Radio Spectrum Access Challenges and Possible Solutions

9th IVTW, Haystack

October 22, 2024

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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. allocation.

U.S. DEPARTMENT OF COMMERCE
National Telecommunications and Information Administration
Office of Spectrum Management

JANUARY 2016

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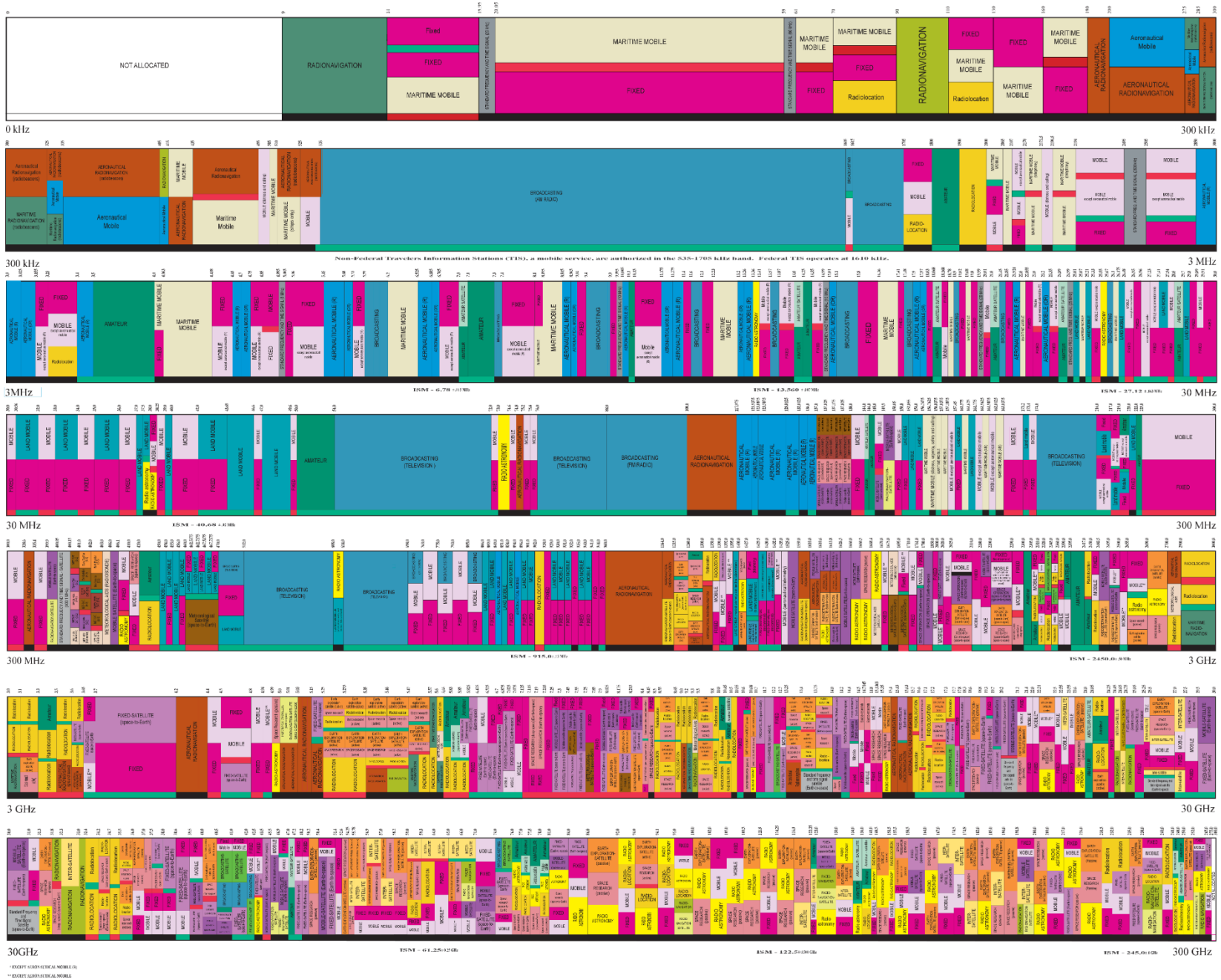

PLEASE NOTE: THE SPACING ALLOTTED THE SERVICES IN THE SPECTRUM SEGMENTS SHOWN IS NOT PROPORTIONAL TO THE ACTUAL AMOUNT OF SPECTRUM OCCUPIED

UNITED STATES FREQUENCY ALLOCATIONS

THE RADIO SPECTRUM

RADIO SERVICES COLOR LEGEND

AERONAUTICAL MOBILE	INTER-SATELLITE	RADIO ASTRONOMY
AERONAUTICAL MOBILE SATELLITE	LAND MOBILE	RADIODETERMINATION SATELLITE
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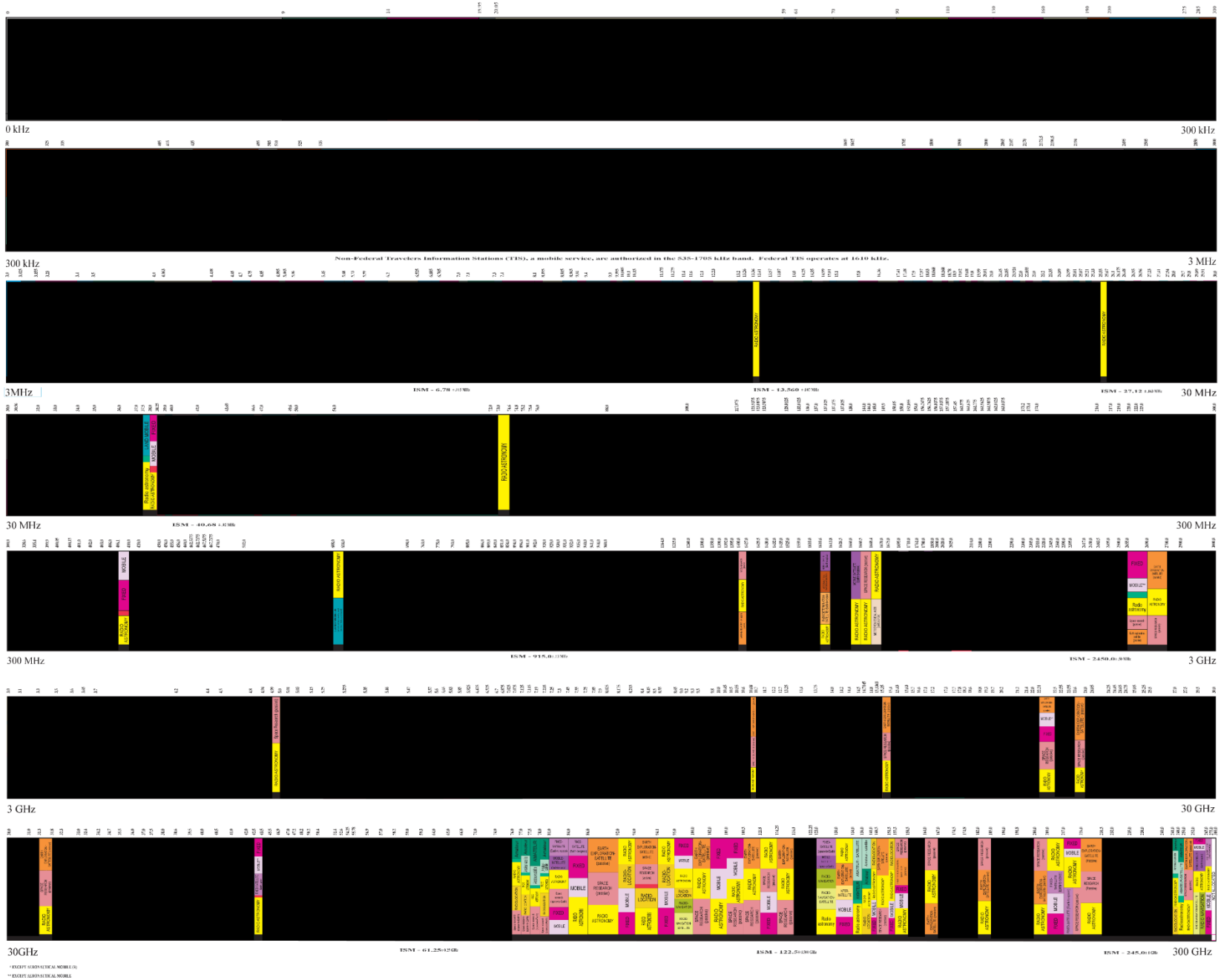


Current Protections and Tools for RAS

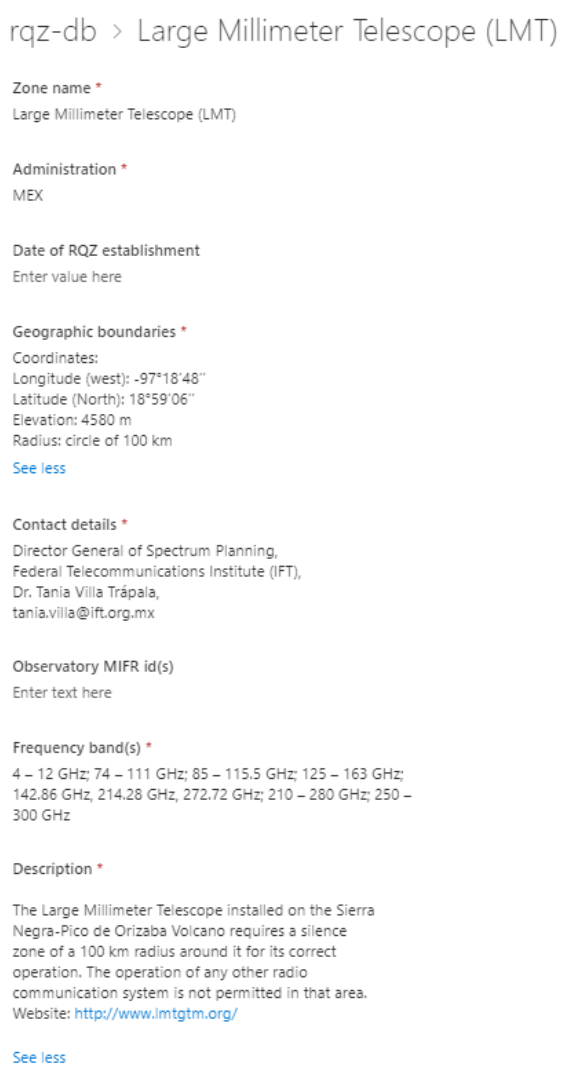
Coordination and Quiet Zones (excludes space applications)

e.g. National Radio Quiet Zone, PR Coordination Zone,
Australian Radio Quiet Zone, Astronomy Advantage Area

ITU-R recently established Radio Quiet Zone Database

Frequency Allocations (mainly for spectral lines; <275 GHz)
and Radio Regulations Footnotes (e.g. 5.149, 5.340, 5.565, US246)

1% of spectrum below 50 GHz are all emissions prohibited
(for comparison 5G 14%)
8% below 100 GHz


rqz-db › Large Millimeter Telescope (LMT)

Zone name *
Large Millimeter Telescope (LMT)

Administration *
MEX

Date of RQZ establishment
Enter value here

Geographic boundaries *
Coordinates:
Longitude (west): -97°18'48''
Latitude (North): 18°59'06''
Elevation: 4580 m
Radius: circle of 100 km
See less

Contact details *
Director General of Spectrum Planning,
Federal Telecommunications Institute (IFT),
Dr. Tania Villa Trápala,
tania.villa@ift.org.mx

Observatory MIFR id(s)
Enter text here

Frequency band(s) *
4 – 12 GHz; 74 – 111 GHz; 85 – 115.5 GHz; 125 – 163 GHz; 142.86 GHz, 214.28 GHz, 272.72 GHz; 210 – 280 GHz; 250 – 300 GHz

Description *
The Large Millimeter Telescope installed on the Sierra Negra-Pico de Orizaba Volcano requires a silence zone of a 100 km radius around it for its correct operation. The operation of any other radio communication system is not permitted in that area.
Website: http://www.lmtgtm.org/

See less

Most of radio astronomy is performed in unprotected parts of the spectrum!

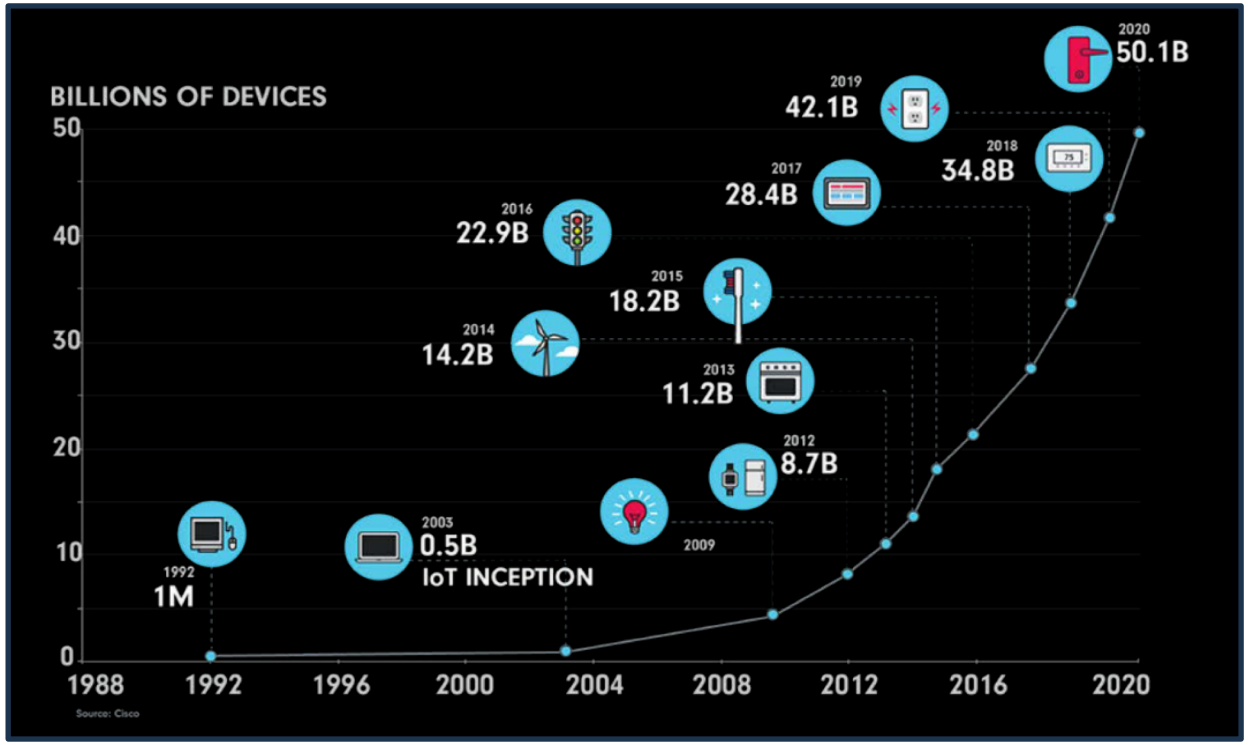
Spectrum access for science – traditional approaches

Design experiments to mitigate interference

Regulatory protection

Move experiments to places where spectrum is clean

Manually coordinate special access for individual experiments



Demands for electromagnetic spectrum availability are increasing rapidly in an already-congested environment

The big picture: A new spectrum era is coming

Spectrum eras end when stress builds to the point of a major failure

- Era 1 from 1890s: most powerful transmitter wins
  - Failure in 1912: congestion collapse of North Atlantic maritime radio communications
- Era 2 from 1927: government decides assignment of transmit frequencies
  - Failure in 1981: licensing workload exceeded capacity of regulators to adjudicate
- Era 3 from 1993: auctions of spectrum licenses

Era 3 is now under increasing stress

- Spectrum auctions — low-hanging fruit is gone, becoming excessively hard/expensive to meet demand
- Unlicensed bands — noise floor rising, can't do long-range or reliable IoT
- Interference enforcement — mostly impotent due to lack of resources and an increasingly dynamic environment

Era 3 failure likely in next 20-25 years, maybe sooner, e.g.

- Failure of a major auction to cover costs of moving incumbents
- A reallocation fight reaches a major deadlock, leaving no good options

Threatening trend for remote locations

RFI affected data for VLA in New Mexico, USA, grew significantly from 2014 to 2023

Trend accelerating

many cellular bands about to open to satellite transmission

Band (Frequency)	Fractional Loss 2014	Fractional Loss 2023	Change in 9 years
P-band (224-480 MHz)	n/a	40%	n/a
L-band (1-2 GHz)	23%	37%	+61%
S-band (2-4 GHz)	32%	38%	+19%
C-band (4-8 GHz)	10%	17%	+70%
X-band (8-12 GHz)	6%	16%	+167%
Ku-band (12-18 GHz)	9%	9%	little change
K-band (18-26 GHz)	5%	8%	+60%
Ka-band (26.5-40 GHz)	< 1%	< 1%	no change
Q-band (40-50 GHz)	< 1%	< 1%	no change
Total Fraction Loss (1-25 GHz)	10%	15%	+50%

Observation times increase as available bandwidth decreases

Total science return from telescopes goes down

Time-domain and multi-messenger astronomy becomes difficult

Analysis of data from the periodic VLA interference scans on NCP / Comparison in D configuration (worst-case)

Estimates derived by selecting a power threshold and counting bins where RFI exceeds that power level

Agenda Item 1.7: ITU-R Resolution 256 (WRC-23)

Sharing and compatibility studies and development of technical conditions for the use of International Mobile Telecommunications (IMT) in the frequency bands

- 4 400- 4 800 MHz,
- 7 125-8 400 MHz (or parts thereof),
- and 14.8-15.35 GHz

for the terrestrial component of IMT

Strategic Objective 1.2 | Ensure spectrum resources are available to support private sector innovation now and into the future

Outcome 1.2(a): Adoption of study plans and schedules for completing in-depth studies

The Strategy identified the following spectrum bands for near-term, in-depth study to determine whether they may be repurposed for non-Federal or shared Federal and non-Federal use: (1) 3.1-3.45 GHz; (2) 5030-5091 MHz; (3) 7.125-8.4 GHz; (4) 18.1-18.6 GHz; and (5) 37.0-37.6 GHz. The study plans will be developed jointly by NTIA and the affected Federal agencies. The studies will consider various typically employed spectrum management mechanisms to assess fully the possibilities for expanded or more efficient uses of the spectrum. The study plans will be mutually agreed to between NTIA and affected Federal agencies. The Appendix provides the approach to band studies and details on adoption of study plans. It also lists the top-line schedule for completing studies of these spectrum bands.

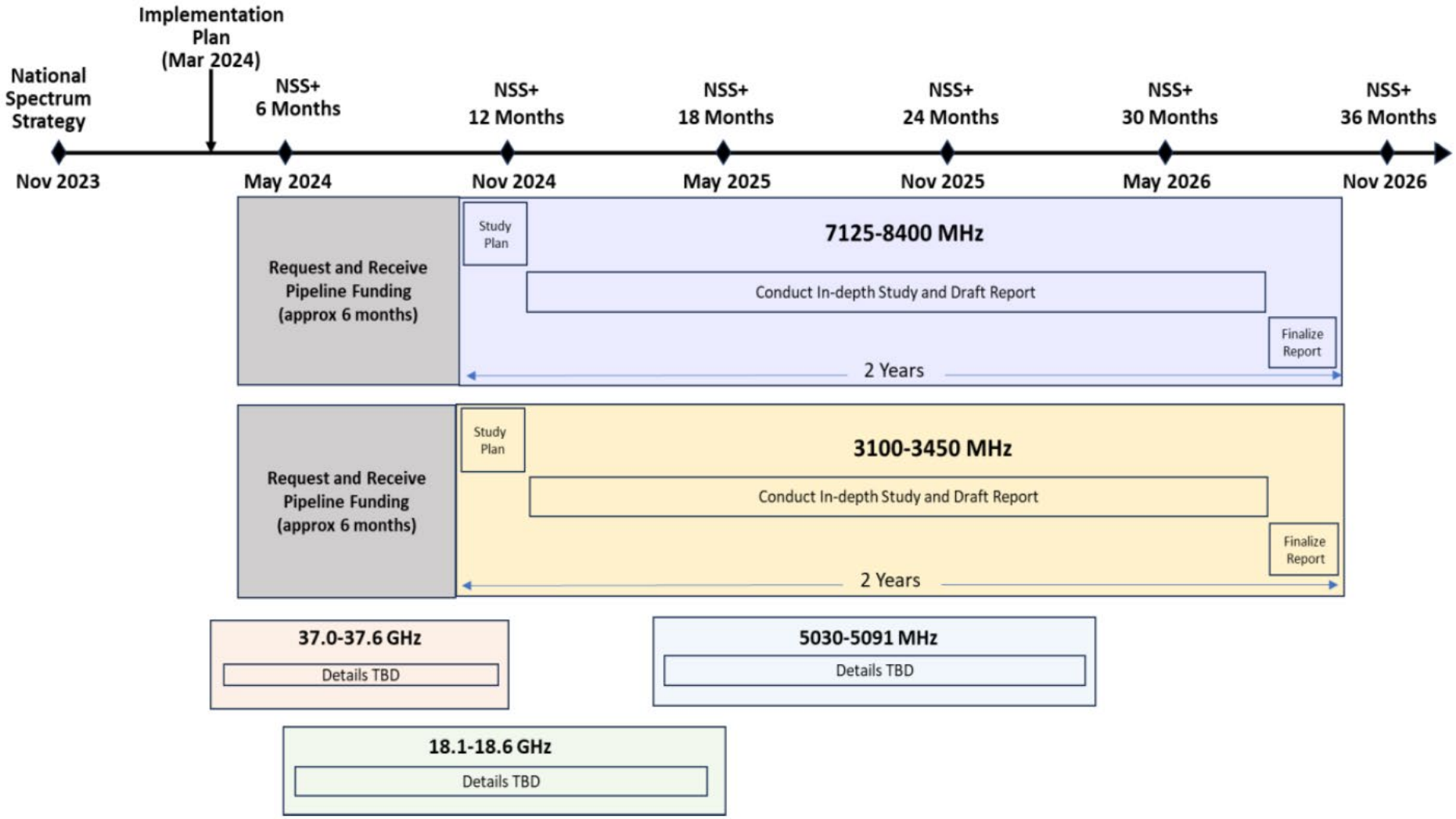
NATIONAL SPECTRUM STRATEGY IMPLEMENTATION PLAN

NATIONAL TELECOMMUNICATIONS AND INFORMATION ADMINISTRATION

Alan Davidson
Assistant Secretary for Communications and Information

March 12, 2024

Timeline for U.S. Band Studies

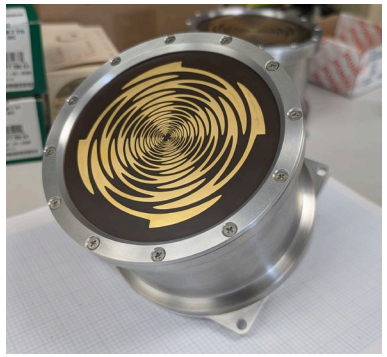


1. Perform Field Tests at VLA/VLBA Pie Town in collaboration with NTIA/ITS (Summer 2025)

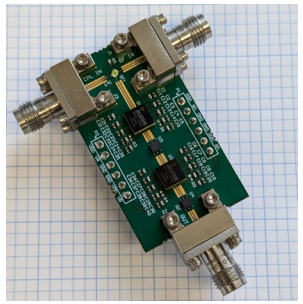
2. Spectrum Usage Monitoring around Radio Astronomy Sites using NRAO's Advanced Spectrum Monitors (ASM)

Receiver Panel Assembly

- Contains four highly-integrated FE receiver module to cover: 1-20, 18-30, 28-40, 38-50 GHz
- Solid State IF Multiplexer
- Receiver monitoring and controls

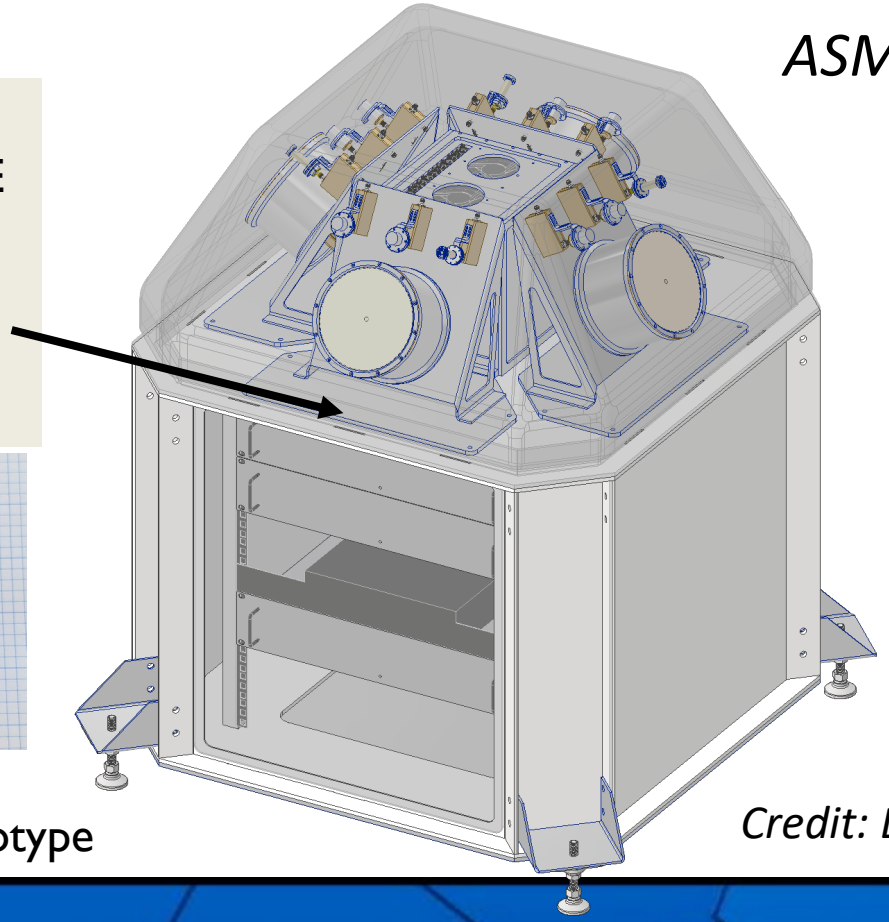


Prototype Sinuous Antenna



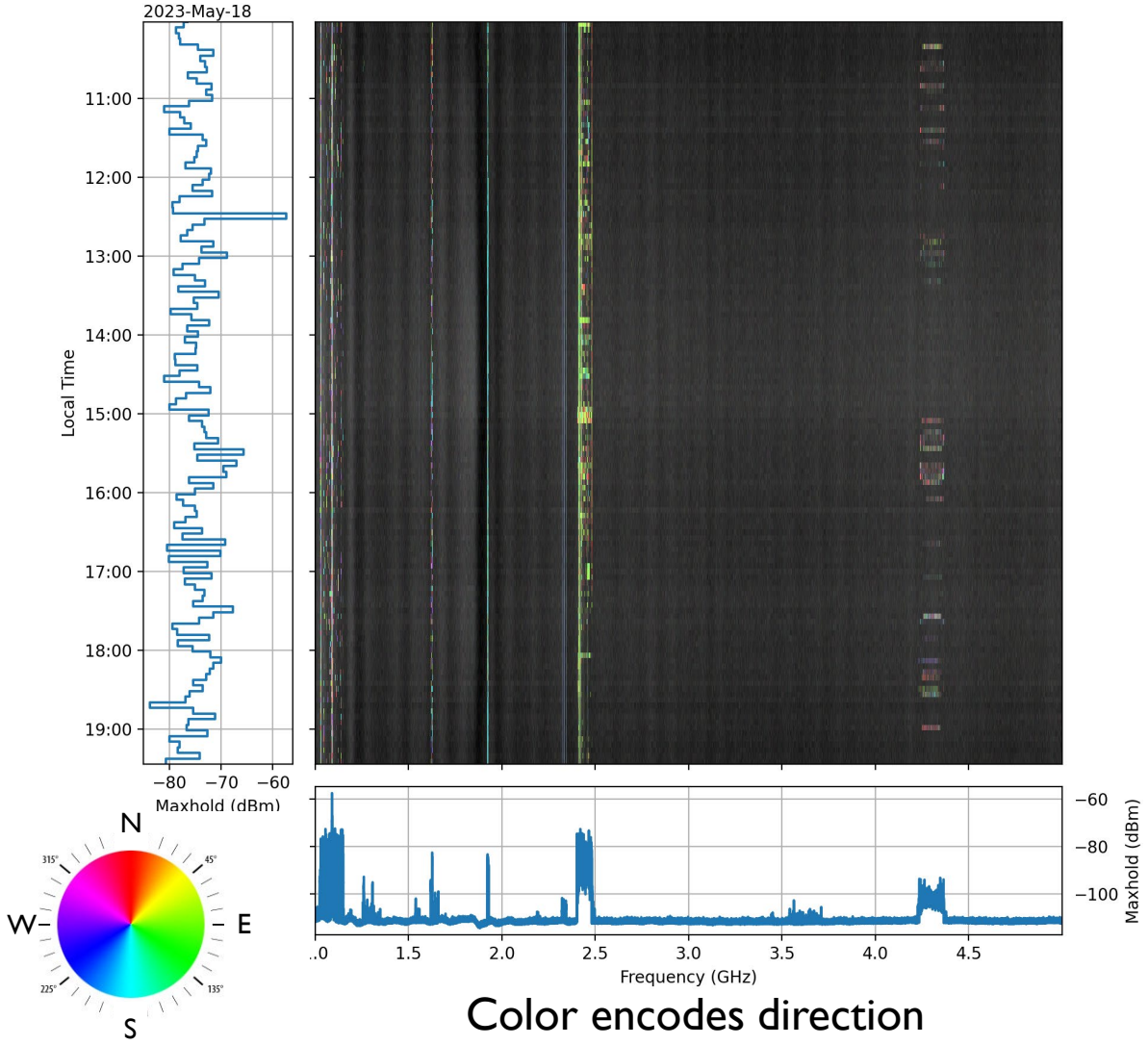
20-50 GHz RF Frontend Prototype

ASM-2 design



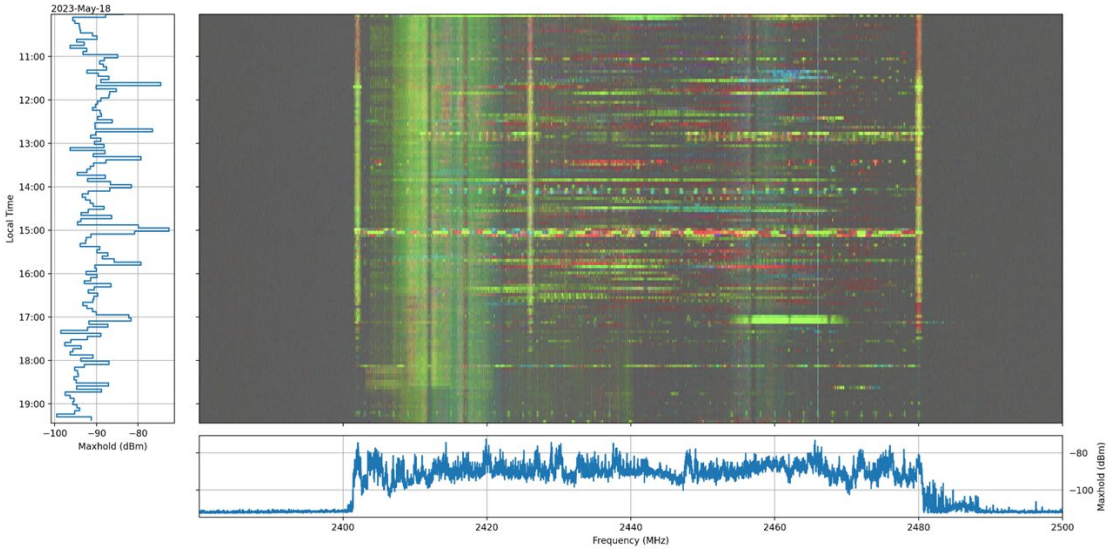
Credit: David Bordenave/NRAO/CDL

ASM-1 Field Tests



Color encodes direction

WiFi /Bluetooth



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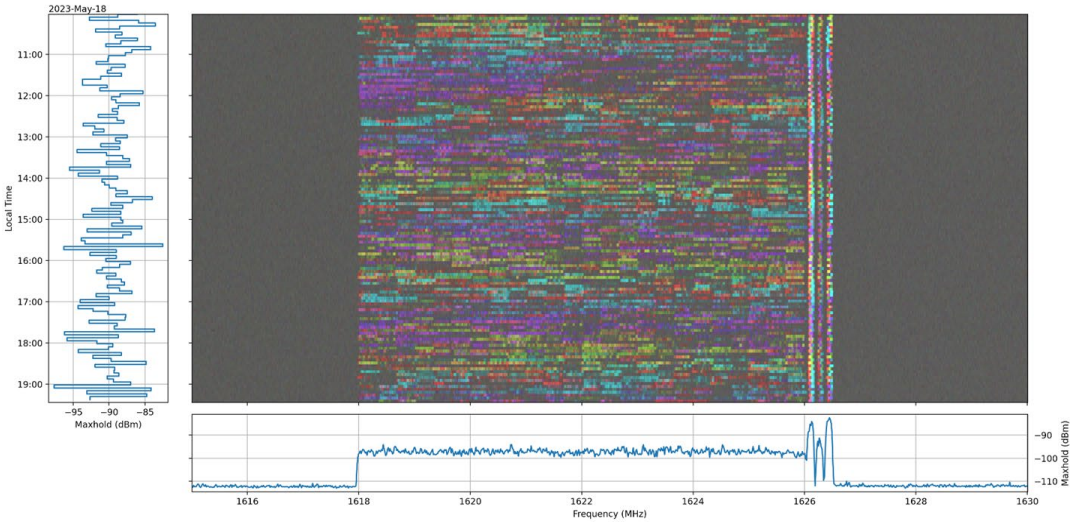
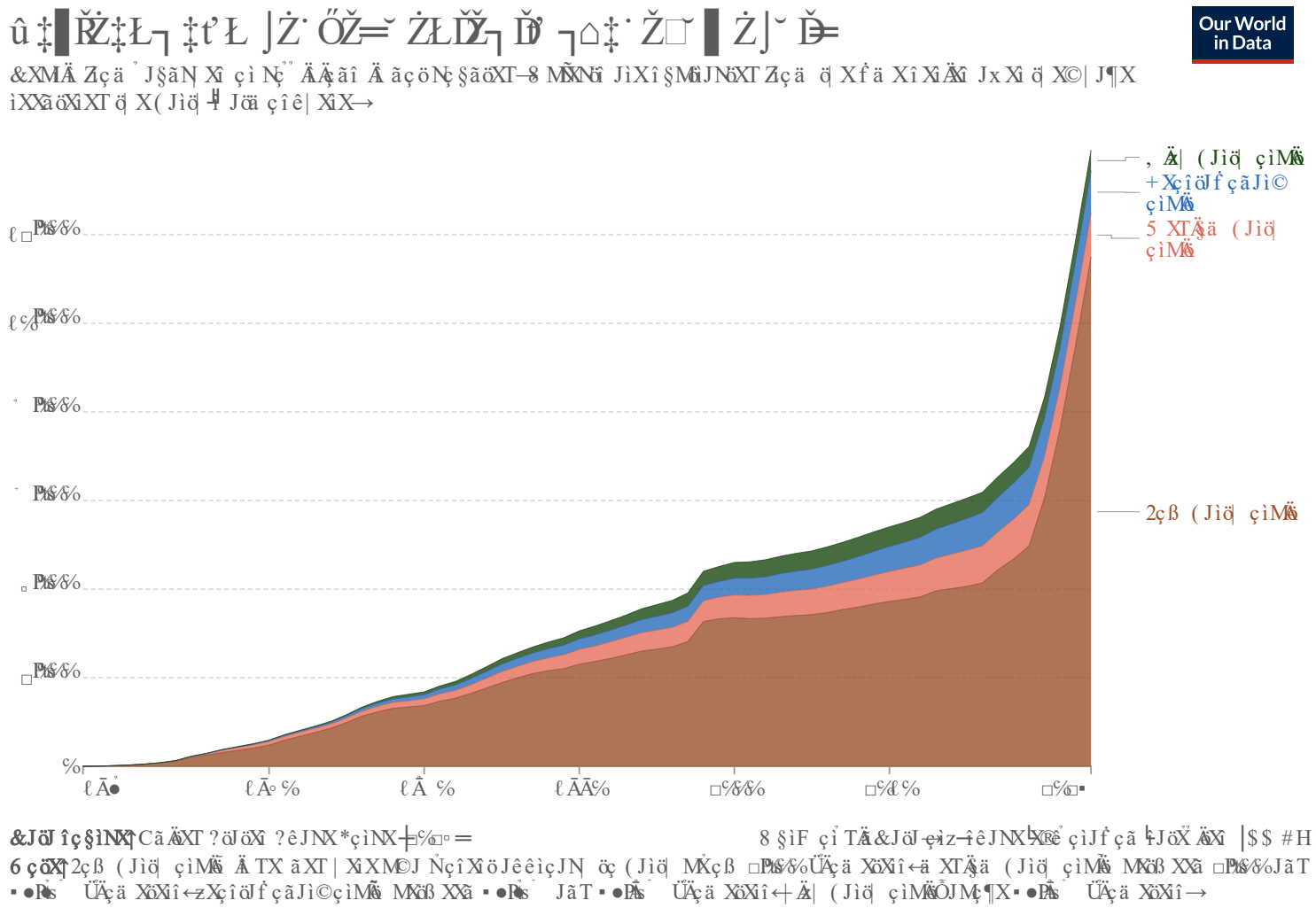


Credit: David Bordenave/NRAO/CDL



"The global space economy will grow from $630 billion in 2023 to $1.8 trillion by 2035, serving an Increasingly connected and mobile world" *World Economy Forum; Inside Report April 2024 in partnership with McKinsey & Company*

Coordination Agreements

NSF Coordination Agreement with SpaceX

- 10.6-10.7 GHz coordination (2019)
- Darkening of Gen2 satellites (2022)
- Dynamic coordination with radio observatories (2023)
- Direct2Cell coordination

NSF Eutelsat/OneWeb Coordination Agreement (2023)

NSF working on coordination agreements with:

Amazon/Kuiper, AST/SpaceMobile, Planet Labs, …

FCC introduced license requirement to coordinate with NSF for LEO constellations

Will exclude satellite systems not requesting landing rights in U.S. (e.g. Chinese Qianfan)

Possible Coexistence Schemes

Zone Avoidance

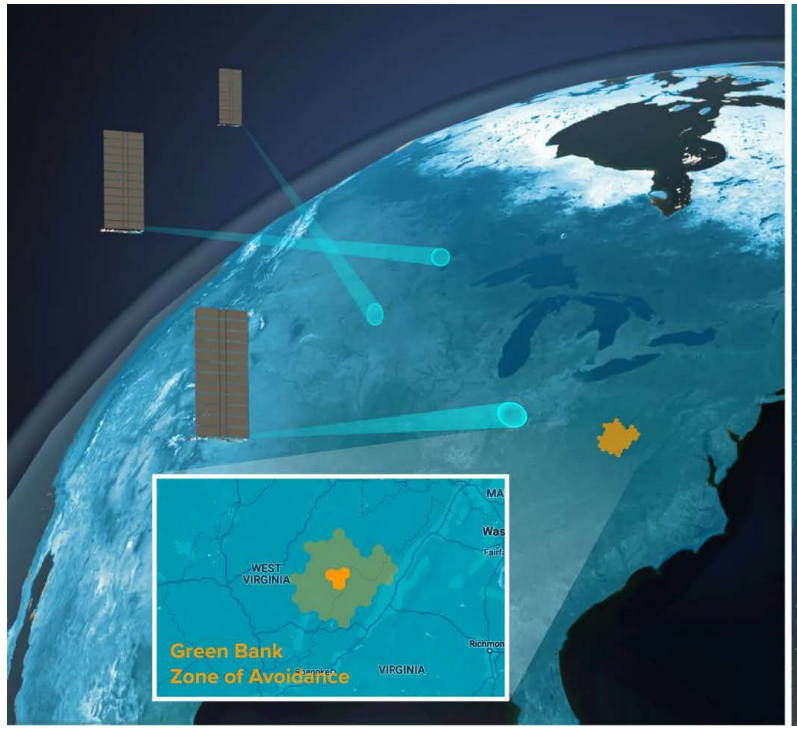
Downlink beam placement to avoid radio telescopes

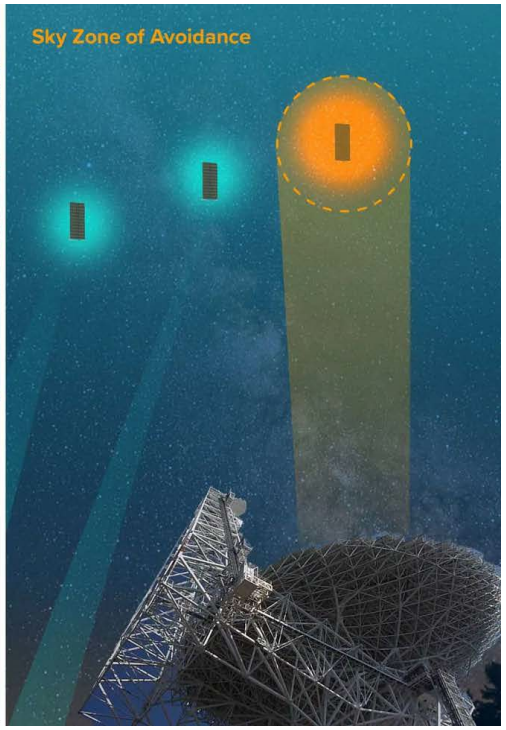
Boresight Avoidance

Momentarily disable downlink (<3-5s) when close within a certain telescope's boresight threshold

Frequency Avoidance

Only downlink at sub-bands not being used by the telescopes

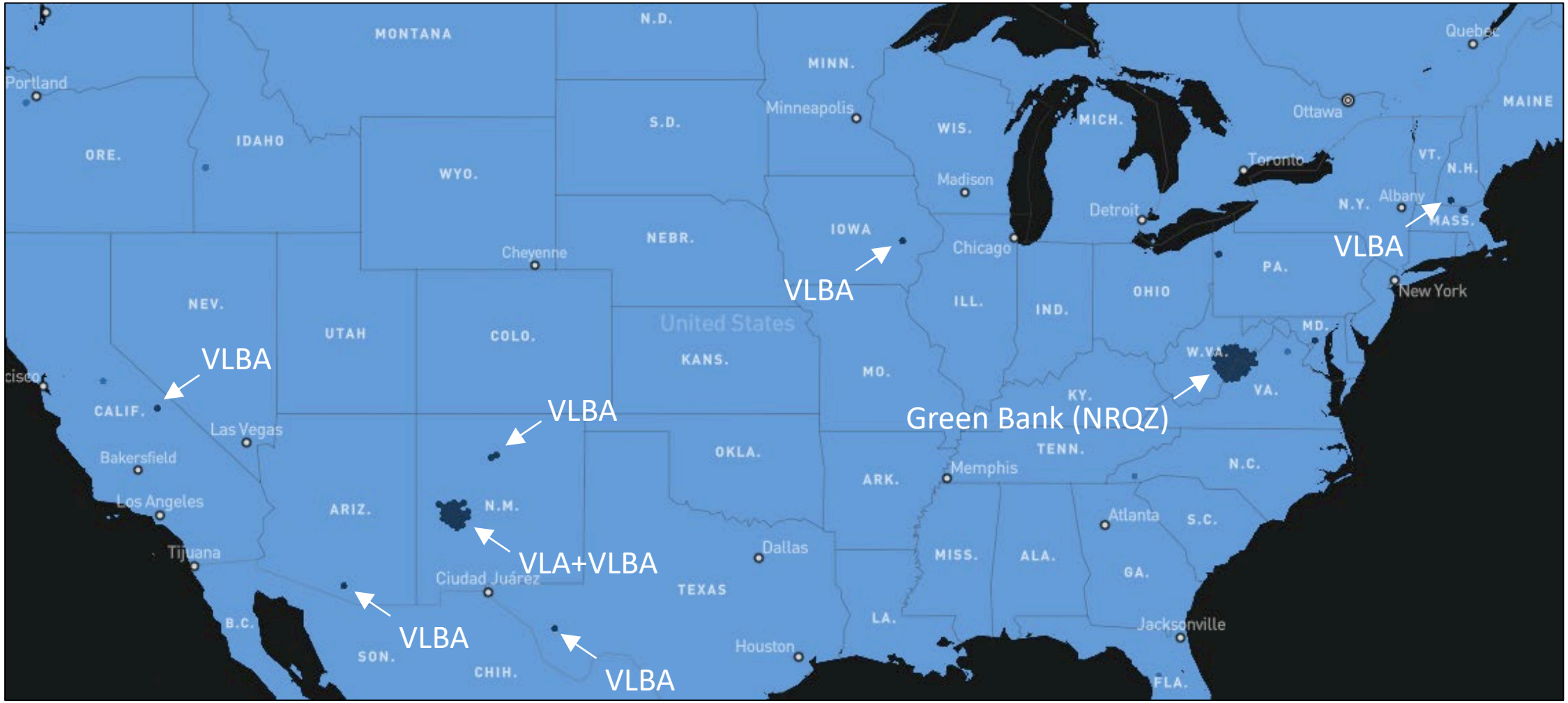




Chan #	1	2	3	4	5	6	7	8
Band Name	X							Ku
Freq (GHz)	10.7-10.95	10.95-11.2	11.2-11.45	11.45-11.7	11.7-11.95	11.95-12.2	12.2-12.45	12.45-12.7
RA Telescopes	In-use					Available		
LEO	No downlink					**Downlink**		
RA Telescopes	Available				**In-use**			
LEO	**Downlink**				No downlink			

Slide credit: B. Nhan (NRAO)

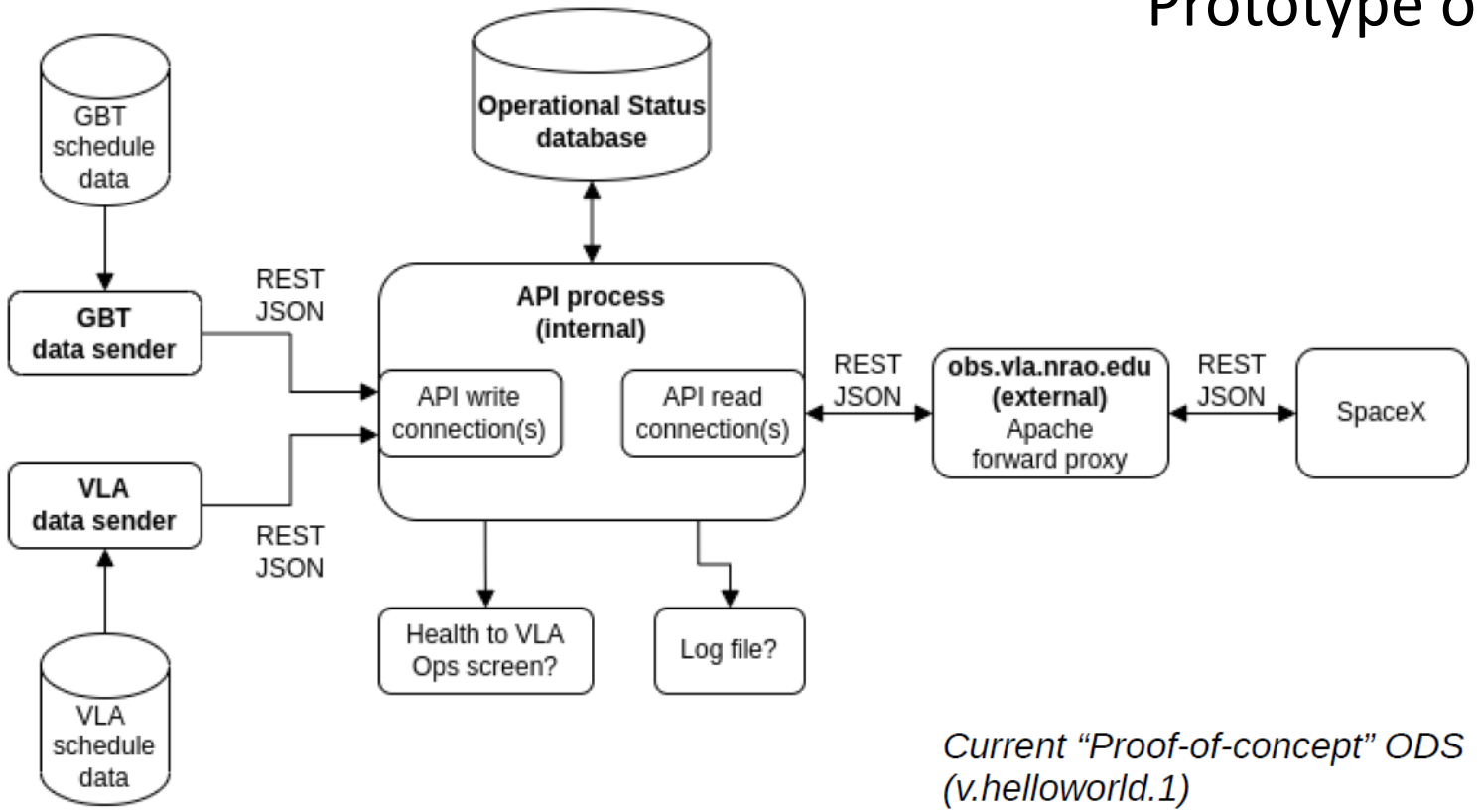
Starlink collaboration benefit: protection for the Very Long Baseline Array (VLBA) from user terminals



Starlink availability map, April 2024: https://www.starlink.com/map

Operational Data Sharing (ODS)

GBT Testing of Boresight Avoidance: Nhan, B.; De Pree, C.; et al. (2024), ApJ Letters, Vol 971, issue 2



Current "Proof-of-concept" ODS (v.helloworld.1)

Prototype of Automated Coexistence Scheme

- Self-hosted by NRAO
- Currently reporting VLA&GBT from observation scheduler database
- Queried by space operators
- Standardized data format and API specifications for broader adoption

Development by NRAO supported through NSF:
SII NRDZ: Dynamic Protection and Spectrum Monitoring for Radio Observatories (AST-2232159),
SWIFT-SAT: Observational Data Sharing (AST-2332422)

ODS's REST API JSON data format

Provides information of upcoming observations in an array of JSON objects for observtories participating in the project.

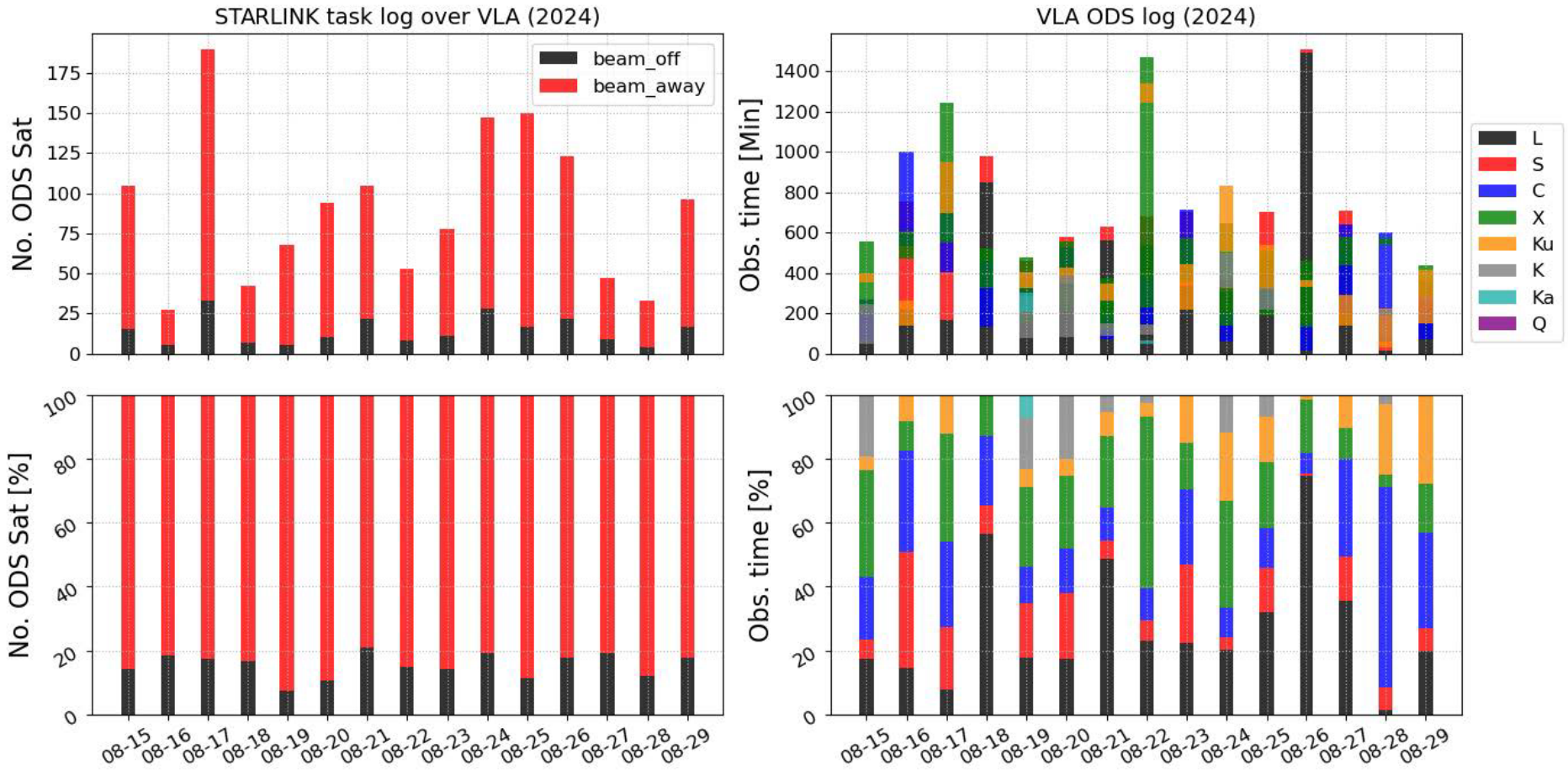
Response	Description
200	Successful Operation - Returns array of JSON objects with these attributes:

	Attribute	Type	Format	Example	Description
	site_id	string		vla_D	Identifier of the observatory/instrument. In the example '_D' indicates VLA 'D' configuration. The possible 'site_id's for the VLA are: vla_A, vla_A-to-D, vla_D, vla_D-to-C, vla_C, vla_C-to-B, vla_B, vla_B-to-BnA, vla_BnA, vla_BnA-to-A.
	site_lat_deg	number	decimal-degrees +/- DD.D	34.07874917	the latitude of the observatory/instrument
	site_lon_deg	number	decimal-degrees +/- DDD.D	-107.6177275	the longitude of the observatory/instrument
	site_el_m	number	decimal-meters	2124	the elevation of the observatory/instrument
	src_id	string		J1056+7011	identifier of source/target observed during time interval
	src_is_pulsar_bool	boolean		false	true = src is a pulsar, false = src is not a pulsar
	corr_integ_time_sec	number		3	correlator integration time in seconds (if 'src_is_pulsar_bool'=false)
Where	src_ra_j2000_deg	number	decimal-degrees	70.88181332916666	right ascension of the source/target
Where	src_dec_j2000_deg	number	decimal-degrees	34.685184469444444	declination of the source/target
Where	src_radius	number	decimal-degrees	0.0034	radius of beam around the source/target
When	src_start_utc	string	date-time	2023-08-16T15:23:47.000541	start time of this observing interval
When	src_end_utc	string	date-time	2023-08-16T15:26:16.000723	end time of this observing interval
	slew_sec	number		130.8	the time taken for the array to reach the source (counted from 'src_start_utc')
	trk_rate_dec_deg_per_sec	number	decimal-degrees per second	0	declination tracking rate of src (if not sideral)
	trk_rate_ra_deg_per_sec	number	decimal-degrees per second	0	right ascension tracking rate of src (if not sideral)
What	freq_lower_hz	number	decimal-Hz	26000000000	lower limit frequency used during this interval
What	freq_upper_hz	number	decimal-Hz	40000000000	upper limit frequency used during this interval
	notes	string		inAdv:True	notes that add context to the data

404	Resource Not Available
500	Internal Server Error

Online documentation: https://obs.vla.nrao.edu/ods/

VLA ODS full-time avoidance activated by SpaceX



Boresight shutoff threshold = 0.2 degree

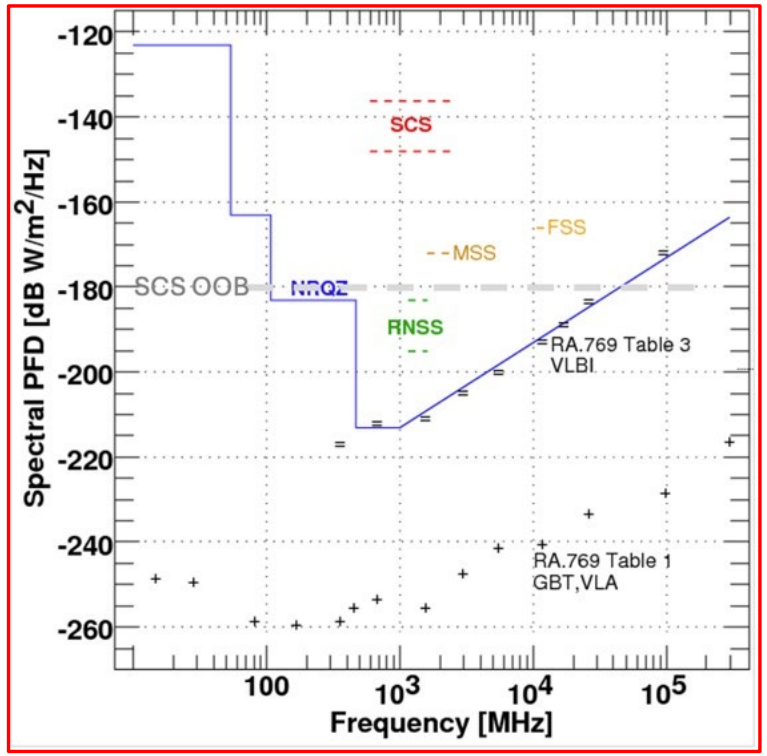
beam_off = shut off downlink (DL) beam

beam_away = place DL beam far from VLA

Agenda Item 1.13: ITU-R Resolution 253 (WRC-23)

Studies on possible new allocations to the mobile-satellite service for direct connectivity between space stations and International Mobile Telecommunications (IMT) user equipment to complement terrestrial IMT network coverage

Frequency ranges under consideration for study: 698-960 MHz, 1427-1518 MHz, 1710-2200 MHz, 2300-2690 MHz.



FCC ADVANCES SUPPLEMENTAL COVERAGE FROM SPACE FRAMEWORK

New Rules Take Steps Toward a Single Network Future that Harnesses the Power of Satellites to Fill Wireless Coverage Gaps

Comparison of satellite (space-Earth) service levels, radio astronomy protection levels in Rec. ITU-R RA.769 and the National Radio Quiet Zone, and the out of band emissions limit for SCS. Frequency ranges are shown schematically. Note the disparity between the power levels used for Supplemental Coverage from Space and those of other space services. *Credit: Harvey Liszt (NRAO)*

MIDLAND, Tx., September 12, 2024

AST SpaceMobile Announces Successful Orbital Launch of Its First Five Commercial Satellites

AT&T is working with AST SpaceMobile to one day offer voice, data, text and video services in remote, off-grid locations. Learn more.

08/28/2024 | **Networks & Platforms** | **Building the future**

Verizon teams up with satellite service provider Skylo to launch direct-to-device messaging for customers

SpaceX/T-Mobile USA

1910-1915 MHz (Earth-to-space)

1990-1995 MHz (space-to-Earth)

SpaceX
@SpaceX

SpaceX and @TMobile have been given emergency special temporary authority by the @FCC to enable @Starlink satellites with direct-to-cell capability to provide coverage for cell phones in the affected areas of Hurricane Helene.

The satellites have already been enabled and started broadcasting emergency alerts to cell phones on all networks in North Carolina. In addition, we may test basic texting (SMS) capabilities for most cell phones on the T-Mobile network in North Carolina.

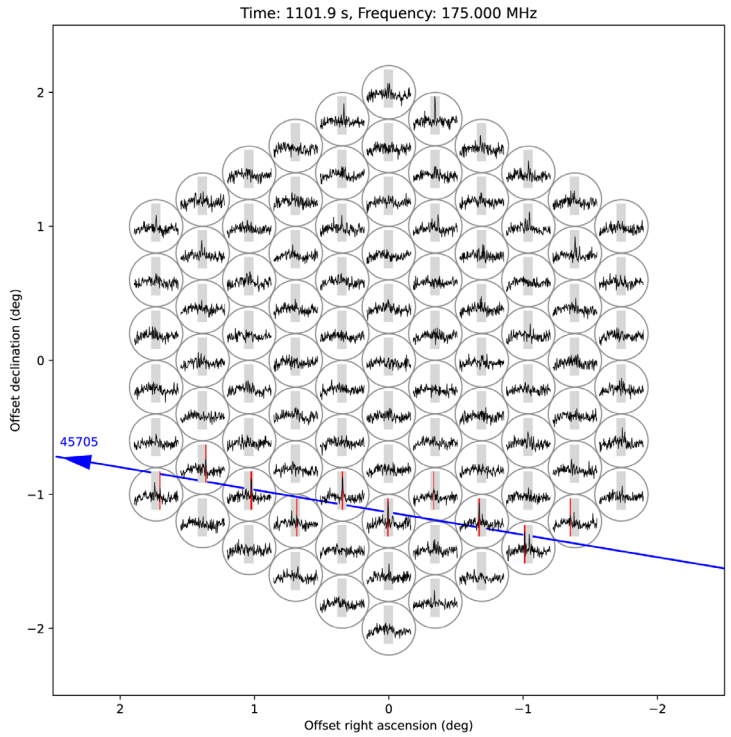
SpaceX's direct-to-cell constellation has not been fully deployed, so all services will be delivered on a best-effort basis.

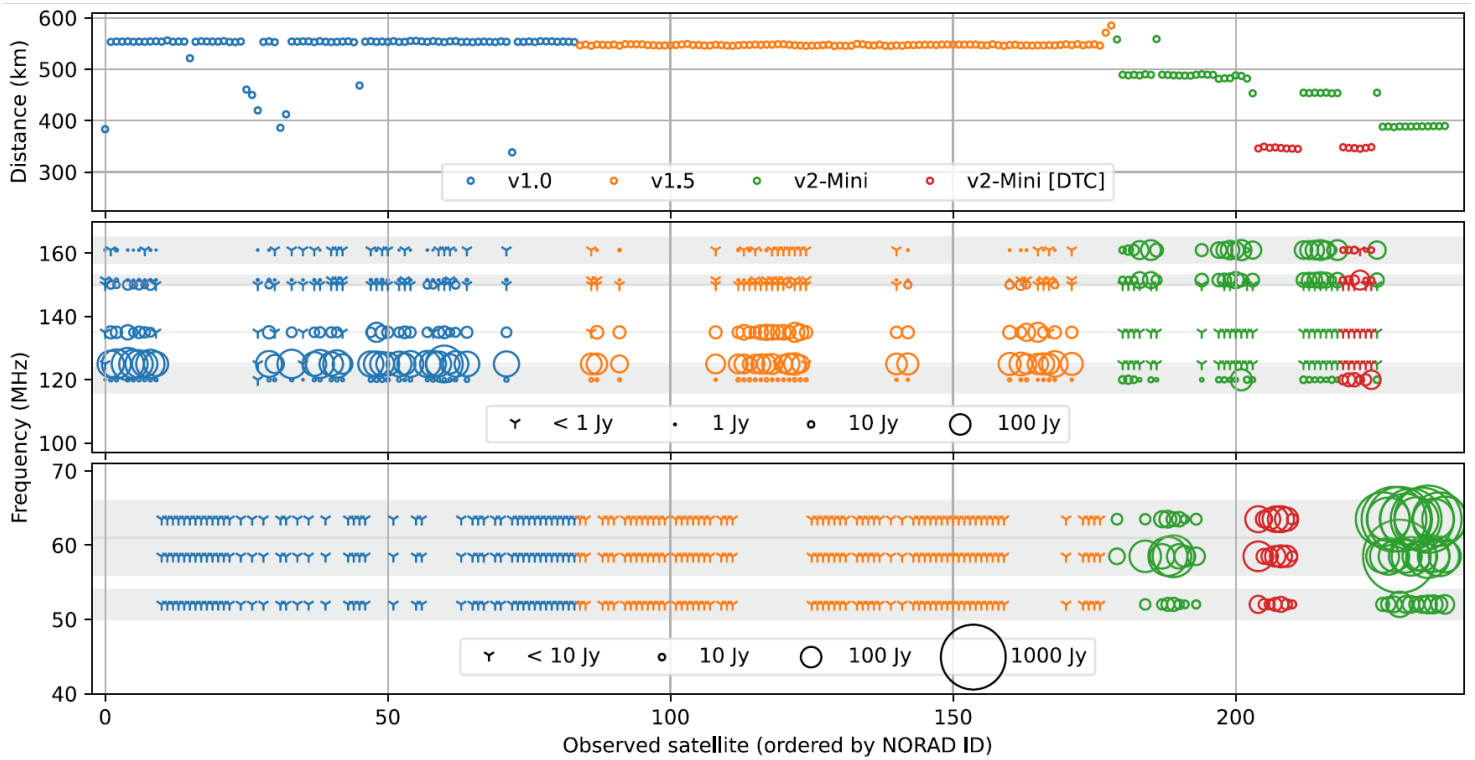
2:00 PM · Oct 6, 2024 · **1.9M** Views

Testing/development of possible mitigation measures is needed!

Unintended electromagnetic radiation from Starlink satellites

Example of when radio astronomers identify a problem;
can only solve through collaboration with Starlink, without antagonizing!





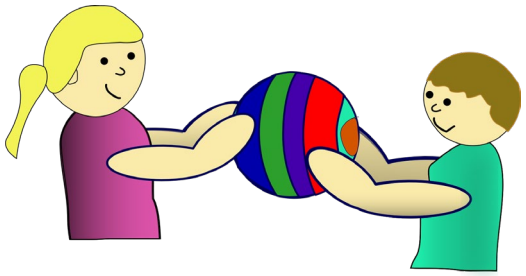
[Di Vruno, F. et al. 2023, Astronomy & Astrophysics, Volume 676, id.A75]
[Bassa, C.G. et al. 2024, Astronomy & Astrophysics, Volume 689, id.L10]

Fundamental change is needed

Traditional approaches for scientific spectrum access are losing viability

Must change the current spectrum ecosystem

From dominantly exclusive static assignment to dominantly spectrum sharing



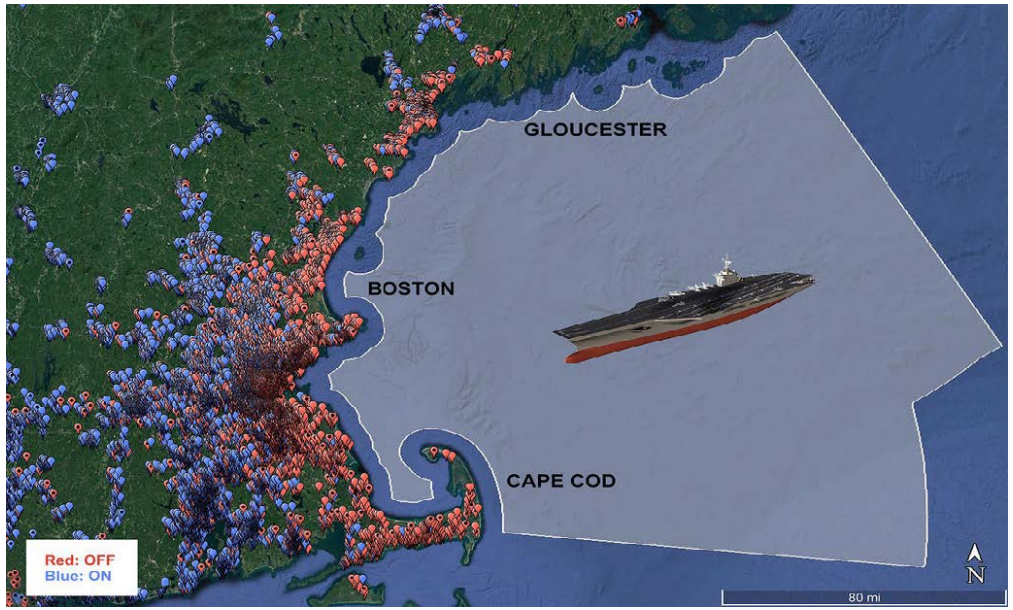
Demand for spectrum access is growing rapidly… Dynamic spectrum sharing is one key to meet these growing demands.

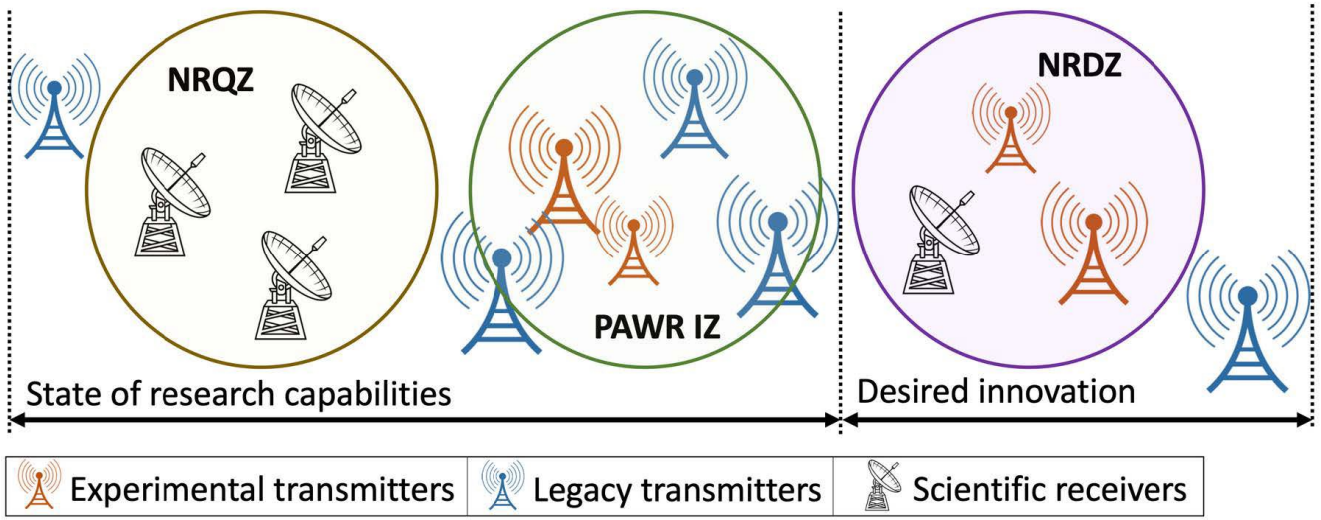
National Spectrum Strategy, Nov 13, 2023

Rethinking Concept of Coordination Zones Spectrum Sharing and NRDZ

U.S. Commercial Prototype:

The Citizens Broadband Radio Service (CBRS) 150 MHz (3.55 – 3.70 GHz) of spectrum made available for commercial broadband use on a shared basis with the federal government.





Concept of Radio Dynamic Zones

[CHIPS Articles: National Radio Quiet and Dynamic Zones]

Summary

Problem

- ***The radio spectrum is becoming more efficiently used, i.e. more congested***
- ***Existing regulatory schemes are under pressure***
- ***Remote areas are not immune due to increased spectrum use and density by satellite services***

Possible Solutions

- ***Coordinate with system operators to reduce impact on radio telescopes***
  - Spectrum Monitoring / Awareness
  - Operational Data Sharing -> Extend to ATA, VLBA, include Amazon/Kuiper in testing -> other observatories?
- ***Develop and design concepts/standards for dynamic spectrum sharing of active and passive services in defined geographic areas***
- ***Consider spectrum access when operating and designing radio telescopes***
- ***Define new regulatory concepts***

Opportunity to lead concepts for spectrum co-existence and to regain lost spectrum access

There is almost always a technical solution (it might take time and be expensive)