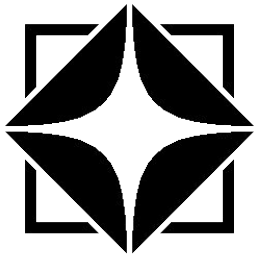
Characterizing Narrowband Emission from Magnetar J1809-1943

Pulak Mohapatra

Collaborators: Yogesh Maan, Yash Bhusare, Ankit Narolia, Banshi Lal

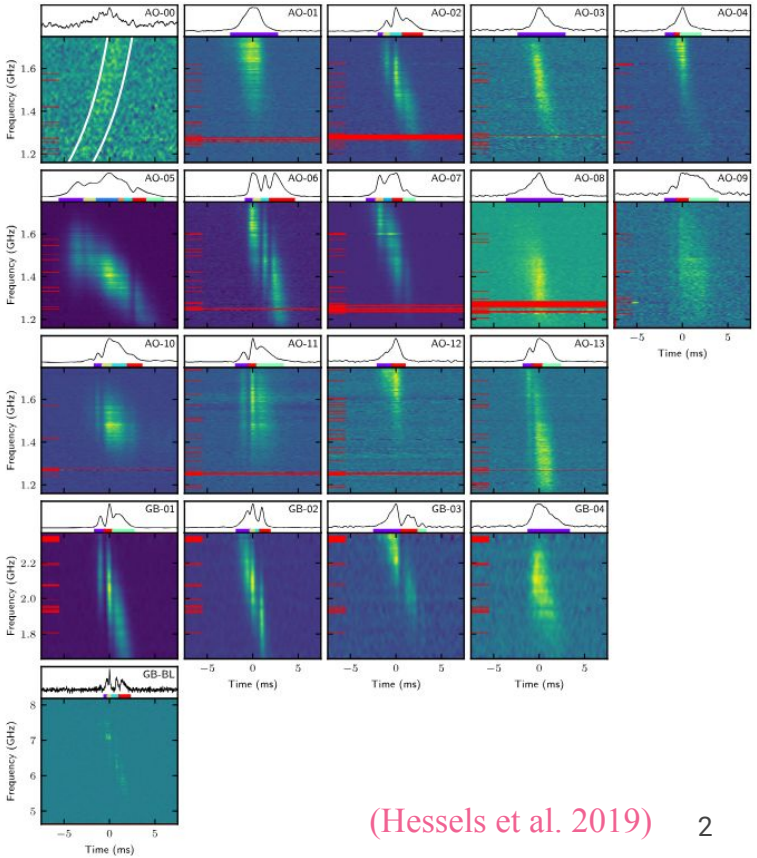


FTSky, ICTS

16th October, 2025

Spectral structure of FRBs

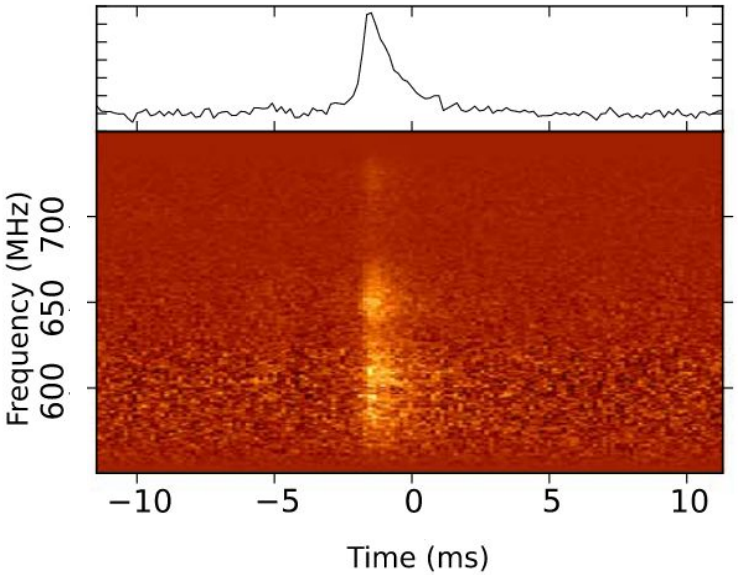
- Fast radio bursts (FRBs) - short, bright, extragalactic bursts of unknown origin.
- **Magnetars** leading candidate!
- Studying such potential progenitors in detail helps us make **phenomenological links** and draw connections with the FRBs
- Intriguingly, FRBs show intrinsic band limited features and complex spectral structure (eg. Hessels et al. 2019)



(Hessels et al. 2019)

Why is J1809-1943 interesting?

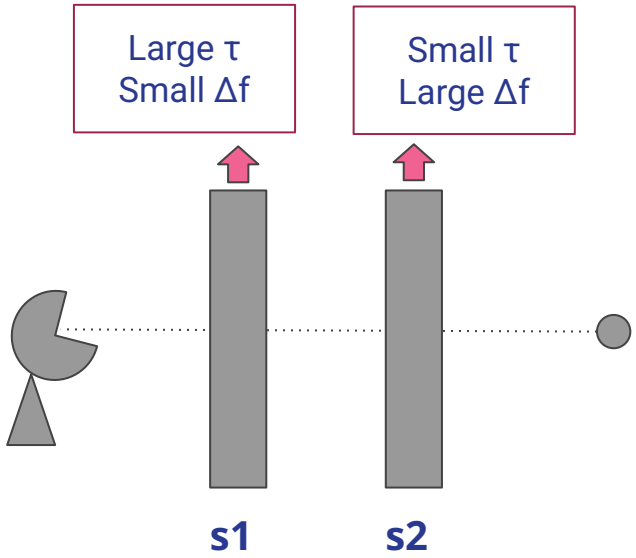
- PSR J1809-1943 (XTE 1810-197)— first one to be discovered in radio following the outburst in X-ray (Camilo et al. 2006), stopped after three years, reactivated in December 2018 (Lyne et al. 2018)
- Study of single pulse revealed spectral features that appeared intrinsic (Maan et al. 2019)
- Only a few objects have shown such features
  - Giant pulses of the Crab pulsar and PSR J0540−6919 (Hankins et al. 2016, Geyer et al. 2021)
  - PSR J1745-2900 (Pearlman et al. 2018)



(Maan et al. 2019)

Scintillation?

- Scintillation Bandwidth from scattering time < 1
- Scintillation Bandwidth ~ 150 Hz (Marthi and Maan, 2025)
- Supported by electron density models (Yao et al. 2017)
- **But scintillation can't be ruled out completely**



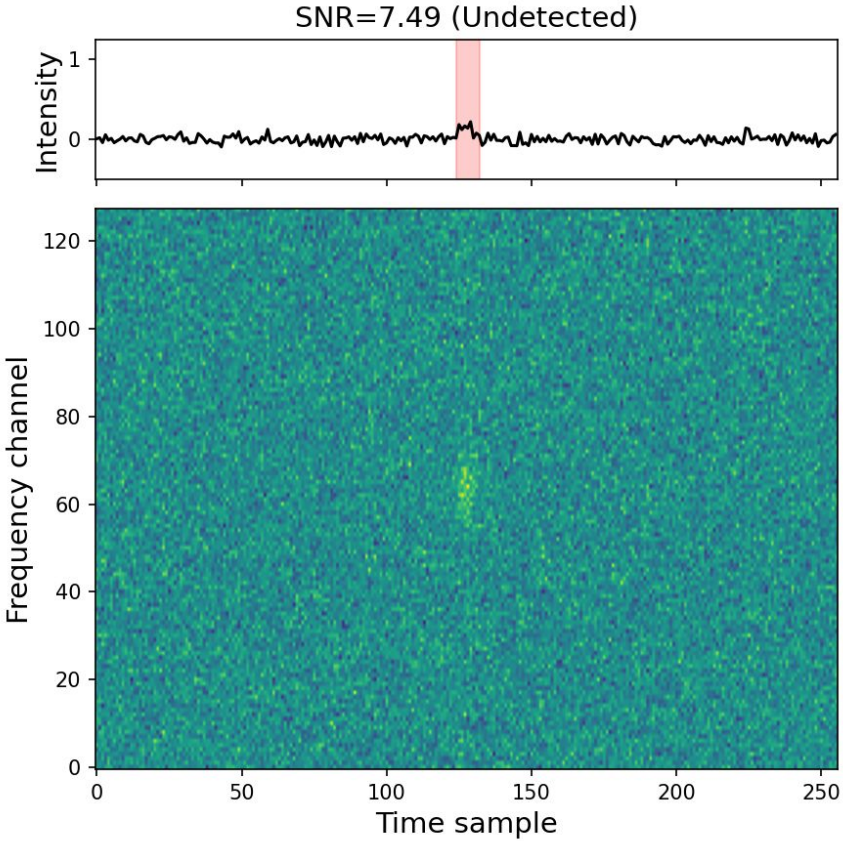
Data

- Outburst in 2018 it has been constantly monitored using the uGMRT (eg. Joshi et al. 2018; Maan et al. 2019, 2022)
- Subset of these epochs will be discussed here
- 5 epochs from December, 2018 to February, 2019
- Band 4 (550 MHz - 750 MHz)

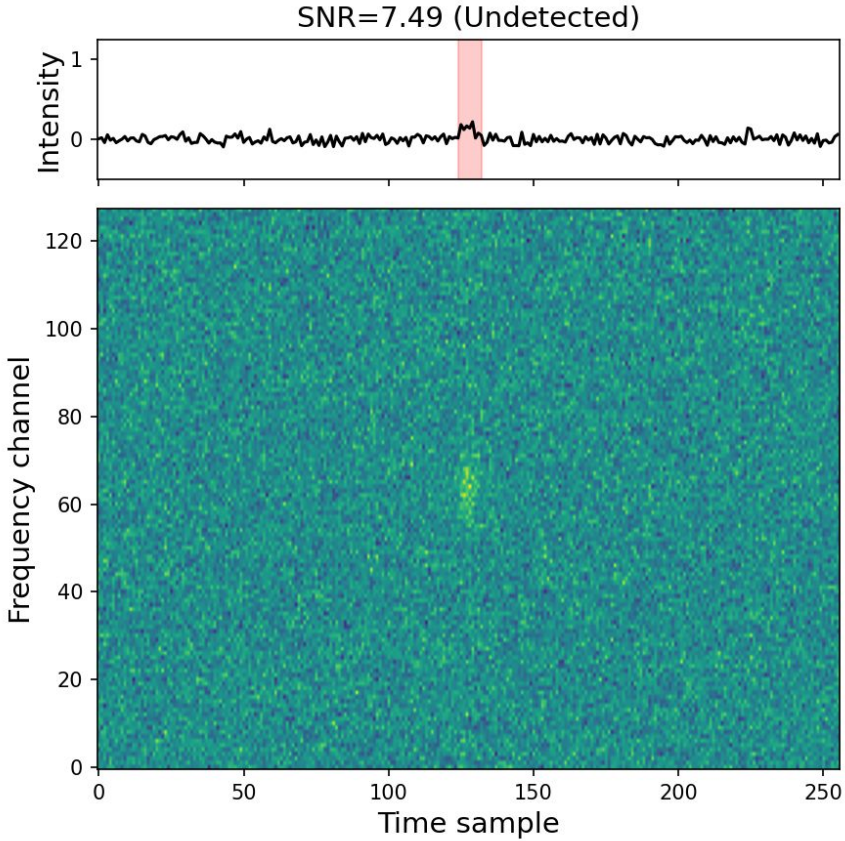
Goal

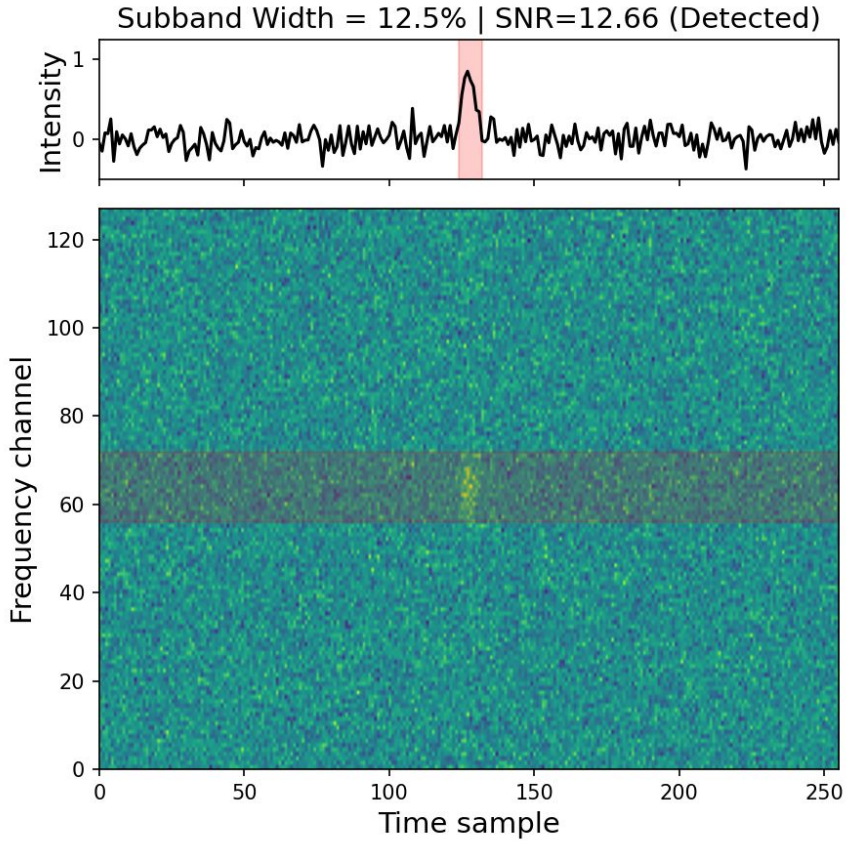
- **Search for the signals with spectral features**
  - Possibility of narrow band faint bursts that go undetected in the full band search
  - Need to find all the bursts showing these spectral features
- **Characterize their spectral nature**
  - Characterize the bandwidth and spectral structure of the bursts
- **Compare the results with scintillation**
  - Compare with what we expect from scintillation

The pipeline



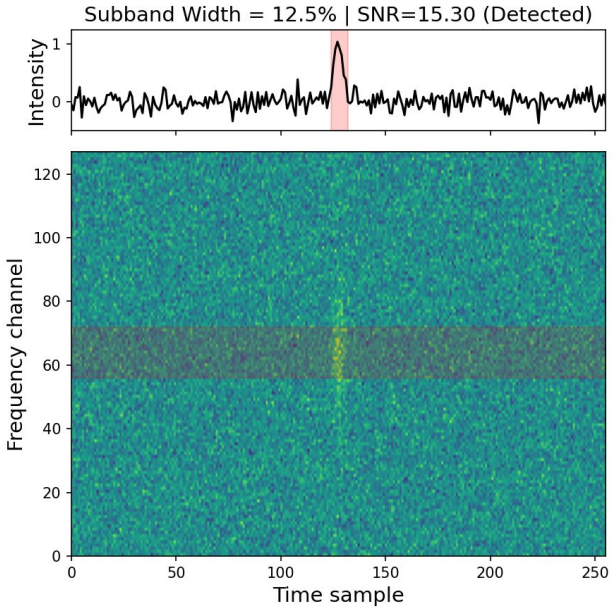
The pipeline

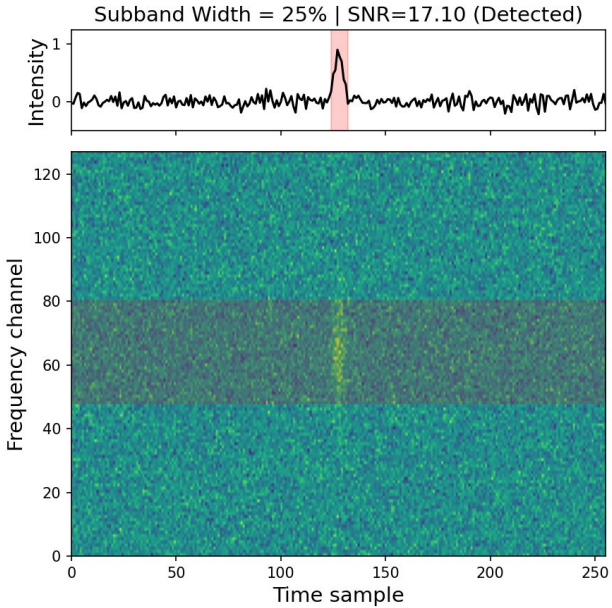


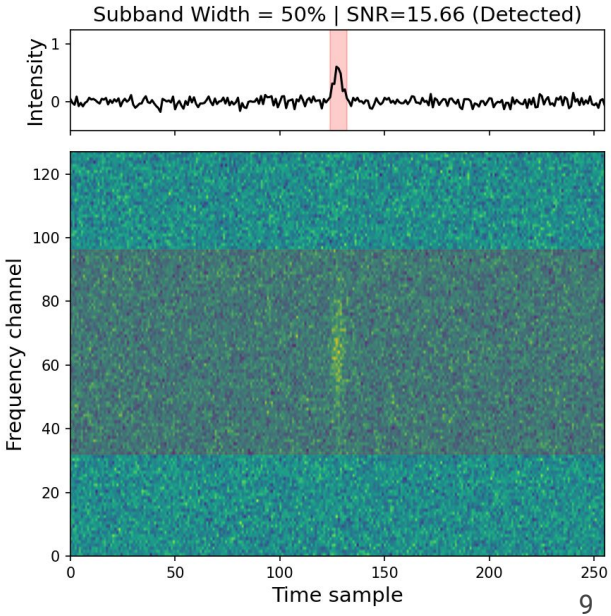


The pipeline

Search → Sorting → Initial conditions → Fitting

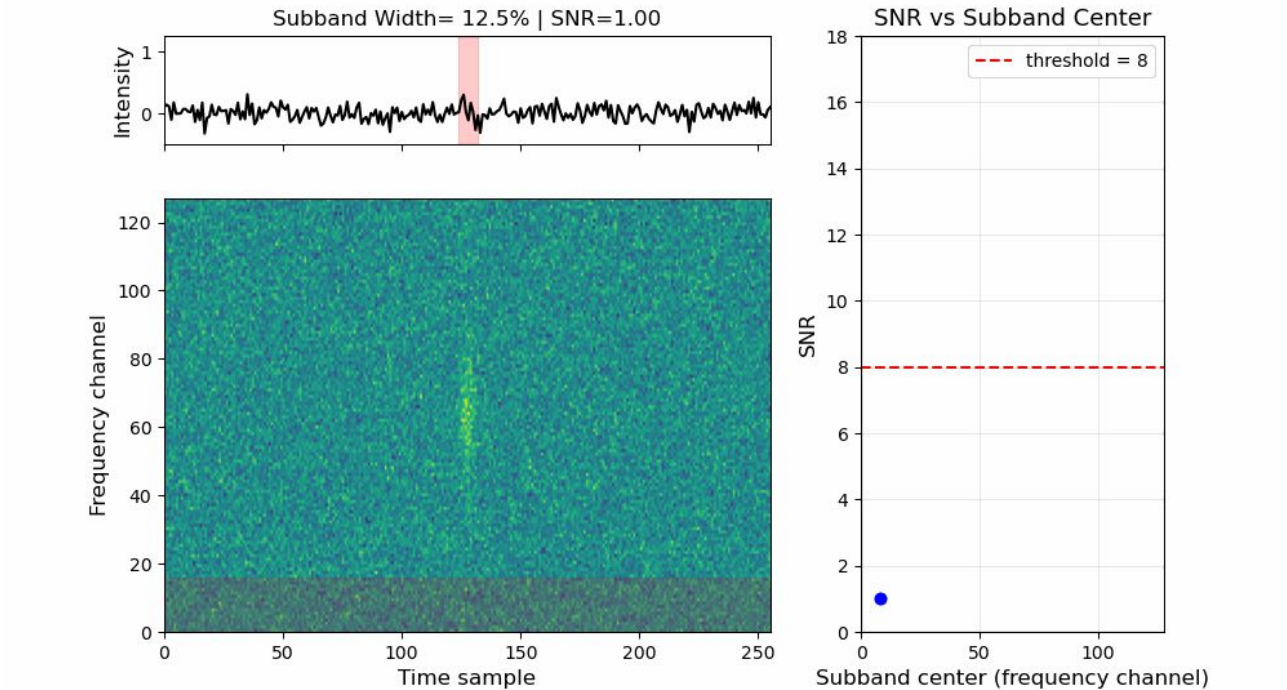




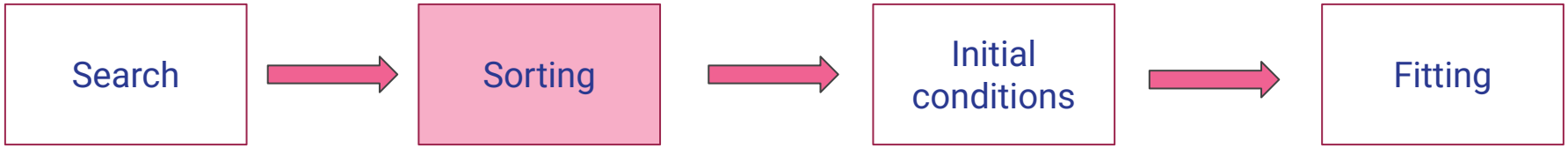


The pipeline - Search

Search → Sorting → Initial conditions → Fitting

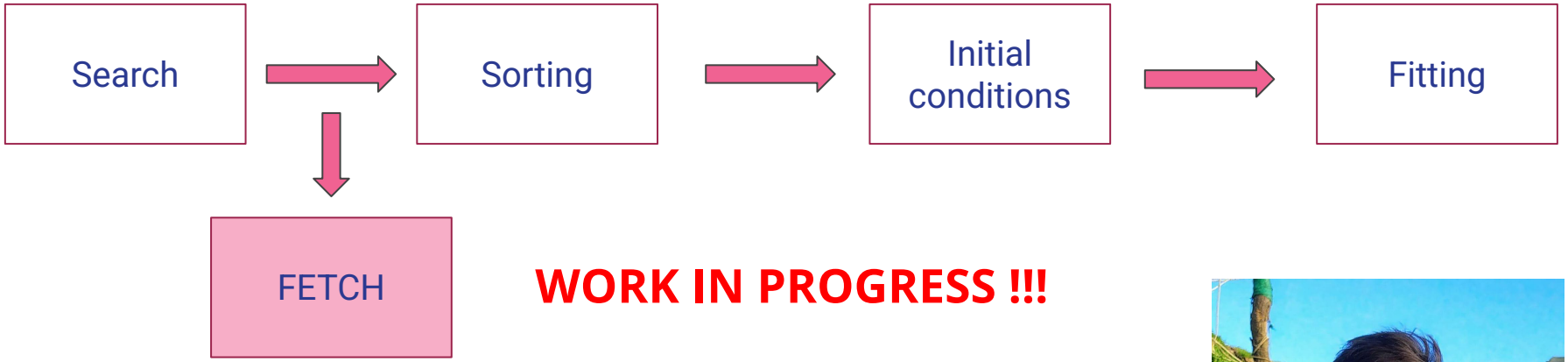


The pipeline - Sorting

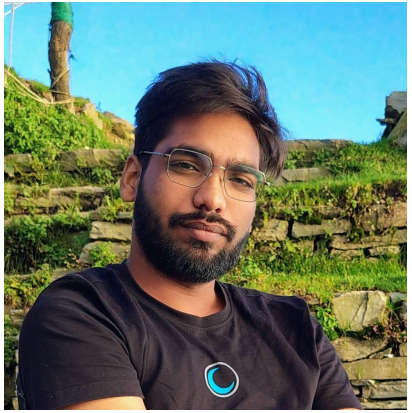


- Due to subband search we have a long list of duplicates
- Algorithm to do the subband filtering
- Compare overlapping subbands and checks for duplicates
- Comparing the difference to the arrival times with the width and keep the ones with a higher SNR
- Finally we have a list of narrowband candidates

The pipeline - Sorting

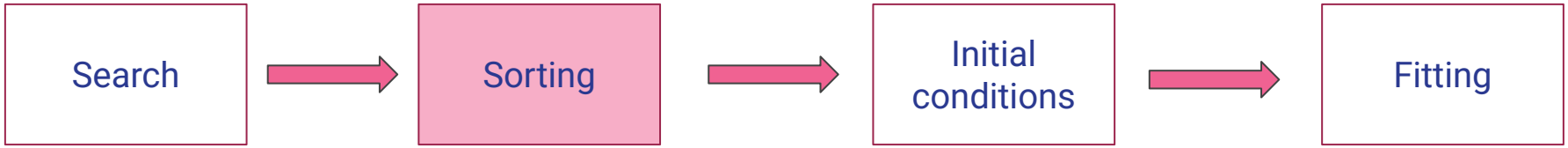


WORK IN PROGRESS !!!



- RFI messes with the **filtering algorithm** and results in lots of **false positives**
- FETCH retrained using narrowband bursts by Ankit Narolia, improved performance from 78% to 95% for narrow band bursts.
- Also testing the full pipeline on an injected dataset, doing good

The pipeline - Sorting

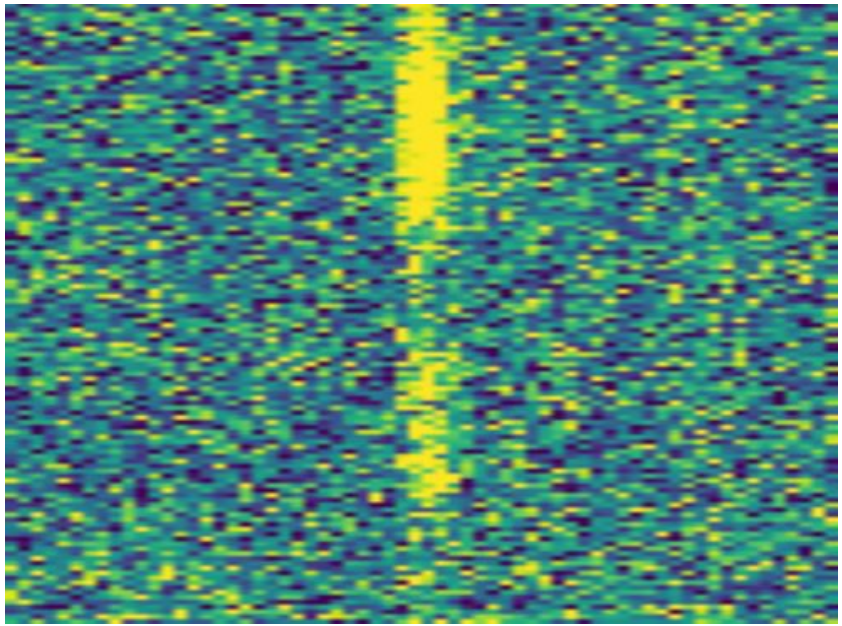


- Due to subband search we have a long list of duplicates
- Algorithm to do the subband filtering
- Compare overlapping subbands and checks for duplicates
- Comparing the difference to the arrival times with the width and keep the ones with a higher SNR
- **Finally we have a list of narrowband candidates**

The pipeline - Initial condition

Search → Sorting → **Initial conditions** → Fitting

- BFF (by Yash Bhusare) to generate images of the dynamic spectra*

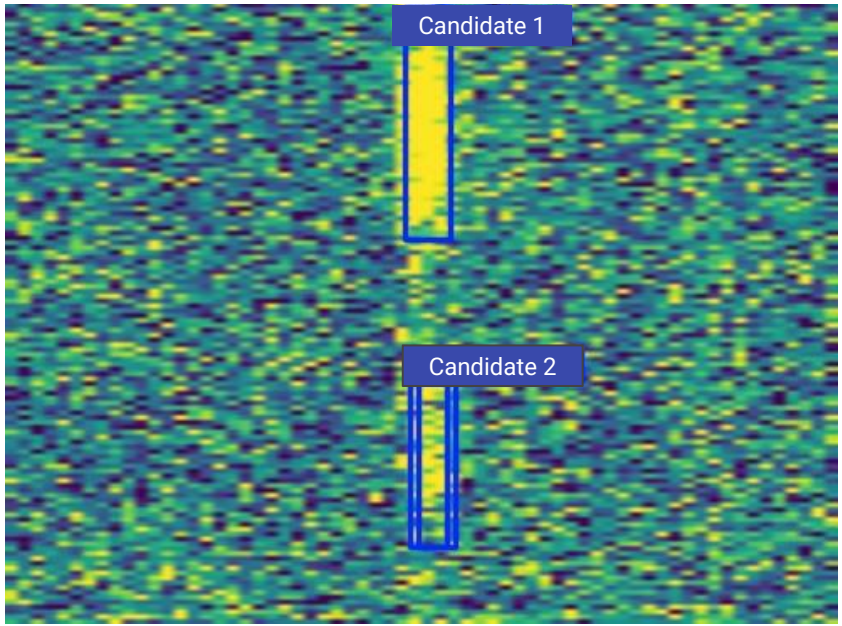


*https://github.com/YashBhusare/BFF

The pipeline - Initial condition

Search → Sorting → **Initial conditions** → Fitting

- BFF (by Yash Bhusare) to generate images of the dynamic spectra*
- YOLO — object detection model — identify the bursts — trained by Yash Bhusare (Redmond et al. 2016)

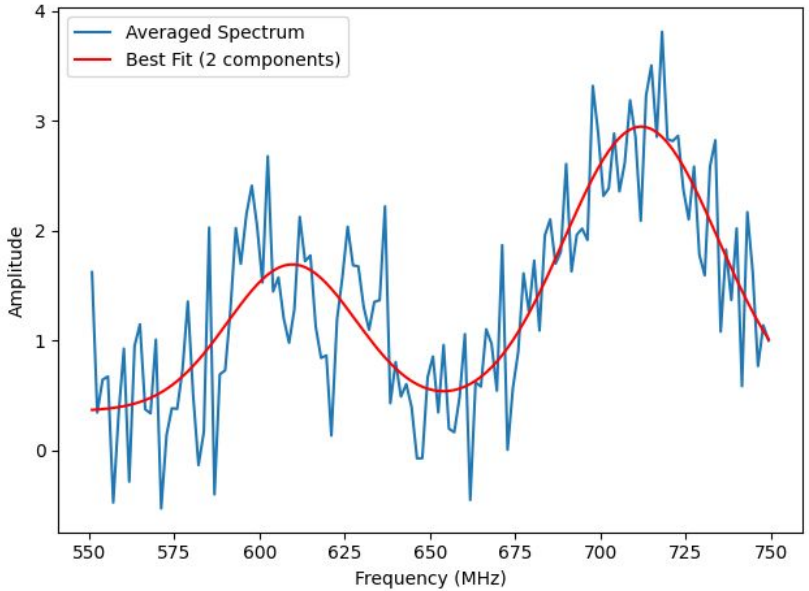


*https://github.com/YashBhusare/BFF

The pipeline - Fitting

Search → Sorting → Initial conditions → **Fitting**

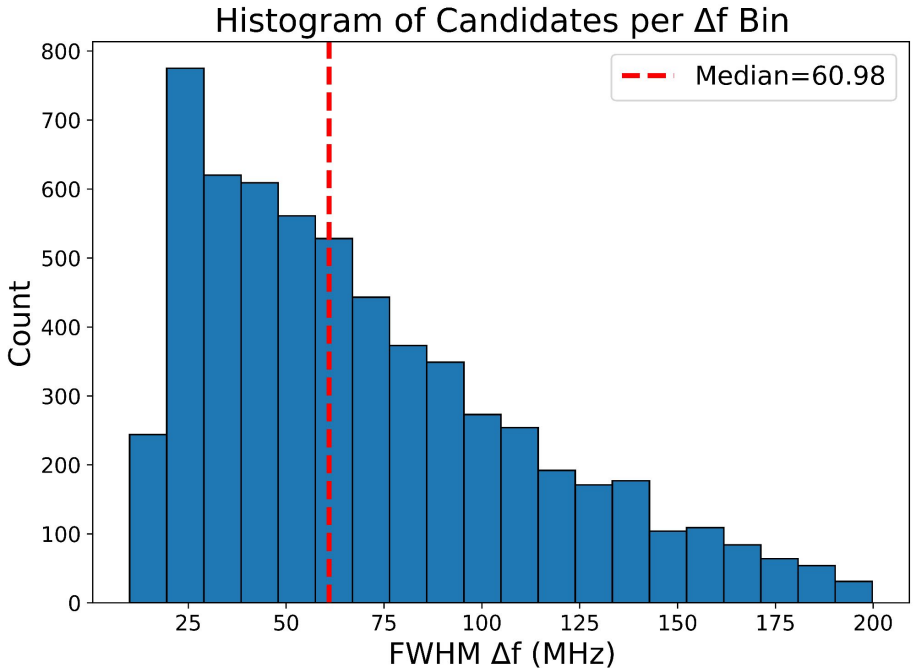
- BFF (by Yash Bhusare) to generate images of the dynamic spectra*
- YOLO — object detection model — identify the bursts — trained by Yash Bhusare (Redmond et al. 2016)
- Fit spectra using the initial conditions from YOLO



*https://github.com/YashBhusare/BFF

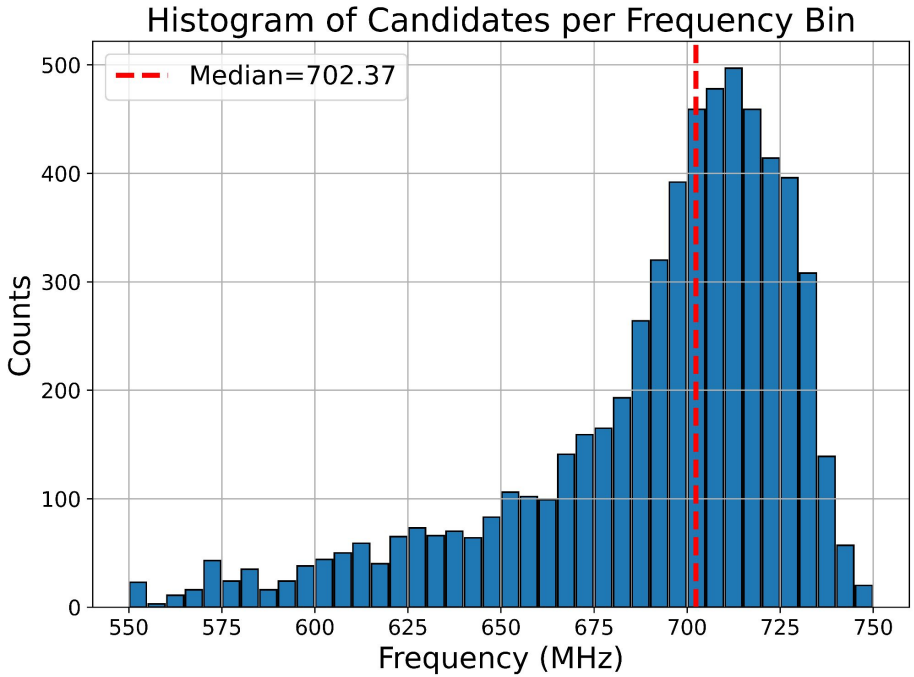
Results (preliminary)

- Most bursts were narrow ~ 60 MHz



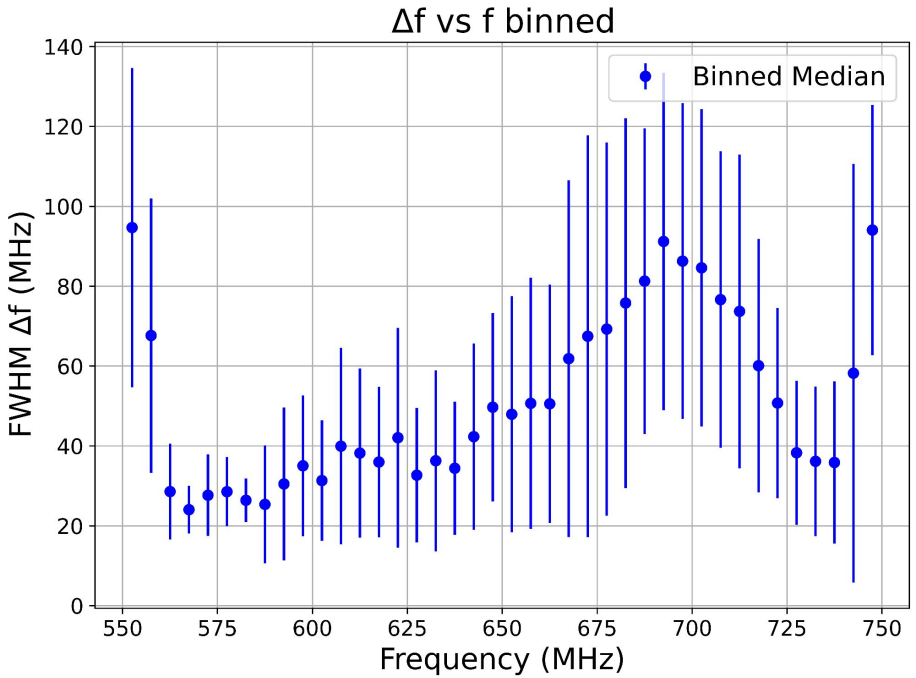
Results (preliminary)

- Most bursts were narrow ~ 60 MHz
- Most of these bursts were found around 700 MHz



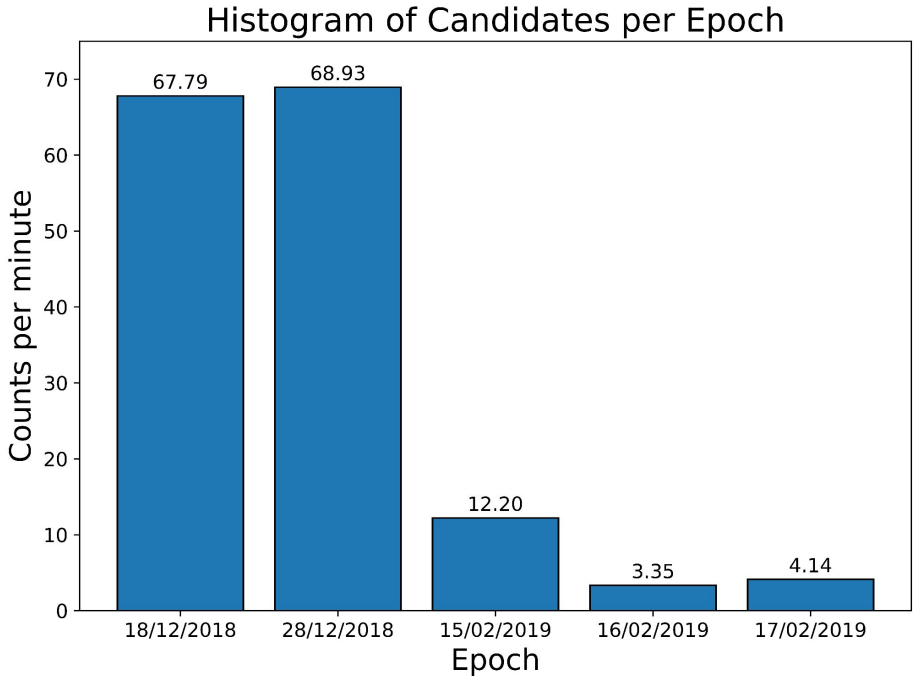
Results (preliminary)

- Most bursts were narrow ~ 60 MHz
- Most of these bursts were found around 700 MHz
- Feature in FWHM vs frequency — Peak around 700 MHZ - **edge effect??**



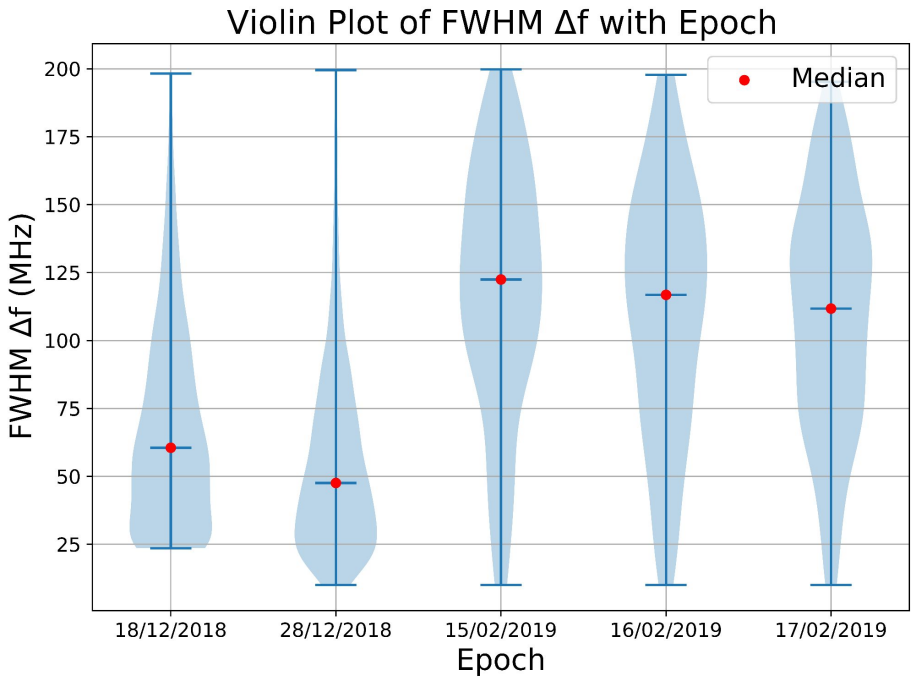
Results (preliminary)

- Most bursts were narrow ~ 60 MHz
- Most of these bursts were found around 700 MHz
- Feature in FWHM vs frequency — Peak around 700 MHZ - **edge effect??**
- Dominated by two epochs (close to it's detection)



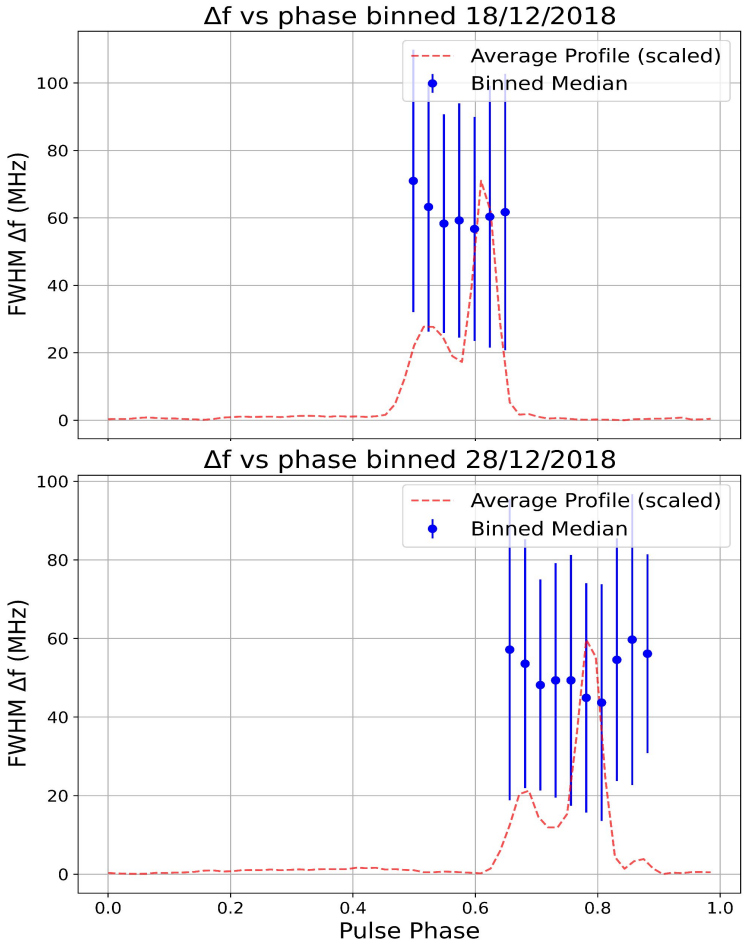
Results (preliminary)

- Most bursts were narrow ~ 60 MHz
- Most of these bursts were found around 700 MHz
- Feature in FWHM vs frequency — Peak around 700 MHZ - **edge effect??**
- Dominated by two epochs (close to it's detection) — Typically lower bandwidths in these epochs



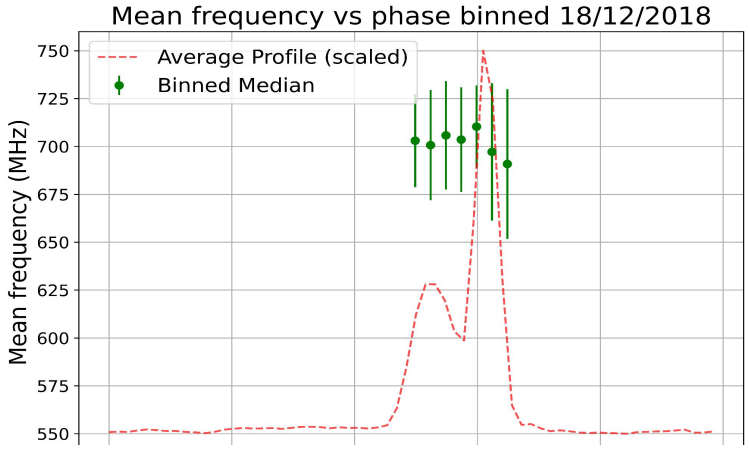
Results (preliminary)

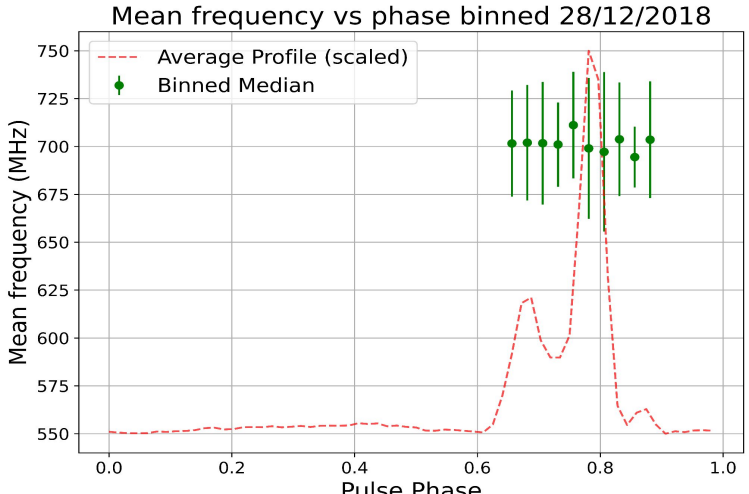
- Most bursts were narrow ~ 60 MHz
- Most of these bursts were found around 700 MHz
- Feature in FWHM vs frequency — Peak around 700 MHZ - **edge effect??**
- Dominated by two epochs (close to it's detection) — Typically lower bandwidths in these epochs
- No clear pattern with the pulse phase



Results (preliminary)

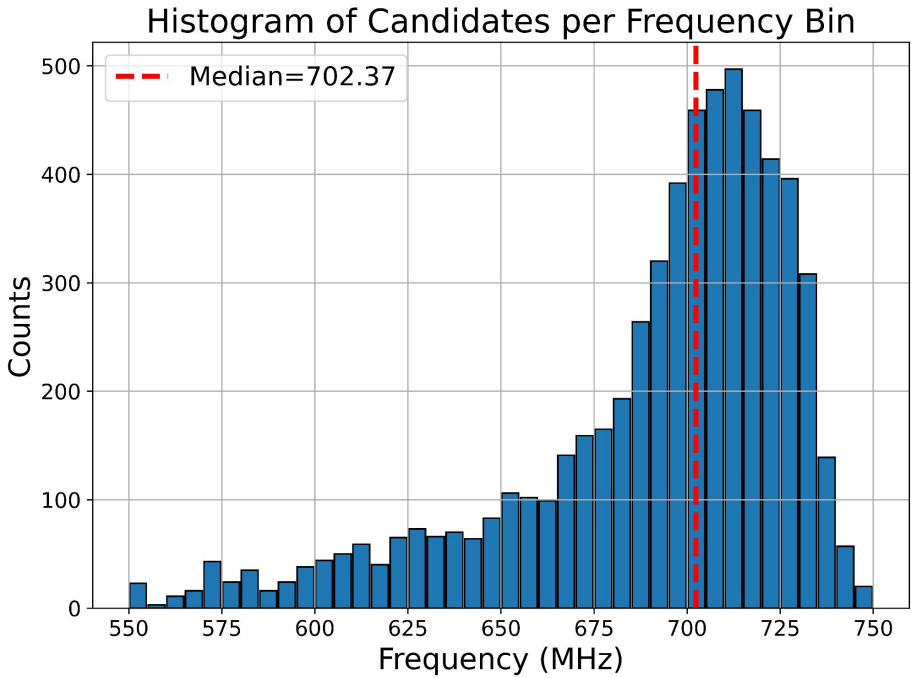
- Most bursts were narrow ~ 60 MHz
- Most of these bursts were found around 700 MHz
- Feature in FWHM vs frequency — Peak around 700 MHZ - **edge effect??**
- Dominated by two epochs (close to it's detection) — Typically lower bandwidths in these epochs
- No clear pattern with the pulse phase





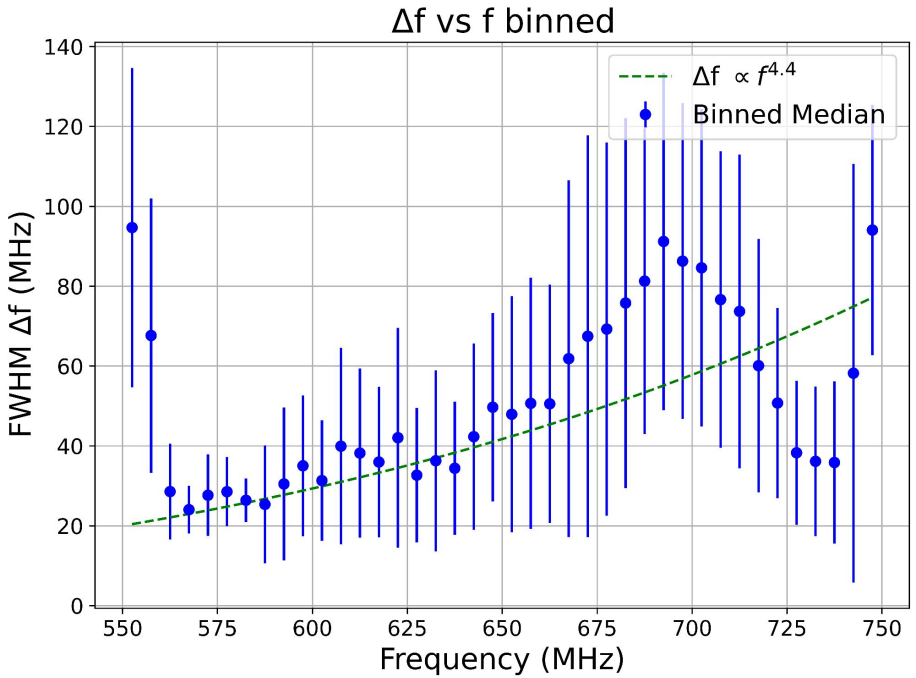
Scintillation??

- Preferred frequency not expected by scintillation
- Diffraction scintillation timescales
- Expect a power law relation between FWHM and f due to scintillation, with the index = 4.4 for Kolmogorov turbulence (Cordes et al. 1985)
- Issue due to band edge effects?
- Candidates — FWHM decreases with frequency

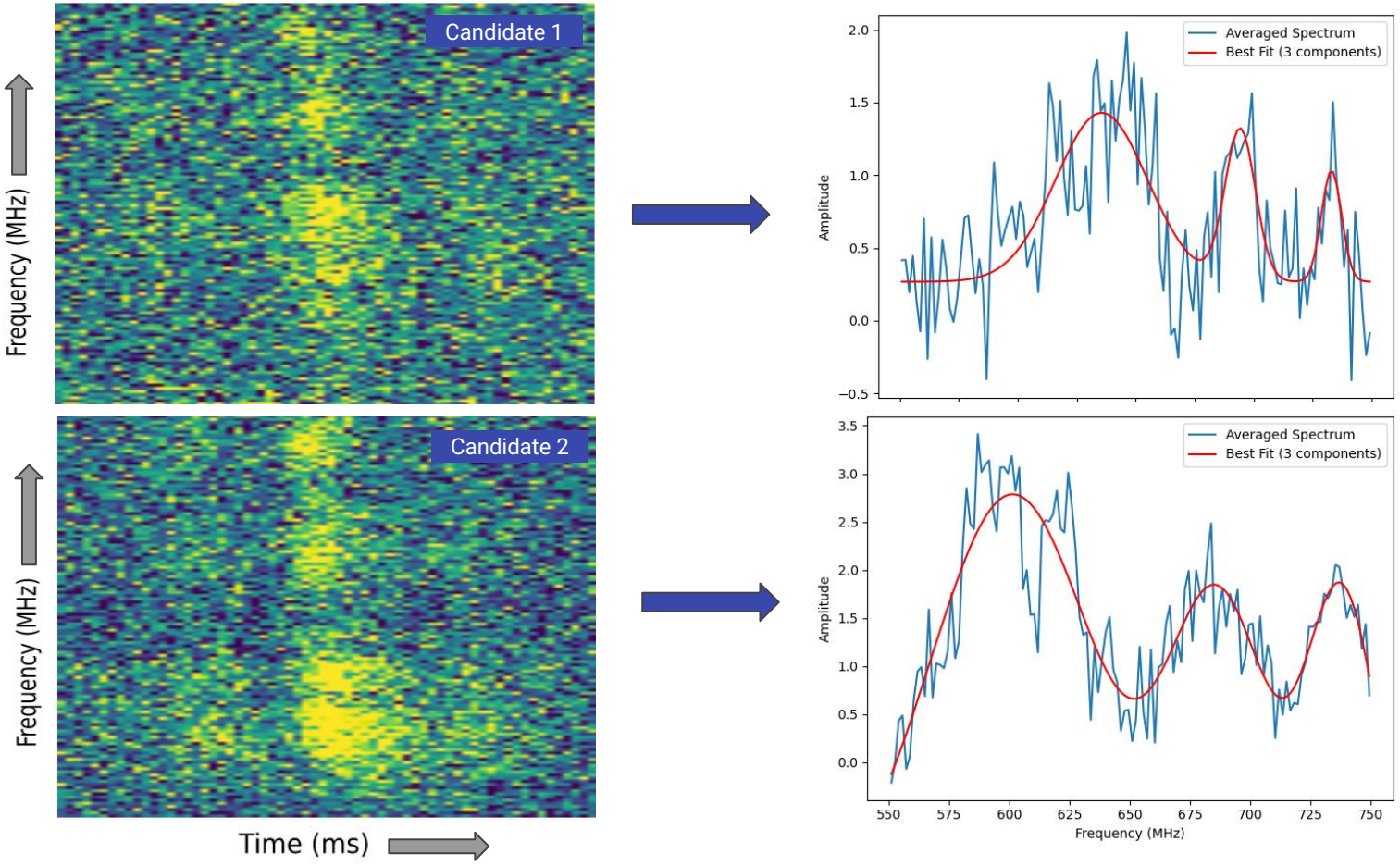


Scintillation??

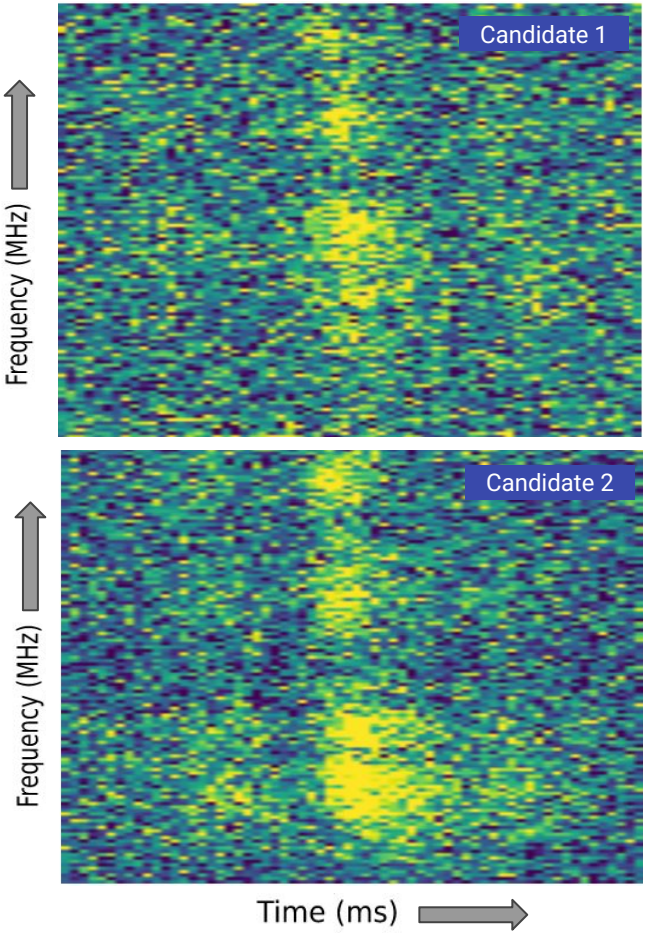
- Preferred frequency not expected by scintillation
- Diffraction scintillation timescales
- Expect a power law relation between FWHM and f due to scintillation, with the index = 4.4 for Kolmogorov turbulence (Cordes et al. 1985)
- Issue due to band edge effects?
- Candidates — FWHM decreases with frequency

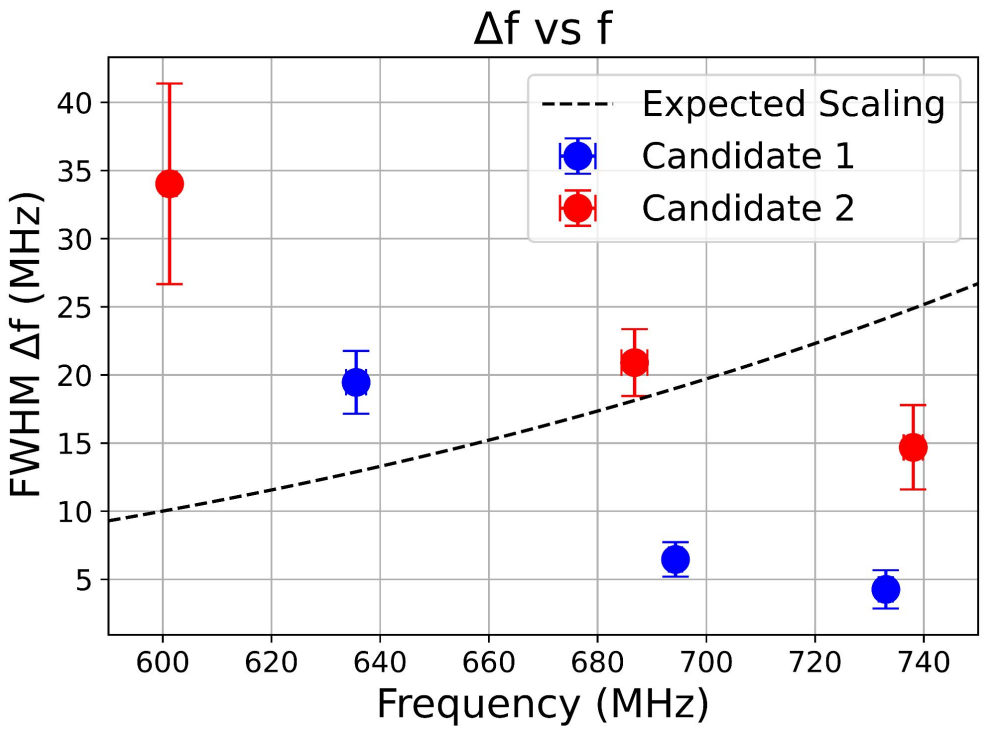


Scintillation??



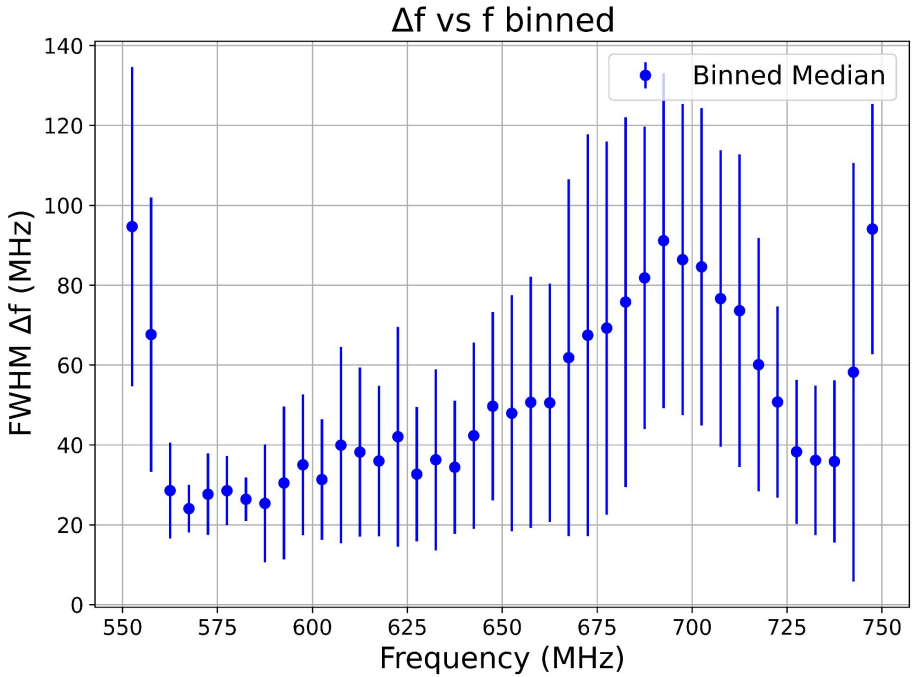
Scintillation??





Discussion

- Evidence suggesting these bursts being intrinsic and not due to scintillation
- Narrow band emission can be caused by: Plasma lensing, Absorption, underlying emission (Yang et al. 2023)

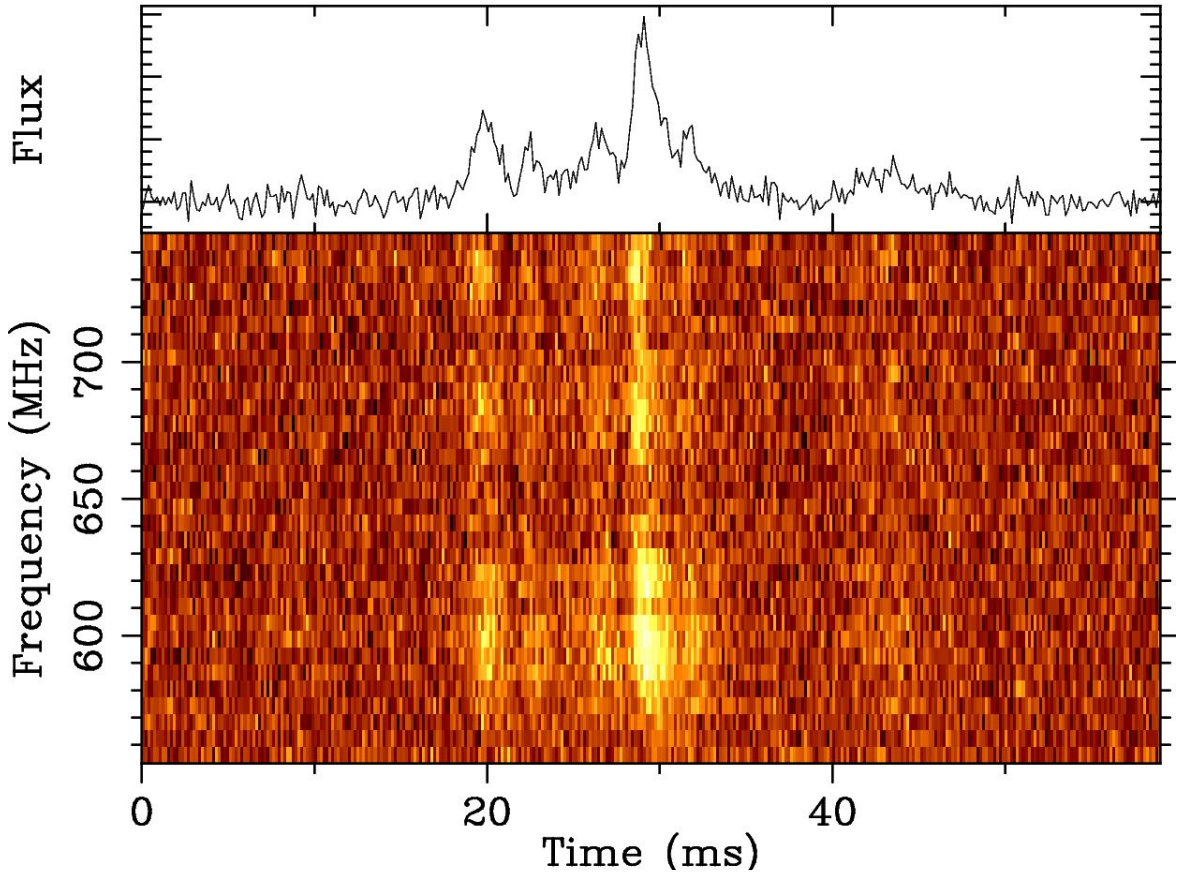


Conclusion

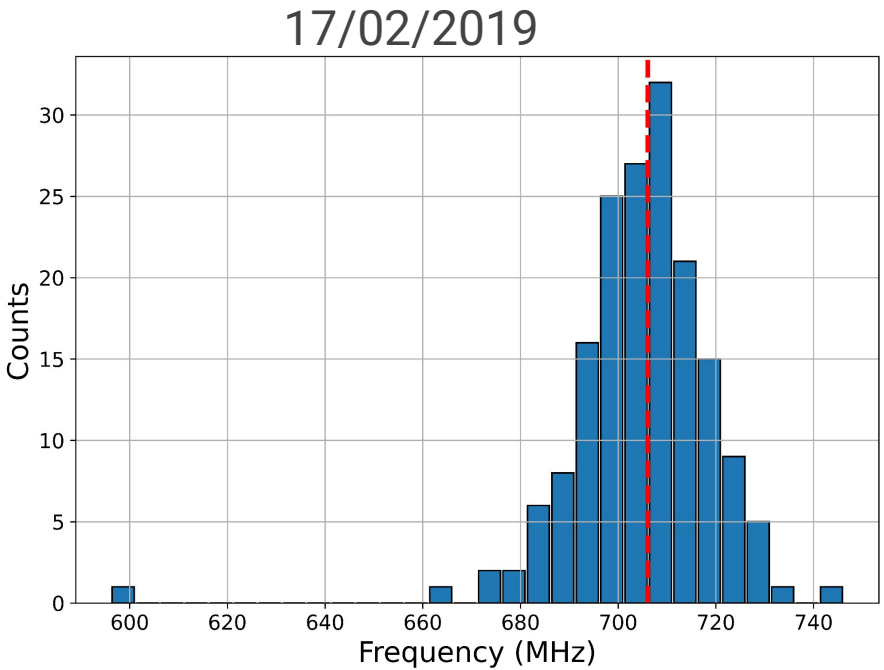
- Spectral features of FRBs are not well understood — insights to the emission mechanism
- J1809-1943 also exhibited such band limited features in the single pulses
- Whether this was scintillation or not?
- Developed a pipeline to search and characterize for such narrow band pulses

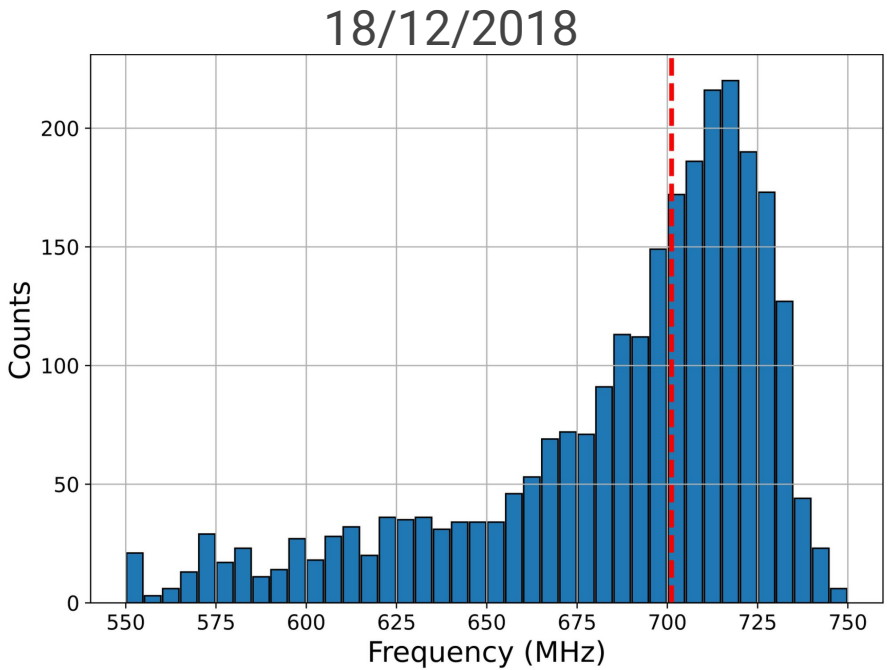
  (Feel free to suggest a name)
- Prelim results suggests that the features are not due to scintillation using timescale as well as the expected relation between the bandwidth and the frequency
- Establishes a phenomenological link with the FRBs and can shed light on the emission mechanisms

Backup slides



Backup slides





Results

- Most bursts were narrow ~ 60 MHz
- Most of these bursts were found around 700 MHz
- Feature in FWHM vs frequency — Peak around 700 MHZ - **edge effect??**
- Dominated by two epochs (close to it's detection)