An NSF Spectrum Innovation Center

Fixed Satellite Service (FSS) & Radio Astronomy Service (RAS) Coexistence

@ V-band

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Introduction to Analog and Digital Communications (Fall 2022)

Who we are

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Introduction

Incumbent: Radio Astronomy (RAS) operates throughout V-band (40-75 GHz)[13]

Entrant: Fixed Satellite Service (FSS) Broadband Satellites, 37.5-42.5 GHz (Space-to-Earth)[14]

Coexistence Issues: Adjacent and In-band Interference

Radio frequency interference from NGSO FSS constellations poses a threat to Radio Astronomy[1][7][8]

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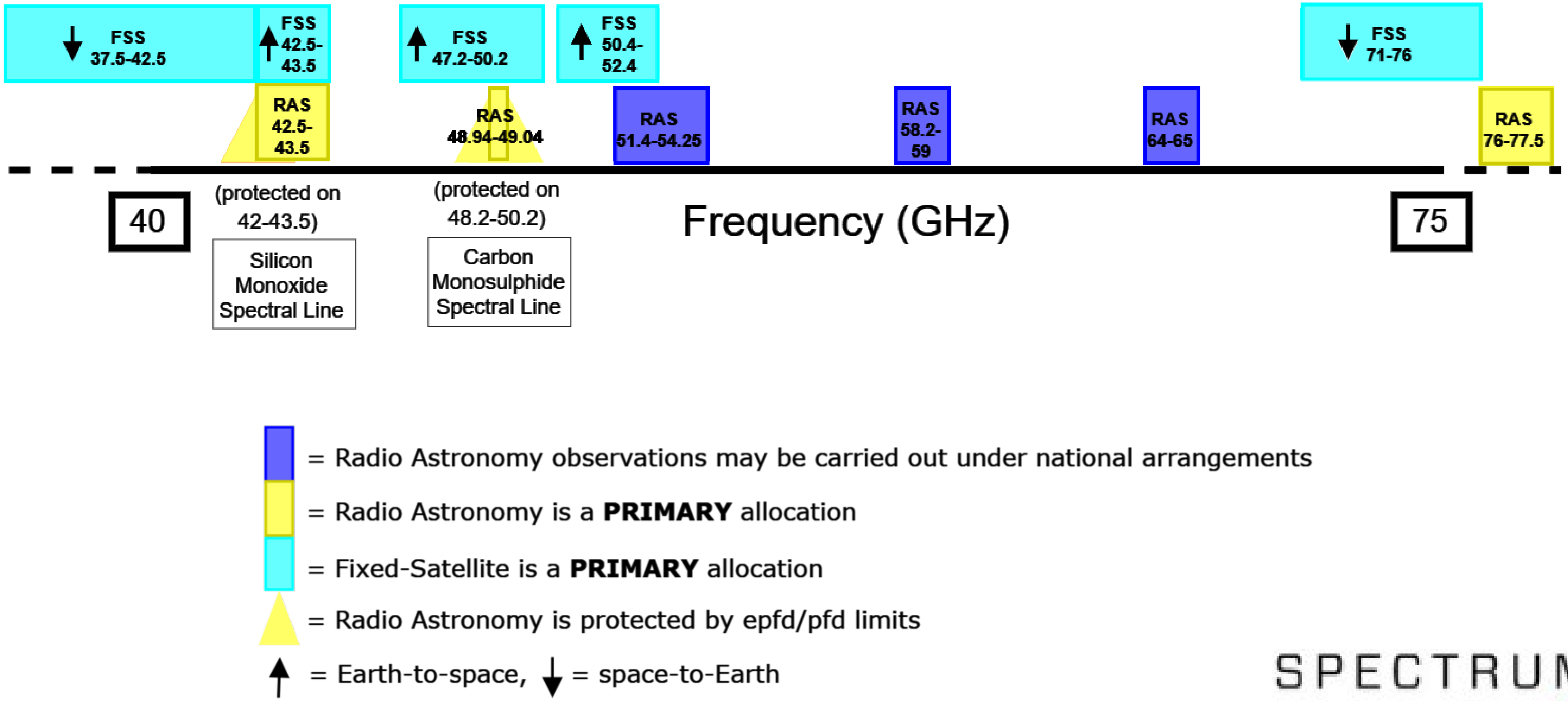
ITU Radio Regulations 2020 (Region 2)
V-Band [40-75 GHz]



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Radio Astronomy (RAS)

Incumbent

- Radio telescopes study celestial objects at frequencies outside the visual range[4][15]
    - Black holes, pulsars, cosmic microwave background[3]
- Continuum Emission: Radiation at a wide range of wavelengths (ex. thermal emission)[19]
- Spectral Lines: Radiation at specific wavelengths (elements and molecules have spectral lines)[19]

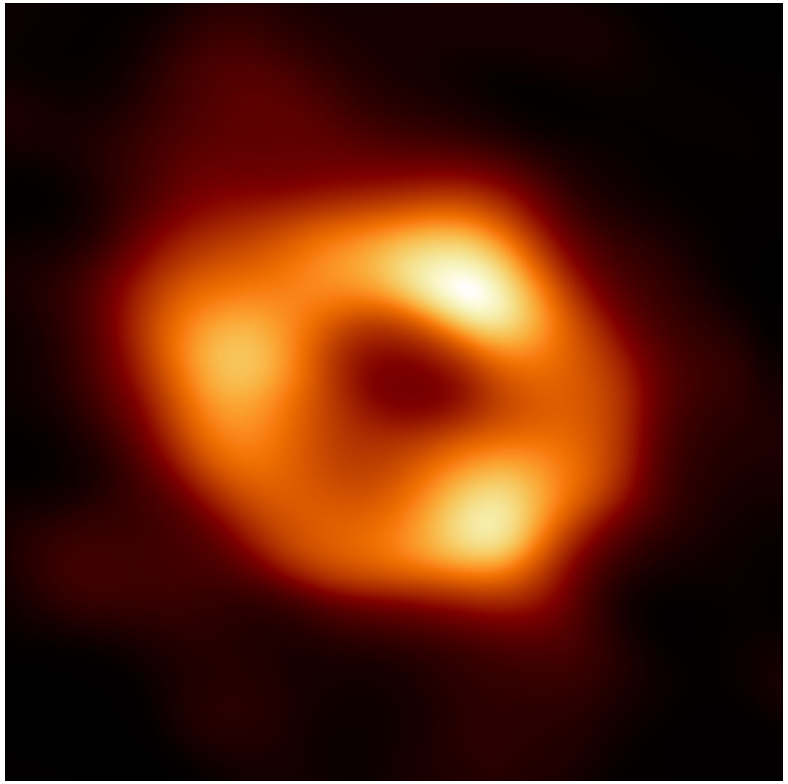

Figure 1: Sagittarius A*, the black hole at the center of our galaxy[18]

Radio Astronomy (RAS)

Incumbent

- Require large antennas and extremely sensitive receiving equipment to pick up very faint and far-away signals[1][4]
- Telescope arrays are built in remote high desert areas[1][4]
- Radio emissions may cause radio frequency interference (radio quiet zones)[1][4]
- Satellites in the path of highly sensitive radio telescopes are dangerous to radio astronomy - cannot escape interference[1]

Figure 2: Very Large Array in New Mexico (NRAO)[18]

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Fixed Satellite Service (FSS) NGSO Constellations

- FSS: Radiocommunication service between earth stations at given positions, when one or more satellites are used[14]
- Compared to K-band, V-band allows more bandwidth and throughput. However, higher frequencies are more susceptible to fade[10]
- “The history of wireless communications has been a slow migration to higher frequencies over time” - Armand Musey, Summit Ridge Group[12]

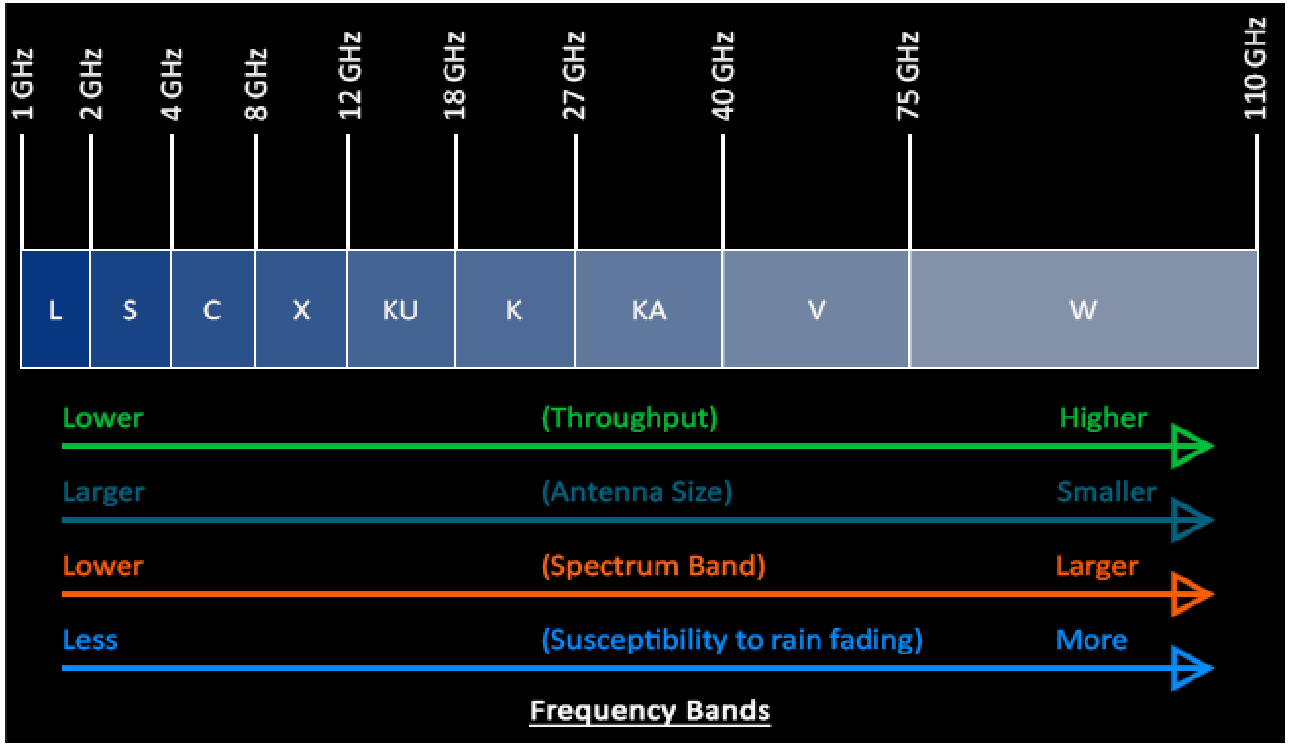

Figure 3: Comparison of V-band and other frequency bands

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Fixed Satellite Service (FSS) NGSO Constellations

- Over 4,000 NGSO FSS satellites launched since 2019, operating primarily in K-band
- By November 2021: Non-geostationary satellite constellations seek FCC approval for nearly 38,000 V-band satellites for new or expanded broadband networks[12]
- V-band Players: Amazon, Astra, Boeing, Inmarsat, Intelsat, Hughes, OneWeb, SpinLaunch, Telesat, SpaceX[12]

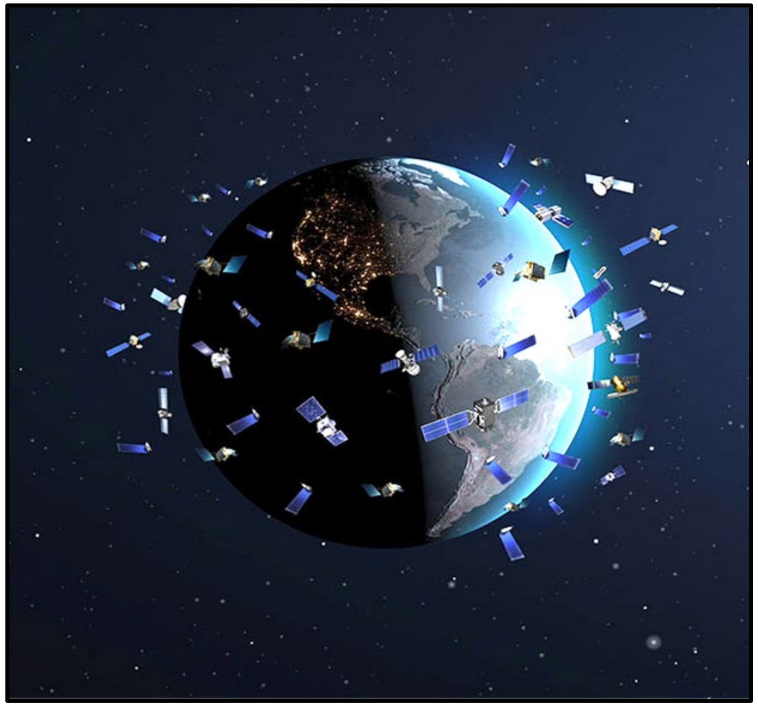

Figure 4: Constellations in orbit (concept art)[11]

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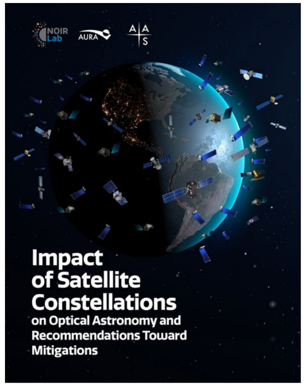
Karl Jansky
1932

National Radio Quiet Zone established
1957

1980
Very Large Array built

May 2019
SpaceX Starlink first launch[6]



SATCON1[9]
June 2020

SATCON2[5][11]
July 2021

November 2021:
FCC filings for nearly 38,000 V-band satellites[12]

Centre for the Protection of the Dark and Quiet Sky from Satellite Constellation Interference
CPS
IAU NOIRLab SKAO

Centre for the Protection of the Dark and Quiet Sky[7]
April 2022

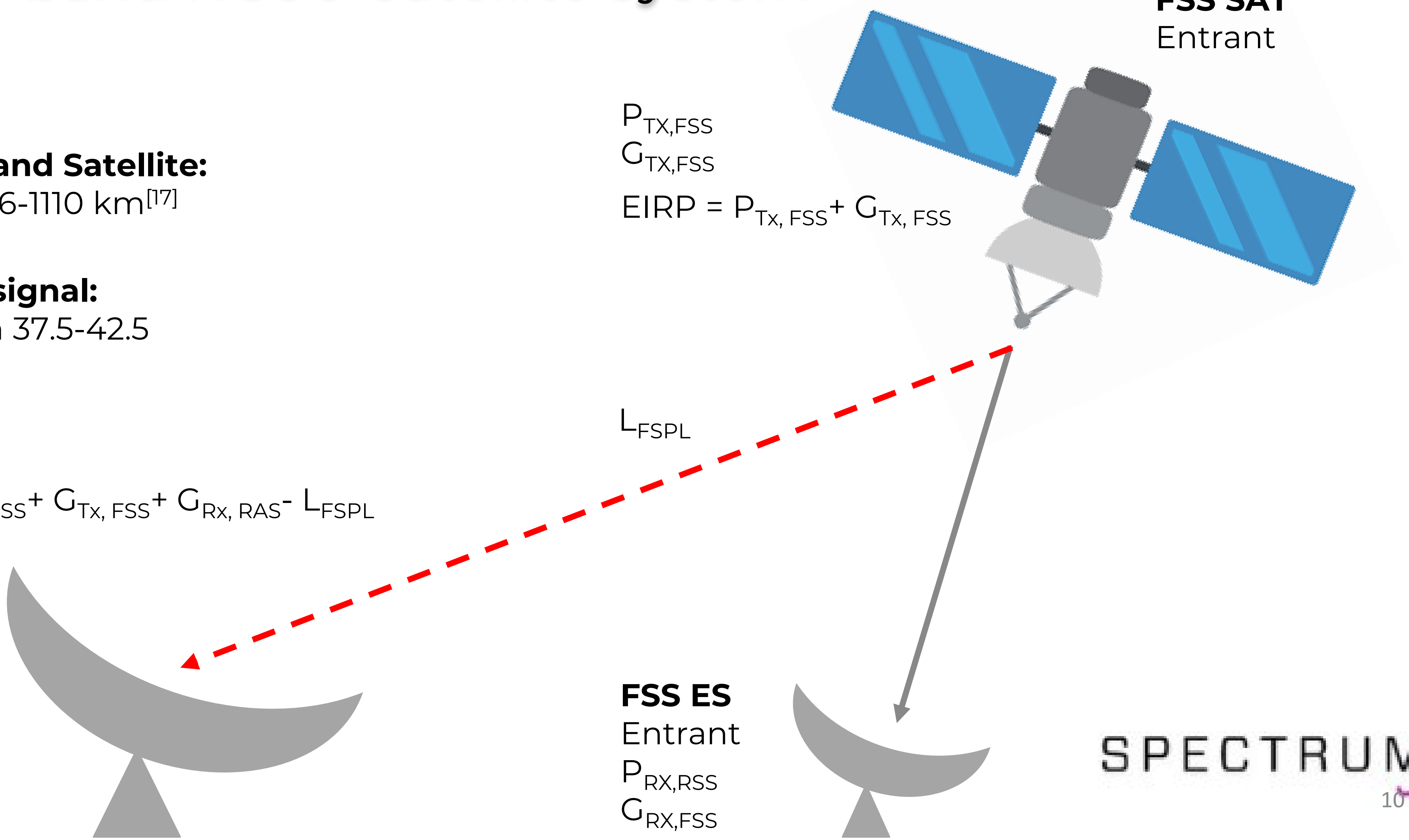
Interference Geometry

SpaceX V-band NGSO Satellite System

SpaceX V-band Satellite:
Altitude: ~336-1110 km[17]

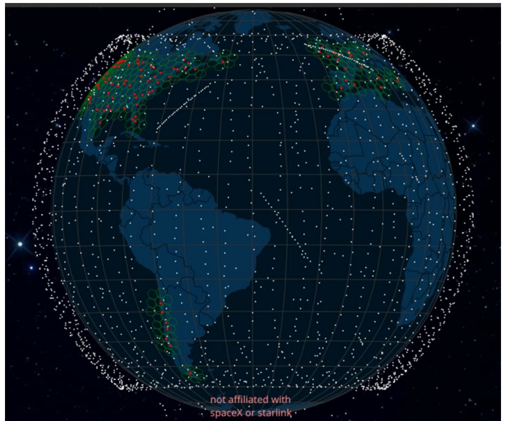
Interfering signal:
Downlink on 37.5-42.5 GHz[17]

$P_{Rx,\,RAS} = P_{Tx,\,FSS} + G_{Tx,\,FSS} + G_{Rx,\,RAS} - L_{FSPL}$



Proposed Mitigations

- SatHub: software tools for astronomers to avoid satellite passes in observations or correct affected observations[5][9][11]
  - Share more accurate satellite position data to enable astronomers to avoid satellites in observations (SpaceX)[5][9][11]
  - Less effective the more satellites there are[20]
- Arrayed telescopes less vulnerable to RFI than single beam[1]
- Radio filters on satellites to protect RAS (OneWeb)[2]



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Proposed Solutions

- **Coordination**: NRAO and SpaceX continue to collaborate on experiments to study interference from FSS to RAS[20]
  - Steer satellite transmitters away from telescope sites[20][16]
  - Finding success using phase delay[20]
- Center for Protection of the Dark and Quiet Sky (CPS)[7]
- **Policy**: Find ways to inform FSS about RAS operations to allow them to adjust operations to avoid those downlink channels - NRAO Dr. Chris De Pree[20][1]
- Regulate limits on radio frequency interference (RFI)[1]
  - EPFD and Interference-to-Noise (I/N) recommendations[14]

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Recommendation on Equivalent Power Flux Density (EPFD) in 42.5-43.5 GHz
ITU Radio Regulations Chapter II Article 5[14]

EPFD is basically the power of the interferer's (FSS satellites) transmissions that are received by the victim (radio telescopes)

5.551H The equivalent power flux-density (epfd) produced in the frequency band 42.5-43.5 GHz by all space stations in any non-geostationary-satellite system in the fixed-satellite service (space-to-Earth), or in the broadcasting-satellite service operating in the frequency band 42-42.5 GHz, shall not exceed the following values at the site of any radio astronomy station for more than 2% of the time:

-230 dB(W/m^2) in 1 GHz and -246 dB(W/m^2) in any 500 kHz of the frequency band 42.5-43.5 GHz at the site of any radio astronomy station registered as a single-dish telescope; and

-209 dB(W/m^2) in any 500 kHz of the frequency band 42.5-43.5 GHz at the site of any radio astronomy station registered as a very long baseline interferometry station.

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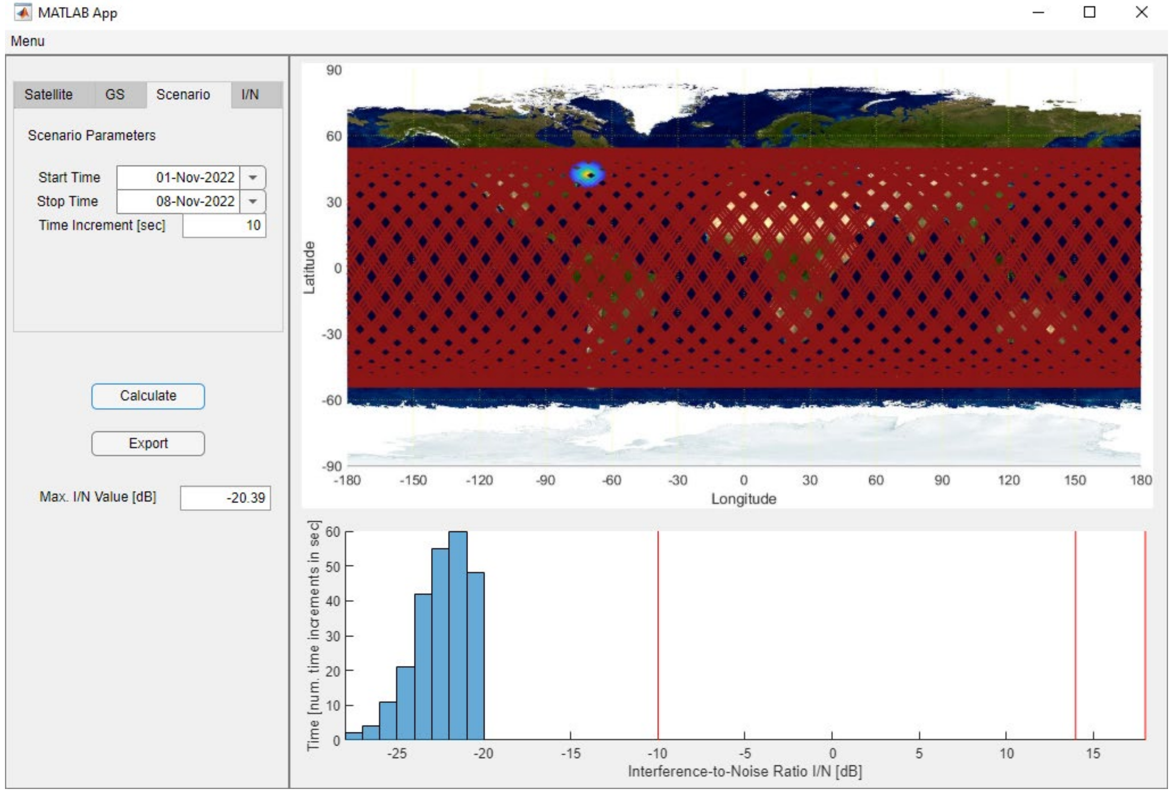
Interference-to-Noise (I/N)

- Another metric of RFI
- Quantify Interference using Dynamic Interference-to-Noise Analysis
- OSSTP currently working on a tool for this
- First step to mitigating inter-ference is understanding it



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In Conclusion

- Inform satellites about RAS operations and adjust operations to avoid those downlink channels
- Require operators to steer satellite beams away from telescope sites and consider the use of additional RF filters on their satellite systems
- Further work on RFI Limits and mathematical modeling of EPFD and I/N

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Questions?

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