HF and VHF Radio Emission from Meteor Trails

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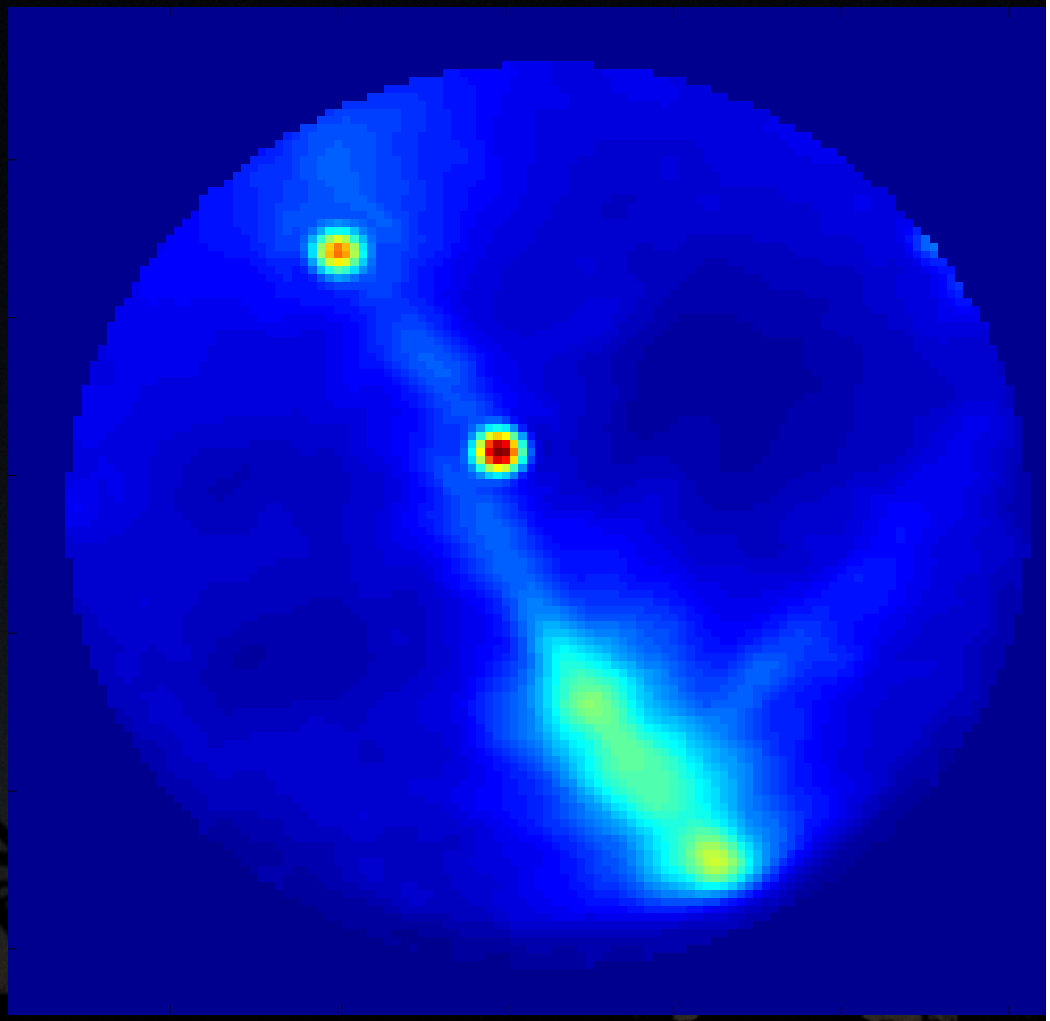
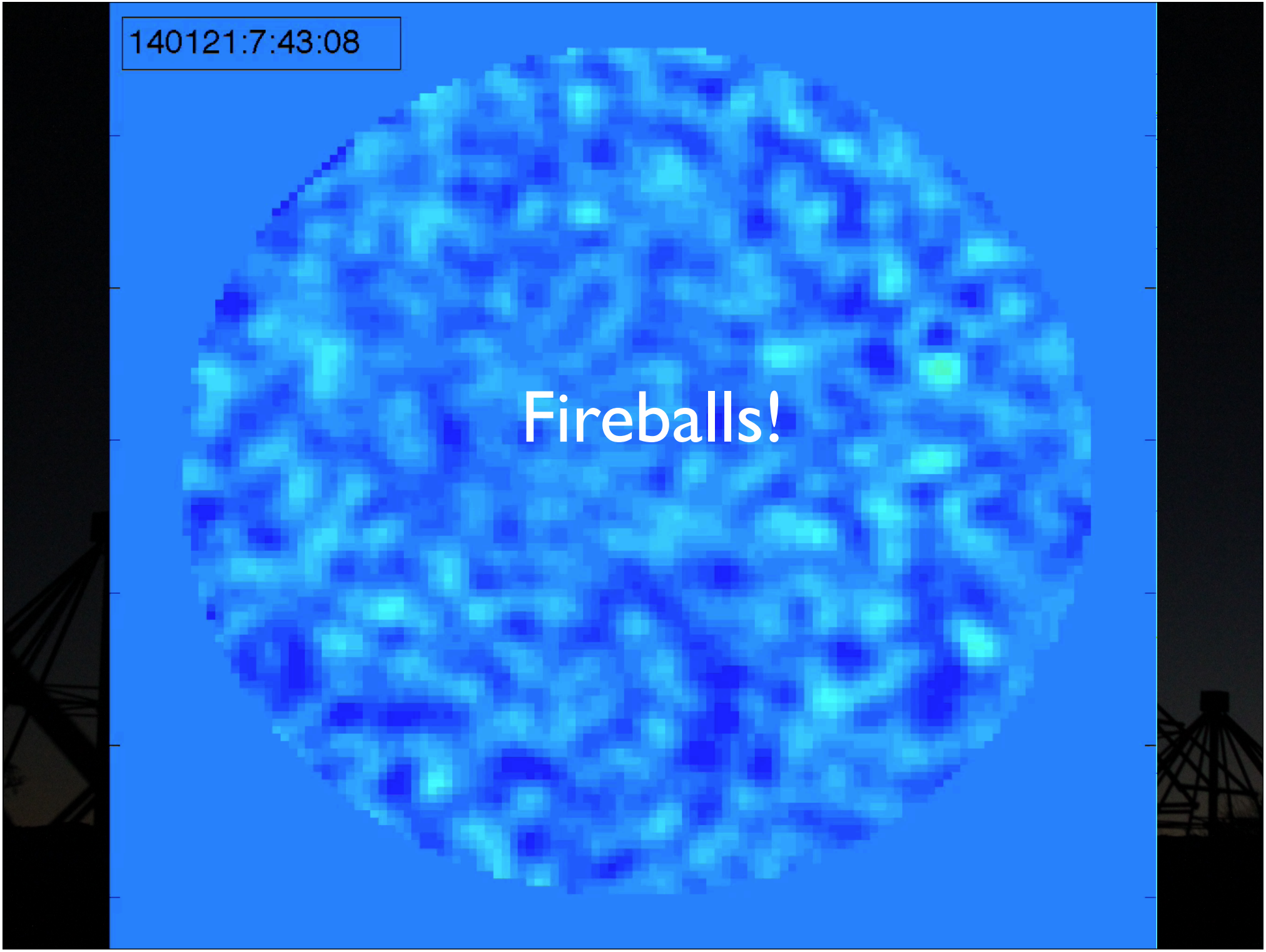
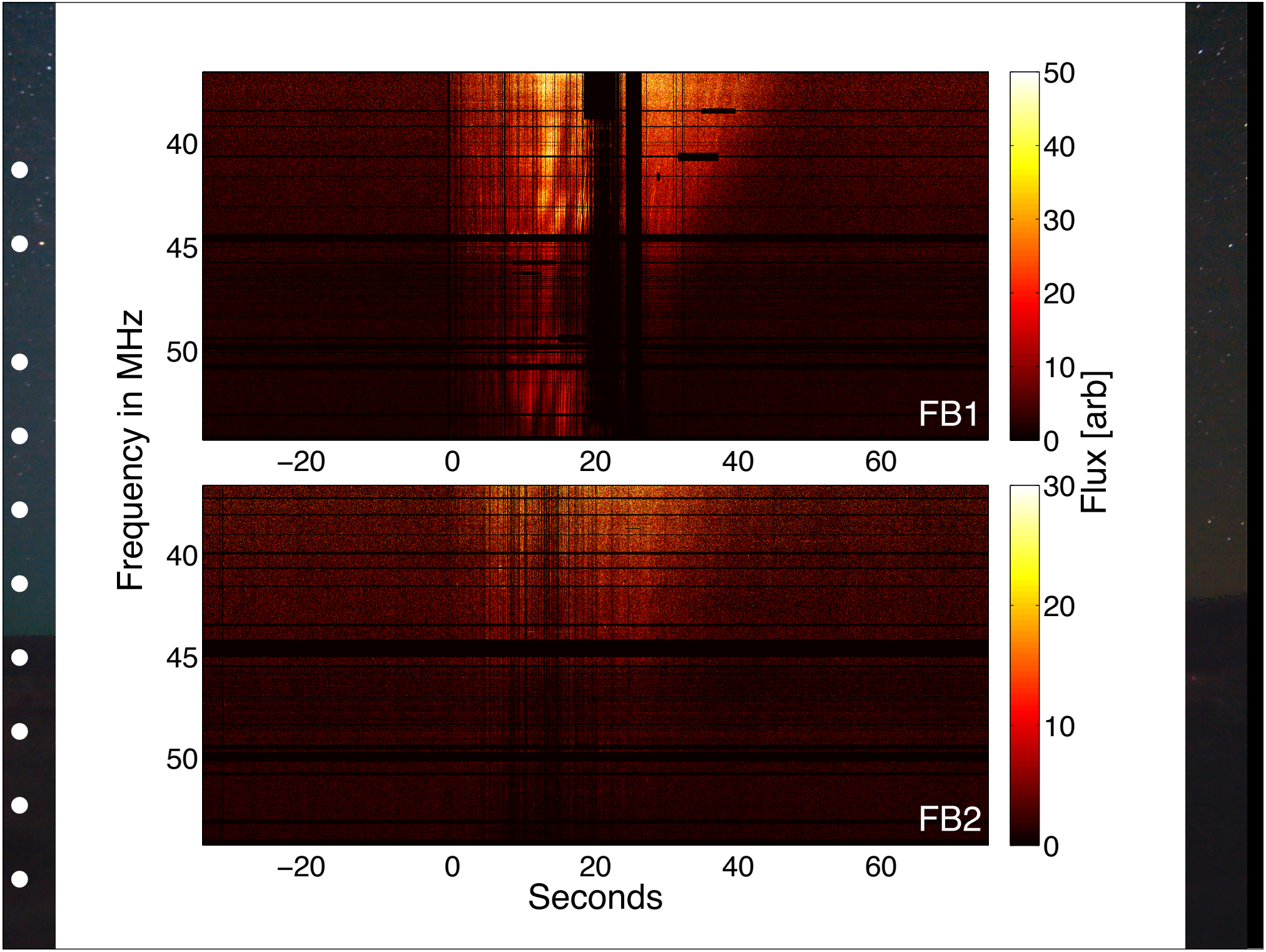
LWA1 & Prototype All Sky Imager

- Operates between 10 - 88 MHz (HF-VHF)
- Correlates live stream from all antennas
- Create all-sky images
- 5 second integrations
- 6 channels covering 75 kHz




140121:7:43:08
Fireballs!


Frequency in MHz
40
45
50
FB1
−20
0
20
40
60
50
40
30
20
10
0
Flux [arb]
40
45
50
FB2
−20
0
20
40
60
30
20
10
0
Seconds

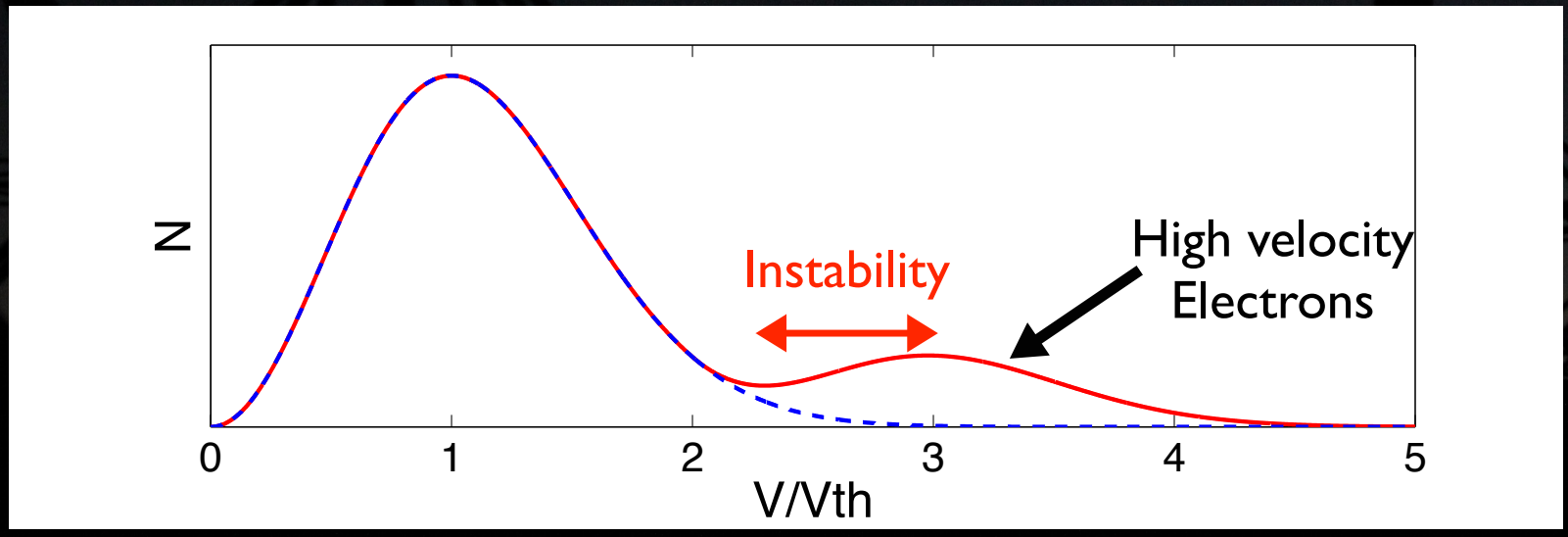
Plasma Waves

- The emission is likely due to EM conversion of Langmuir waves analogous to type II or III solar bursts?
- Electron Plasma waves (Langmuir) are electron oscillations within a plasma, they occur at the plasma frequency, which is proportional to the square root of the electron density
- Meteor Trails co quencies to be observable with
- Langmuir waves ion mechanism is mysterious. Stee aid this emission process
- Perhaps antenna mechanism? Size scales are similar to wavelength scales (~10 m)

$$f_p = \sqrt{\frac{n_e e^2}{\pi m_e}},$$

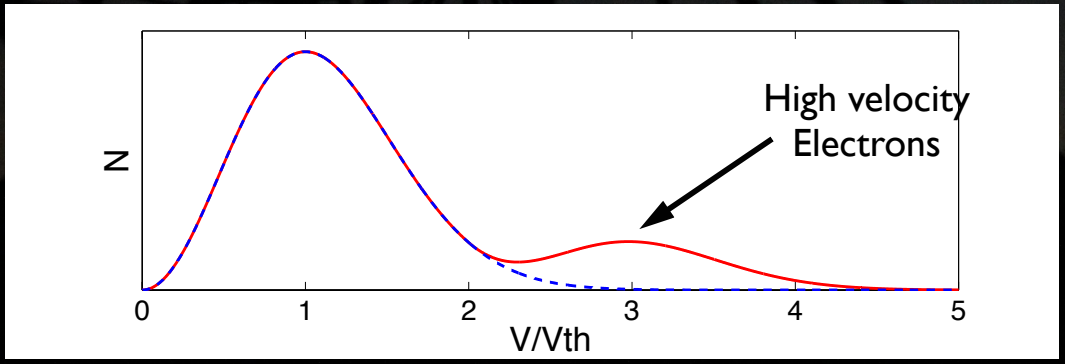
Wave Growth

- The electron/neutral collision frequency is very high (0.3 MHz)
- These collisions remove energy from electrons.
- For Plasma waves to exist both the plasma frequency and growth rate need to be greater than the collision frequency, so they can be driven
- Plasma frequency is ~100 times greater
- So we need a driving mechanism with a large growth rate
- A bump-on-tail instability can drive waves, but since the electrons would thermalize very quickly, you need a continual source of hot electrons



Persistent Trains

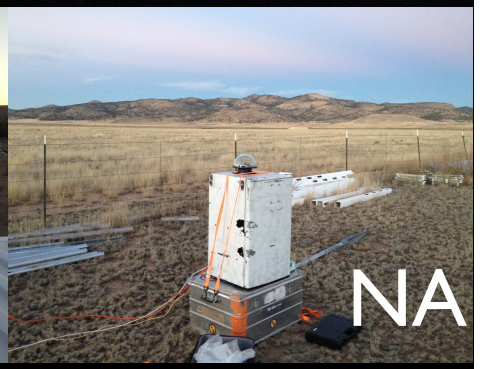
- Bright fireballs are occasionally followed by bright persistent trains
- Exothermic chemical reactions continually ionize the air
- Vibrationally excited molecules radiate a broadband Infrared - Optical spectrum
- Electrons may interact with these molecules and gain energy for a short while, creating a bump-on-tail velocity distribution.
- Oyama et al. 2011 suggest similar process to explain non-Maxwellian electrons in E-region

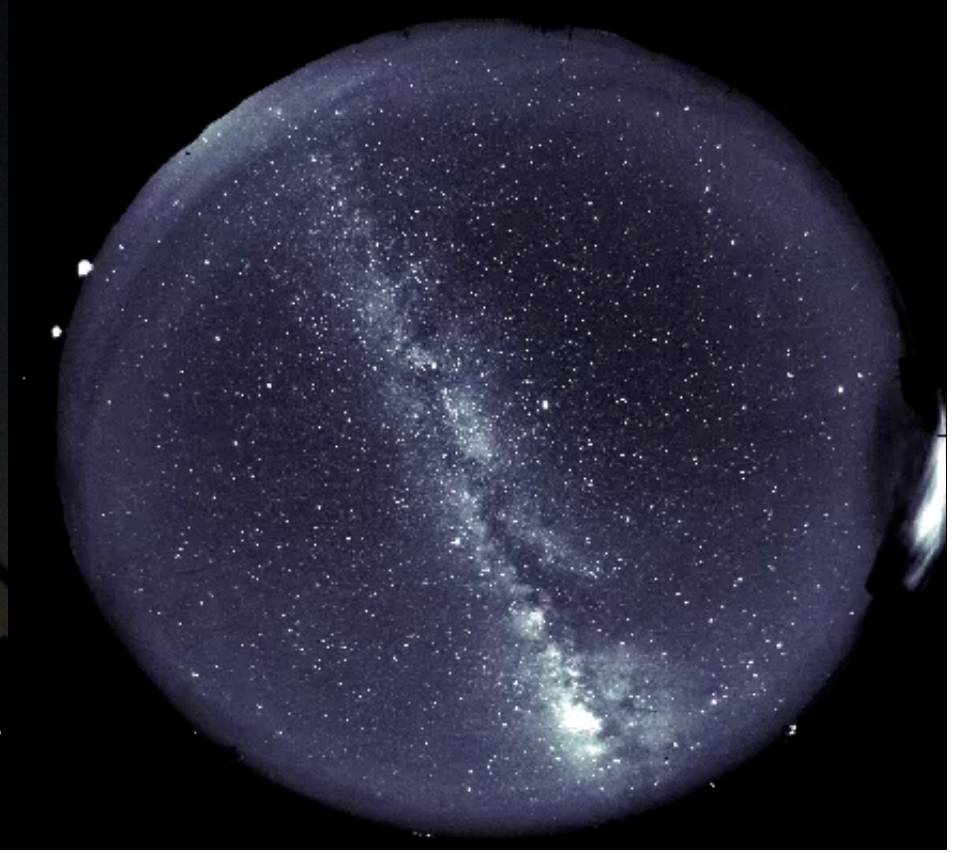


Daniel Catoni 2013

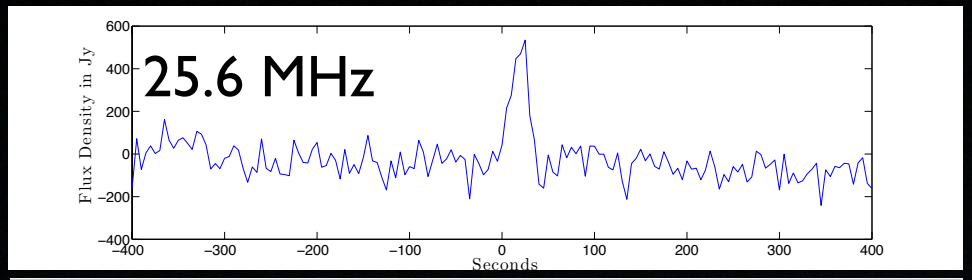
Simultaneous Search for Radio and Optical Trains

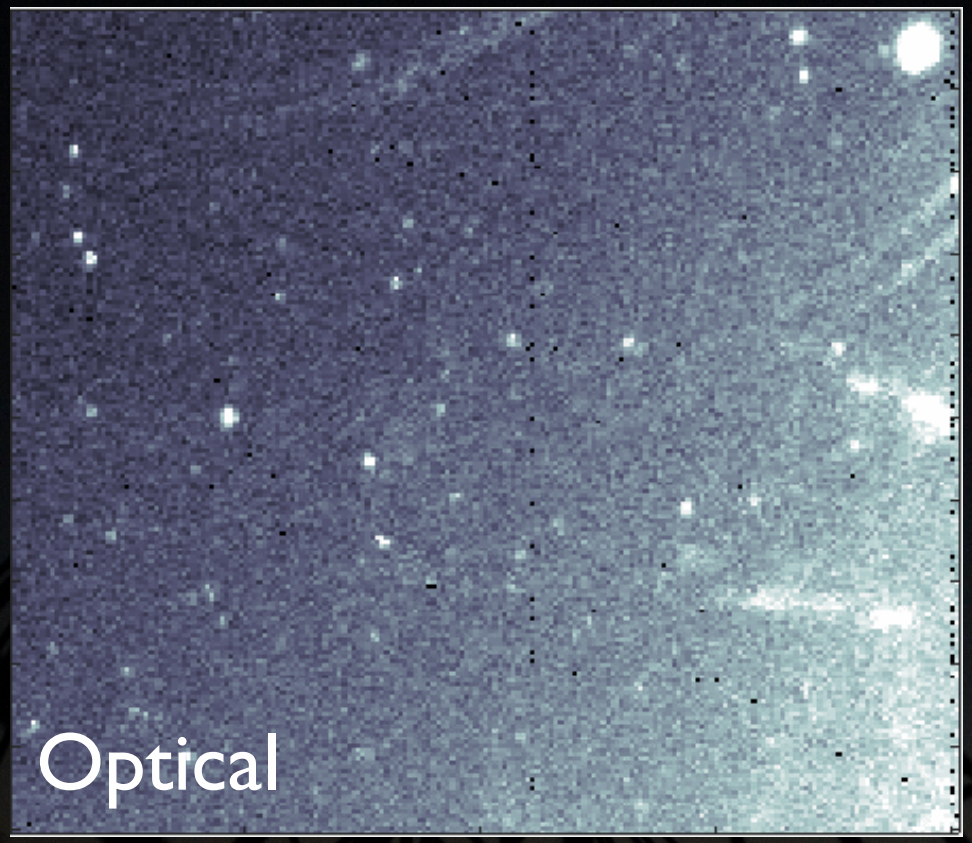
- Goal is to see if the persistent trains are associated with the radio emission
- Run the LWA1 All-Sky imager
- Simultaneously Image the sky with two all-sky lenses attached to cooled CCDs
- take 5 s integrations every ~ 7-10 seconds
- Created a pipeline using the Hough Transform to pick out meteors
- We have detected 75 bright meteors in 13 nights, of observing during the Perseids and Leonids
- We also found 3 radio fireballs simultaneous with clear night observations

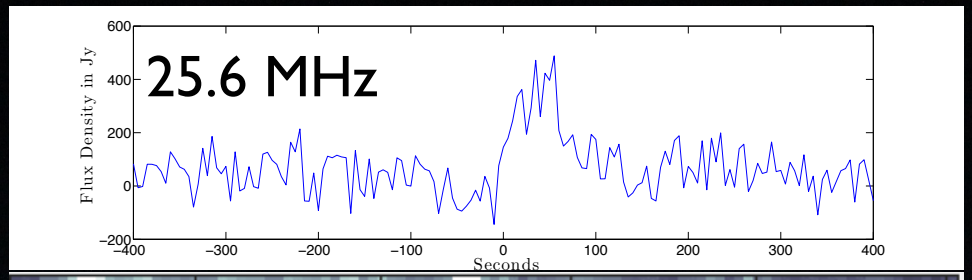


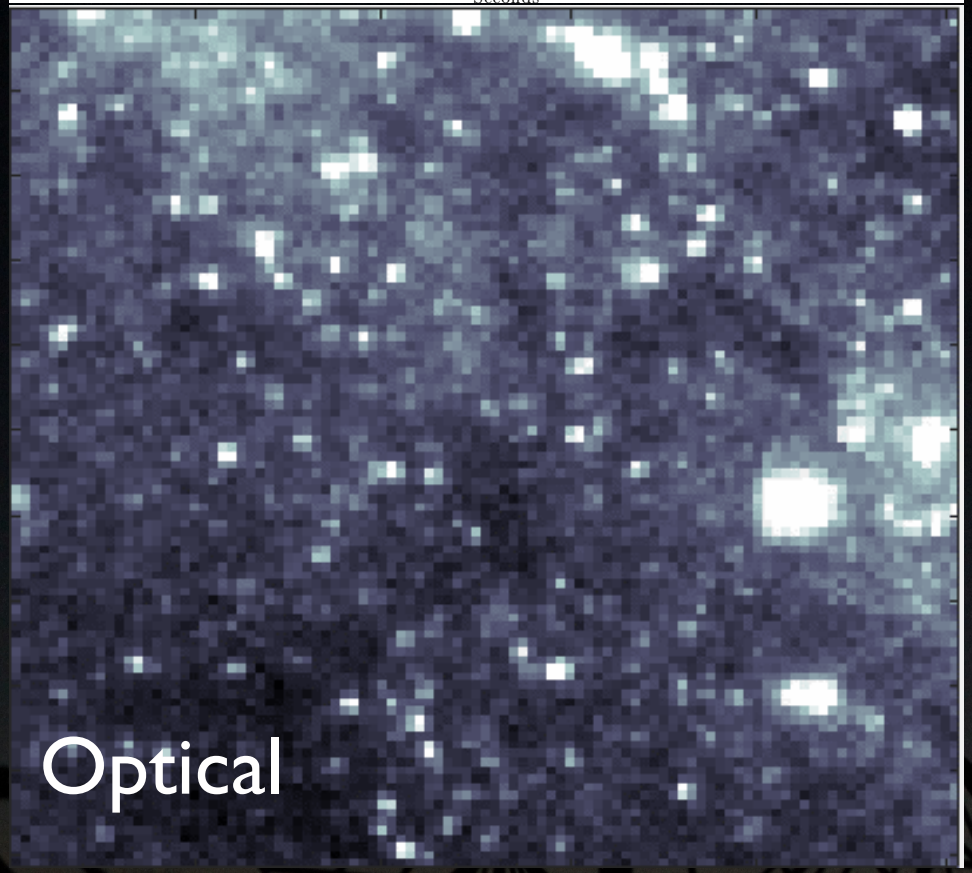


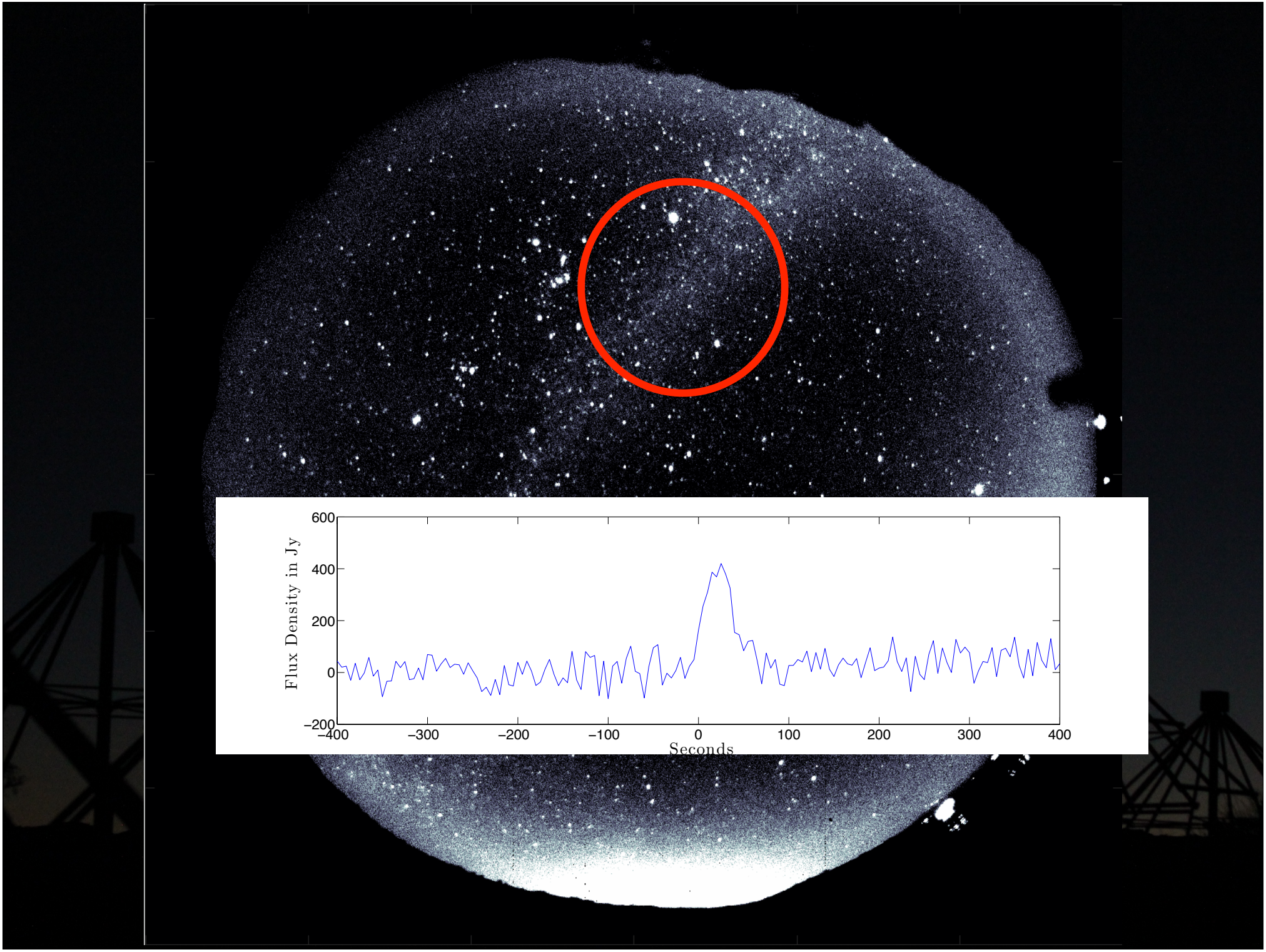
Radio Emission without Persistent Train Detection

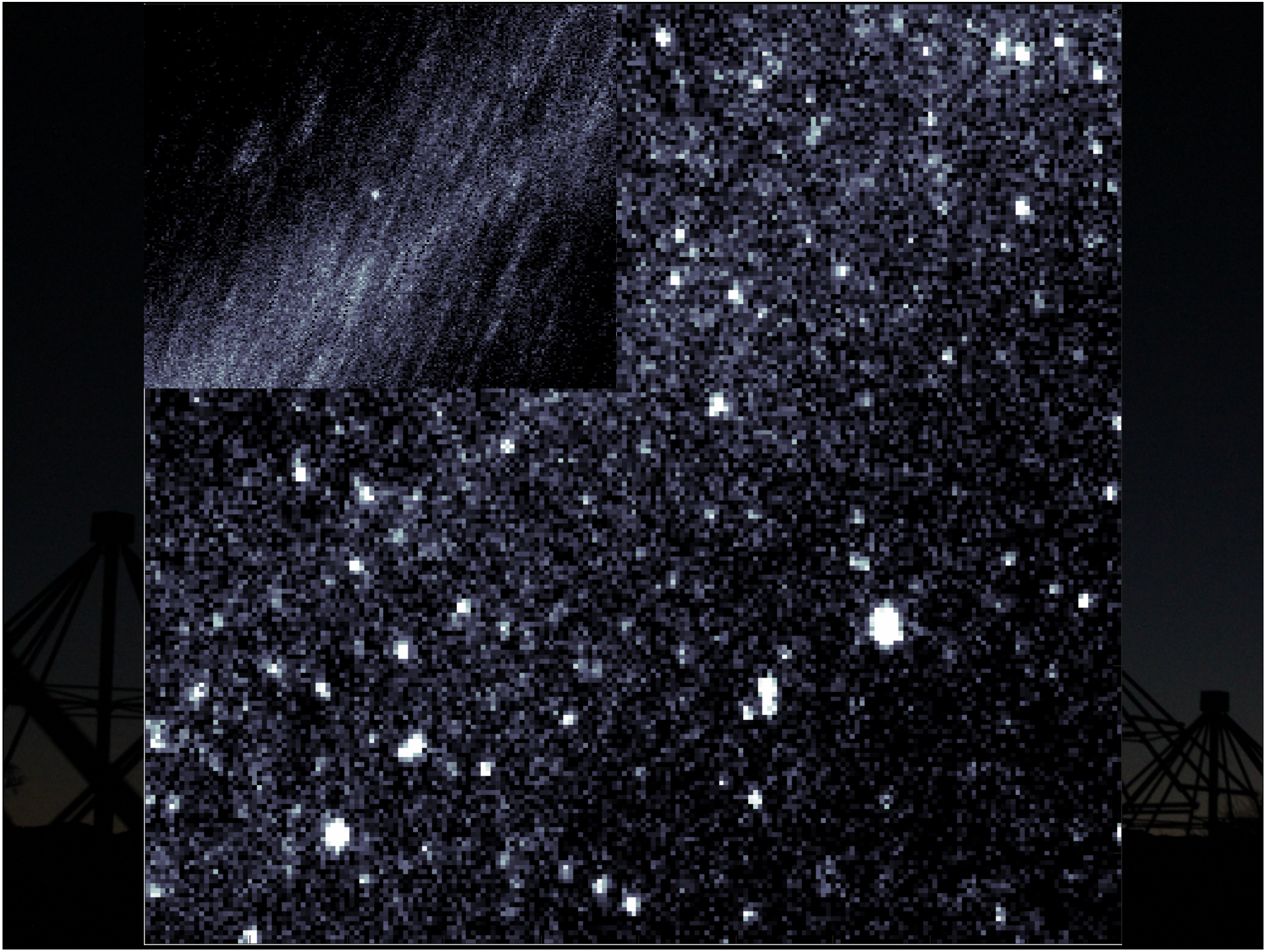






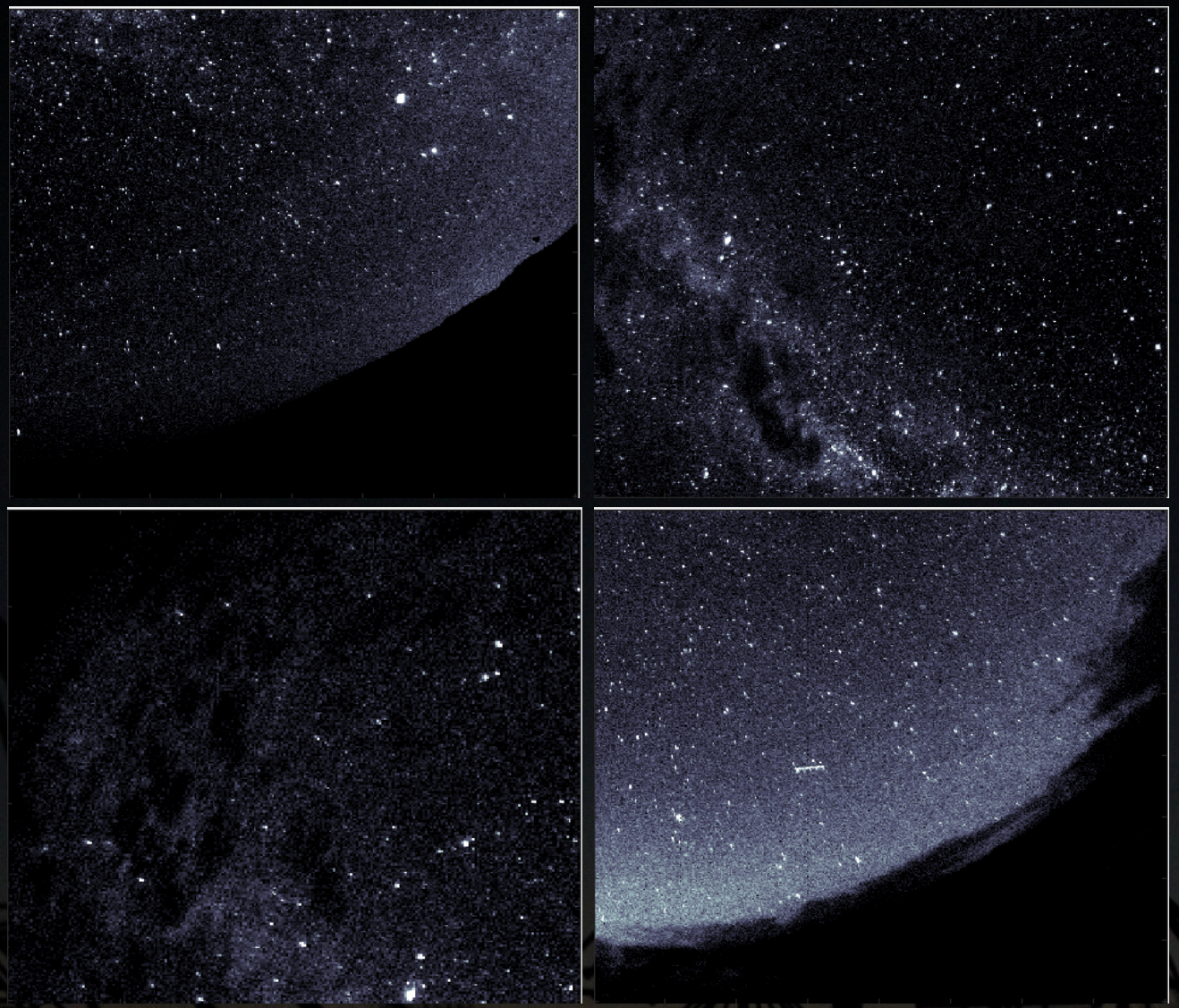



600
400
200
0
−200
Flux Density in Jy
−400
−300
−200
−100
0
100
200
300
400
Seconds



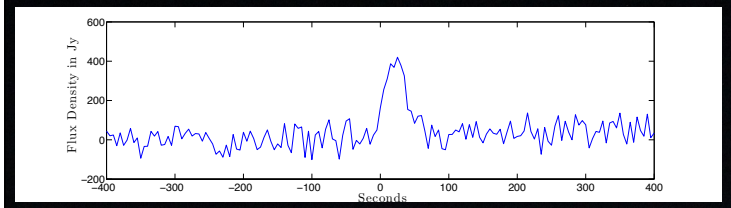
Fireballs without Persistent Trains

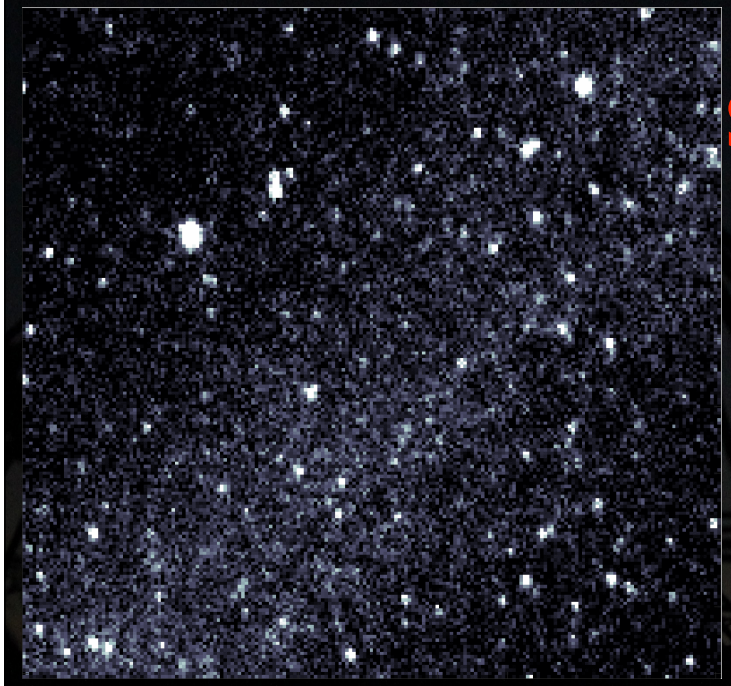
- Out of 75 optical meteors, only 3 were observed to create a persistent train
- Of those 3, only 1 was observable by the LWA1
- There were many very bright fireballs that produced no persistent train and no radio emission



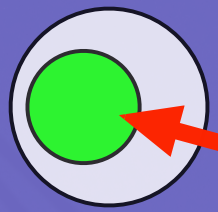
Events Observed during LWA1 Operation

Optical Fireballs
Radio Fireballs
Persistent Trains





WARNING!
Small number statistics!

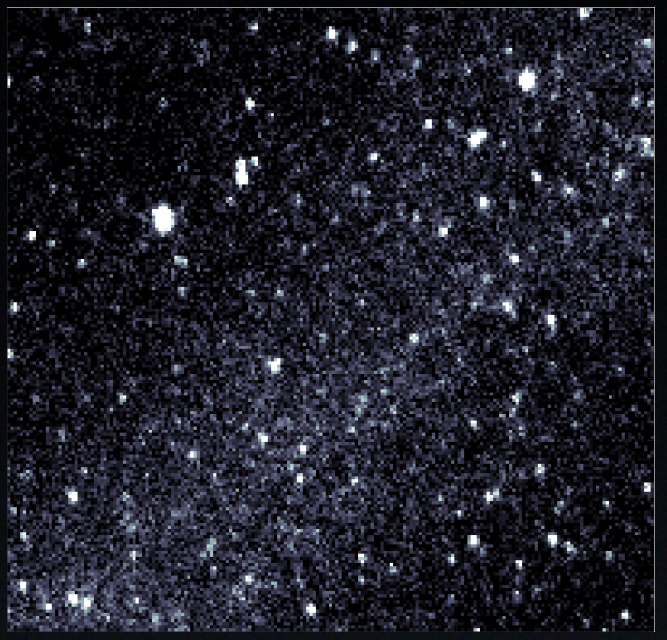


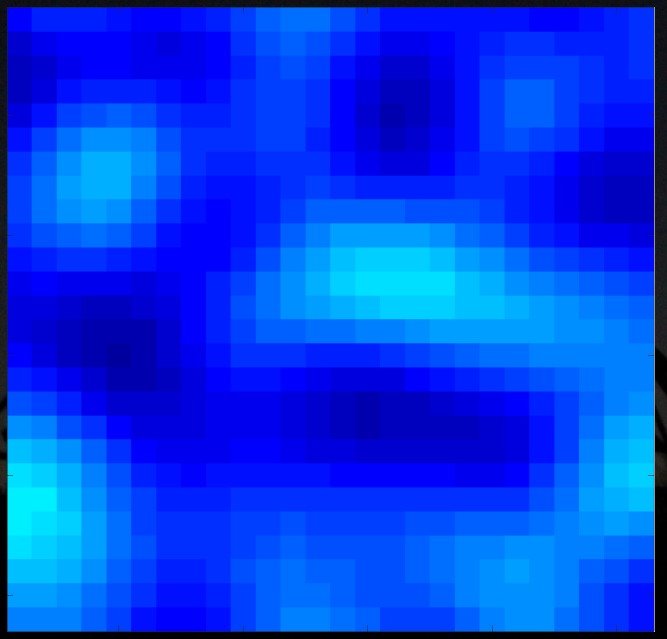
One event!

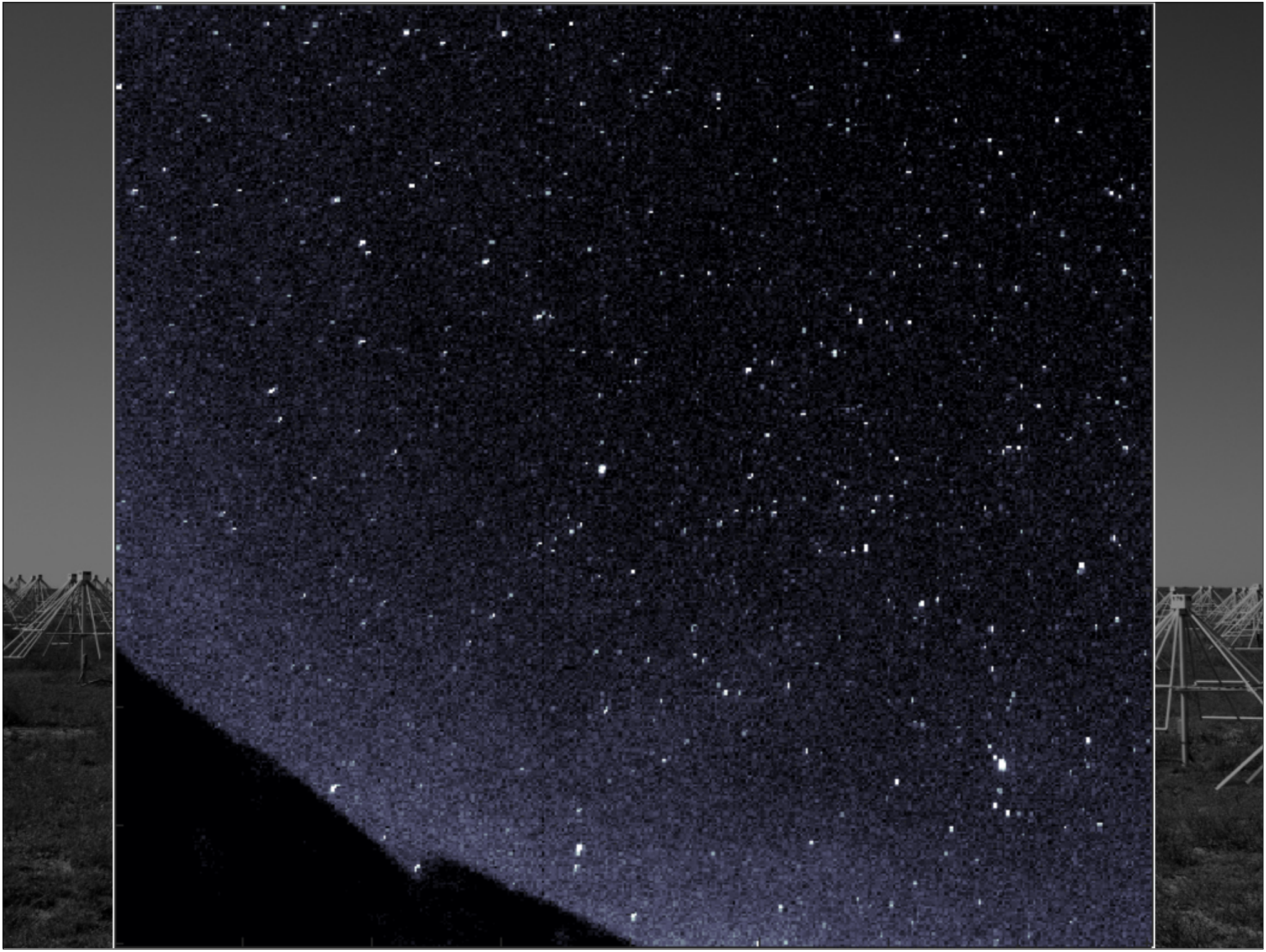
4% chance overlap!

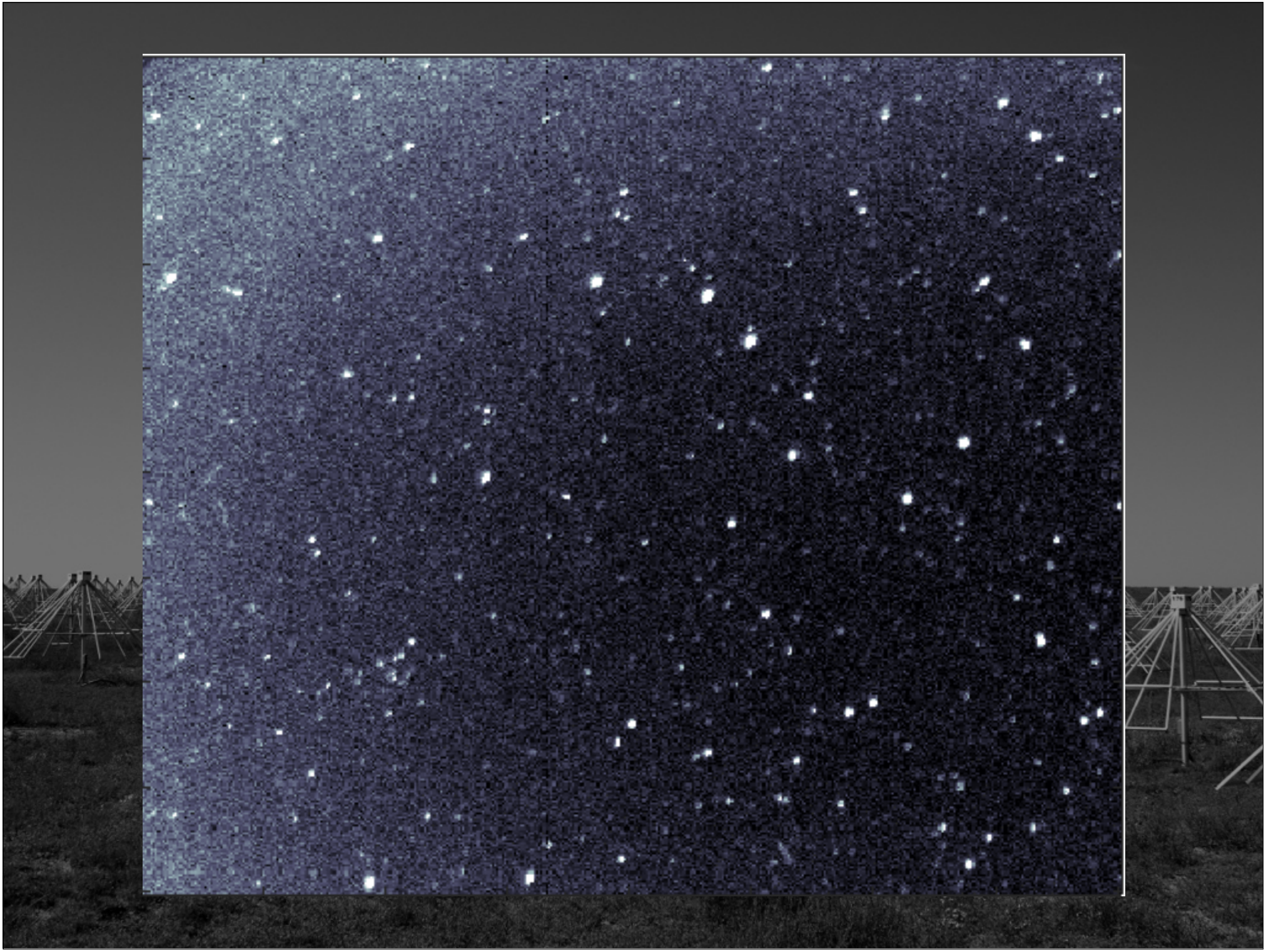
Summary

- We discovered a new emissive phenomenon from fireballs, which were previously unknown to emit in the HF and VHF band
- We have hypothesized that the emission is due to Langmuir wave emission and that the waves could be driven by a bump-on-tail of the electron velocity distribution
- One such way to create a bump-on-tail could be through the chemical reactions thought to cause optical persistent trains
- We are currently testing this hypothesis and the results thus far are promising
- Continuing observations starting next week










Backup-Slides

Future Work

- Search for optical persistent train counterparts.
  - Continue search and build statistics
  - Calibrate images and get minimum magnitude limits
  - Develop persistent train detection pipeline
- Near Field interferometry with LWA1 and LWA-SV
- Eventually use many stations to make high resolution images
- Install Fireball Network Cameras near LWA1 and LWA-SV to get better statistics for understanding what parameters are required for radio emission.

LWA1 to LWA-SV

$$\Theta = 180 + (\text{atan}(X_1/Y) - \text{atan}(X_2/Y))$$

$Y_{min} \sim 80$ km $\qquad\qquad \Theta_{min} = 130^{\circ}$

$SA_{min} = 75/2$ %