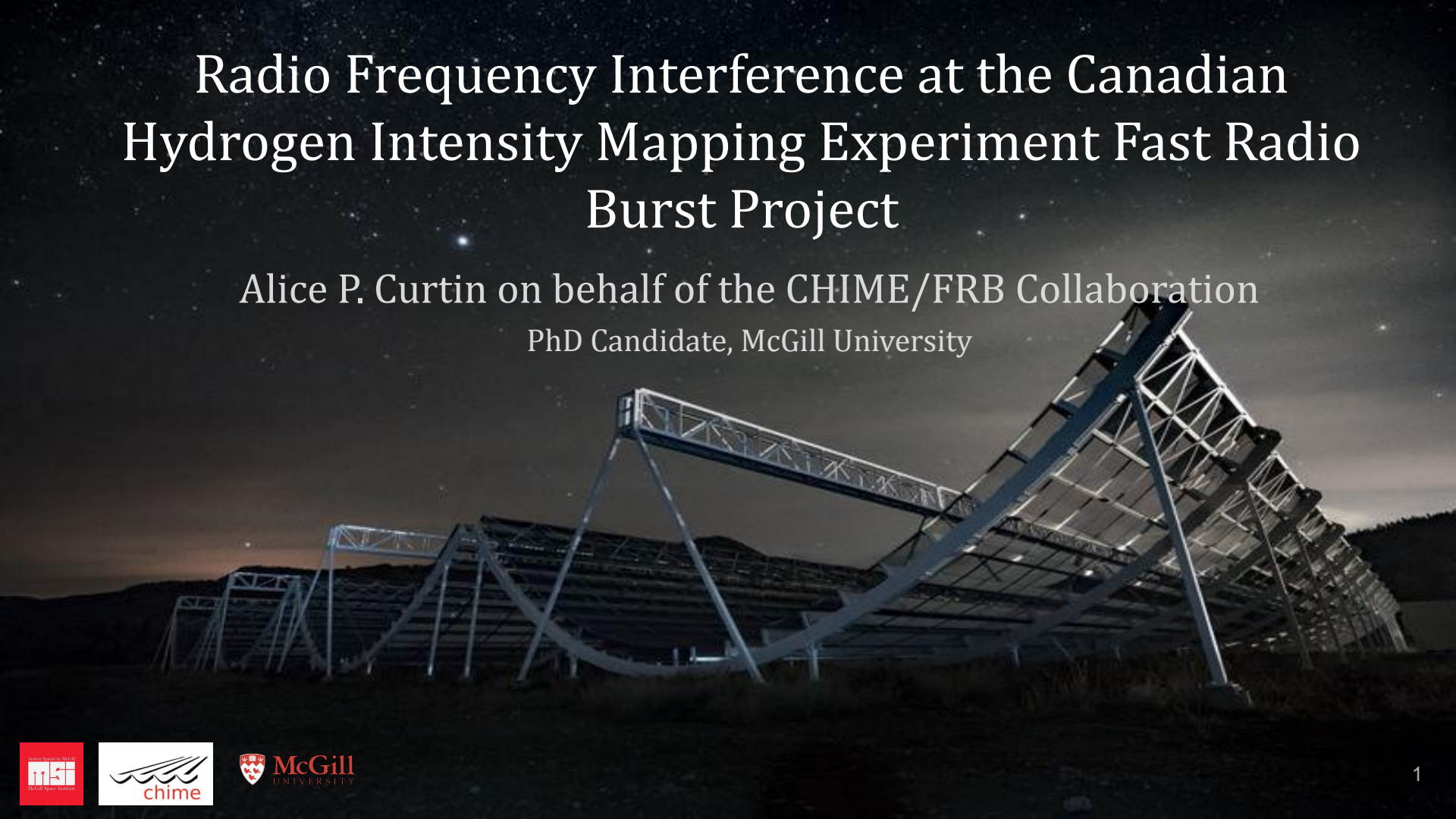
Radio Frequency Interference at the Canadian Hydrogen Intensity Mapping Experiment Fast Radio Burst Project

Alice P. Curtin on behalf of the CHIME/FRB Collaboration

PhD Candidate, McGill University

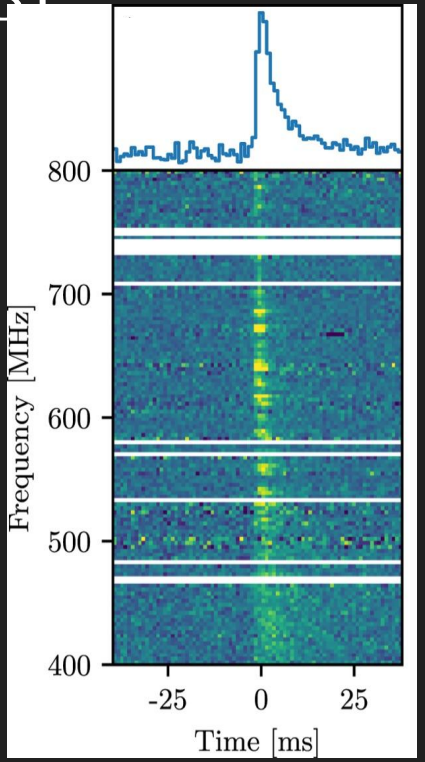


Canadian Hydrogen Intensity Mapping Experiment (CHIME)

- Transit telescope located in a radio-quiet zone in Penticton, BC
- Originally built to study 21-cm hydrogen emission
- Four, 100-m x 20-m cylindrical parabolic reflectors
- 400 to 800 MHz with 1024 dual polarization feeds
- Large FOV ~250 deg^2
- Powerful FX correlator

Canadian Hydrogen Intensity Mapping Experiment Fast Radio Burst Project (CHIME/FRB)

- Transit nature and large FOV = great candidate for blind radio transient searches e.g. fast radio bursts (FRBs)
- FRBs:
  - Fast (~millisecond), highly energetic (~Jy), extragalactic bursts of energy
  - Very energetic with origins still unknown!
  - New probe for studying cosmological parameters and questions along with Galactic and extragalactic environments
- Since its commissioning in 2019, CHIME/FRB detected >2000 FRBs



Z. Pleunis et al. (2021)

So how does CHIME/FRB do it?

Large data rate of ~142 Gb/s = real-time pipeline

L0: FFT Beamforming -> 1024 formed beams

L1: RFI removal process; Event detection algorithm

L2/L3: Groups events to determine whether something is astrophysical or RFI; Improves localizations; Determines whether an event is Galactic or Extragalactic; Decides future actions for the event

L4: Implements actions decided in L2/L3

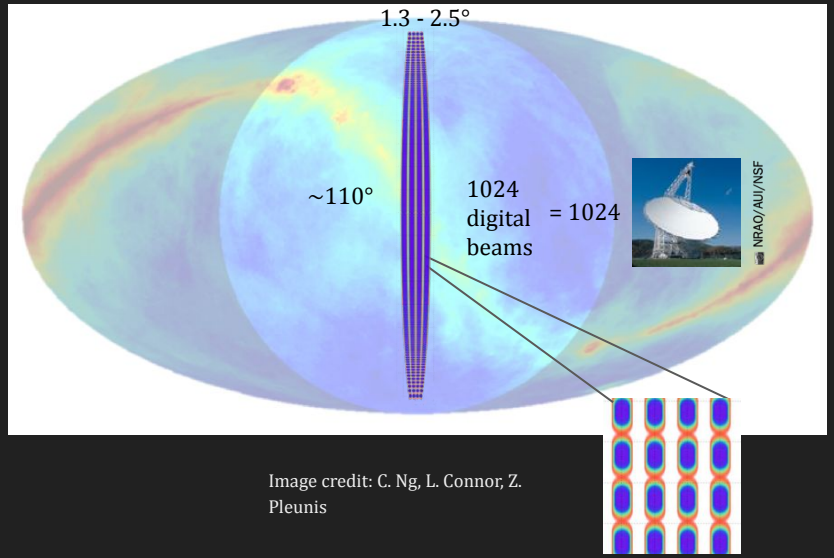
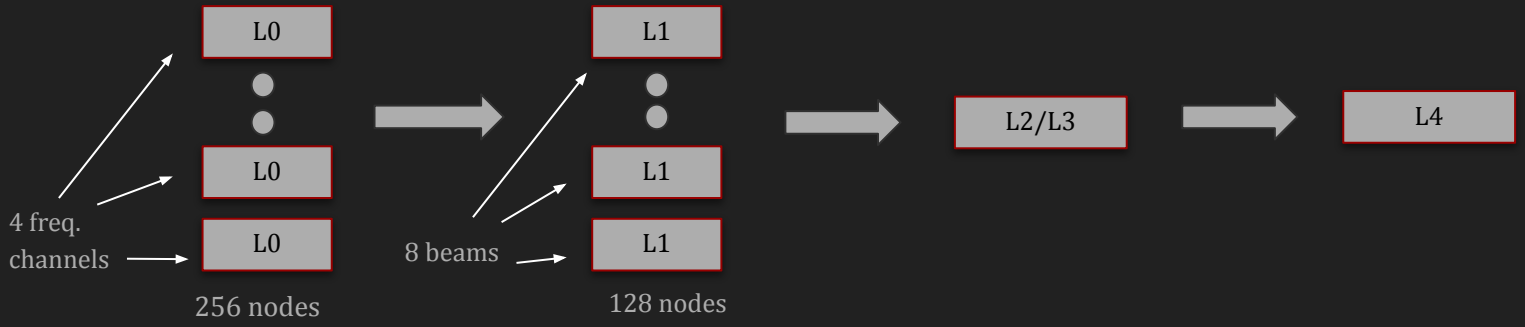


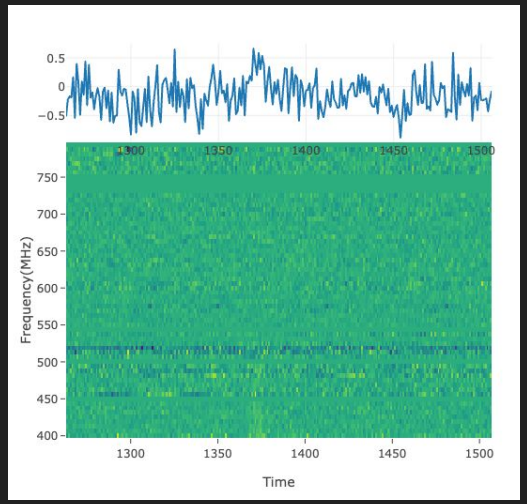
Image credit: C. Ng, L. Connor, Z. Pleunis

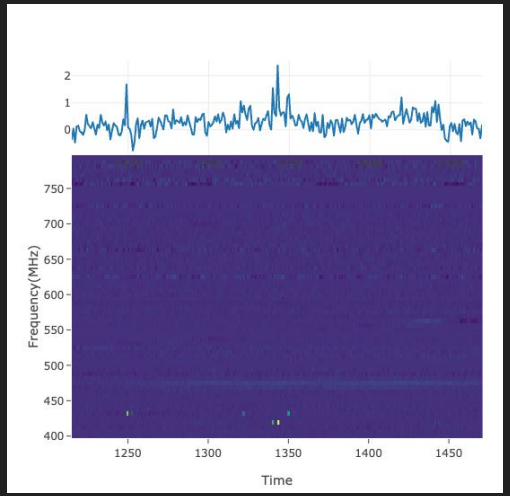


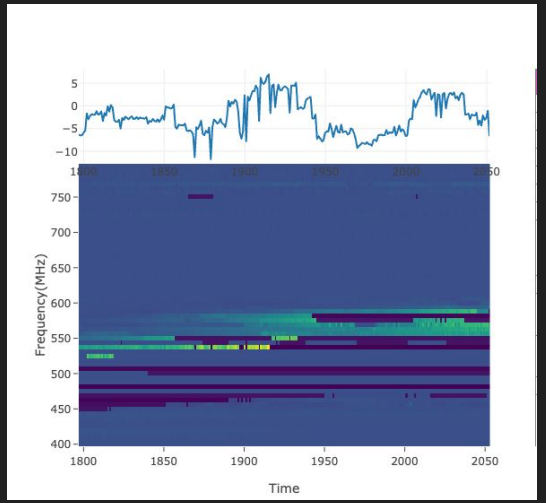
Why is RFI mitigation and characterization essential here?

What is RFI? An FRB?

*Times in milliseconds

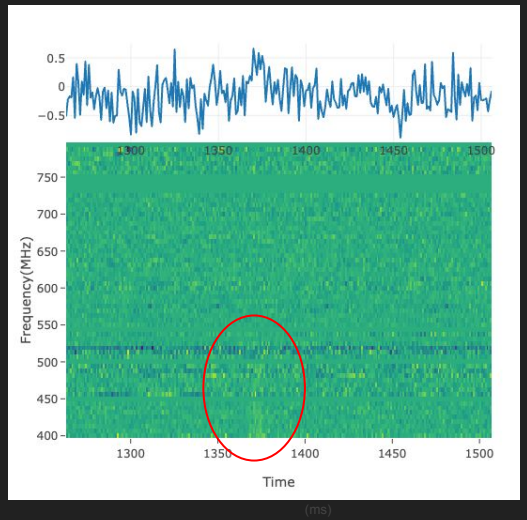




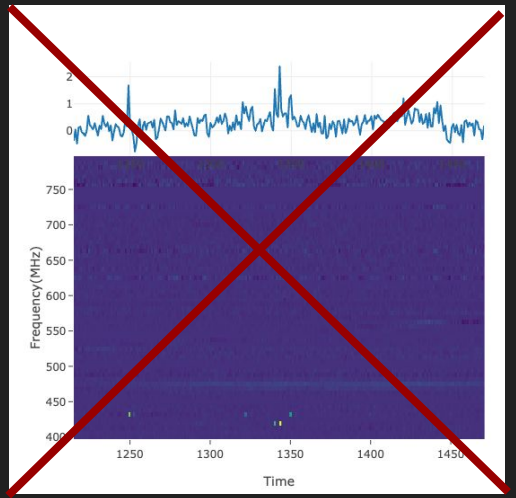


Why is RFI mitigation and characterization essential here?

FRB

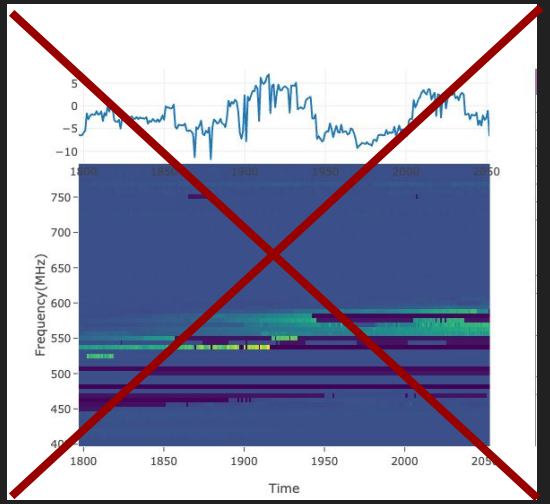


RFI



RFI

*Times in milliseconds



~2-3 FRBs per day while 20k-30k RFI events

Diving into CHIME/FRB's RFI Removal Process

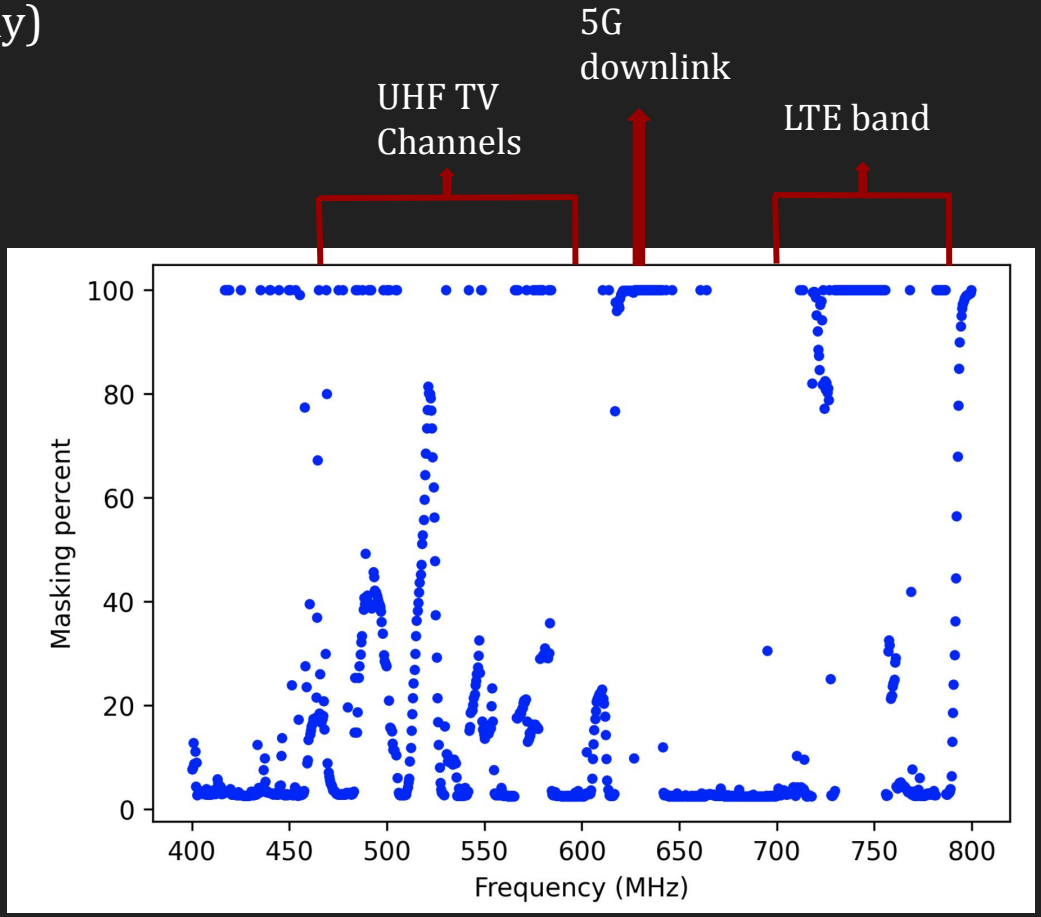
CHIME/FRB's L1 masking process: (see talk by M. Rafiei-Ravandi on Friday at 2:40 pm ET for further details)

- Initial input = gaussian signal (FRB) + non-gaussian outliers (RFI)
- Non-gaussian outliers removed through a chain of transforms
  - Each transform operates on a four second chunk of data (intensity + weights)
  - Clippings: specified intensity amplitude cutoff
  - Detrender: polynomial and spline along both the frequency and time axis to capture broadband RFI signals
  - Sequence of clippings/detrending repeated multiple times

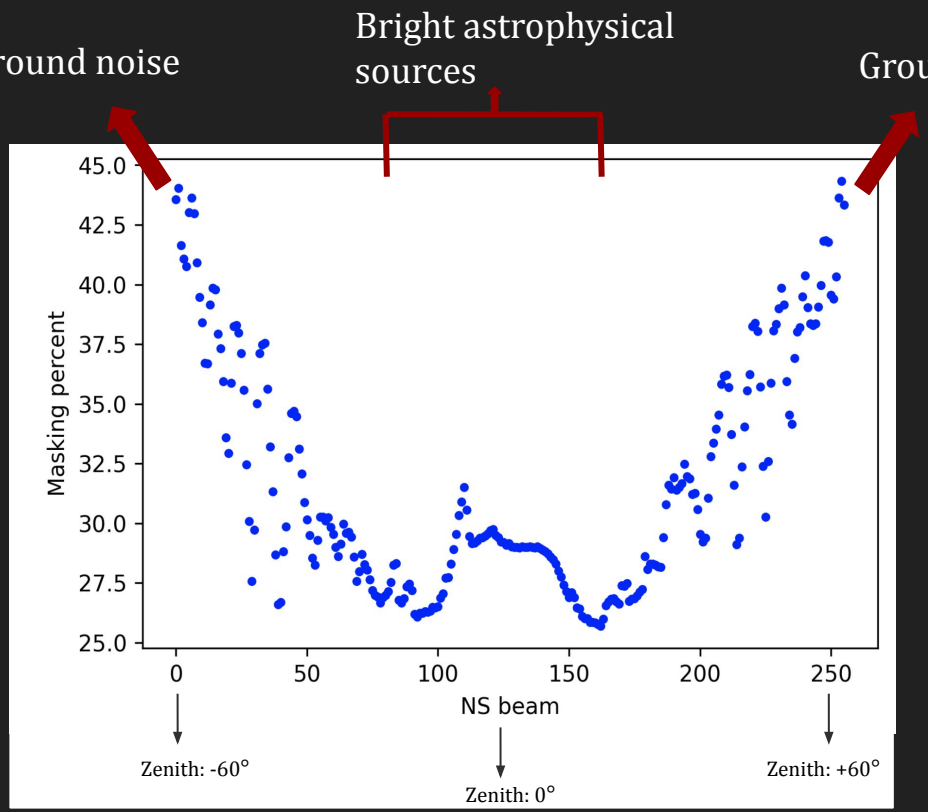
Flagged RFI: Frequency Structure
(averaged spatially & temporally)

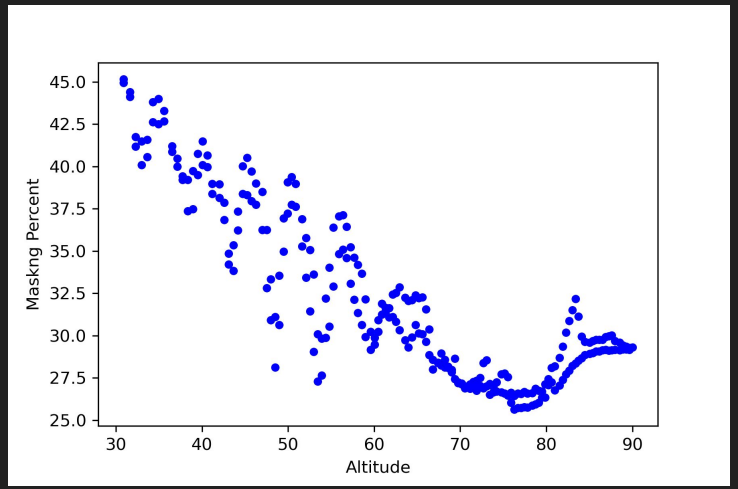
L1 RFI masking pipeline, *rf-pipelines*, flags ~22% of our data

This is highly dependent on both frequency channel, and beam number



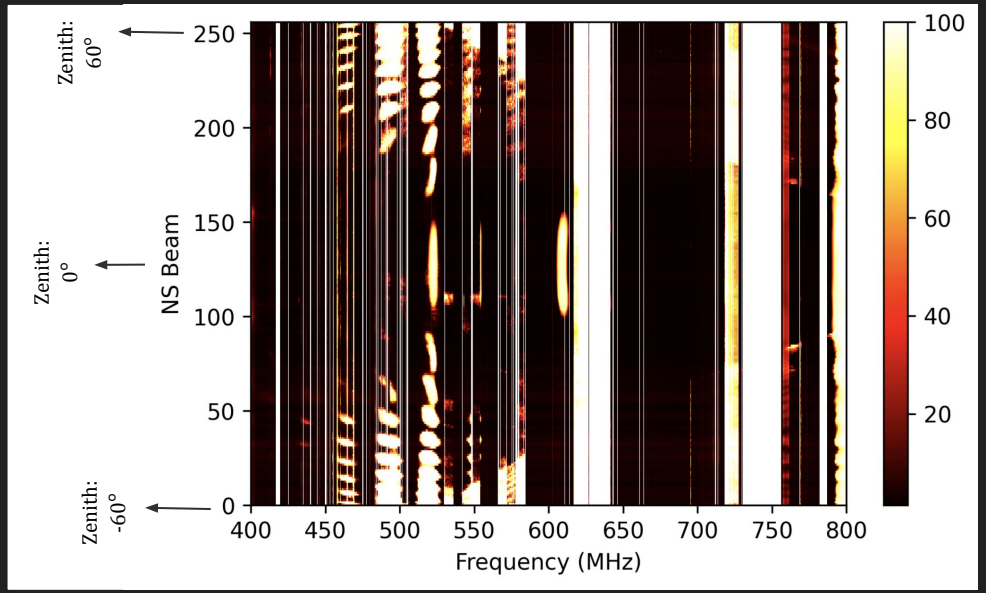
Structure of RFI: Spatial
(averaged in frequency & temporally)



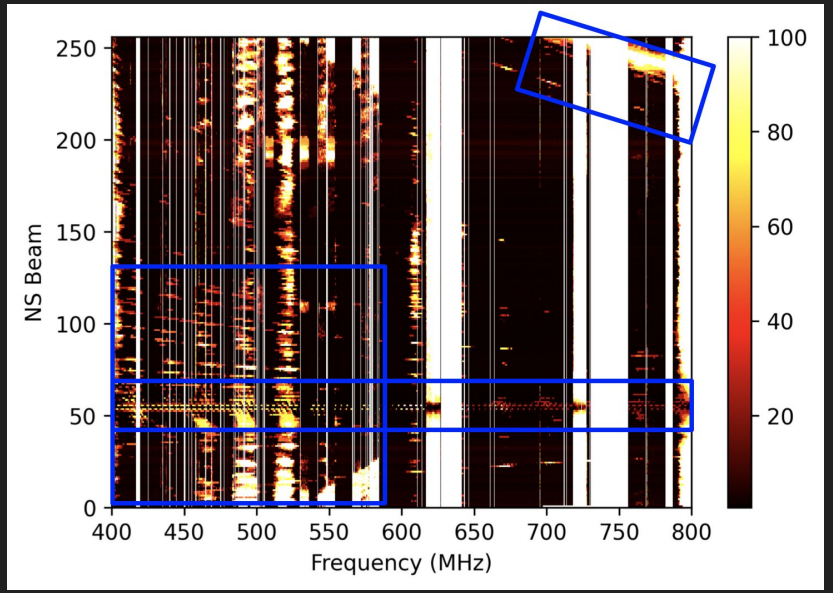


The effects of the sun

Non-peak Sun Rise



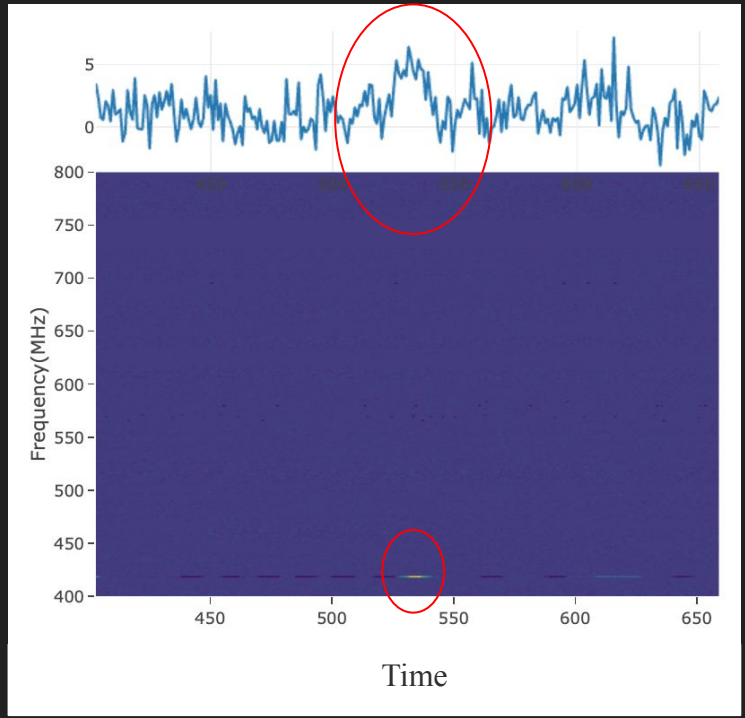
Peak Sun Rise



A detailed look at the frequency and spatial structure over time

New sources of RFI: “*rfi-storms*”

- Started in late 2020, continued to present
- Enormous number of RFI events per day, with a peak of 1.7m events/day
  - Typically detect ~20k to 30k events per day
- What are these new RFI events? Likely new, narrow band RFI signals not captured by our RFI algorithms which, when combined with other RFI within the band, is detected as an “event”
- Named these huge influxes“*rfi-storms*”



Category I *rfi-storms*

- Cadence: ~20 minute timescale
- Spatial dependence: edge North-South beams
- Frequency range: 781.8 - 786.7 MHz, 418.2 - 419.2 MHz, 417.2 - 417.6 MHz, 440.2 - 440.4 MHz
    - 700 MHz signals: new LTE sources?
    - 400 MHz signals: unknown!

Category II *rfi-storms*

- Cadence: ~8 seconds
- Spatial dependence: No clear dependence, although slight fall-off towards edge beams
- Frequency range: 627.2 to 641.4 MHz
    - Downlink for 5G telecommunications within this frequency range

Thus-far solutions

- Statically mask out the problematic frequency channels. So far, this has increased the percent of our data that we are masking by ~6%
- However, more sources of *rfi-storms* keep appearing, and further masking is needed
- Could easily end up masking another 5-10% of our data
- Not a great long-term solution – need improved dynamic masking in the future to catch these storms

Summarizing

- Even located in a radio-quiet zone, CHIME/FRB suffers from considerable RFI, with ~22% of the data masked
- The RFI is highly dynamic, and is not only dependent on terrestrial sources but also astrophysical sources
- Many new sources of RFI
  - Masked data percent has increased by ~5-10% over the last two years
  - New LTE bands
  - Unknown sources
- However, despite complex RFI, CHIME/FRB still accomplishing incredible science!

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