Spatial filtering experiment with the Murchison Widefield Array

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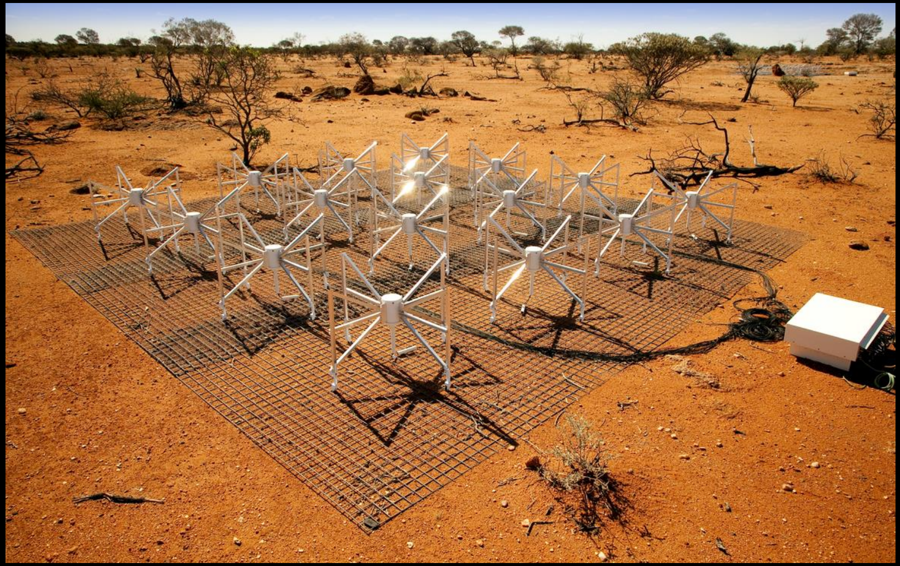
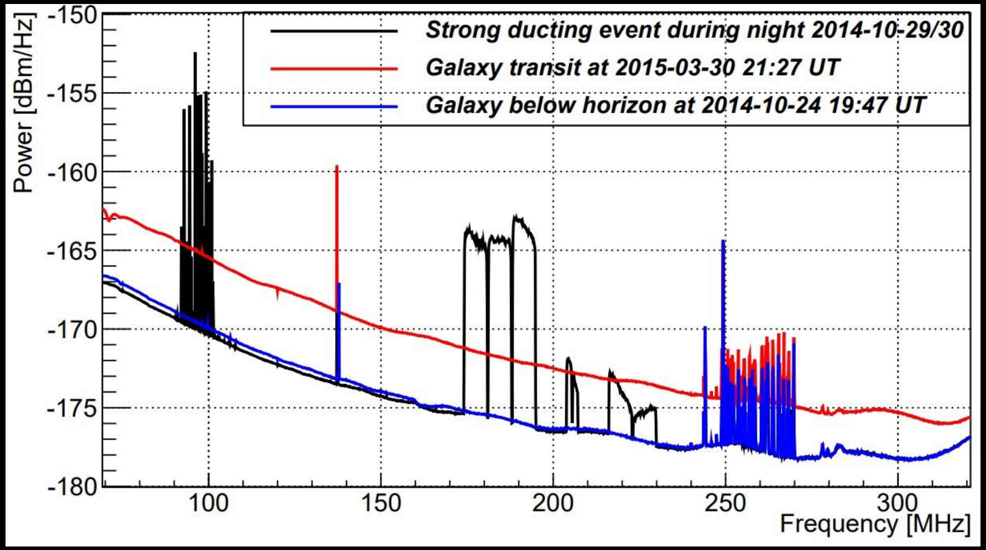
Murchison Widefield Array

- Low frequency telescope (80 – 300 MHz)
- Located in Western Australia
- 128 tiles of 16 dual-polarization antennas
- Instantaneous bandwidth : 30.72 MHz
- Voltage capture system
- FoV : 15-50 deg



Radio Frequency Interference

- RFI is minimized at the MWA through remote location and administrative protection (radio quiet zone)
- Most detected RFI come from air- and spaceborne transmitters (satellites, airplanes…) or distant FM / digital TV transmitters due to tropospheric ducting



Sokolovski et al. 2016

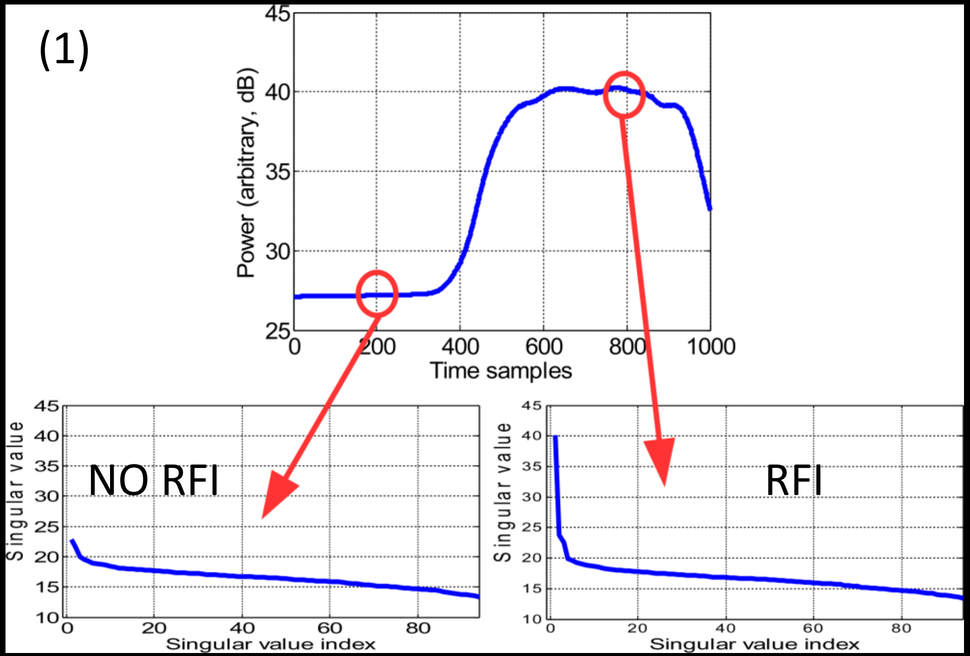
Spectra highlighting RFI occupancy during strong tropospheric ducting events

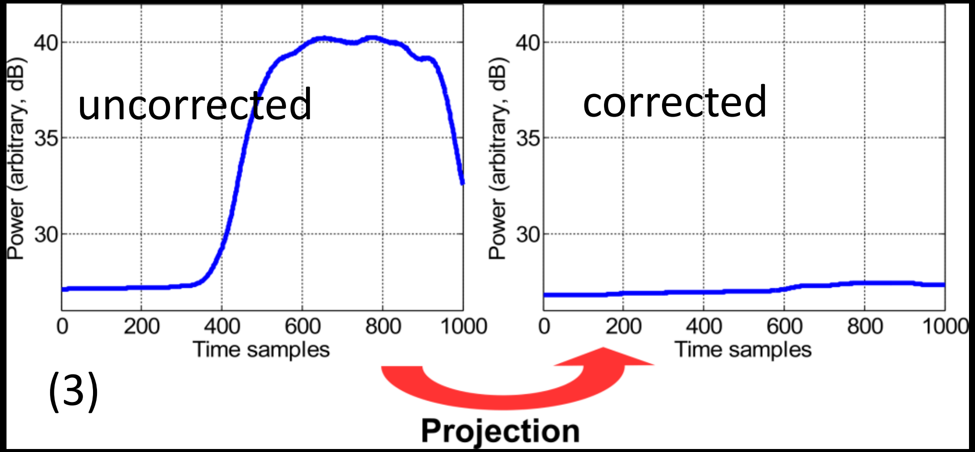
Impacts of RFI

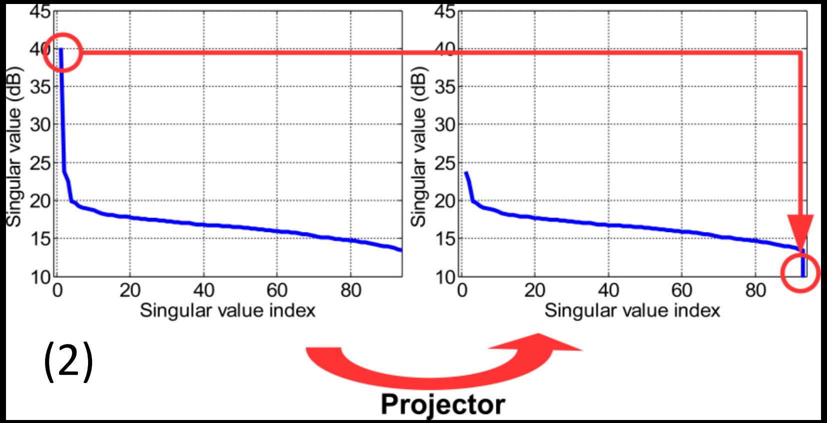
RFI can have various impacts on astronomical data:

- Mask signal of interest (up to 10^9 stronger than astronomical sources)
  - Spectral lines / polarization
  - Non-repeatable transient experiments
- Mislead observation interpretation or false positives (transients, SETI...)
- Loss of data
  - Increases operational cost
  - Reduces instrument sensitivity / availability
- Calibration solution unsolvable
  - Mimics artificial additional sources
  - Time-critical calibration (pulsar timing)
- System deterioration

Spatial filtering in practice







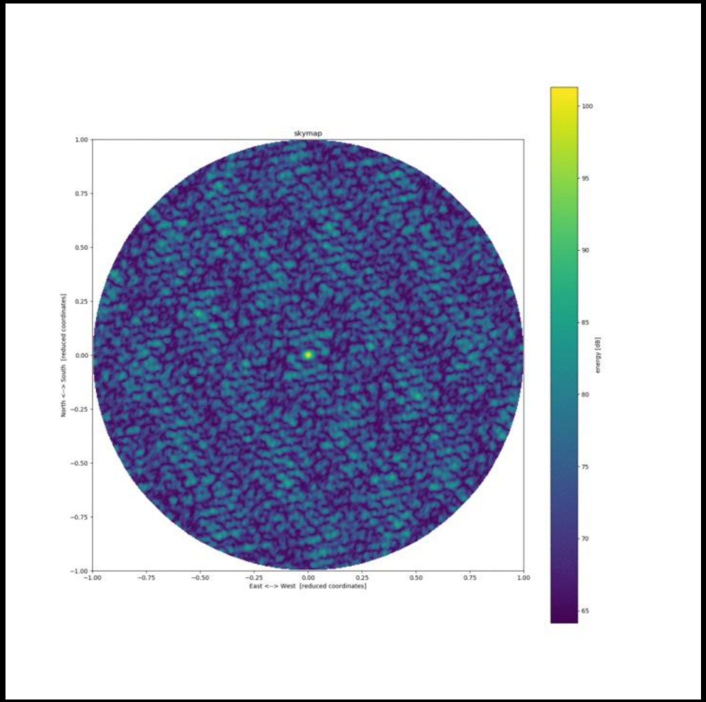
(1) Identify array covariance matrix dominant eigenvalue appearing commensally with the source RFI

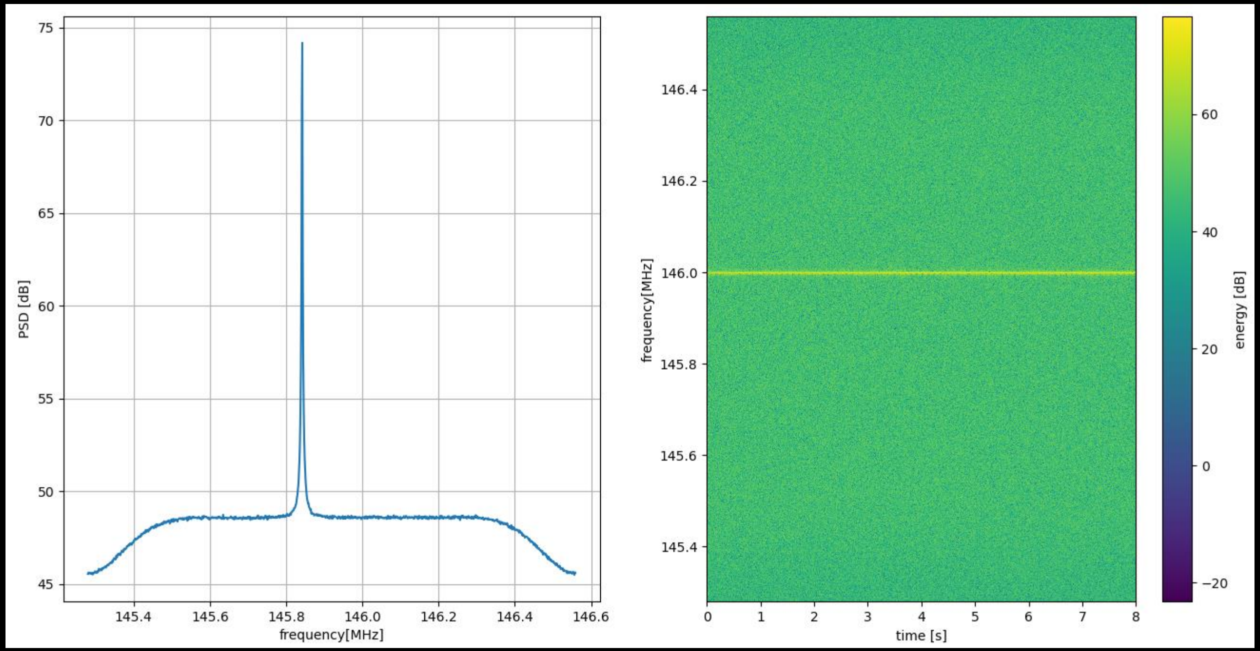
(2) Set the dominant eigenvalue to 0

(3) Reconstruct beamformed signal with corrected covariance matrix

Data set

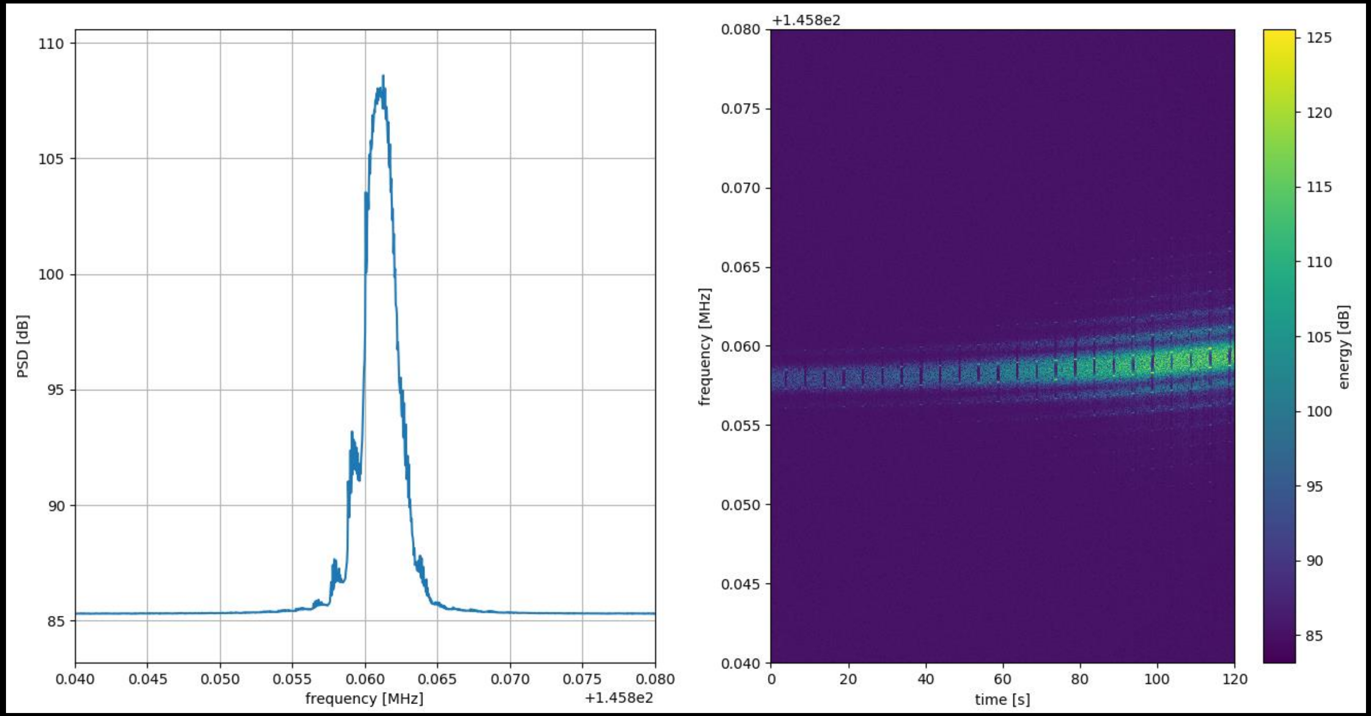
- Downlink transmission from the ARISS system (Amateur Radio on the International Space Station) @ 185.86 MHz
- Data captured on 2019-07-22 at 15:00:06 UTC over 2 mins





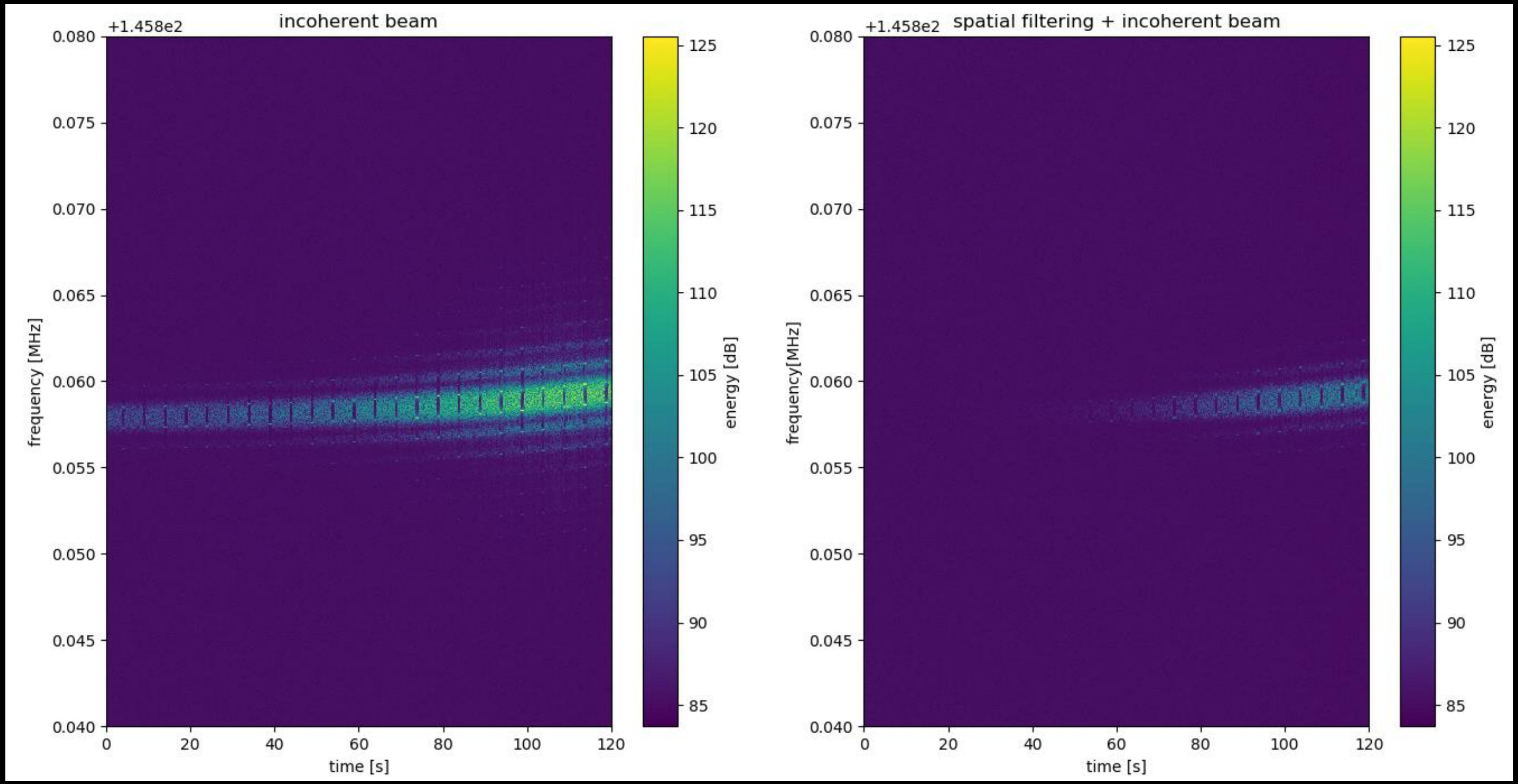
Data set (2)

- Further channelization down to 40 kHz shows digitally modulated features, as well as a Doppler frequency shift due to relative motion between ISS and the telescope, and a power increase due to the telescope lobe crossing



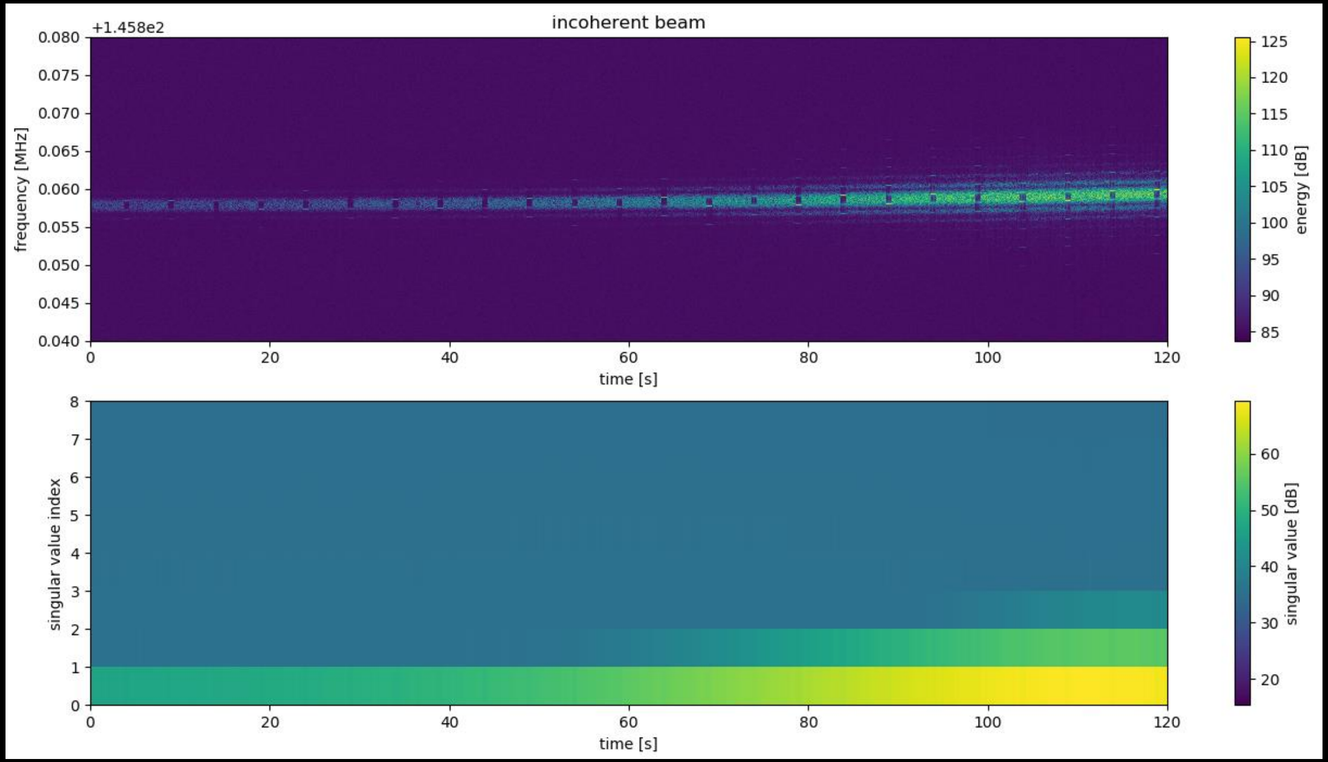
ARISS spatial filtering

- 1 dimensional spatial filtering over 1.28 s data blocks reveals to be inefficient during spacecraft relative acceleration (high Doppler shift)



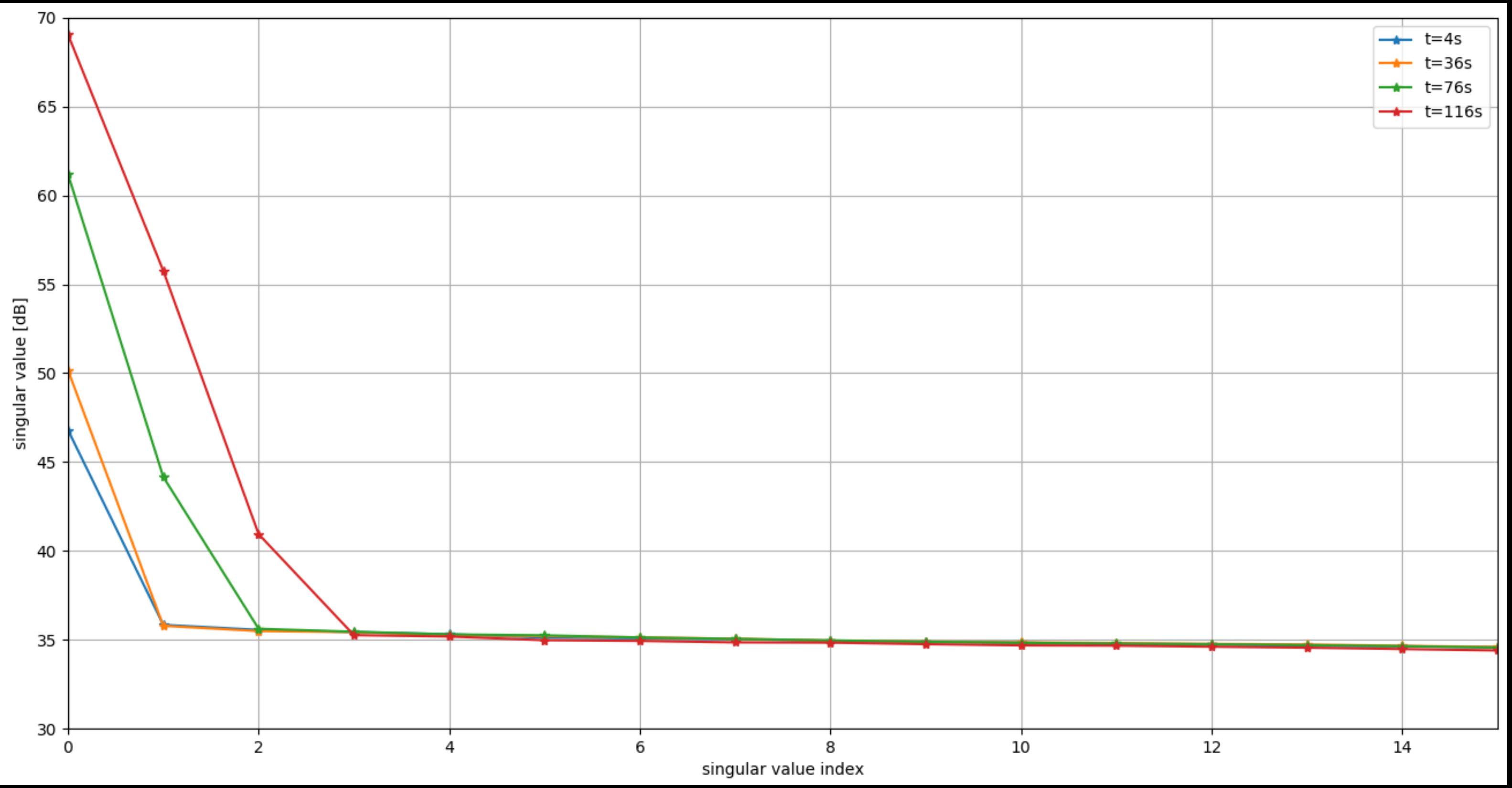
Singular values analysis

- Figure shows the dominant singular values as a function of time
- 2^{nd} and 3^{rd} singular values become non-negligible during the high Doppler shift phase (after 60 s)
- This effect is called subspace smearing



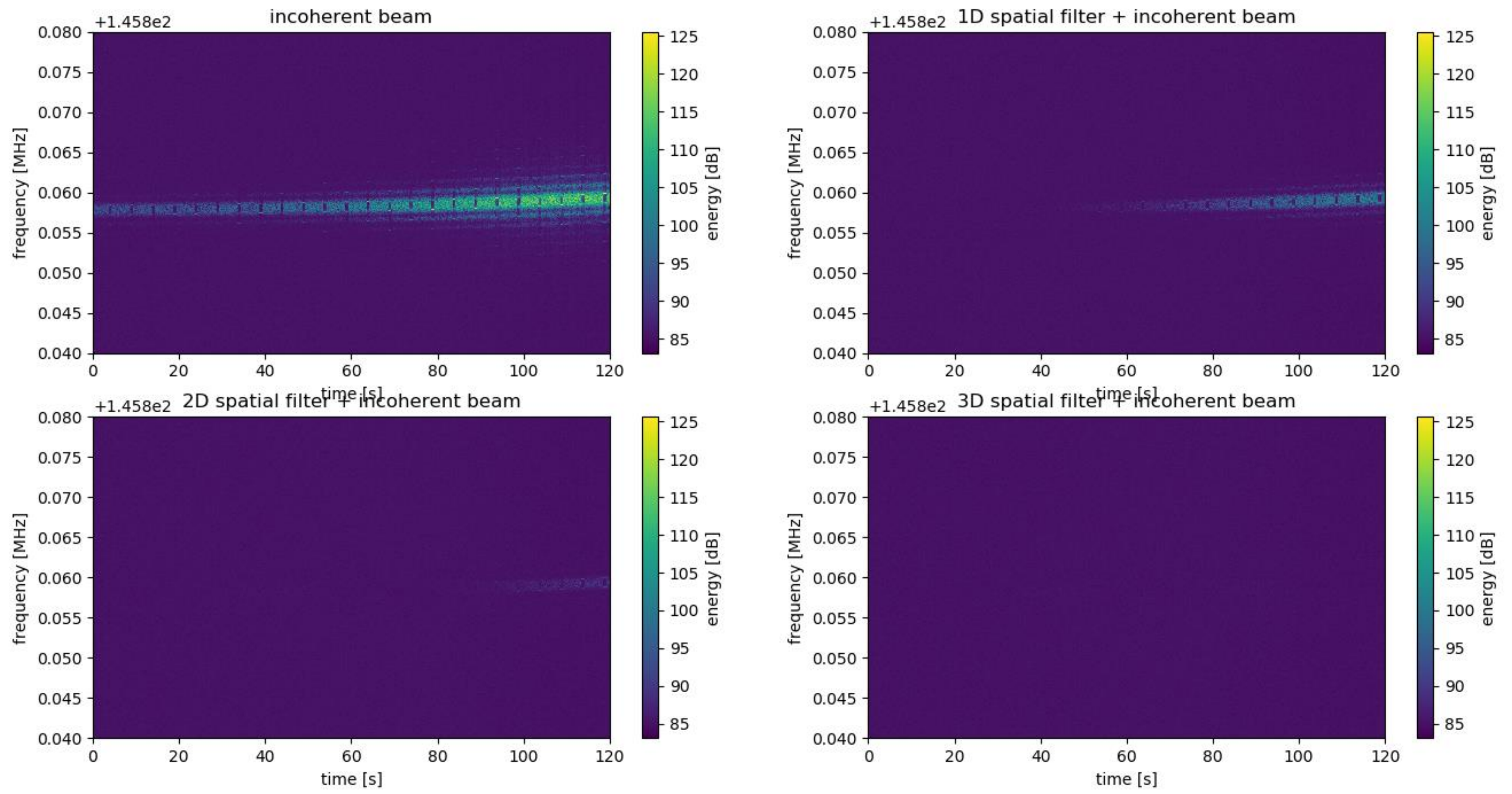
Singular values analysis (2)

- Singular values comparison at 4 different times in the data set



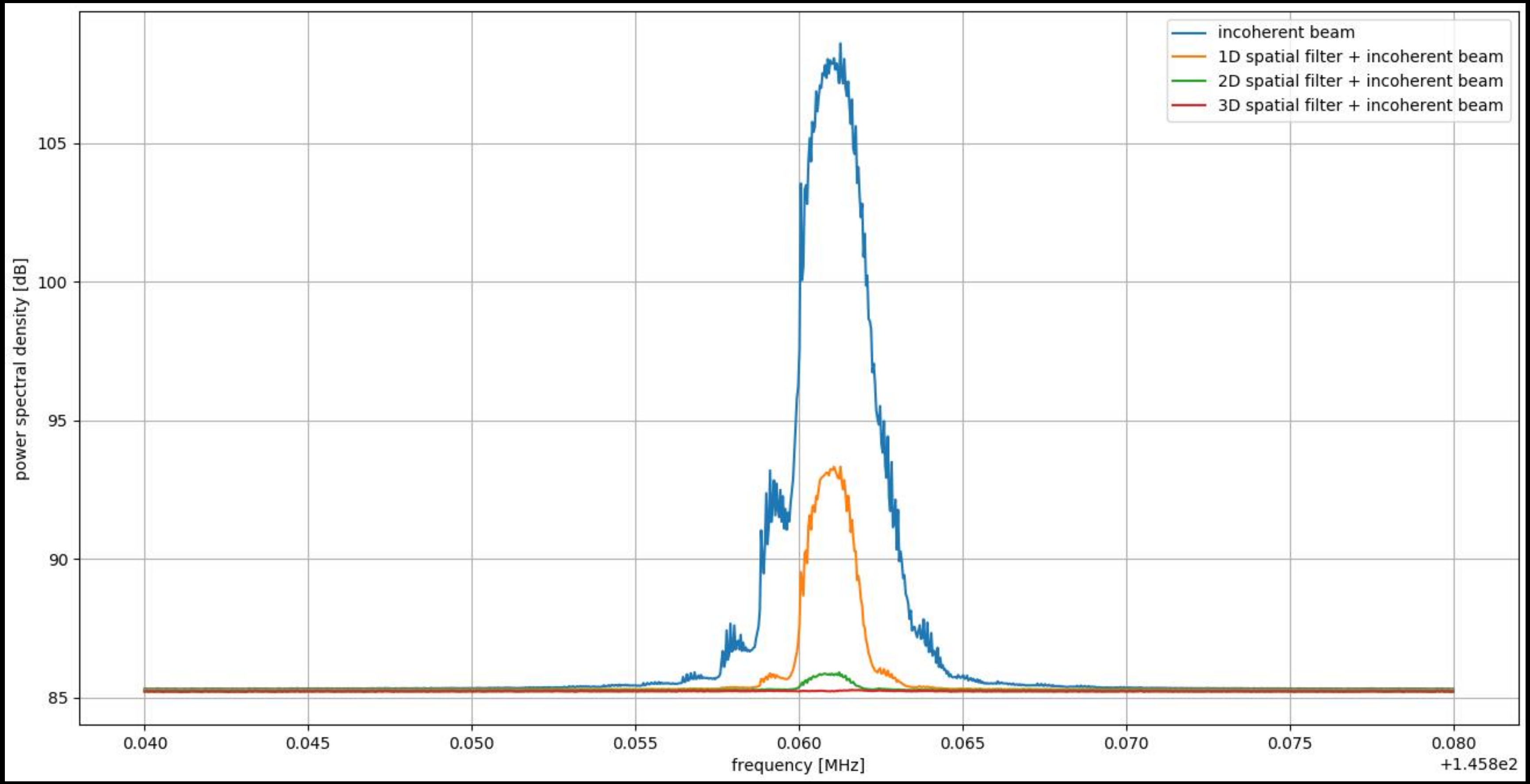
Multi-dimensional filtering

- Increase in spatial filter dimensionality (= number of eigen/singular values nulled) allows more robust RFI filtering



Multi-dimensional filtering

- Comparison of recovered spectra after multi-D filtering



Attenuations:

1D filter : 15 dB
2D filter : 22 dB
3D filter : reaches noise floor

Conclusion

- Spatial filtering offers good RFI rejection and possibility to recover underlying data
- Subspace smearing is the main limitation to spatial filtering due to an increase of data rejection, potentially affecting the signal of interest
- A GPU version of the spatial filter is being developed for real-time RFI mitigation on the MWA
- Further performance assessments, including the comparison of images produced with uncorrupted, unfiltered, and filtered data is required to quantify the impact of the filter on instrument calibration and astronomical information recovery