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Observations and Modeling of RFI from Mega-Constellations on Radio Telescopes

9th International VLBI Technology Workshop

October 21, 2024

Samuel Thé

MIT Haystack Observatory

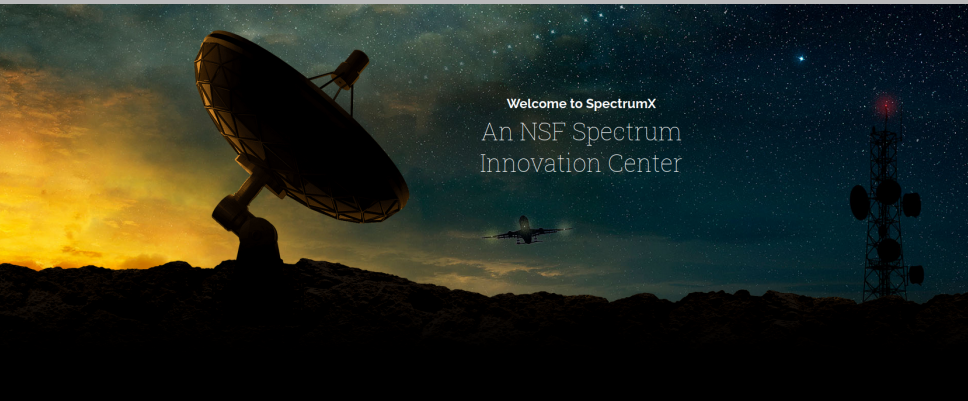
What is SpectrumX?



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Welcome to SpectrumX

An NSF Spectrum Innovation Center

Who We Are

A diverse and interdisciplinary group of scientists, engineers, and educators with backgrounds in EE, CS, Aero, Astronomy, Geoscience, Economics, Policy, and Workforce Development.

What We Do

Conduct strategic research and workforce development projects to transform spectrum management.

Why It Matters

Radio frequency spectrum has become a vital resource in need of balance that can be achieved through innovative advancements in policy and technology.

<https://www.spectrumx.org/>



What is SpectrumX?

Collaboration is Key to the SpectrumX Mission



30
Partner
Institutions

56
Researchers
and Staff

82
Students

12
Active
Collaborations



Collaboration Advisory Board ("CAB") Members



Collaborating Partners

RC - Economics,
Rights, & Policy

RC - Technology &
Measurements

RC - Models,
Algorithms, & AI/ML

Research
Communities (RC)

FP1 - Spectrum
Awareness

FP2 - Scientific
Coexistence

Flagship Projects
(FP)

5G Sharing

AI/ML for Spectrum
Mgmt

Valued-Based
Spectrum Mgmt

Interference
Analysis

NTIA Liaisons



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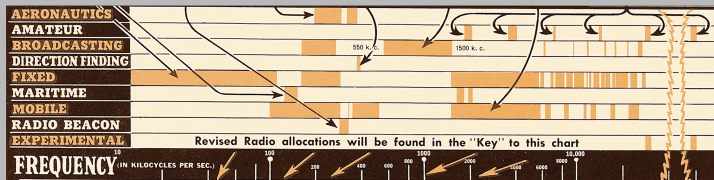
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Spectrum Sharing

UNITED STATES FREQUENCY ALLOCATIONS

THE RADIO SPECTRUM

1944





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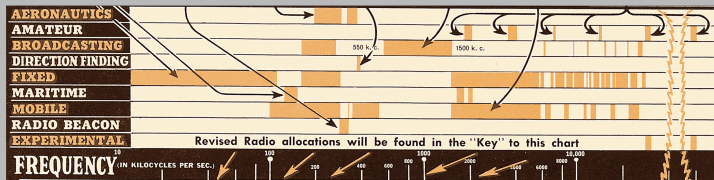
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Spectrum Sharing

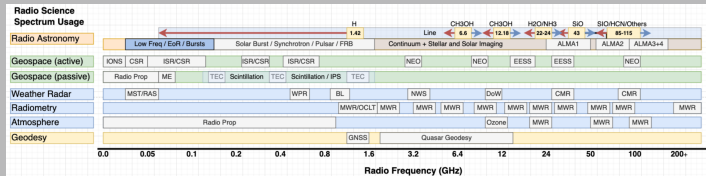
UNITED STATES FREQUENCY ALLOCATIONS

THE RADIO SPECTRUM

1944



NOW



THE RADIO SPECTRUM

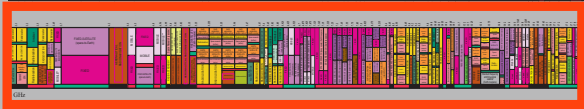
THE RADIO SPECTRUM



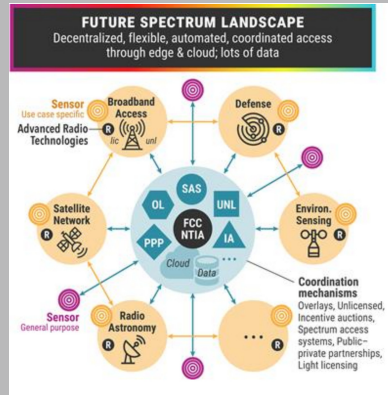
THE RADIO SPECTRUM

ALLOCATIONS

THE RADIO SPECTRUM



- Flexible management of spectrum.
- Dynamic, data-driven and automated access/allocation.
- Education and outreach for a better understanding of spectrum use.
- Policy engagement for coexistence between commercial, scientific and government applications.



3 GHz

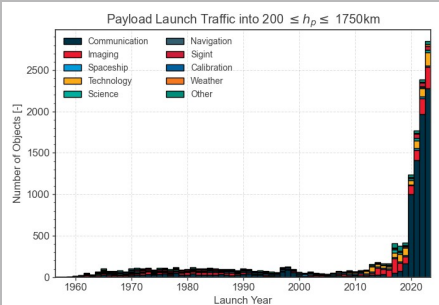
Starlink Mega-Constellations



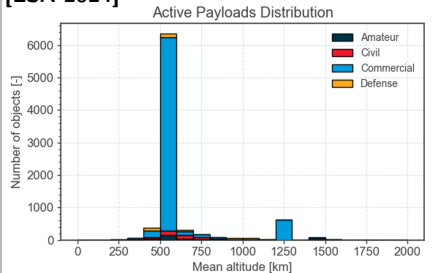
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- Rapid growth of communication satellites.



[ESA 2024]



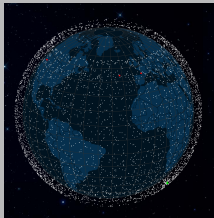
Starlink Mega-Constellations



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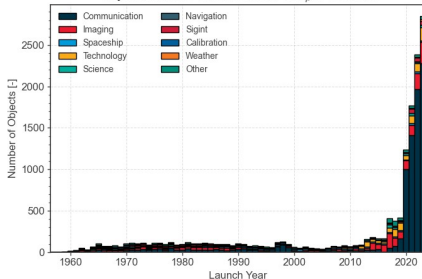
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- Rapid growth of communication satellites.
- Starlink is one of the most complete (for now).
- Internet access to ground antennas (Ku-band), cellphones (L-band).
- No service available around Haystack.



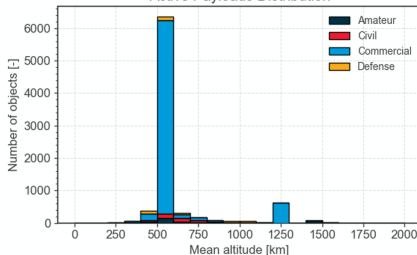
<https://satellitemap.space/>

Payload Launch Traffic into $200 \leq h_p \leq 1750\text{km}$



[ESA 2024]

Active Payloads Distribution



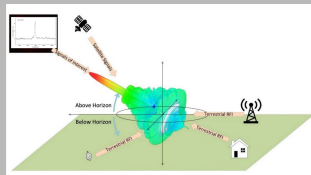
Radio Frequency Interference



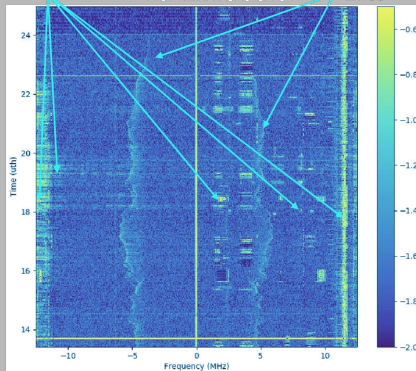
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- Signals of scientific interest very low ($\text{SNR} \ll 1$).
Sensitivity $\ll 1 \text{ Jy} = 10^{-26} \text{ W.m}^{-2}.\text{Hz}^{-1}$.
- Interferences from different sources.
- Boresight and sidelobes interactions.



RFI

Millstone UHF Radar
440.2 MHz 2020-02-04Plasma
Lines

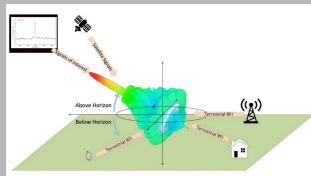


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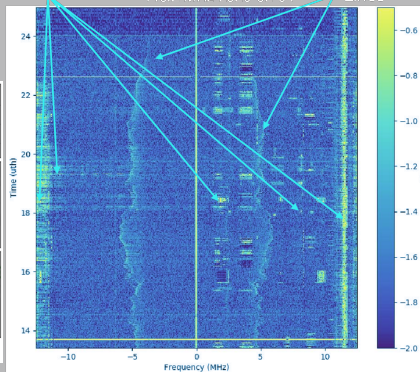
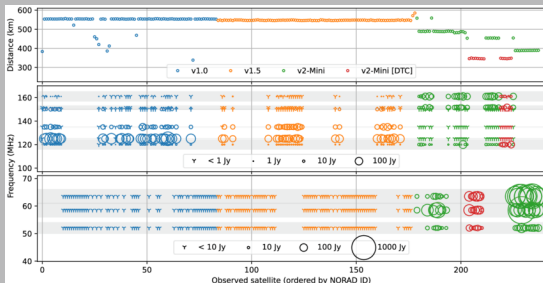
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Radio Frequency Interference

- Signals of scientific interest very low ($\text{SNR} \ll 1$).
Sensitivity $\ll 1 \text{ Jy} = 10^{-26} \text{ W.m}^{-2}.\text{Hz}^{-1}$.
- Interferences from different sources.
- Boresight and sidelobes interactions.
- Unintended interferences of satellites are a challenge [Di Vruno et al. 2023, Bassa et al. 2024].
- Protected bands are already impacted.



RFI

Millstone UHF Radar
440.2 MHz 2020-02-04Plasma
Lines

[Bassa et al. 2024]

Westford Antenna

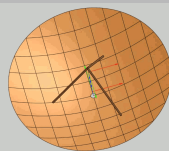
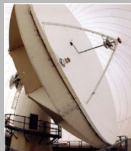


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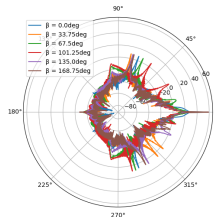
Aim of the study:

- Model the aggregated power of the constellations on a radio telescope.
- Observe the in-band and out-of-band emissions of the satellites.
- Using the 18.3m Westford antenna.
- NASA-VGOS feed for geodesy (VLBI).
- Transit observations of satellites.



Parameter	Westford
primary reflector shape	symmetric paraboloid
primary reflector diameter	18.3 meters
primary reflector material	aluminum honeycomb
feed location	primary focus
focal length	5.5 meters
antenna mount	elevation over azimuth
antenna drives	electric (DC) motors
azimuth range	$90^{\circ} - 470^{\circ}$
elevation range	$4^{\circ} - 87^{\circ}$
azimuth slew speed	3° s^{-1}
elevation slew speed	2° s^{-1}
Frequency range 2–14 GHz	
T_{sys} at zenith	40–70 K
aperture efficiency	0.25–0.60
SEFD at zenith	1800–4500 Jy

Antenna gain in dB along polar angle α for some azimuthal angles β



Ku-band Starlink

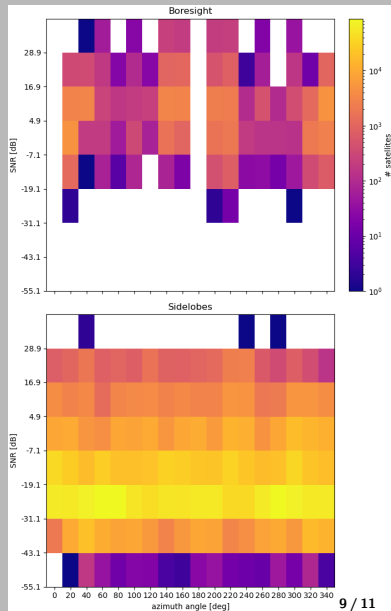


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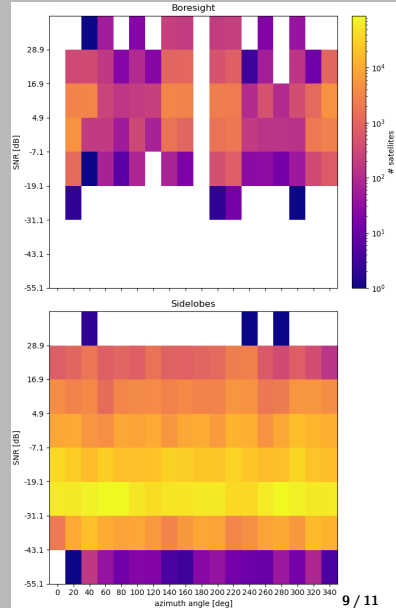
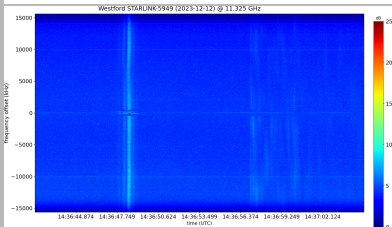
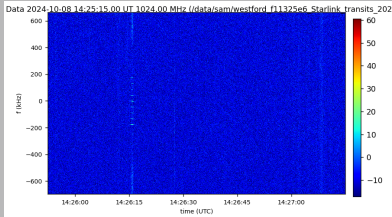
- Predict the SNR levels of interference.
- Account for sidelobe interactions.





Ku-band Starlink

- Predict the SNR levels of interference.
- Account for sidelobes interactions.
- identify RFIs high and low SNR.

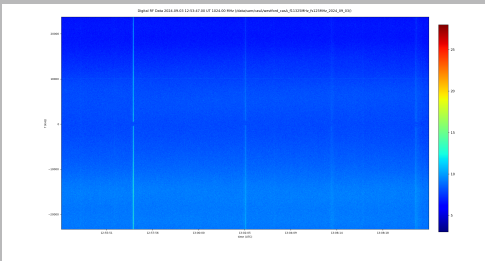




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- Astronomical observations are already impacted in-band.



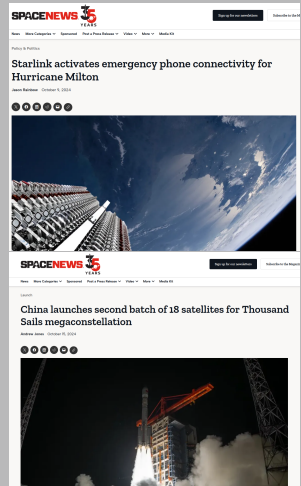
What's next?



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- Future plans:
 - Out-of-band observations (protected bands and harmonics).
 - Refine model with better account of satellite gain pattern, atmospheric temperature and bandwidth usage.
 - Other constellations to model.
- Coexistence strategies:
 - Flagging and processing.
 - Boresight avoidance [Nhan et al. 2024].
 - Flexible allocations.
- Fast growth, with more and more interests and uses:
 - Emergency usage.
 - More constellations (Kuiper, OneWeb, Thousands Sails).
 - Direct-To-Cellphone capabilities (L-band).





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Questions?