Studying Meteor Radio Afterglows with the Long Wavelength Array

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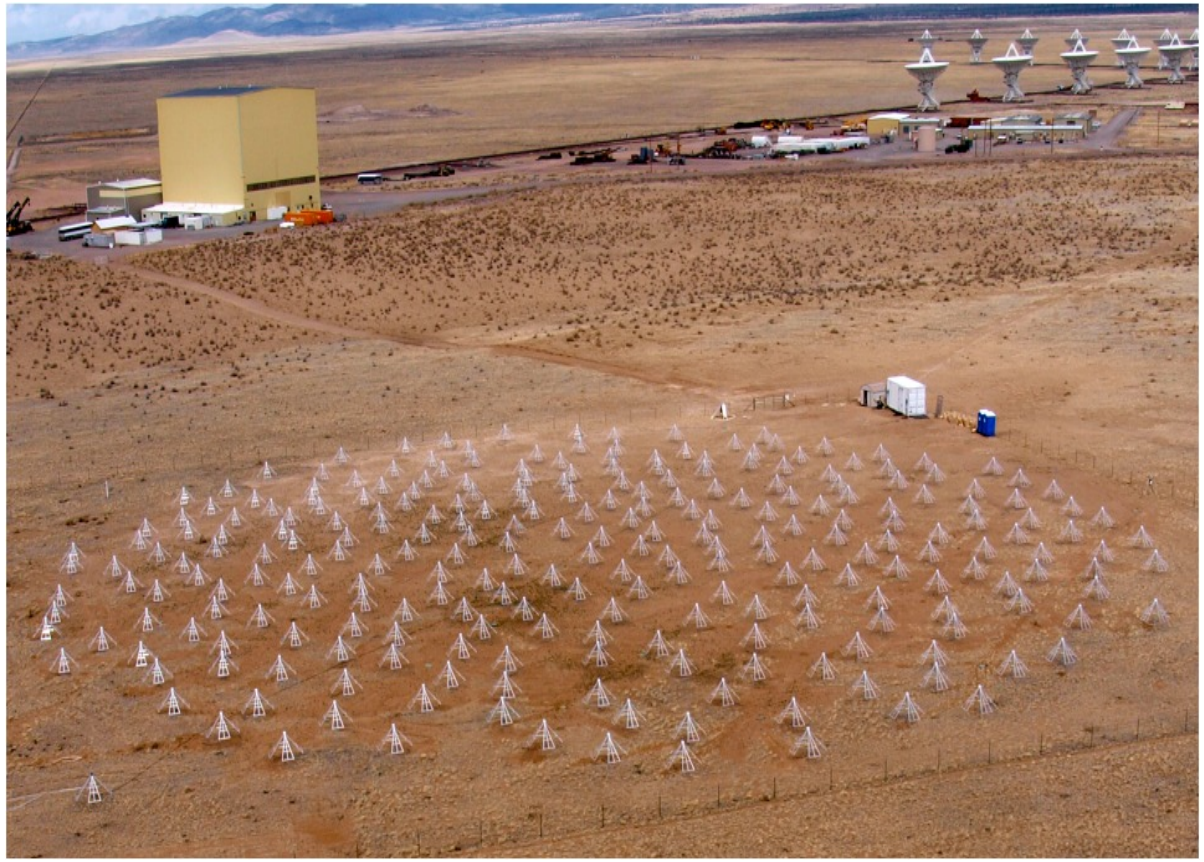
LWA Users Meeting 2020

Albuquerque, July 30 , 2020

Long Wavelength Array (LWA 1 and LWA-SV)

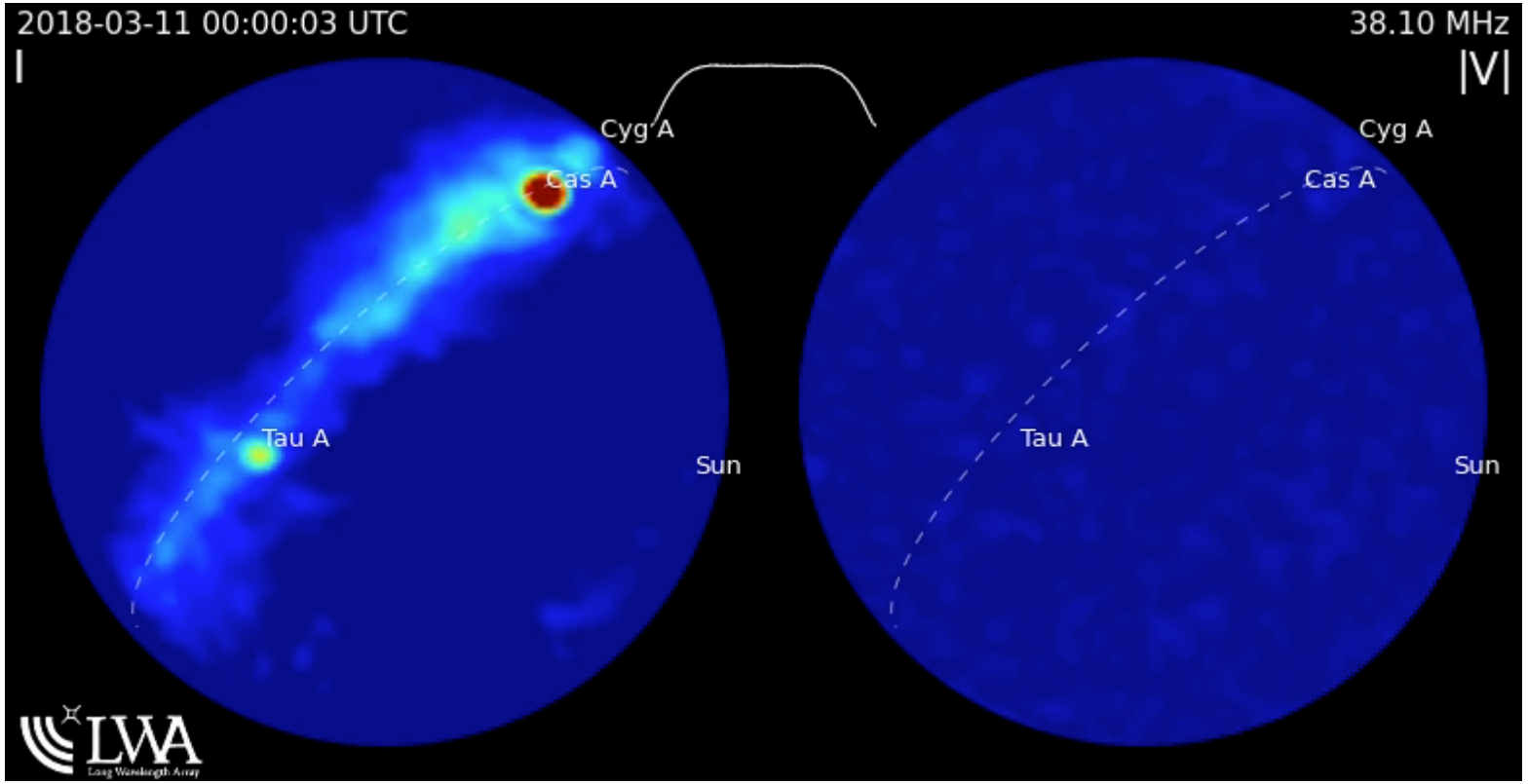


75 km separation

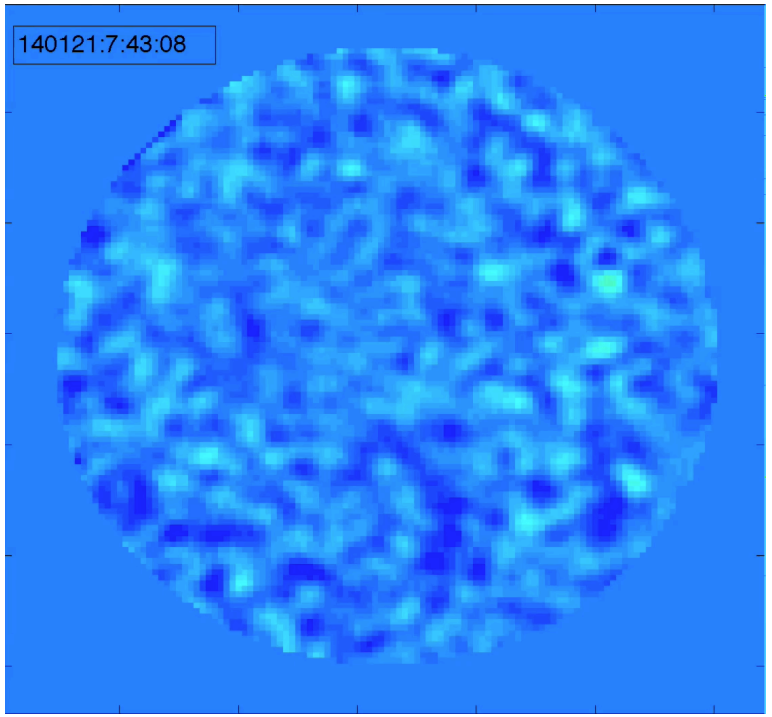
- Operating frequency 10-88 MHz for LWA1 and 3-88 MHz for LWA-SV
- 256 dual- polarization dipole antennas
- Distributed within a 100 × 110 m ellipse
- Beamforming and All-sky mode

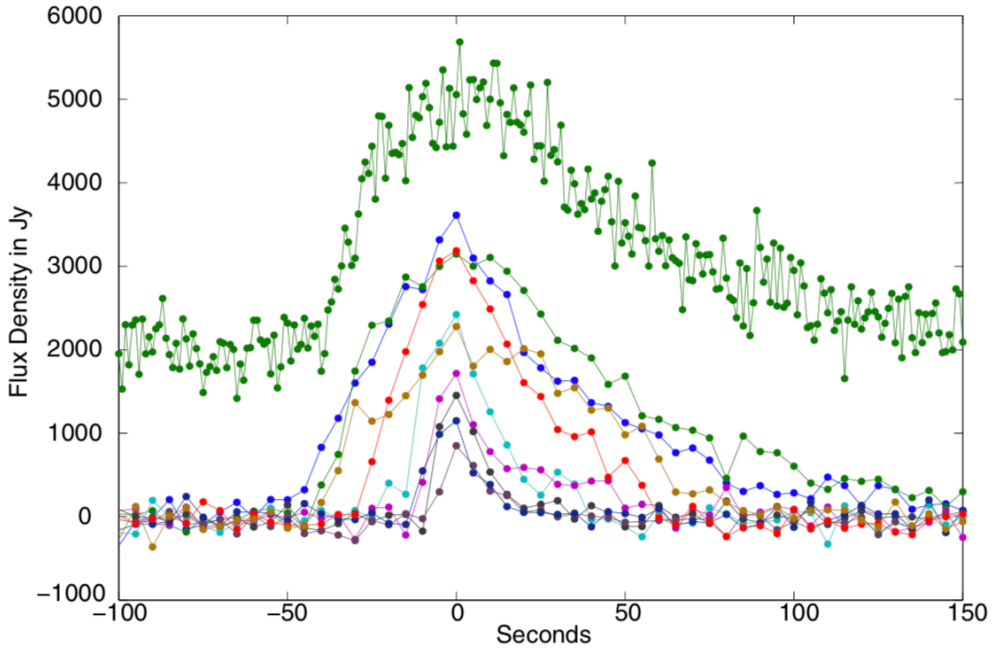
Transient Buffer Narrowband (TBN) & LWA TV

- (TBN)- continuous collection of voltage time series data at 100 kHz.
- LASI (LWA all-sky imager/correlator) produces all-sky images every 5 s.
- Study transient sources.



First Detection of Meteor Radio Afterglow (MRA)





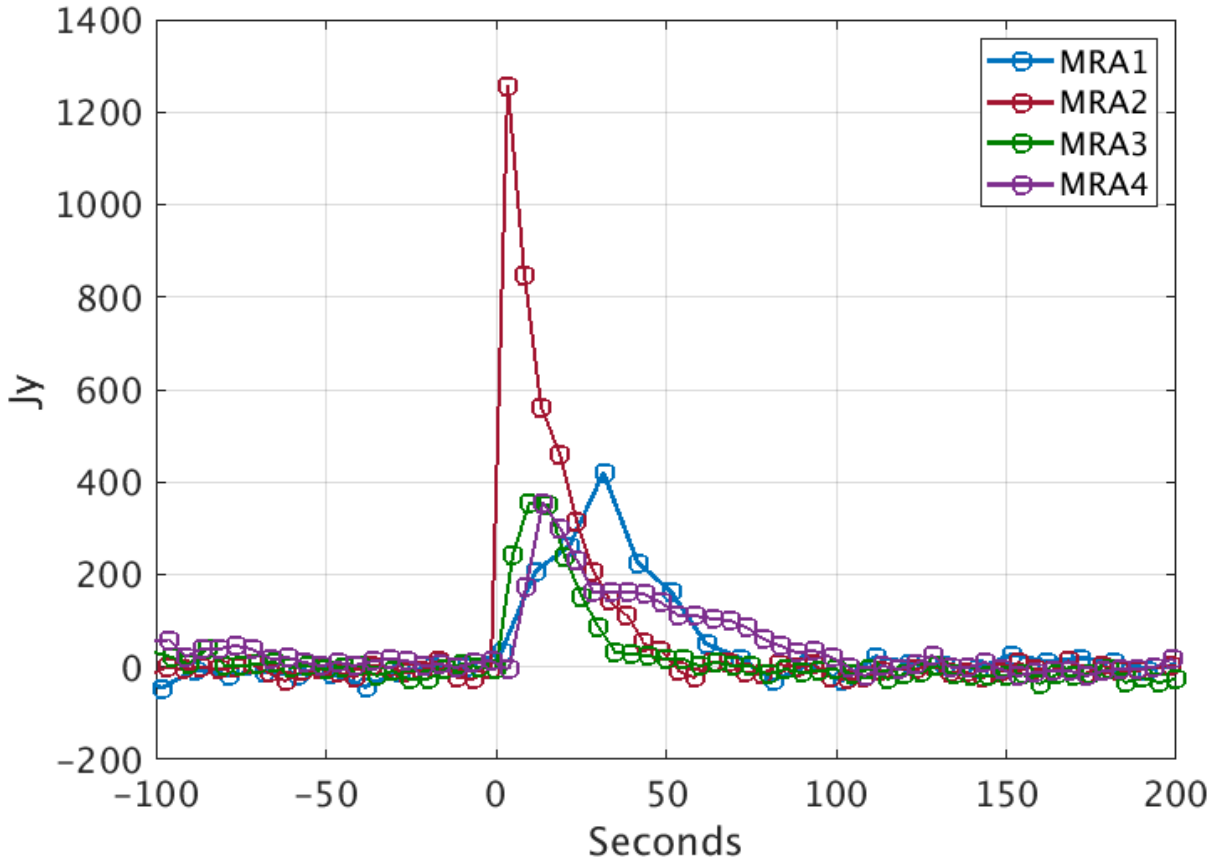
- **Smooth and broadband 20-60 MHz**
- **Isotropic emission**
- **Altitude cutoff ~ 90 km**
- **Radiation mechanism ??**
- **Plasma wave hypothesis: electron plasma waves emitting from turbulent ionized trail at plasma frequencies.**
- **Transition radiation from hot electrons**

Requires energy source of suprathermal electrons

Obenberger et al. 2014, Varghese et al. 2020

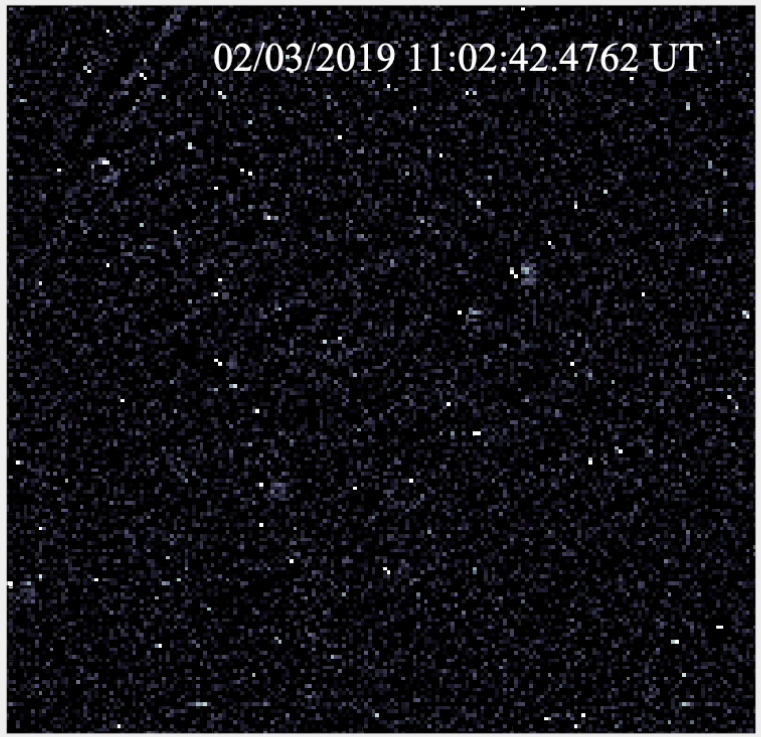
Association between MRAs and Persistent Trains(PT)

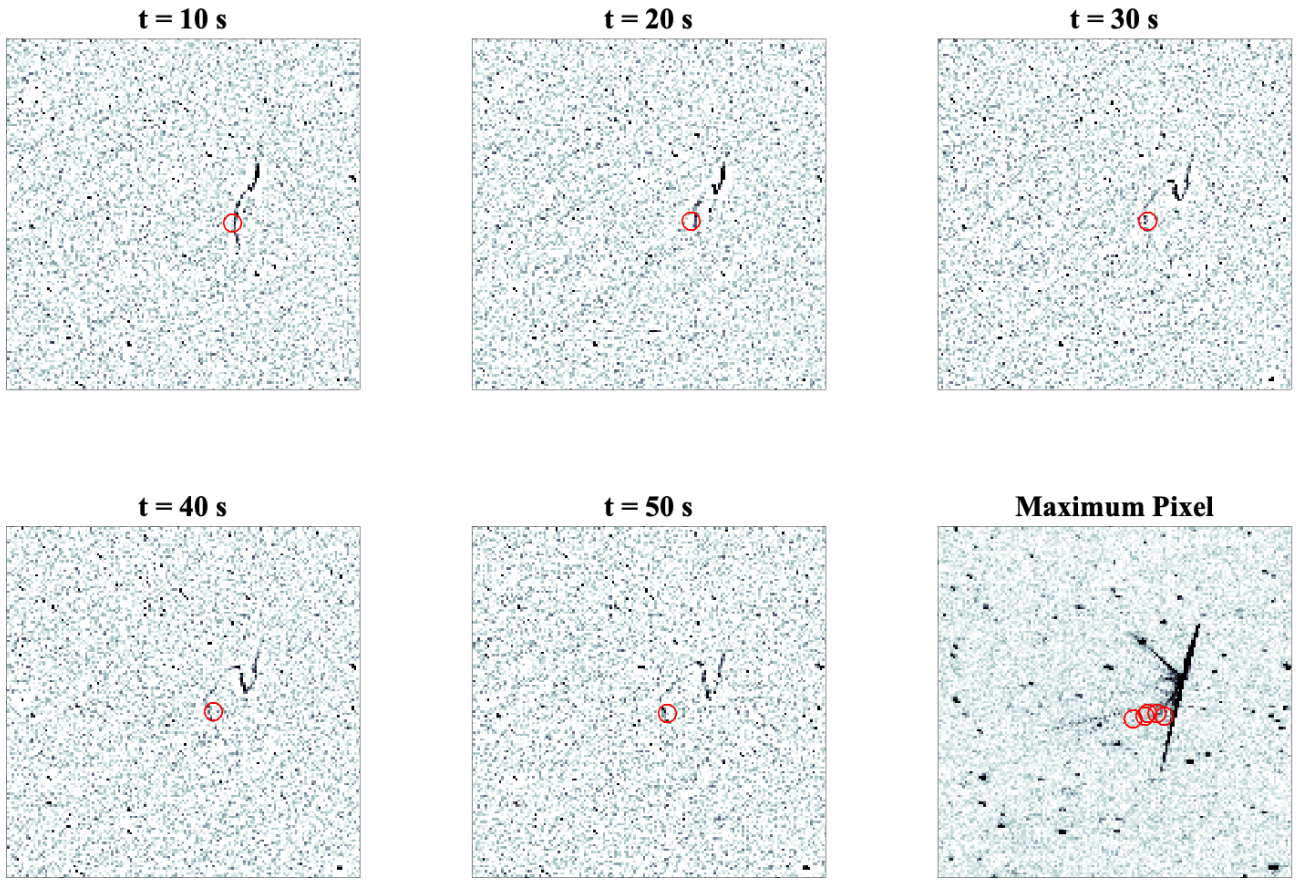
- Long lasting emission in optical and NIR
- Exothermic reactions between ablated meteoric particles and atmospheric oxygen
- Suprathermal electrons to drive MRA emission
- Widefield Persistent Train Camera (WiPT) in LWA-SV
- Snapshots of the all-sky every 6.3 sec between 7 pm- 5 am local time when sun and moon below horizon
- 4 MRAs and associated PTs on clear moonless night



Obenberger et al. 2020, JGR Space Physics accepted

MRA1 & PT1





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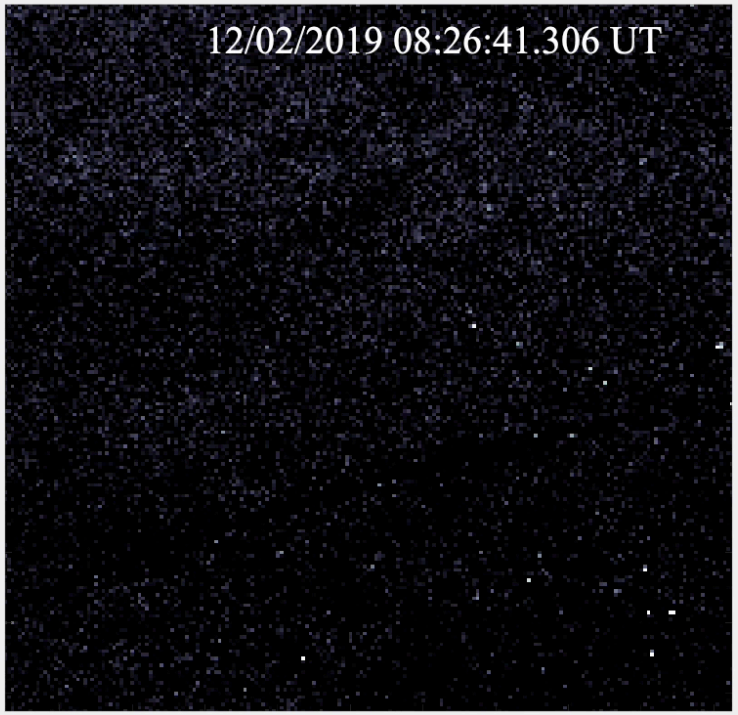
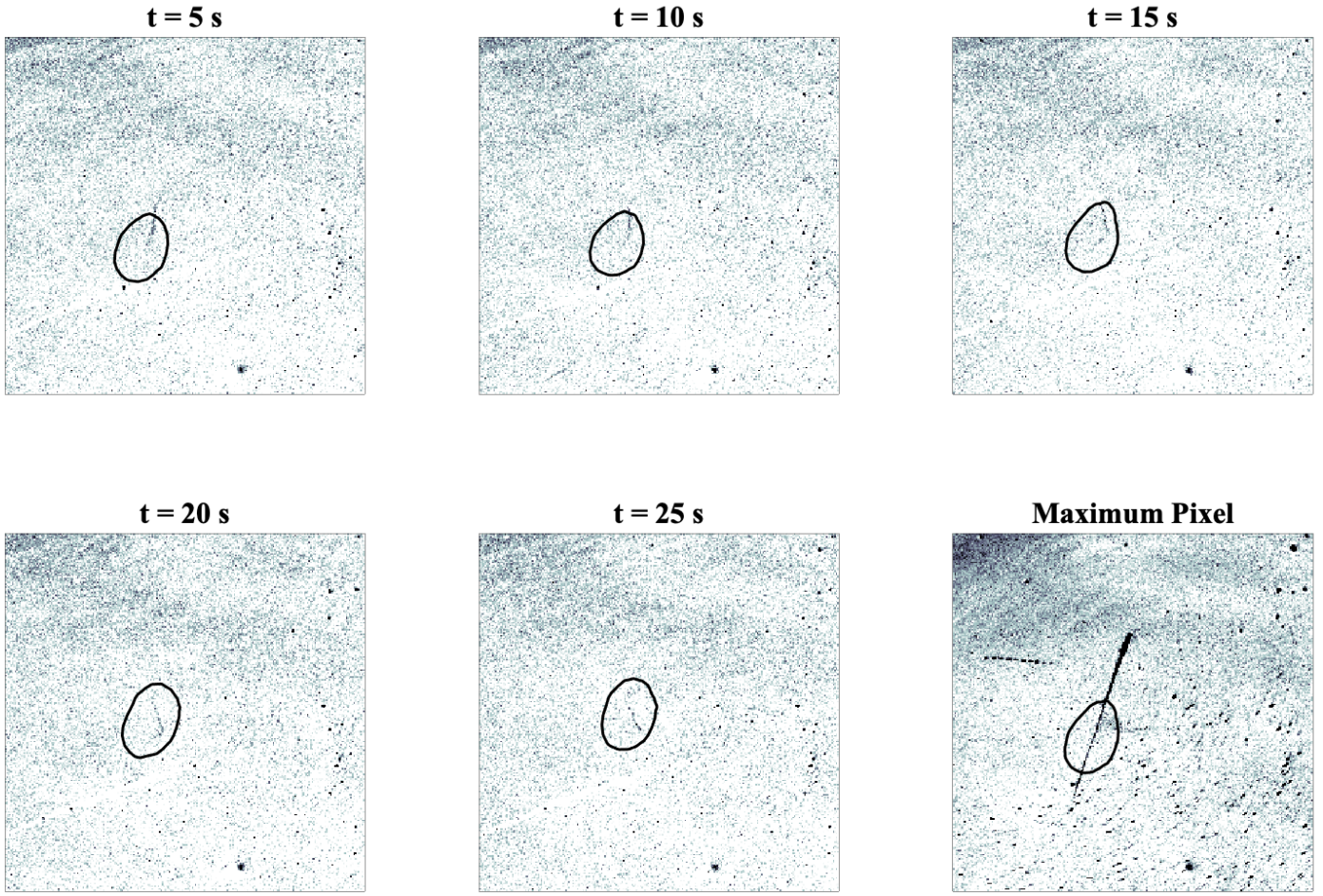
MRA2 & PT2





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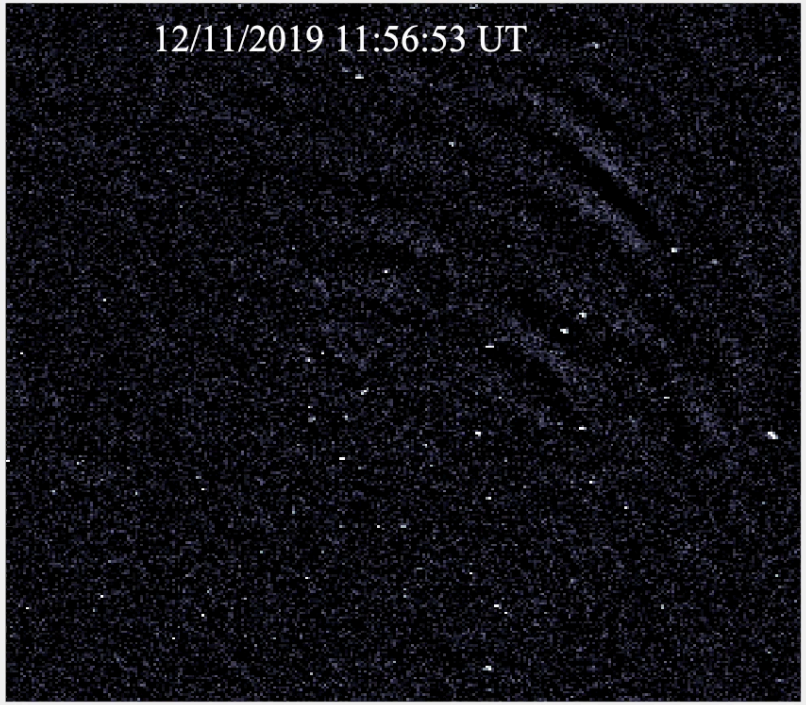
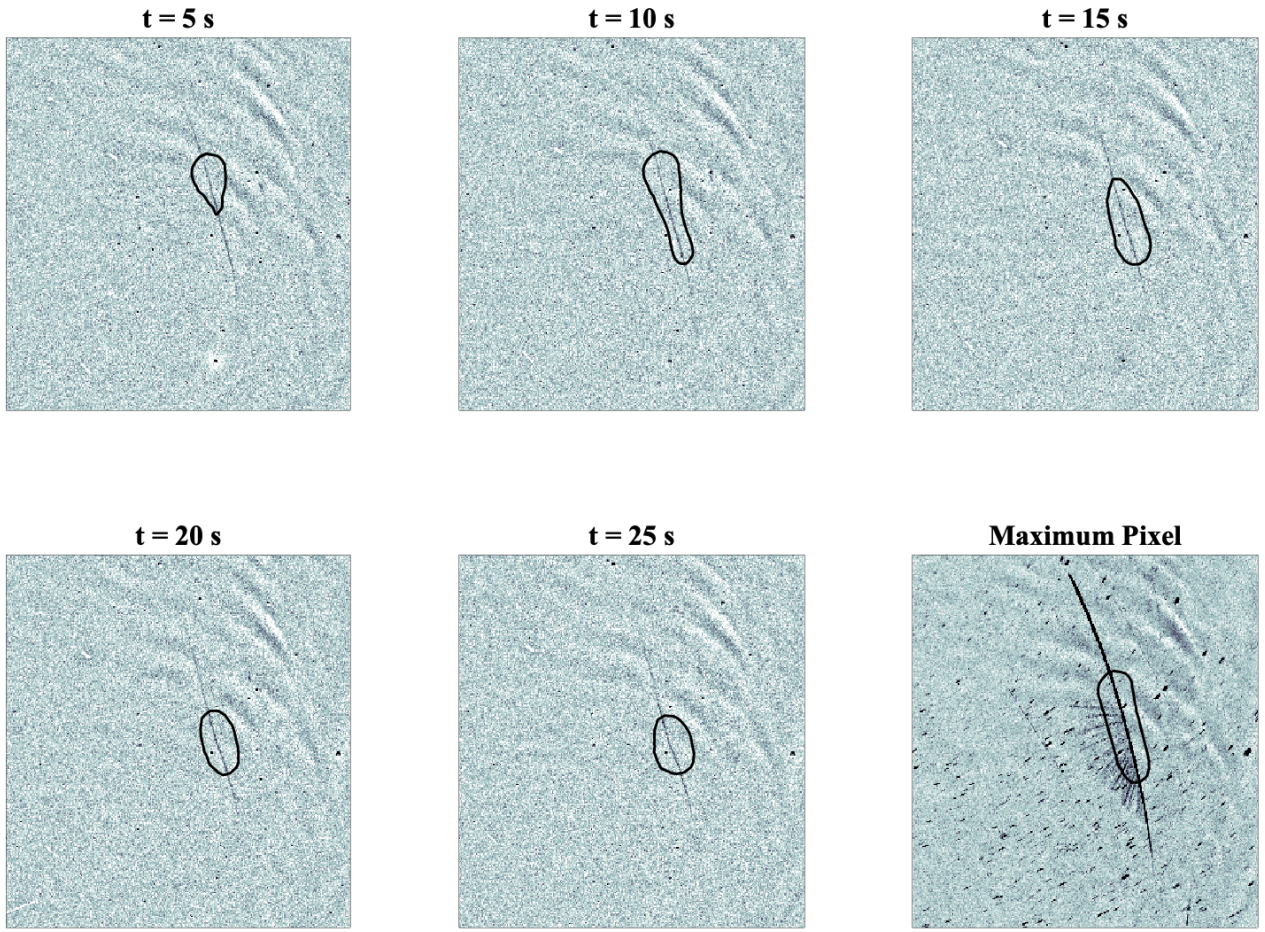
MRA3 & PT3

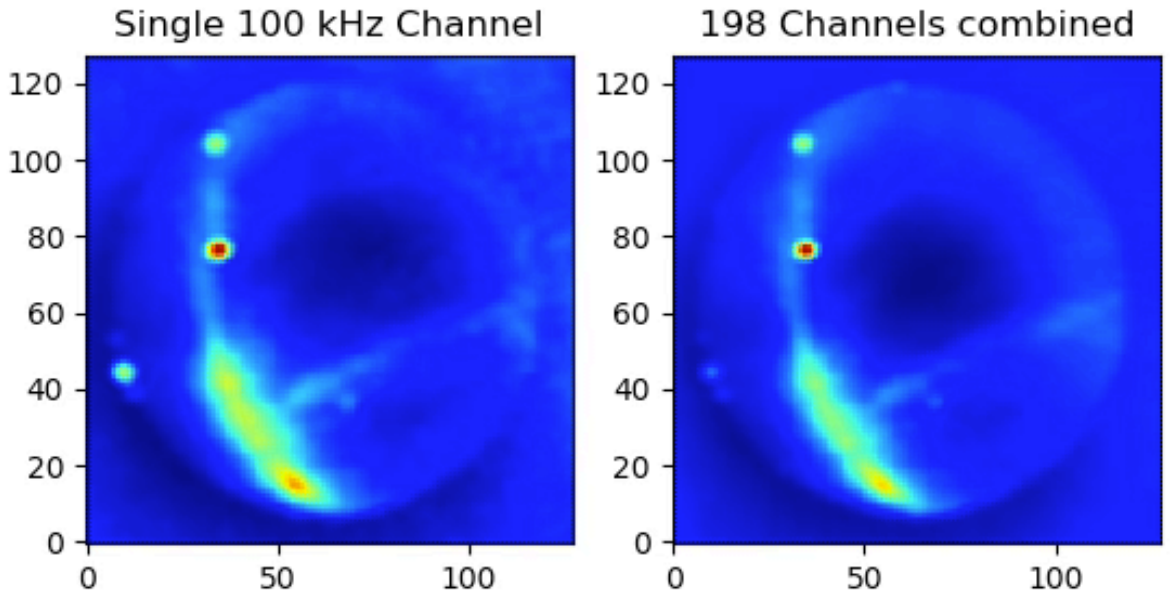




Obenberger et al. 2020, JGR Space Physics accepted

Broadband Imager at LWA-SV

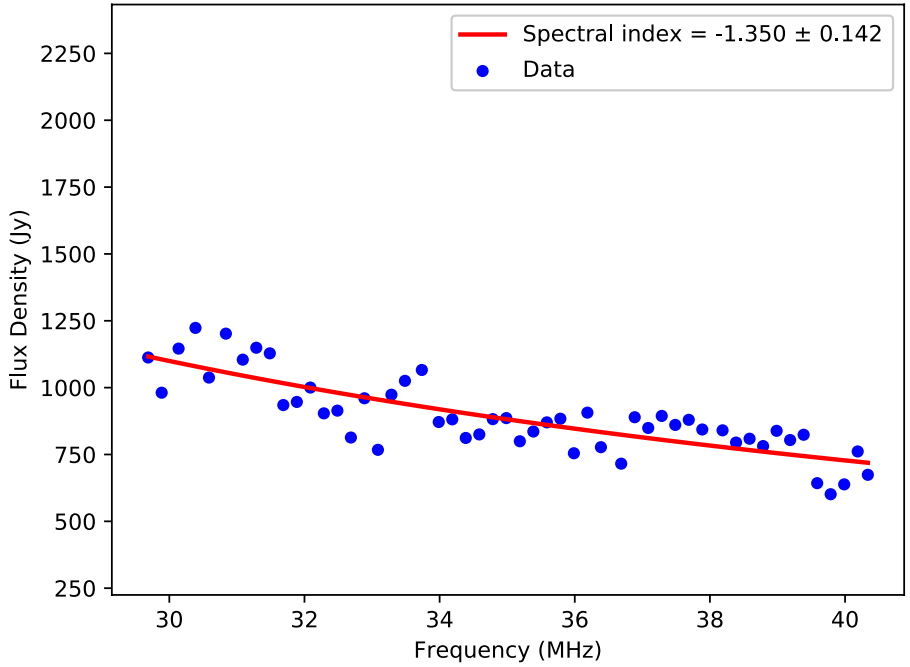
- 20 MHz bandwidth and 5 sec integrations.
- 100 kHz to 20 MHz
- GPU based Bifrost pipeline
- Collected data at 10 MHz and 10 s cadence in first 4 months
- **Goals:**
  - **Transient search using broadband data**
  - **Collect the broadband spectrum of MRAs**

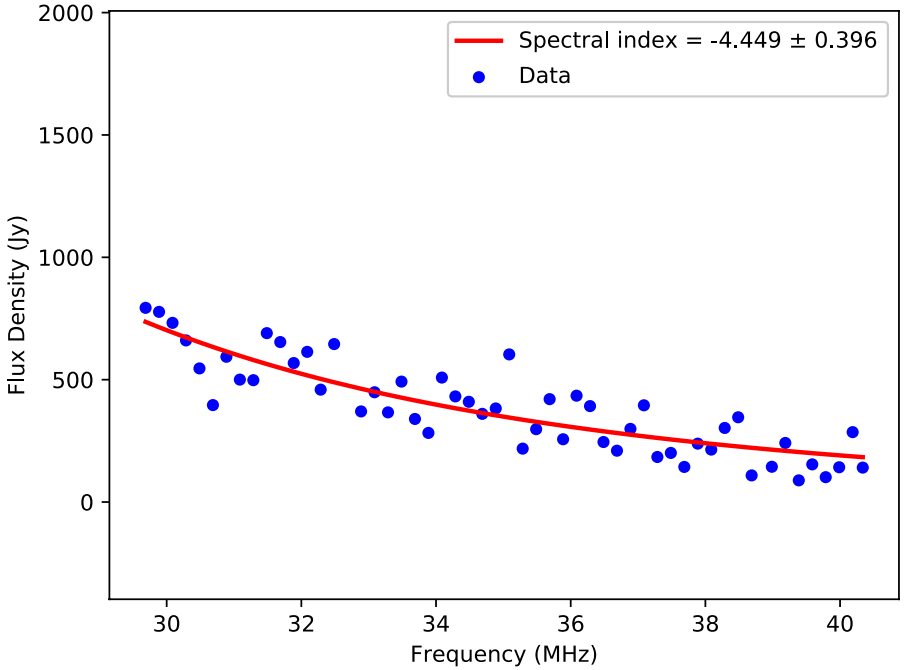


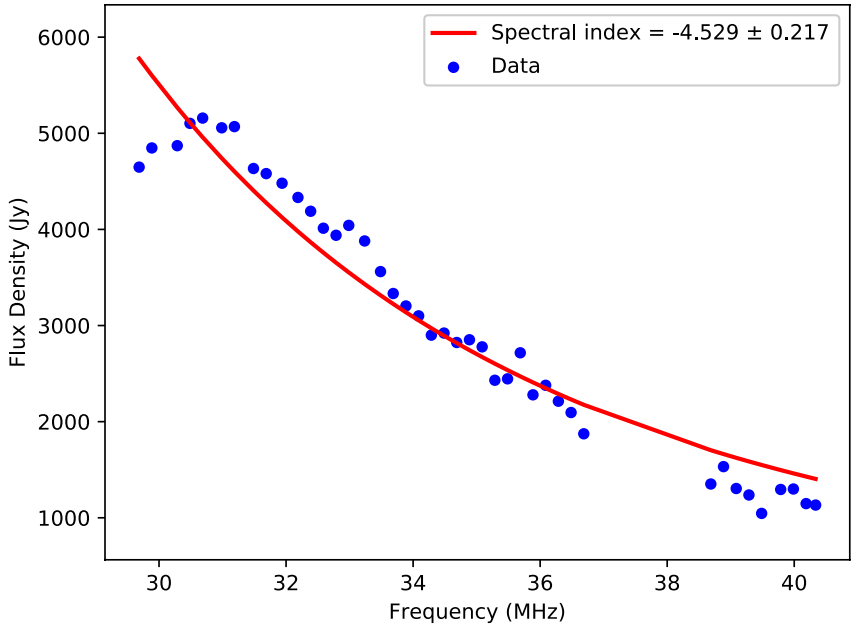
Broadband spectrum of MRAs

- 1 TB of images and 2000 transients in Stokes I
- Spectrum of 49 MRA events (10 MHz) greater than 10 sigma.
- Fitted with power law as

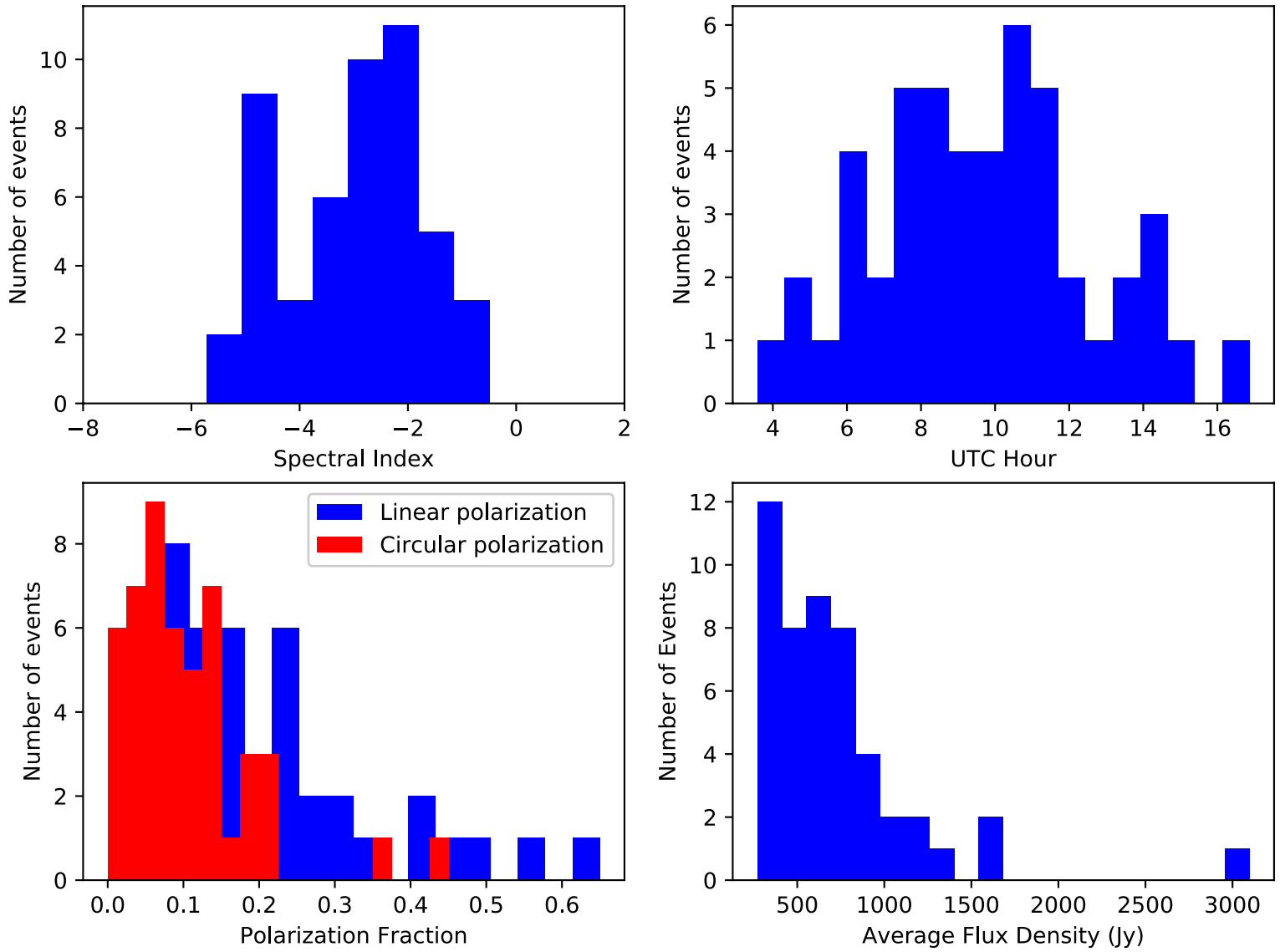
  $F \propto \nu^{\alpha}$
- Spectral index varies from -**0.495** to **-5.714**







Varghese et al. in prep



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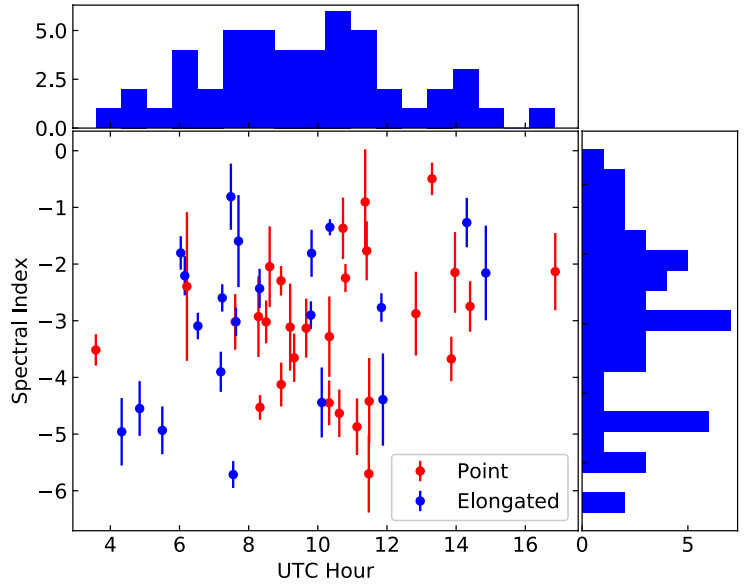

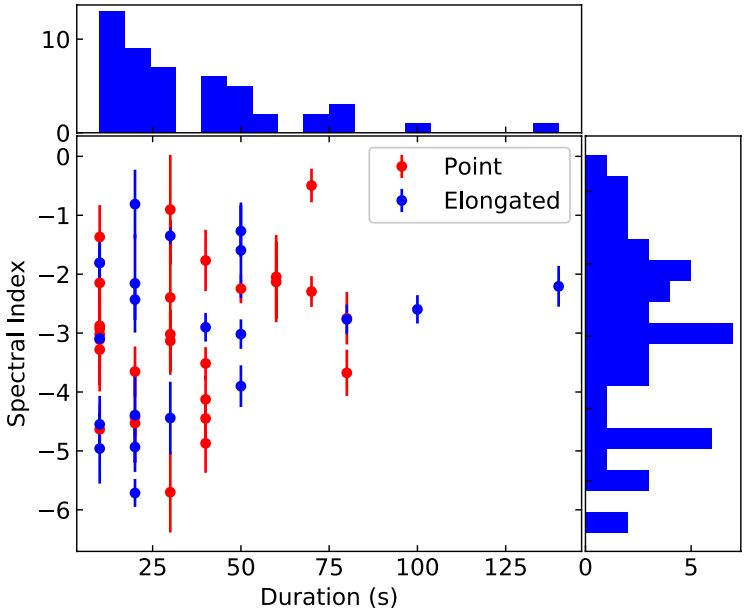

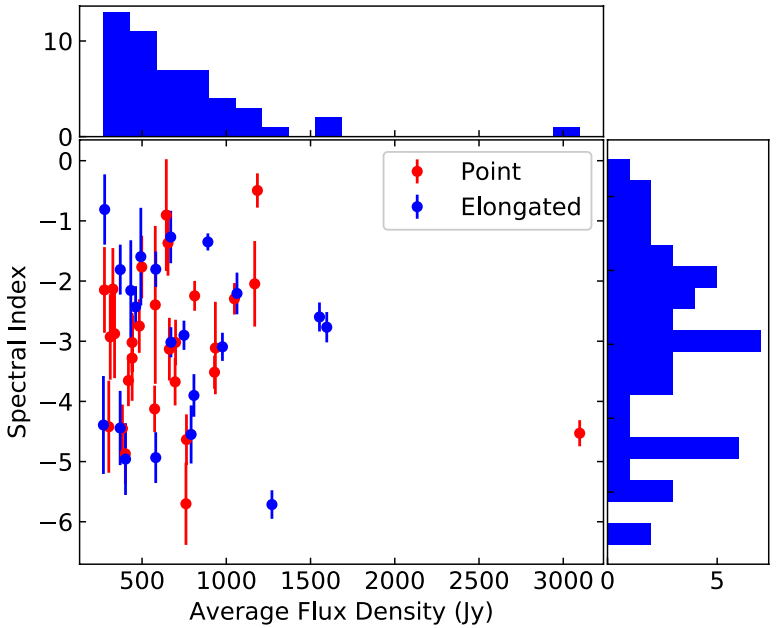

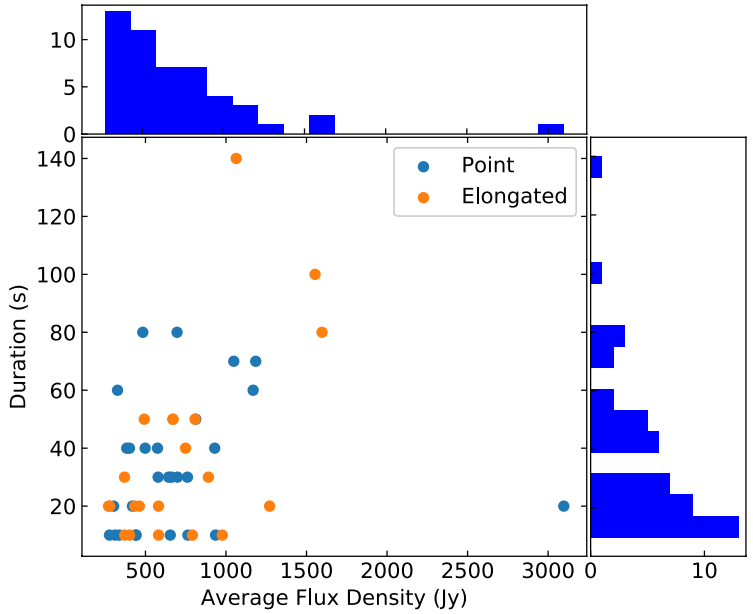

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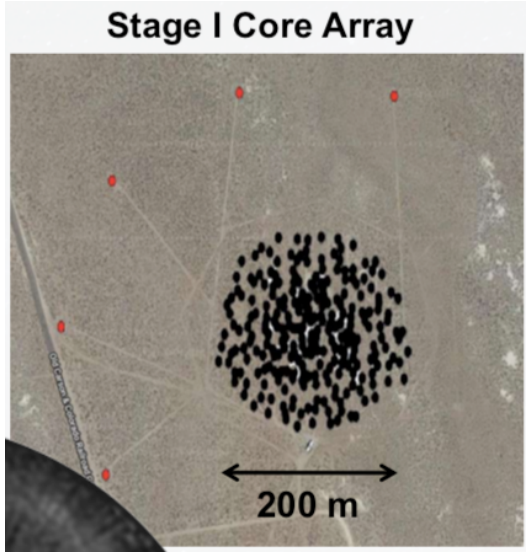
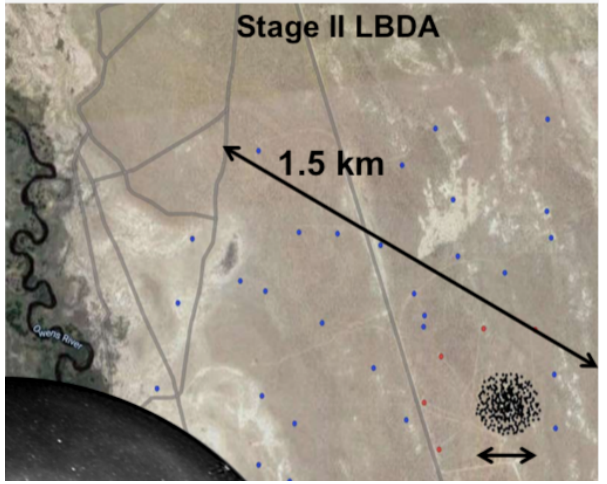
High resolution observation of MRAs with Owens Valley LWA

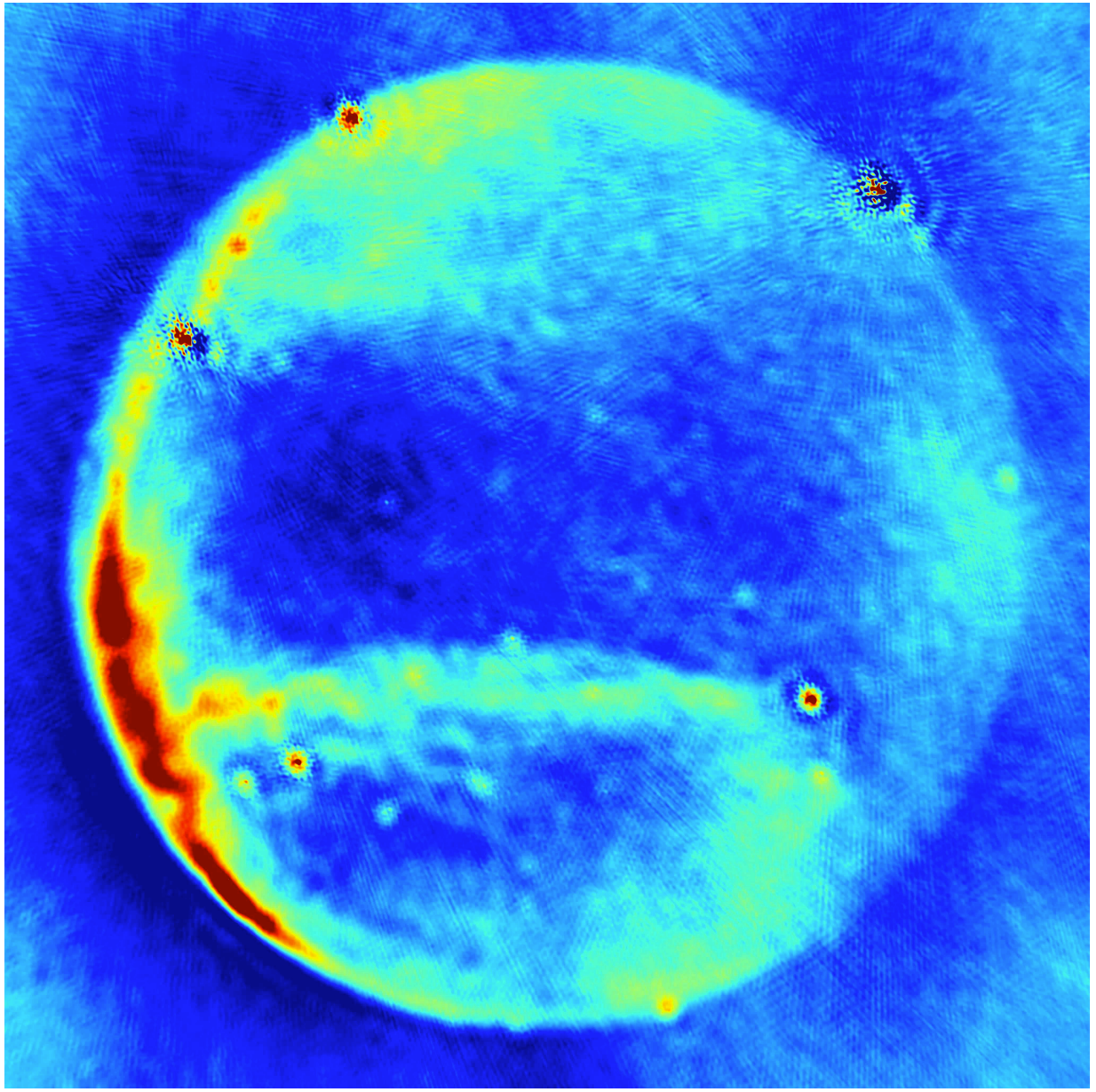
- Isotropic radiation pattern: Incoherent emission or incoherent addition of small coherent regions
- Operates between 27-84 MHz
- 251 element inner core and 32 element extending to 1.5 km
- Angular resolution - 7 arcmin at top of the band
- 4 days of data during Perseids meteor shower 2018 -> 9 TB of data
- Four sub bands of data between 30 -50 MHz separated by 2.6 MHz





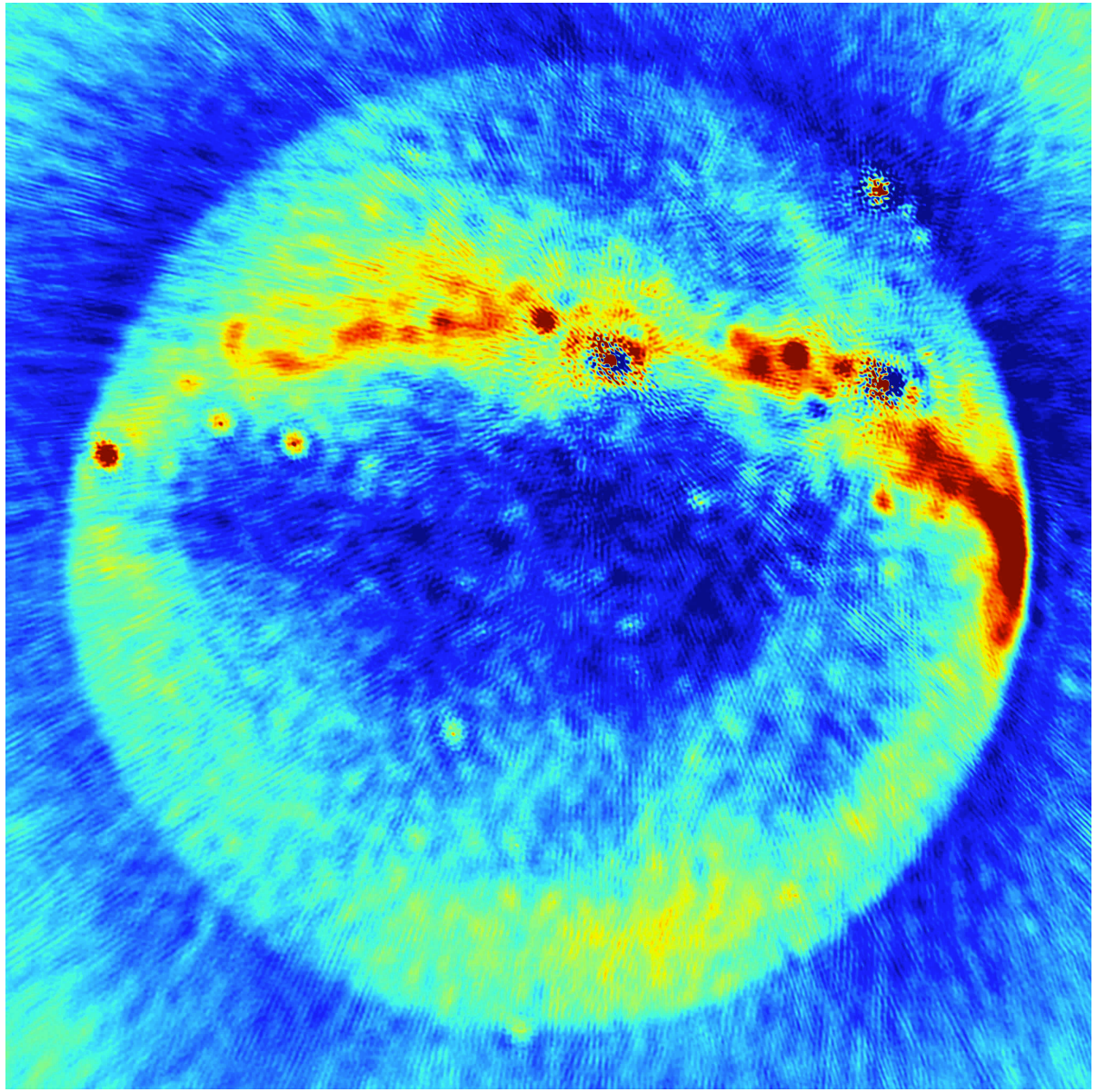
Calibration and Imaging

- Flagged bad antennas, baselines and channels.
- A simplified two source sky model with Cygnus A and Cassiopeia A
- CASA bandpass task using this model to derive antenna gains per channel
- Solutions derived per integration basis when Cyg A at higher elevations.
- MS imaging and deconvolution using CASA Clean task
- Deconvolution- time expensive
- UNM HPC for parallelizing the imaging and deconvolution.



Transient Search

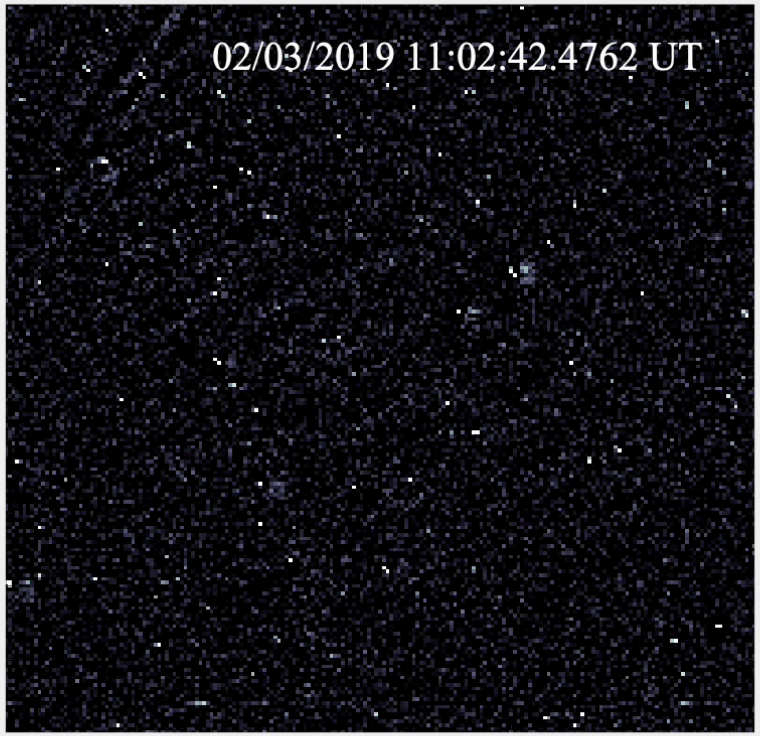
- Modified the existing pipeline for continuous image subtraction
- Meteor reflection events and airplanes detected through manual inspection
- Transient search still in progress
- Peeling of bright sources

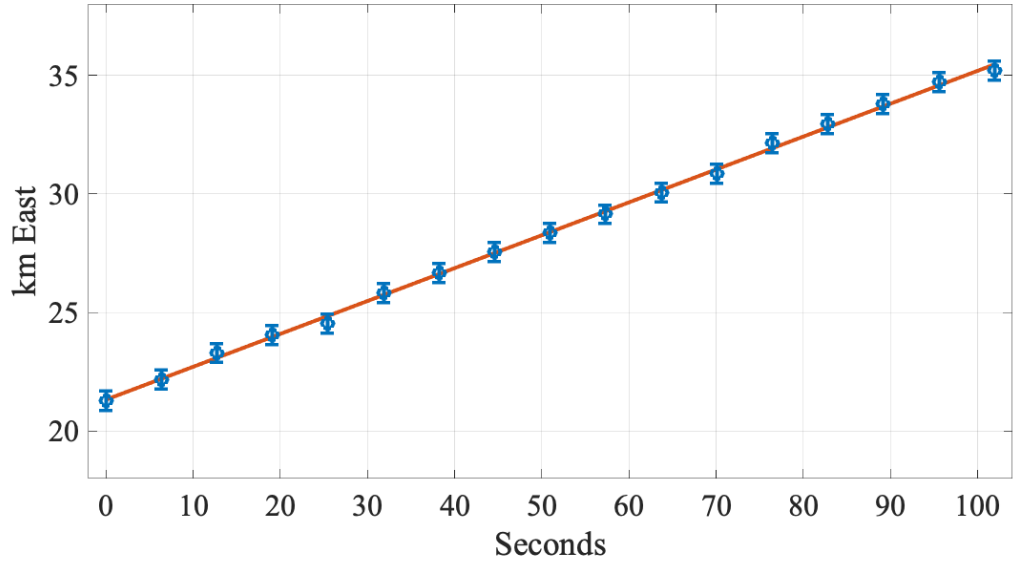


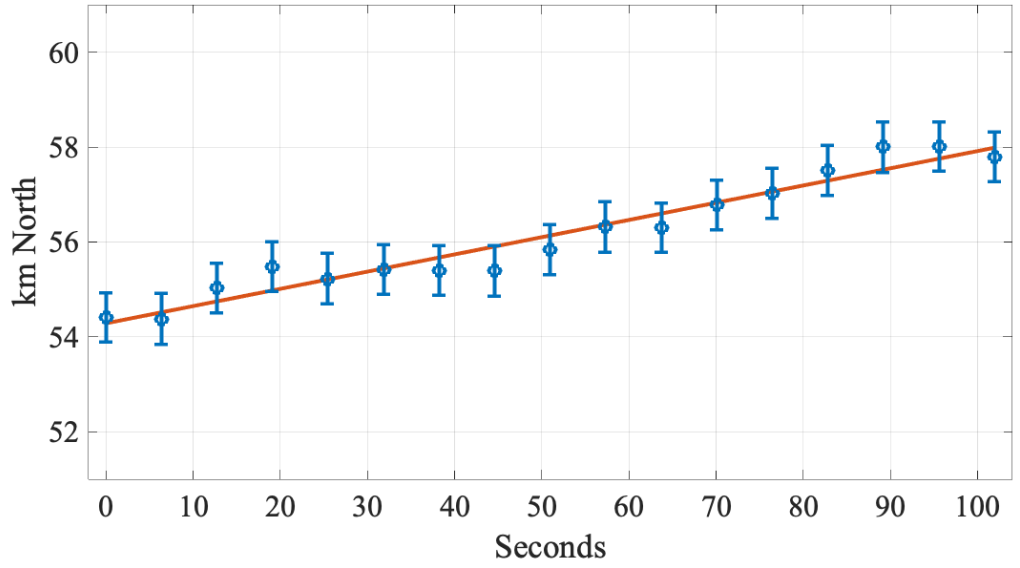
Summary

- 4 MRAs on clear moonless nights correlate spatially and temporally with PT regions.
- Origin of MRAs associated with the region of PT activity.
- Exothermic reactions powering PTs could be the source of suprathermal electrons which drives MRAs
- Measured spectral index of MRAs peaks near **-3.0 and -4.5.**
- Long duration events tends to be flatter and weak correlation between spectral index and hour of occurrence.
- LWA-OVRO data: Peeling of bright sources and search for MRAs in progress.


QUESTIONS?

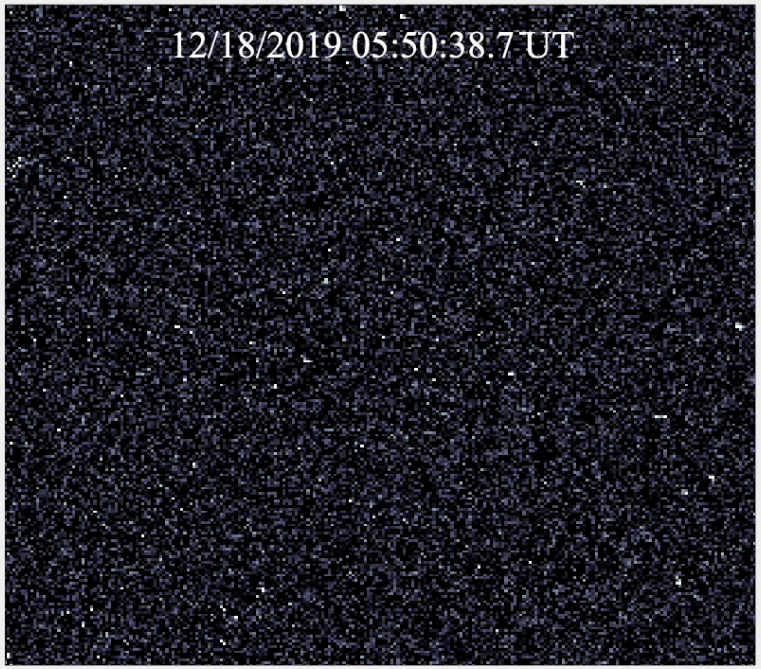


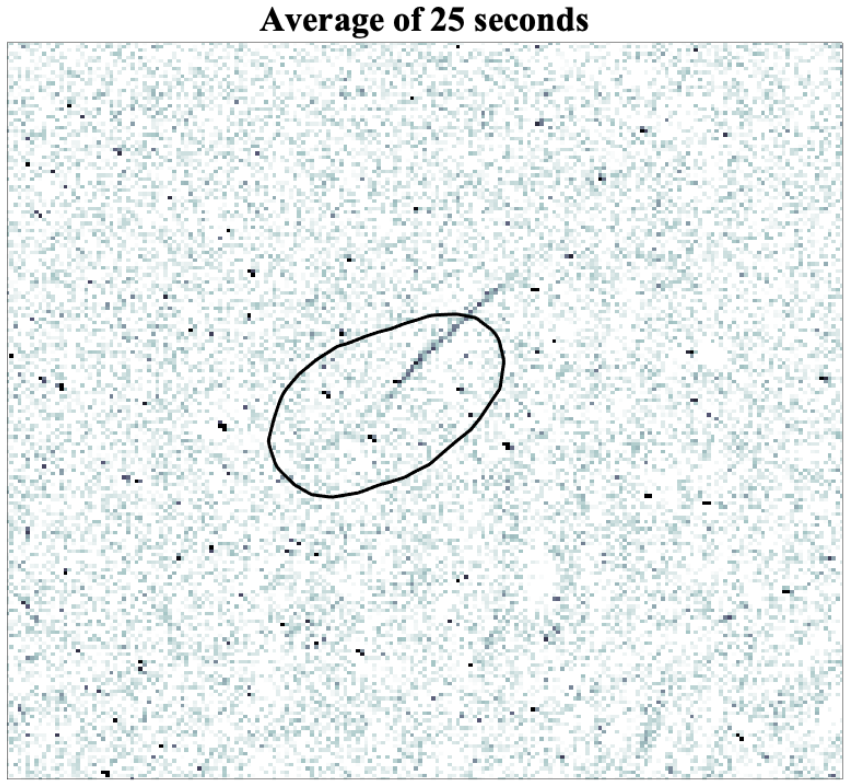




Measured wind Speed of 143 m/s
Horizontal wind model predicts ~
58 m/s between 90-110 km

MRA4 & PT4

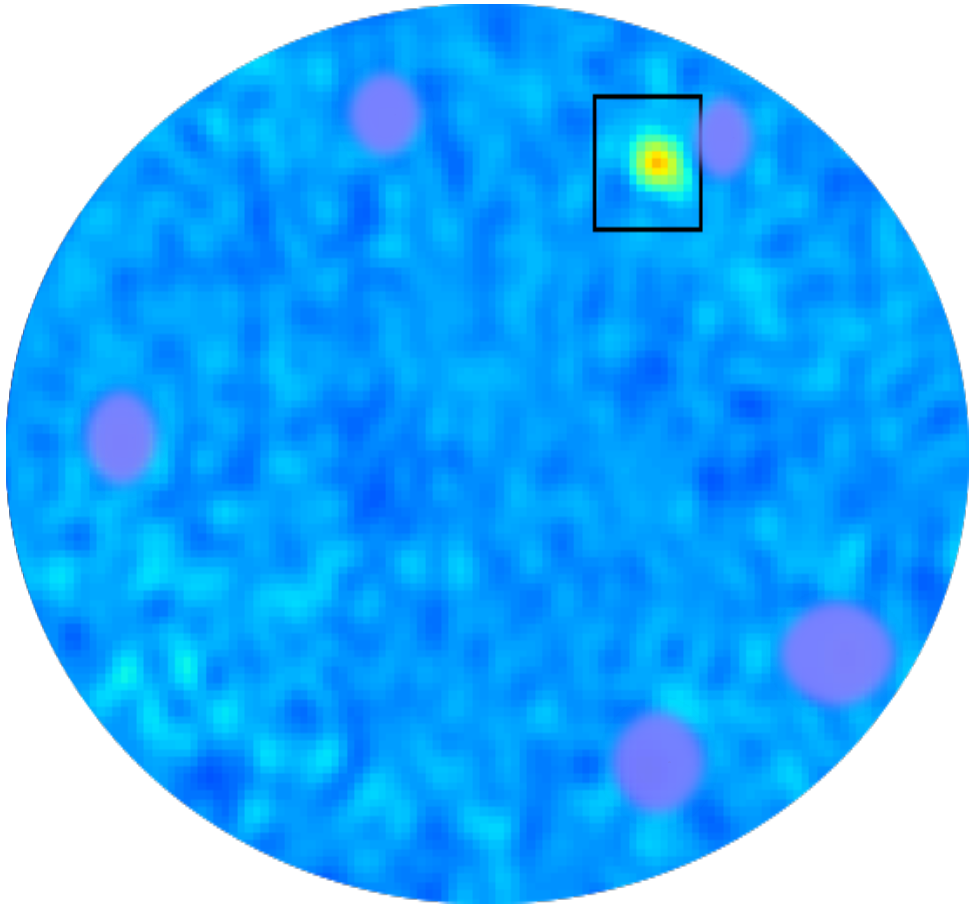




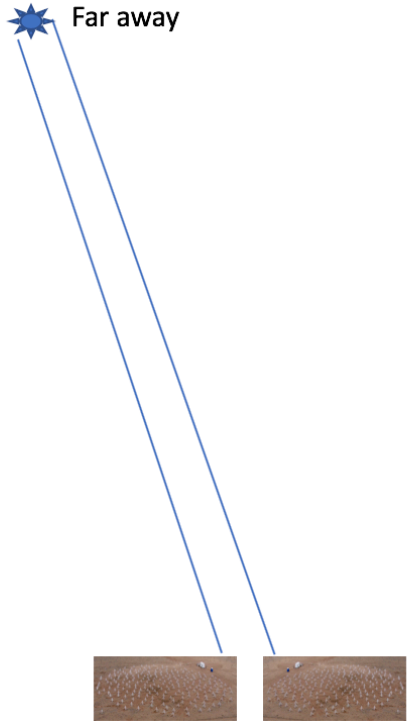
Obenberger et al.in prep

Transient Search Pipeline

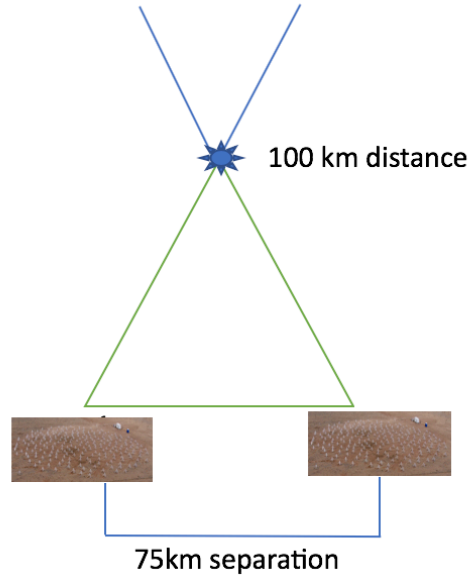
- Image subtraction algorithm
- Average of previous 4-6 images subtracted from a running image
- Marks pixels greater than 6σ



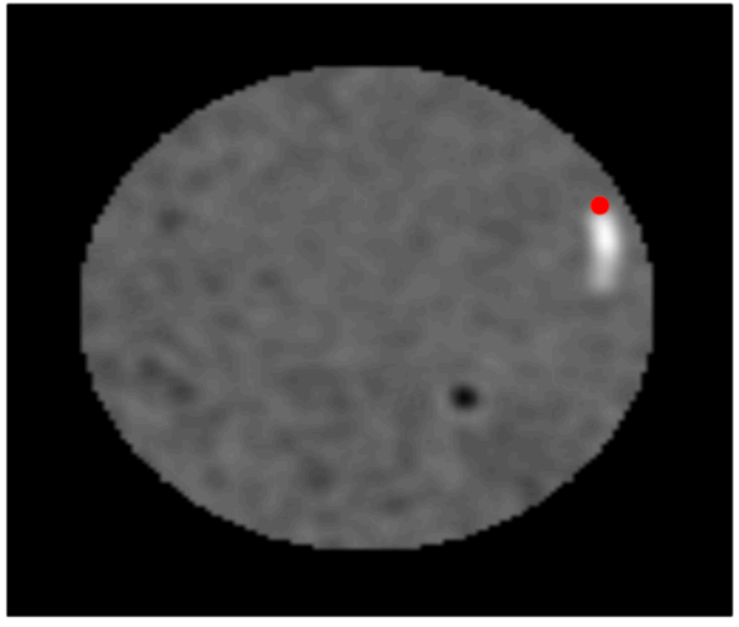
Cosmic transient candidate



MRA candidate

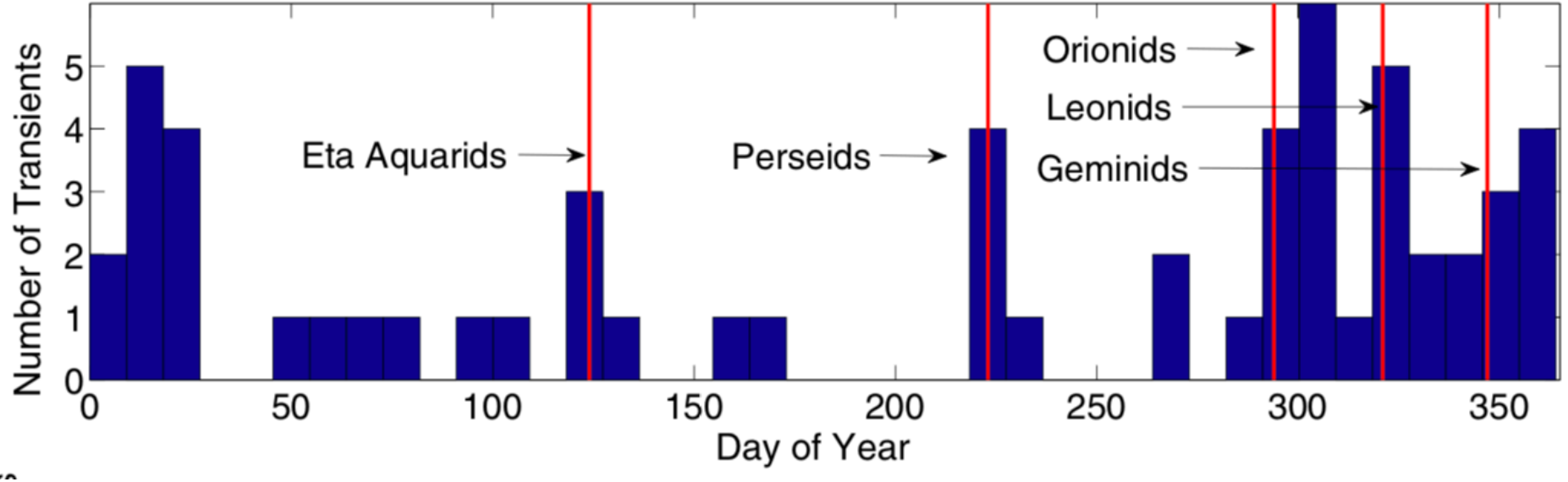


Detected transients are associated with meteor shower



NASA All-Sky Fireball Network station located in Mayhill, NM (left) and LASI (right)

Obenberger et al. 2014



Emission mechanism: Langmuir waves (Plasma oscillations)??

- Current hypothesis: electron plasma waves emitting from turbulent ionized trail at plasma frequencies

$$w_p = \sqrt{\frac{4\pi n_e e^2}{m}}$$

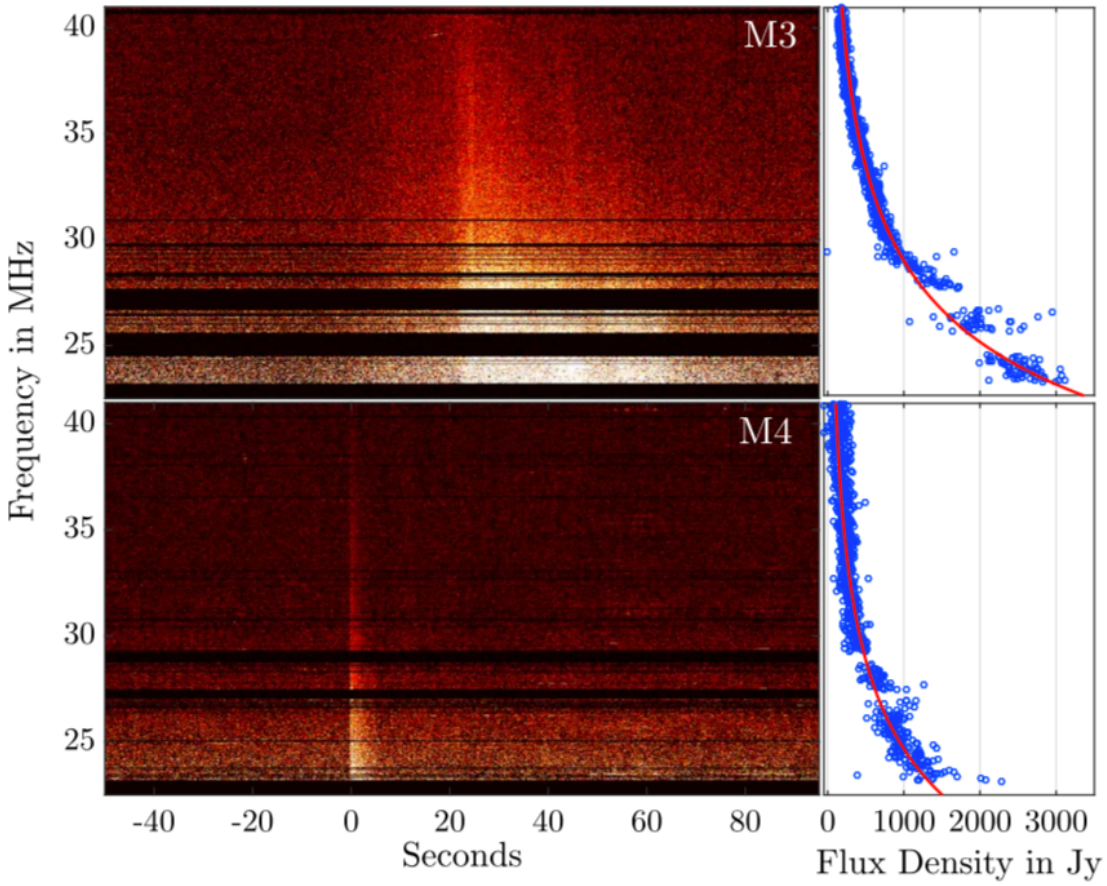
- Collision of electrons with neutral atom and ion would suppress plasma oscillations in shorter time scales
- But we observe radio afterglow for longer time scales
- Some driving mechanism is needed to inject energy into emission process

Wideband Spectrum from Beamformed Observations

- 3 beams around zenith at azimuth angle 60°, 180°, 240° at an elevation of 87°
- Emission is broad band
- Follows a power law dependence on frequency for 4 cases

$$S \propto \nu^{\alpha}$$

- Spectral index >> -4.8 for M3 and -4.4 for M4



Obenberger et al. 2016