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

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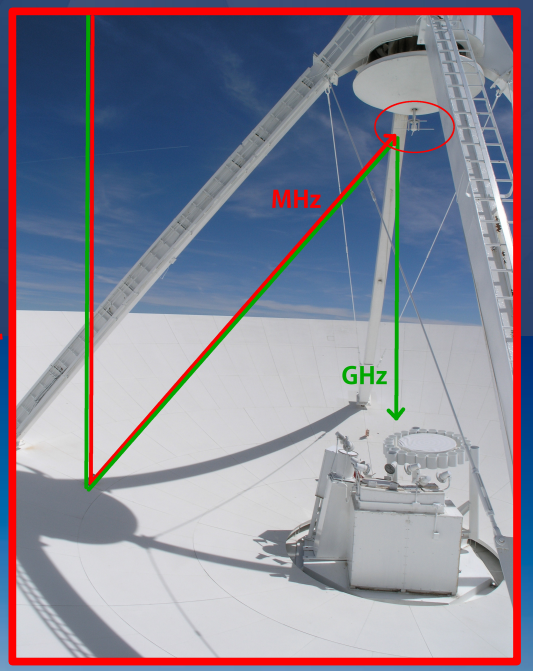
J. Helmboldt, M. Kerr, E. Polisensky, P. Ray
and the NRAO VLITE team



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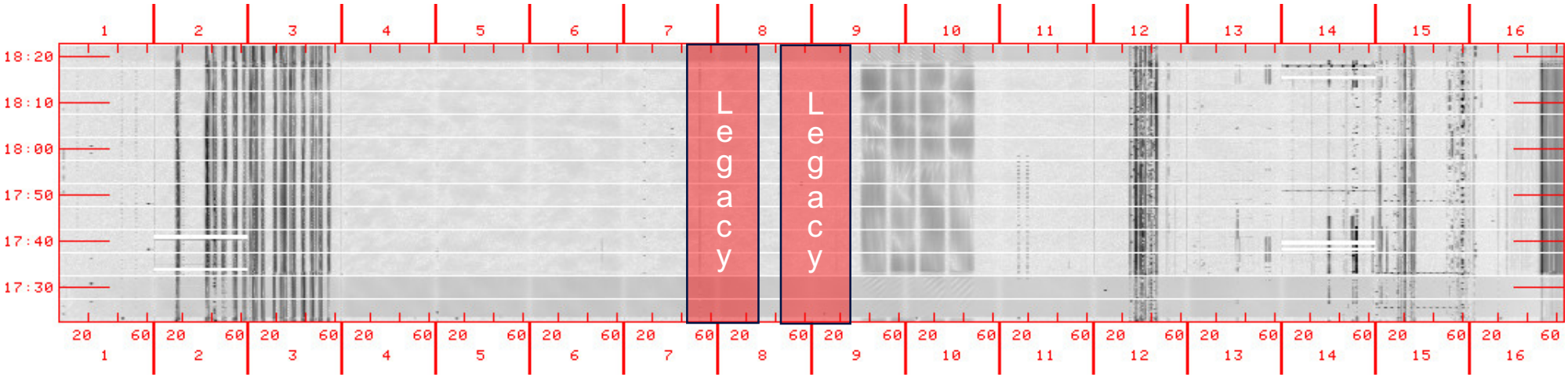
JVLA Broadband Low Frequency Receiver

- 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
- New receiver is the foundation of the commensal VLITE system



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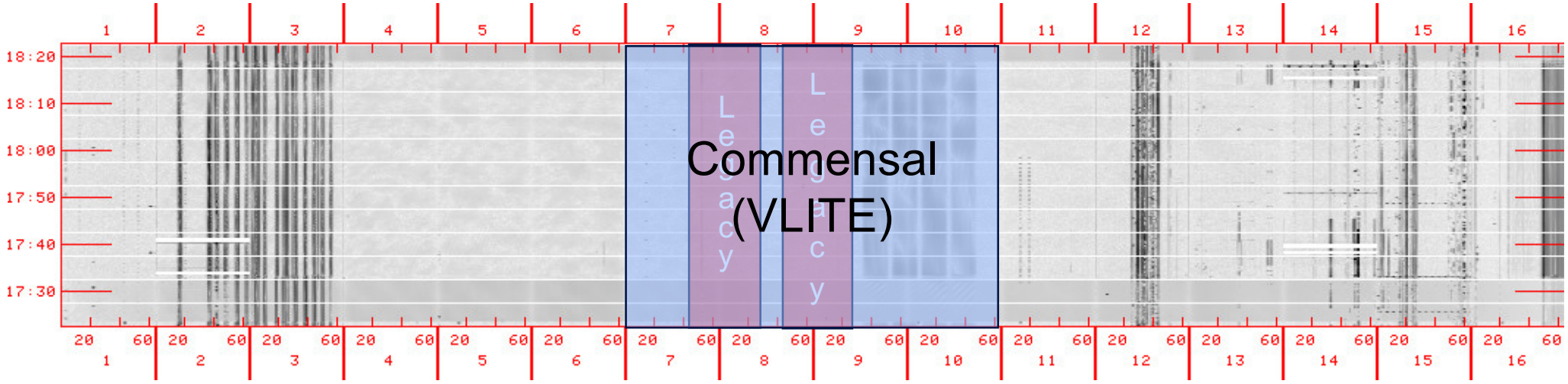
VLA Low-band Ionosphere and Transient Experiment (VLITE)

- Correlates 330 MHz band for 10* VLA antennas

$320<\nu<384$ MHz	$\Delta\nu_{chan}$ = 100 kHz	Δt = 2s
FoV ~ 12 square deg	5” < θ < 3’	0.3 < σ < 10 mJy/bm	LAS ~ 1°
Data rate: 2 GB/hr -> 7 GB/hr	On-sky wall time: ~70% (actual)	



- Minimal impact on VLA infrastructure & operations

vlite.nrao.edu

Clarke et al. (2016, 2018)
Polisensky et al. (2016)
Helmboldt et al. (2019)

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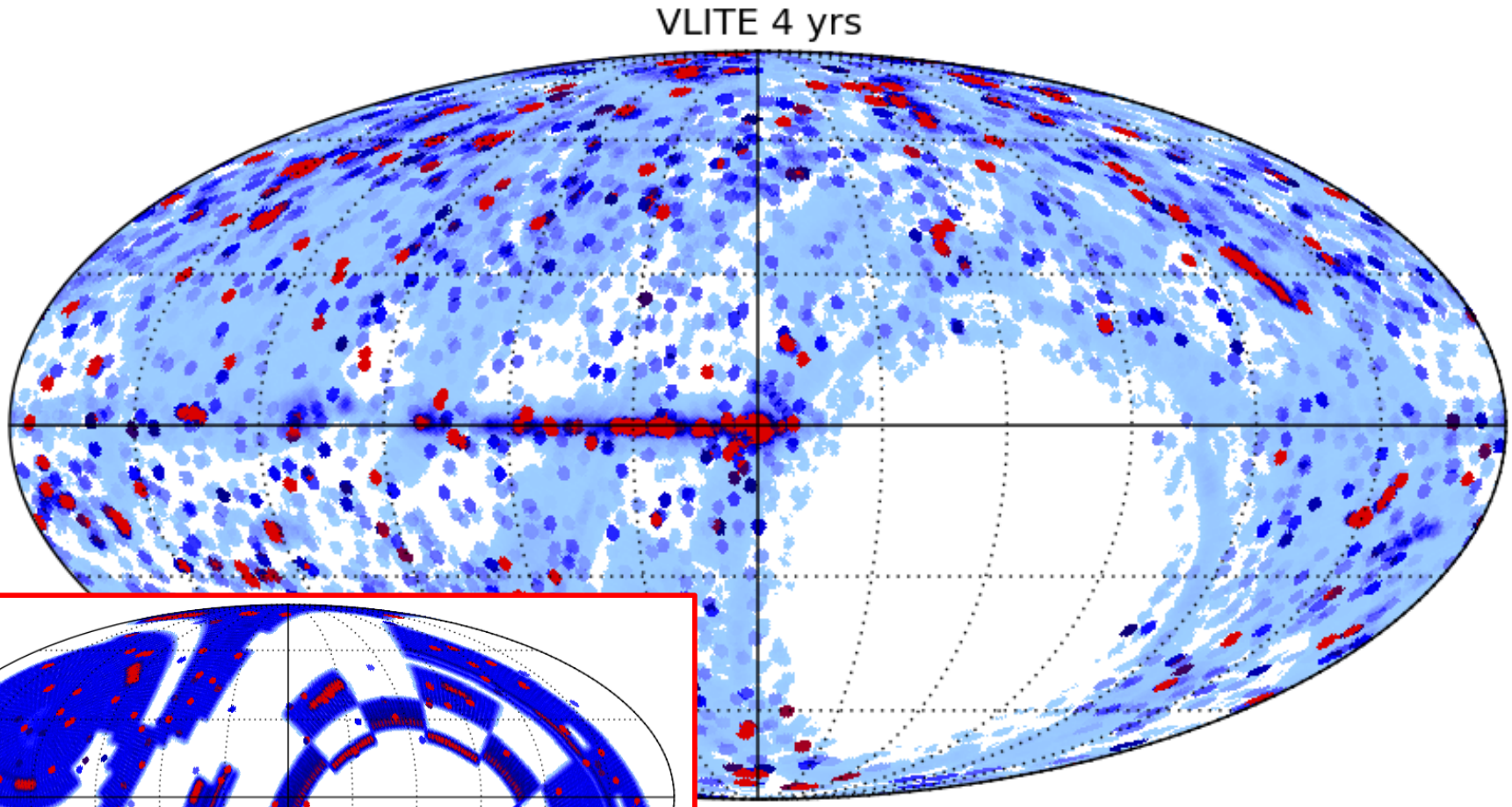
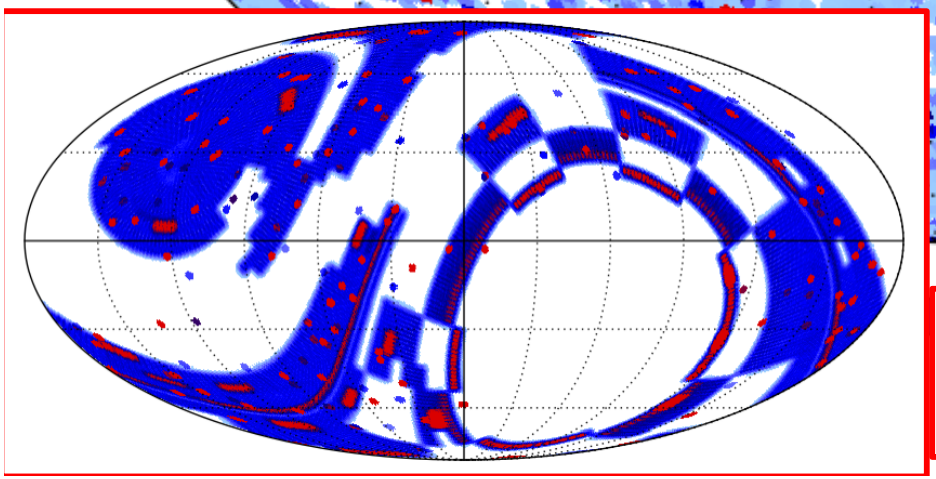
The Power of a Low Frequency Commensal System: Sky Coverage

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





* VLITE Commensal Sky Survey (VCSS: ~818 hr)

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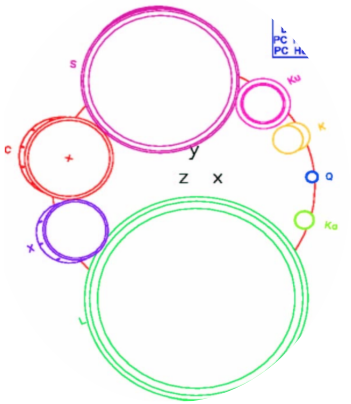
PIPELINE PROCESSING VLITE



- Processing is non-standard: pipeline must be functional over a wide range of operational cases
- Calibration relies on choices of higher frequency observer + subreflector focus and rotation

VLITE Compute Cluster

- Processing 24/7 VLITE data for 18 antennas plus commensal on-the-fly survey requires significant processing resources.
- NRL's VLITE processing array:
  - 4 computer servers with up to 32 CPUs per server
  - Memory up to 1 TB on servers
  - Nearly 1 PB of data storage for raw and processed products archive

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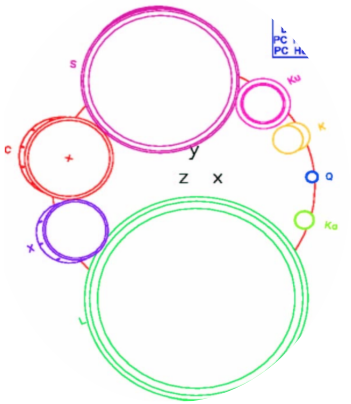
PIPELINE PROCESSING VLITE



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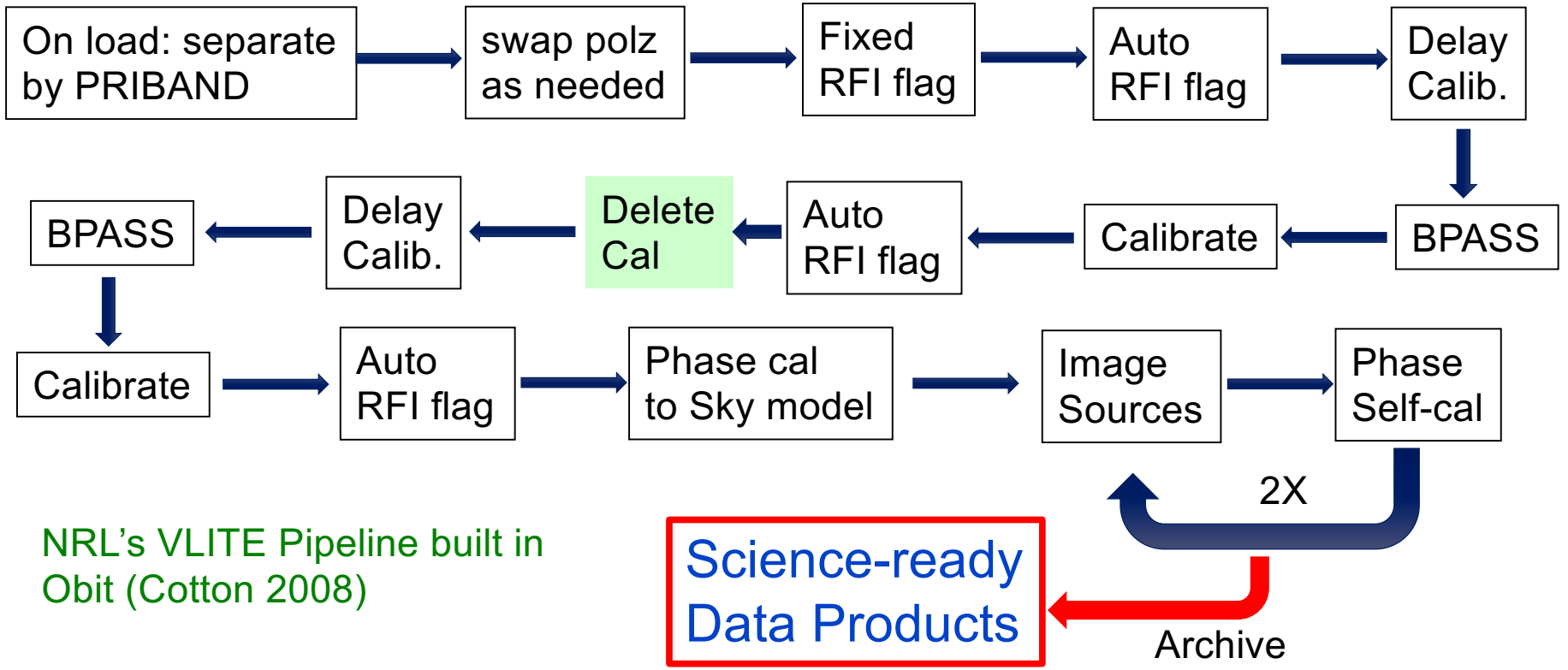
Overly simplified Pipeline flow



NRL's VLITE Pipeline built in Obit (Cotton 2008)

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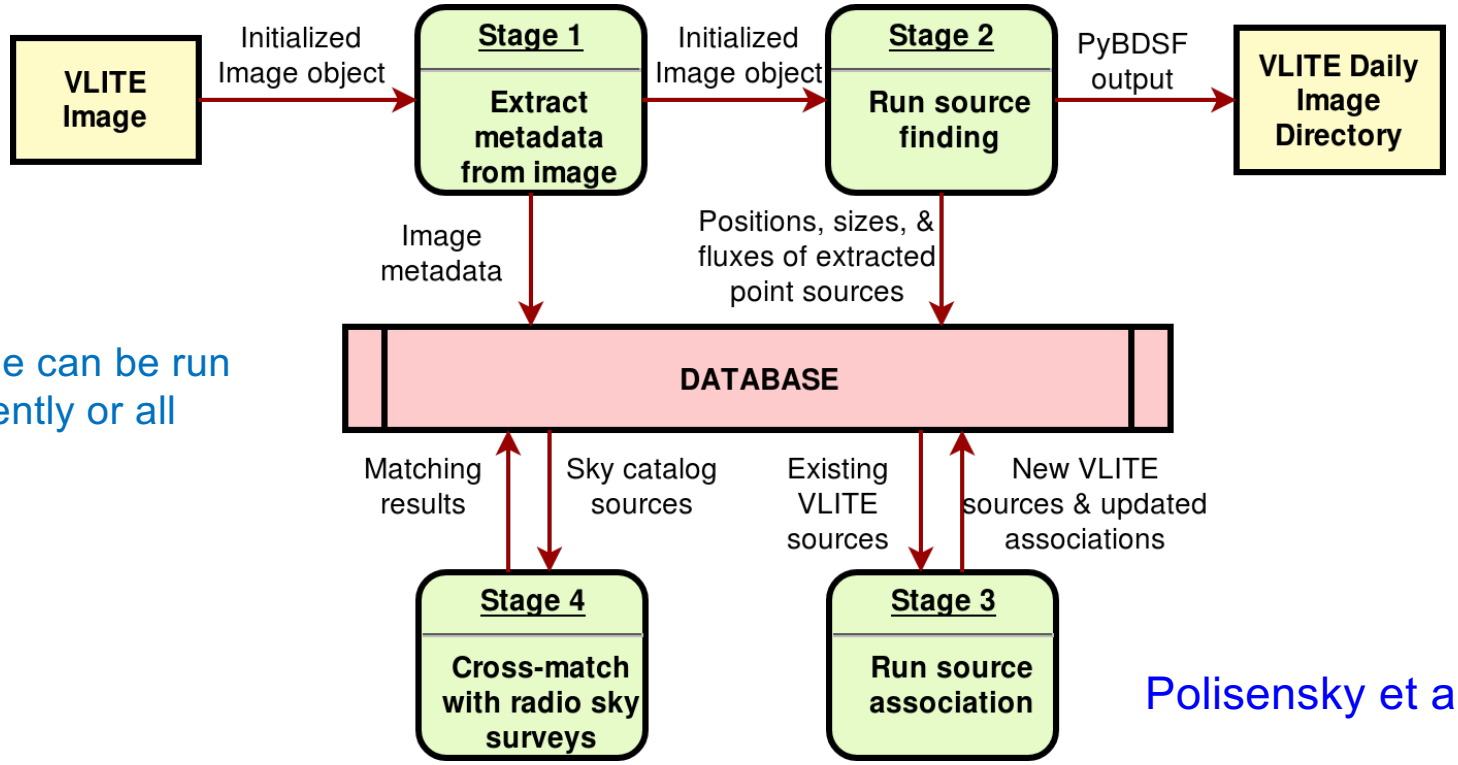
VLITE Database Pipeline (VDP)

- Every image processed runs through VDP
- SQL Database contains metadata, quality assurance flags, source catalogs, cross-matches
- Enables easy light curves, transient searches, catalog matching, etc

Another Overly simplified Pipeline flow



- Each stage can be run independently or all together

Polisensky et al. (2019)

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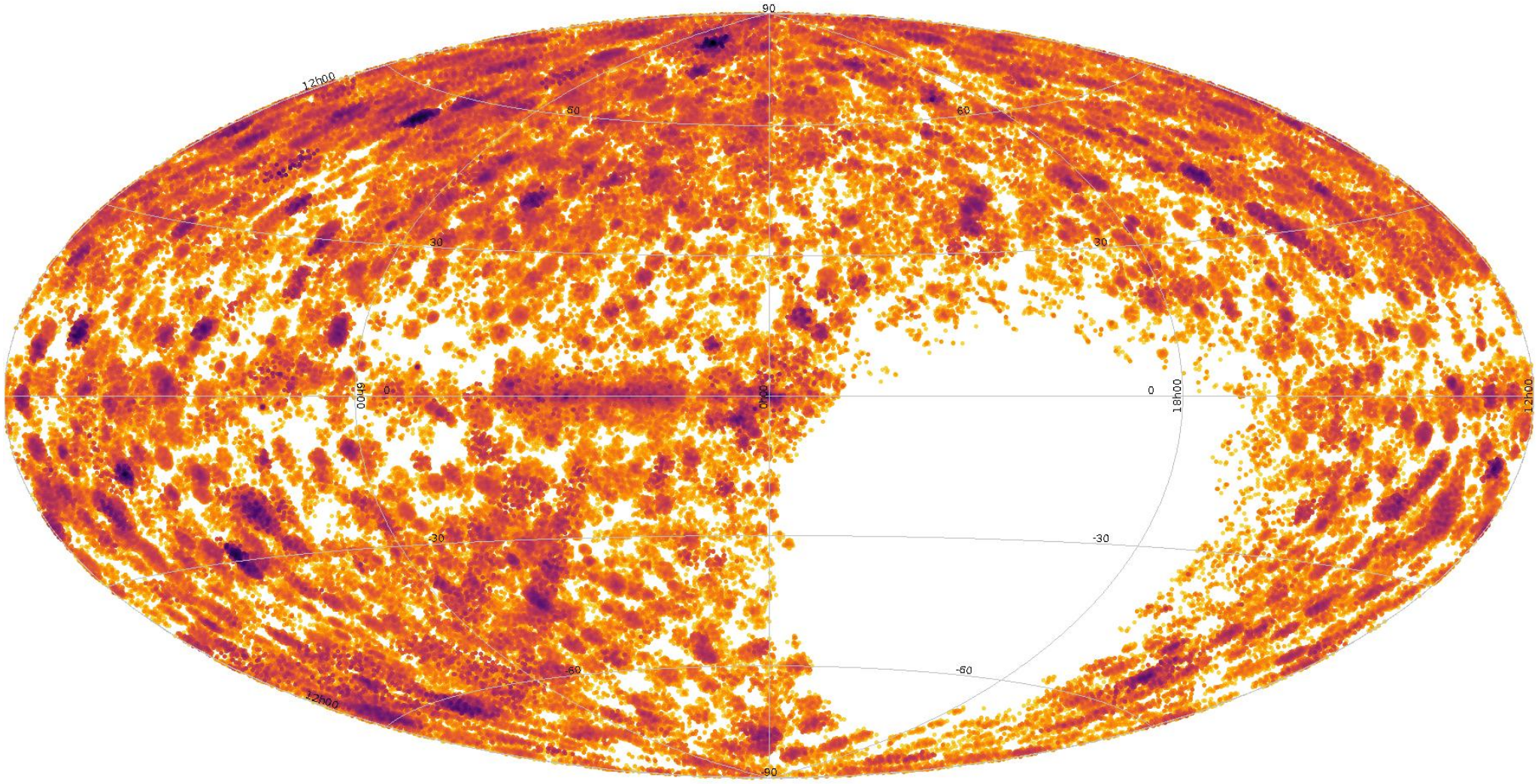
VLITE Source Distribution

- VLITE cataloged over 2.1 million sources (non-unique) sources since 2017 upgrade



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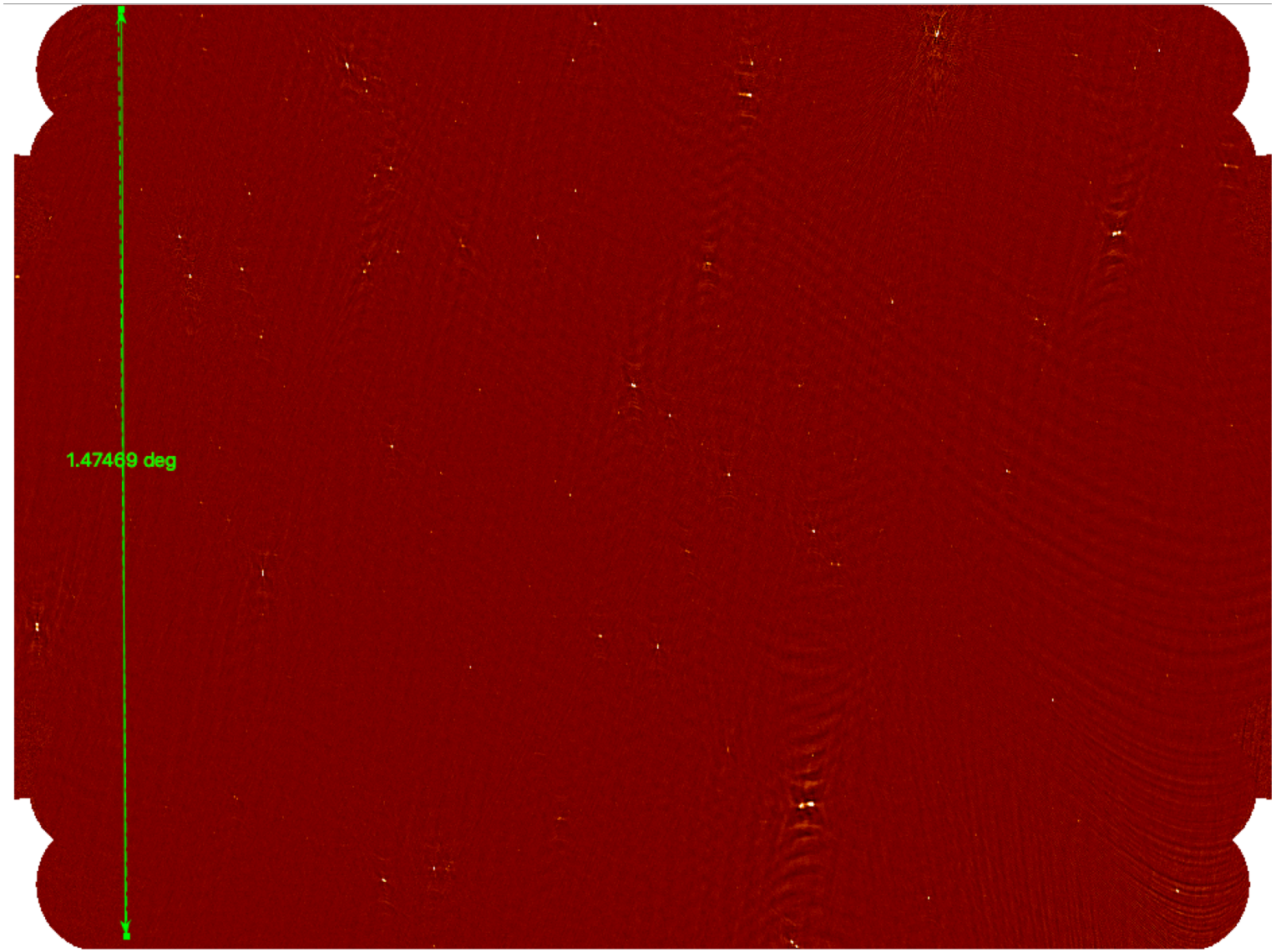
VLITE DEEP IMAGING

- HUDF observed for over 50 hours with the VLA in B config. (15” resolution for VLITE)
- Combined 28 hours of images to form a deep image (rms~251 μJy/bm)



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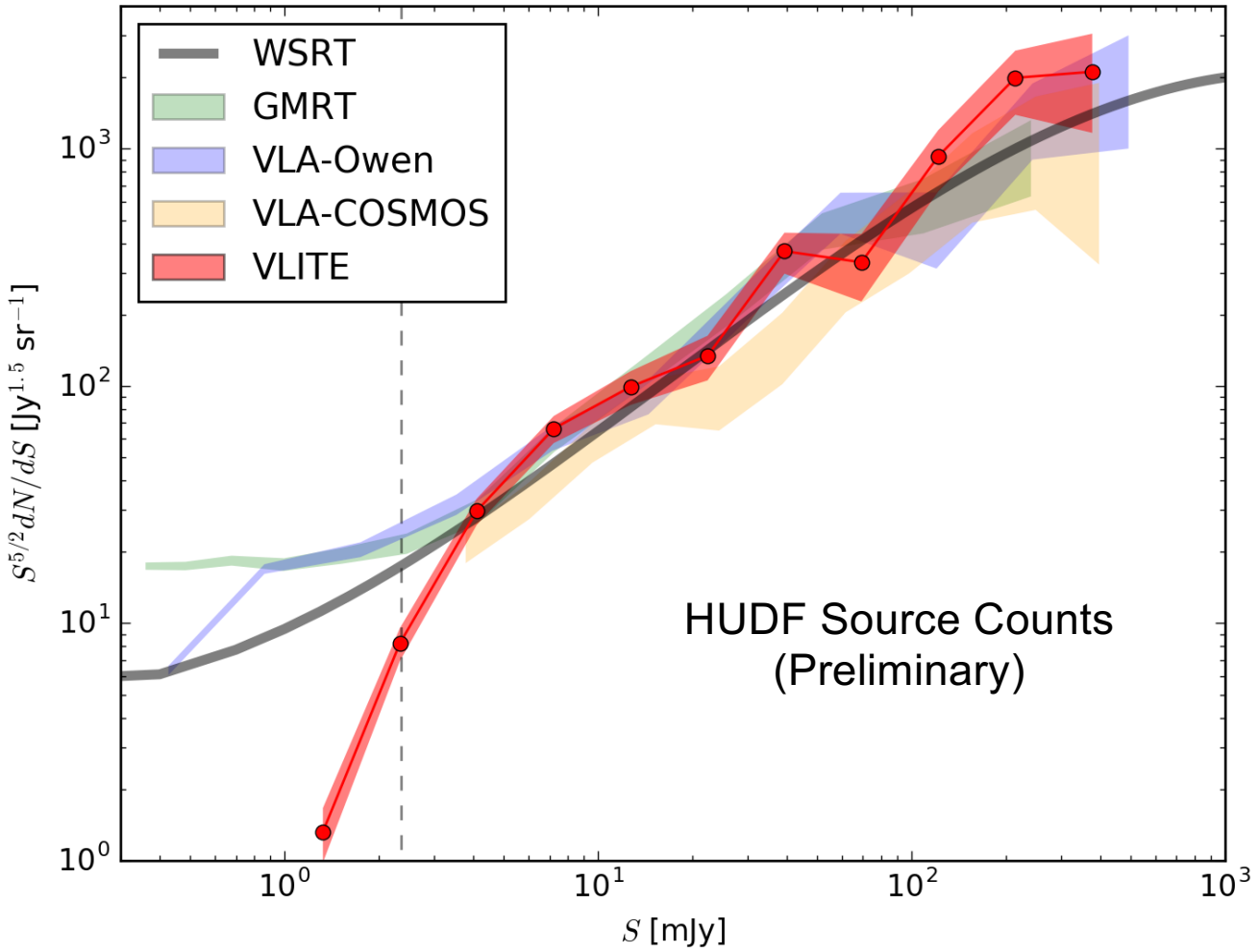
VLITE DEEP IMAGING

- HUDF observed for over 50 hours with the VLA in B config. (15” resolution for VLITE)
- Combined 28 hours of images to form a deep image (rms~251 μJy/bm)
- Currently working on completeness by injecting fake sources and cataloging
- Working on advanced imaging techniques to reduce artifacts and improve rms



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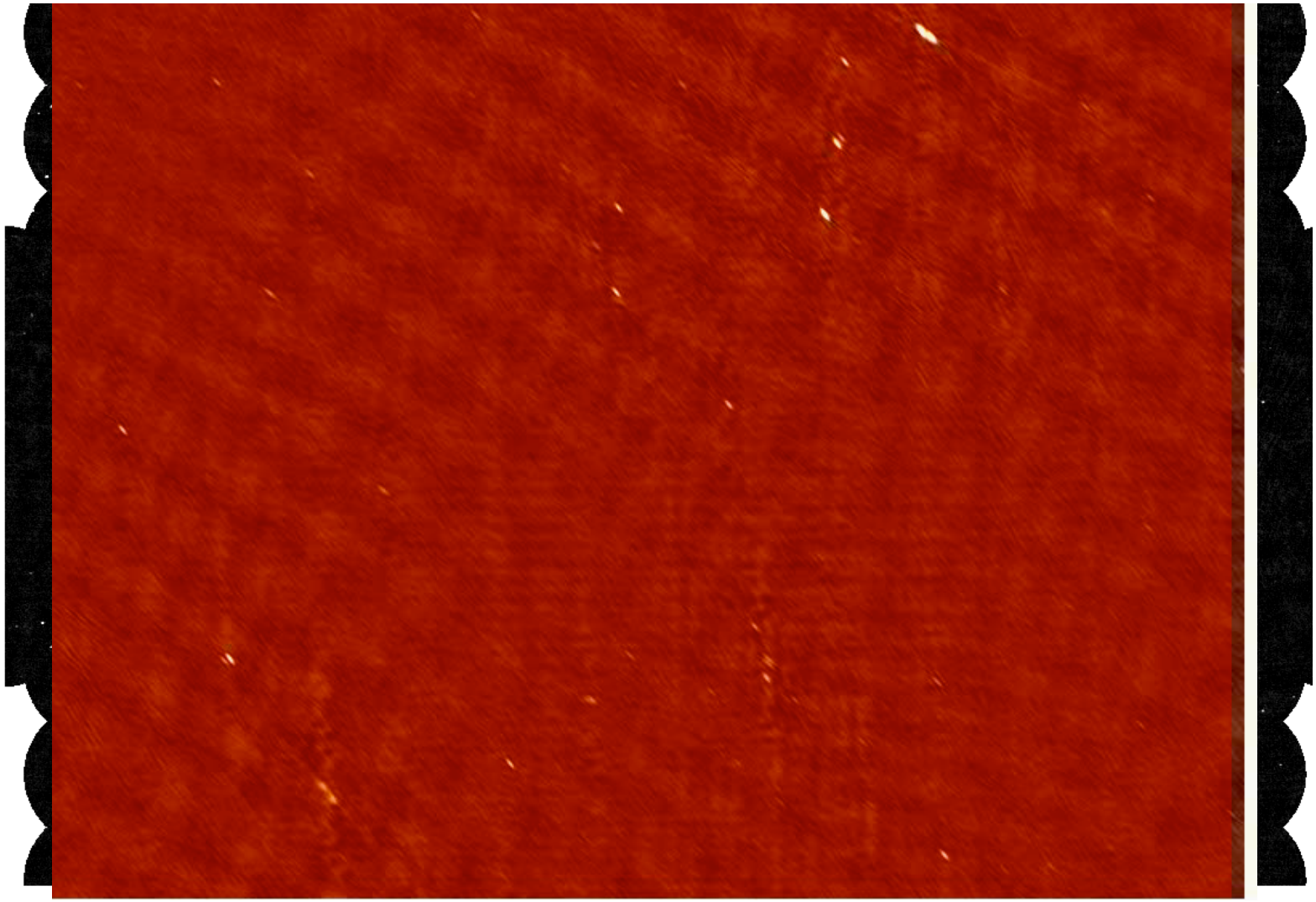
Deep Single Observations

- VLITE images cover a range of on-source times from 24s to > 10 hours.
- Recently a 14 hour observation (M. Kao) processed in B config to 251 μJy/bm
- Split in 30 minute chunks looking for outbursts



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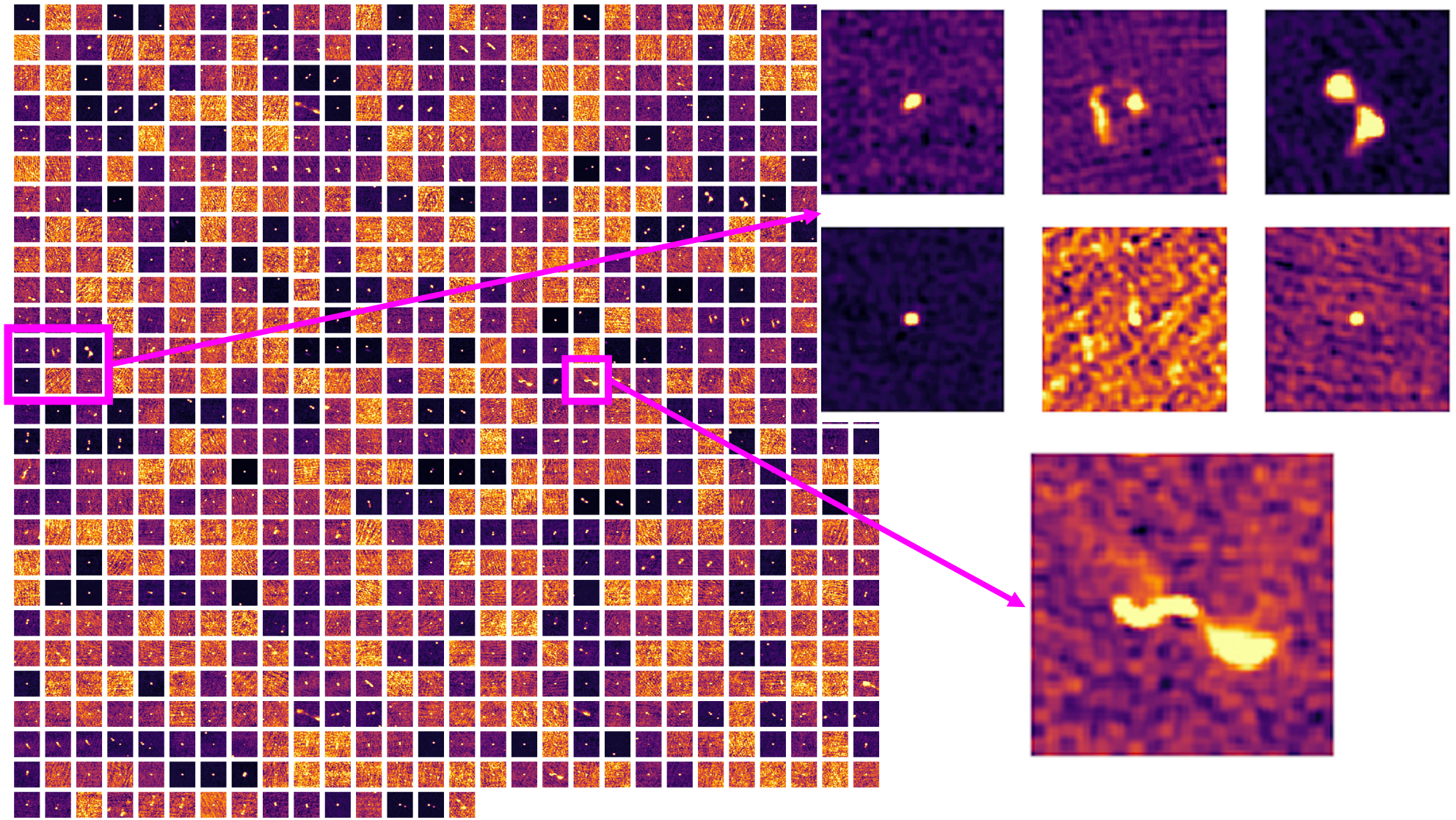
Deep Single Observations

- VLITE images cover a range of on-source times from 24s to > 10 hours.
- Recently a 14 hour observation (M. Kao) processed in A config to 251 μJy/bm
- Running our standard source finding (PyBDSF) we cataloged 741 sources



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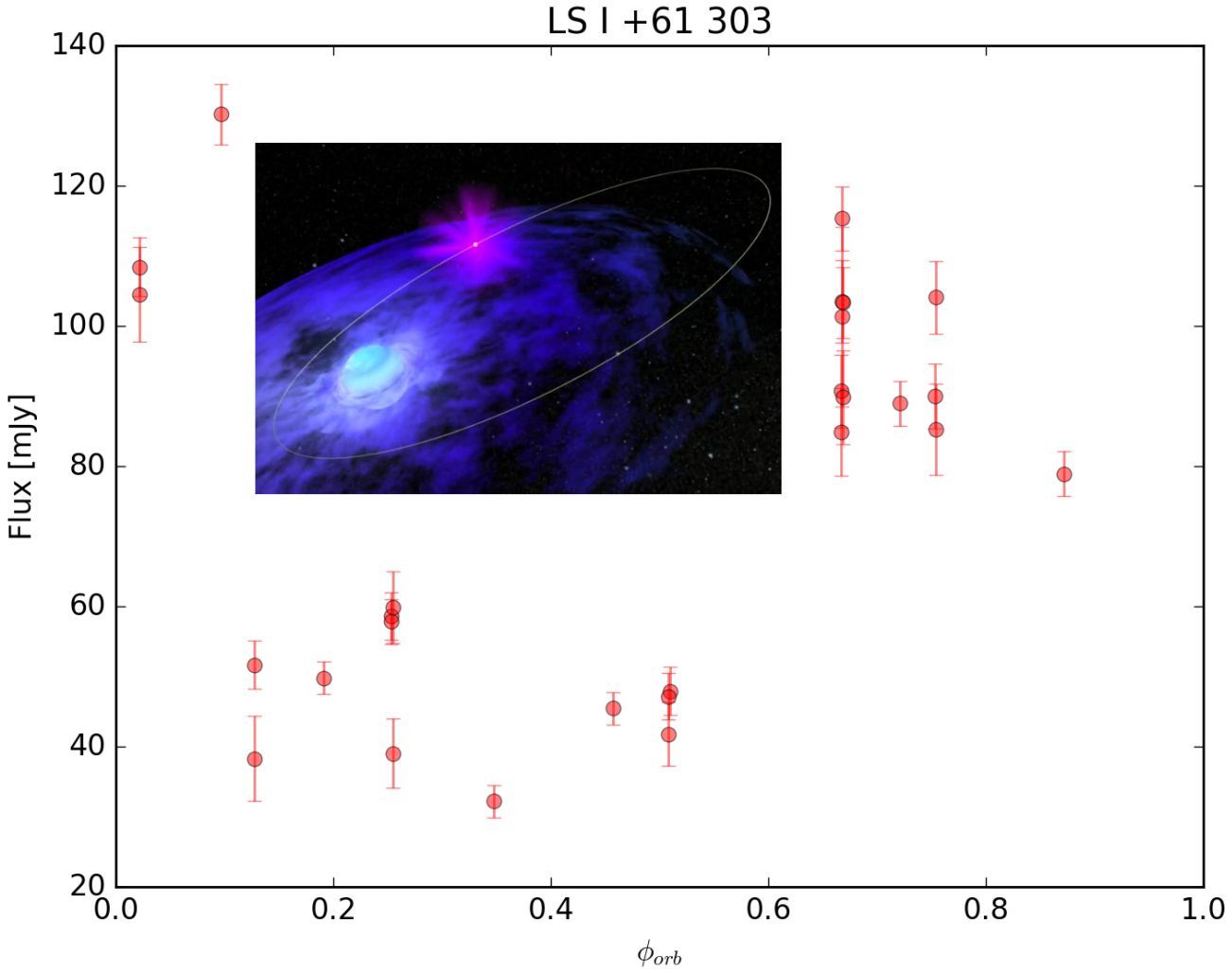
VLITE Slow Transients Hunting

- VLITE associated source catalog can be used to look at source light curves

High mass X-ray binary outbursts from a bursting neutron star orbiting (26.496 day) a Be star. Source ~1º from image centers, flux folded on orbital period.



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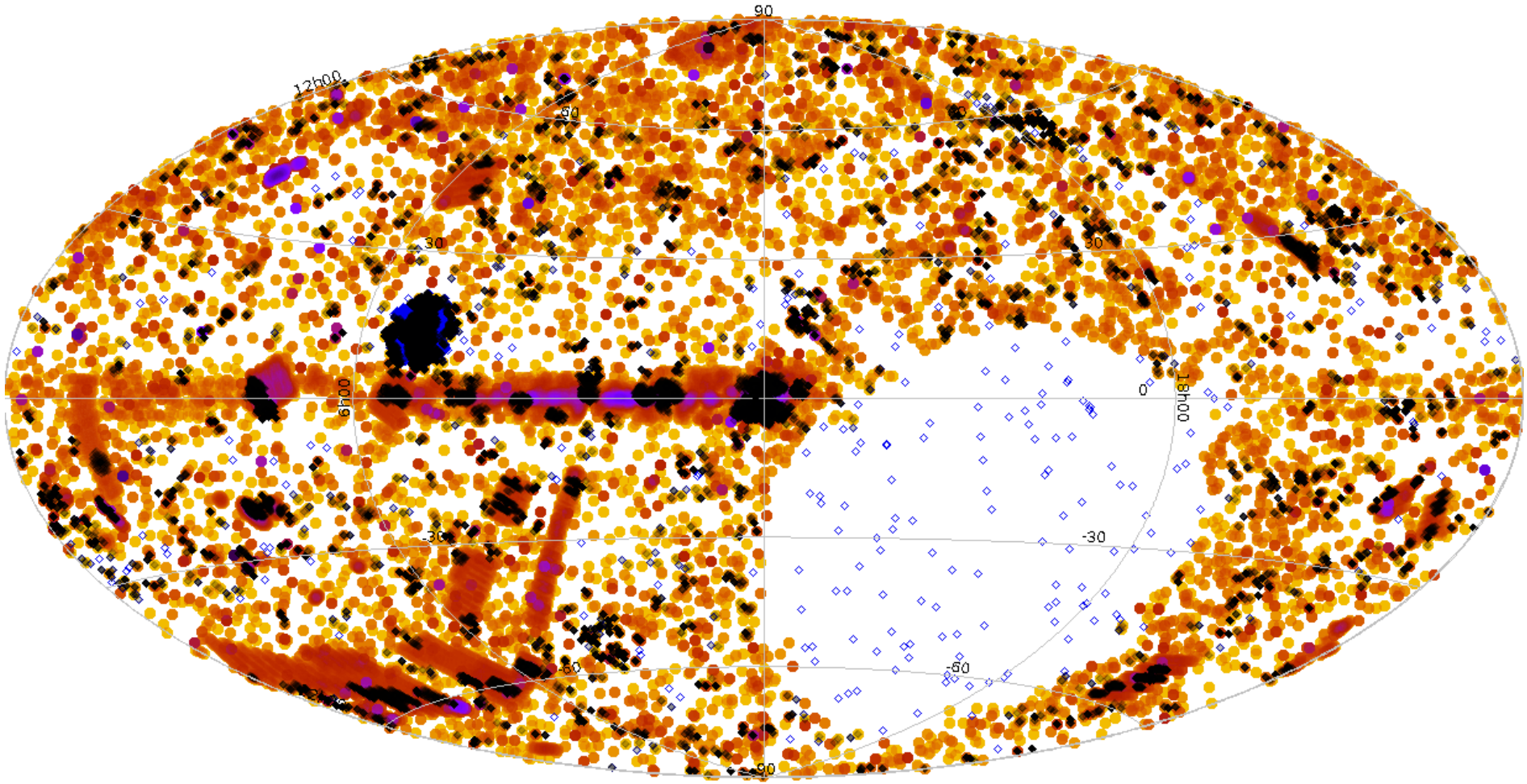
VLITE Catalog Matching Samples: Exoplanets

- VLITE associated source catalog match to sources of interest (e.g. exoplanets)
- Over 70,000 images with exoplanets in FoV



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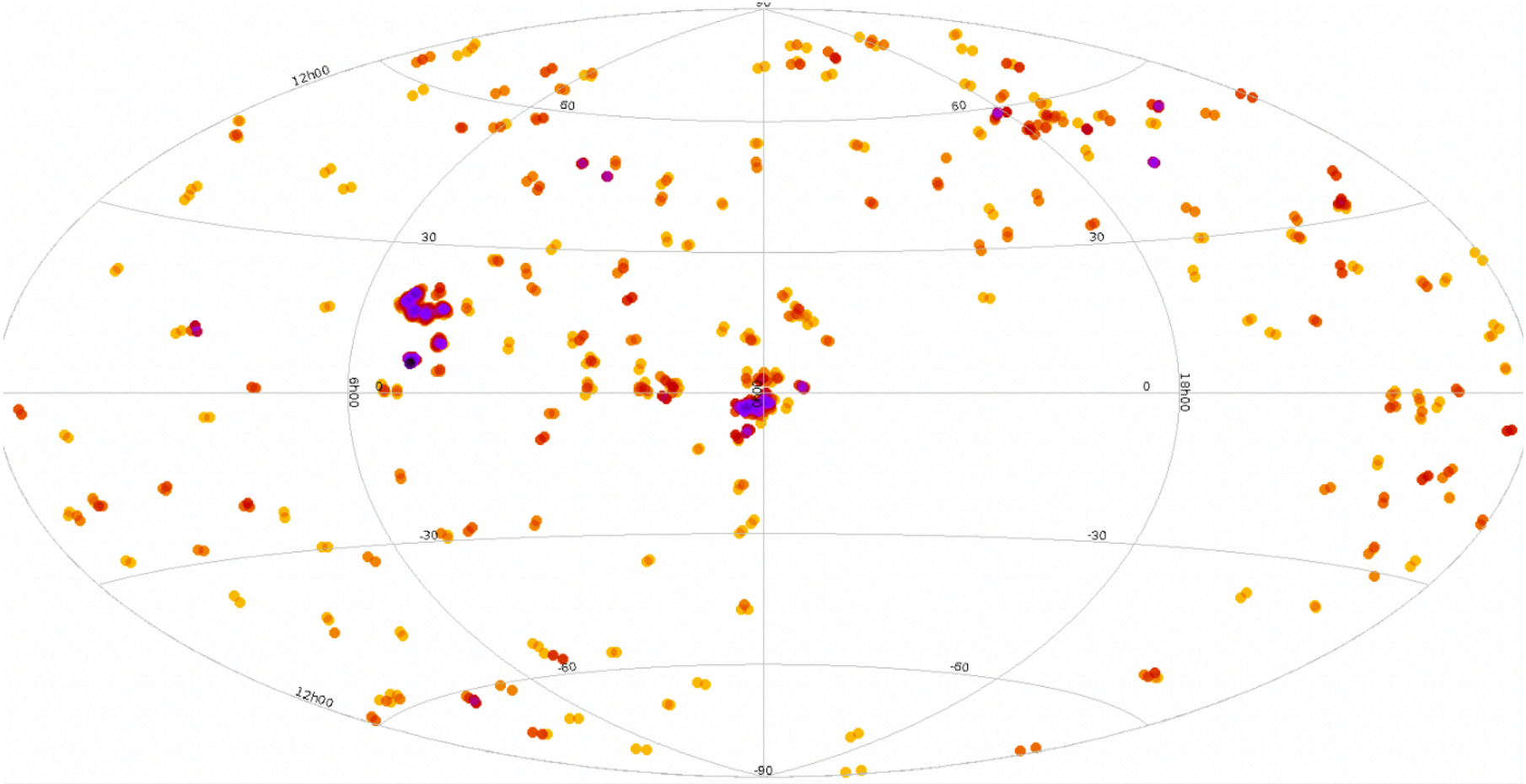
VLITE Catalog Matching Samples
Exoplanets

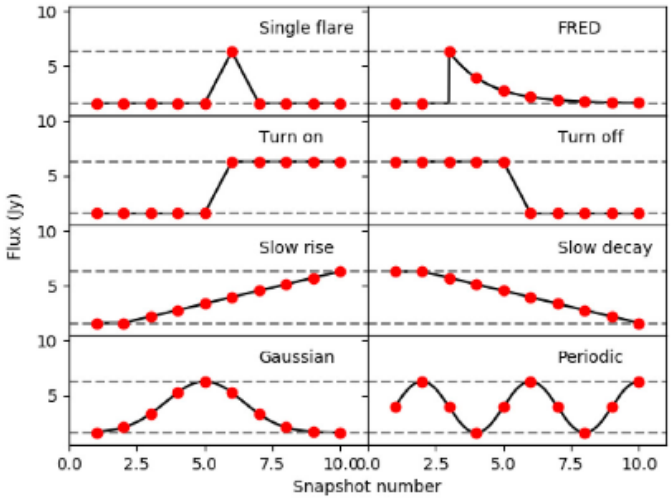
- VLITE associated source catalog match to sources of interest (e.g. exoplanets)
- VLITE A config. (5” resolution) has over 2000 image which contain exoplanet systems
- Current images are integrated over full observing time, starting to make temporal snapshots of images of interest



Machine Learning Transient Identification

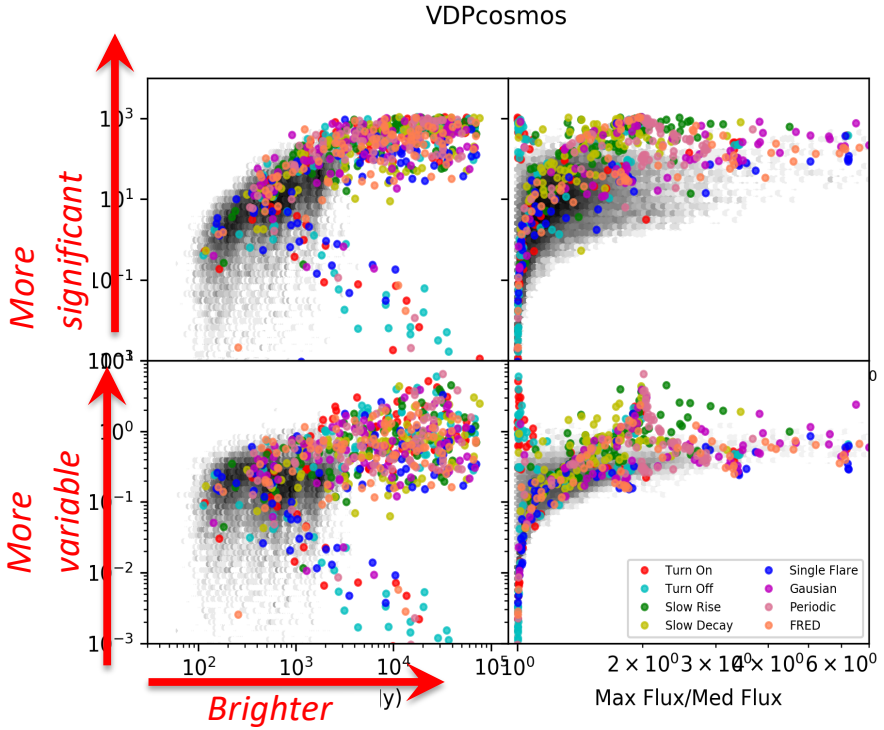
A. Weikert: Senior project at George Washington University (GWU advisor: A. van der Horst; NRL mentor: E. Polisensky)

Inject simulated transients into images to train machine learning algorithms to identify transients via light curve metrics.



VDP results similar to LOFAR (Rowlinson et al. 2019). Initial issue with VDP source association due to resolution class choice.

Machine learning training will begin Fall 2019.



VLITE light curve metrics, injected transients in color

Summer 2019:

- Injected 440 simulated transients into 4400 COSMOS field images, 10 min cadence
- 55 of each transient class, varied SNR
- Cataloged with VDP, TraP in progress

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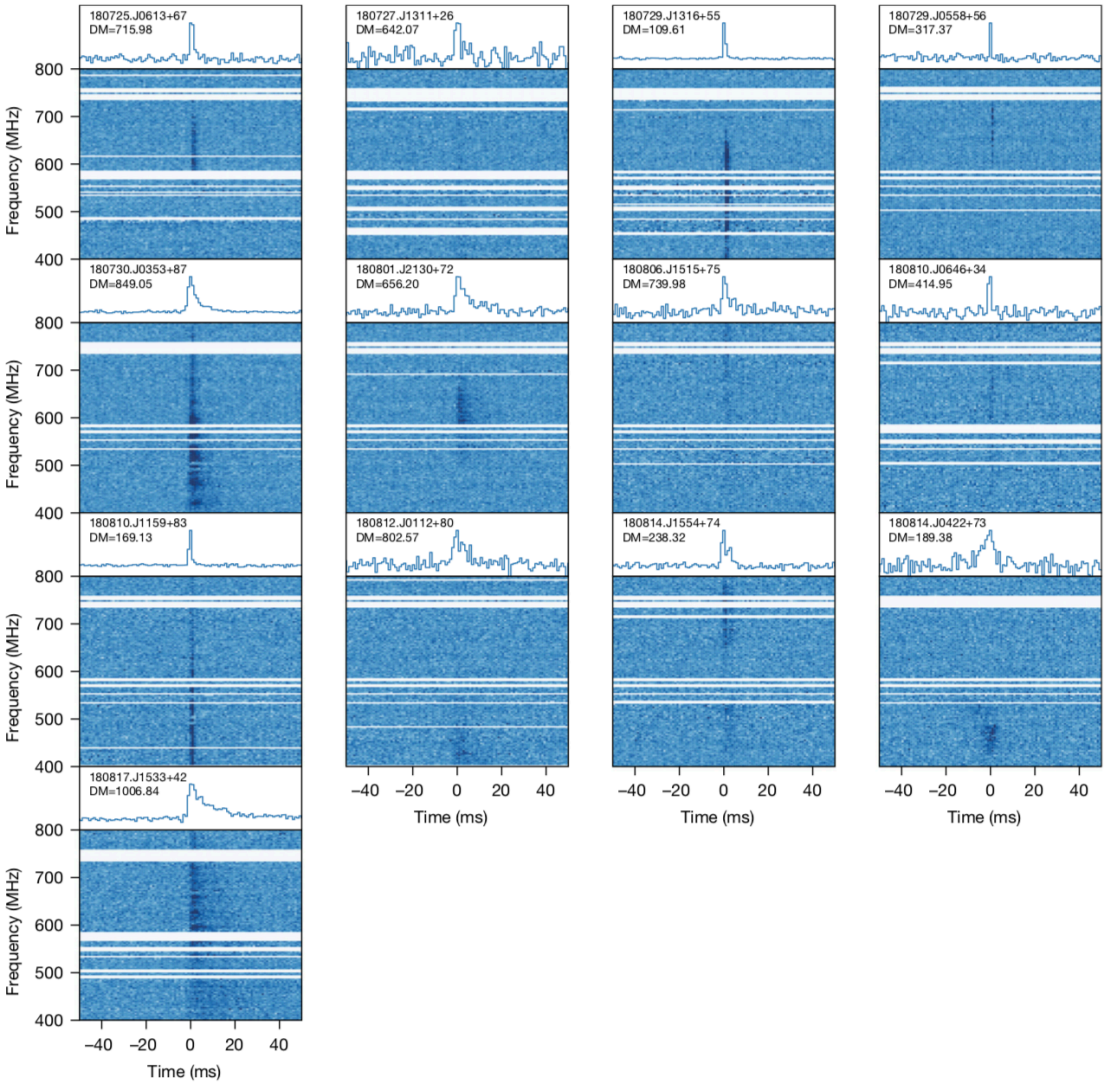
Fast Transients: Low-frequency detection of FRBs

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



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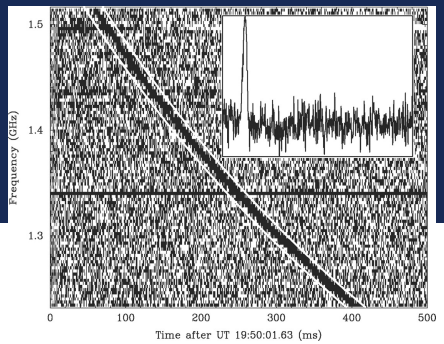
VLITE-Fast: GPU based transient search



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

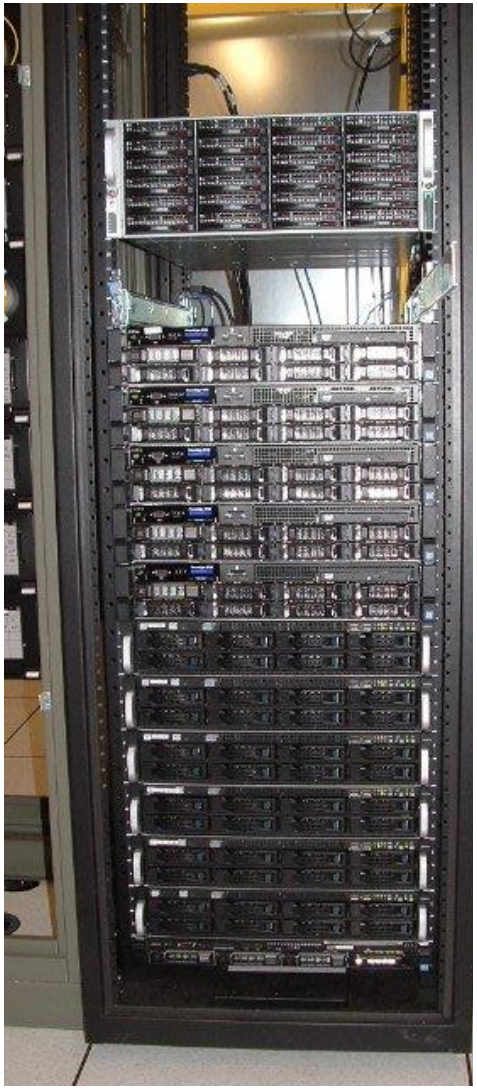
Ring Buffer (dynamic spectra)

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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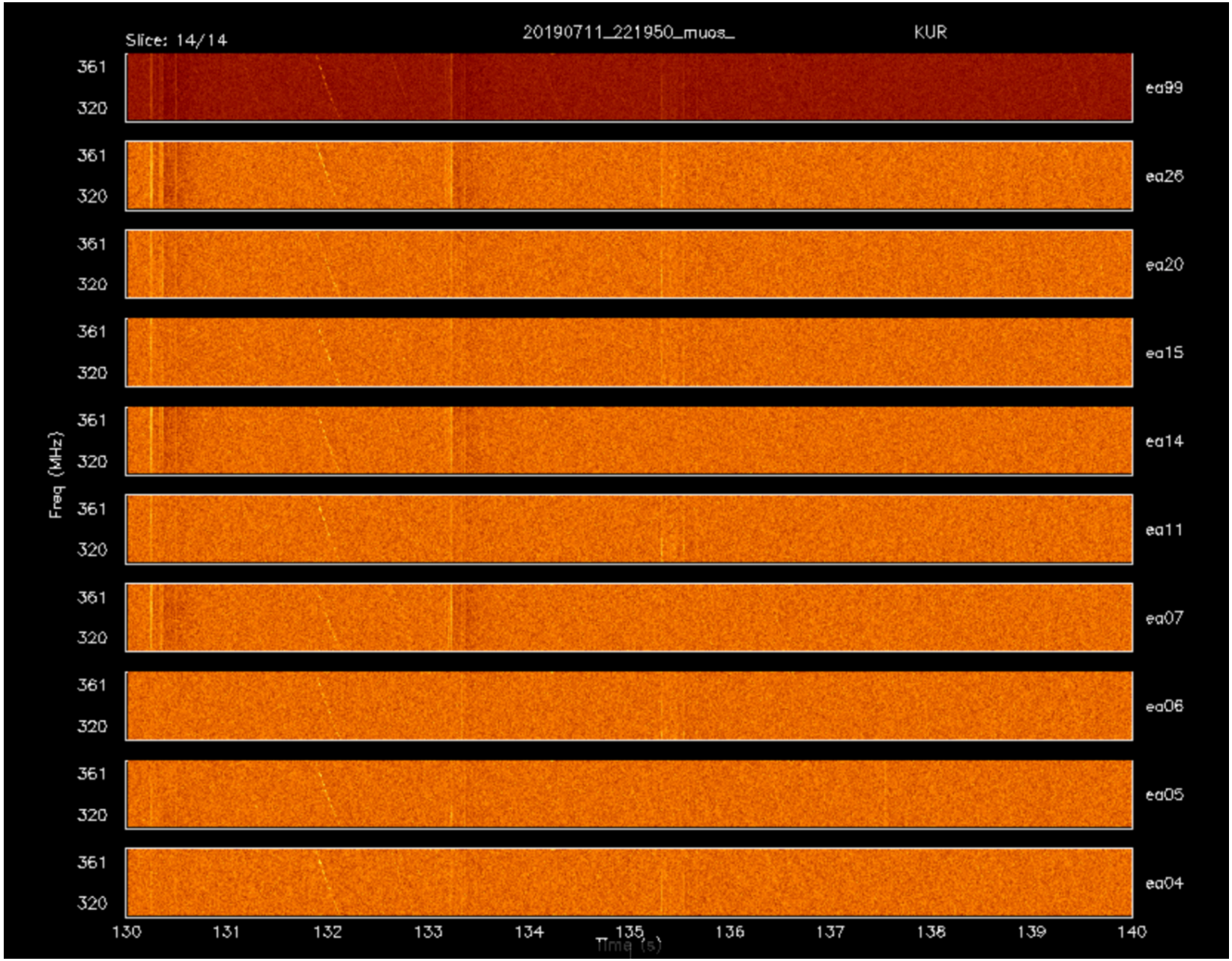
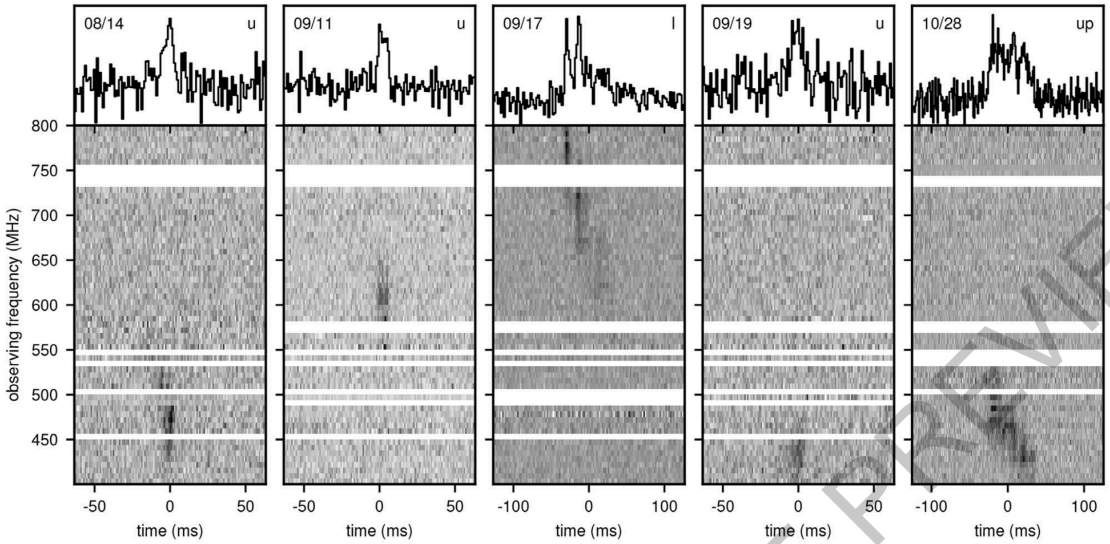
VLITE-Fast Pulsar Testing



Kerr (NRL) and Bethapudi (UTRGV)

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 with VLITE-Fast but VLITE slow clearly identified an NVSS source that was ‘missing’ in VLASS and initially of interest (not faded, just extended as seen by VLITE multiple resolution images)



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SUMMARY AND LOOKING FORWARD

- VLITE-18 more sensitive, stable and increasingly versatile

- SRDPs from VLITE: calibrated *uv* data, images, and SQL database
  - Each VLITE source is matched to known catalogs at similar resolution
  - Working on adding 'vanished' source identification to database
- 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 2019 (close but some CUDA issues left)
  - Expect 6 to 30 FRB hosts in B config. and nearly same for A

- Summer 2019+ working to develop machine learning transient hunting and add polarization (Stokes V) search capabilities

- Future: development of a broadband LOw Band Observatory (LOBO) on VLA potentially including LWA stations

NRC postdoc opportunities at NRL with deadlines:
Feb 1, May 1, August 1, November 1