Studying Meteor Radio Afterglows (MRAs) with the Long Wavelength Array

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LWA Users Meeting

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Motivation:

- Testing the radiation pattern of meteor radio afterglows (MRAs) and to compare it with what we expect from transmitter reflections from meteors (meteor scatters)

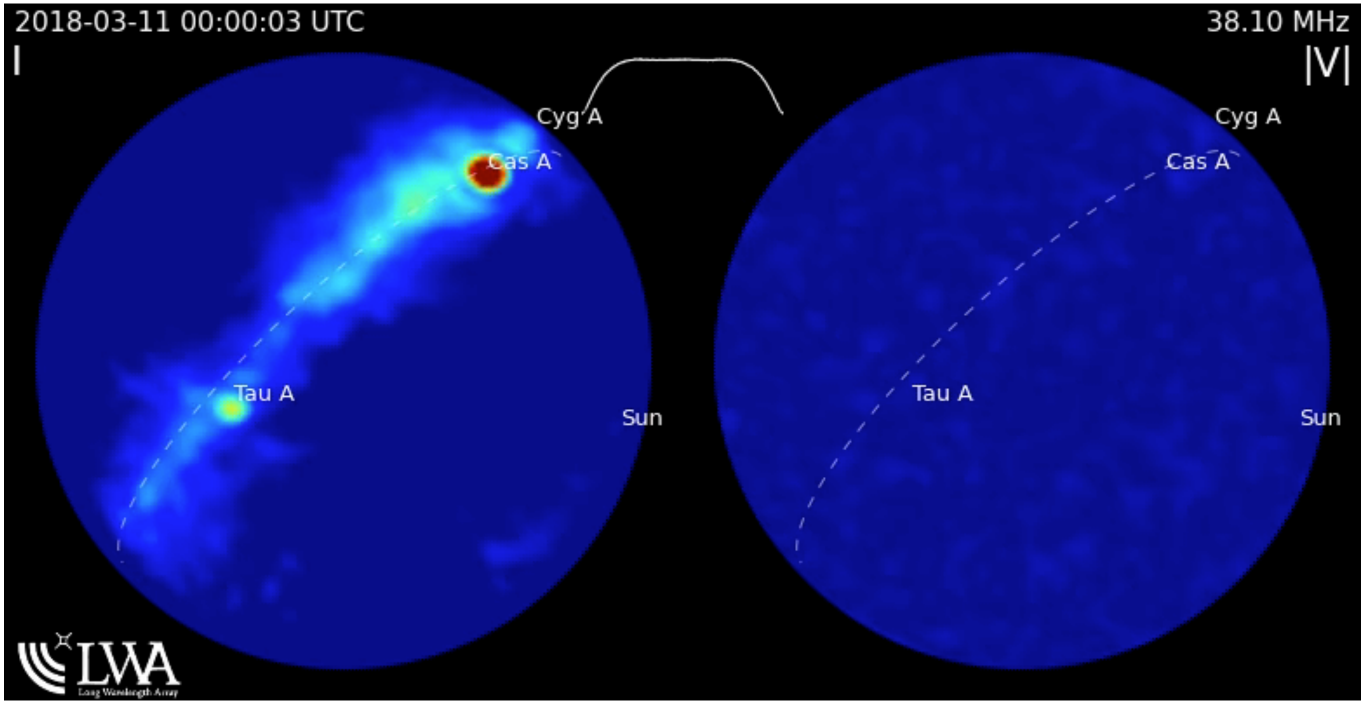
- Understand the emission mechanism of meteor radio afterglows by studying their spectral information

Long Wavelength Array (LWA 1 and LWA-SV)

- Operating frequency 10 – 88 MHz
- 256 dual- polarization dipole antennas
- Distributed within a 100 × 110 m ellipse

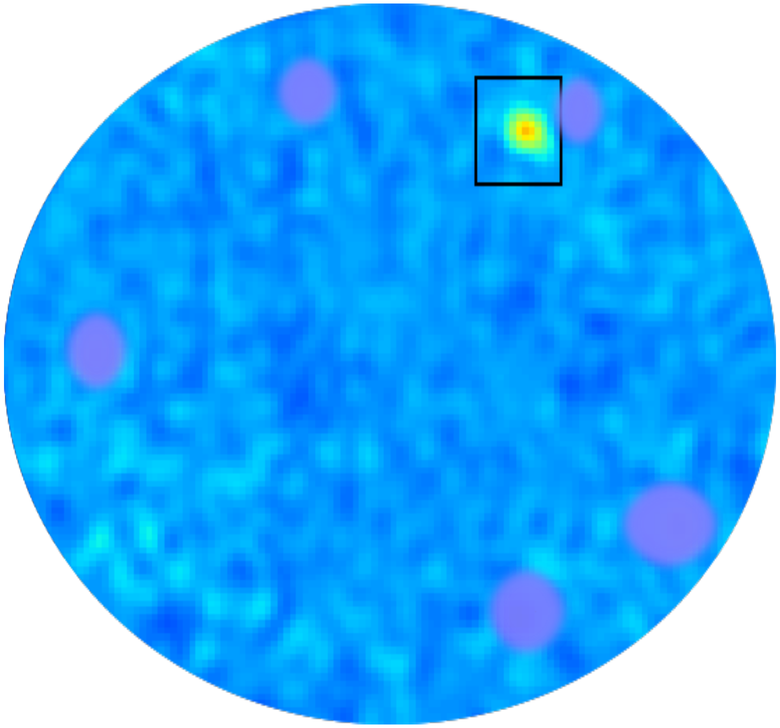
Transient Buffer Narrowband (TBN) & LWA TV

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

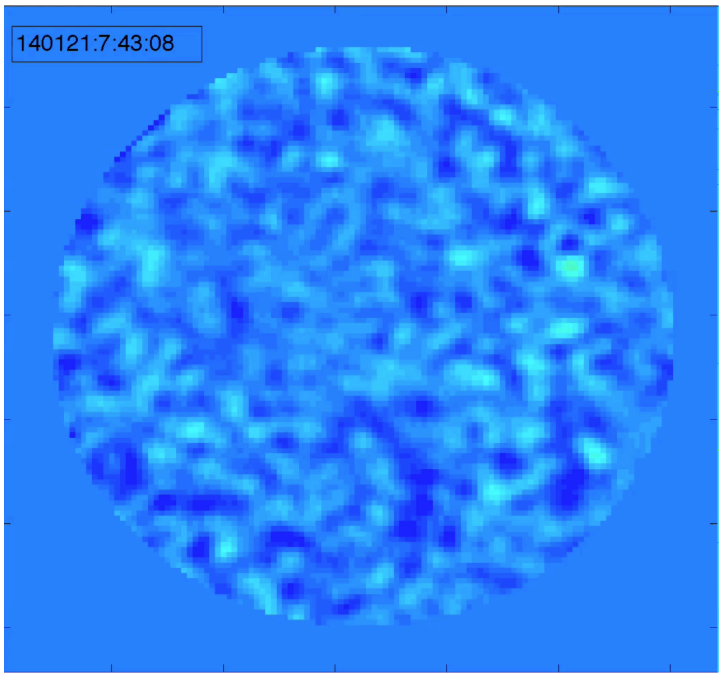


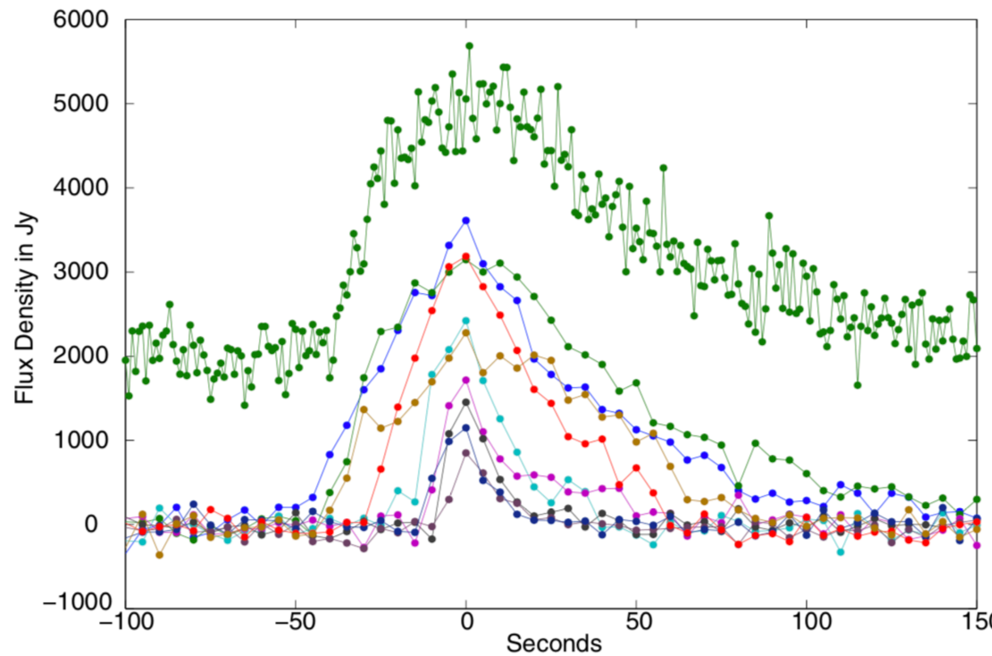
Transient Search Pipeline

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



First Detection of Meteor Radio Afterglow (MRA)

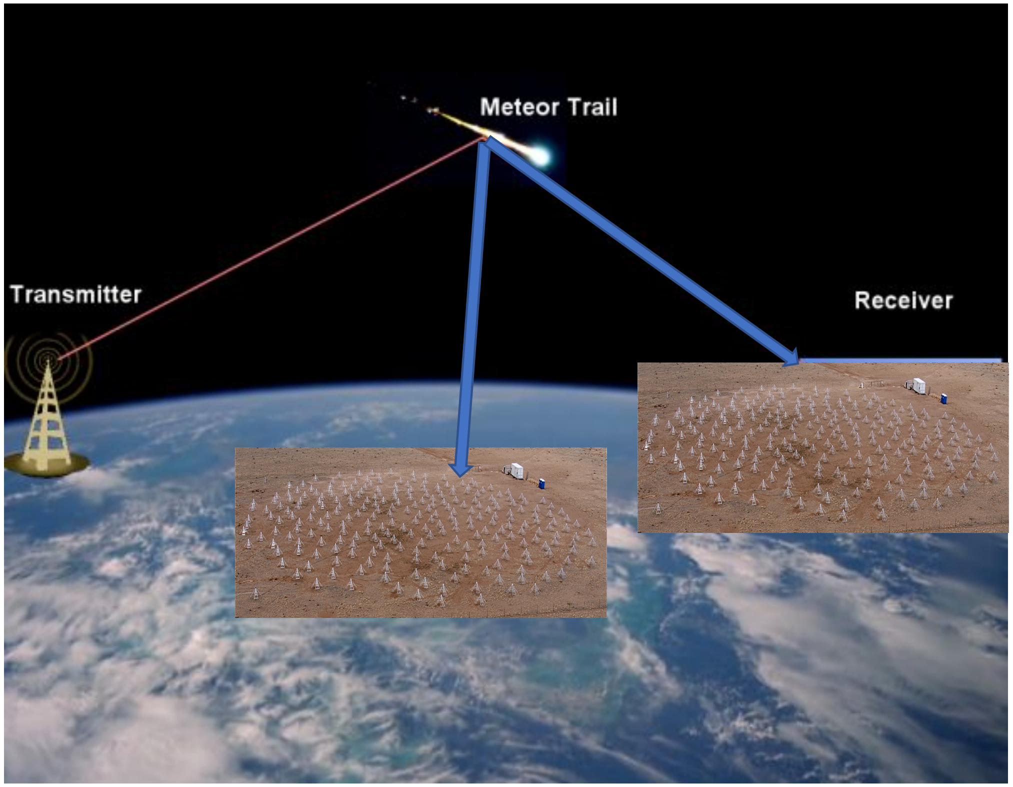




Obenberger et al. 2014

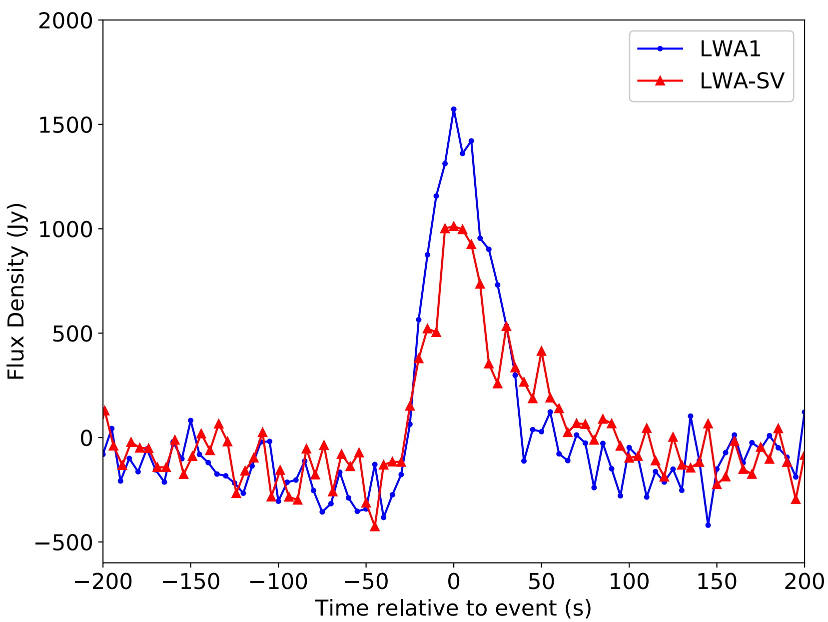
Transmitter Reflections from Meteors (Meteor scatters)

- Highly linearly/circularly polarized
- Narrow line width in time and frequency
- Specular reflection of incident waves to both stations due to warping of meteor trails



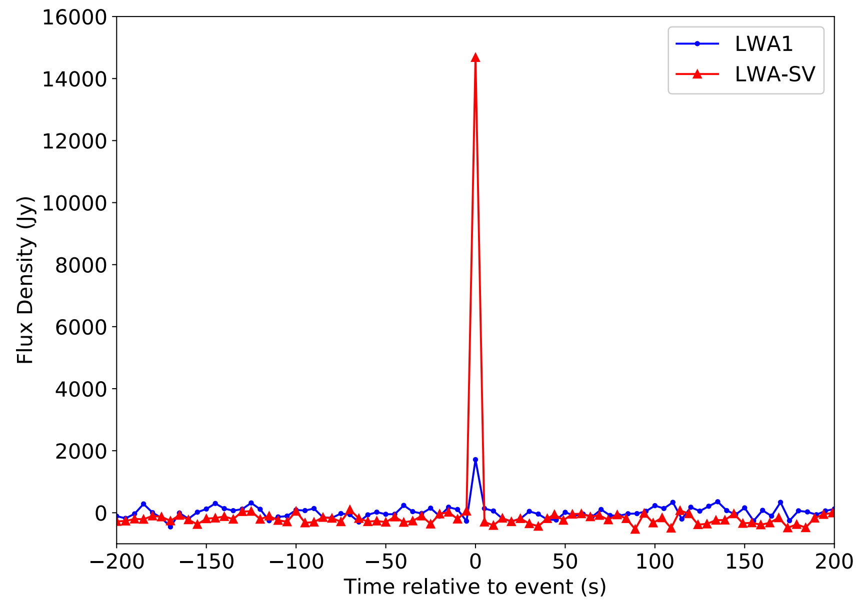
Co-observed MRA & Transmitter Reflections from Meteors

MJD 58243



MRA-Broadband and unpolarized

MJD 58172



Meteor scatter- Narrowband and polarized

Varghese et al. 2019, submitted to JGR Space Physics

Testing the Radiation Pattern

- Are meteor afterglows isotropic emitters?
- $F = \frac{L}{4\pi r^2}$

  F - flux observed, L- Luminosity,

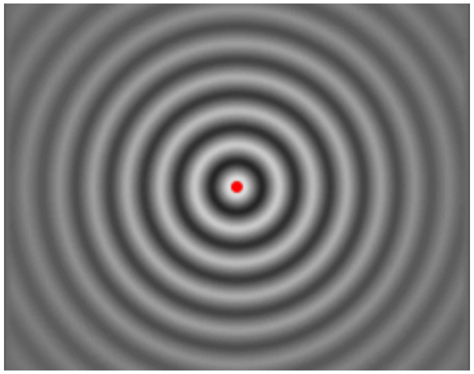
  r – distance
- Flux of the transients from each station can be measured

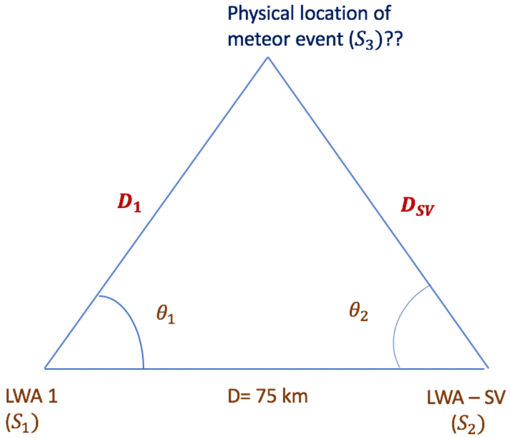
  $\boldsymbol{F_1}$ **-LWA 1 ,** $\boldsymbol{F_{sv}}$ **- LWA-SV**
- Station locations are known >> distance

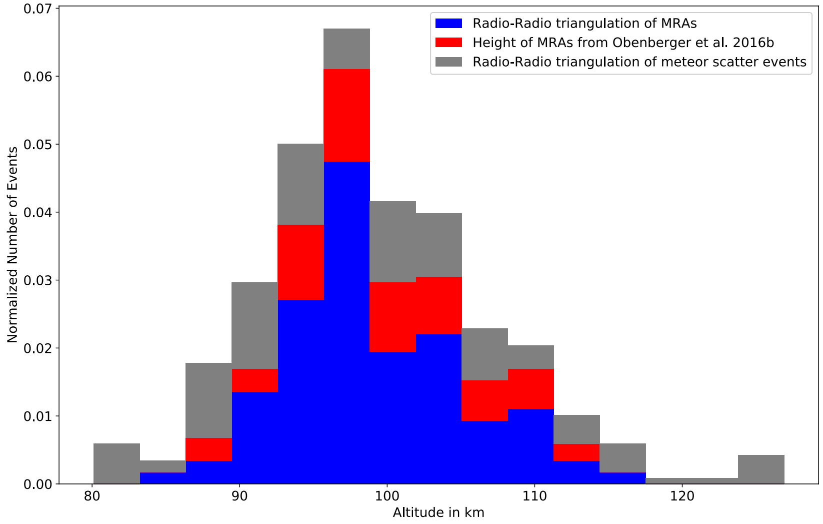
  $\boldsymbol{D_1}$ **-LWA 1 ,** $\boldsymbol{D_{sv}}$ **- LWA-SV**
- If isotropic:

$$\boldsymbol{L_1 = L_{SV}}$$

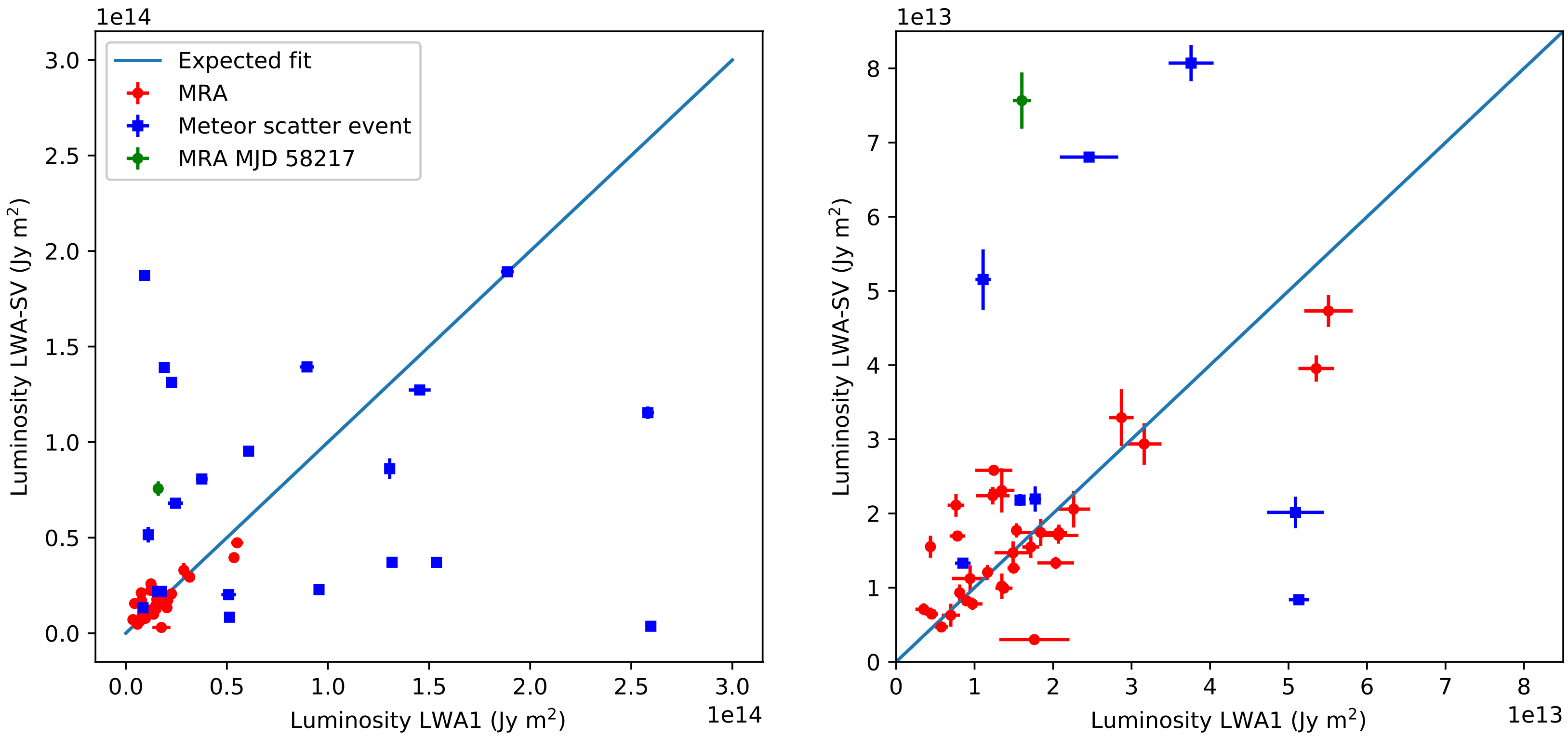
$$\boldsymbol{F_1 {D_1}^2 = F_{SV} {D_{SV}}^2}$$





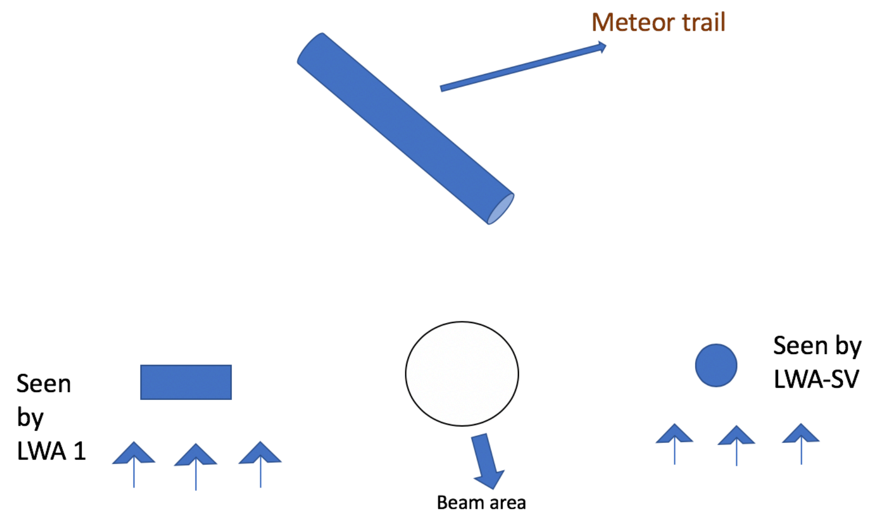


Results for 32 MRAs and 21 transmitter reflections from meteors



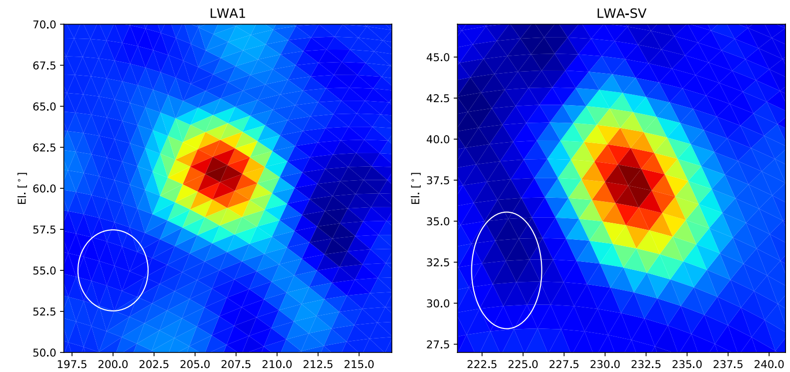
Varghese et al. 2019, submitted to JGR Space Physics

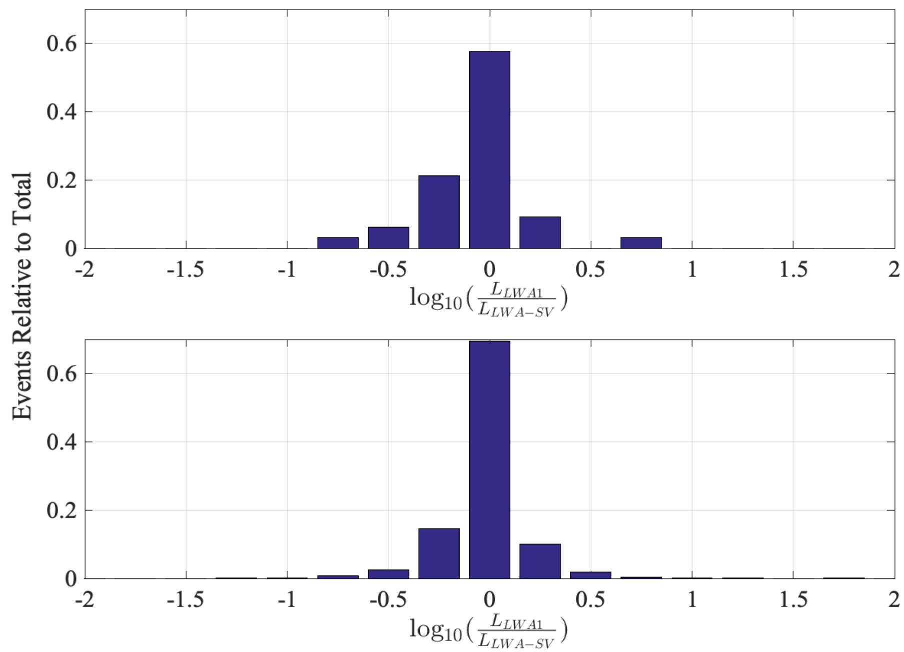
Projection effects



Varghese et al. 2019, submitted to JGR Space Physics

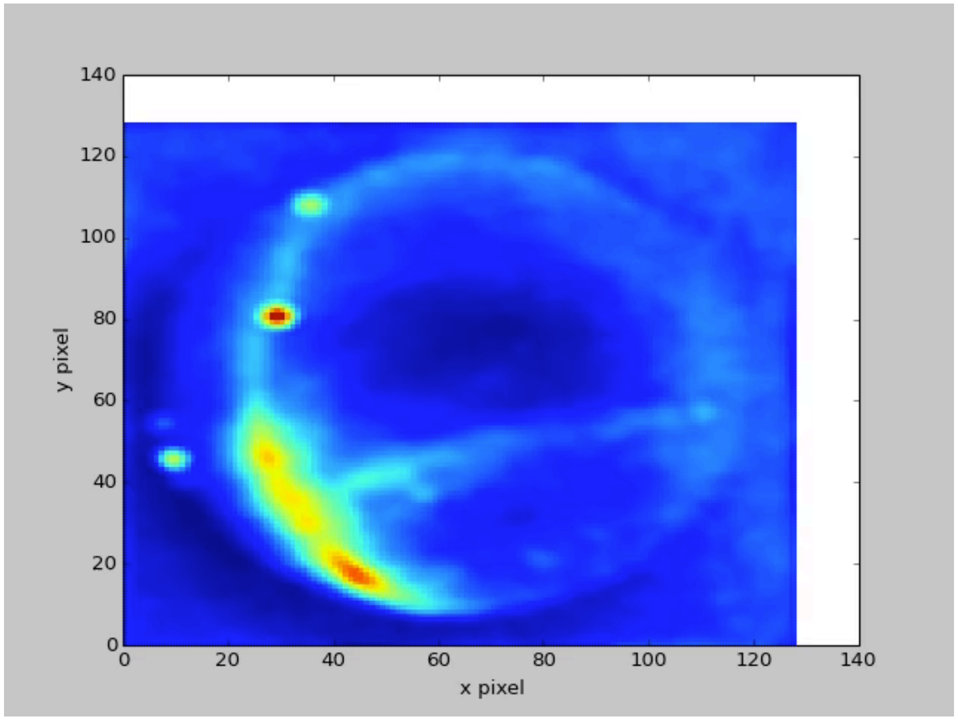
MRA MJD 58217



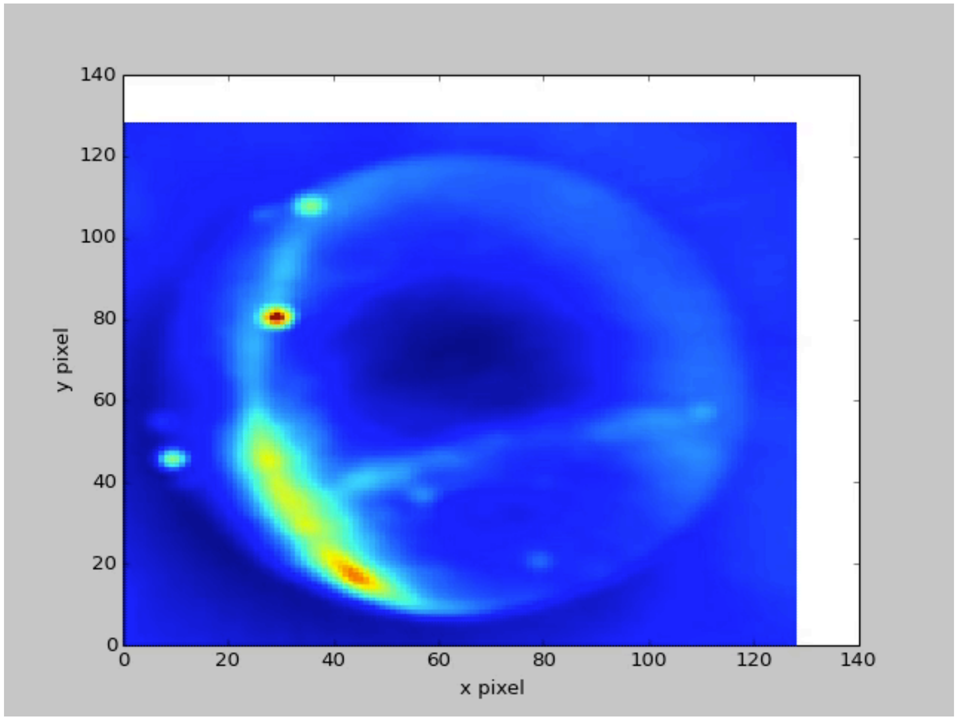


New Broadband Imager

LASI (100 kHz)



Broadband Imager in LWA-SV (10.8 MHz)



Goals:

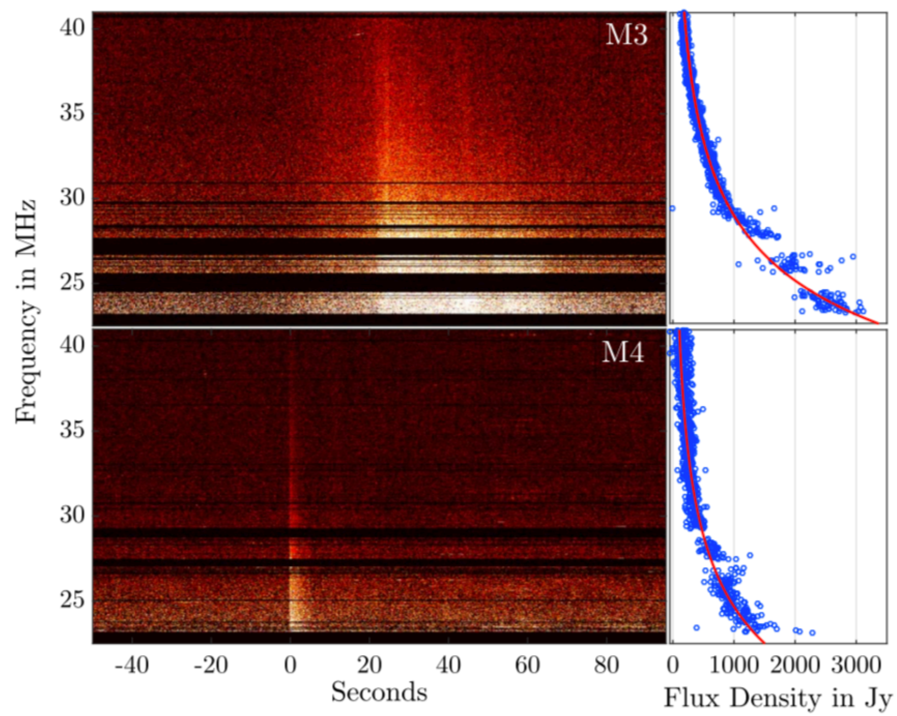
- ❑Collect the broadband spectrum of MRAS
- ❑Transient search using broadband data

Broadband Spectrum from Beamformed Observations

- 3 beams around zenith at azimuth angle 60°, 180°, 240° at an elevation of 87°
- 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



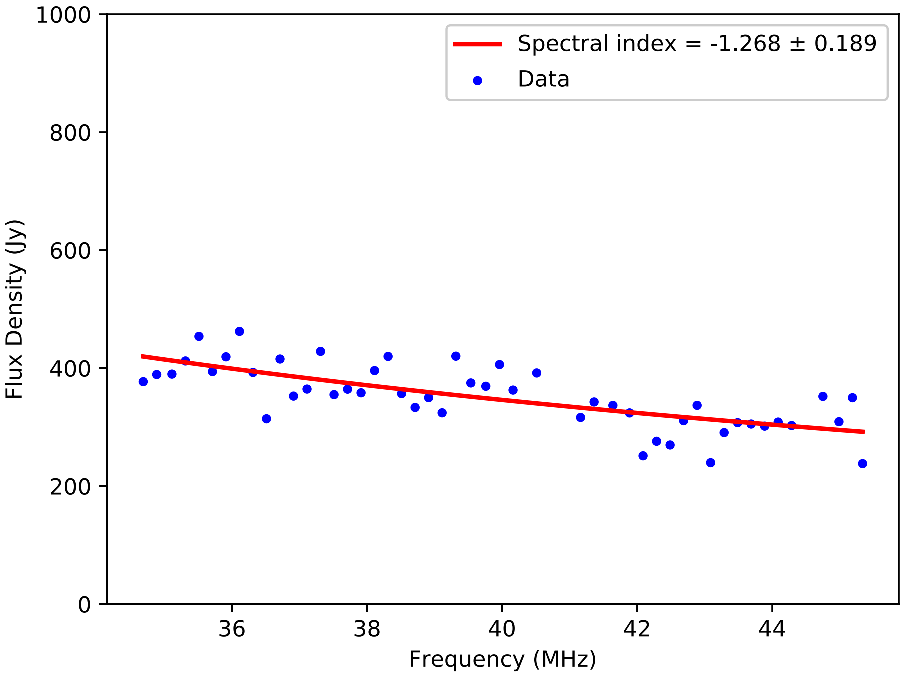
Obenberger et al. 2016

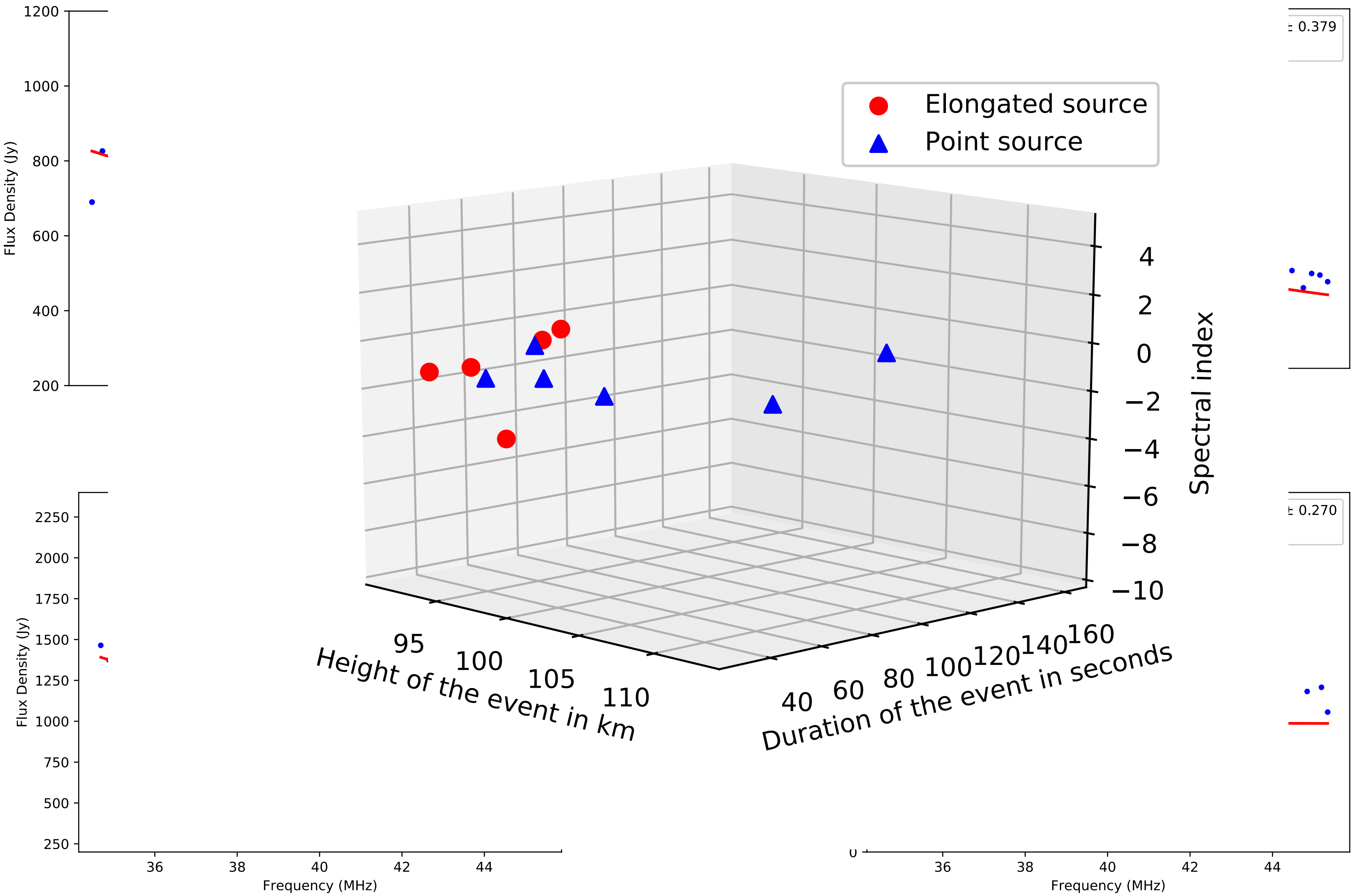
Wide band spectrum of MRA

- Collected spectrum of 14 MRA events
- Fitted with power law as

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

- Measured spectral index varies from -**3.269** to **0.213**




Elongated source
Point source
Height of the event in km
95
100
105
110
Duration of the event in seconds
40
60
80
100
120
140
160
Spectral index
4
2
0
−2
−4
−6
−8
−10
Flux Density (Jy)
1200
1000
800
600
400
200
Flux Density (Jy)
2250
2000
1750
1500
1250
1000
750
500
250
36
38
40
42
44
Frequency (MHz)
0.379
0.270
0
36
38
40
42
44
Frequency (MHz)

Summary

- MRAs follow an **isotropic radiation pattern** and they are distinct from the transmitter reflections from meteors
- Projection effects causes deviations from the expected fit and isotropically emitting cylinder is a good working model.
- No clear correlation between spectral index, duration, height and source structure for 14 MRA events

Future

- **Process of MRA emission mechanism leading to different energy spectrum and their evolution**
- **Developing AI algorithms for transient detection**
- **Hunting low flux density MRAs as well as cosmic transients from the broadband data**
- **Implement de-dispersion of images to search for cosmic transients**


QUESTIONS?

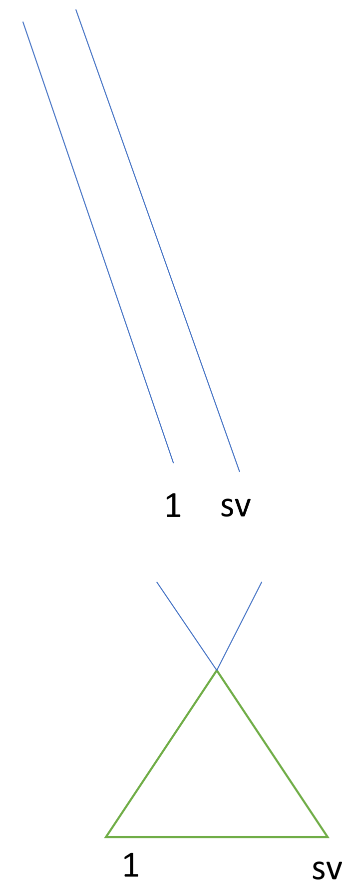
Comparison of Transient Candidates

- Comparison of events from both stations
- Looks at associated events
- If ΔS (change in coordinates) < 3 degrees

  ➡ **Cosmic transient candidate**

- If ΔS (change in coordinates) > 3 degrees

  ➡ **Meteor Radio Afterglow candidate**



Advantages

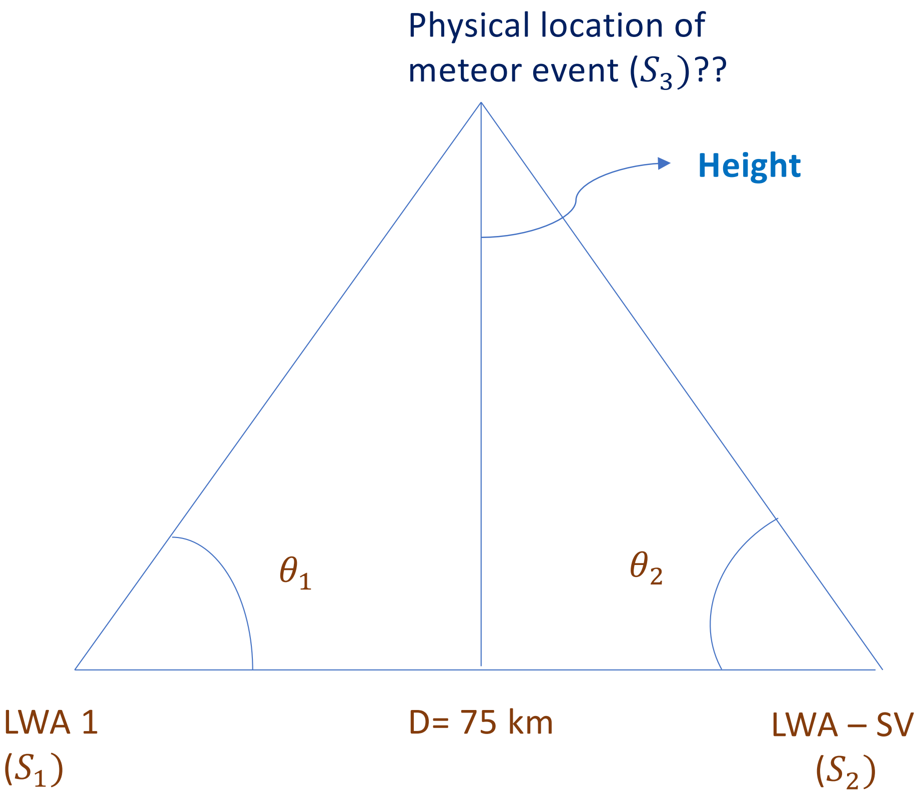
- Removes the local RFI effects near each station
- List cosmic or meteor afterglow candidates

Disadvantages

- Correlate scintillation of bright radio sources
- Produces false positive events
- Scintillation- scintillation, RFI-RFI events, RFI- scintillation events

Triangulation Method

- Process of forming a triangle from two known points and directions to find third unknown point
- Finds location of meteor afterglow with good accuracy
- Removes 95 % of false positive from MRA candidates



Automated Pipeline

- Transient search script
- Comparison of events and classification
- Triangulation for MRA candidates.
- Email output with results.

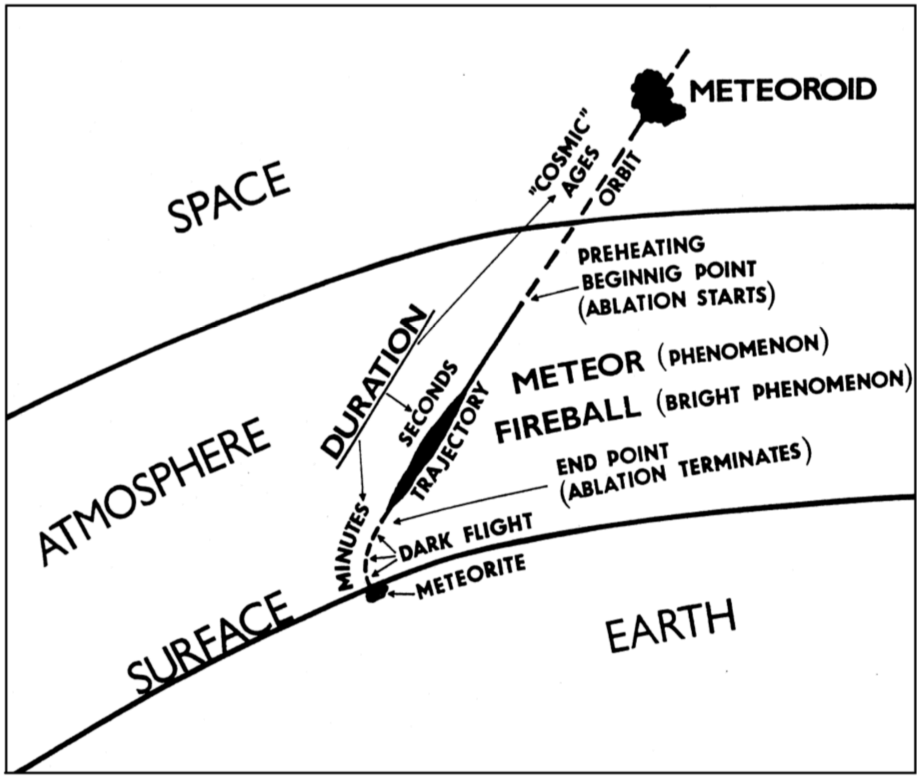
CD Cron Daemon <root@hercules.phys.unm.edu>
Tue 4/10/2018 5:45 PM
To: Savin Shynu Varghese; obenken@icloud.com; Gregory Taylor

Reply all

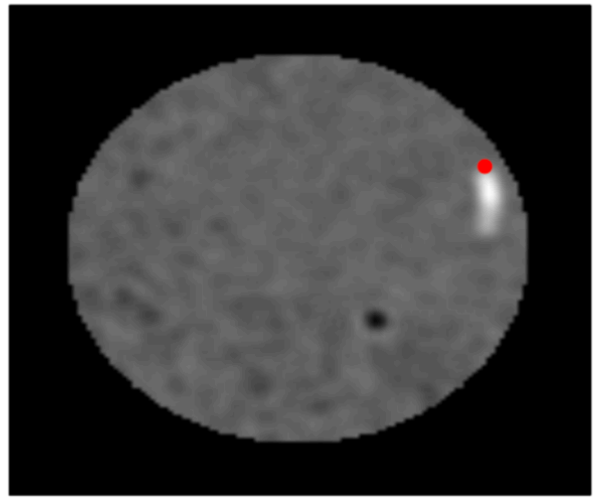
FB in LWA1 at 18.0 55.0 37.0 UTC (2.17, 6.86),SV at 18.0 55.0 51.0 UTC (339.87,-4.62) at (Lat=33.6,Lon= -107.9,Ele= 105.7 Km)
# of fireball event obseved on MJD 58217 at 5s and 5s integrations is 1
No unknown events observed on MJD 58217 at 5s and 5s integrations
No cosmic transients observed on MJD 58217 at 5s and 5s integrations
FB in LWA1 at 18.0 55.0 32.0 UTC (357.87, 8.92),SV at 18.0 55.0 31.0 UTC (337.68,-3.24) at (Lat=33.6,Lon= -108.0,Ele= 109.6 Km)
FB in LWA1 at 18.0 55.0 37.0 UTC (2.17, 6.86),SV at 18.0 55.0 31.0 UTC (337.68,-3.24) at (Lat=33.6,Lon= -107.9,Ele= 99.4 Km)
# of fireball event obseved on MJD 58217 at 5s and 15s integrations is 2
No unknown events observed on MJD 58217 at 5s and 15s integrations
No cosmic transients observed on MJD 58217 at 5s and 15s integrations
No fireball observed on MJD 58217 at 5s and 60s integrations
No unknown events observed on MJD 58217 at 5s and 60s integrations
No cosmic transients observed on MJD 58217 at 5s and 60s integrations
FB in LWA1 at 18.0 55.0 47.0 UTC (3.26, 6.64),SV at 18.0 55.0 51.0 UTC (339.87,-4.62) at (Lat=33.6,Lon= -107.9,Ele= 102.9 Km)

Meteors

- Meteors occur when high velocity meteoroid particle collide with earth's atmosphere and produce light
- Hypersonic velocity (10 – 80 km/s) impacts enters the dense region and get heated up due to friction
- Preheating takes place at 300 – 100 km and last for few seconds
- Temperature rises rapidly up to 900 K
- During ablation temperature rises to 2500 K and starts evaporating
- Ablation consumes most of kinetic energy
- Dark flight has no light and finally impact

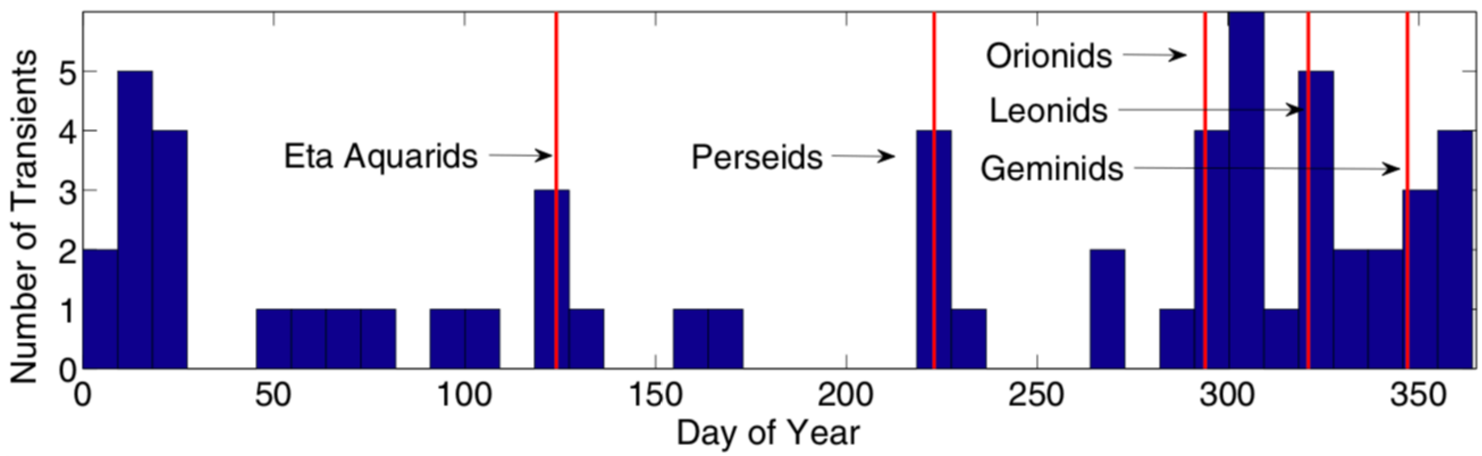


Detected transients are associated with meteor shower



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

Obenberger et al. 2014



Emission mechanism: Langmuir waves (Plasma oscillations)??

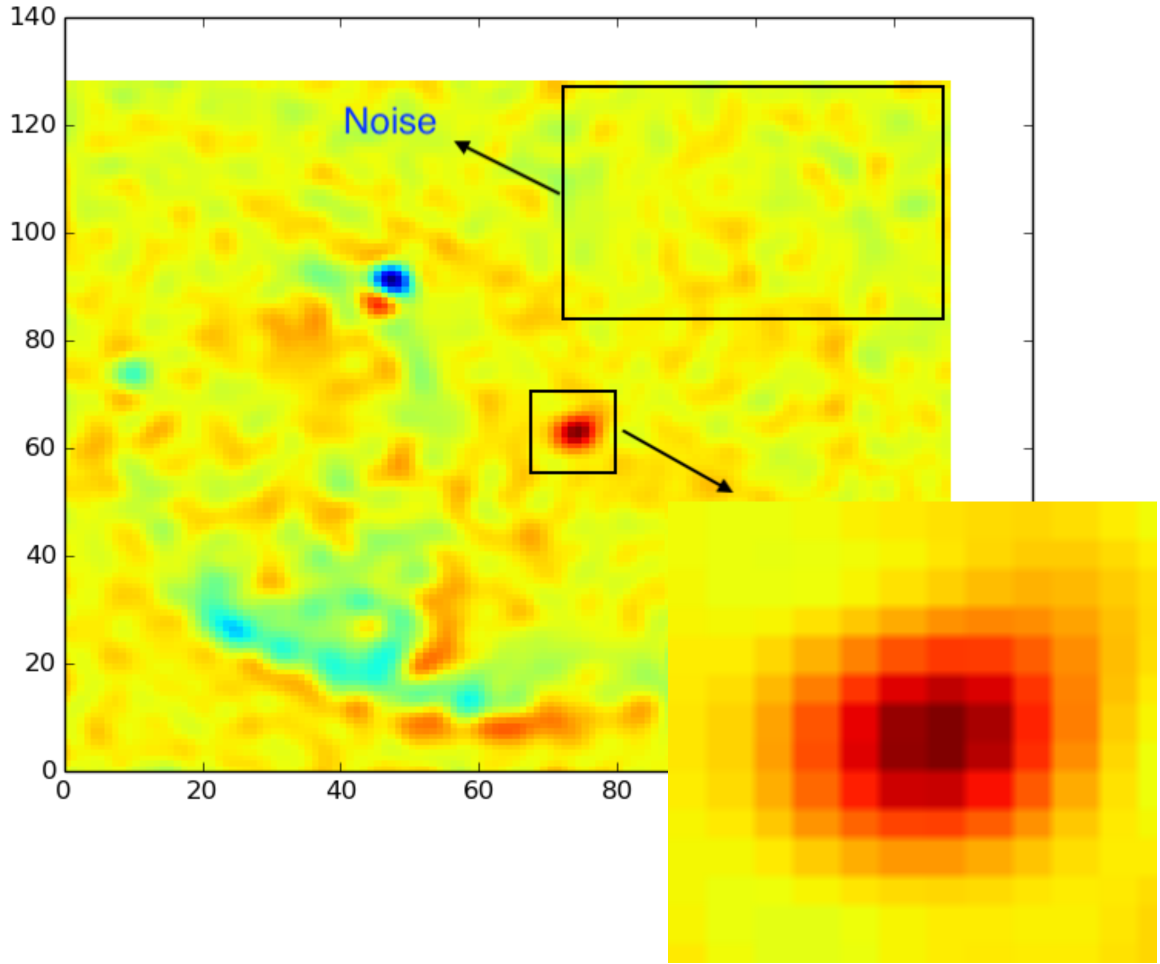
- Current hypothesis: electron plasma waves emitting from turbulent ionized trail at plasma frequencies

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

- 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

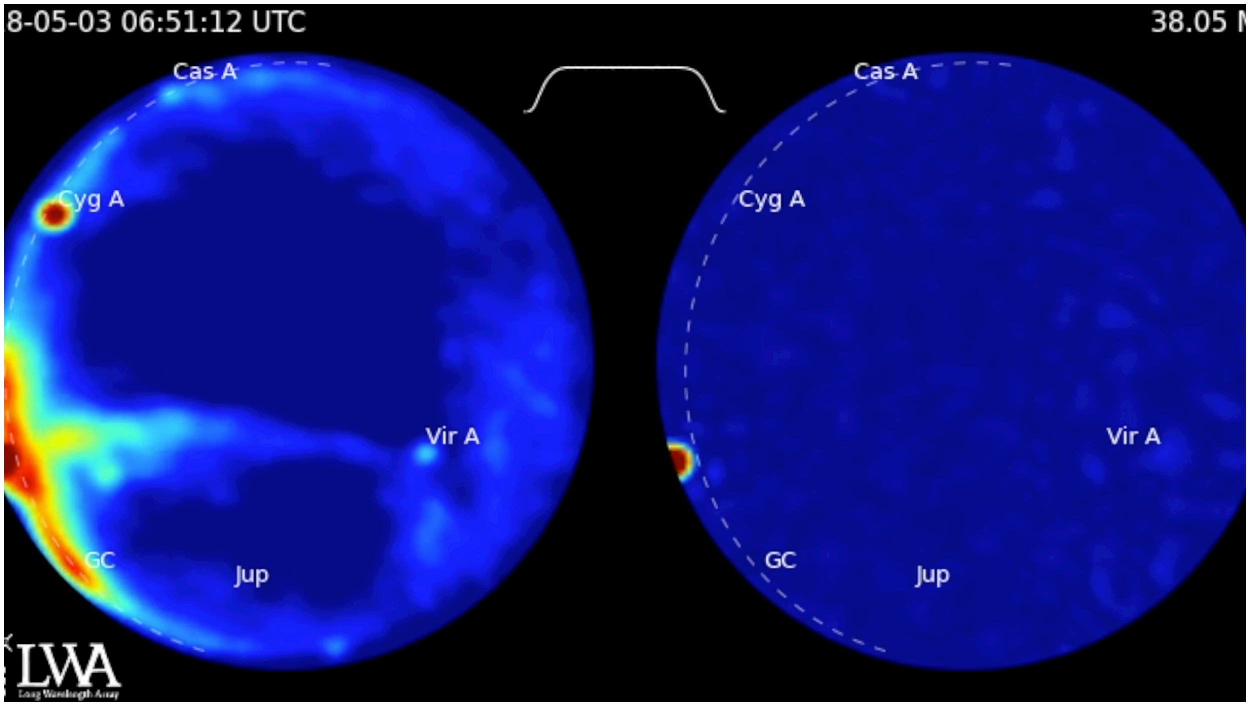
Flux measurement

- Light curve gives the peak flu
  and time of emission.
- Average of 10 images is subtracted from the peak flux image.
- Look for peak value pixel
- Gives flux values in arbitrary values.
- Needs flux calibration



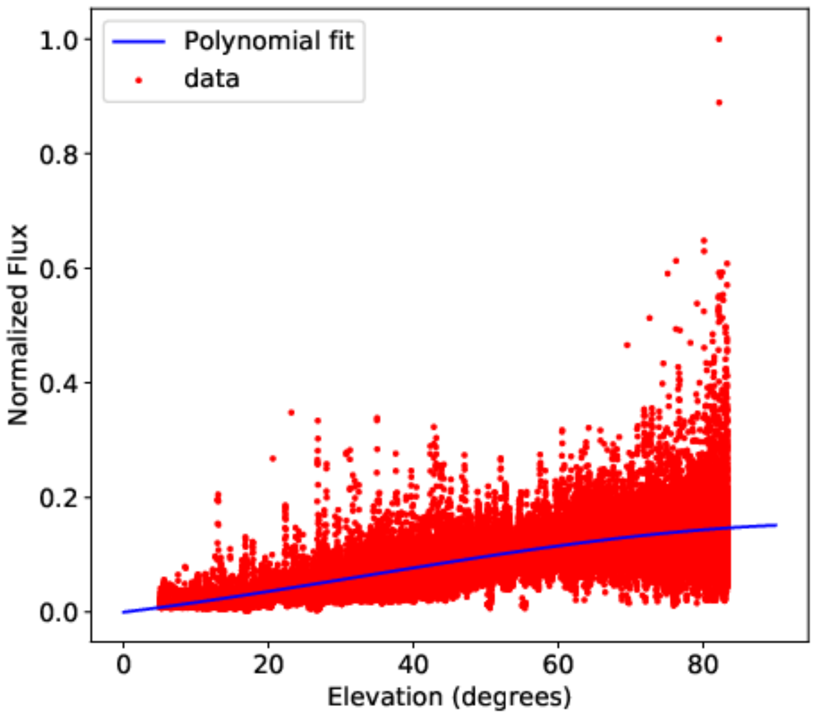
Flux Calibration

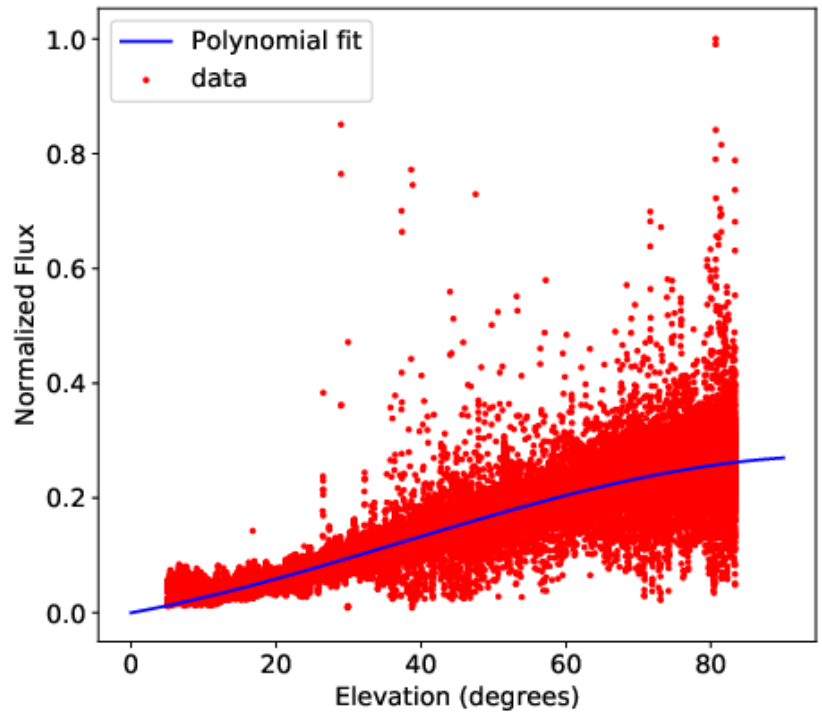
- LASI produces dirty maps.
- Cygnus A - good calibrator
- Track Cyg A as it transit across sky
- Measure the peak value of flux from image
- Flux -> function of frequency and elevation



$$\frac{Flux_{meteor}(elev) \quad (Jy)}{Flux_{meteor}(elev) \;\; (arbitrary\ unit)} = \frac{Flux_{Cyg\ A} \quad (Jy)}{Flux_{Cyg\ A}(elev) \;\; (arbitrary\ unit)}$$

LWA 1   34 & 38 MHz





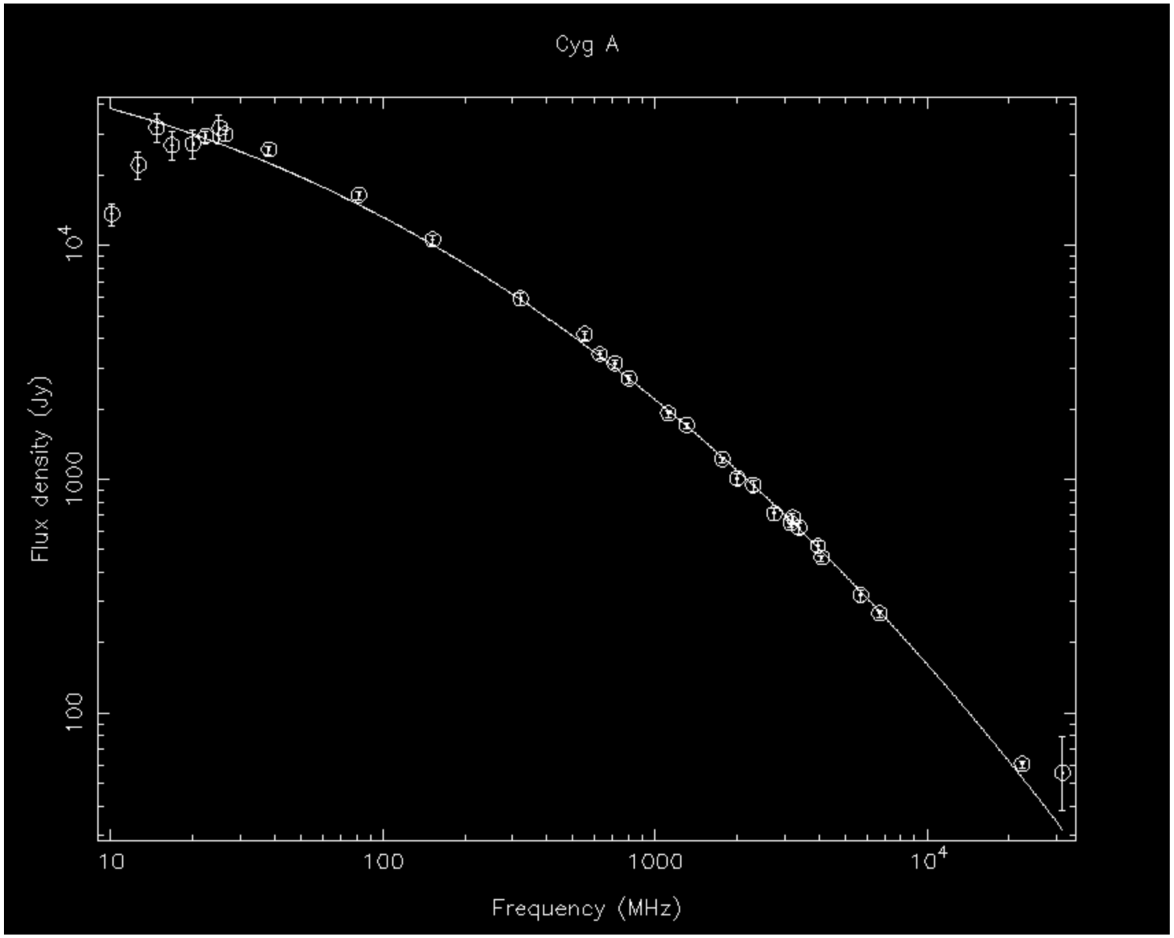
The VLSS Bright Source Spectral Calculator: used to calculate Flux density at 38 and 34 MHz

Used data from Baars et al. (1977) for **3C405 (Cyg A)**

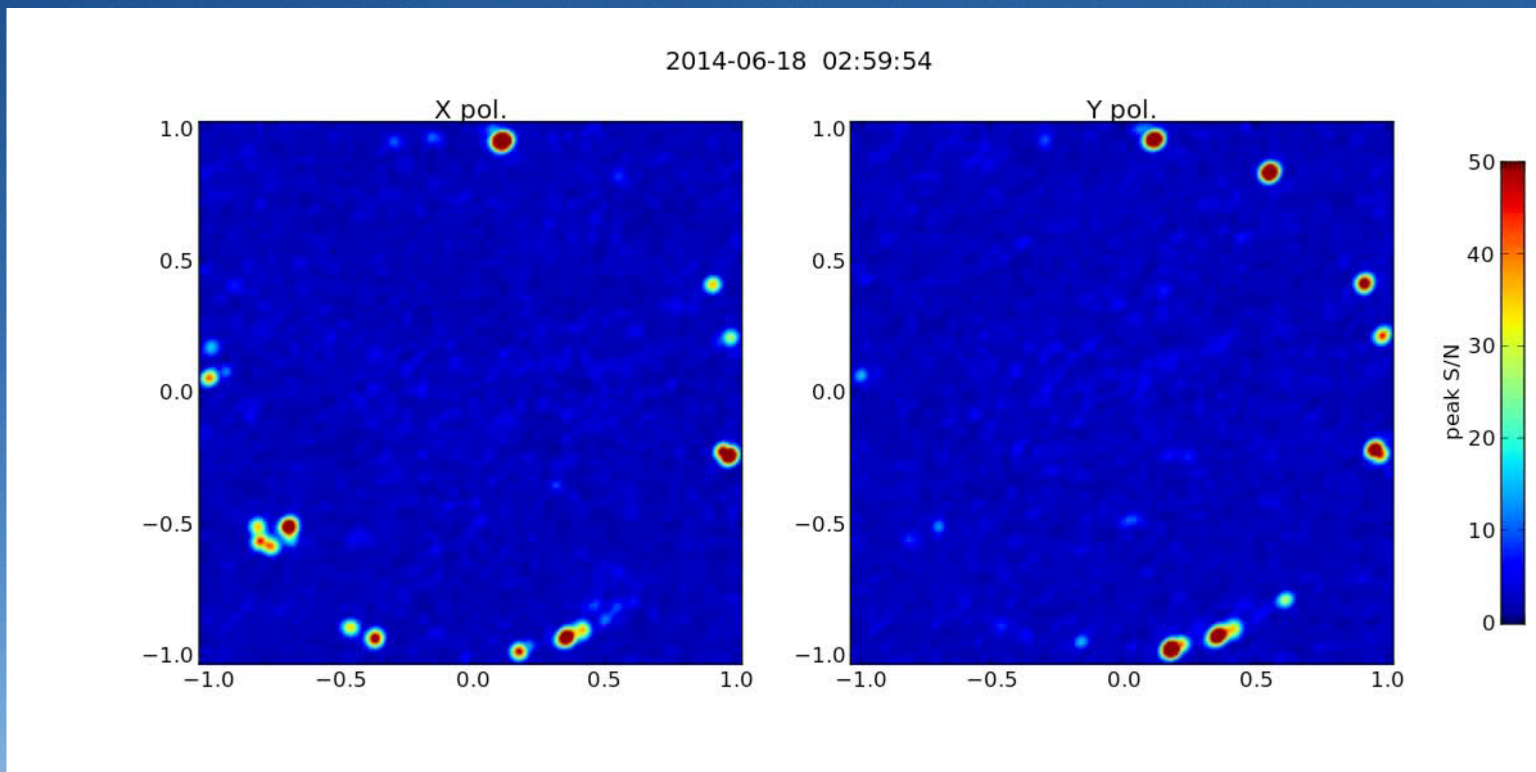
Flux density at **38.00** MHz from:

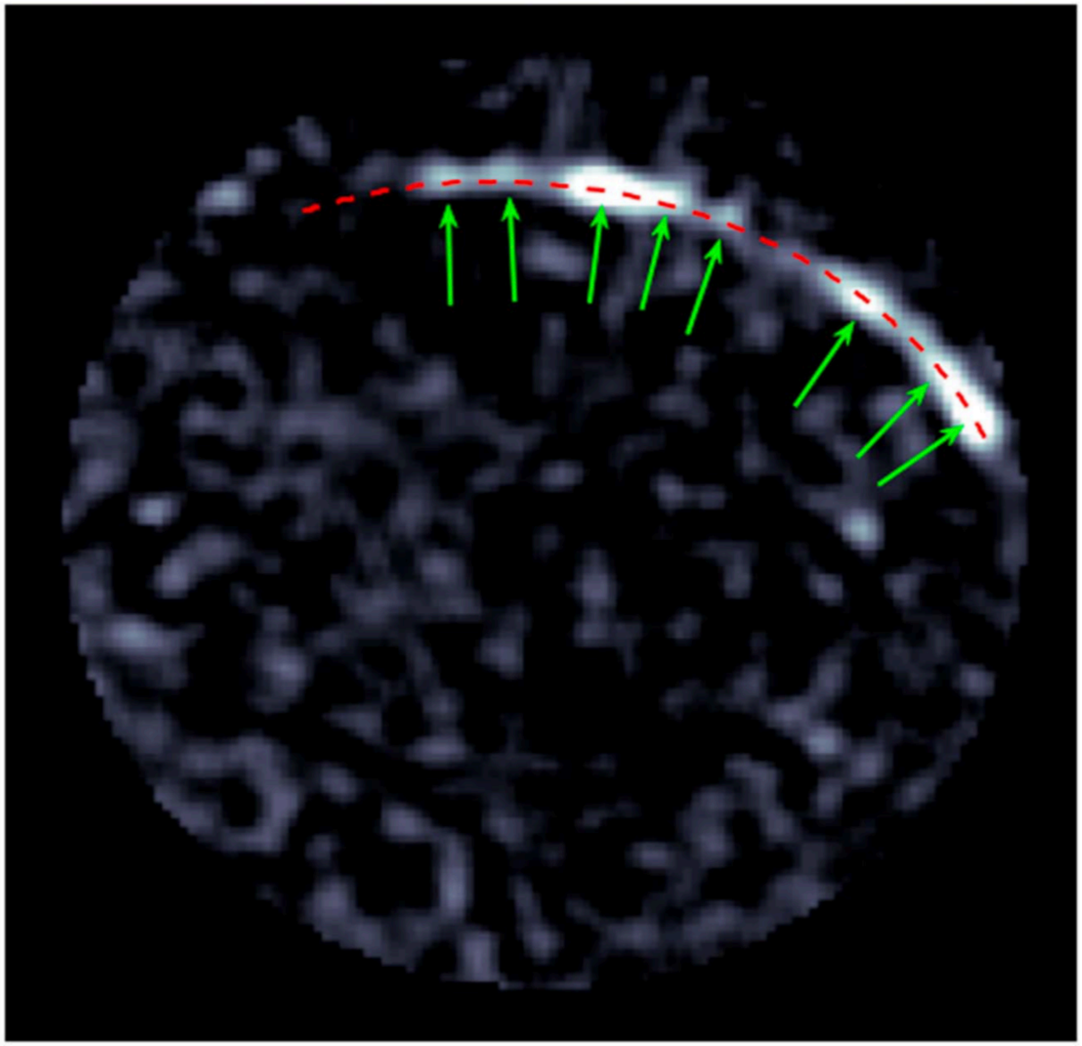
interpolation = **25500.01 Jy**

model fit = **22522.44 Jy**



Meteors – by reflection at 55.25 MHz





Broadband Imager

Going from 100 kHz to 10.8 MHz

Data rate, processing speed and sensitivity of images – function of bandwidth

Post processing in two steps

- conversion of visibility data to CASA measurement sets (MS)
- Conversion of MS files to image of the sky

Serial implementation takes 72 hours for one hour data

UNM Center for Advanced Research Computing