

# Radio Observations of Satellite Constellations

Monitoring communication satellites through DIY antennas and machine learning techniques

*Taylor Pomfret*

*Project Partner: Neha Yasin*

*Supervisor: Mike Peel*

# Overview

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  - Count plots
  - Occupancy plots
- Analysis of spectral management
  - Incorporating ML techniques such as EMPCA, to globally describe the Ku-Band usage.

# Current active satellite distribution

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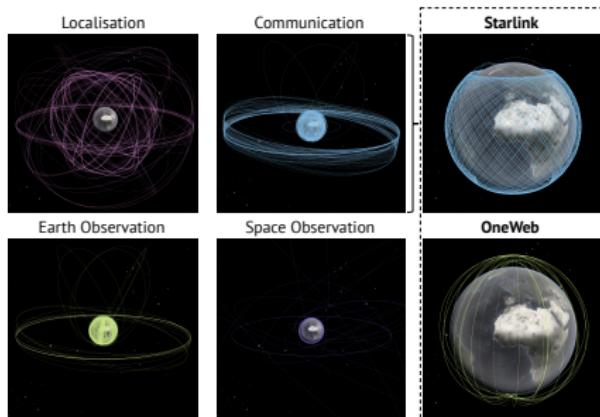


Figure 1: Orbits of satellites; adapted from Sat Tracker GitHub [1].

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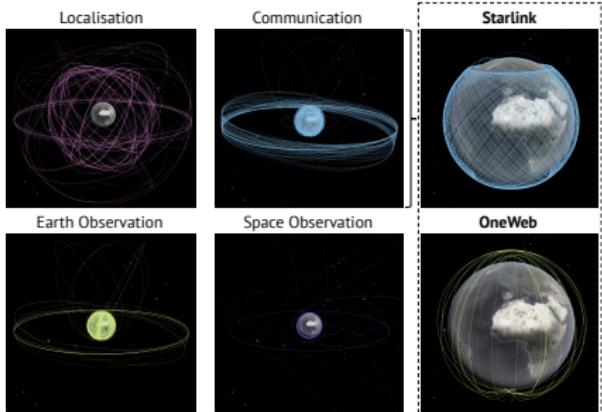


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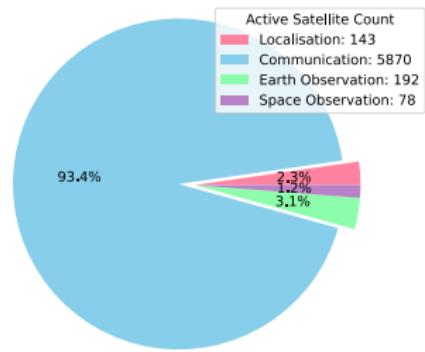


Figure 2: Distribution of active satellite count [2].

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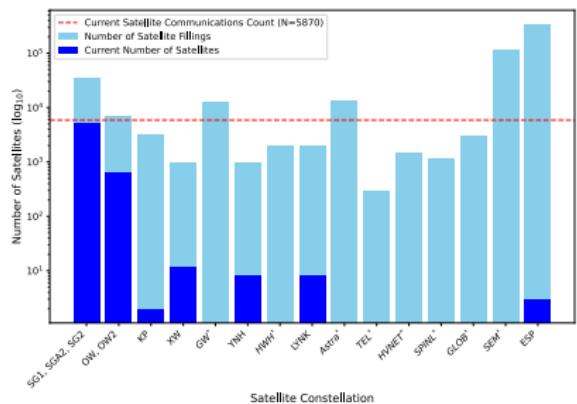


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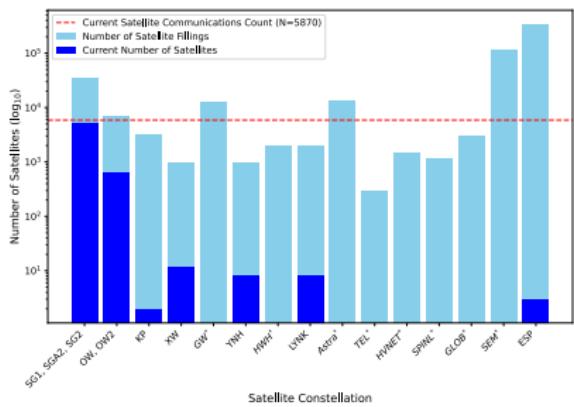


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## A surge in satellites

Cumulative growth in the number of satellites filed in the International Telecommunication Union (ITU) "As Received" database from 1 January 2017 to 31 December 2022.

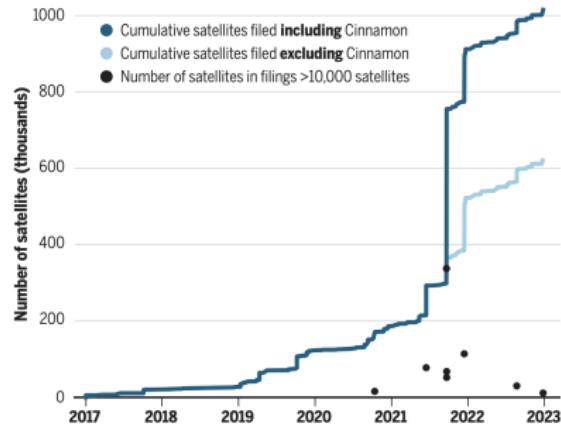


Figure 4: Cumulative proposal count, extracted from [3]

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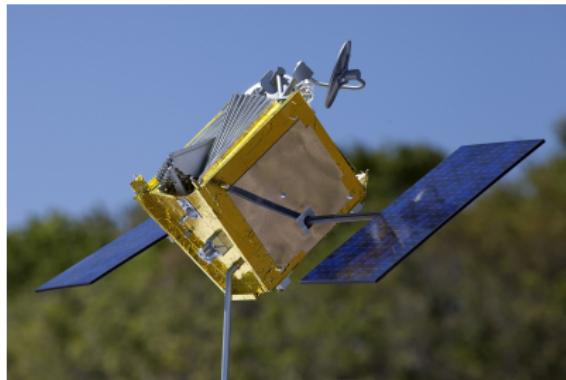


Figure 5: OneWeb Satellite [4]

## Monitoring communications satellites

- Starlink and OneWeb's Downlink signal operates in the Ku-Band, specifically 10.7-12.7GHz.

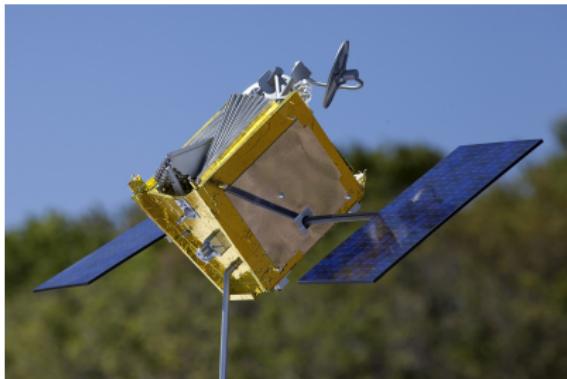


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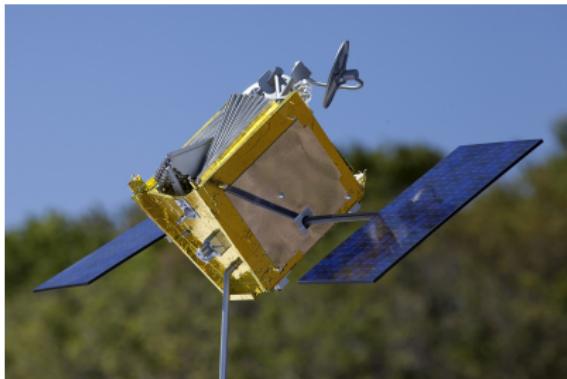


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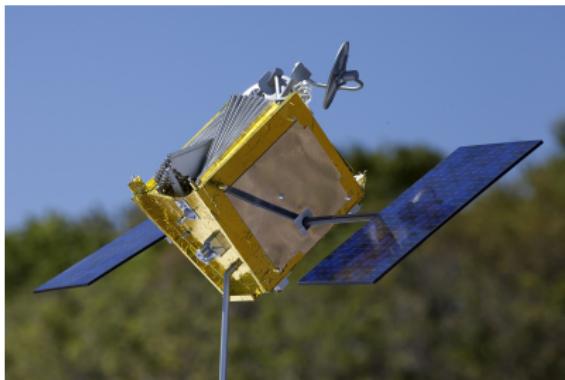


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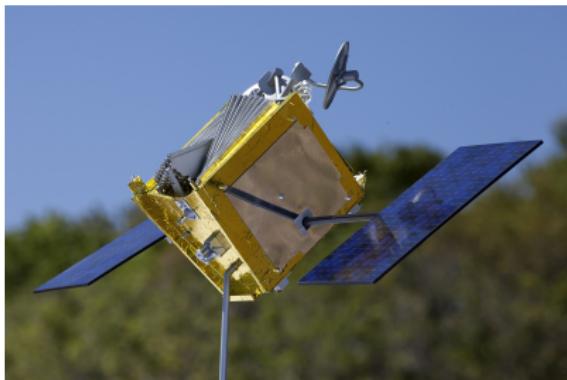


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- Motivation to monitor: spectrum management, protected frequency band.

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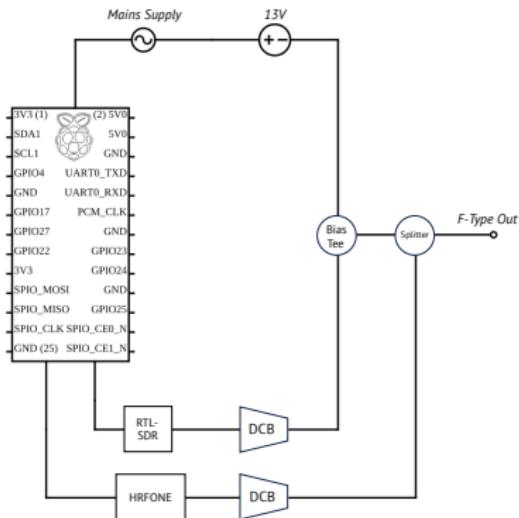


Figure 6: Schematic of radio circuit

# Experimental set-up

- HRFONE: Downlink signals

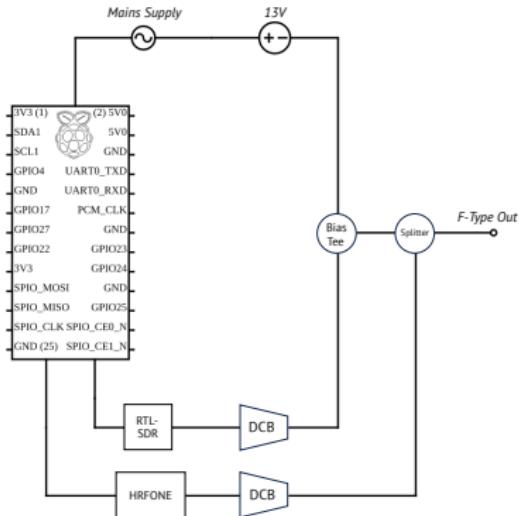


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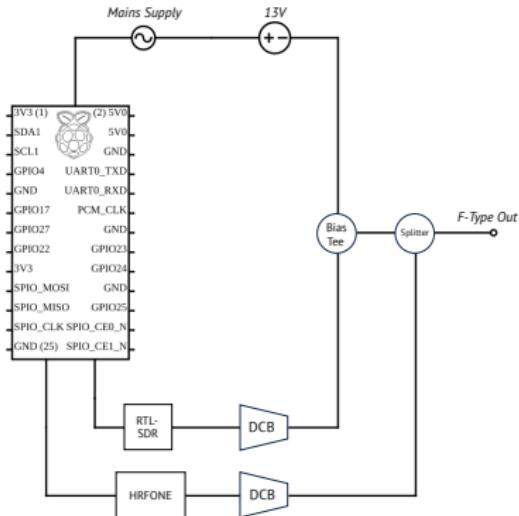


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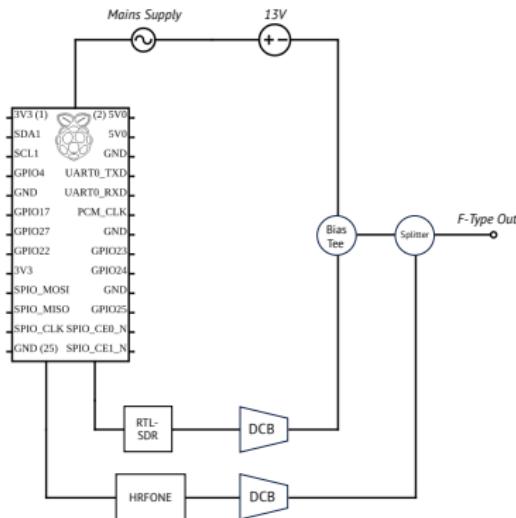


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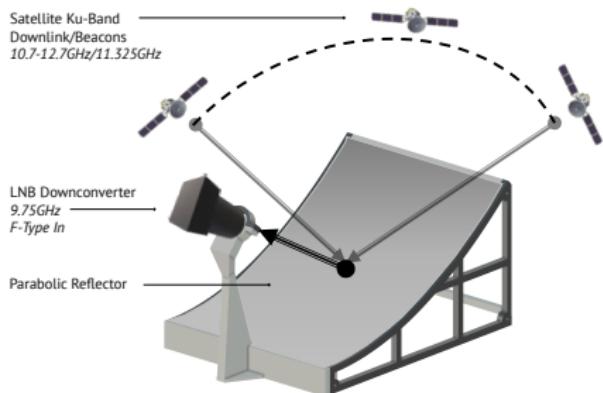


Figure 7: Receiver unit

# Data Collection Process

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### Raspberry Pi data collection routine [6]

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launch_SDRs	HackRF: 250-2350MHz power spectrum; RTL-SDR: 1574.5-1575.5MHz power spectrum
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## Downlink Analysis

Utilise data collected over a 3 day period, encompassing a total of **1,004,319 scans** within the **10GHz - 12.1GHz** frequency range distributed across 420 frequency bins.

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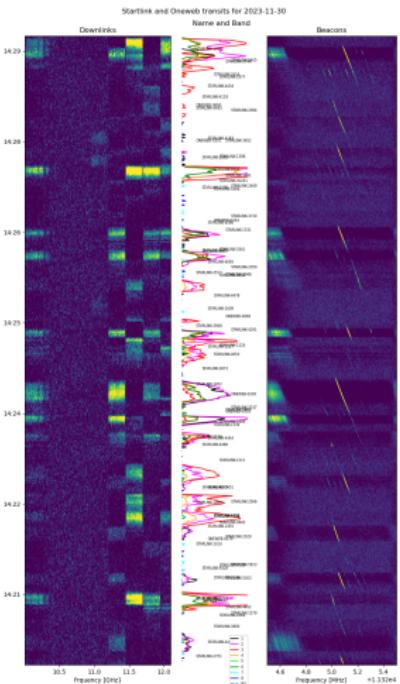


Figure 8: Waterfall plot taken on 30/11

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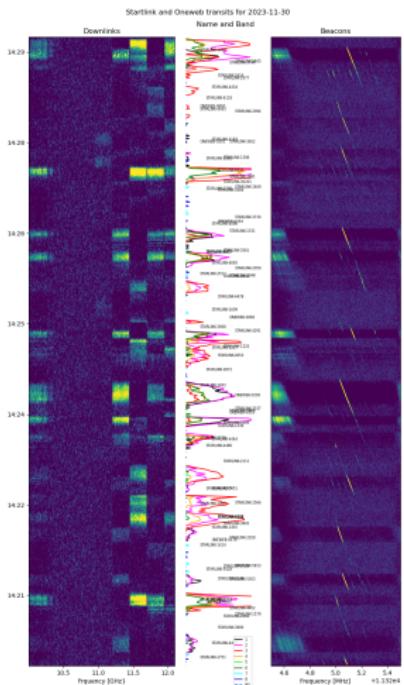


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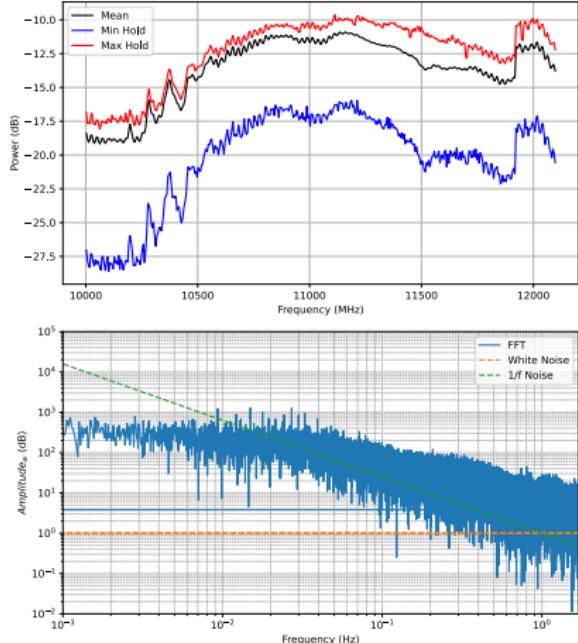


Figure 9: Scanned spectrum (top), Fourier Transform of Waterfall data (bottom)

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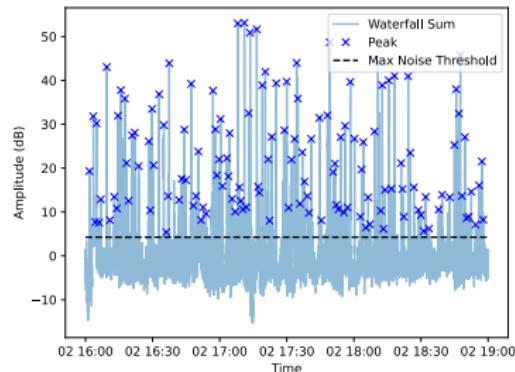


Figure 10: Peak detection algorithm

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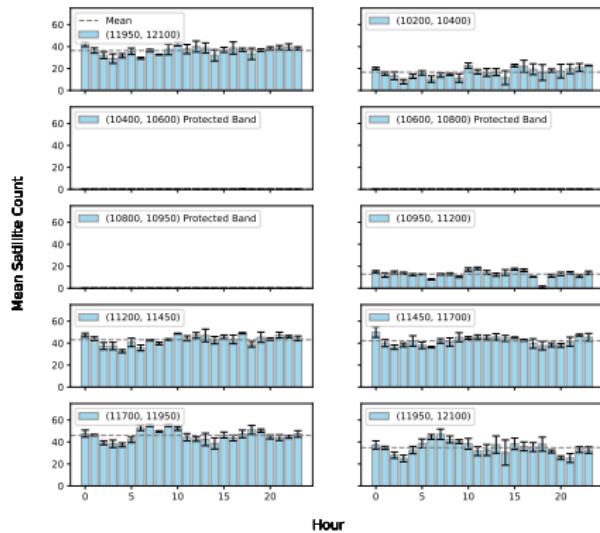


Figure 11: Satellite Count Plot

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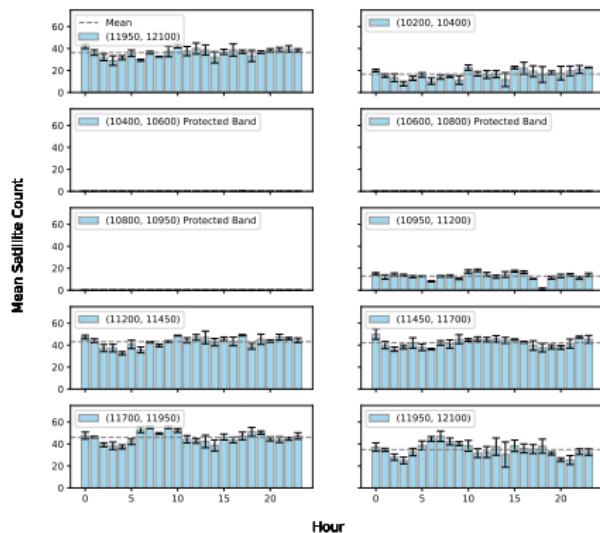


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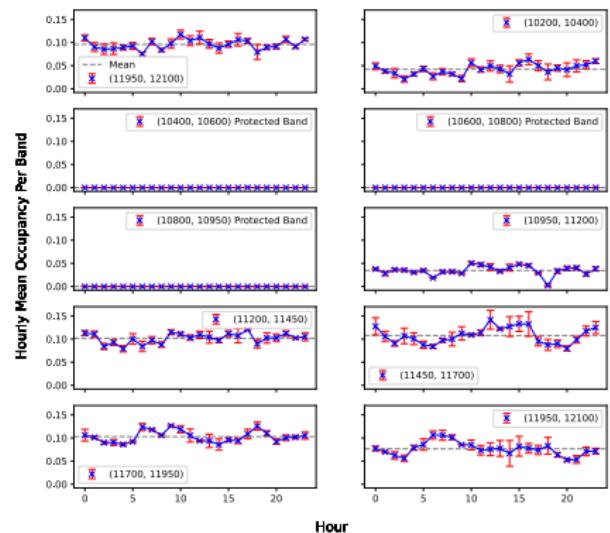


Figure 12: Occupancy plot

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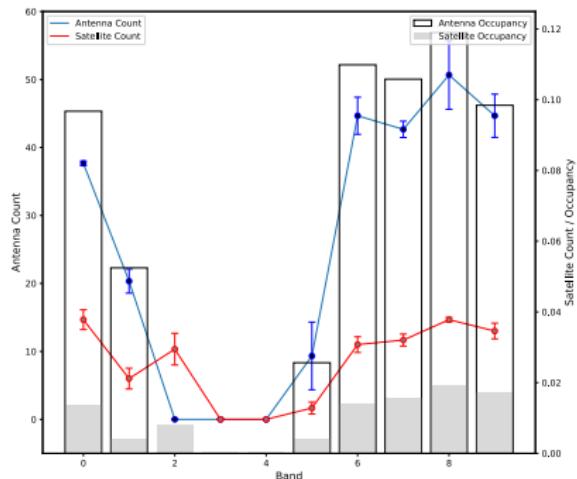
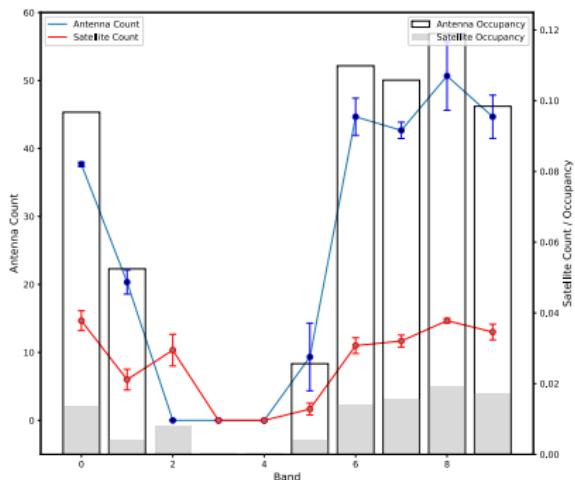


Figure 13: Count and occupancy plot for 3 hour samples of satellite and antenna data

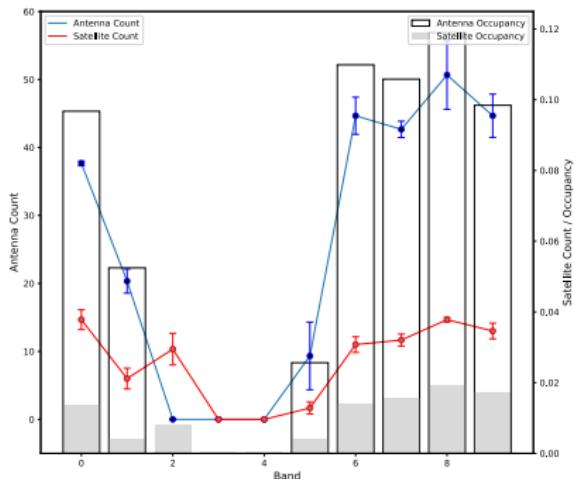
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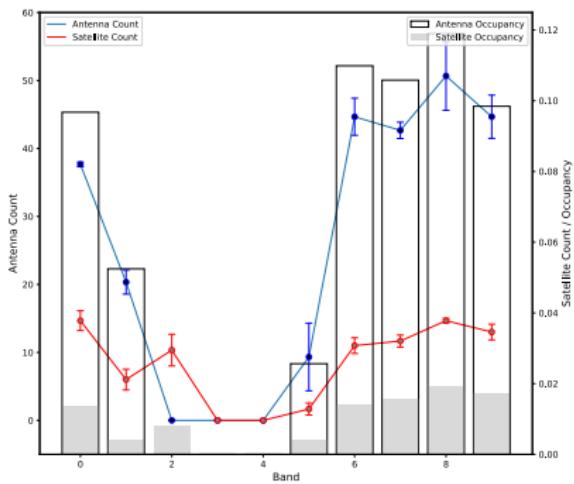
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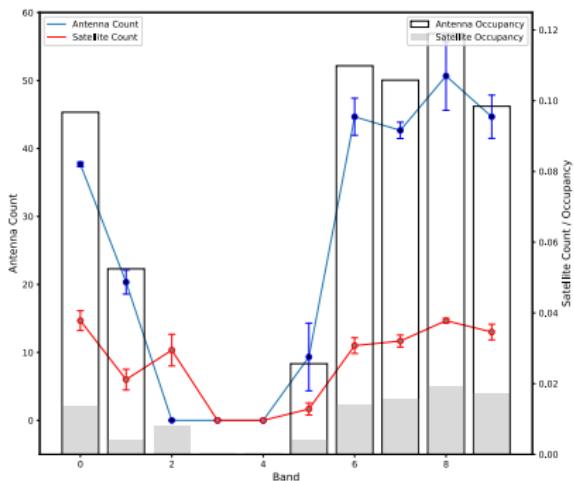


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- Antenna gives a long 4 x 40 degree stretched-out beam oriented N-S.

# Principal Component Analysis: EMPCA

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- To treat noisy data, EMPCA [7] incorporates a weights matrix  $\mathbf{W}$  on the data to solve the minimisation problem:

$$\chi^2 = \sum_i \sum_j \mathbf{W}_{ij} [\mathbf{X} - \mathbf{PC}]_{ij}^2 \quad (2)$$

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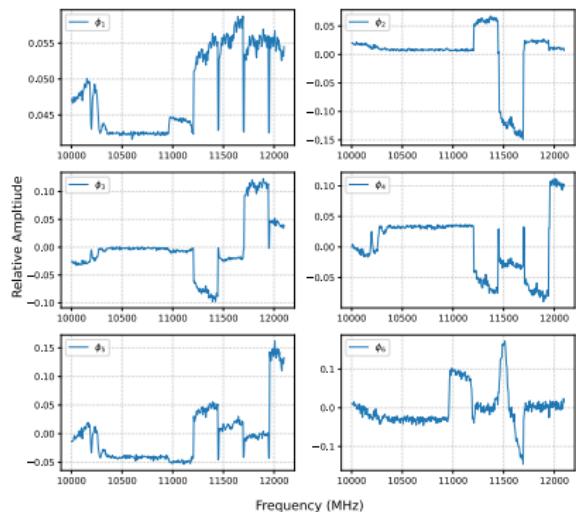


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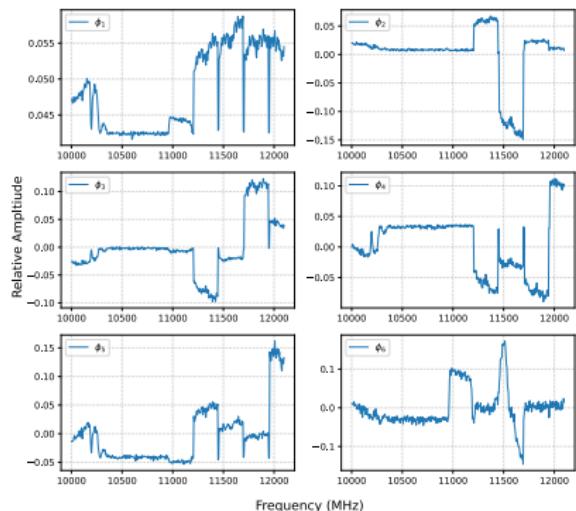


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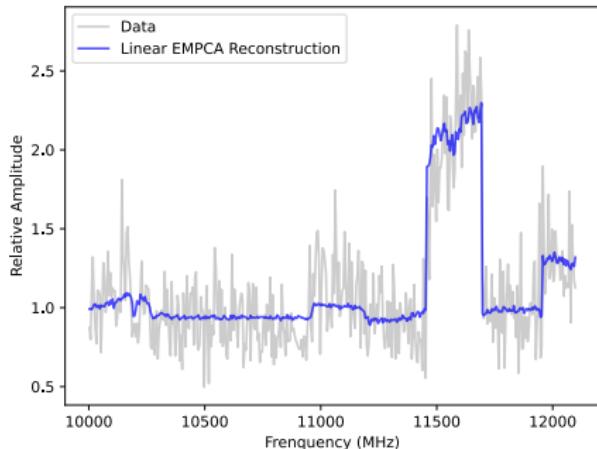


Figure 15: EMPCA reconstruction of sample waterfall spectra

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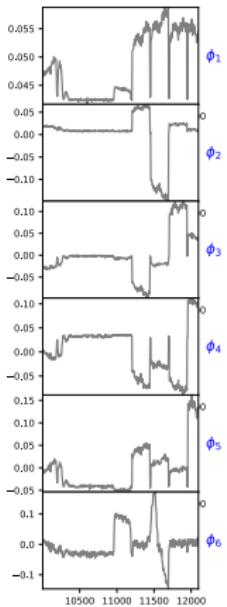
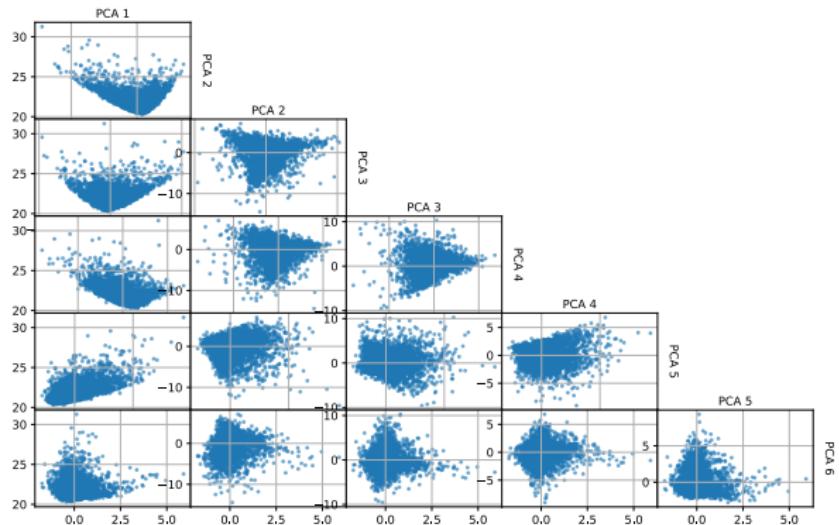


Figure 16: EMPCA coefficients grid

# Count, Occupancy and EMPCA Summary Statistics

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Frequency Range	Count	Occupancy	$\phi_1$	Rel. Amp.
10 - 10.2GHz	$36 \pm 2$	$0.10 \pm 0.01$		0.469
10.2 - 10.4GHz	$17 \pm 2$	$0.04 \pm 0.01$		0.421
10.4 - 10.6GHz	$0 \pm 0$	$0 \pm 0$		0
10.6 - 10.8GHz	$0 \pm 0$	$0 \pm 0$		0
10.8 - 10.95GHz	$0 \pm 0$	$0 \pm 0$		0
10.95 - 11.2GHz	$13 \pm 1$	$0.034 \pm 0.004$		0.142
11.2 - 11.45GHz	$43 \pm 2$	$0.10 \pm 0.01$		0.852
11.45 - 11.7GHz	$42 \pm 2$	$0.11 \pm 0.01$		1.000
11.7 - 11.95GHz	$46 \pm 2$	$0.10 \pm 0.01$		0.888
11.95 - 12.1GHz	$35 \pm 2$	$0.08 \pm 0.01$		0.874

Table 1: Summary of Count, Occupancy and EMPCA results

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- Next steps: incorporate ML to characterise each transit and map to coefficients; develop interferometric techniques.

## References

- [1] Satellite Tracker GitHub,  
<https://github.com/itsmedmd/satellite-tracker.git>.
- [2] Jonathan's Space Report, <https://planet4589.org/index.html>.
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