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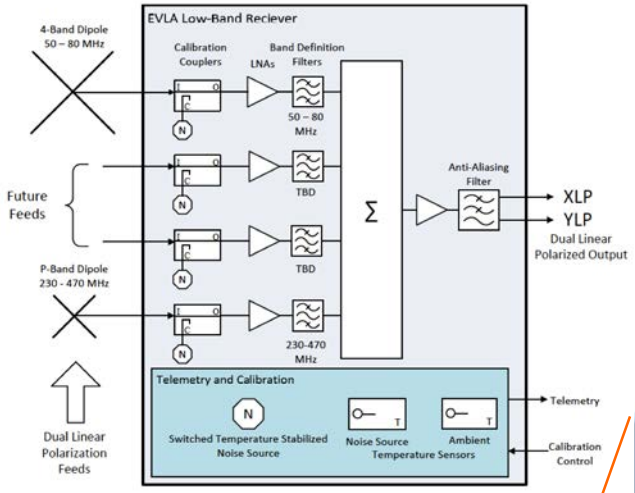
Commensal Low Frequencies on the NRAO VLA: The VLA Low-band Ionosphere and Transient Experiment (VLITE) and VLITE-Fast

Tracy Clarke

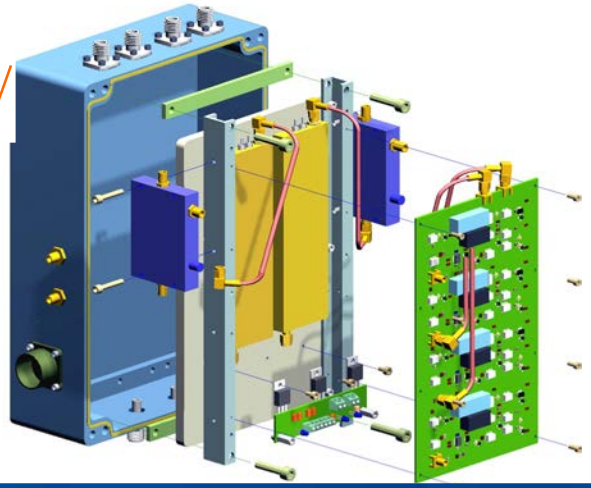
Naval Research Laboratory

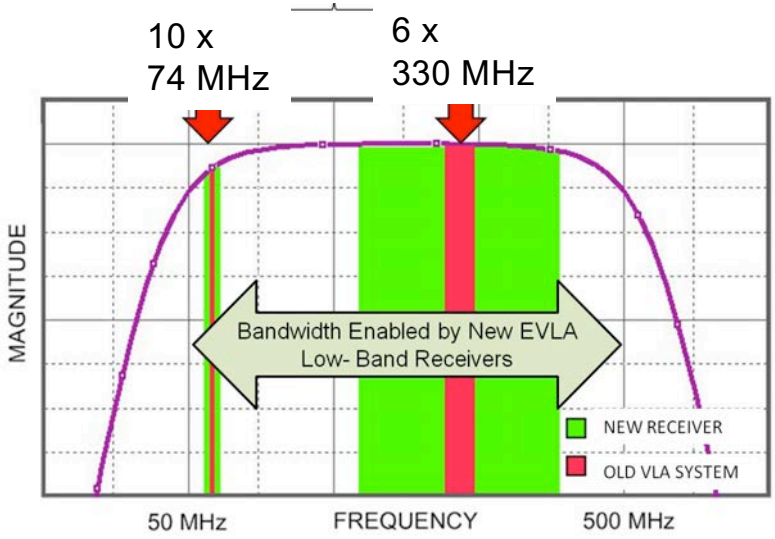
N. E. Kassim, S. Giacintucci, W. Peters,
M. Kerr, P. Ray, E. Polisensky, J. Helmboldt

JVLA Broadband Low Frequency Receiver



- NRL and NRAO co-designed a new wideband receiver in 2010 to replace legacy system
- Single 4 channel receiver near prime focus
- Populated 74 and 330 MHz channels
- First light in 2012, science operations in 2013





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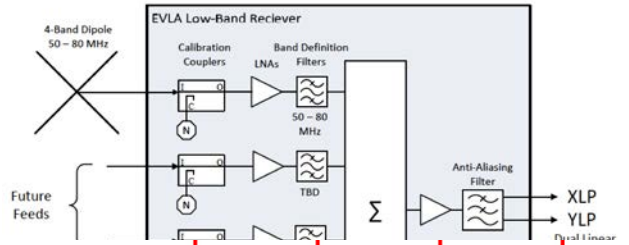

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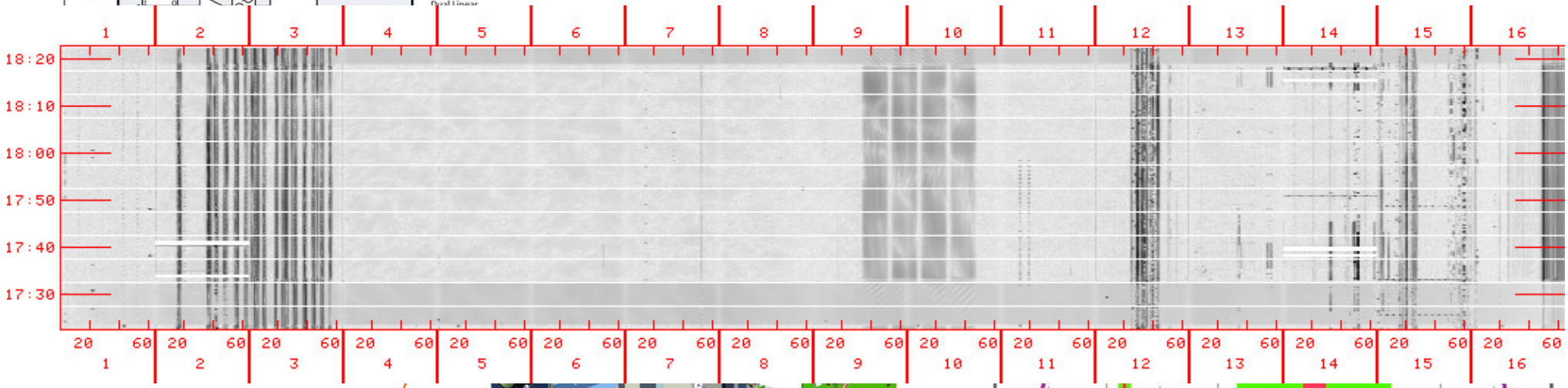

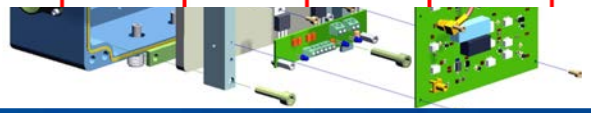

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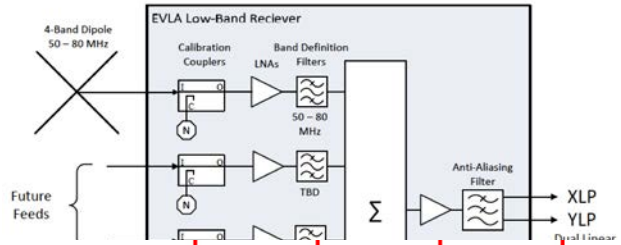
JVLA BROADBAND LOW FREQUENCY RECEIVER



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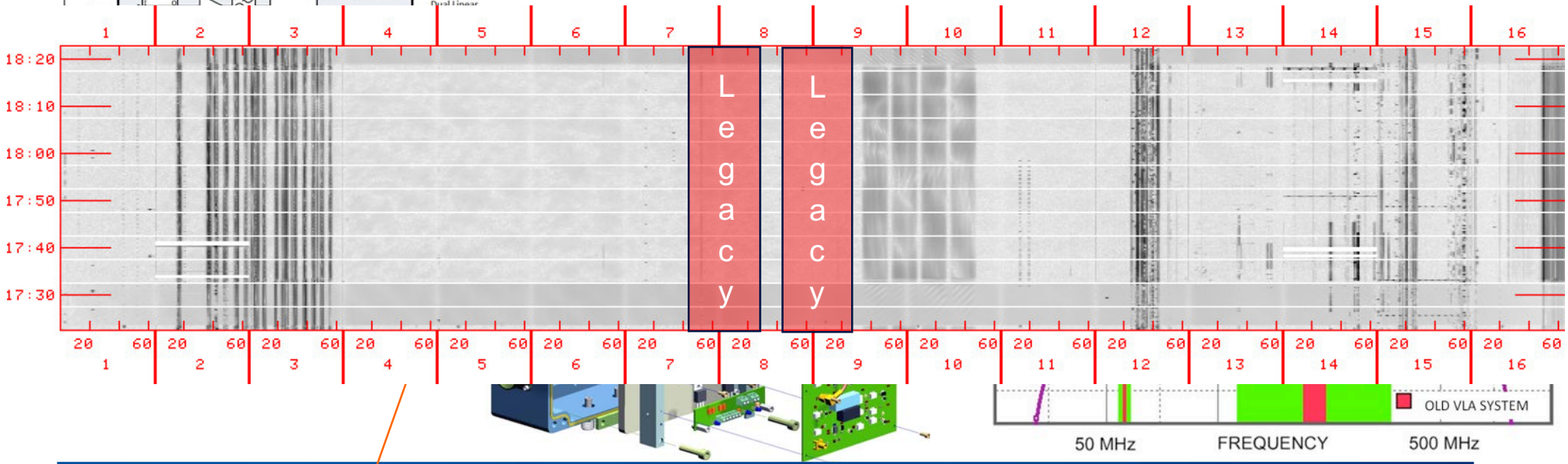

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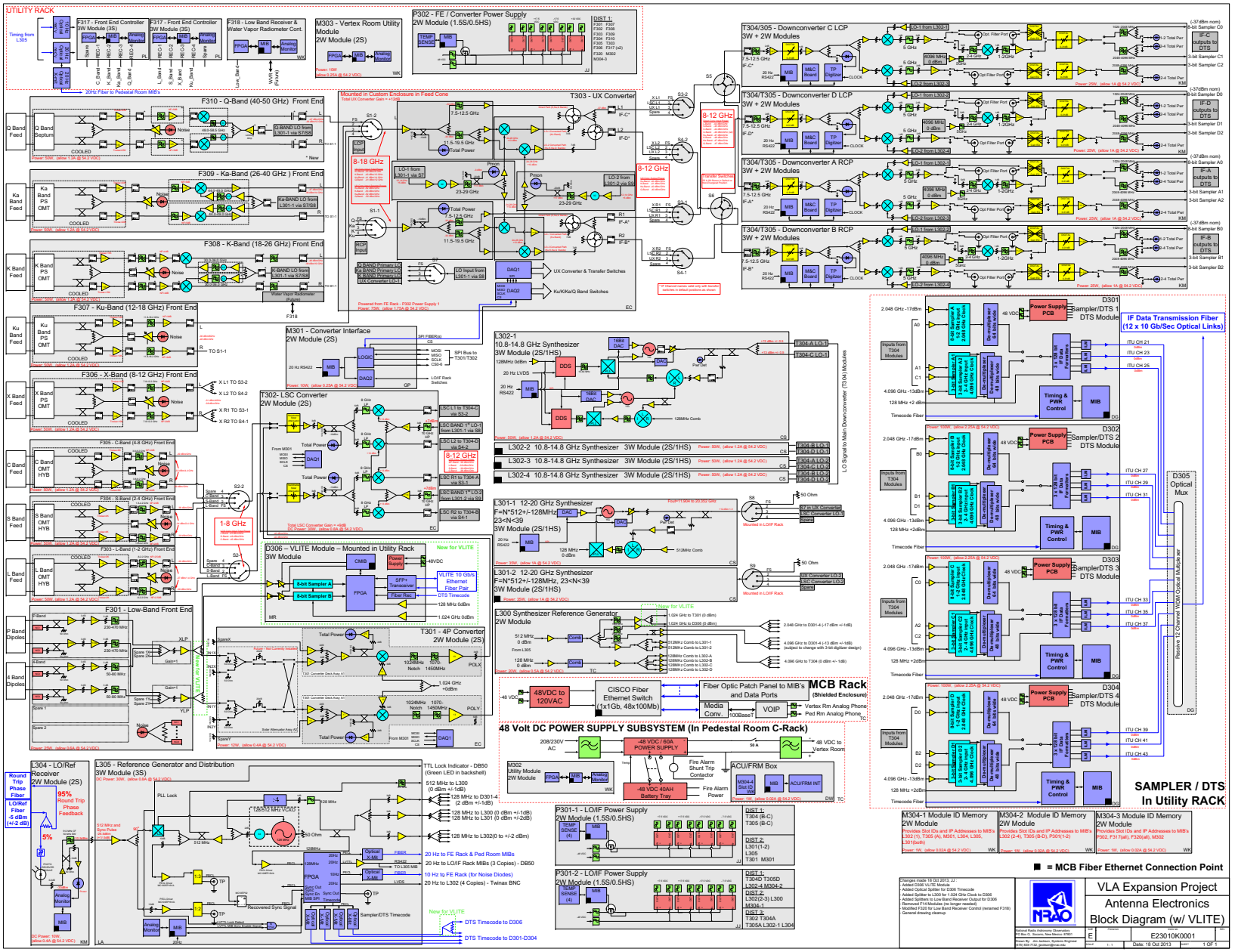
JVLA ANTENNA BLOCK DIAGRAM



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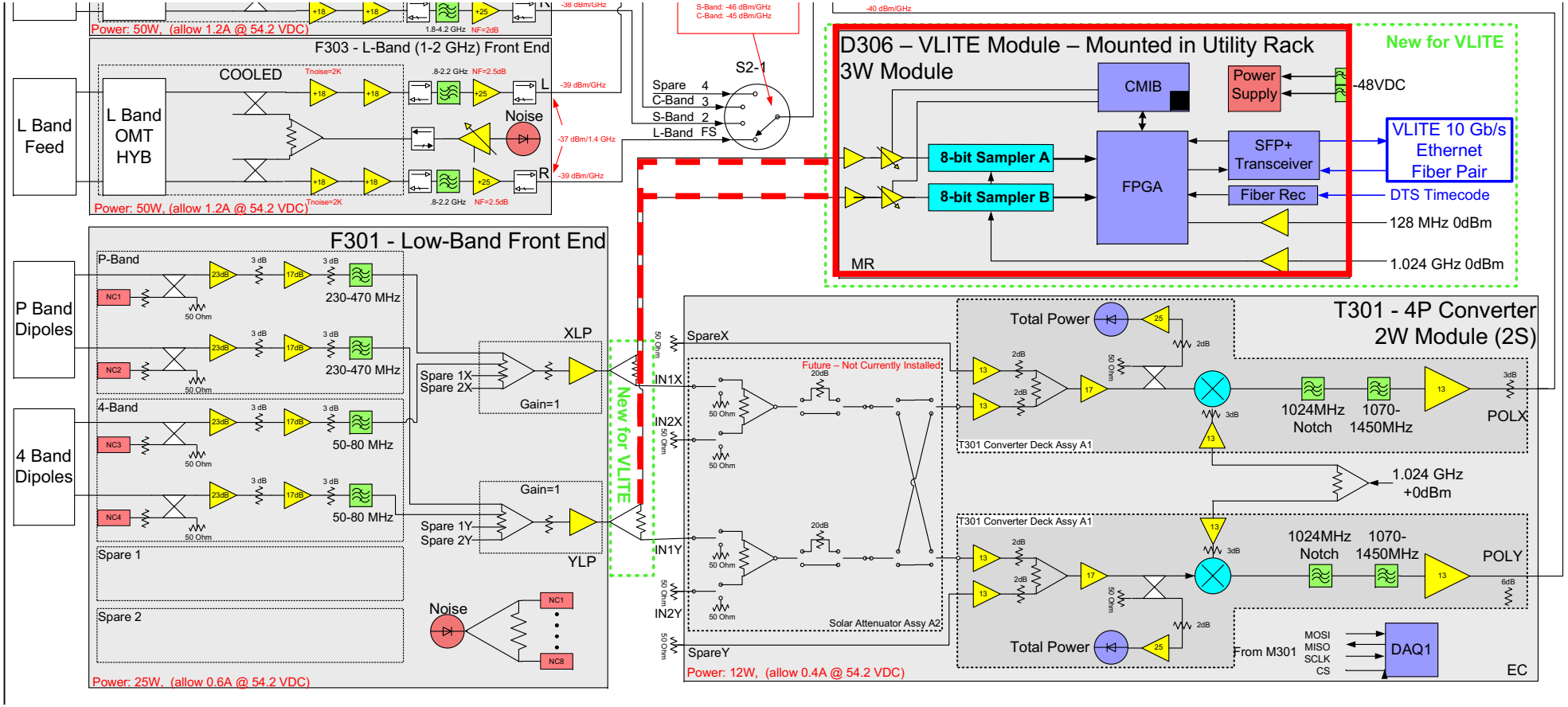
ADDING A COMMENSAL MODULE: VLITE BLOCK DIAGRAM



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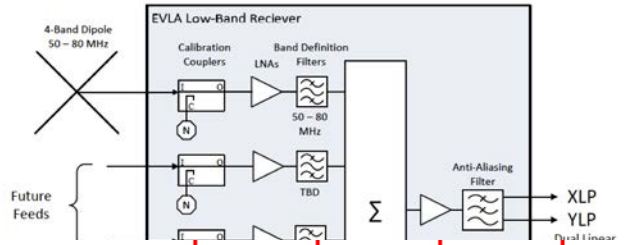

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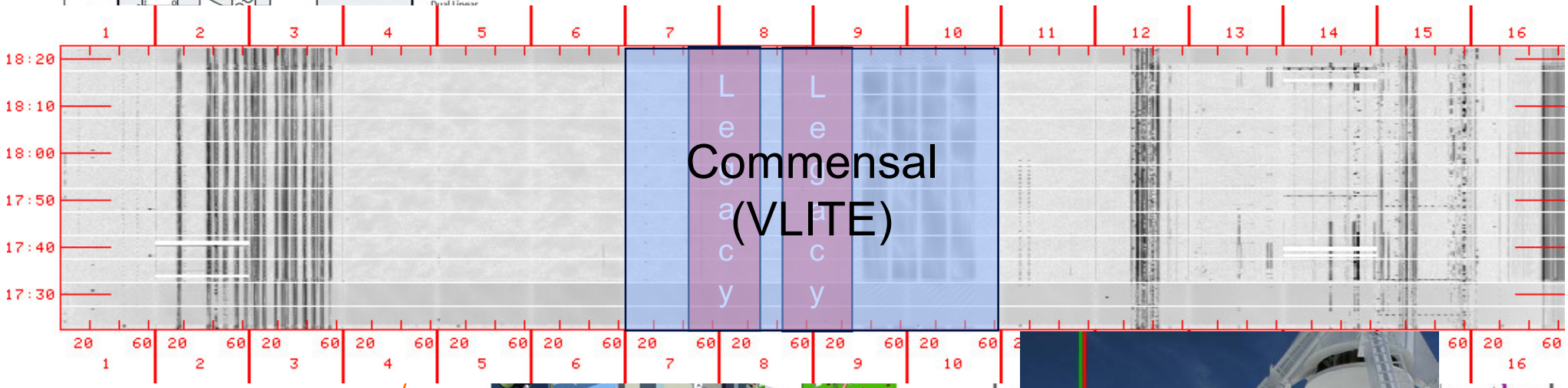

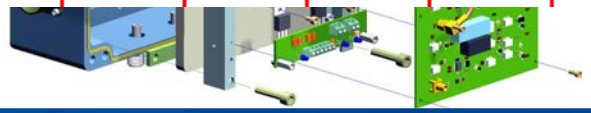

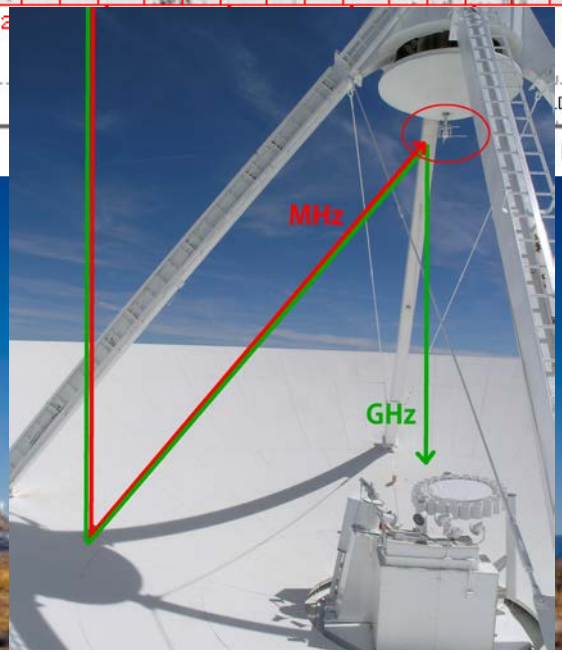

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VLA Low-band Ionosphere and Transient Experiment (VLITE)

- Correlates 330 MHz band for 10* VLA antennas

320<ν<384 MHz | $\Delta\upsilon_{chan}$ = 100 kHz | Δt = 2s

FoV ~ 12 square deg | 5” < θ < 3’ | 0.3 < σ < 10 mJy/bm

Data rate: 2 GB/hr -> 5 GB/hr | On-sky wall time: ~70% (actual)

Clarke et al. (2016, 2018)

*Upgrade: 1.5 years (2016) to on-the-fly correlator capability

2.5 years (2017) from 10 to 16 antennas (working to 18)

VLITE-16 became operational in 07/22/2017

- Minimal impact on VLA infrastructure & operations
- No impact on primary observer program resources

vlite.nrao.edu

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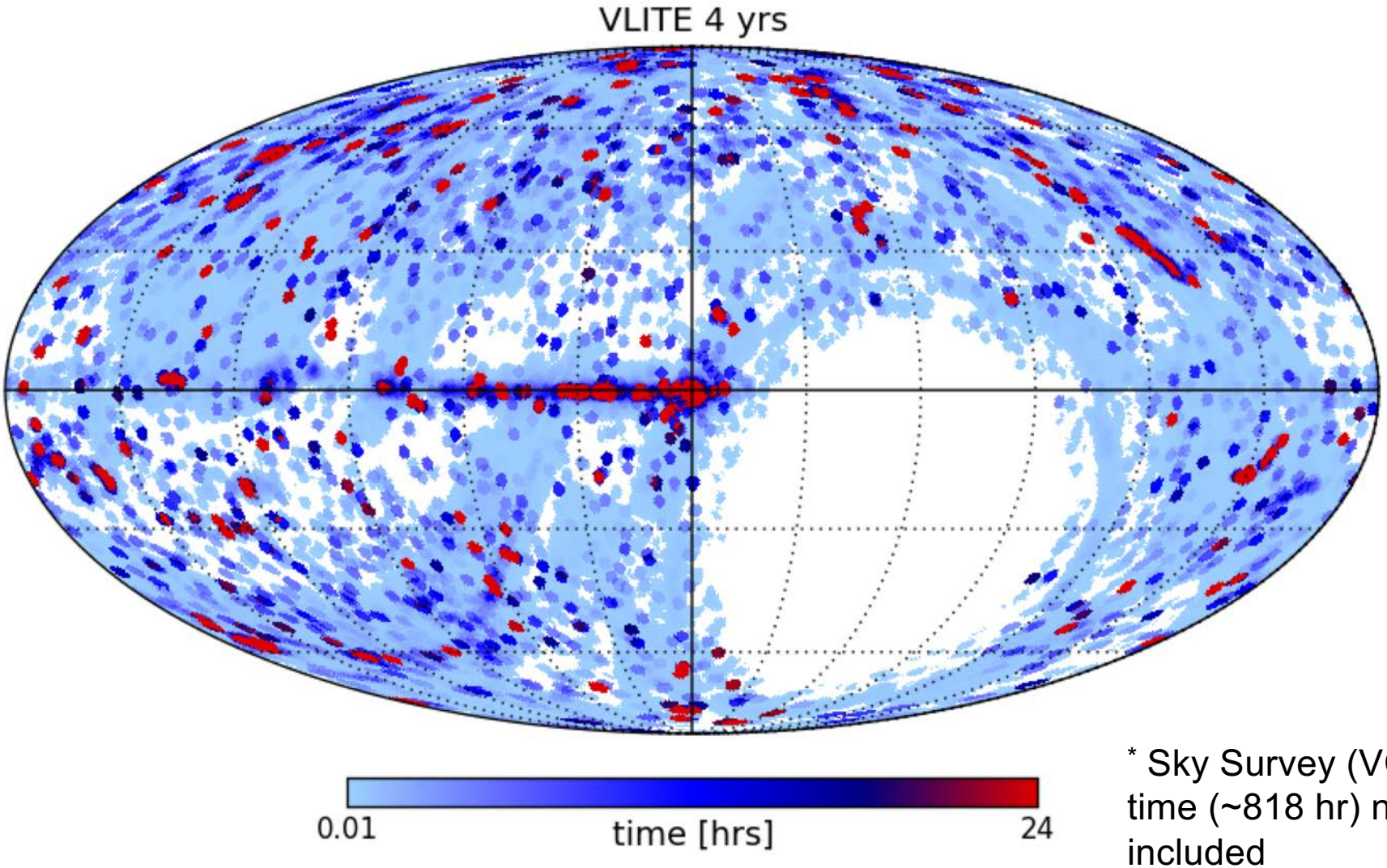
The Power of a Low Frequency Commensal System: Sky Coverage

4 years: 1,412,910 scans (24,232 hr), 71,797 images (~16,730 hr)*

VLITE 48 month δ>-40° : ~93% to > 30 s, ~50% to > 36 m, ~25% to > 3 h



* Sky Survey (VCSS) time (~818 hr) not included

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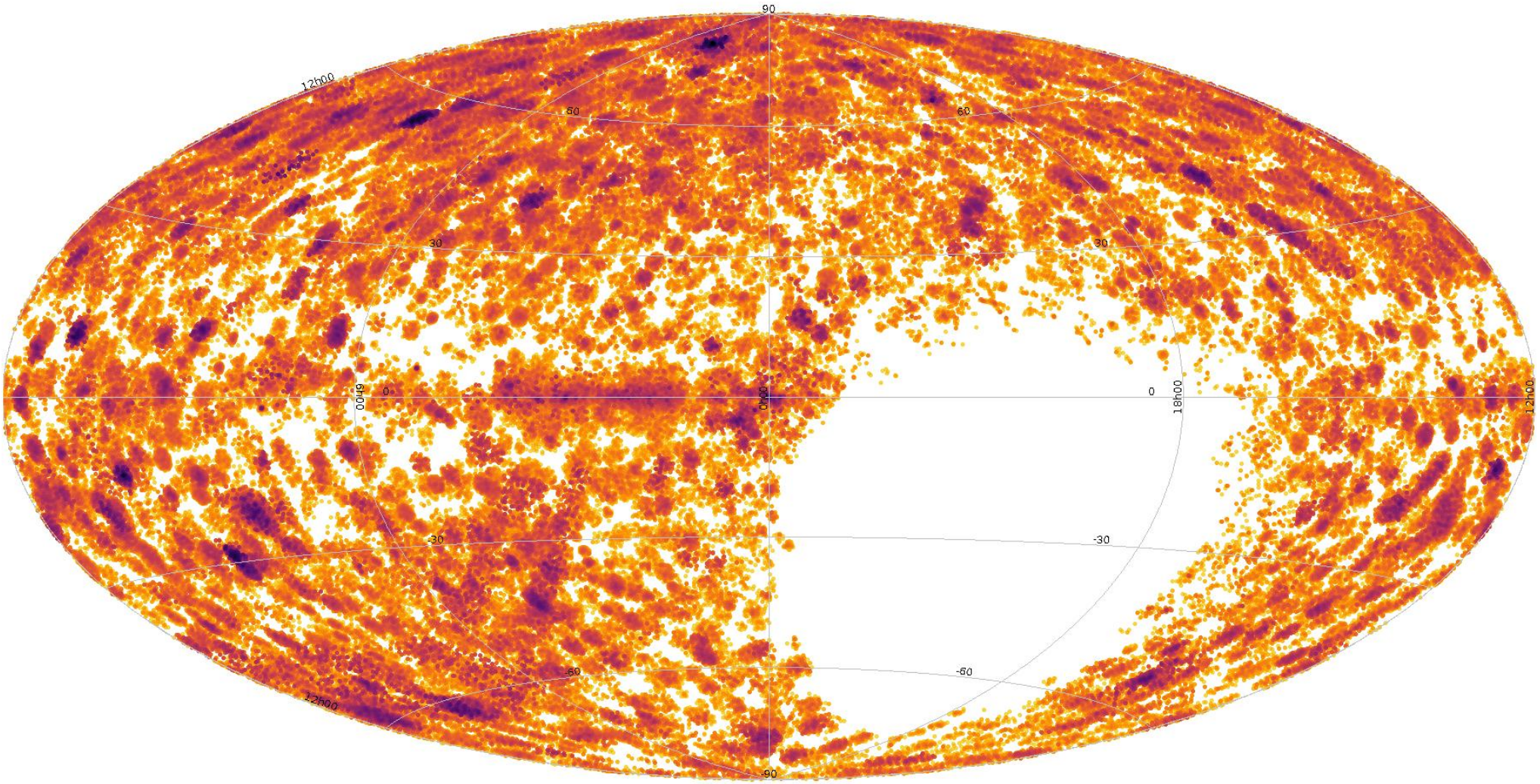
VLITE 4 Year Source Distribution

- Over 4 year period, VLITE cataloged 2.1 million sources (non-unique)
- VLITE catalog generated in PyBDSF and information stored in SQL database



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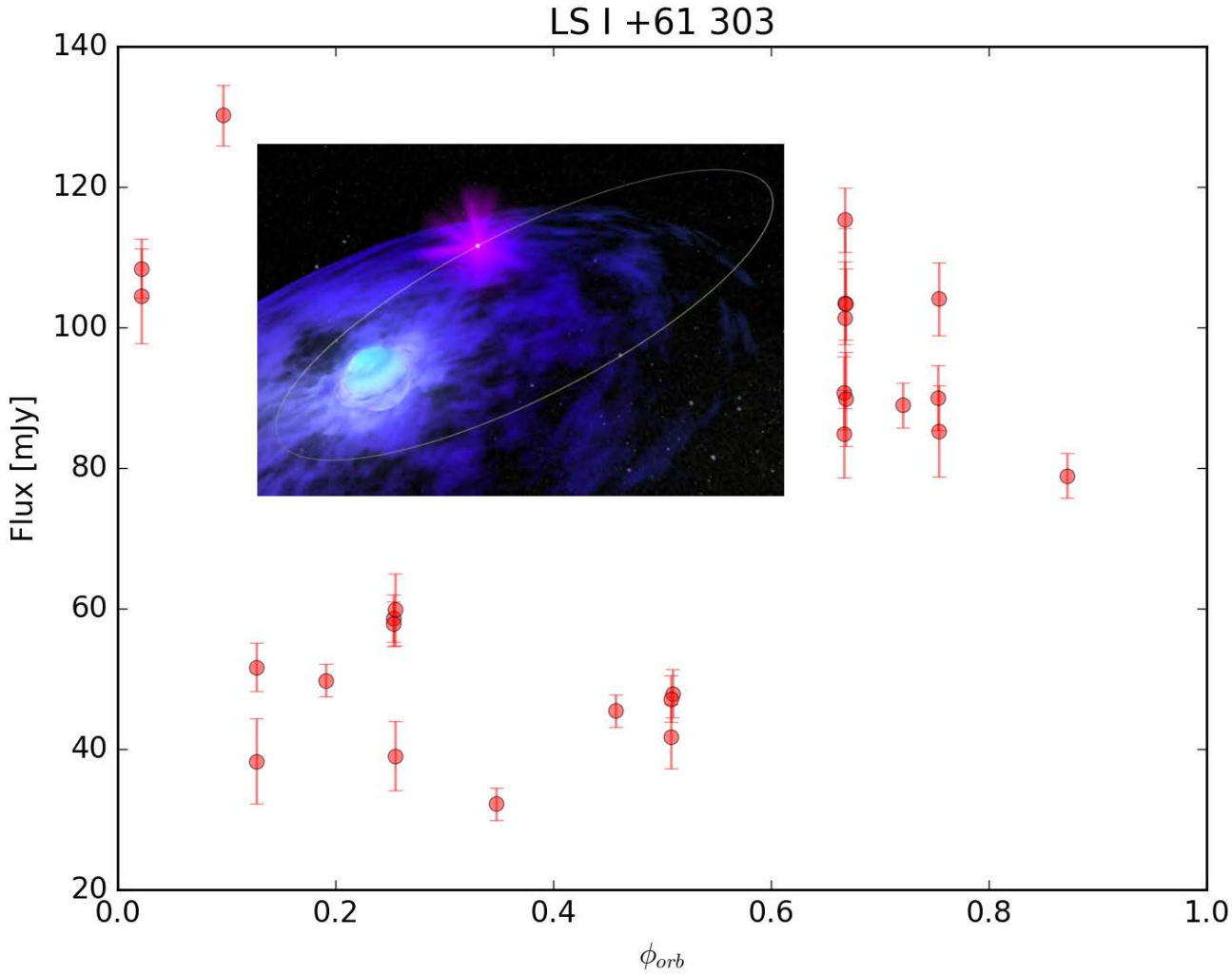
VLITE Slow Transients Hunting

- Over 4 year period, VLITE cataloged 2.1 million sources (non-unique)
- VLITE catalog generated in PyBDSF and information stored in SQL database

Example: High mass X-ray binary outbursts from a bursting neutron star orbiting (26.496 day) a Be star. Source ~1º from image centers.



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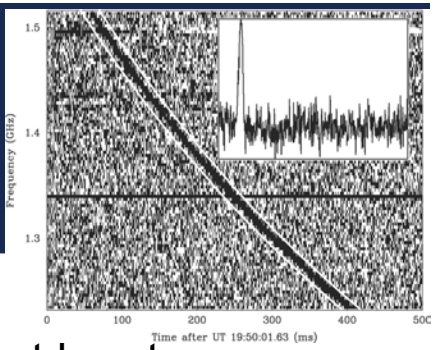
The Path to Fast Radio Bursts: FRBs



- Pulsars have been known since their discovery by Jocelyn Bell in 1967
- Lorimer et al. (2007) discovered a new type of (mostly) non-repeating fast burst
  - Dispersion measure (DM) >> Galactic + scattering → extragalactic
- Thornton et al. (2013) identified multiple FRBs
- Many more FRBs detected since then

- FRB origins energetic phenomena, e.g.:
  - Evaporating black holes (Barrau+2014)
  - Magnetar flares (Popov & Postnov 2007)
  - Cosmic strings (Yu+ 2014)
  - (Super)giant pulses from pulsars / lensing (Cordes & Wasserman 2016, Cordes+ 2017)
- FRB importance includes:
  - Measure IGM turbulence
  - Probe of missing baryons and dark energy
  - Probe intergalactic magnetic fields

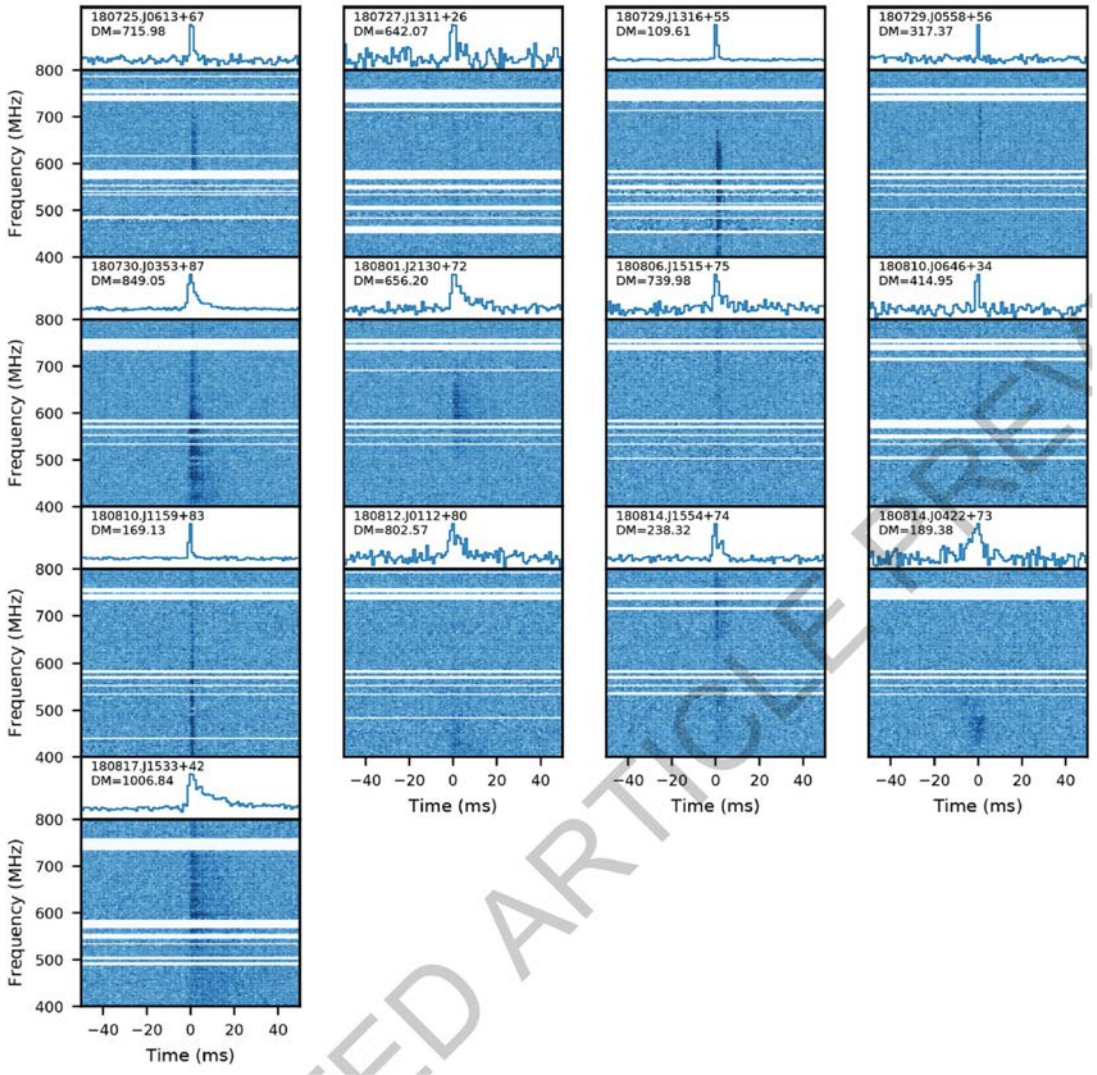
Search for FRB is a two-pronged attack: large etendue, low-angular resolution efforts to collect many FRBs, and efforts to detect FRBs with low rates with interferometers.

New Impetus: Low-frequency detection of FRBs

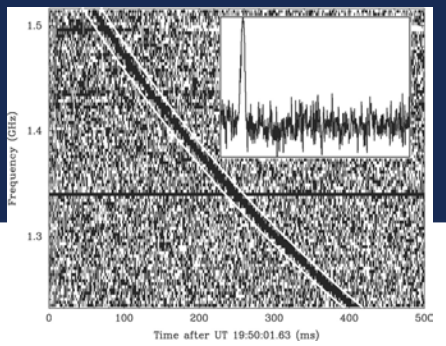
CHIME detection of 13 FRBs from 400 MHz to 800 MHz (**Nature, 01/09/2019**)
- lack of scattering in some events suggest that can be detected < 400 MHz

New repeater detection reported in companion Nature paper (**01/09/2019**)

Localizations limited to ~30 arcminutes



VLITE-Fast – GPU based transient search



Network Interface

Ring Buffer (60s of baseband voltages)

Local SSD (on trigger)
Offline FRB localization

GPU
- Channelization
- RFI Filtering
- Detection
- Bandpass normalization
- Polarization summing
- Time averaging

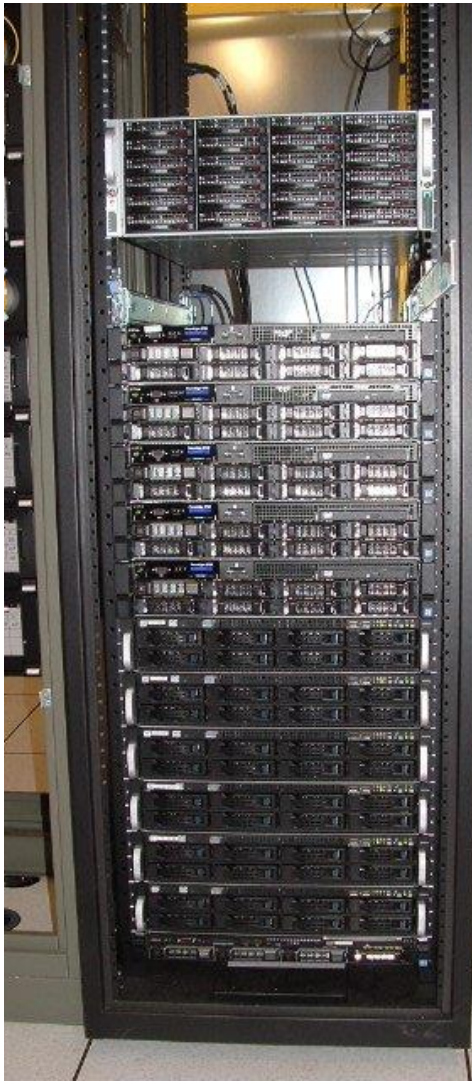
Ring Buffer (dynamic spectra)

GPU
Transient Search in pulse width and dispersion

Disk (NFS)
- Offline FRB search
- Pulsar/RRAT search
- RFI/Data Quality

Candidates

CPU
- RFI monitoring
- Coincidence
- Trigger



8.5s will elapse between the arrival of an FRB with a DM of 1000 at 360 MHz and the arrival at 320 MHz

Different technique compared to **realfast**, which is an imaging-based search.

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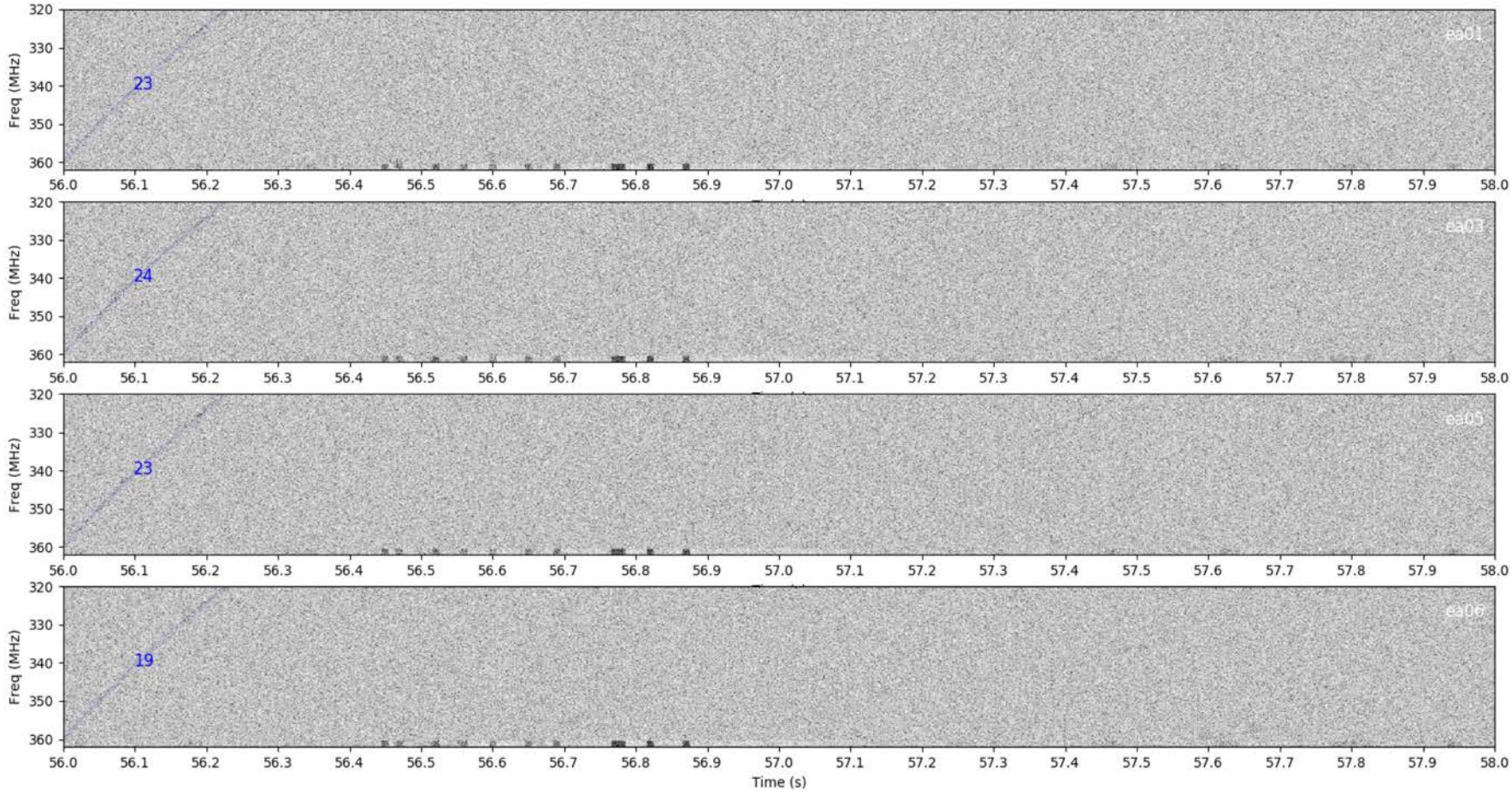
Typical VLITE-Fast data: PSR B0329+54



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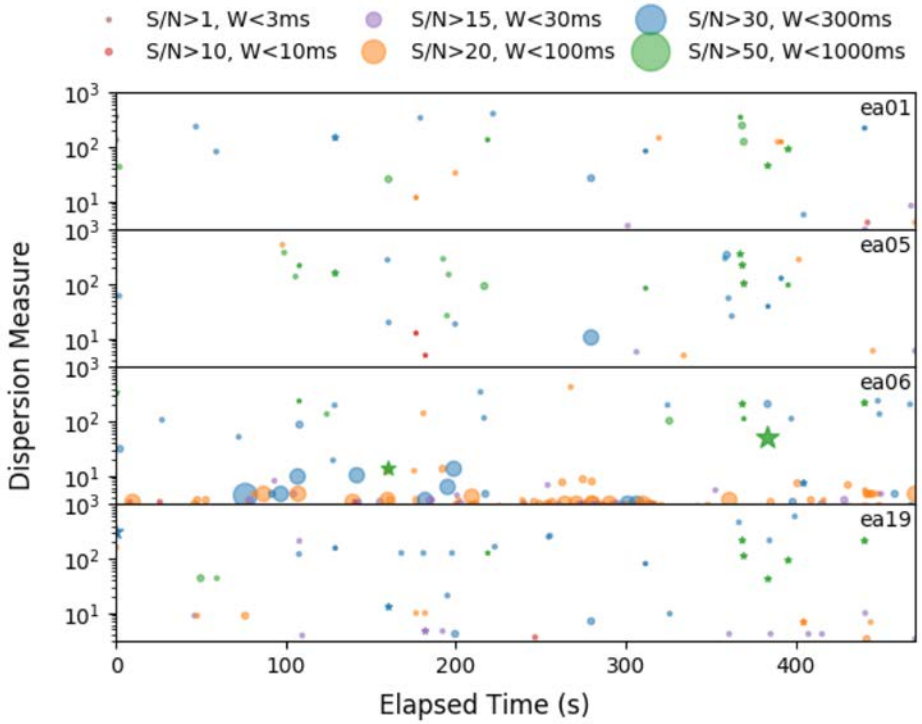
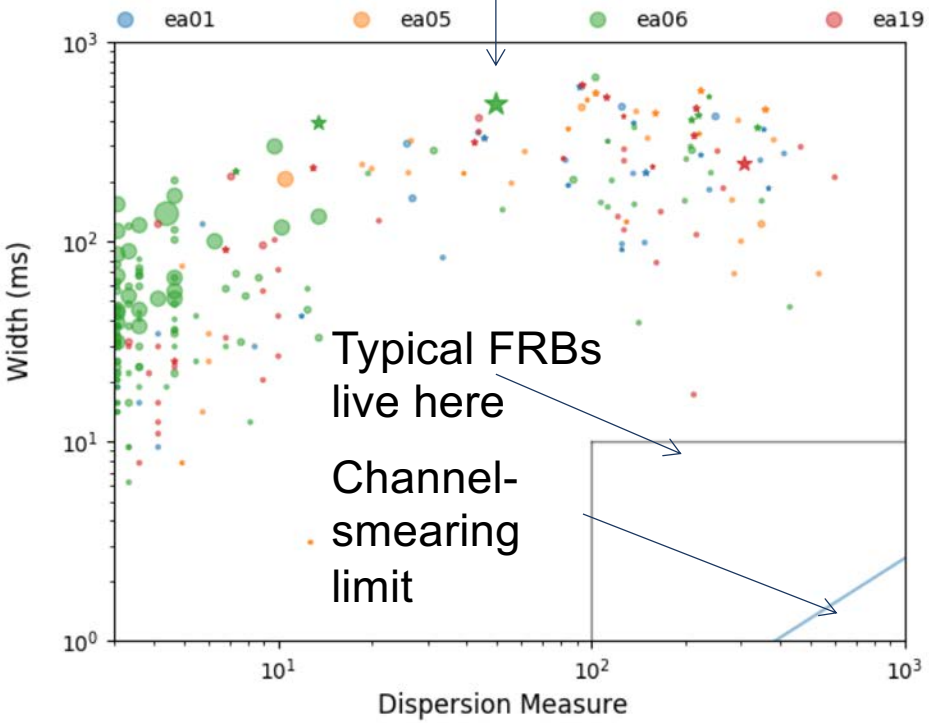
Same data, now looking at transient candidates



Stars indicate candidates with common time + DM



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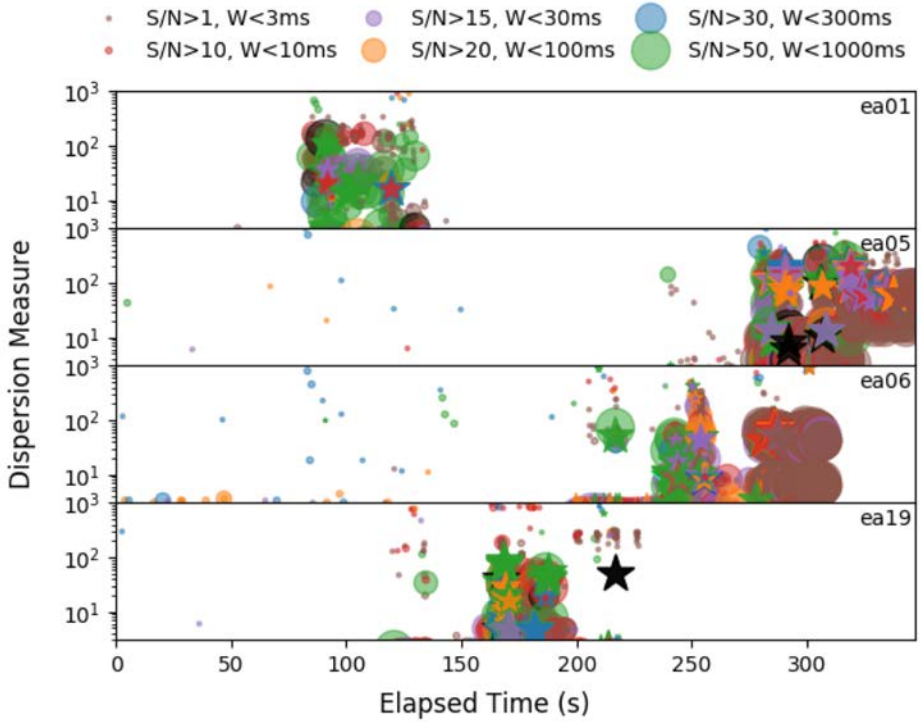
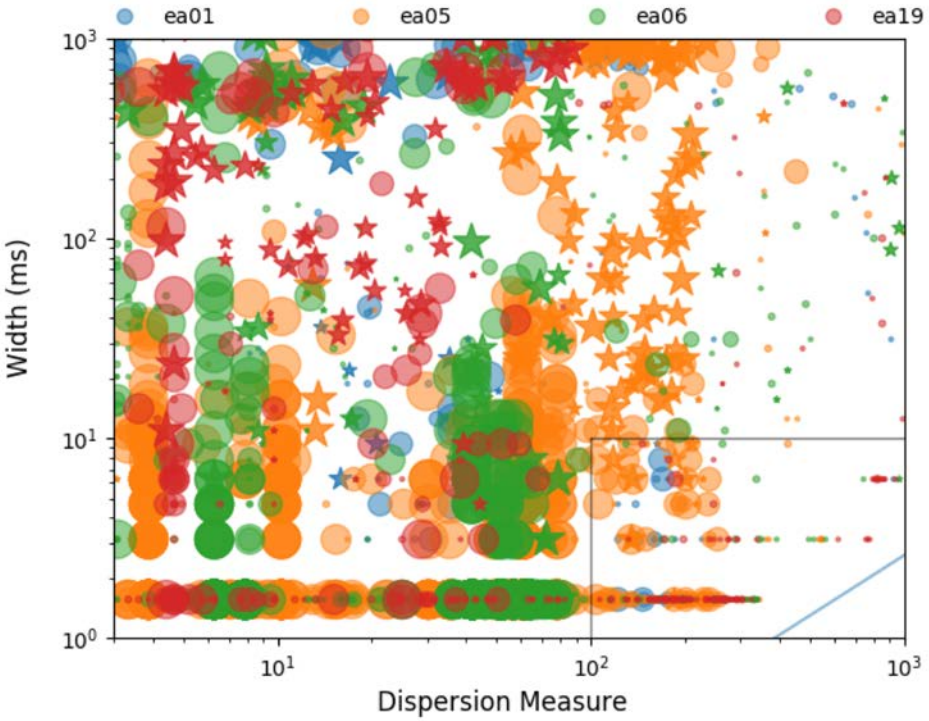
RFI Strikes

This is the big push now, to become robust to this RFI to avoid filling up disks with false positives.





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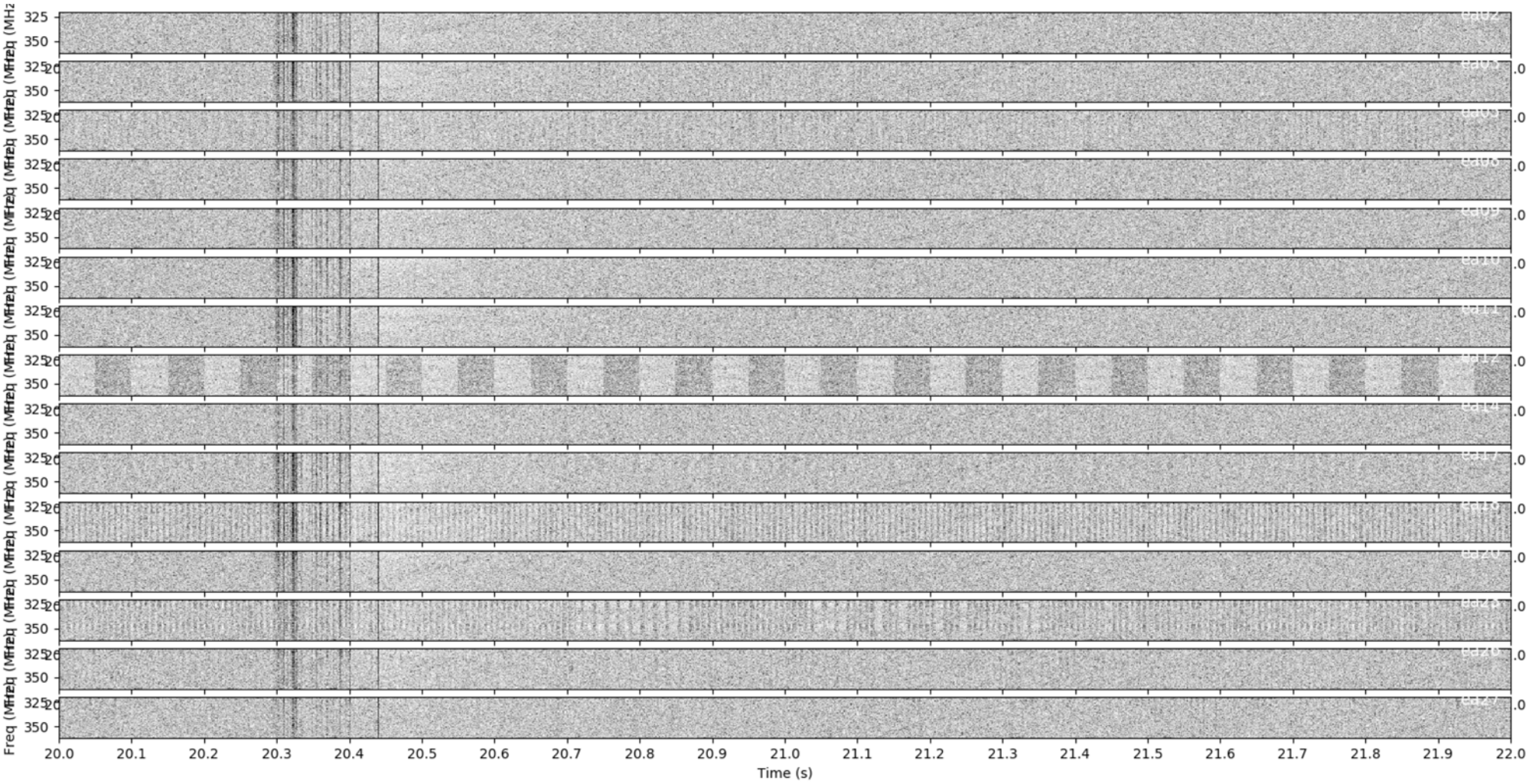
VLITE-Fast Latest Status: 15 antennas!



- ms broadband interference composed of μs structure
- use temporal kurtosis filter remove contaminated data

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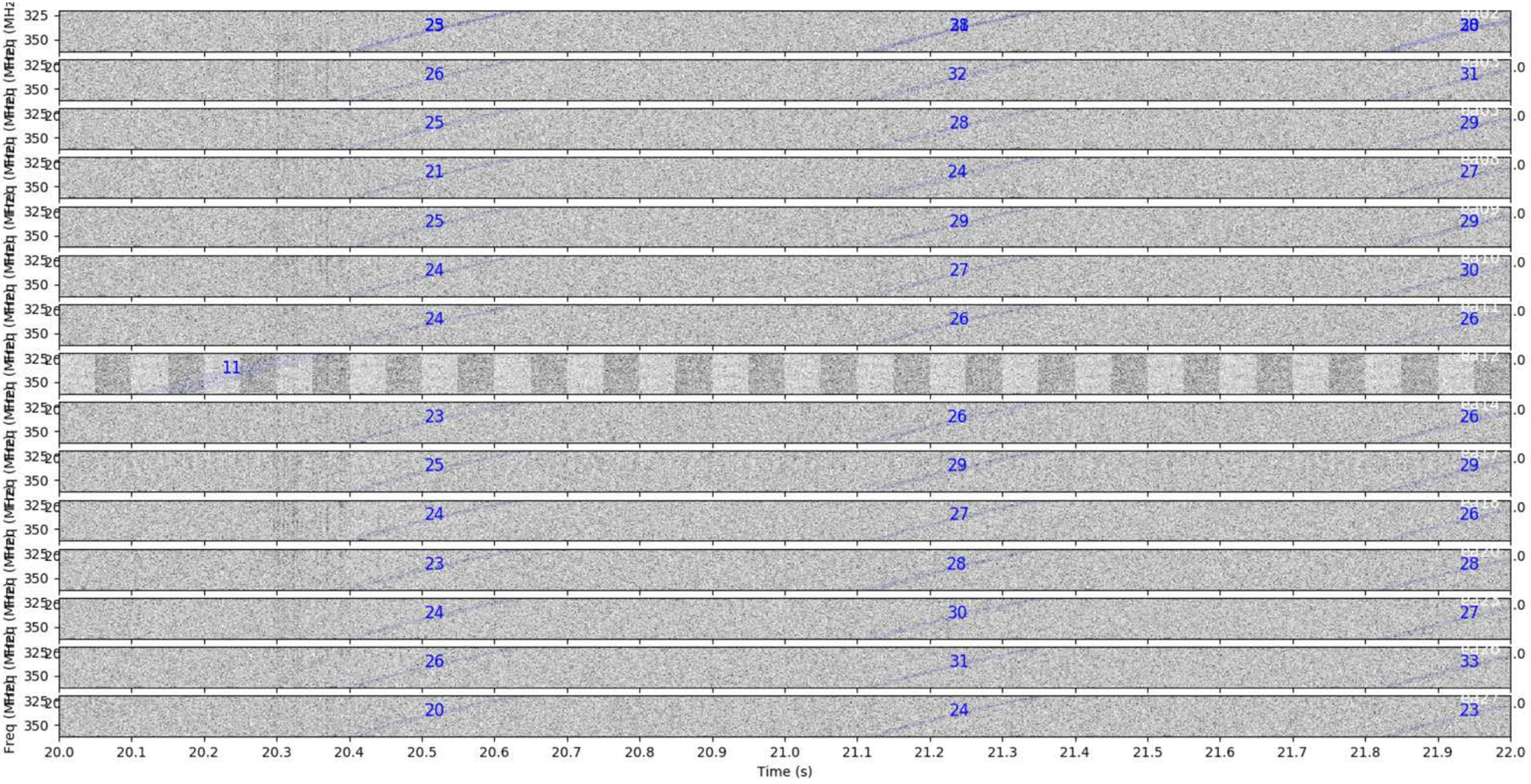
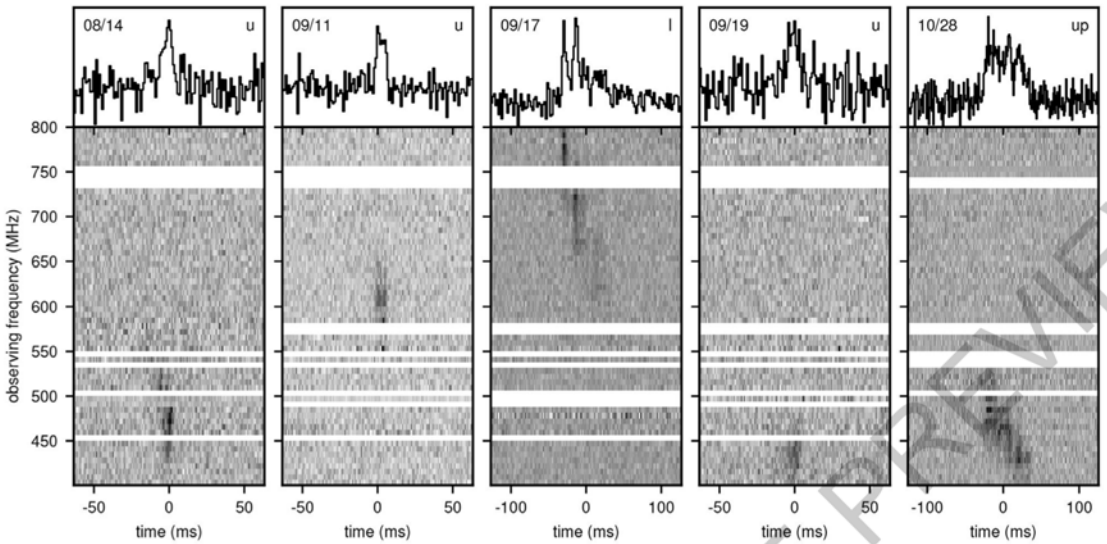


VLITE-Fast Search for Chime Repeater

- CHIME repeater (FRB 180814.J0422+73) followed up at the JVLA and with *realfast*
- VLITE-Fast joined efforts to search at low frequency with some additional development
- No detection yet with VLITE-fast but VLITE slow clearly identified an NVSS source that was ‘missing’ in VLASS and of possible interest (not faded, just extended)



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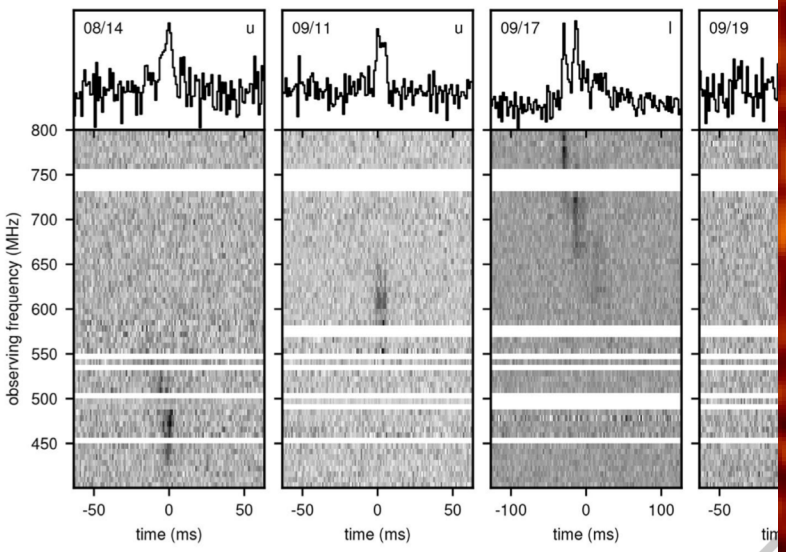

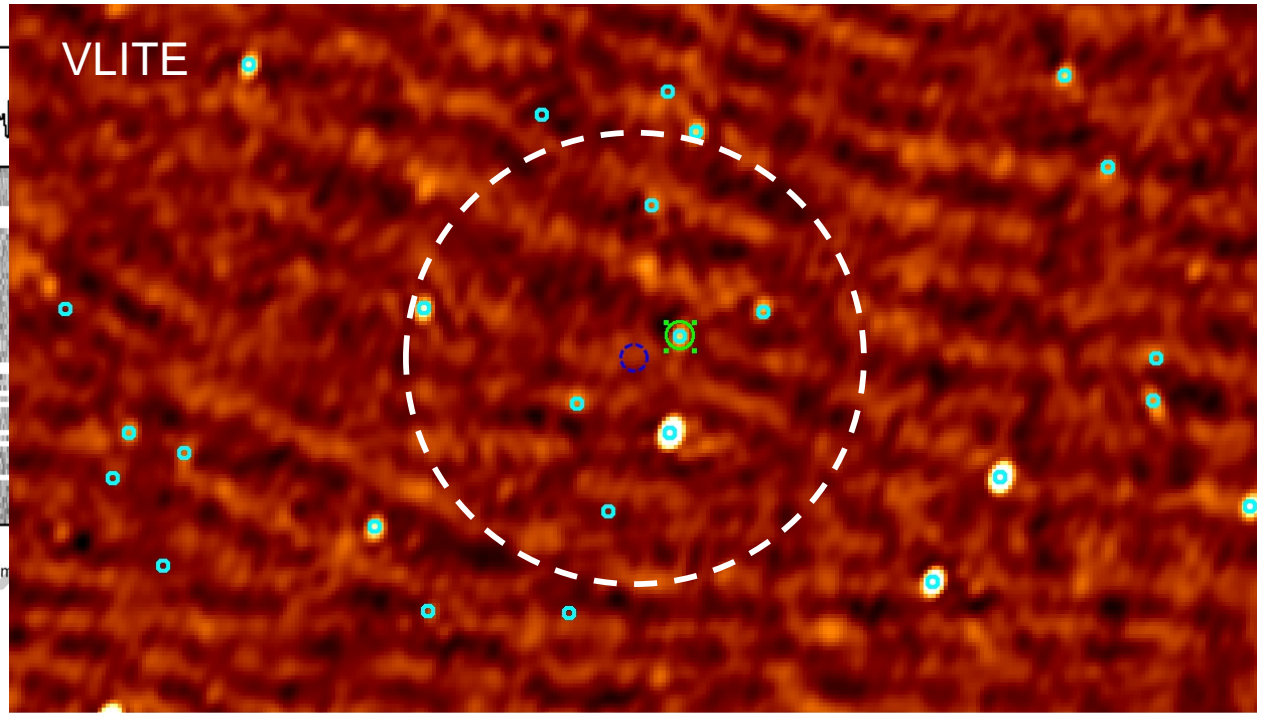

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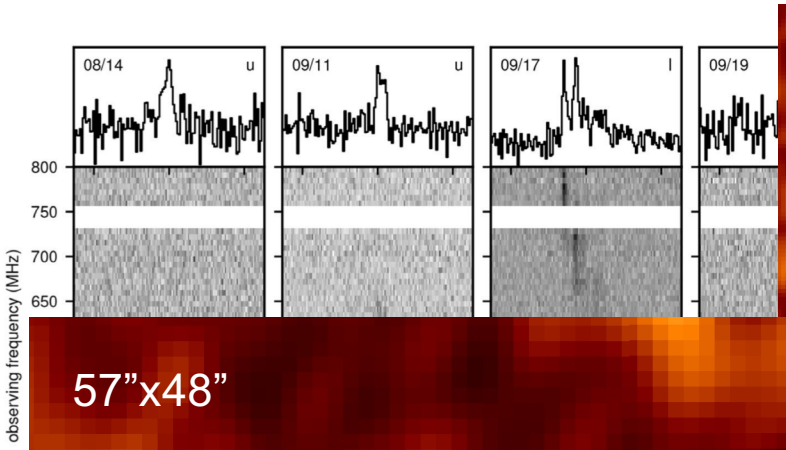

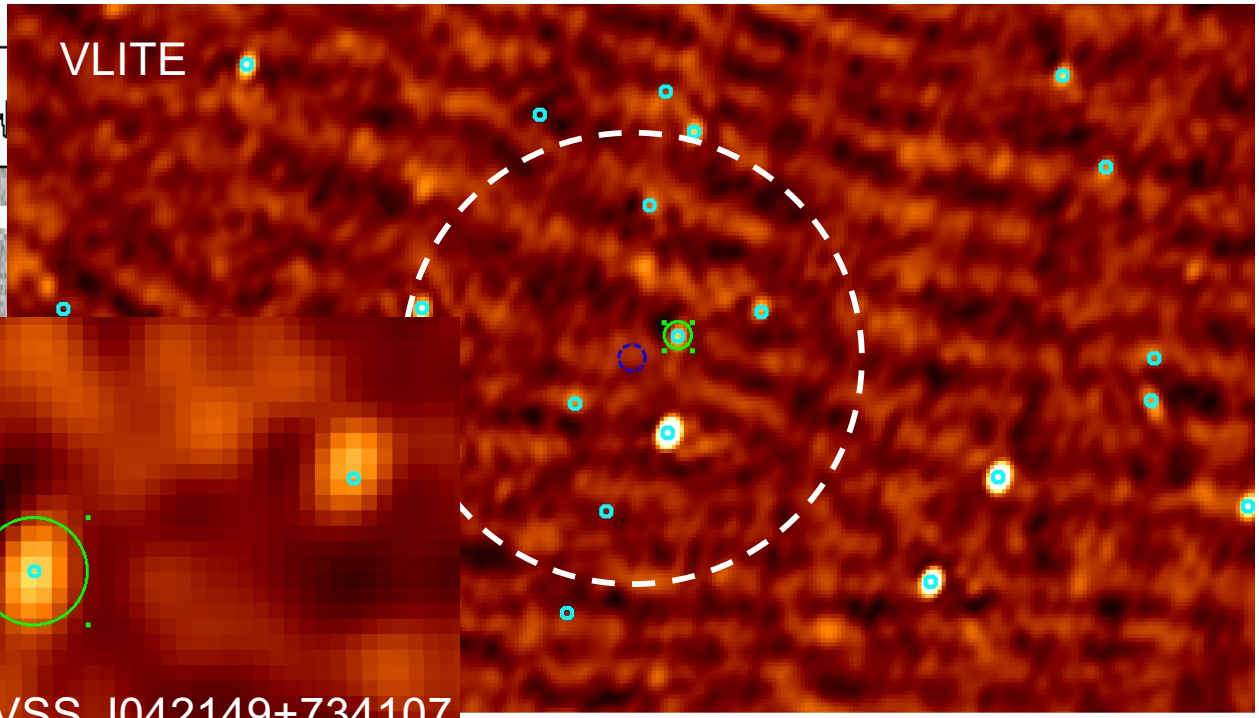

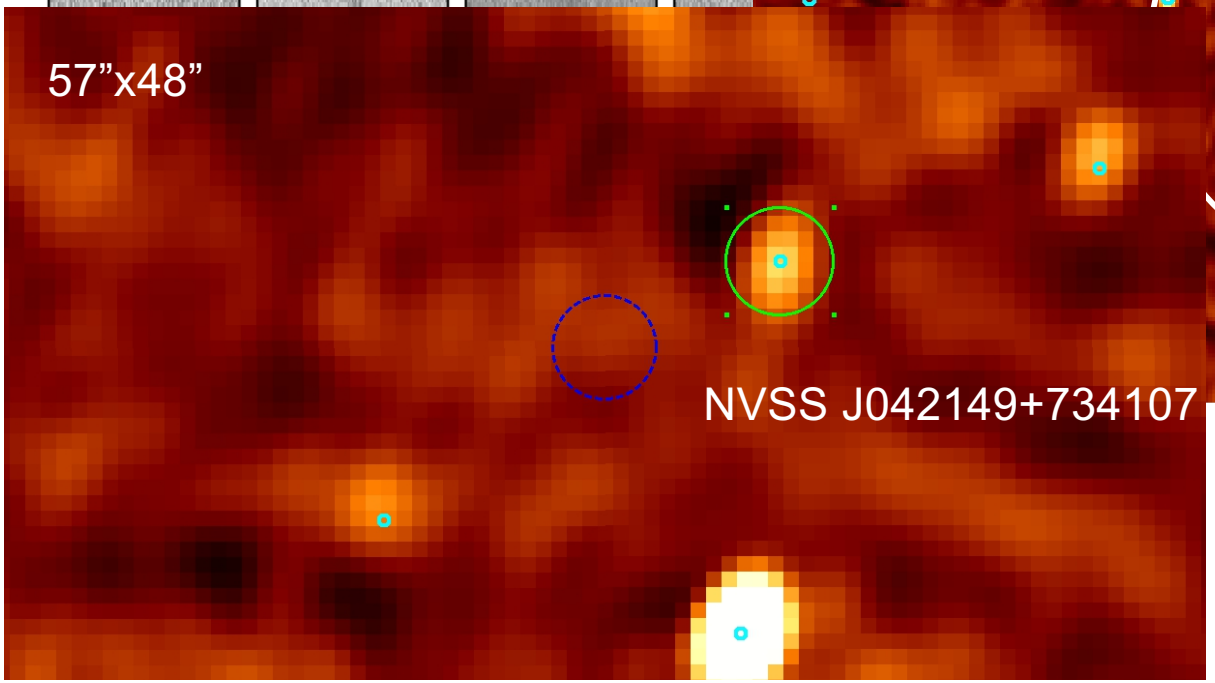

VLITE Commensal Sky Survey (VCSS)

VLITE-Fast Search for Chime Repeater

- CHIME repeater (FRB 18
- VLITE-Fast joined efforts
- No detection yet with VL
  was 'missing' in VLASS a

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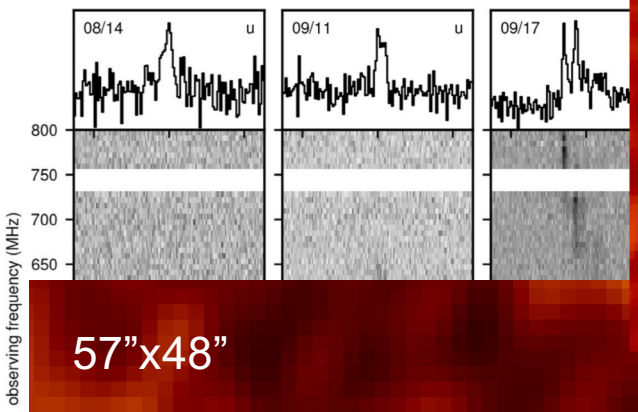
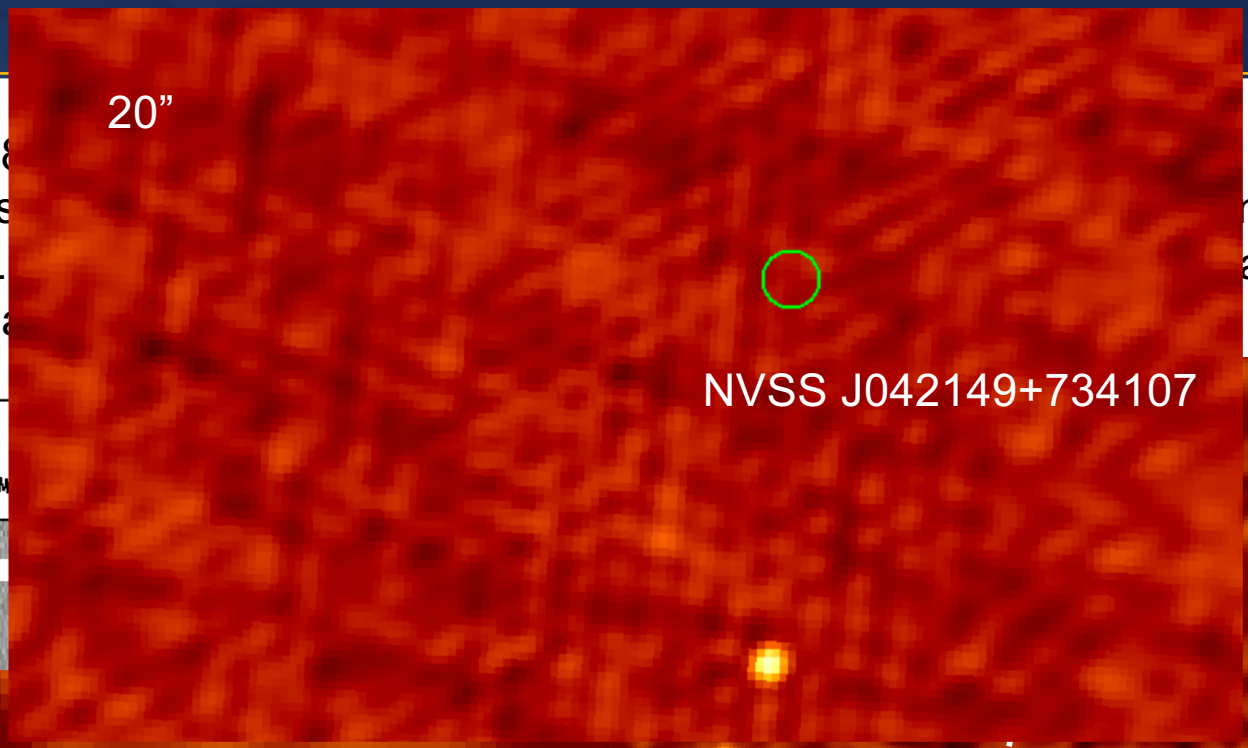
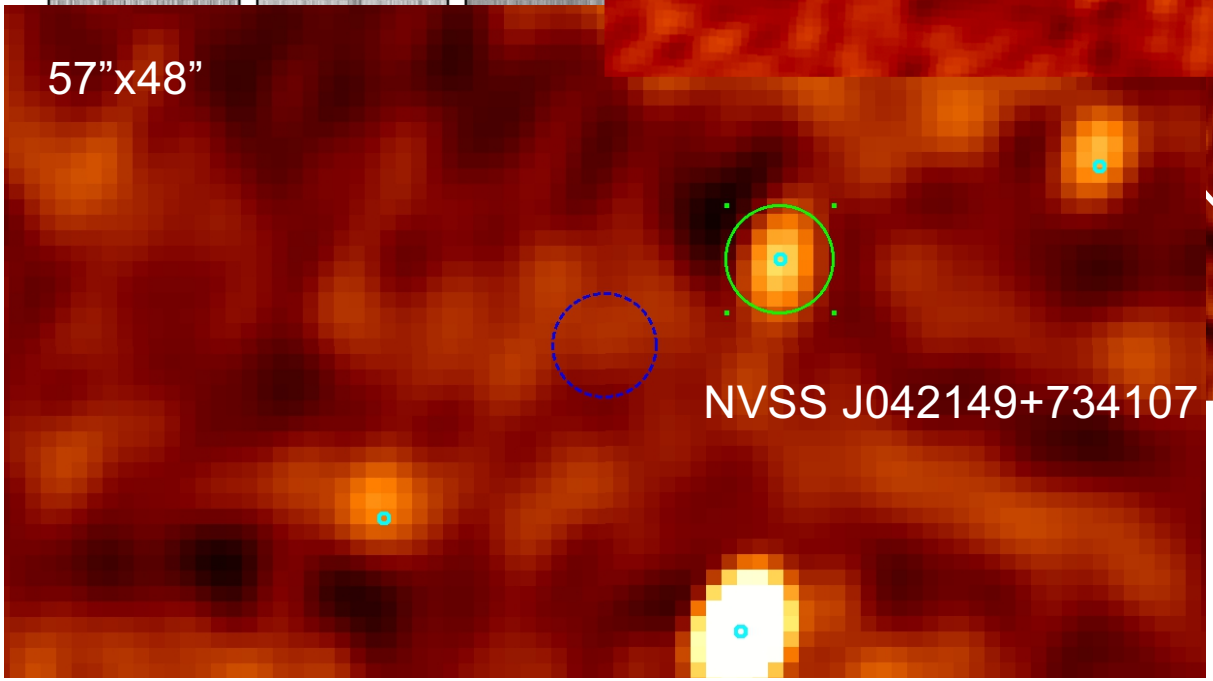
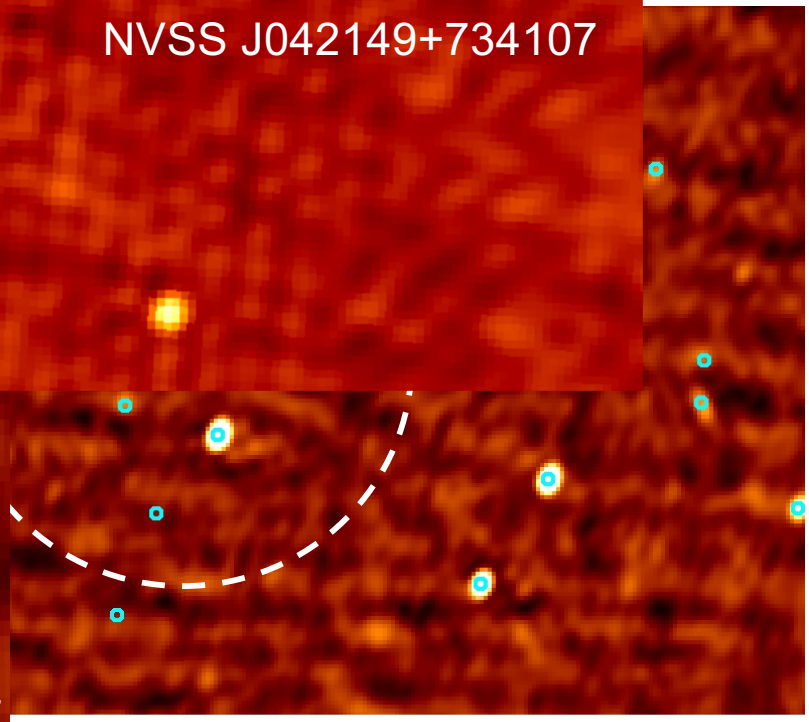








VLITE Commensal Sky Survey (VCSS)

VLITE-Fast Detection Rate (1)

$$S_{min} = \frac{\sigma_{min}\left(T_{sys} + T_{sky}\right)}{G\sqrt{N_{ant}\ N_{pol}\ \Delta f\ W_{obs}}}$$

Single VLITE Antenna:

$$S_{min} = 18.6\ \underbrace{\sigma_{min}/\sqrt{W_{obs}}}\ \text{Jy}$$

Contains intrinsic pulse width, scattering physics (uncertain host galaxy, distance); 16 antennas to use in coincidence.

$$F_{min} \approx 100\ \text{Jy ms}$$

VLITE-Fast Detection Rate (2)

ASKAP Mean Spectral Shape: $S(\nu) \propto \nu^{-1.8}$ (Macquart et al. 2018)

ASKAP LogN-LogS: $N(F > 42\ \mathrm{Jy\ ms}) = \frac{17}{\mathrm{sky\ day}} F^{-2.1}$ (James et al. 2018)

ASKAP LogN-LogS: $N(F > 510\ \mathrm{Jy\ ms}) = \frac{17}{\mathrm{sky\ day}} F^{-2.1}$@ 350 MHz

ASKAP LogN-LogS: $N(F > 100\ \mathrm{Jy\ ms}) = \frac{510}{\mathrm{sky\ day}} F^{-2.1}$@ 350 MHz

VLITE-FAST sees ~1/10000 of the sky.

- 1 FRB every 20 days (single antenna mode)

Factor of 4 from incoherent addition:

- 1 FRB every 4 days!

Need to run 400 MHz numbers based on new CHIME papers!

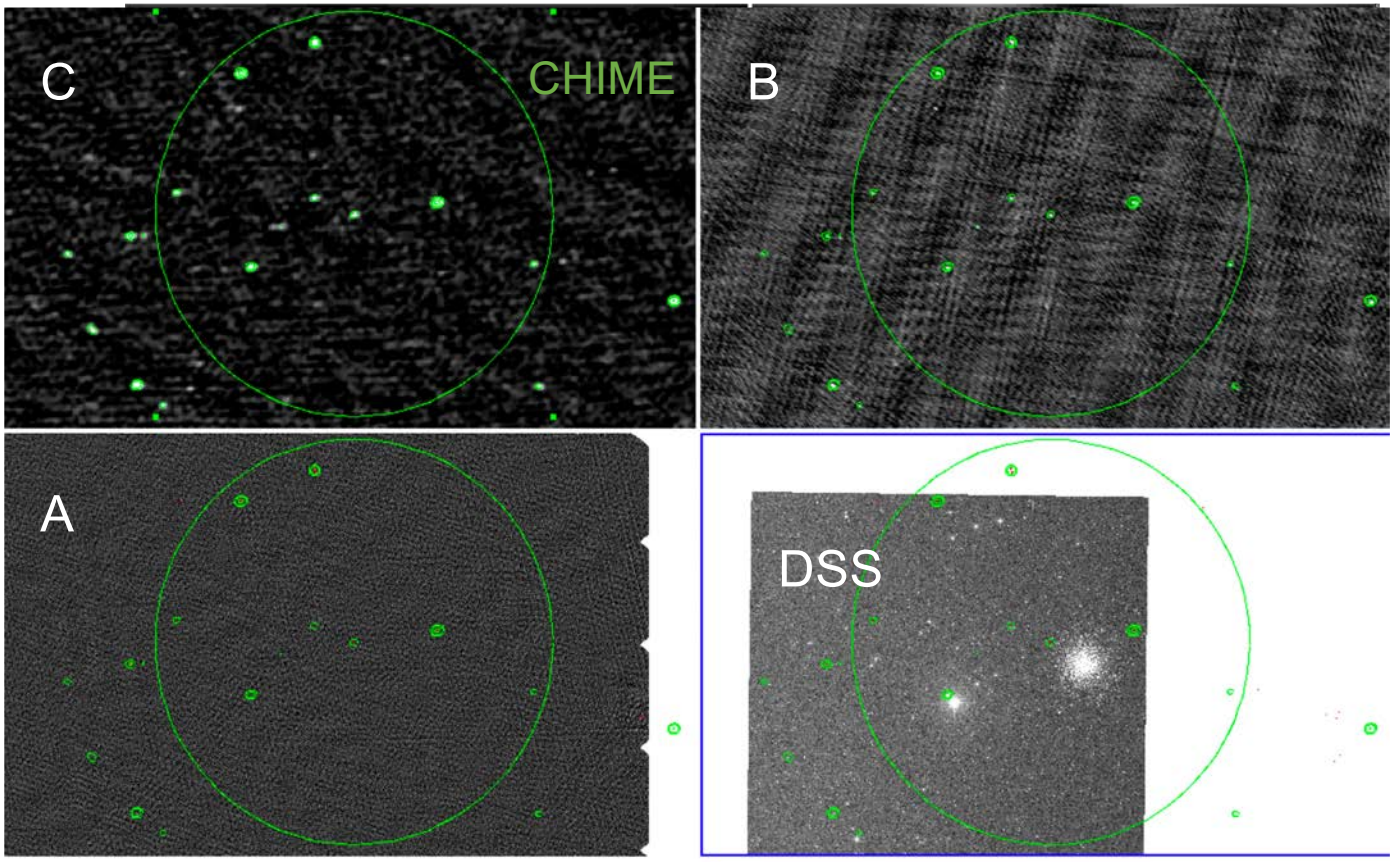
VLA Configurations: Uniquely Identify Host Galaxy

D Config.: ~180”

C Config. (now): ~50”

B Config. (Feb 20, 2019) ~15”

A Config. (Aug 2, 2019) ~5”



With a bit of luck, VLITE could uniquely identify FRB host galaxies in B config.

VLITE will definitely uniquely identify host galaxies of FRBs detected in A configuration.

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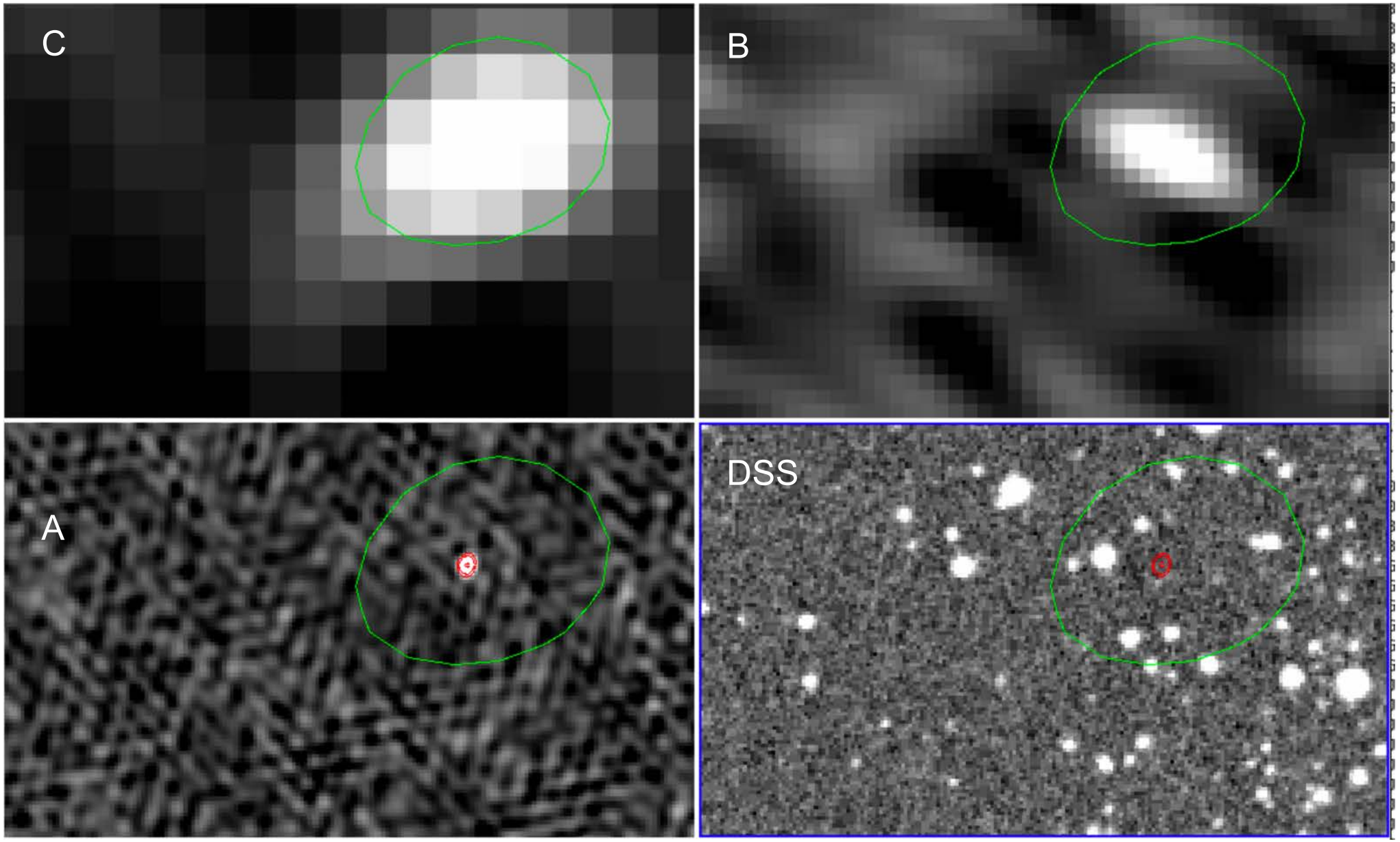
VLA Configurations: Uniquely Identify Host Galaxy



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SUMMARY AND LOOKING FORWARD

- VLITE-16 more sensitive and more stable

- SRDPs from VLITE: calibrated *uv* data, images, and SQL database
  - Each VLITE source is matched to known catalogs at similar resolution

- Automated health diagnostics: rapid identification of issues that impact both VLITE and more broadly JVLA P-band

- VLITE-Fast goal is to be fully operational in B config. (Feb 20, 2019)
  - Expect 6 to 30 FRB hosts in B config and nearly same for A
  - Currently debugging system to get to 16 antenna operation

- Near future: development of the broadband LOw Band Observatory (LOBO)
- Further future: LOBO may combine with NRAO's ngVLA and UNM's eLWA to become ngLOBO-low and ngLOBO-high (Taylor et al. 2017)

NRL encourages anyone interested in data to contact us. NRC postdoc opportunities at NRL with deadline Feb 1, May 1, August 1, November 1