

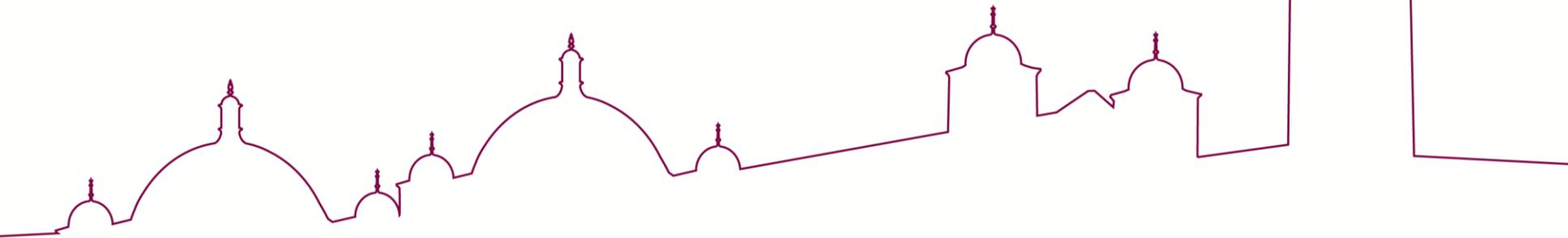
Wideband characterisation of equatorial ionospheric scintillation using MUOS transmissions

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Purpose of experiment

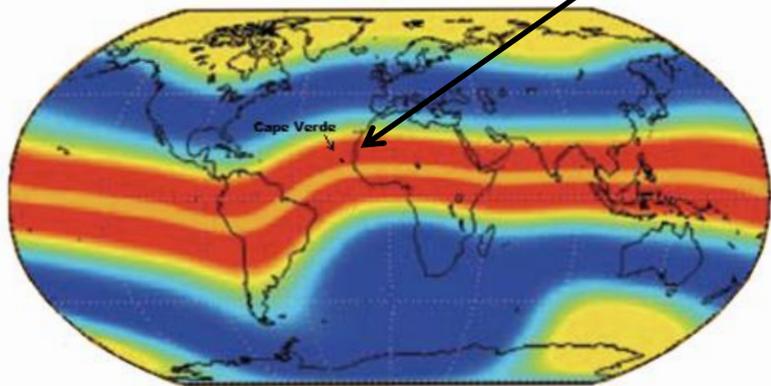
- Understanding wideband equatorial and polar ionospheric channel critical to design of UHF SATCOM systems
- *Cannon et al* (2006) carried out wideband experiments using ALTAIR at 150 MHz and 400 MHz, but relatively little data could be collected.
 - UHF coherence bandwidth (CB) was typically 1.6 MHz at 400 MHz.
- We recently proposed to use wideband signals from the COSMIC-2 constellation and collect a substantial database, but COSMIC-2 has only just been launched.
- In the interim we have elected to make measurements using MUOS.

MUOS-3 UHF Transponder

- Mobile User Objective System (MUOS) is a wideband UHF geosynchronous SATCOM system serving the United States Department of Defense (DoD).
- Downlink has four 5 MHz wide downlink CDMA channels
 - i.e. 20 MHz total bandwidth
 - Centered on 370 MHz.
- Spreading codes unknown - **analysis relies on power only.**
- One satellite lies over the Atlantic.
 - MUOS-3

Deployment of Ground Station

- Cape Verde Atmospheric Observatory (CVAO).
 - São Vicente; 16.9N, -24.9E.
 - 23.15N, 50.67E, dipole.
- On edge of equatorial anomaly.
- MUOS3 at (SE to station):
 - $\sim 71^\circ$ elevation.



Ionospheric scintillation frequency map at solar maximum.



Receiving system

- Antenna - Taco H-105
 - 300-520 MHz
 - 14.8 dBi.
- Preamplifier and bandpass filter on the mount.
- 50 m of LMR900 feed to receiver in cabin.
- USRP B200 receiver tuned to 370 MHz with 20 MHz bandwidth.
- Data recorded
 - December 2018 to April 2019
 - 1800 LT to 0500 LT.



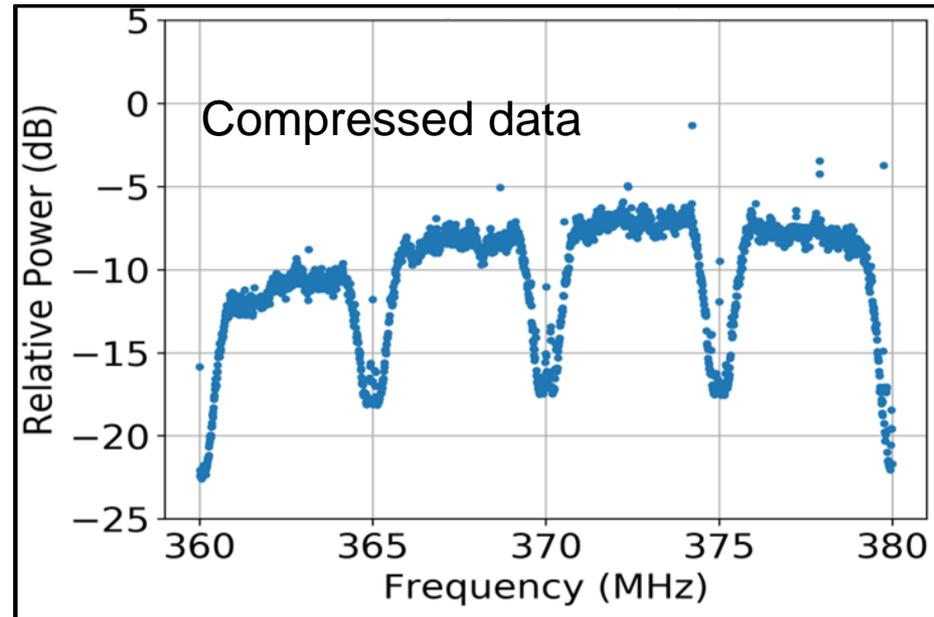
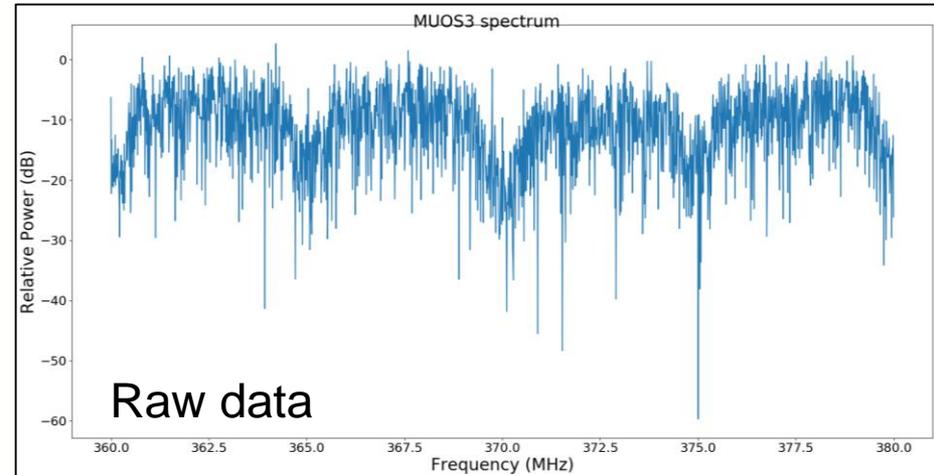
Rx PC with
USRP B200 and
storage

Mount PC
hosting mount
control software

Track command and
control via ethernet.

Data Reduction

- 4 TB of data collected per night.
- Compression needed for months of data.
- Processed and compressed for storage.
 - Take 2000 samples (0.1 ms) and FFT.
 - Average 1000 FFTs.
 - Store spectrum every 100 ms (10 FPS), ie 10^3 compression.
- Spectra of four 5 MHz multiplexes
- 600 hours of post sunset data stored.



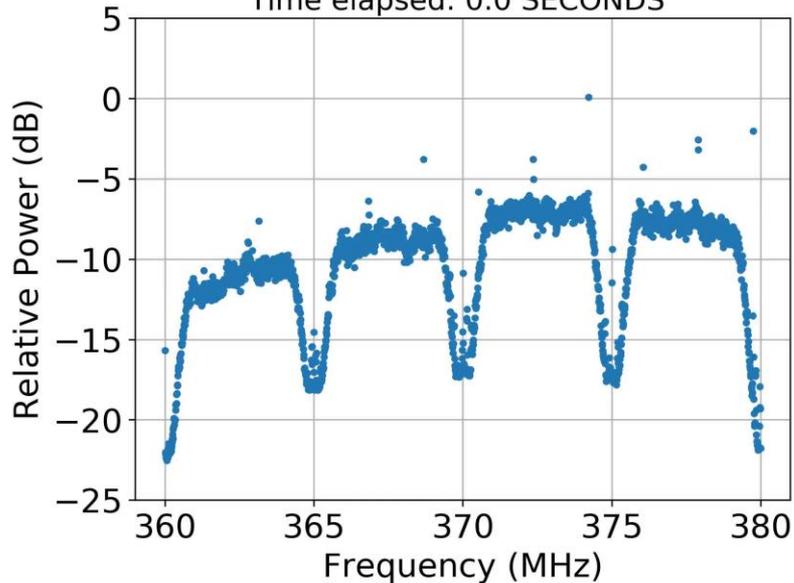
Data summary as a function of S4

- S4 calculated every 30 seconds (mean S4 from frequency bins in each multiplex).
- Highest S4 observed is 0.6 shortly after 19 February 2019, 22:00:00 LT.
- 106 minutes $S4 > 0.4$
- 5.5 minutes $S4 > 0.5$.

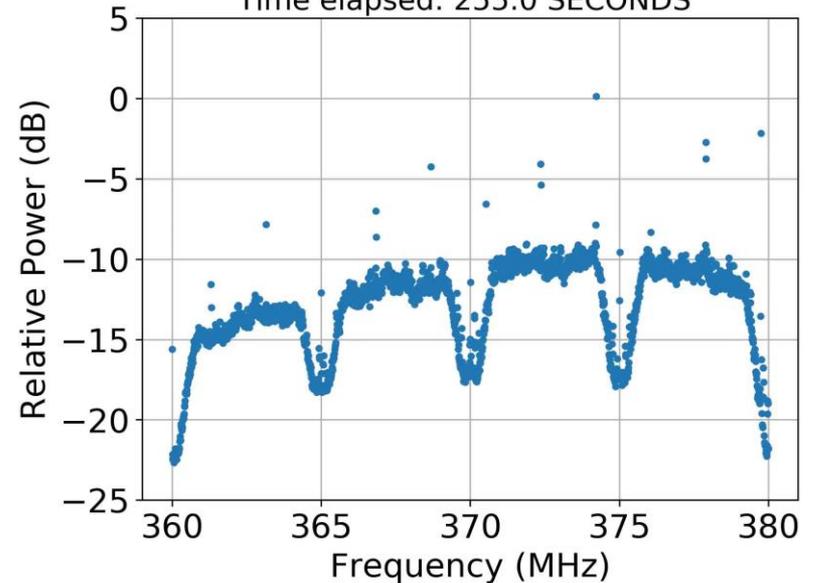
Case studies for discussion

- Two cases chosen from 10 minute recording that started at 21 March 2019, 20:15:01 LT.
- Period chosen for large S4 range
 - 0.03 to 0.46 within the 10 minutes.
- Ionosphere quiet for first minute, appreciable fading after 150 seconds.
- Two cases chosen,
 - Case 1 – quiet ionosphere
 - Case 2 – flat and frequency selective fading, but predominantly flat

MUOS3 spectrum. Record start time 2019-03-21T21:15:01 UT
Time elapsed: 0.0 SECONDS

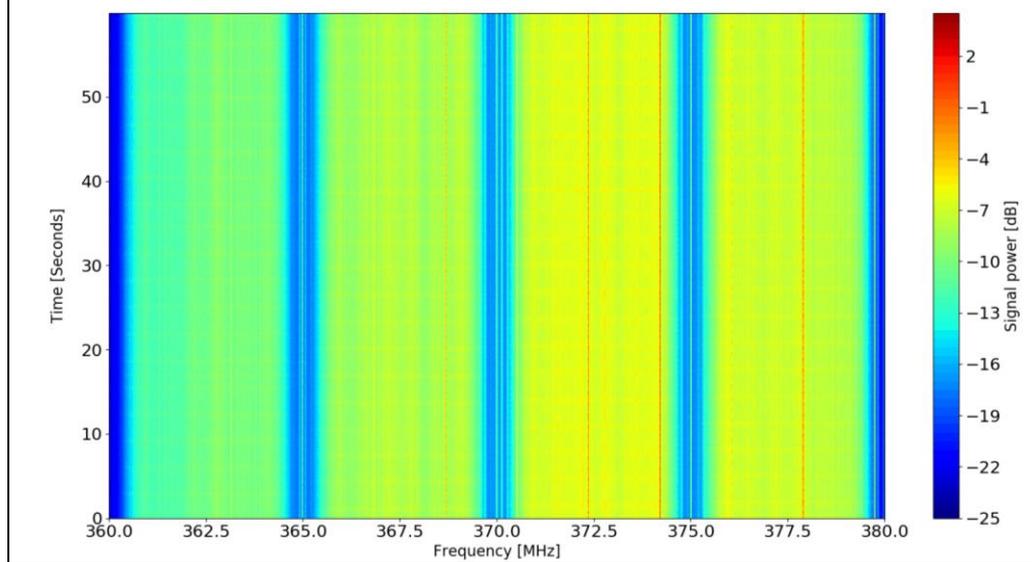


MUOS3 spectrum. Record start time 2019-03-21T21:15:01 UT
Time elapsed: 255.0 SECONDS



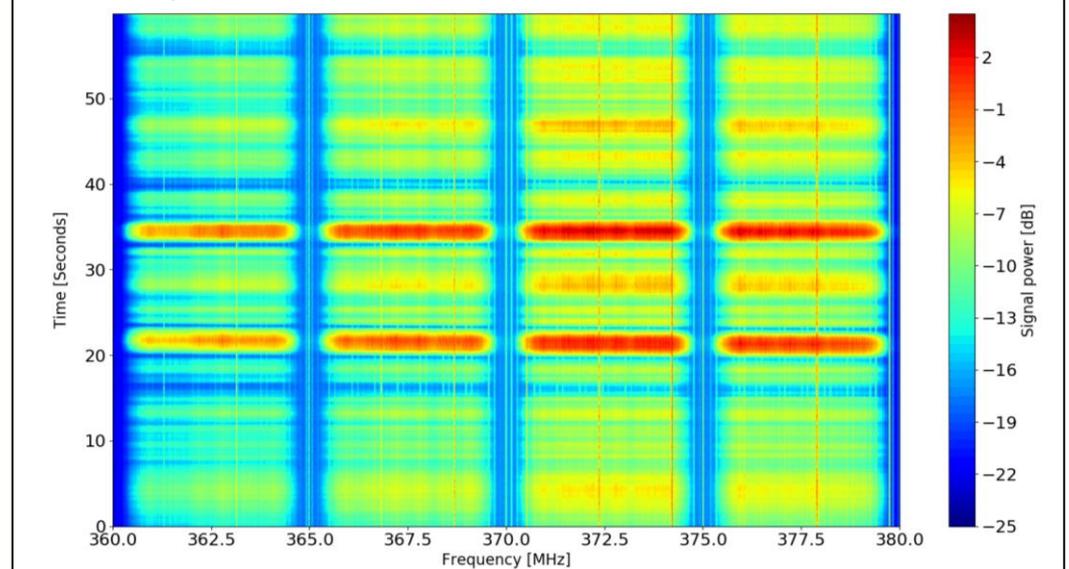
Variation of power with time

MUOS3 spectrum; CASE 1 from 2019-03-21T21:15:01+00:00



- Signal power enhancement and fades; up to 15 dB.

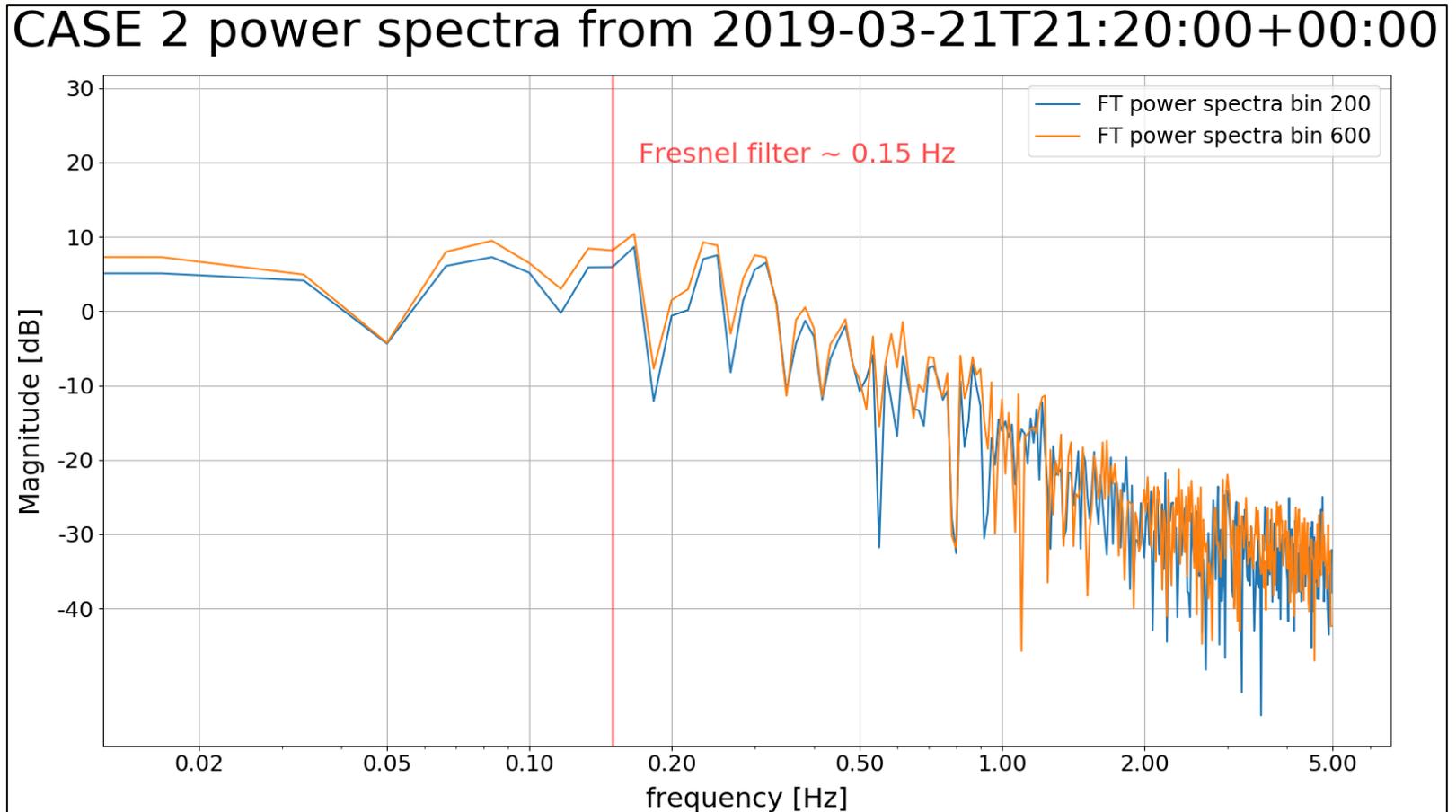
MUOS3 spectrum; CASE 2 from 2019-03-21T21:20:00+00:00



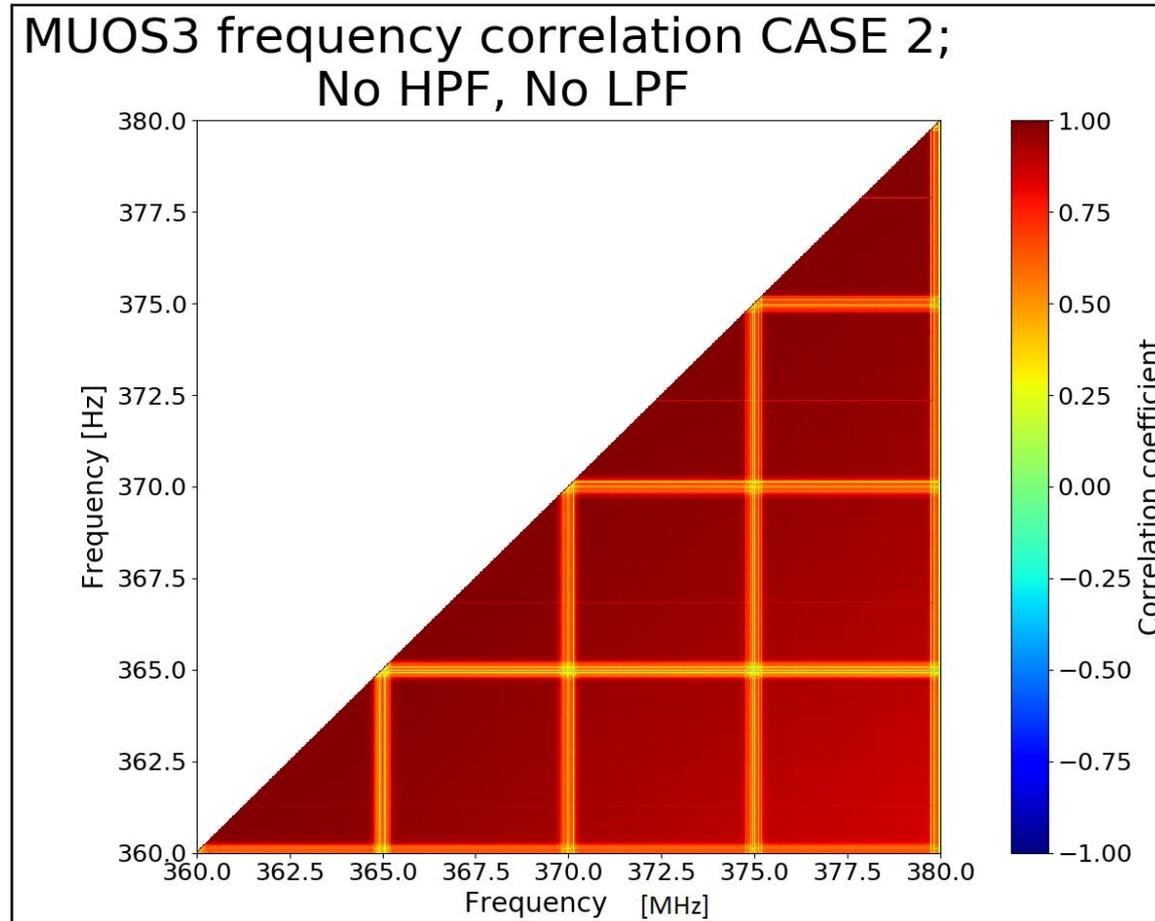
Wideband Coherence

- Cross correlated each frequency with every other frequency.
- 60 seconds of data from CASE 2 used for cross correlation.
- Frequency range from 0.016 Hz (1/60 s) to 5 Hz (10 fps).
- Data filtered to explore variation in correlation in different fading frequency ranges
 - 41 tap FIR filters.

Power spectra Case 2, bin 200 and 600

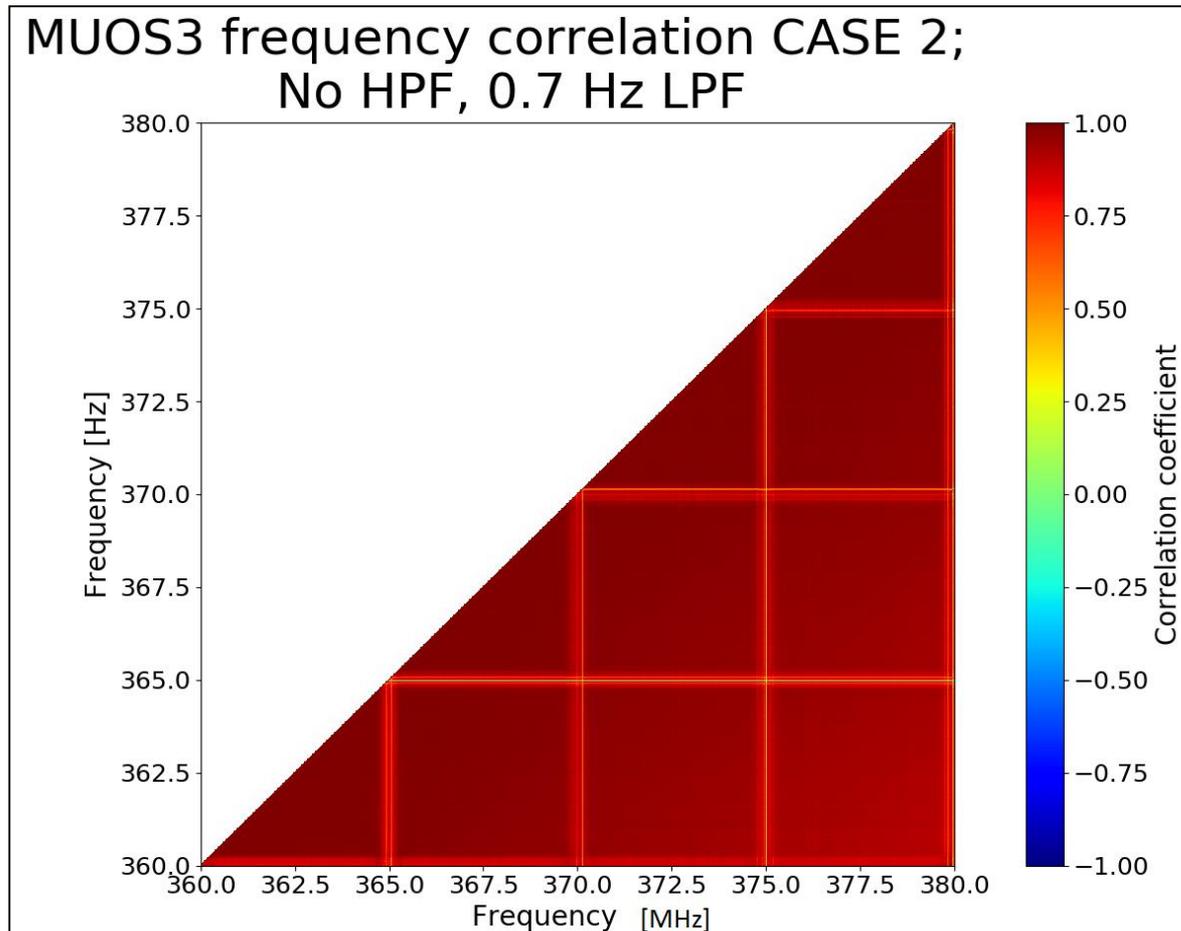


Wideband Correlation Case 2; S4 between 0.4 and 0.6



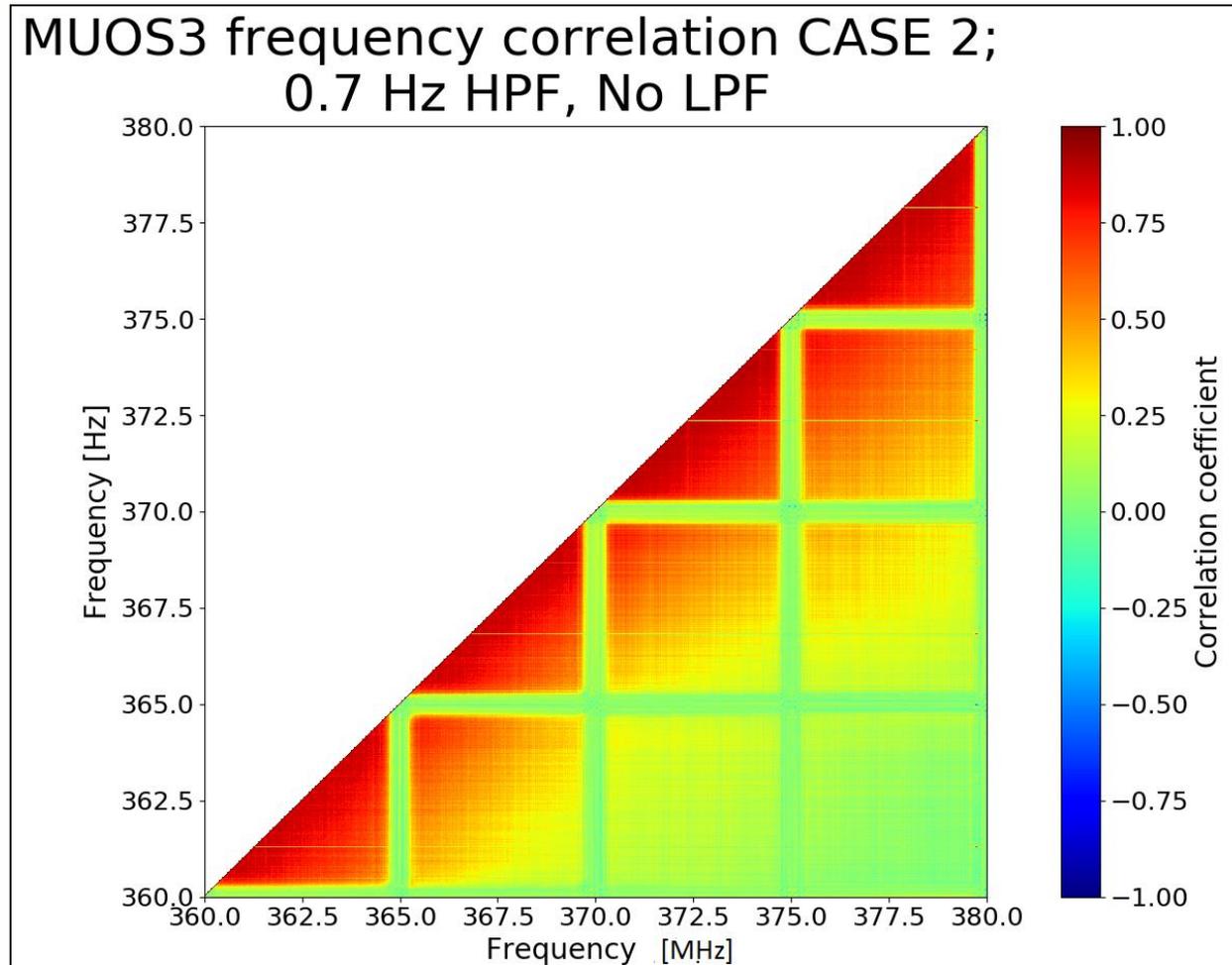
No filtering (0.016 to 5 Hz) – all frequencies well correlated (flat fading).

Wideband Correlation Case 2; S4 between 0.4 and 0.6



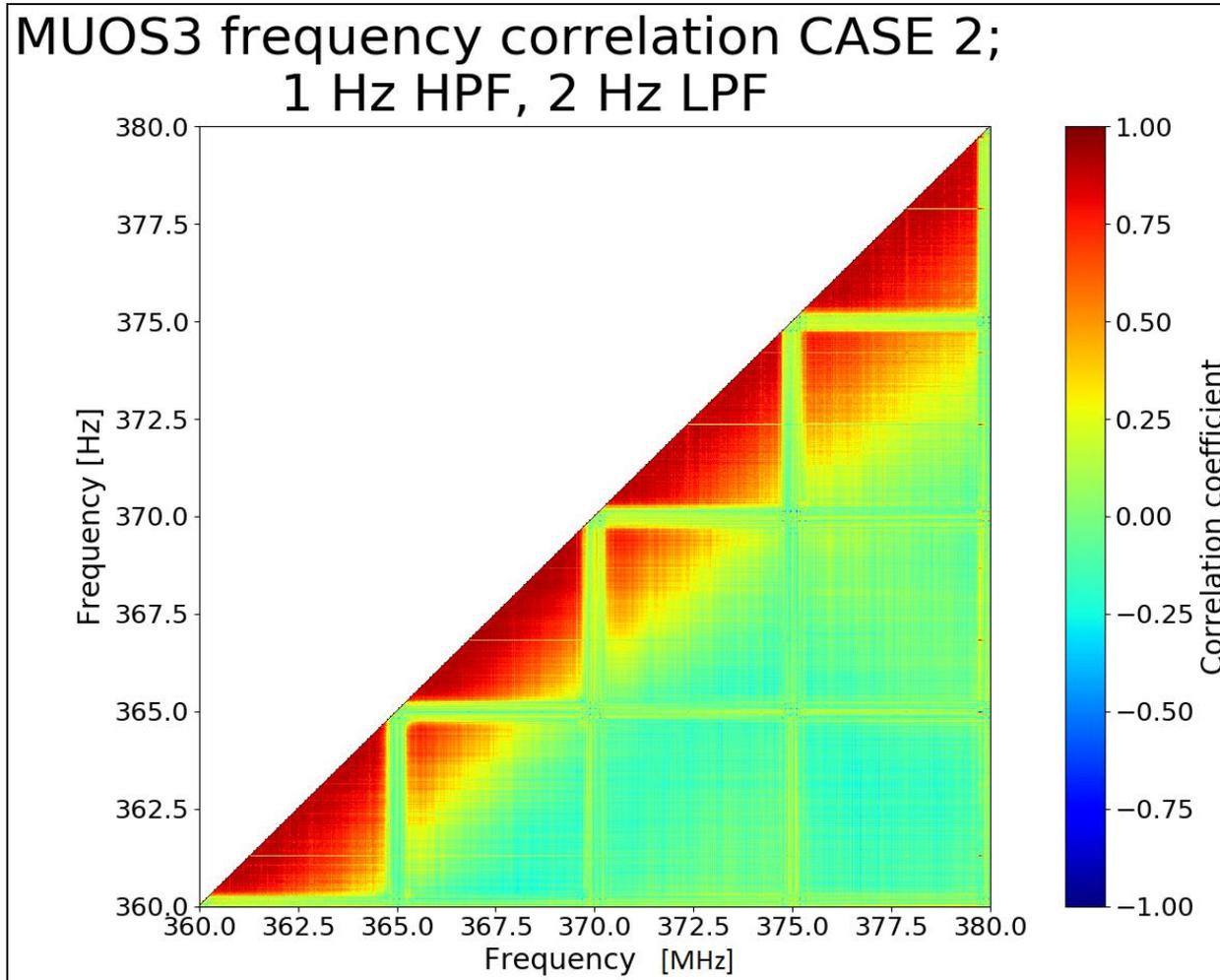
A LPF at 0.7 Hz allows us to examine the predominantly non-diffractive components of the fading. All frequencies remain well correlated (flat fading) and the picture remains similar to the unfiltered case. The correlation bandwidth is likely 20 MHz or more.

Wideband Correlation Case 2; S4 between 0.4 and 0.6



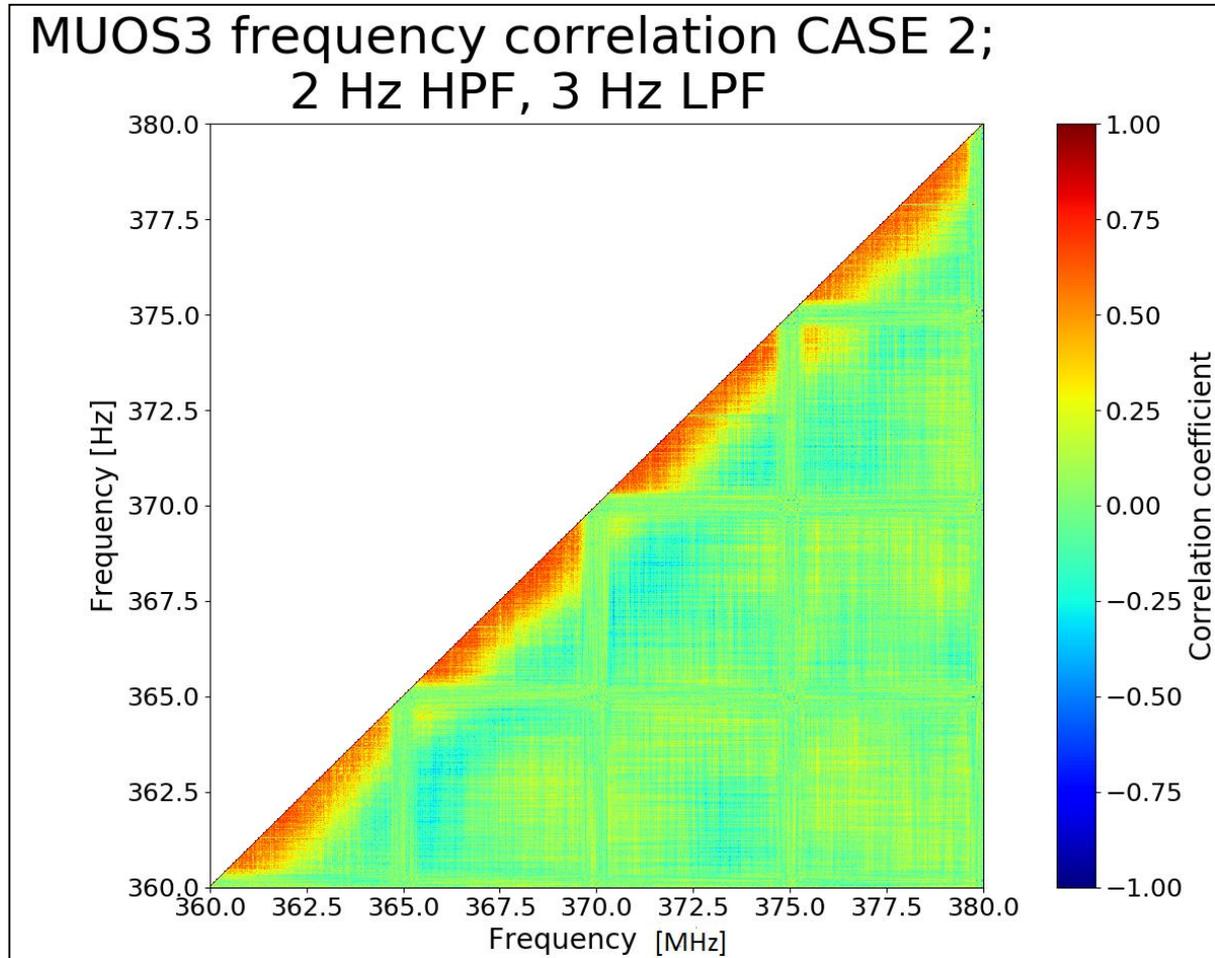
A HPF at 0.7 Hz allows us to examine the predominantly diffractive components of the fading. Now frequencies within one 5MHz multiplex remain well correlated (flat fading) and there is some correlation with adjacent multiplexes out to around 7MHz

Wideband Correlation Case 2; S4 between 0.4 and 0.6



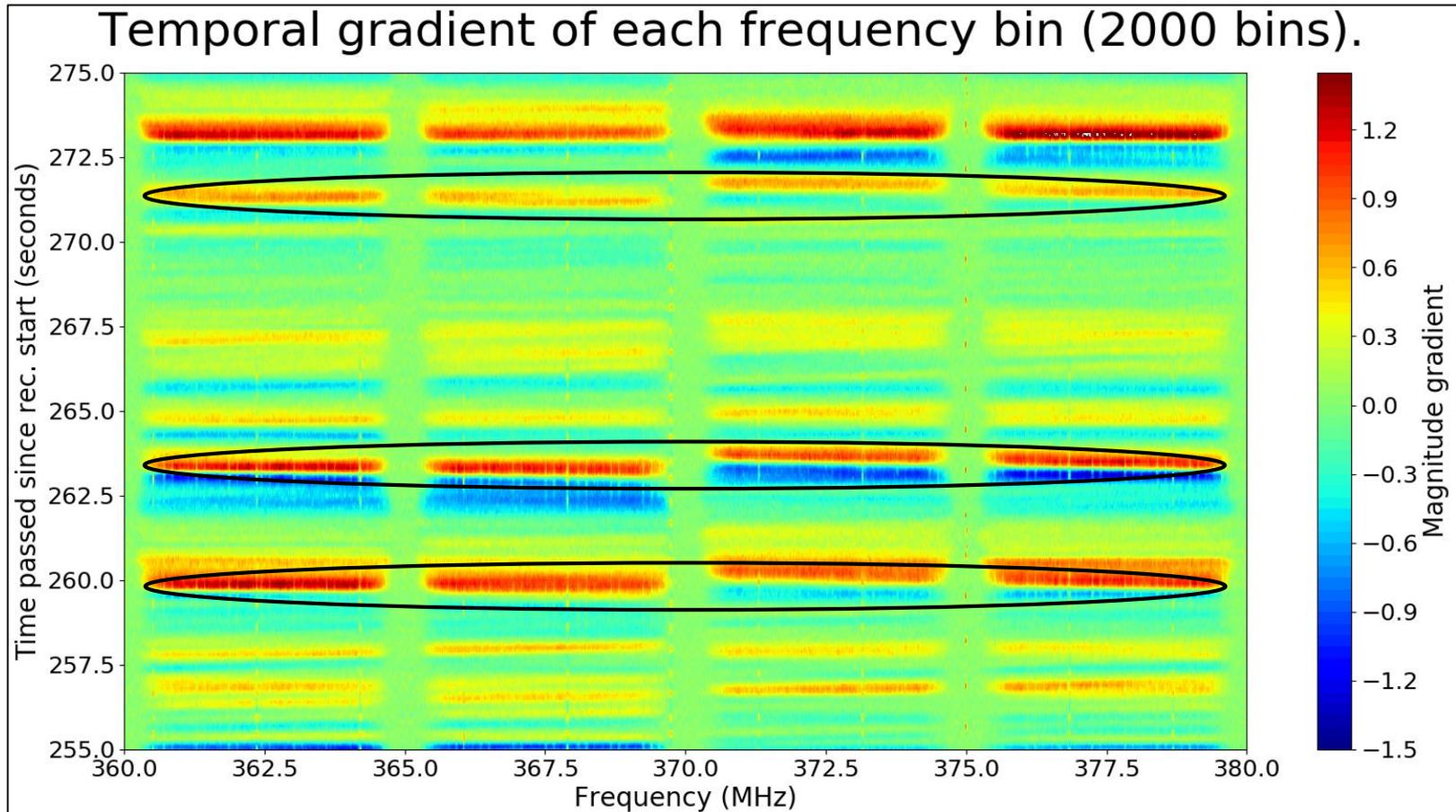
A BPF between 1 Hz and 2 Hz is very similar

Wideband Correlation Case 2; S4 between 0.4 and 0.6



A BPF between 2 Hz and 3 Hz further emphasizes the diffractive components of the fading. Now the correlation bandwidth is below 1 MHz

Frequency selective fading (FSF)



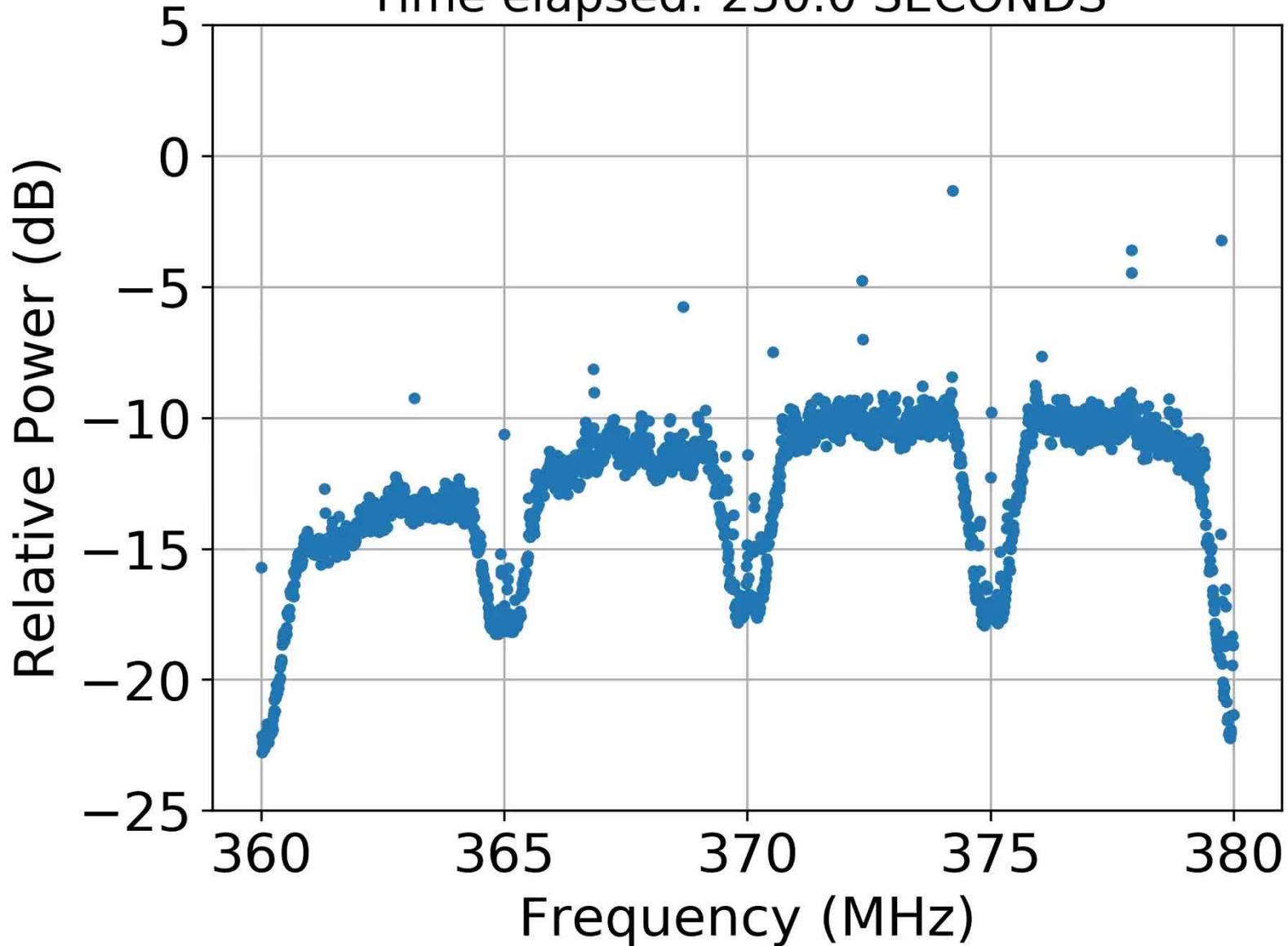
- Only short isolated periods of FSF observed in data set.
- Temporal gradient of 0.7 HPF data at each frequency identifies these instances.
- Illustrates fading periods ~ 1 to 2 s.

Summary and Conclusions

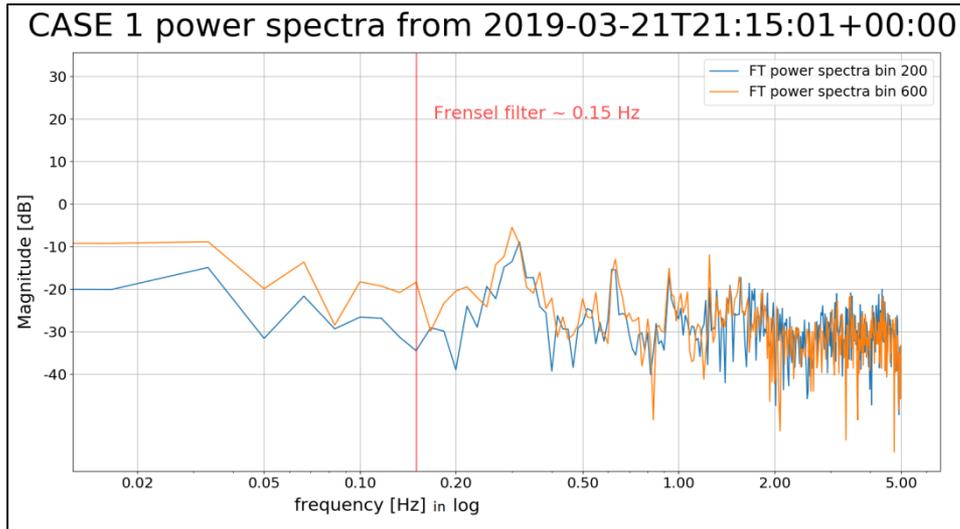
For S4 ~ 0.5

- From correlation:
 - During the identified flat fading period the amplitude fading coherency bandwidth
 - for fading spectral components between 0.3 Hz and 5 Hz was > 20 MHz;
 - for fading spectral components above 0.7 Hz was ~ 7 MHz;
 - for fading spectral components between 1 Hz and 5 Hz was ~ 2 MHz.
 - Therefore, the lower fade frequency, higher power components will define the modem performance and these are amplitude coherent over a wide bandwidth.
- From fading analysis:
 - Given the fade periods, long (1 – 2 second) waveform interleaving would be advantageous.

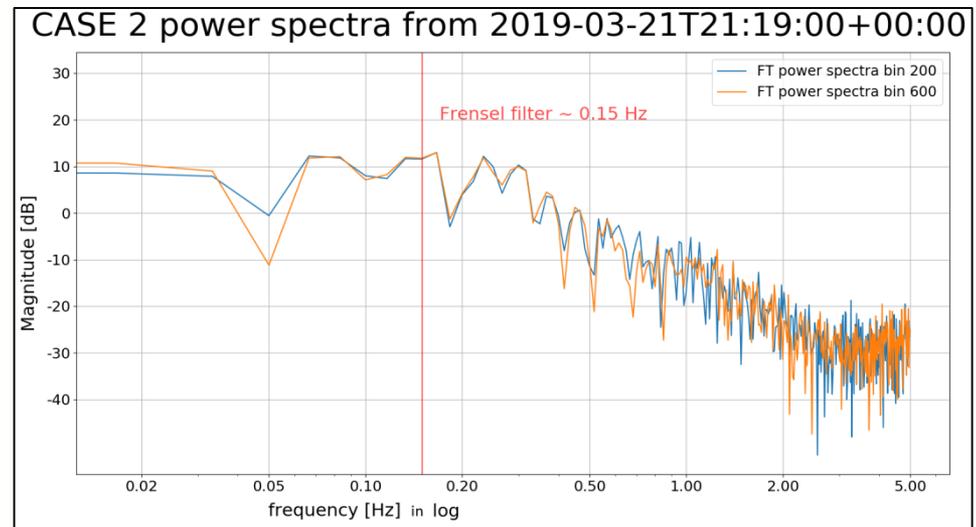
MUOS3 spectrum. Record start time 2019-03-21T21:15:01 UT
Time elapsed: 250.0 SECONDS



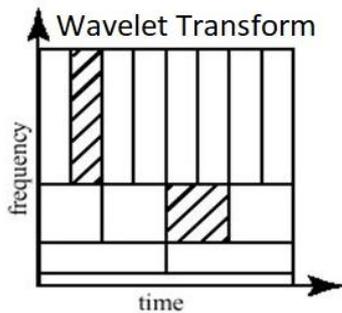
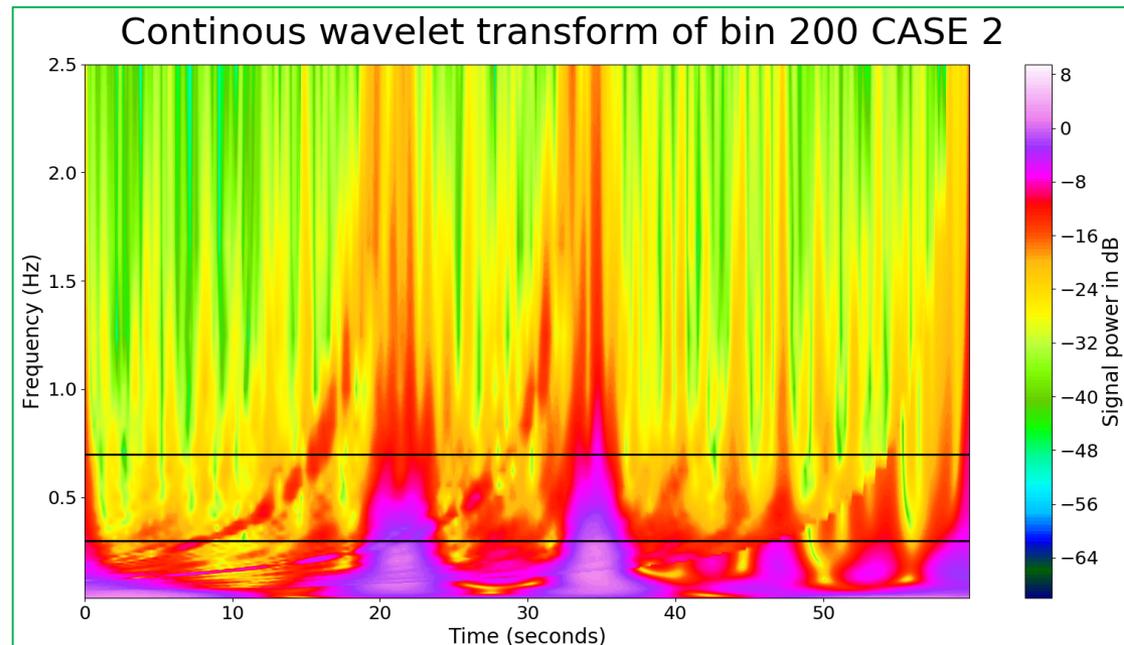
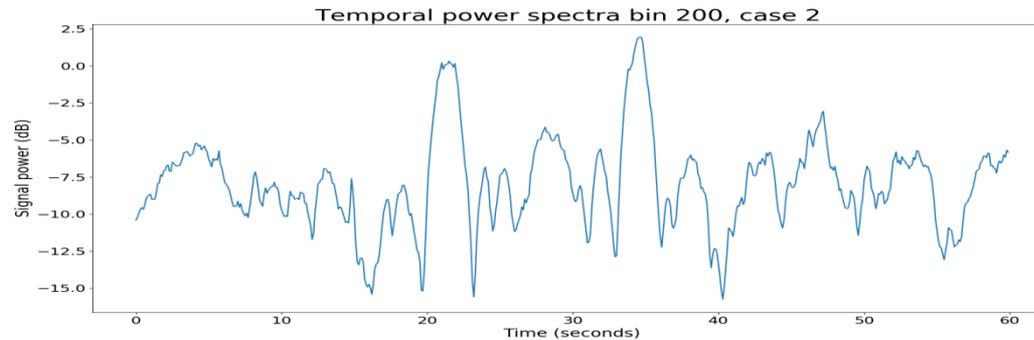
Power spectra, (frequency bins 200 and 600).



- Averaged 1 minute of data.
- Orange and blue lines are different frequencies.
- Case 1—Broadly flat across spectra.
- Cases 2 – Diffractive, multiple scattering regime above ~ 0.15 Hz and a single/small number of scatters at lower frequencies.



Continuous Wavelet Transform, bin 200



- WT of bin 200 shows significant signal levels at low frequencies.
- Higher frequency signals are at a lower amplitude.
- Suggests one break point at ~ 0.7 Hz. Several other cases analysed.