Human Resources