

Coordination efforts between NRAO & satellite constellation operators

NAS-CORF Fall Meeting
20 Nov 2024

Bang D. Nhan

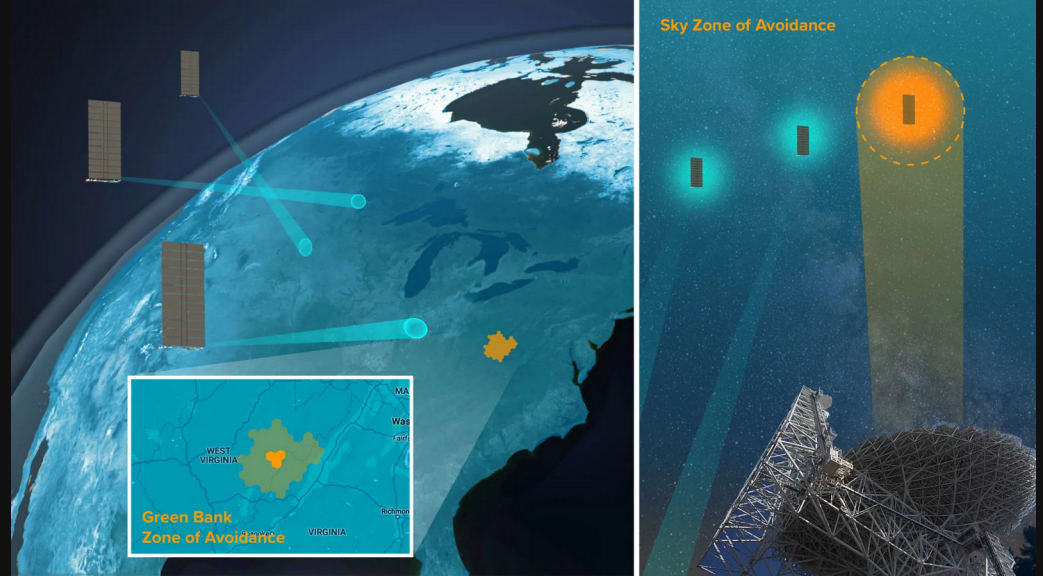
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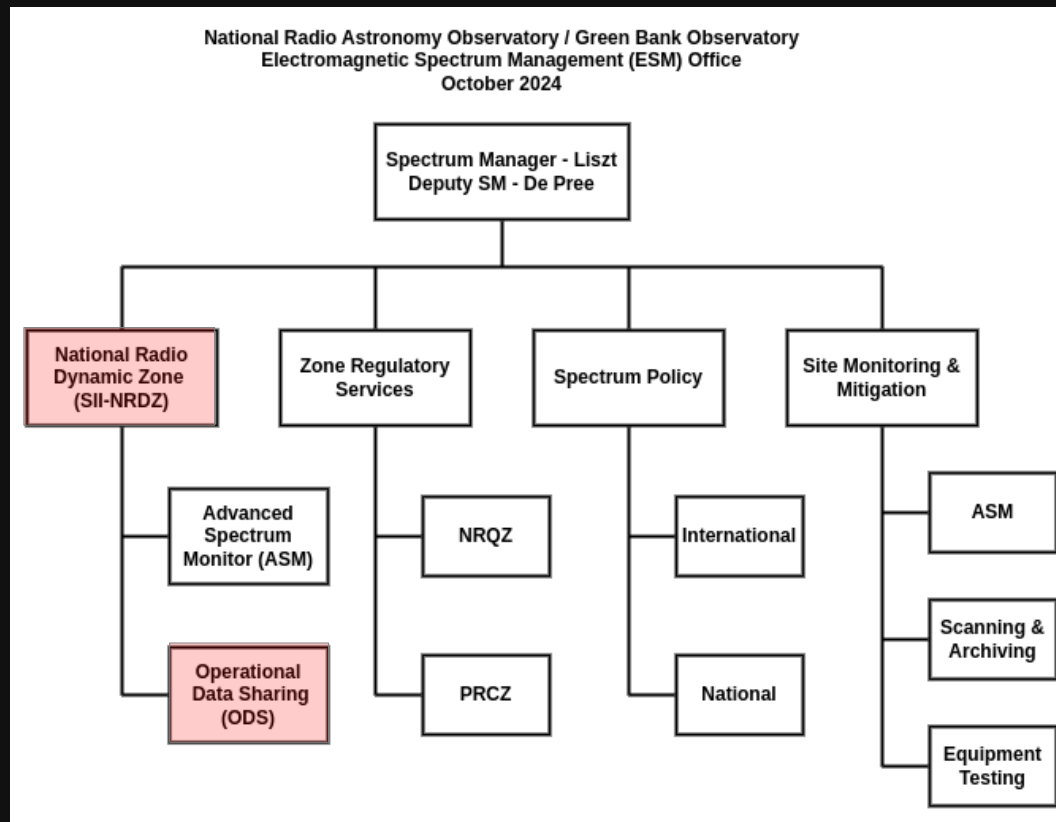
bnhan@nrao.edu



Overview

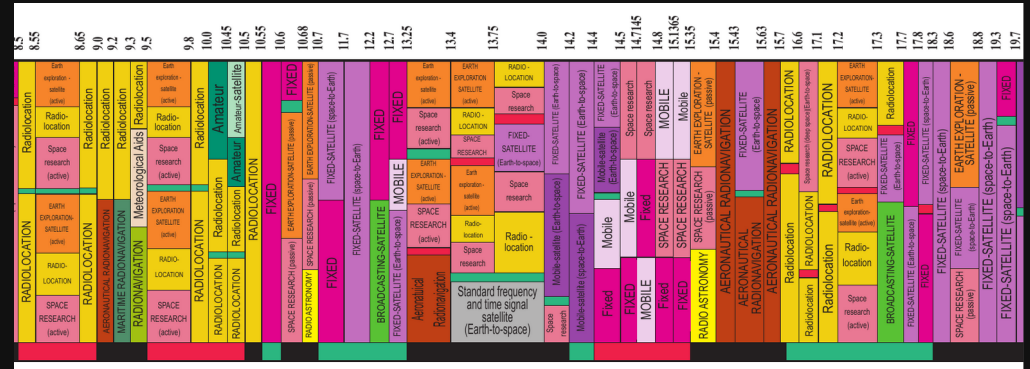
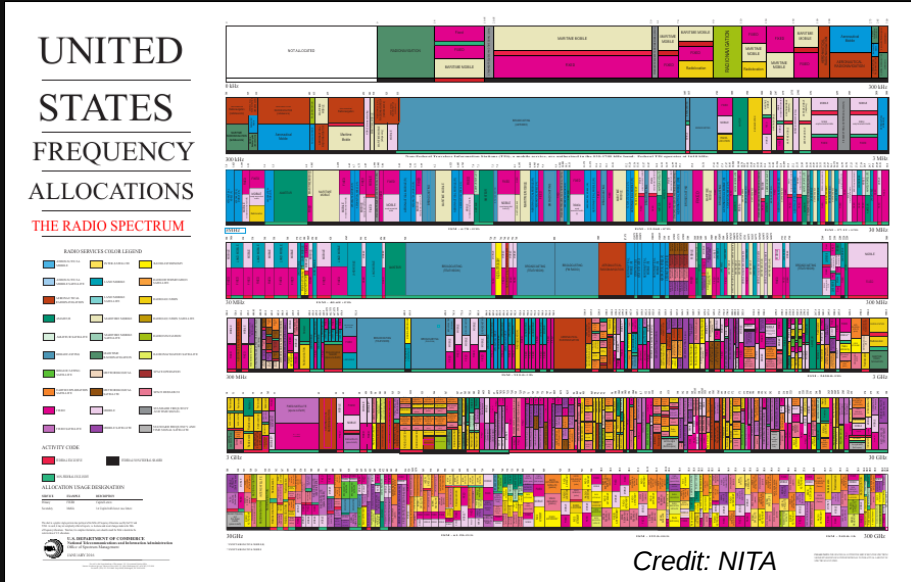
- Motivations
 - Coexistence between passive and active spectrum users
 - Radio Zones:
 - National Radio Quiet Zone (NRQZ)
 - National Radio Dynamic Zone (NRDZ) Concepts
 - LEO internet satellite constellations
- Case study: Coordination between NSF/NRAO with SpaceX
- Operational Data Sharing (ODS)
 - Framework & data format
 - Current status & upcoming plans

NRAO/GBO Spectrum Management Team



- *Spectrum Manager*
Harvey Liszt
- *Deputy Spectrum Manager*
Christopher De Pree
- *Zone Regulatory Services Coordinator*
Sheldon Wasik
- *RFI Scientist*
Bang Nhan
- *RFI Data Analysts*
Aaron Lawson (New Mexico)
Daniel Bautista (GBO)
- *ASM development team*
Richard Bradley (CDL)
David Bordenave (CDL)
- *Green Bank Interference Prevention Group (IPG) lead*
Karen O'Neil
- *New Mexico IPG lead*
Ylva Pihlstrom

Spectrum allocation & sharing/coexistence



↑ ↑

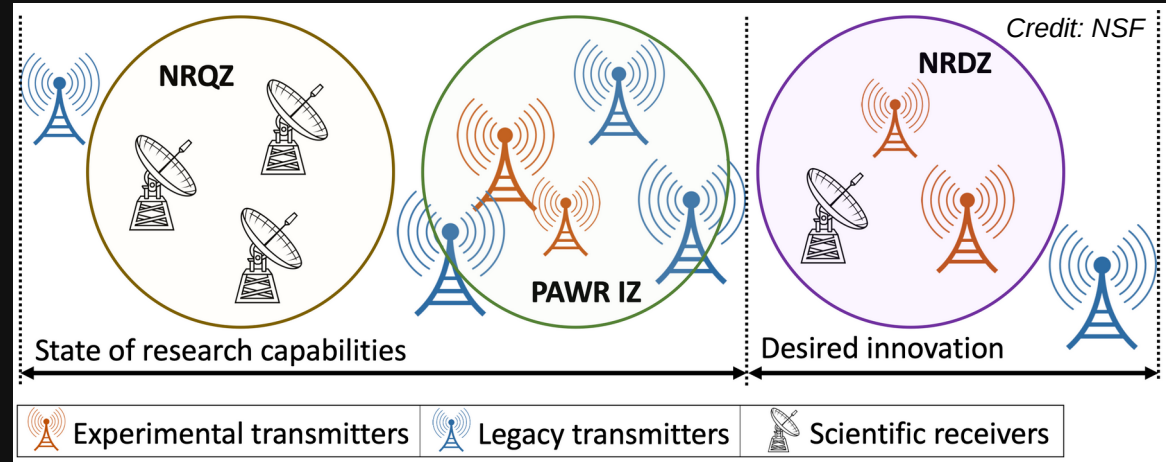
Radio Astronomy (RA)
Fragmented allocation,
Often need continuum
observation

Radio Quiet Zones vs Radio Dynamic Zone Concepts



Established by

- Federal Communications Commission (FCC)
- Docket No. 11745 (November 19, 1958)
- Interdepartment Radio Advisory Committee (IRAC) in Document 3867/2 (March 26, 1958)
- NRQZ ~ 13,000 sq-mile (34,000 sq-km)



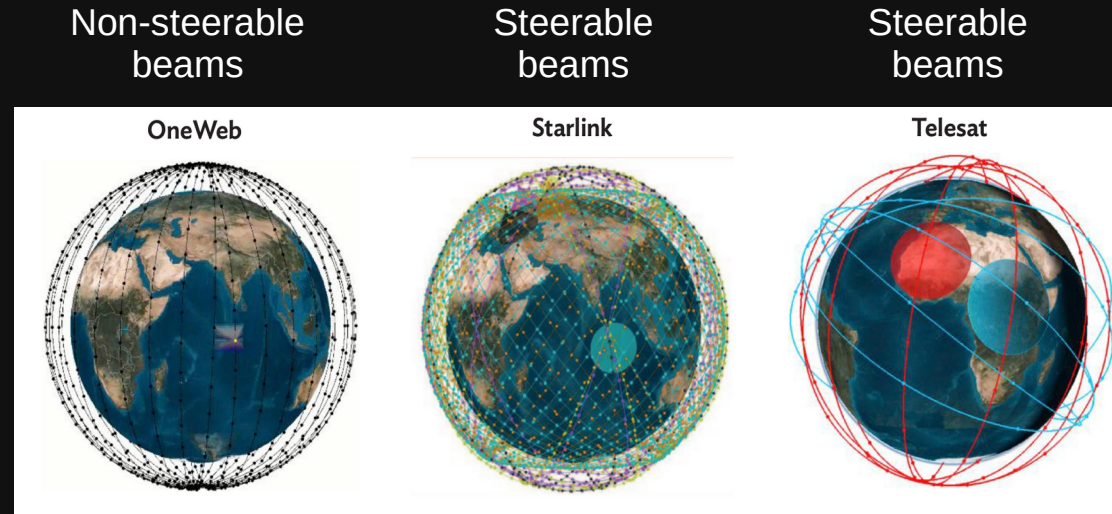
PAWR = NSF's Platforms for Advanced Wireless Research

NRDZ's requirements (NSF, NRDZ-COM2, May 2023)

- Dynamic spectrum sharing (DSS)
 - Independent & dynamic access methods
- Radio Dynamic Zone (RDZ)
 - Control RF energy entering & escaping the zone
 - Zone management framework

LEO satellite constellations

- Geosynchronous Equatorial Orbit (GEO): ~36,000 km
- Medium Earth Orbit (MEO): ~8,000 km
- Low Earth Orbit (LEO): ~1,000 km



Del Portillo, et al. 2019, Acta Astronautica 159

Coordination agreement (NSF & SpaceX)



U.S. National Science Foundation

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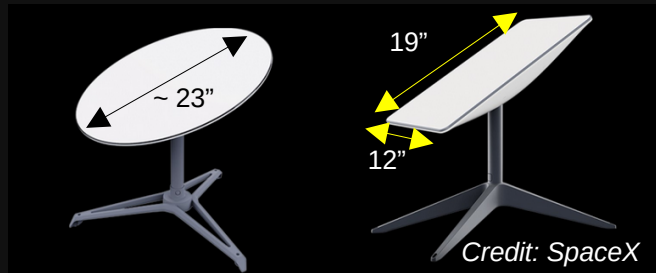
[Home](#) / [News](#) / NSF statement on NSF and SpaceX Astronomy Coordination Agreement

NSF News

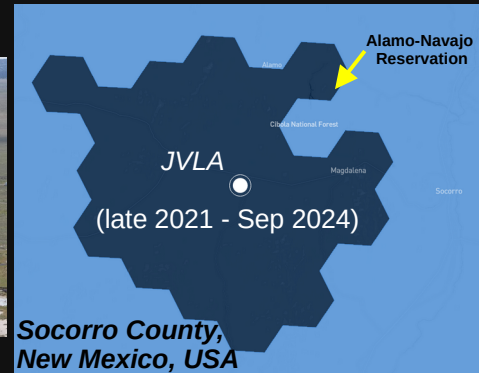
NSF statement on NSF and SpaceX Astronomy Coordination Agreement

January 10, 2023

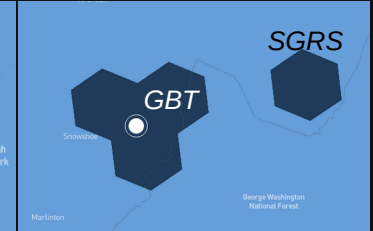
<https://new.nsf.gov/news/statement-nsf-astronomy-coordination-agreement>



Starlink User Terminals



(Sep 2024 - present)



(Oct 2024 - present)

Dark regions:

User terminals for fixed addresses are unavailable, except mobile units (e.g., RVs)

<https://www.starlink.com/map>

<https://public.nrao.edu/news/over-99-5-of-residents-in-the-national-radio-quiet-zone-can-now-receive-satellite-internet-service/>

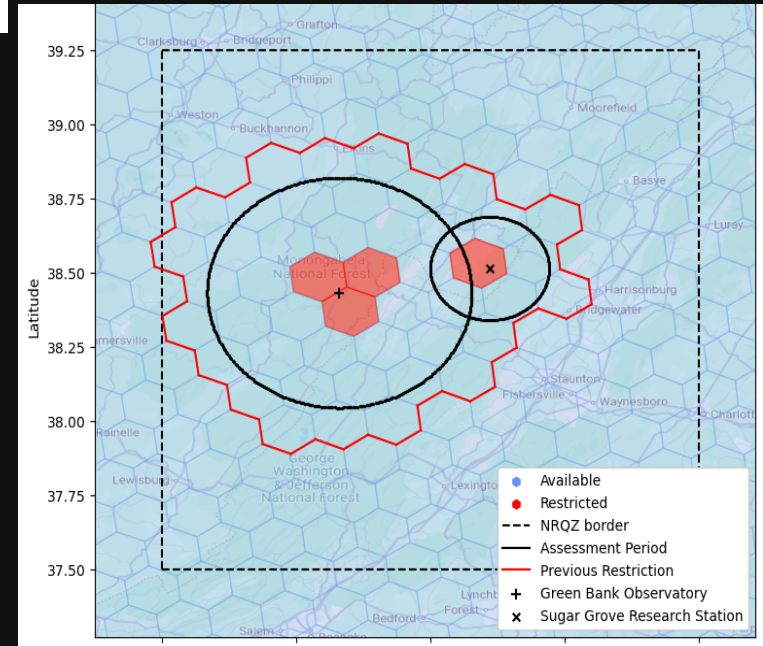
Home > News > News Release: October 25, 2024 at 1:30 pm EDT

Over 99.5% of residents in the National Radio Quiet Zone can now receive satellite internet service

Technical advances enable radio astronomy research to coexist with high speed internet service

“... SpaceX will begin a one-year assessment period to offer residential satellite internet service to 99.5% of residents within the NRQZ starting **October 25.**”

“This collaboration will allow residents to access high quality, high speed internet, and also expand opportunities for improved communication, like those needed by emergency services and first responders,” said Jim Jackson, the NSF Green Bank Observatory Director.



Credit: NSF/NSF NRAO/AUI/S. Wasik and SpaceX

Coordinated vs uncoordinated tests (NRAO & SpaceX)

- **Coordinated** (26 VLA tests & 14 GBT tests since Sep 2021)
 - **Prearrangement** between NRAO & SpaceX on different testing configurations
 - NRAO will schedule and conduct observations (at prearranged time, frequency, and sky position)
- **Uncoordinated** (> 40)
 - NRAO schedules independent observations without coordinating SpaceX (e.g., blind tests)
- **Typical Analysis & Interactions:**
 - Compare and identify Starlink downlink emission observed in VLA & GBT data in
 - X-bands (10.7-12.7 GHz)
 - Supplemental Coverage from Space (SCS) band (1990-1995 MHz)
 - **Assess** observed downlink signal properties:
 - Downlink signal level at the expected bands & potential out-of-band emission (OOBE)
 - Evaluate potential saturation of the telescope's analog or digital receiver chains by strong emission
 - Make **recommendations** to SpaceX team for potential improvement & reschedule for **follow-up tests**

Possible coexistence schemes

- **Zone avoidance**
 - Task downlink beam placement to avoid radio quiet zones
- **Boresight (Sky Zone) avoidance**
 - Momentarily disable downlink (~ few seconds) when close to the telescope's boresight within certain angular threshold
- **Frequency avoidance**
 - Only downlink at subbands 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			

Coordinated tests: Zone avoidance for 10.7-12.7 GHz downlink

VLA test

Chris De Pree, et al. (Apr 2023)
EVLA Memo #222/ RFI Memo #120

- Phase I testing (September 2021) involved running the User Terminal in normal mode at a variety of locations near the Very Large Array and the Pie Town VLBA antenna.
- Phase II testing (October 2021) involved fixed channel downlink frequency illumination of the VLA by Starlink satellites.

GBT test

Chris De Pree, et al. (Oct 2023)
RFI Memo #154

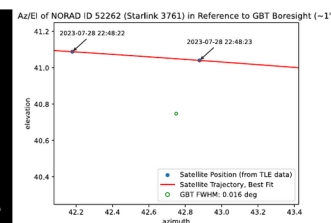
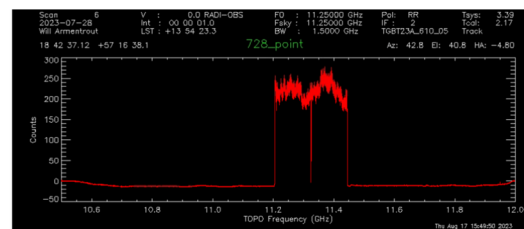
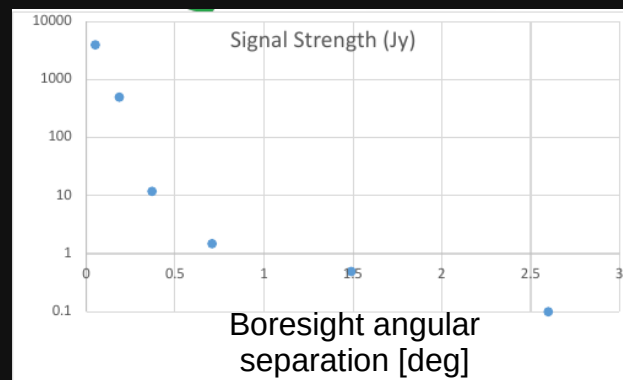


Fig. 10a (Left) Downlink signal detected in Channel 3 (~225 Jy). Time: 2023-07-28 22:48:21.75, Distance to Boresight: 0.27 degrees, Starlink Satellite Number: 3761. (Right) Starlink-3761 trajectory at this time, showing GBT FWHM at 12 GHz. Only Channels 4 and 5 were part of the “active avoidance” experiment from the SpaceX side.

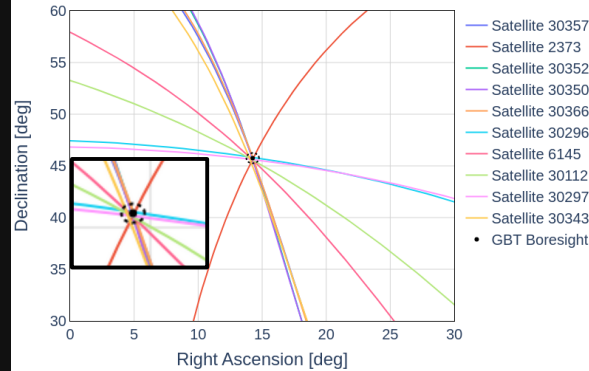
Coordinated test: Boresight avoidance for GBT X-band receiver

Nhan, B.; De Pree, C.; et al. (2024), ApJ Letters, Vol 971, issue 2

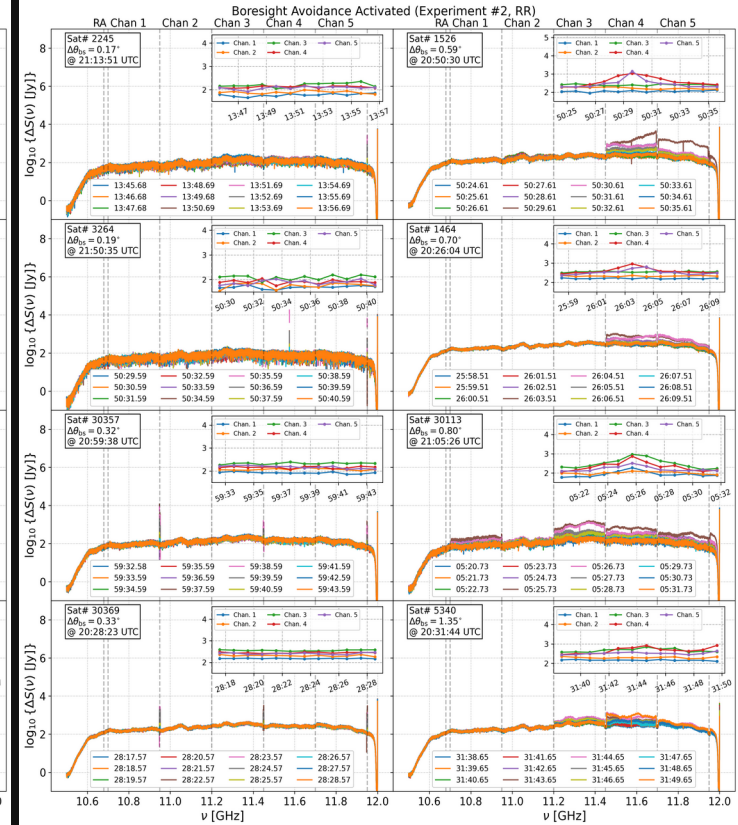
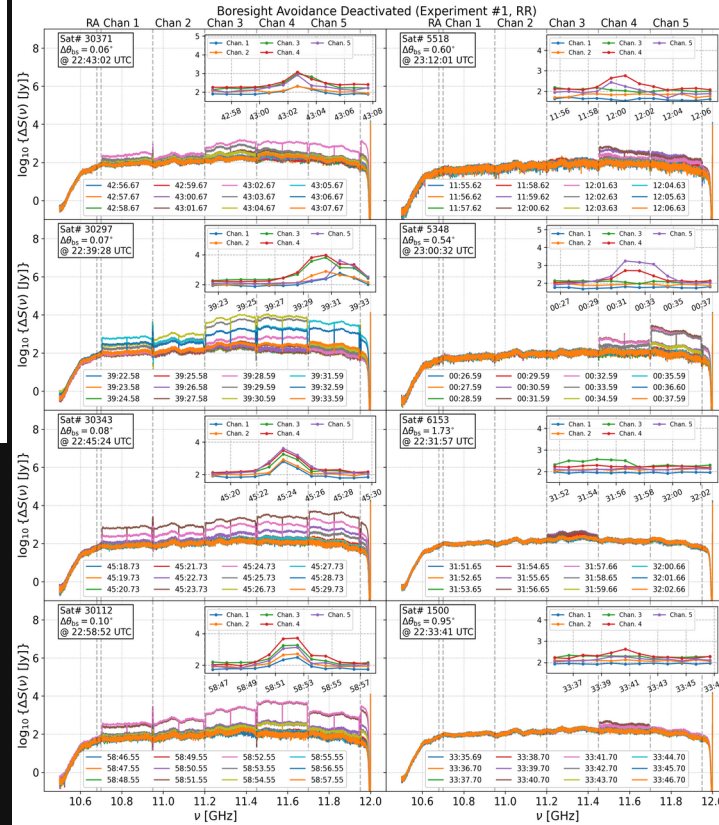
Test 1: No boresight avoidance

Test 2: With boresight avoidance

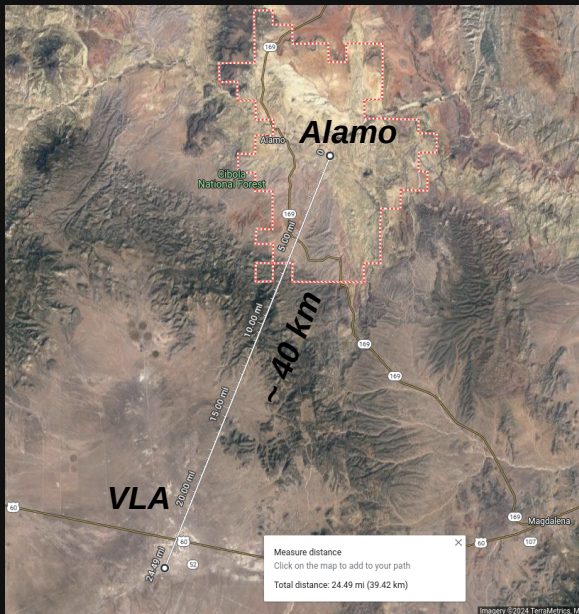
Sample of Satellite Passes, 2023-10-25 Experiment



- Disable downlink < 0.5 deg
- Place downlink beam far from telescope: $0.5\text{-}1.0$ deg



Uncoordinated tests (Alamo-Navajo Reservation with user terminals)

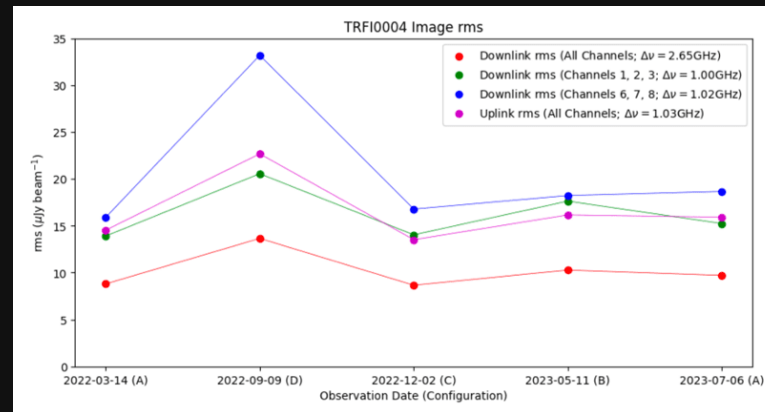
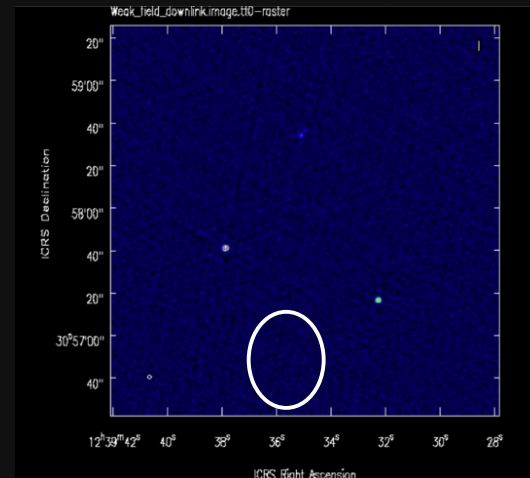


59 UTs
(installed Mar-Jun 2022)

Chris De Pree, et al. (Apr 2023)
RFI Memo #121

Test procedure:

- Observed once per month (Jan 2022 - Mar 2024)
- Once per VLA config (Mar 2024 - present)
- Point at a faint source
- Construct image via standard CASA pipeline
- Check RMS noise level
- ~ 36 tests so far

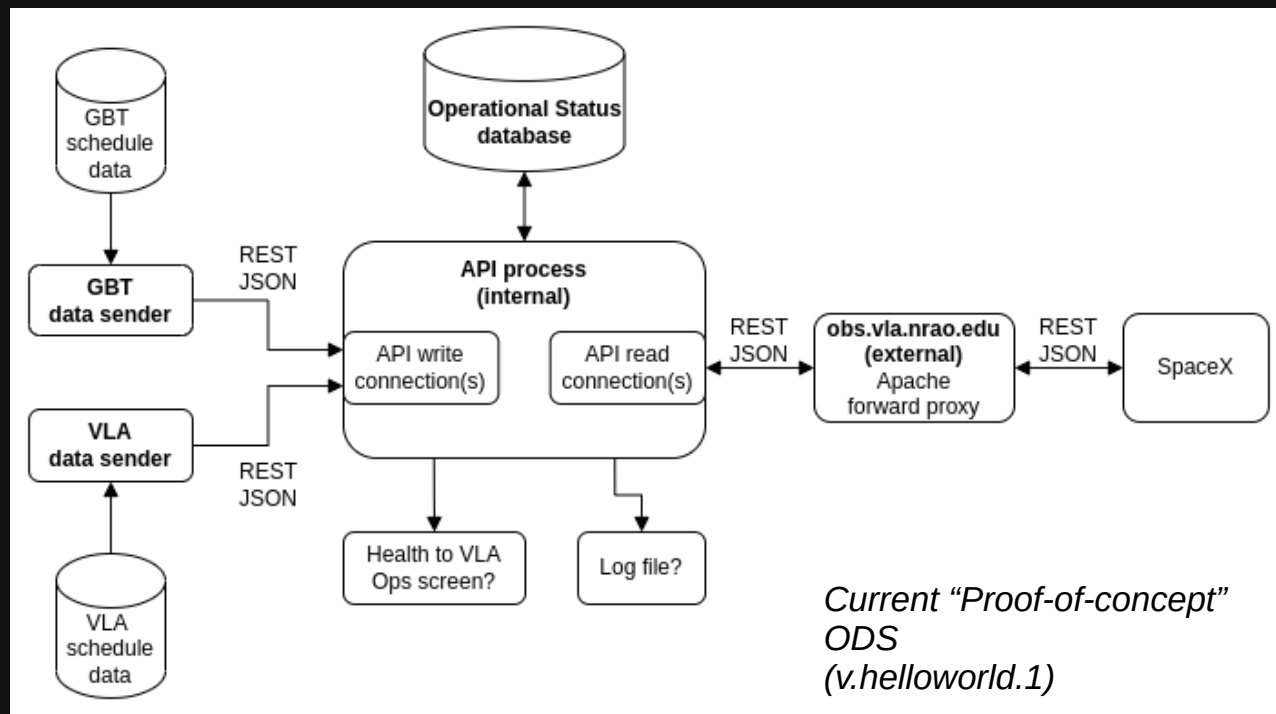


Credit: Aaron Lawson (NRAO)

Operational Data Sharing (ODS)

- Motivations:
 - **Coexistence** between sensitive radio telescope & sat constellations
 - **Automated** framework with **mutual awareness**
- Possible solutions:
 - Real-time self-informing system via Application Programming Interface (API)
 - Satellite operators can query the data & reconfigure satellite tasking (ideally with minimal impact on their network service)
- NRAO's current development scope (Oct 2023-present):
 - Report VLA & GBT observation to the ODS API server
 - Interface with SpaceX (along with others sat operators)
 - Iterate design parameters through continuing coordinated & uncoordinated testing

ODS API Schema



- To **automate** the coexistence schemes
- Self-hosted by NRAO
- Currently reporting VLA from observation scheduler database
- Protected & queried by recognized satellite operators
- **Standardized openAPI** specifications for broader adoption

Build your own ODS API: https://obs.vla.nrao.edu/ods/dev_notes.shtml

ODS's REST API JSON data format

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

Response

200

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

Description

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)
src_ra_j2000_deg	number	decimal-degrees	70.88181332916666	right ascension of the source/target
src_dec_j2000_deg	number	decimal-degrees	34.68518446944444	declination of the source/target
src_radius	number	decimal-degrees	0.0034	radius of beam around the source/target
src_start_utc	string	date-time	2023-08-16T15:23:47.000541	start time of this observing interval
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 sidereal)
trk_rate_ra_deg_per_sec	number	decimal-degrees per second	0	right ascension tracking rate of src (if not sidereal)
freq_lower_hz	number	decimal-Hz	26000000000	lower limit frequency used during this interval
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

Where

When

What

404

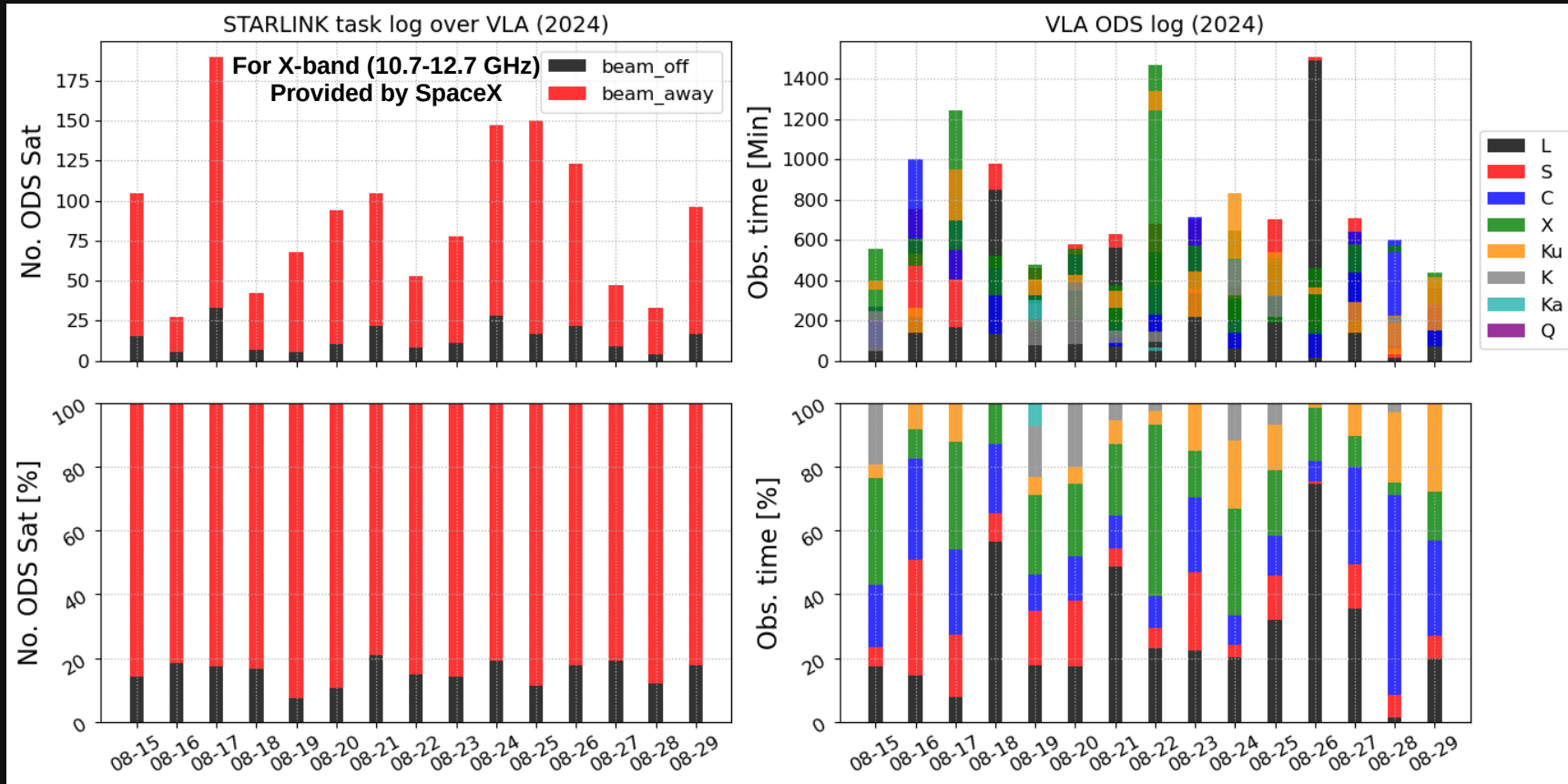
Resource Not Available

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**

B. Nhan - ODS coexistence

beam_off = shut off downlink (DL) beam
beam_away = place DL beam far from VLA

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Current status

- A working “**proof-of-concept**” ODS REST API for reporting VLA & GBT
- **Completed & validated coordinated ODS test** between VLA & SpaceX (May 2024)
- **Live ODS avoidance activated** for VLA by SpaceX for X-band at 10.7-12.7 GHz (since Aug 2024)
 - Receiving weekly status log from Starlink sats using the ODS
- **Ongoing ODS boresight avoidance** tests for VLA with Starlink’s **Direct to Cell (DtC)** downlink at 1990-1995 MHz (Nov 2024 - present)
- **Ongoing improvement on GBT reporting** accuracy before full avoidance activation (Spring 2025)
- **Ongoing iteration** of the ODS system with SpaceX & in discussion with other satellites operators (e.g., Amazon Kuiper)

Takeaways

- ODS data format standard can be considered by other RA facilities:
 - Ideally a **single standard** to encourage satellite operators to adopt
 - A **small number** of the ODS API servers, if not combined in a **single host server**
 - Hat Creek Radio Observatory (**HCRO**) is currently testing their **self-host** version of ODS database based on our standards <https://www.seti.org/hcro/ods>
 - MIT's Haystack team is considering a similar adoption
- Boresight avoidance is viable for a **small percentage of passages** & angular cutoff values, highly dependent on:
 - Telescope's **beam shape** & observation **frequency range**
 - Satellite operators' constraints on **tasking capabilities & service coverage**
- This is an **iterative** and **collaborative process**
 - Need **communication & agreement** between different stakeholders
 - Need **periodic testing & evaluation** due to the dynamic nature of the satellite constellations



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