VLITE-FAST: GPU-based real-time searches for fast transients with the VLA

Paul Ray (NRL), Julia Deneva (NRC Research Associate, resident at NRL),
Emil Polisensky (NRL), Fernando Cardoso (NRL/WVU), Namir Kassim (NRL)

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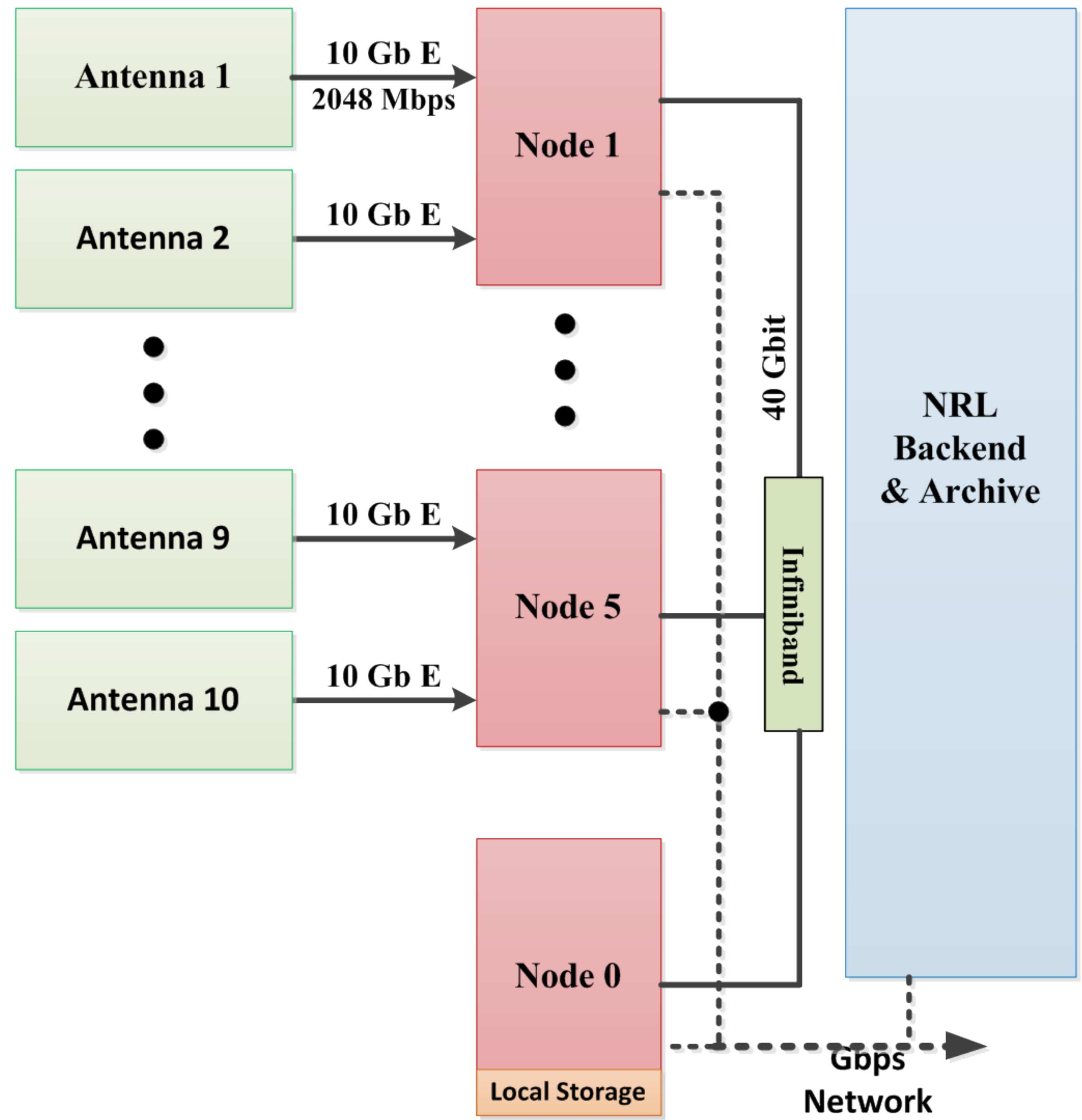
VLITE-FAST

- VLITE DIFX correlator has a dump time of 2 seconds, so imaging transient searches are on that timescale or longer
    - But, faster signals are interesting!
- Raw voltage data could be processed to look for fast, dispersed transients, but data volume and processing requirements are large
    - Requirement: Don't interfere with standard VLITE processing!
    - Solution: Send data stream to GPUs to process on the fly. Trigger dump of buffer for sufficiently interesting candidate events.

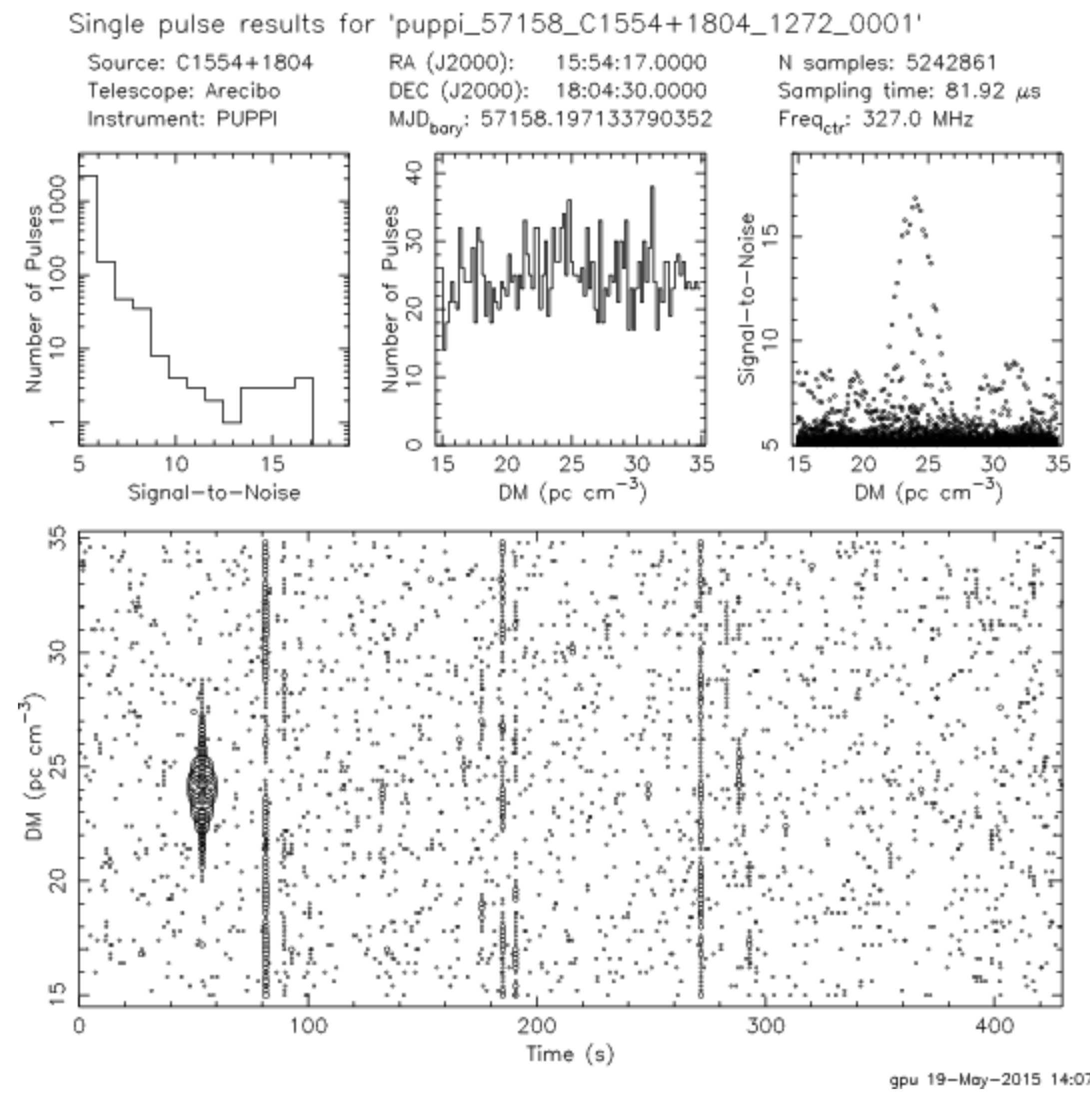


Why Fast Transients?

- VLITE commensal system gets LOTS of time on the sky per year (~6000 hours) and FOV is >2 deg so rare events can be detected
- Single pulse searches for pulsars and RRATs
- Fast Radio Bursts (FRBs)
- Other?

RRATs

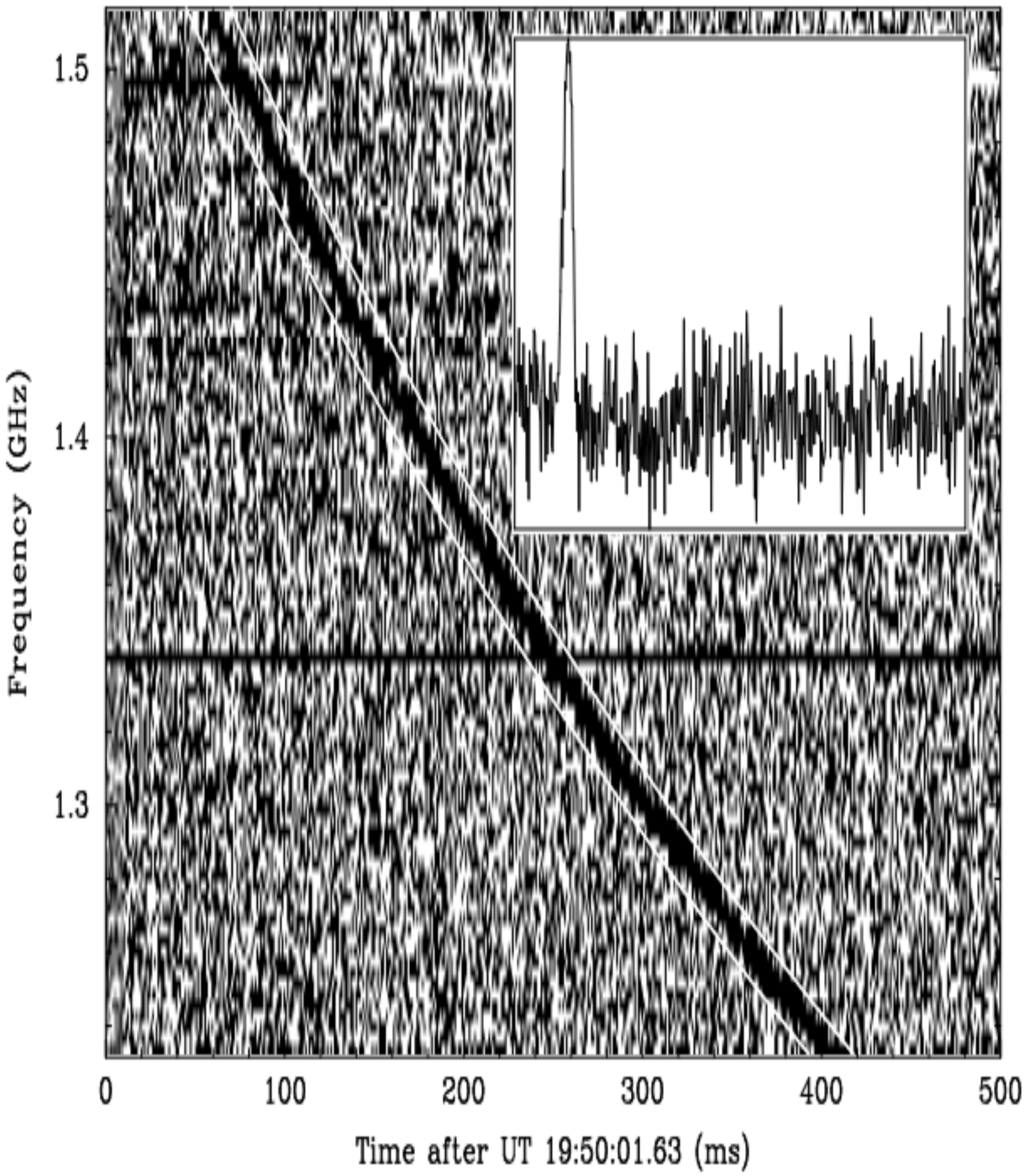
- Rotating Radio Transients
- First found by McLaughlin+ (2006) in Parkes 1.4 GHz data.
- Many found at other frequencies by current surveys.
- ~150 known so far
  - `http://astro.phys.wvu.edu/rratalog/`
- Dispersion measures (DMs) consistent with Galactic origin.
- Reobservations usually yield a period or average pulse rate.
- Periods longer on average than for canonical pulsars, but may be a selection effect



VLITE-FAST can expand the population without spending lots of dedicated observing time.

FRBs

- Fast Radio Bursts
- First found by Lorimer+ (2007) in Parkes 1.4 GHz data.
- DM much larger than expected for a Galactic source at the sky position.
- ~15 detected so far in Parkes 1.4 GHz data, 1 in Arecibo 1.4 GHz data, 1 in GBT 820 MHz data.
- No repeat pulses detected so far despite multiple reobservations → either don't repeat, or repeat on very long timescales
- Latest estimates are 6×10^3 per day full sky



Like GRBs, precise localizations may be the key to understanding!
Detections at different frequencies with different telescopes also important.

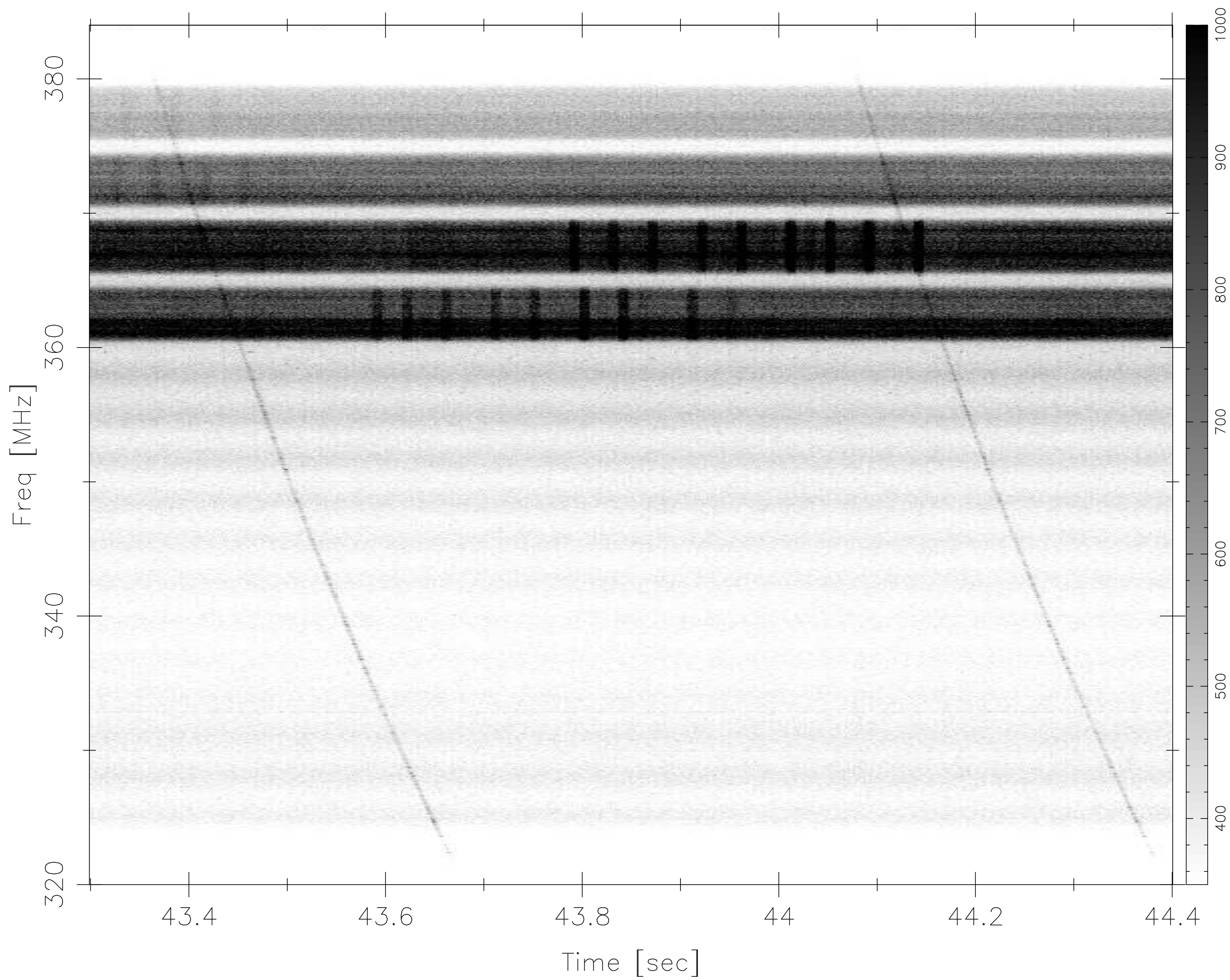
VLITE-FAST Parameters

- Input data is 128 MSPS VDIF voltage stream from 2 polarizations for 10 VLA antennas
    - 64 MHz total bandwidth, but upper 24 MHz unusable due to MUOS satellites
- Sensitivity is such that brightest 10% of FRBs and RRATs should be detectable (with large uncertainties due to spectral index and scattering)

- Bandwidth (Δf) = 40 MHz
- Observing frequency (f_{obs}) = 340 MHz
- System temperature (T_{rec}) = 150 K
- Sky temperature (T_{sky}) = 50 K
- Gain = 0.054 K/Jy
- Sampling time (dt) = 390 μs
- Number of polarizations (N_{pol}) = 2
- Number of channels (N_{ch}) = 3920
- Number of antennas (N_{ant}) = 10

$$S_{min} = \frac{\sigma_{min}\,(T_{rec} + T_{sky})}{G\sqrt{N_{ant}\ N_{pol}\ \Delta f\ W_{obs}}}.$$

First Pulsar Detection

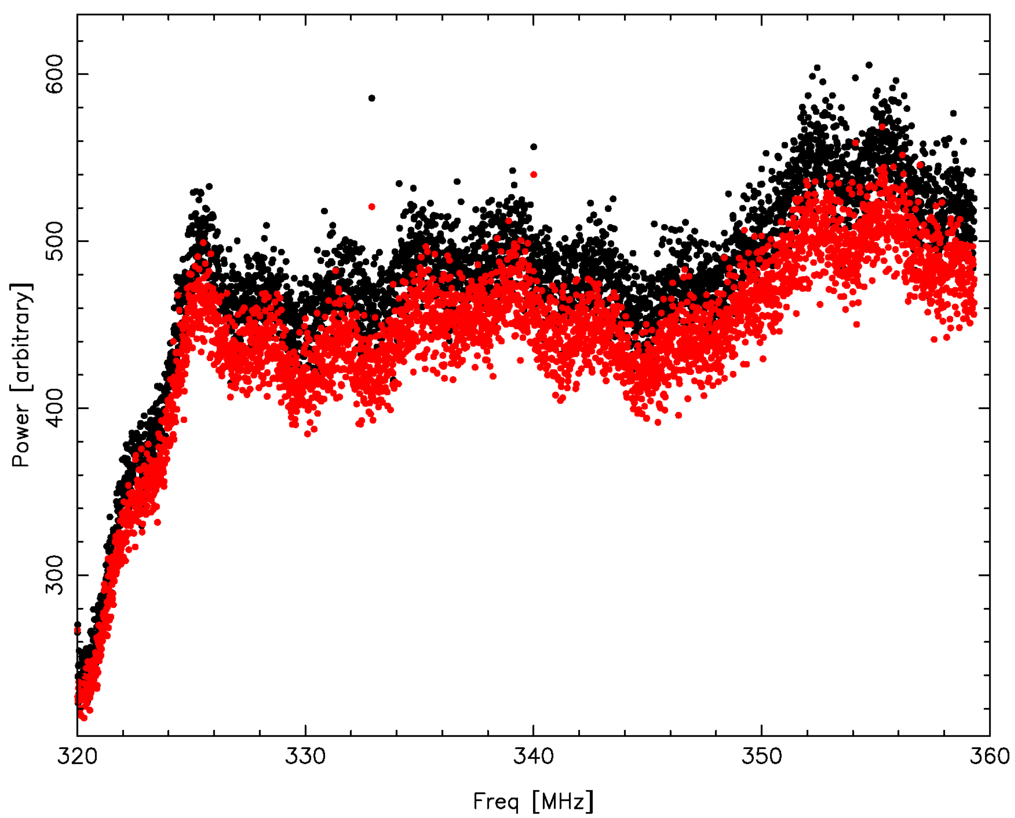


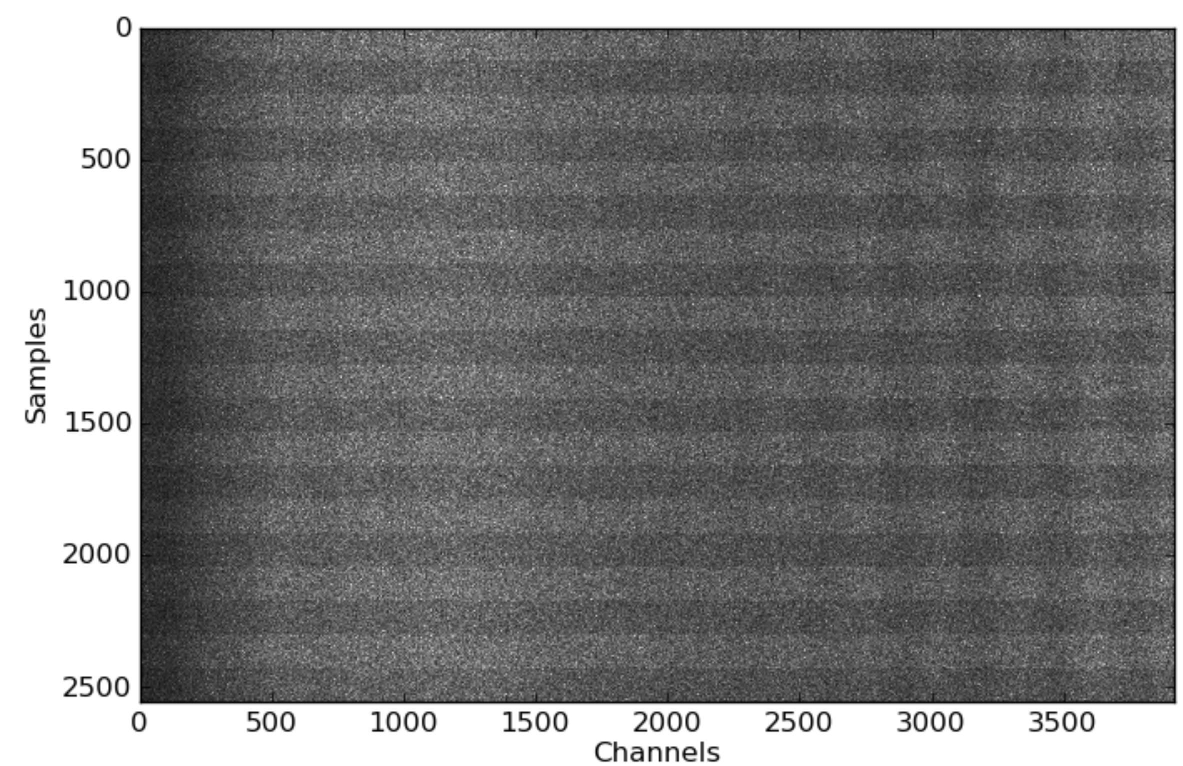
MUOS band!

- PSR B0329+54 (P= 714 ms, DM=27 pc/cm3)

Noise Diode Removal

- Switched noise diode on VLA at 10 Hz, aligned with 1 PPS
- Remove signal and flatten bandpass by dividing by mean bandpass over each 0.05 second segment





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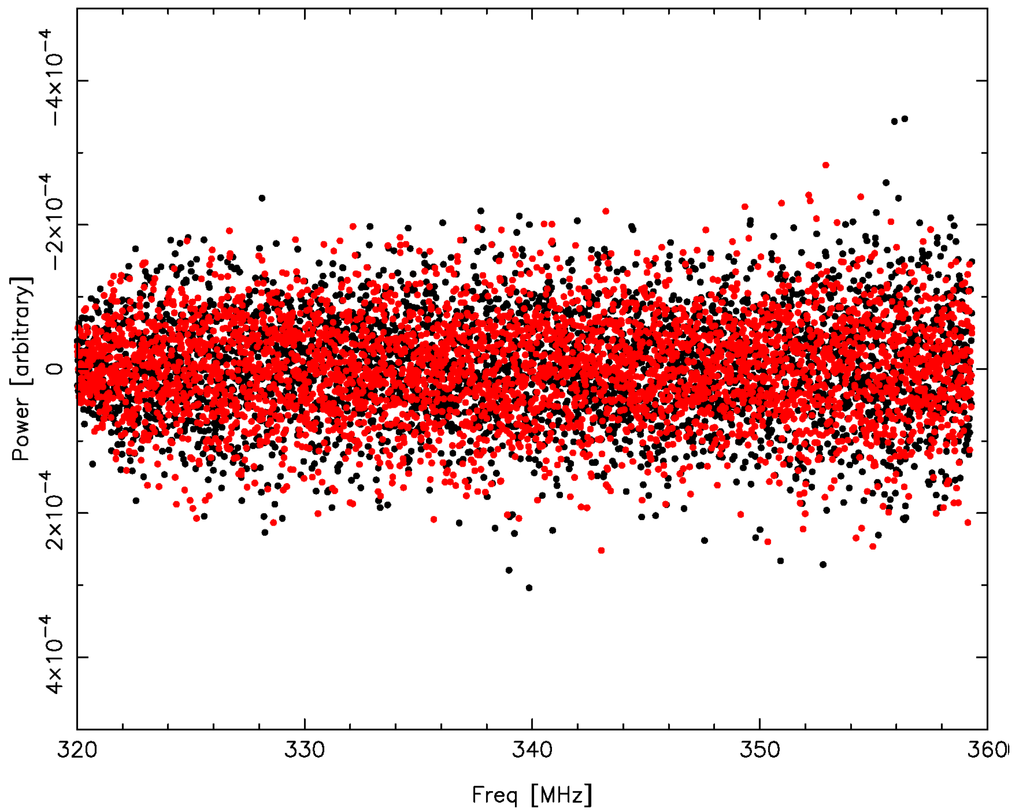
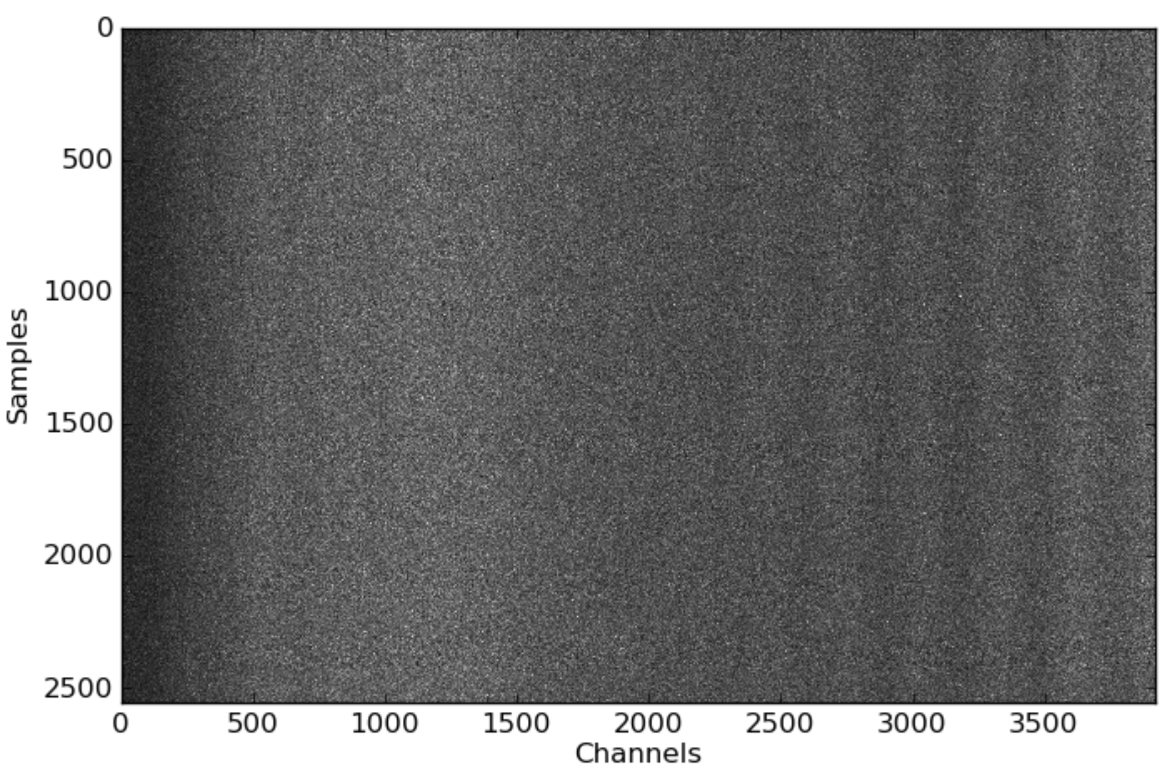
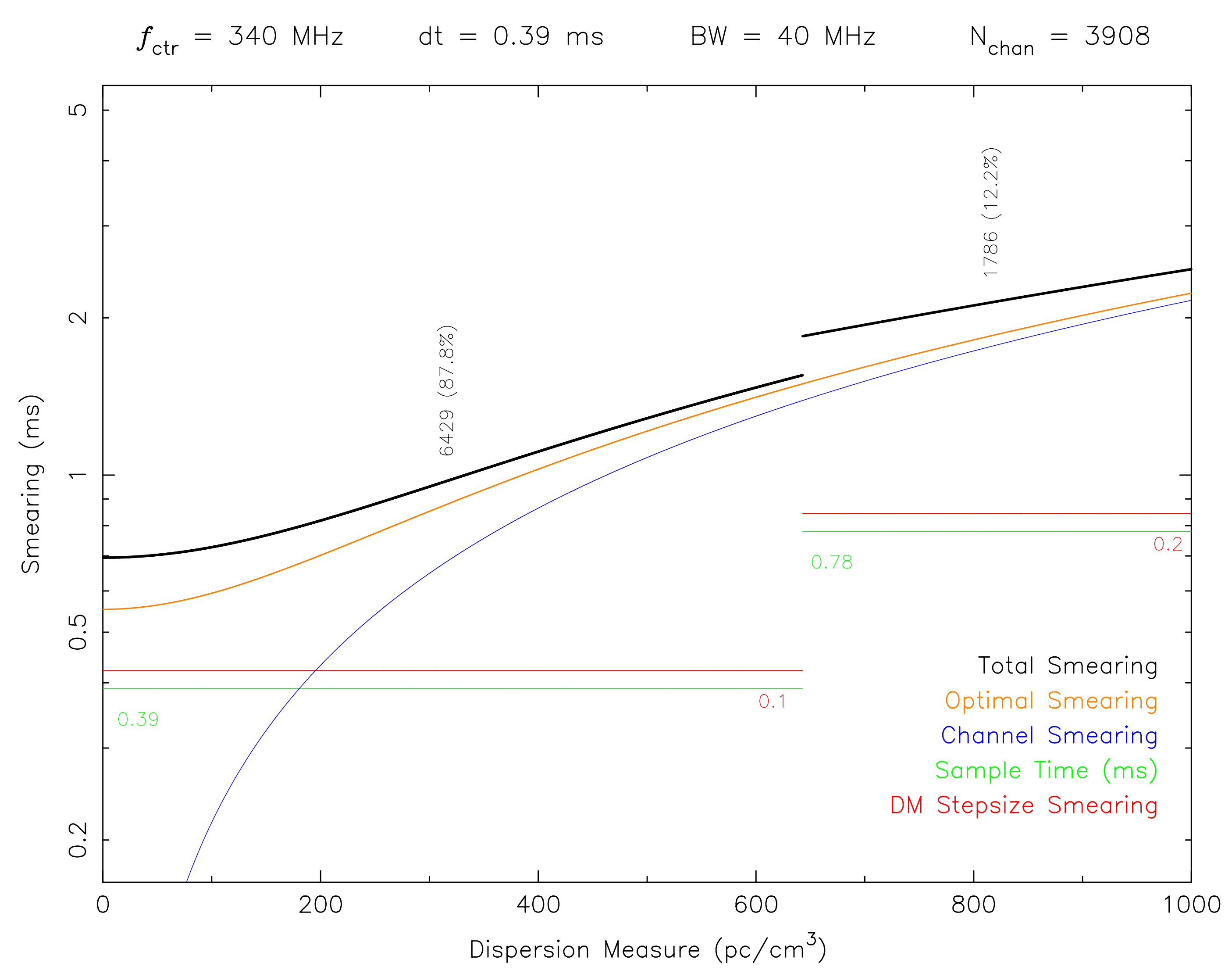


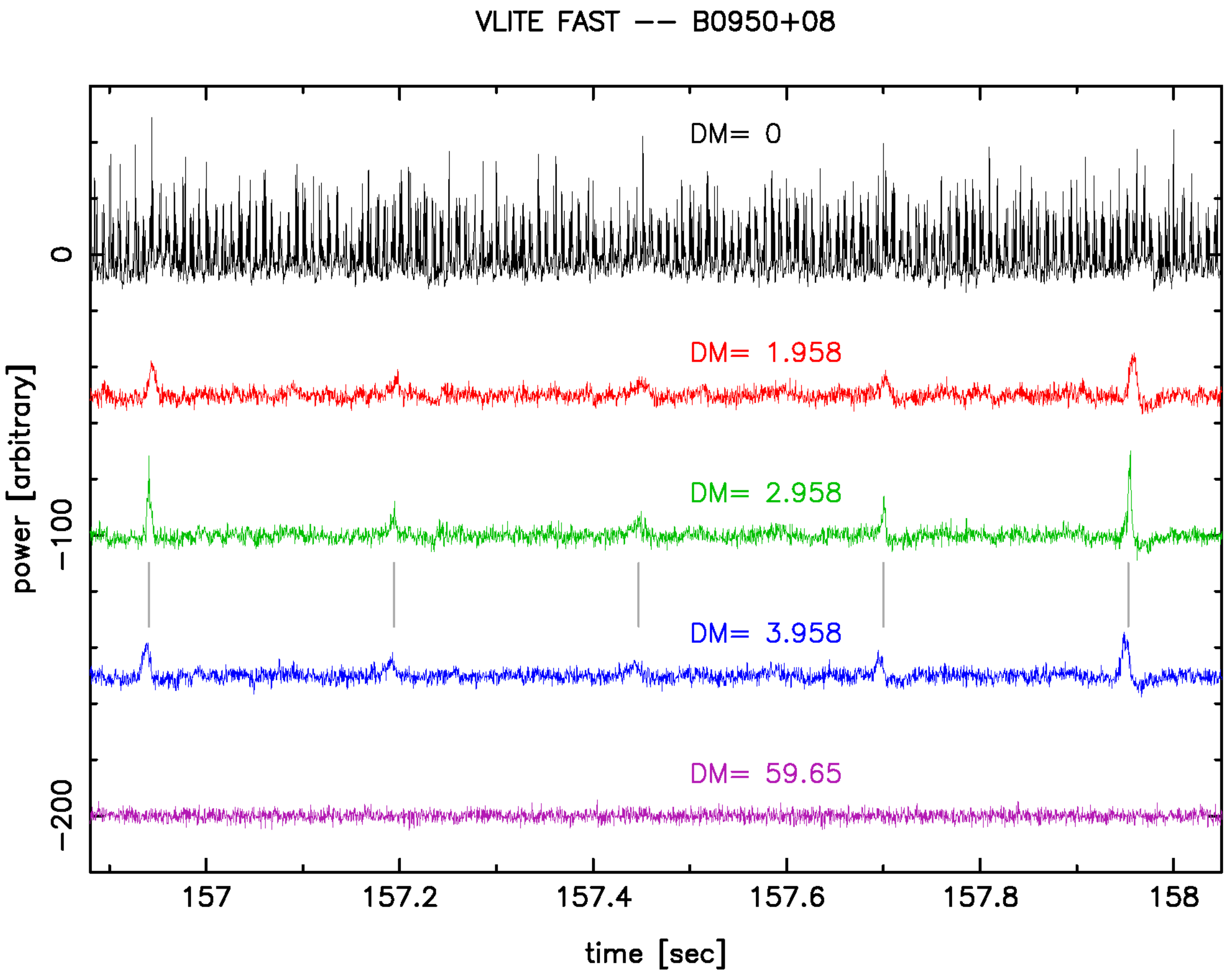


Dispersion

- Dispersion delays across the band are large at these low frequencies!
  - 0.8 s at DM 100
  - 8.4 s at DM 1000
- Large buffers on GPU required for efficient dedispersion
- Order 10,000 DM trials required to sample DMs up to 1000



Dispersion reduces RFI



Processing Pipeline

- On CPU:
  - Read data from raw ethernet port and fill ring buffer using `psrdada` library. Commanding and dumping of buffer on alert is all implemented
- On GPU:
  - Channelize using CUFFT library
  - Remove cal diode and flatten bandpass
  - Perform 2-D dedispersion transform (B. Barsdell's `dedisp` library)
  - Working on pulse search via convolution and thresholding on GPU
- Dump ring buffer from all antennas when significant pulse detected
  - Buffer is 16 GB/antenna, which holds 1 minute of data

GPU Comparison

Model	RAM	GFLOPS (single precision)	# Avail
GTX 780	3072	3977	6
GTX Titan Black	6144	5121	1
GTX Titan X	12288	6144	6

Many thanks to Richard Dodson of ICRAR for 6 new Titan X GPUs!

Plans

- Finish integrating a convolution and peak detection kernel in the GPU pipeline
- Start running on single antennas continuously
- Explore ways to combine antennas without interfering with DIFX operation
  - Incoherently sum 2 polarizations + 2 antennas from each node
  - Pass around moderate significance hits and look for coincidences
- Image the dumped VDIF data to localize the transient to up to few arcsecond precision