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Air Force Research Laboratory



Integrity ★ Service ★ Excellence

Using the LWA Radio Telescopes to Observe the Ionosphere

August 1 2019

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Sample of LWA-SV Ionospheric Science

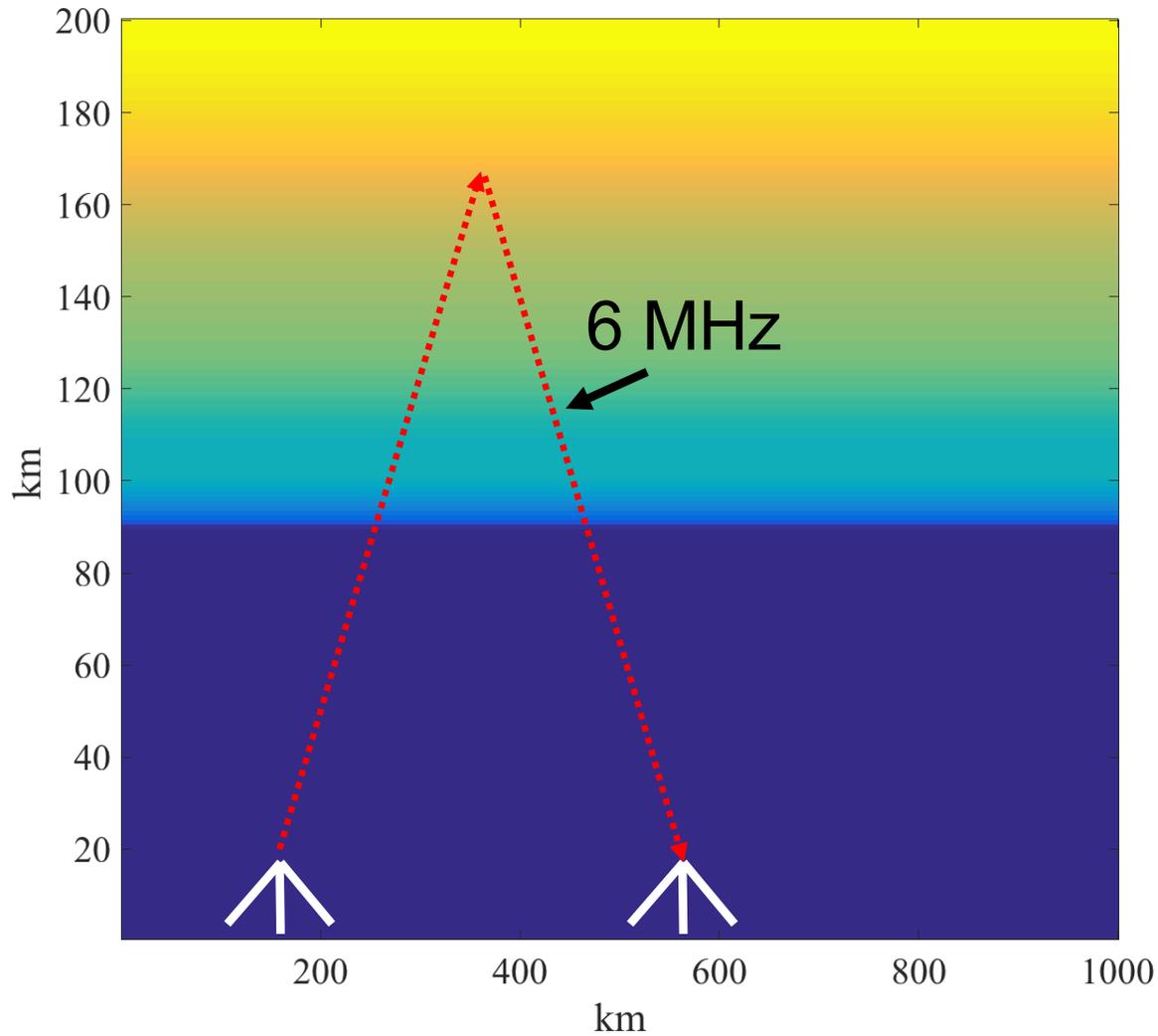


1. **HF sounding with a DPS4D**
2. **HF sounding with Lightning**
3. **VHF imaging of gravity waves in the ionospheric E region**



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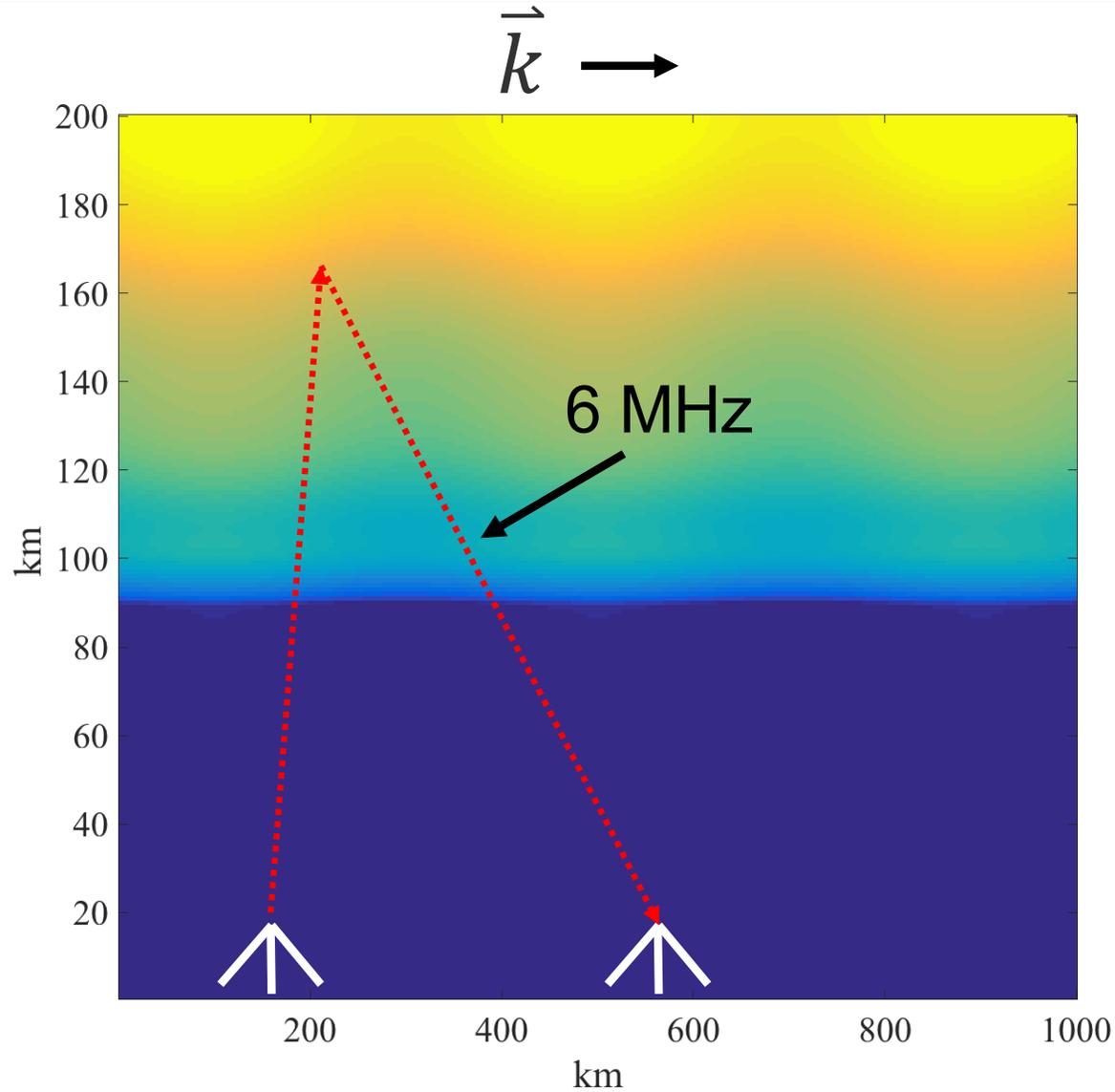
Calm Ionosphere





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Disturbed Ionosphere



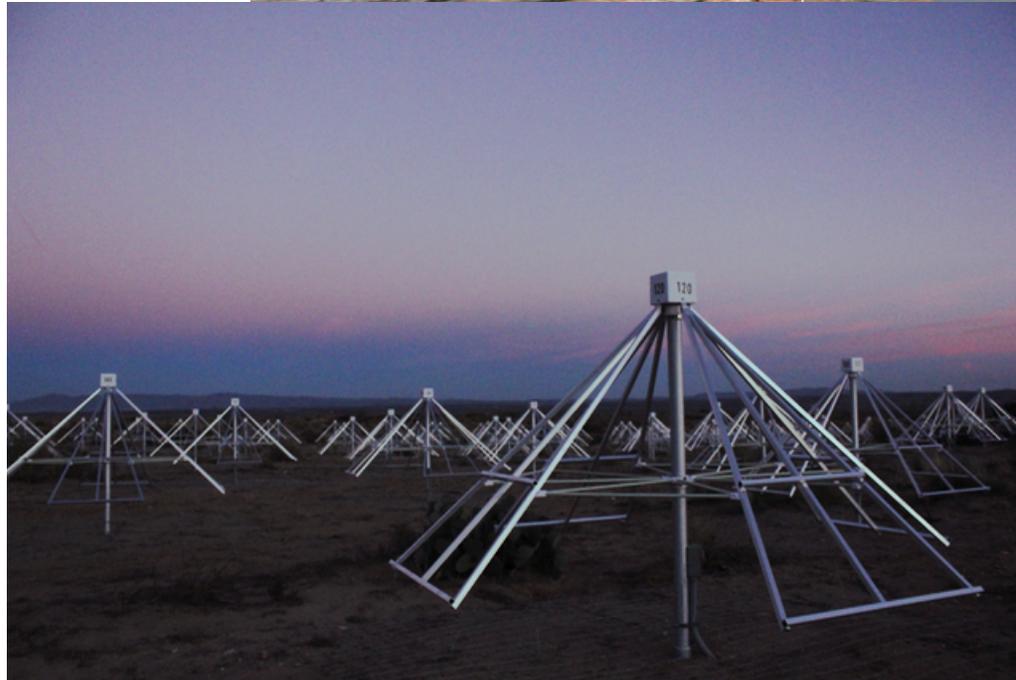
DISTROBUTION A: Cleared for Public Release





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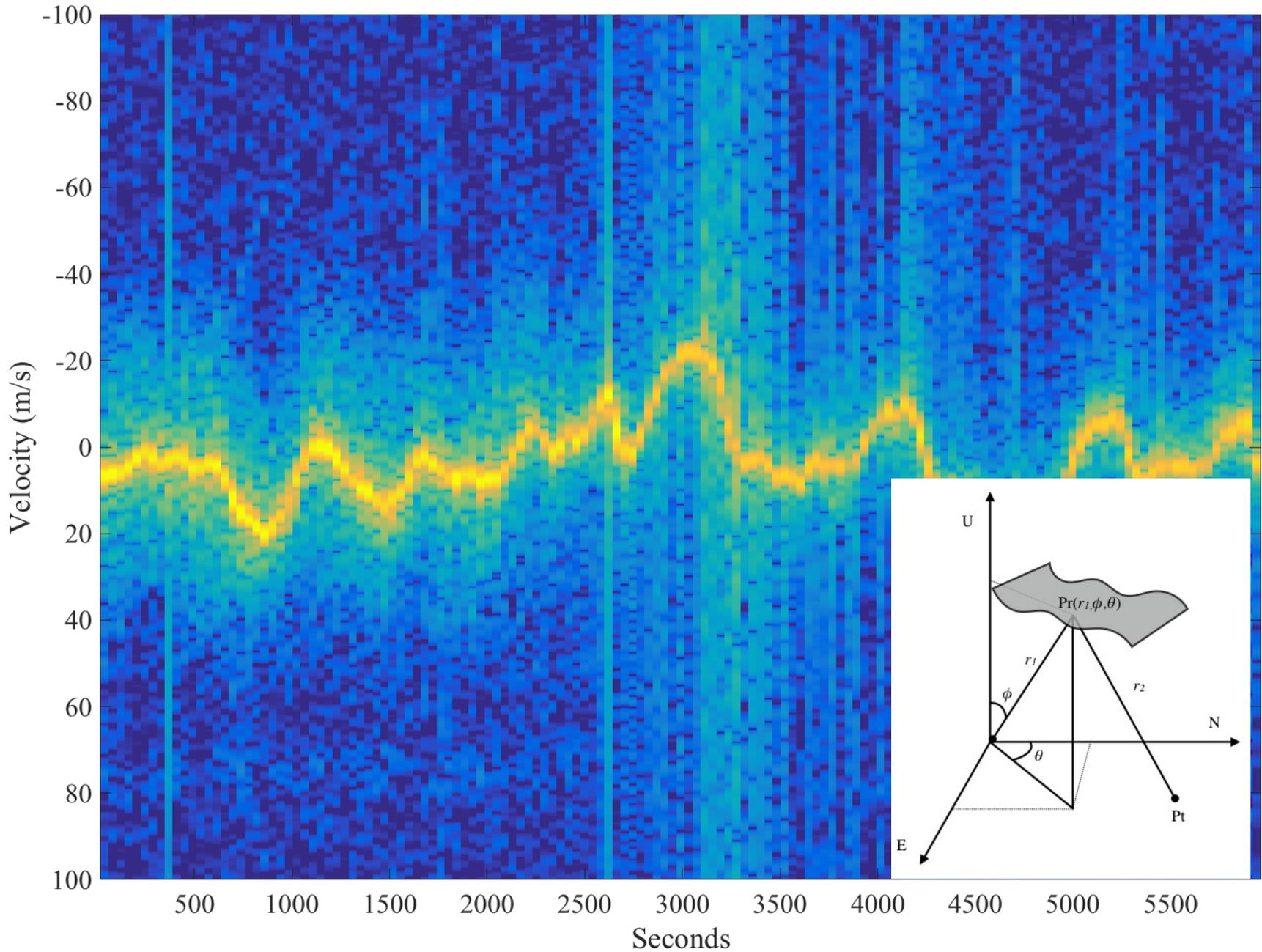
LWA-SV to KAFB





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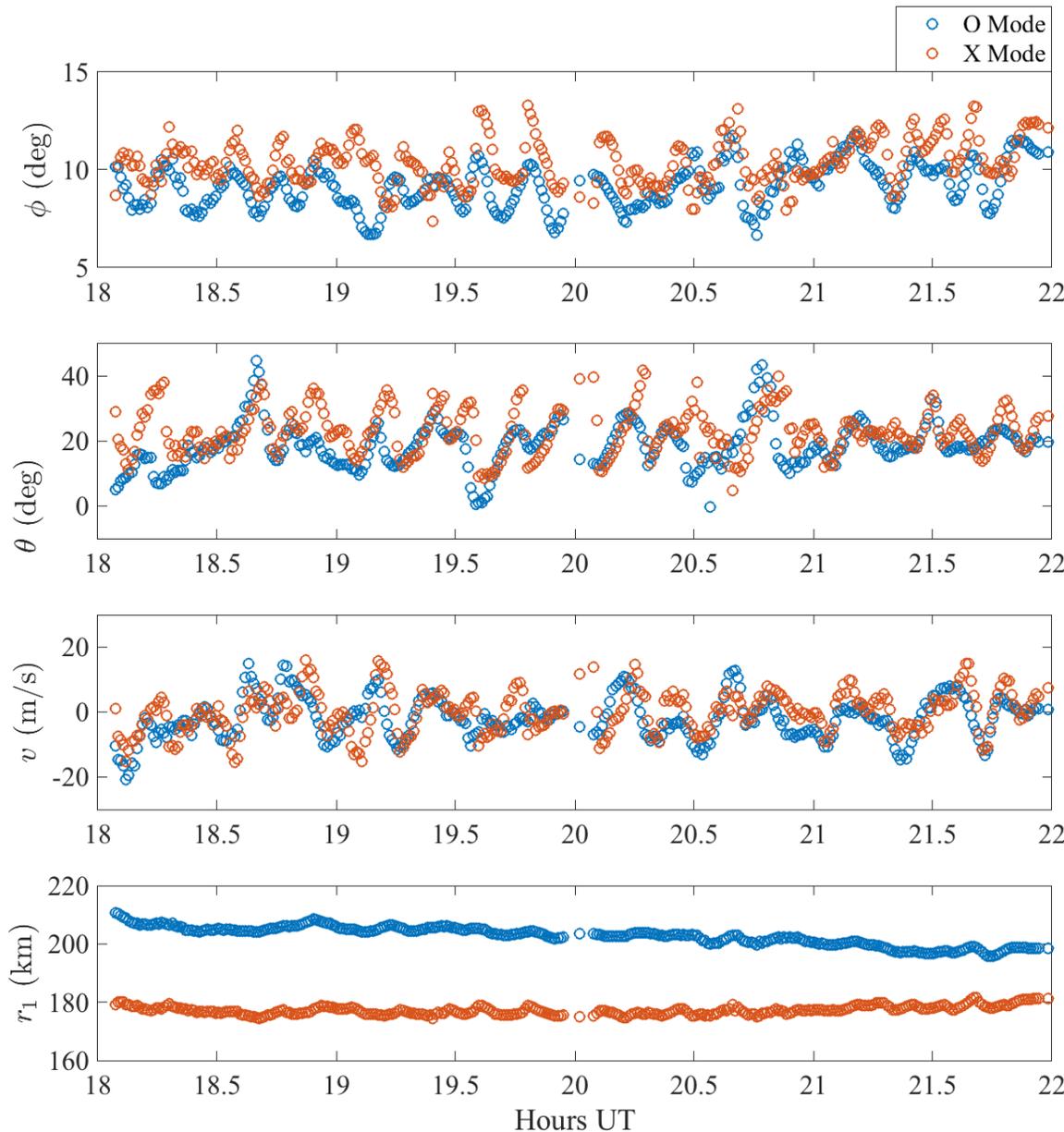
Doppler





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Frequency-and-Angular-Sounding



• FAS relates the power spectra of Az, El, and Doppler (or R) to the spectra of the bottomside Ionosphere (TIDs)

$$\alpha(t) = \frac{D \sin \phi(t) \cos \theta(t) - L}{\sqrt{D(t)^2 + L^2 - 2D(t)L \sin \phi \cos \theta}}$$

$$\beta(t) = \frac{D \sin \phi(t) \sin \theta(t)}{\sqrt{D(t)^2 + L^2 - 2D(t)L \sin \phi \cos \theta}}$$

$$\tan \Theta(\Omega) = \frac{S_\beta(\Omega)}{S_\alpha(\Omega)}$$

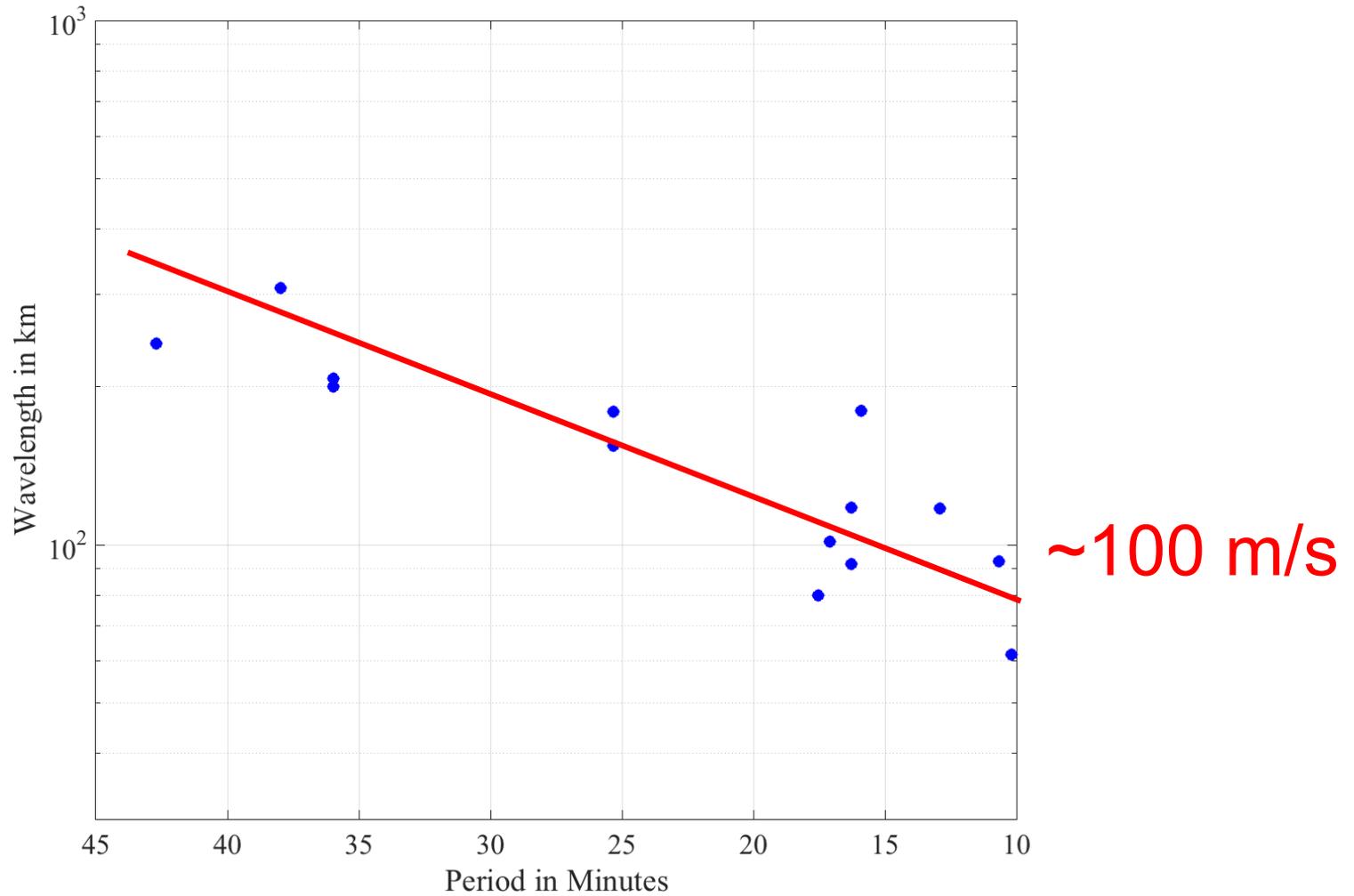
$$K(\Omega) = \frac{4H_0}{cD_0} \sqrt{\frac{|S_\alpha(\Omega)|^2 + |S_\beta(\Omega)|^2}{|S_\tau(\Omega)|^2}}$$

$$\tau = R/c$$



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Wavelength v Period of TIDs



These are a sample of measured of TIDs



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Sample of LWA-SV Ionospheric Science



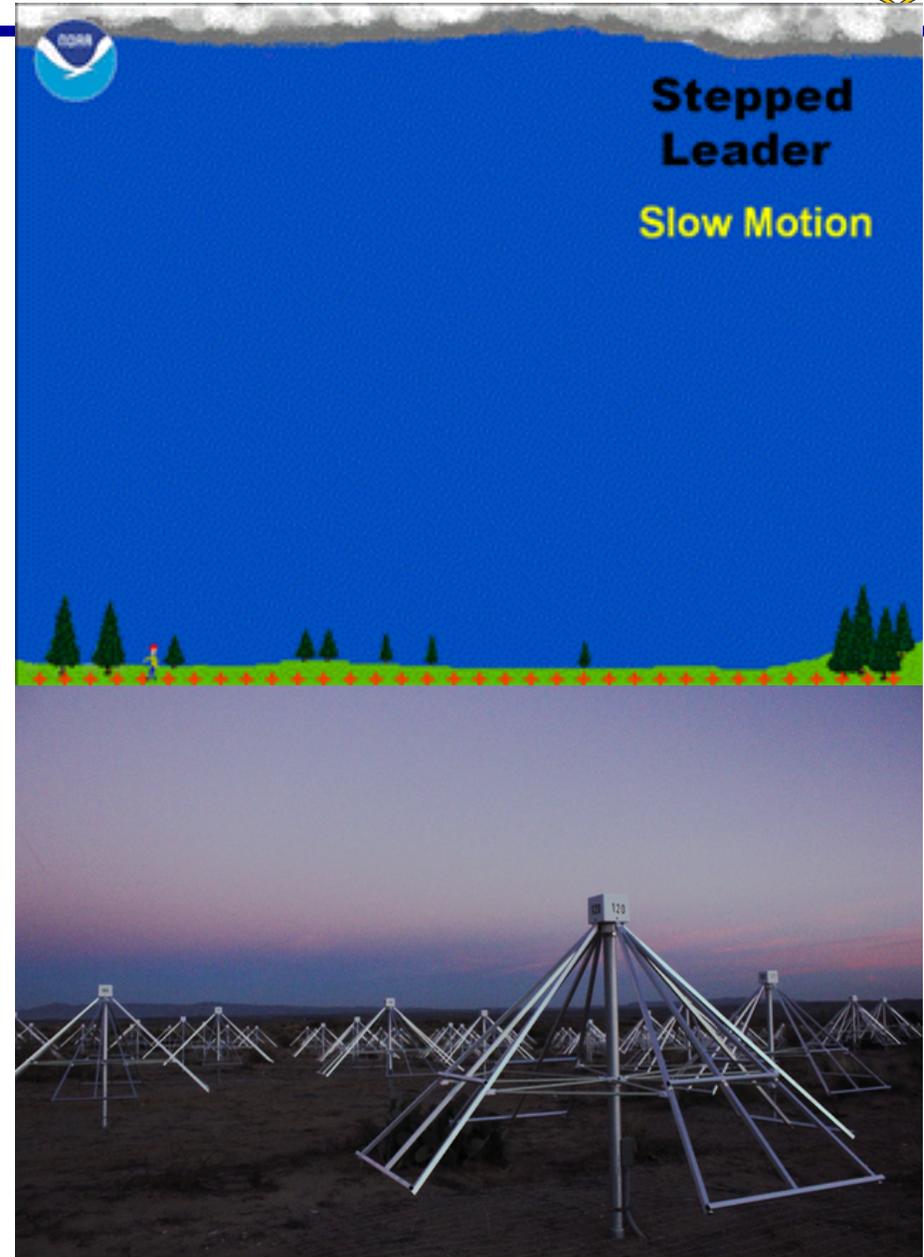
1. HF sounding with a DPS4D
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Radio Emission from Lightning



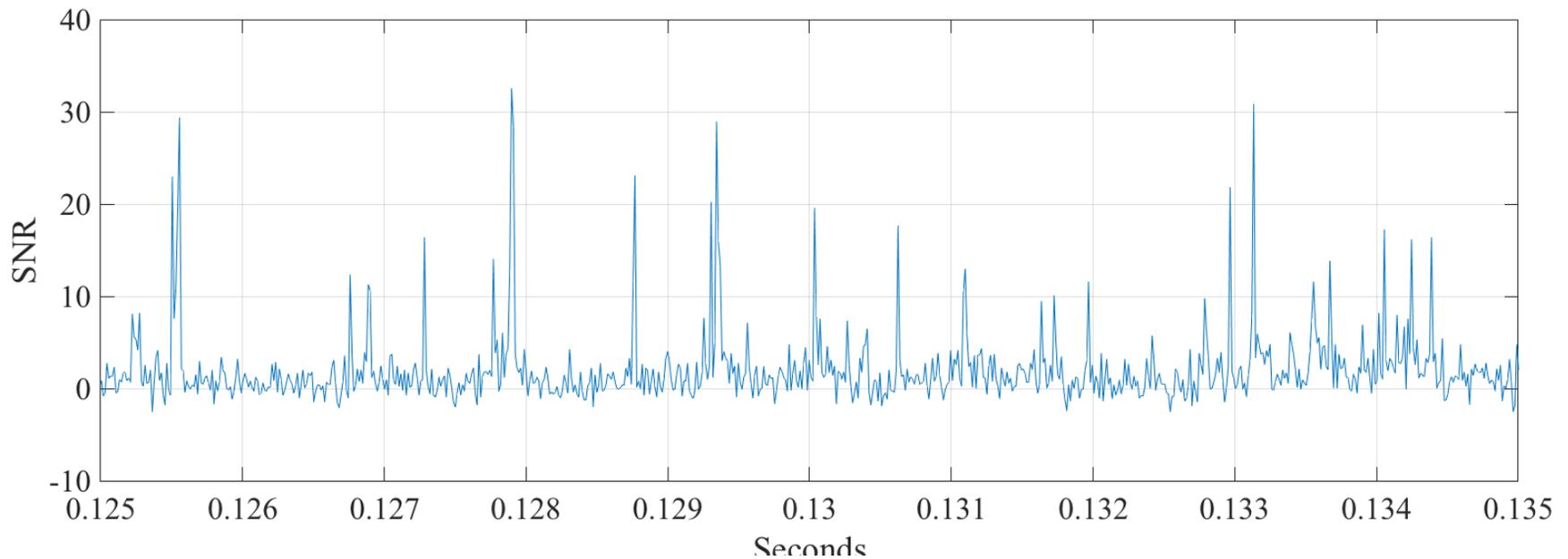
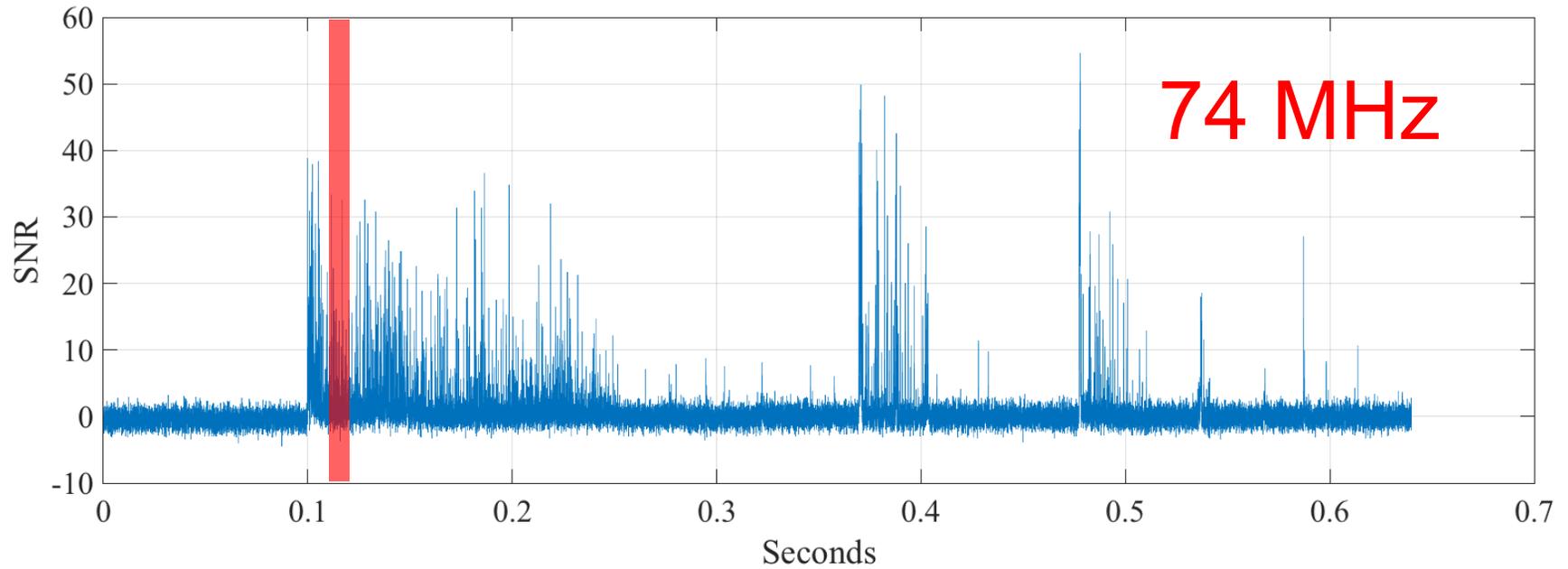
- Breakdown of air often occurs in steps
- Each step produces a short ($\sim 10\mu\text{s}$) broad band (HF – UHF; 3 – 3000 MHz) radio burst
- Easily observed with an antenna or an Array such as the LWA-SV





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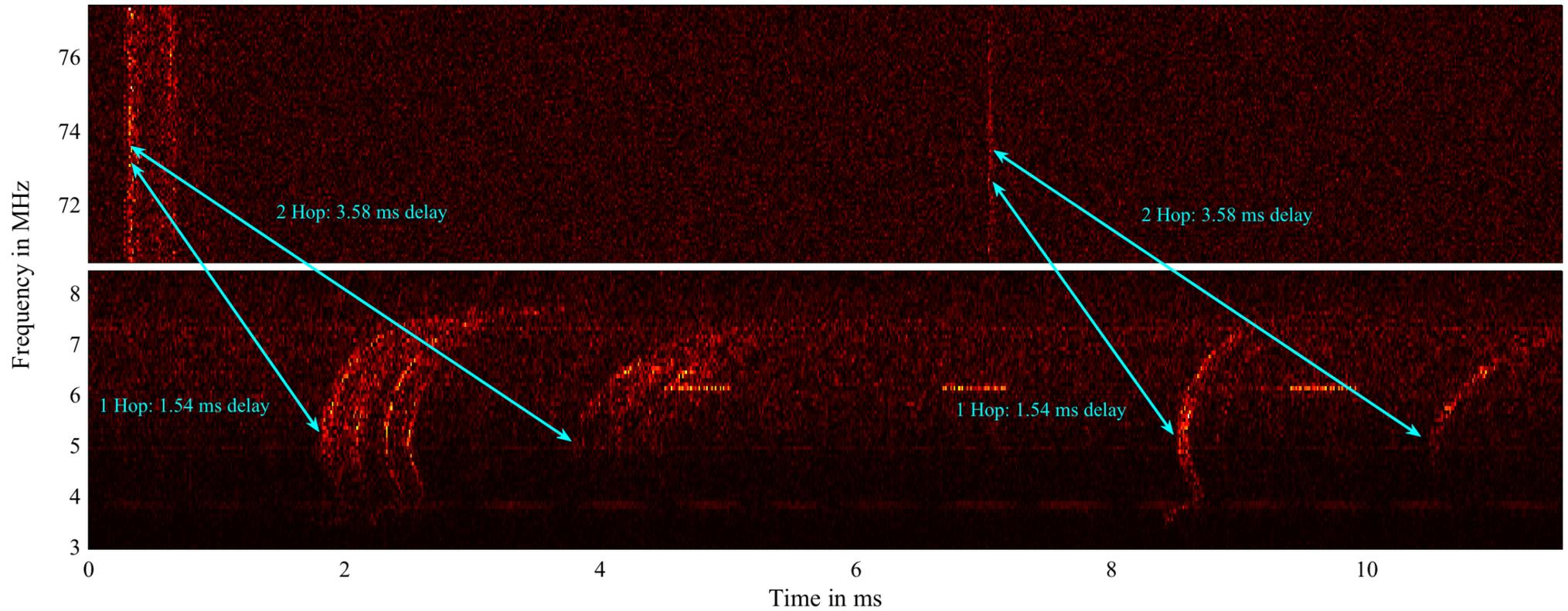
Radio Emission from Lightning





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Observations with LWA-SV



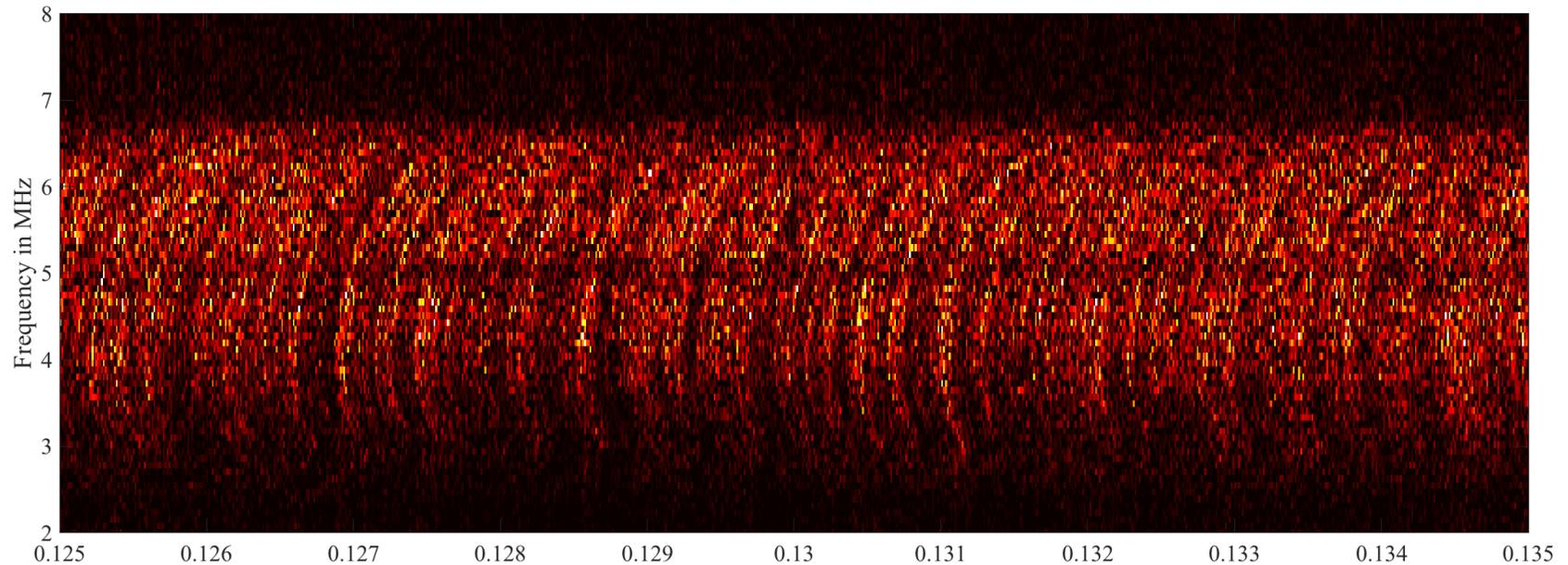
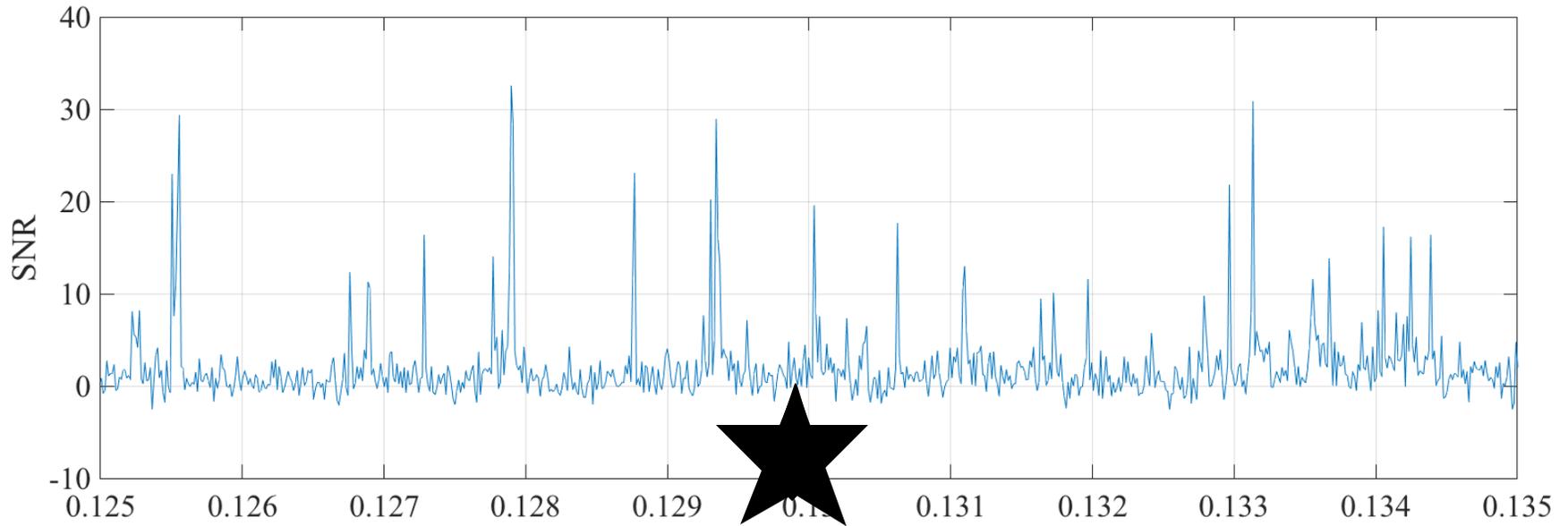
For isolated bursts it is easy to see the 1 Hop and 2 Hop ionospheric reflections



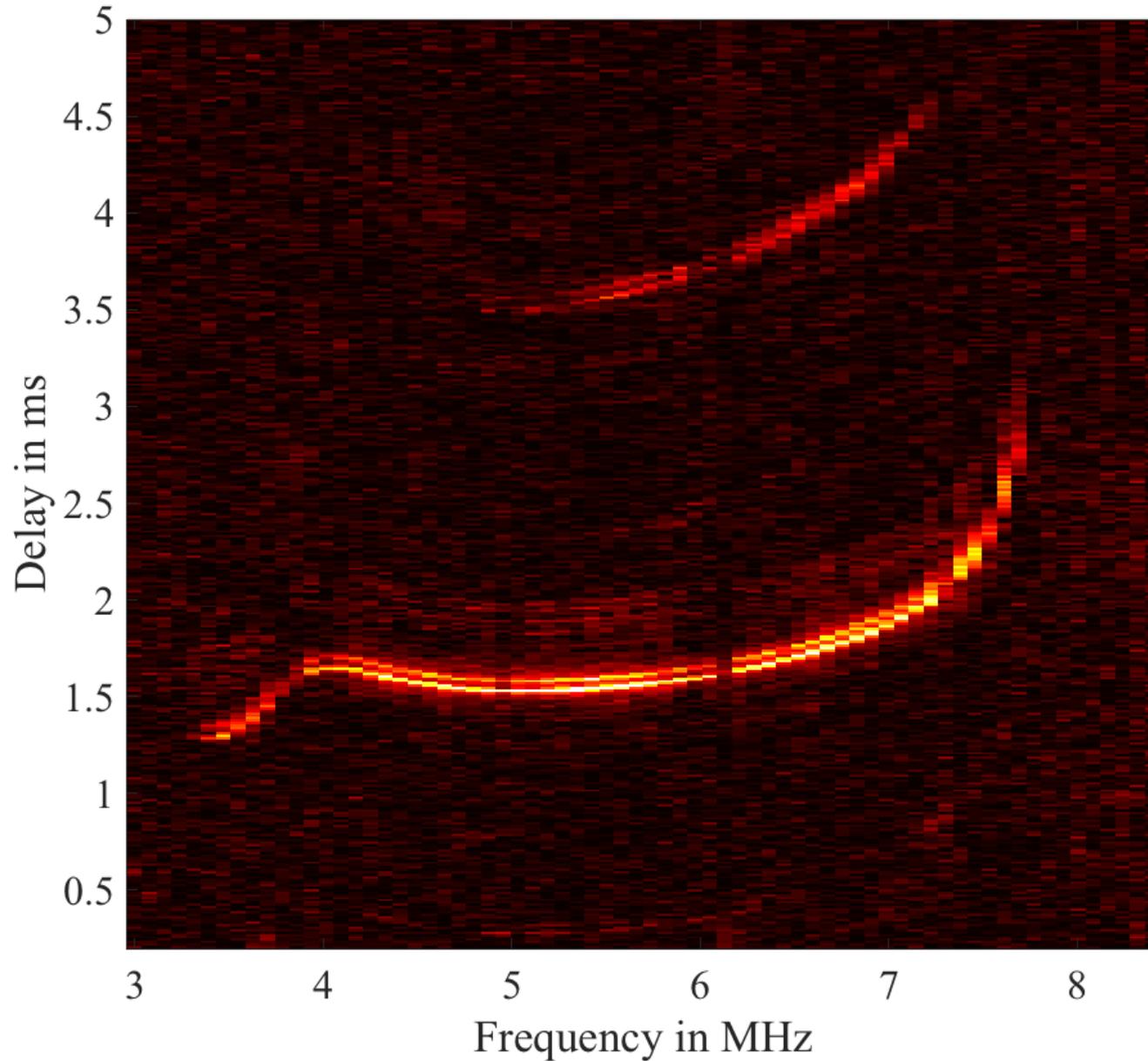
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How to make an Lionogram?



How to make an Lionogram?

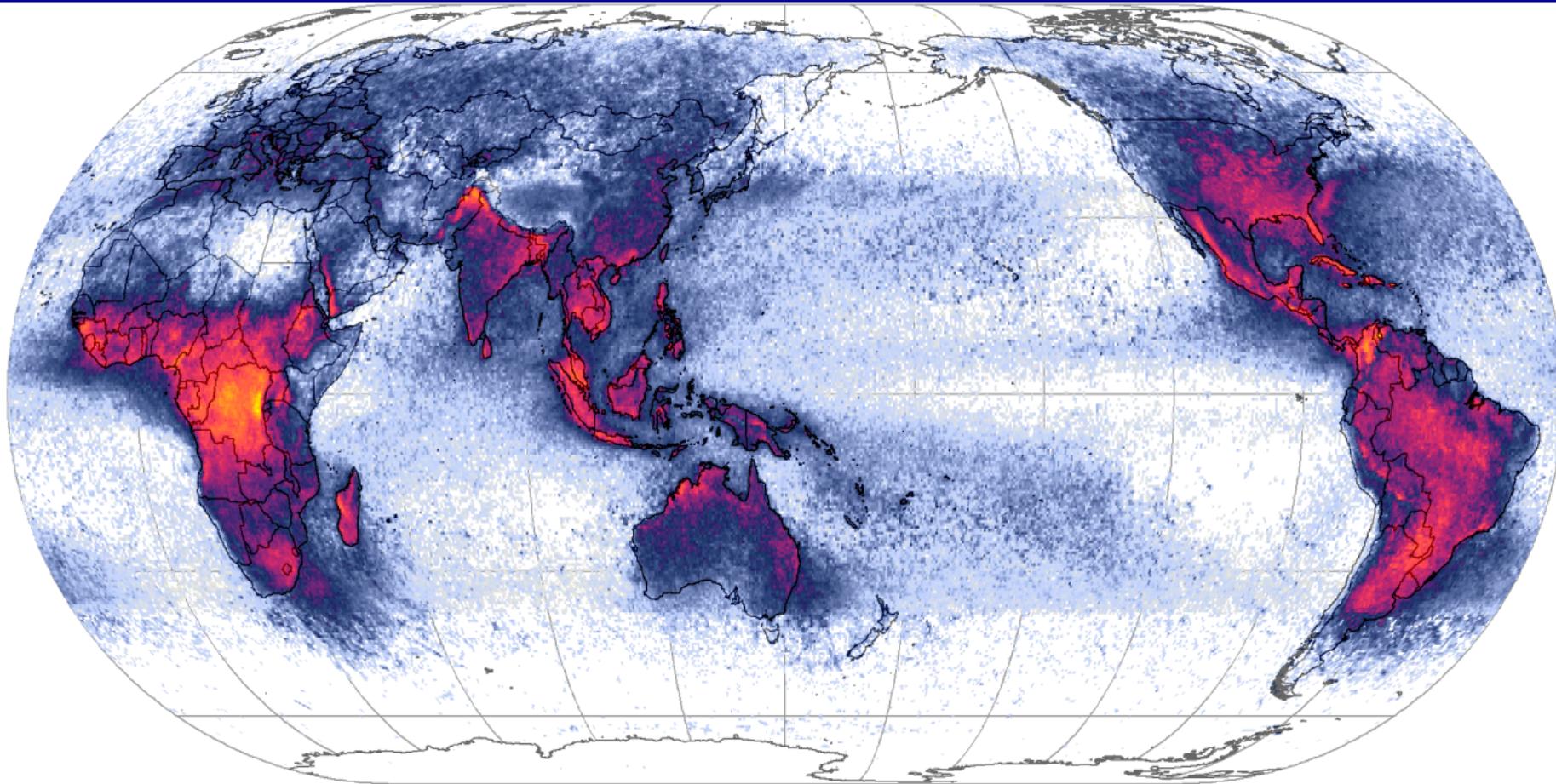




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Potential Worldwide



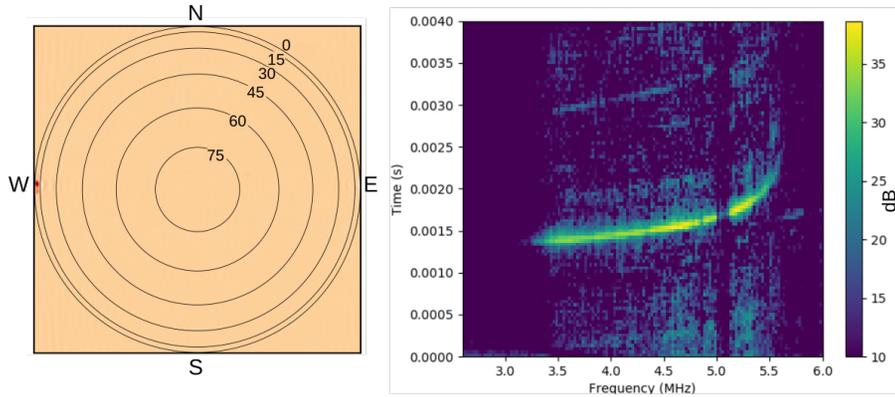
Average strikes per square kilometre per year

0.1 0.2 0.5 1 2 5 10 20 50 100 200

NASA OTD
1998-2003

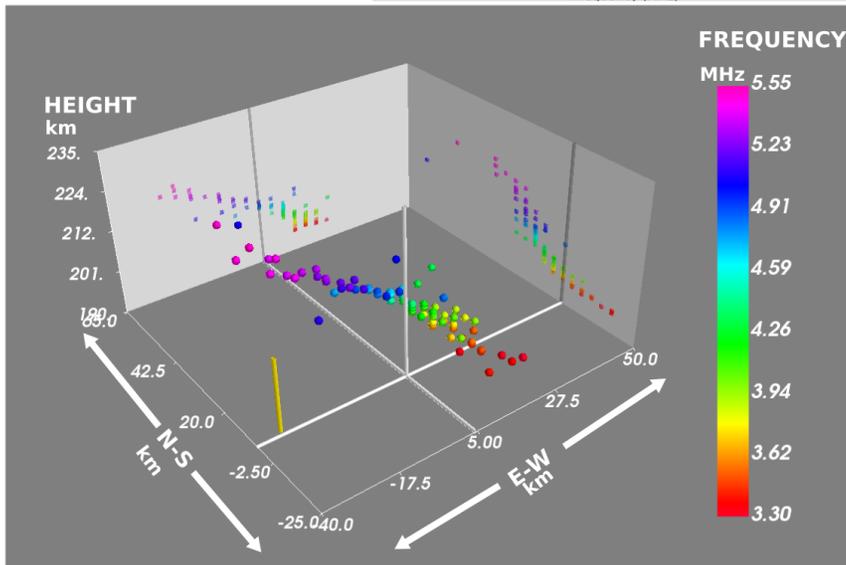
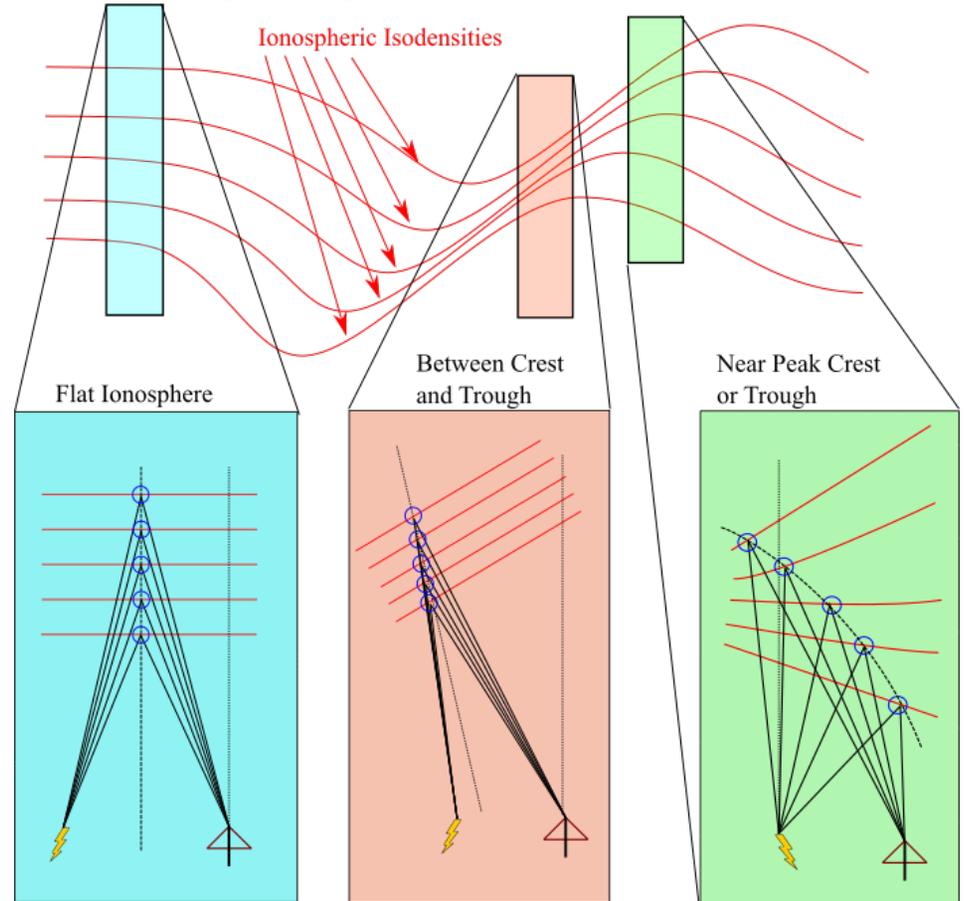


Imaging the Ionograms



How a TID might produce different Ionogram Reflections

An Example out of phase Ionospheric Disturbance





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Sample of LWA-SV Ionospheric Science



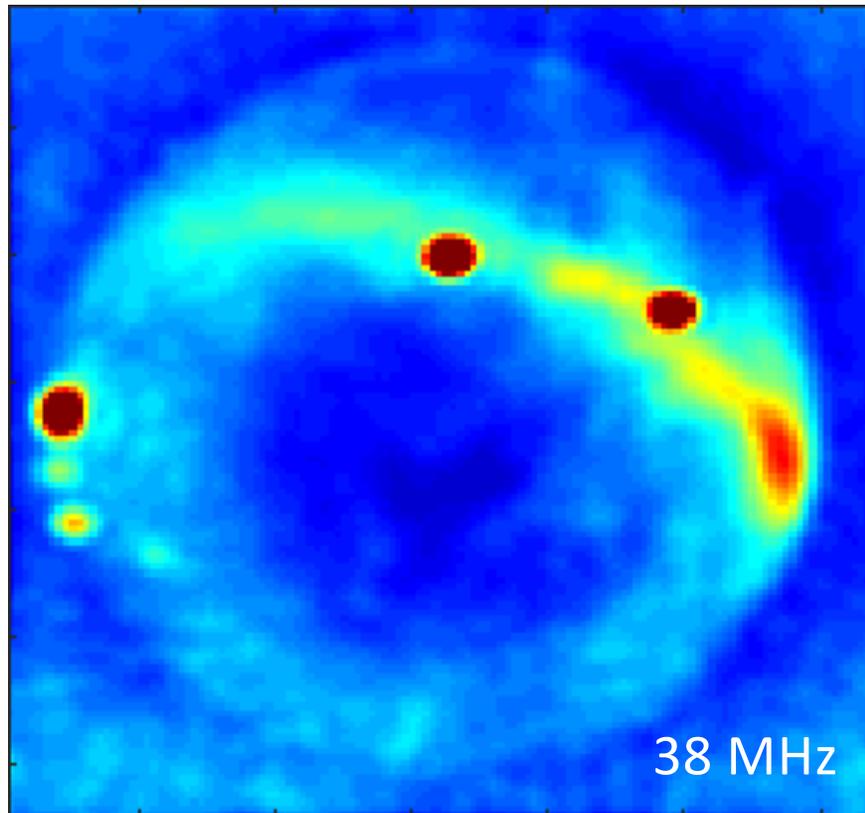
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Traveling Emitting Blobs



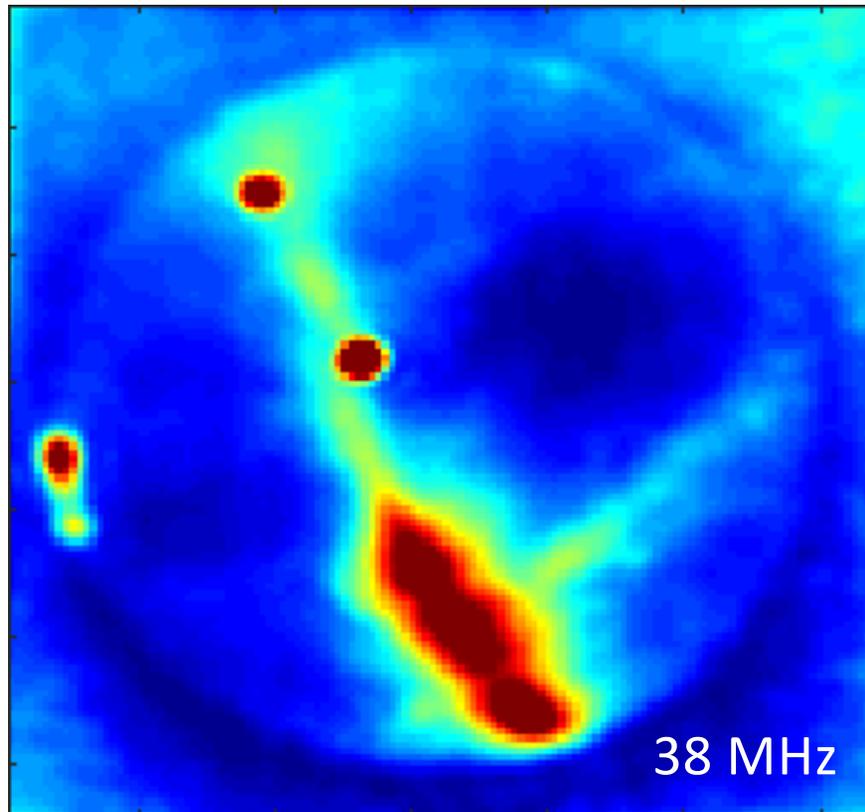
- Traveling Emitting Blobs often form near the horizon of All-Sky Images
- Often seen in the 20 – 70 MHz range
- Sometimes appear to be narrow band, but often broader than 100 kHz band of LASI
- Oftentimes are both linearly and circularly polarized
- Typically move from North to South
- Rarely South to North
- Is 7 times more likely to occur when local foEs is above 6 MHz



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Traveling Emitting Blobs



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Traveling Emitting Blobs

Lowell DIGISONDE

Station	YYYY	DAY	DDD	HMMSS	P1	FFS	S	AXN	PPS	IGA	PS
Kirtland	2019	Jan12	012	035829	RSF	1	713	200	03+	86	

foF2	N/A
foF1	N/A
foF1p	N/A
foE	N/A
foEp	0.38
fxI	N/A
foEs	4.38
fmin	1.82

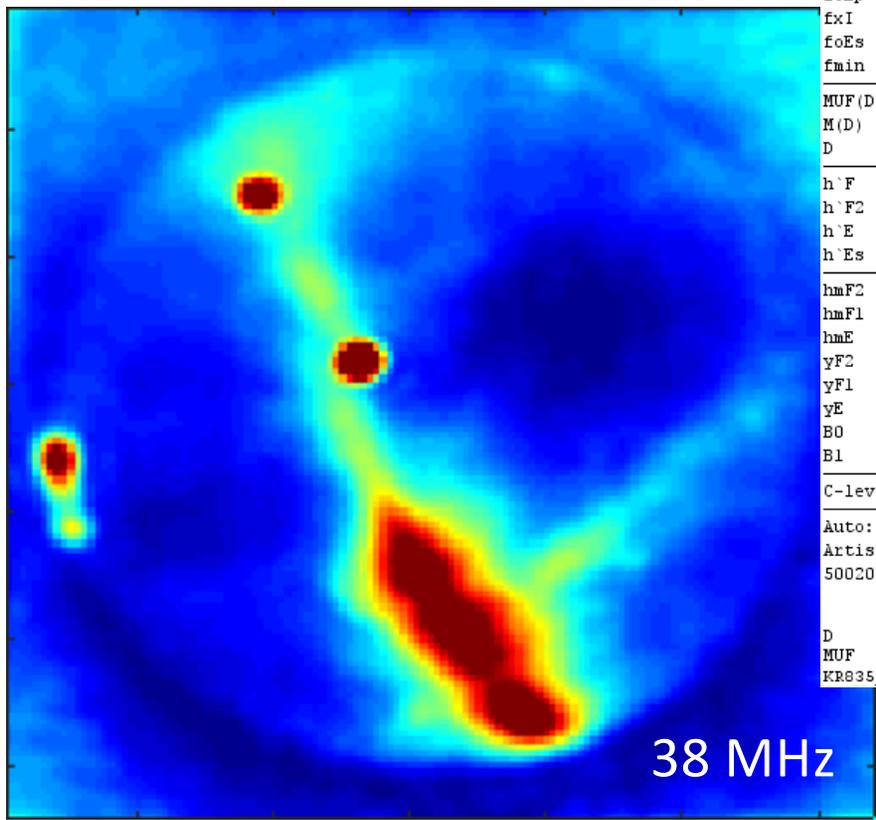
MUF(D)	N/A
M(D)	N/A
D	N/A
h'F	N/A
h'F2	N/A
h'E	N/A
h'Es	100.0

hmF2	N/A
hmF1	N/A
hmE	N/A
yF2	N/A
yF1	N/A
yE	N/A
B0	N/A
B1	N/A

C-level 22
 Auto:
 Artist5
 500200



D 100 200 400 600 800 1000 1500 3000 [km]
 MUF 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 [MHz]
 KR835_2019012035829.RSF / 565fx256h 20 kHz 2.5 km / DPS-4D KR835 991 / 35.0 N 253.5 E Ion2Png 1.3.20



- Is 7 times more likely to occur when local foEs is above 6 MHz

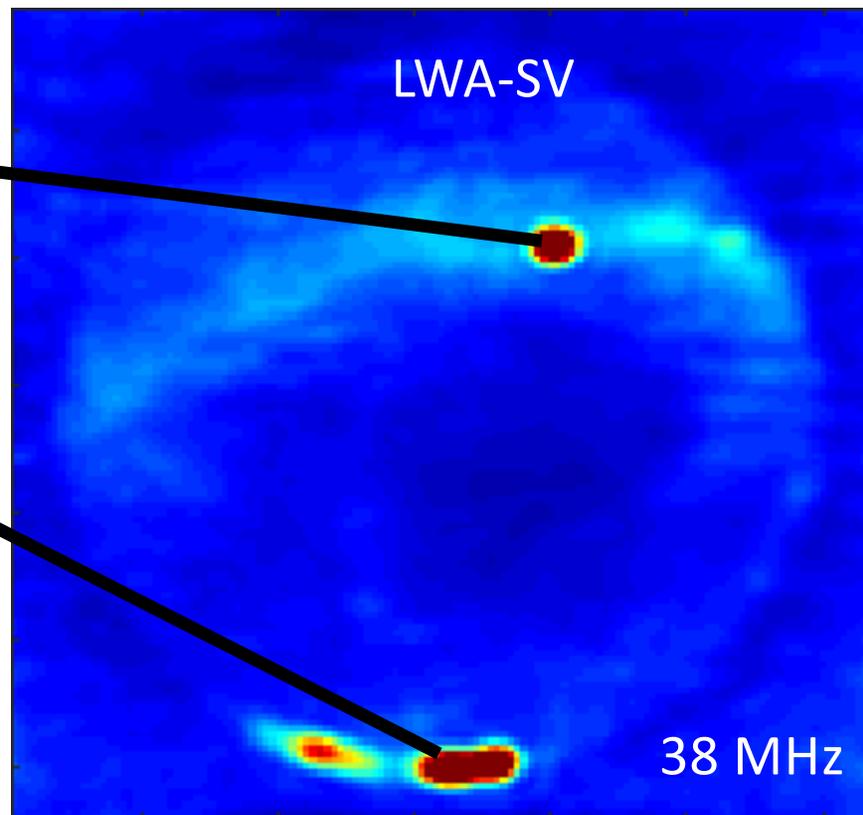
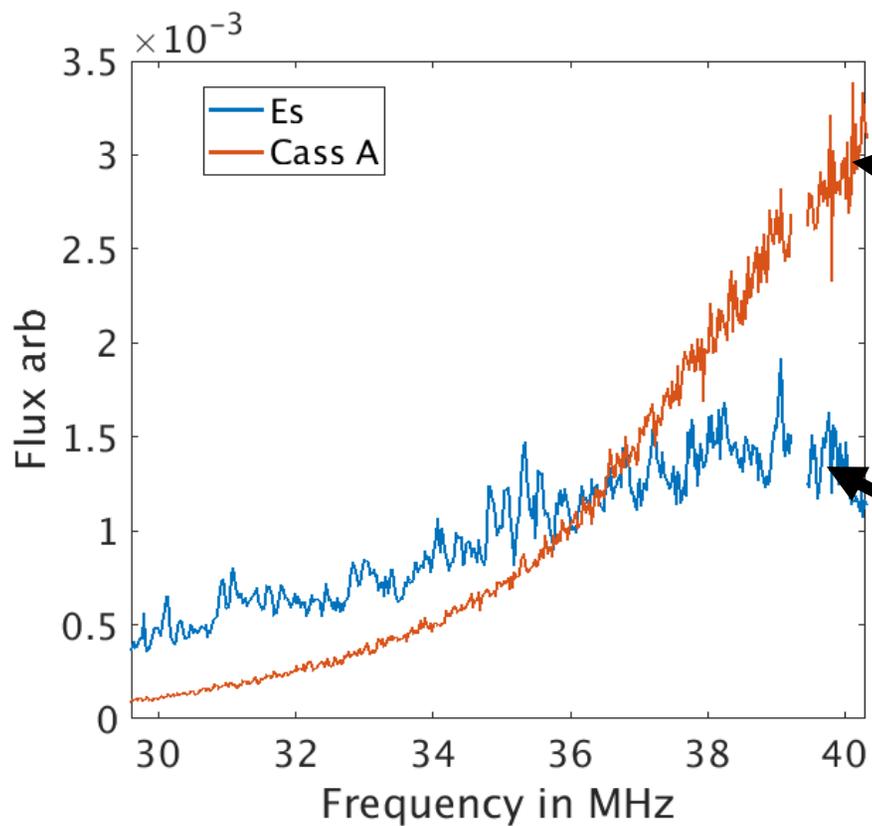




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LWA-SV Broadband Imager

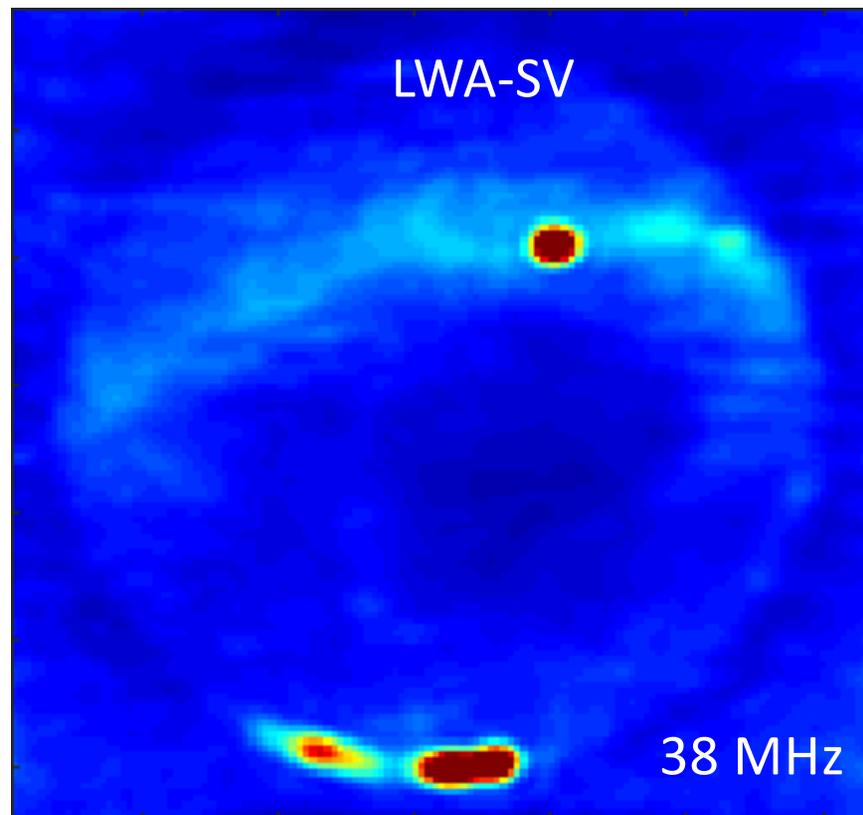
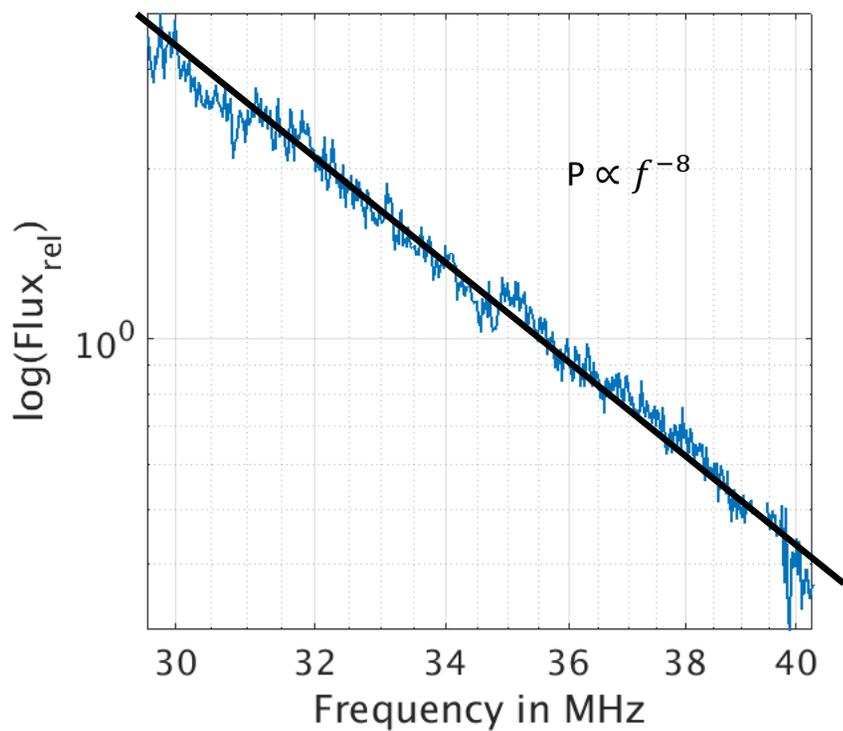




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LWA-SV Broadband Imager





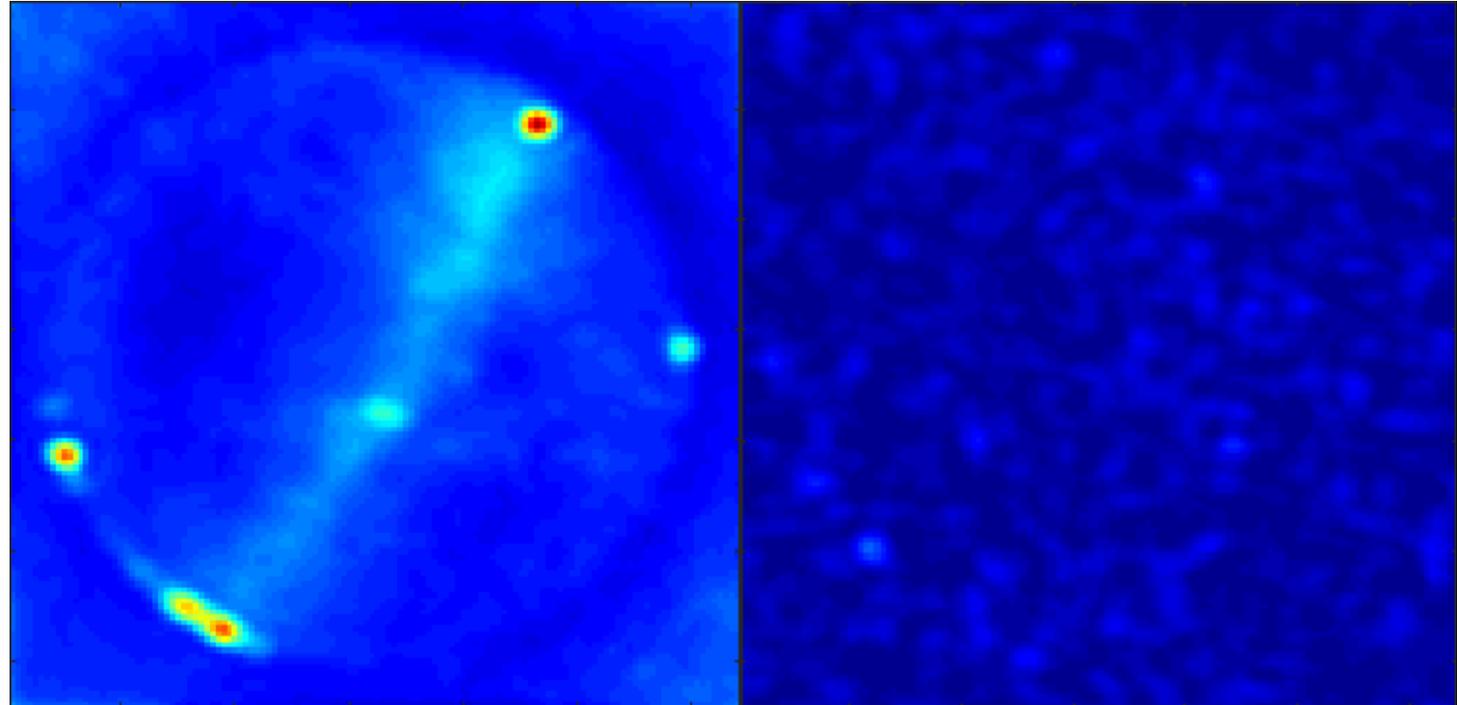
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June 19 2019

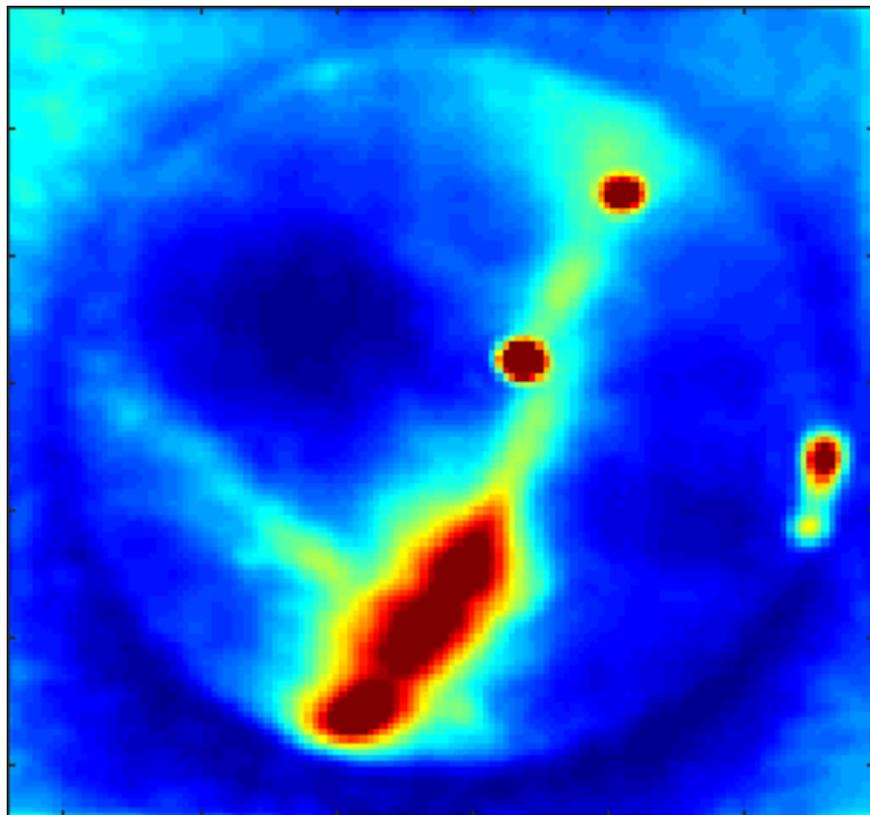
40 μ s All-Sky imaging

- Saved raw TBN data during a typical event
- Imaged at 40 μ s resolution
- Movie shows that blobs are actually composed of short duration bursts (much like lightning)
- However, no lightning within 100s of km

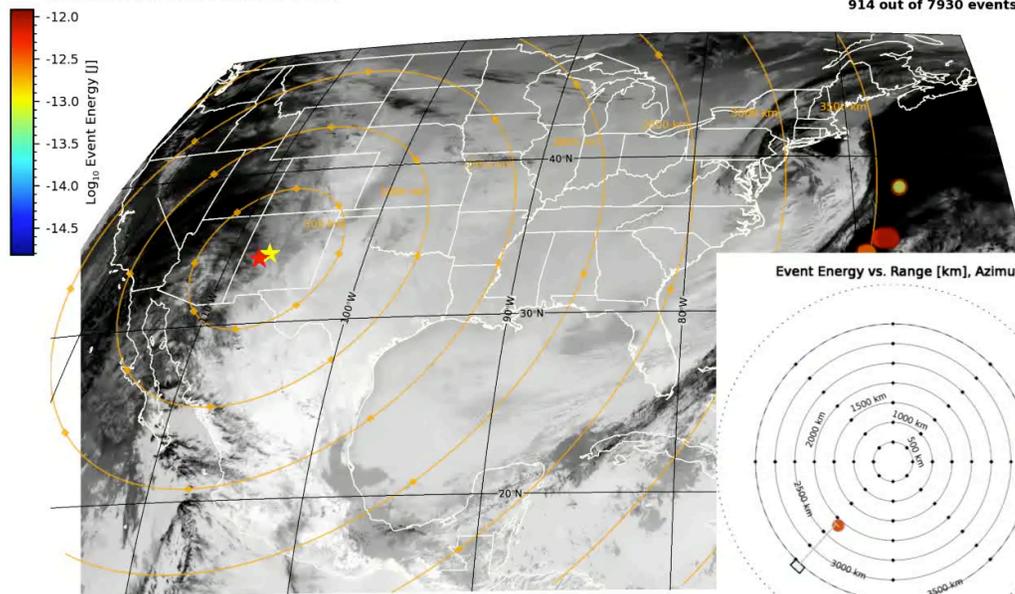




Could Lightning be the source of VHF?



GOES-East ABI L1b Radiances 2019-01-05 18:02:18.1Z
ABI band number: 13 (10.33 um)



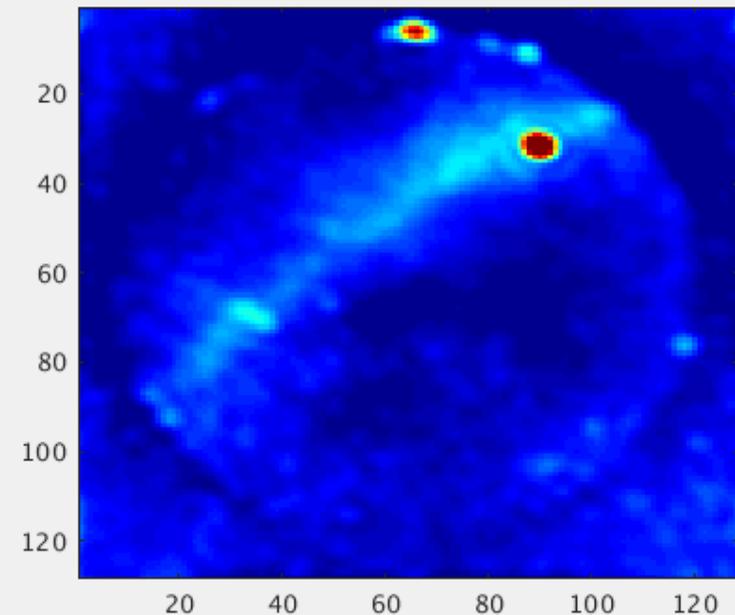
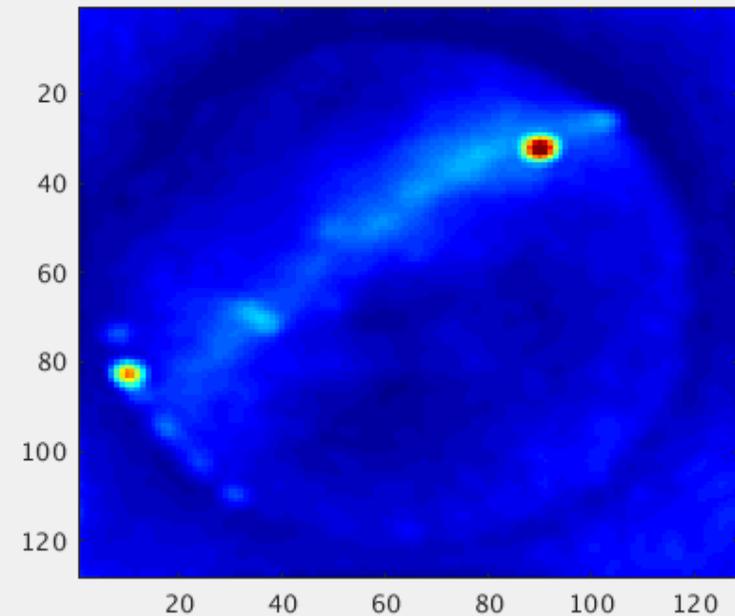
GLM L2 Lightning Detections: Events, Groups, and Flashes (GOES-East) 2019-01-05 18:00:00.0Z





Near Vertical from Both Stations

- The phenomenon seen near vertical from both stations
- Triangulation puts it in the E region (~110 km)
- Velocity puts it at ~60 m/s (AGW speeds)
- Could it be scattering of lightning?
 - it would have to be of ducted modes (2000+ km)
 - Why appear isotropic (both stations point back to scattering region)
- Could it be self emission?
 - Why prefer near horizon?





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Place Proper DISTRIBUTION STATEMENT Here



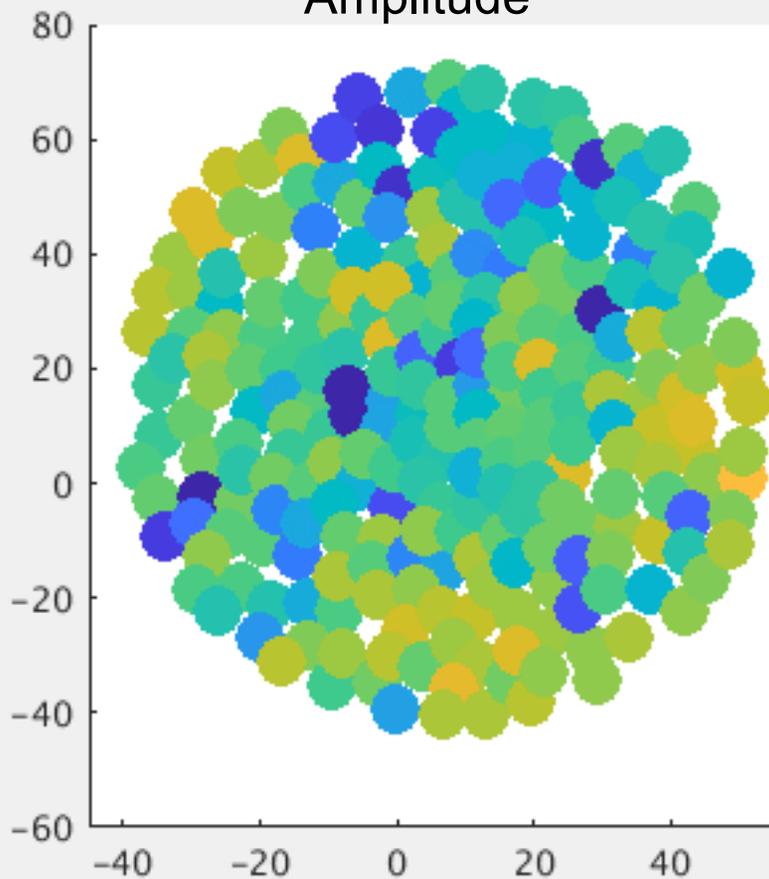


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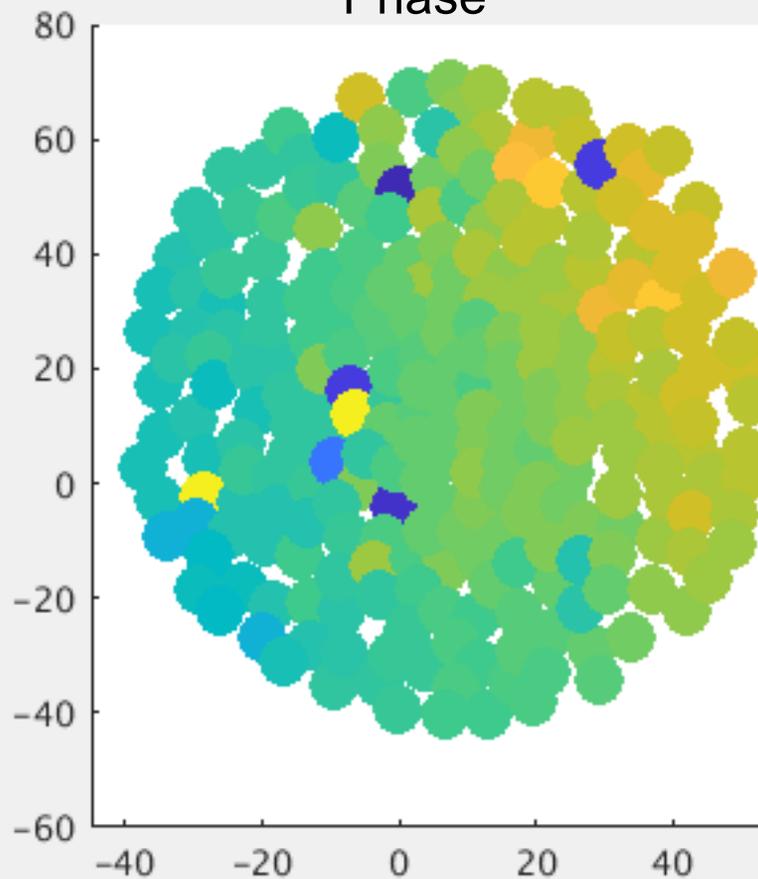
Scintillation pattern across the array



Amplitude



Phase



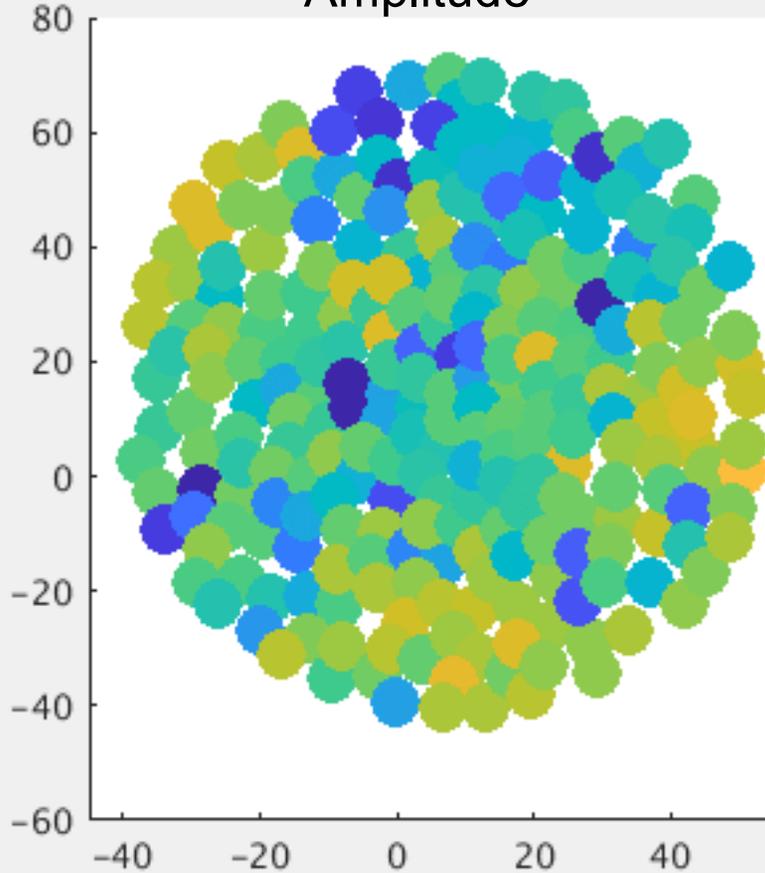


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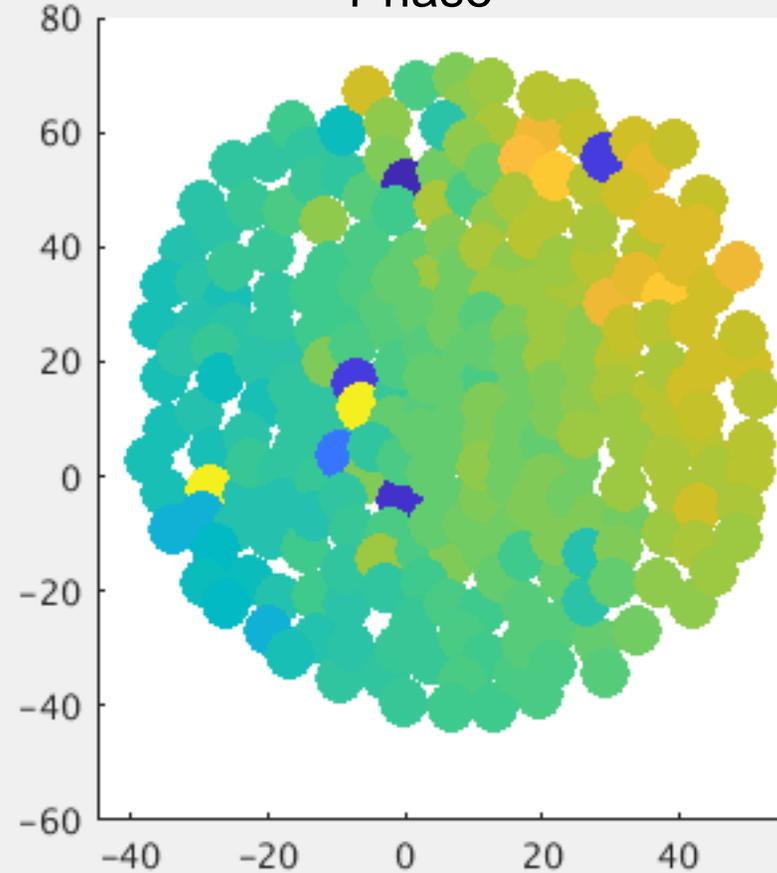
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Amplitude



Phase



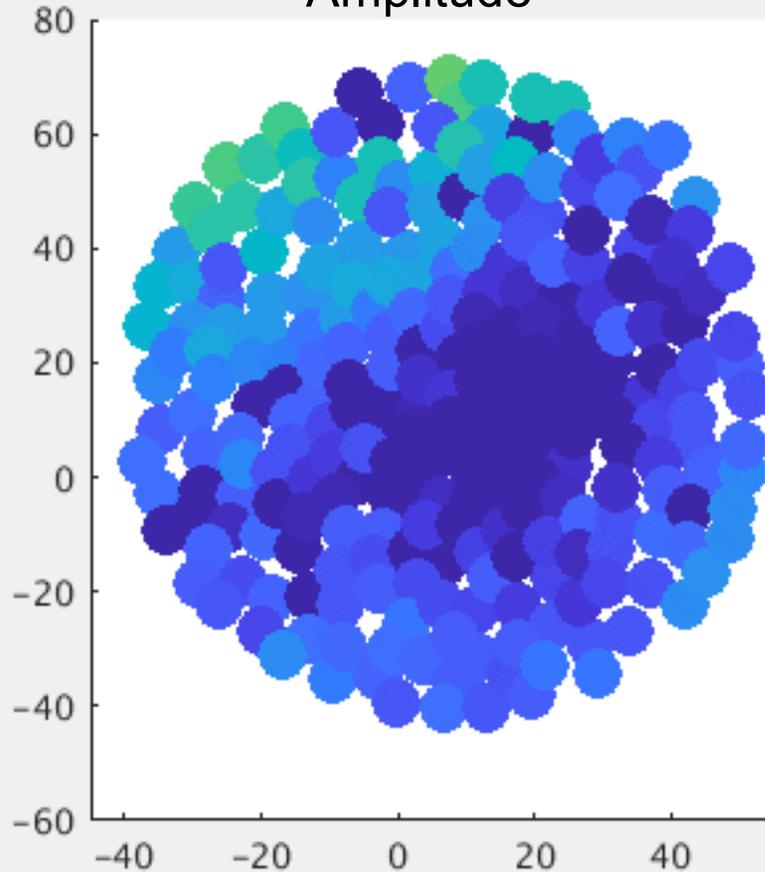


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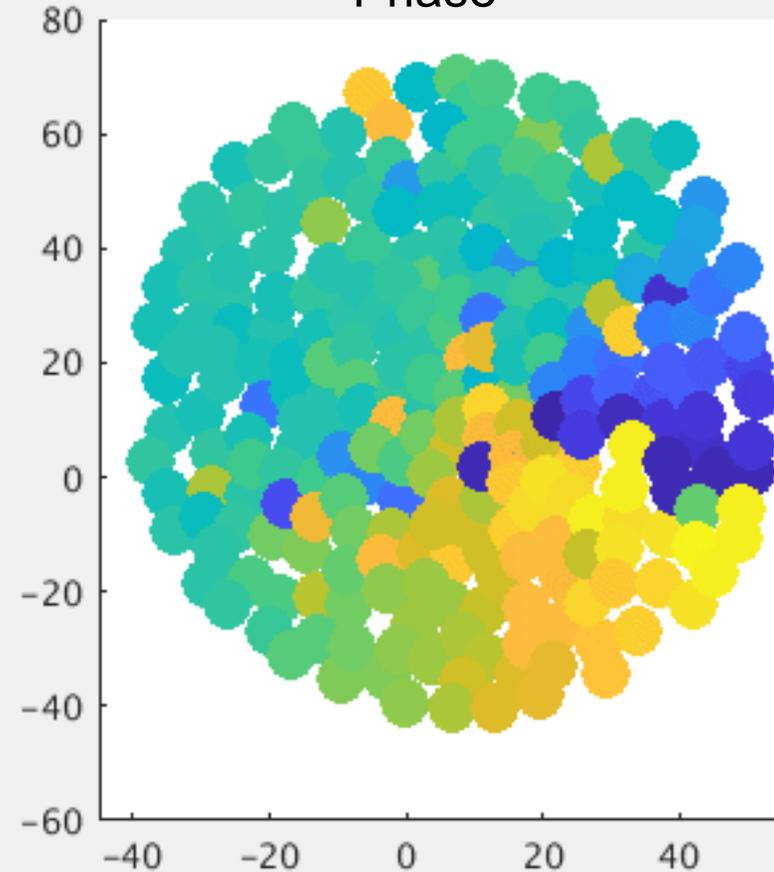
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Amplitude



Phase

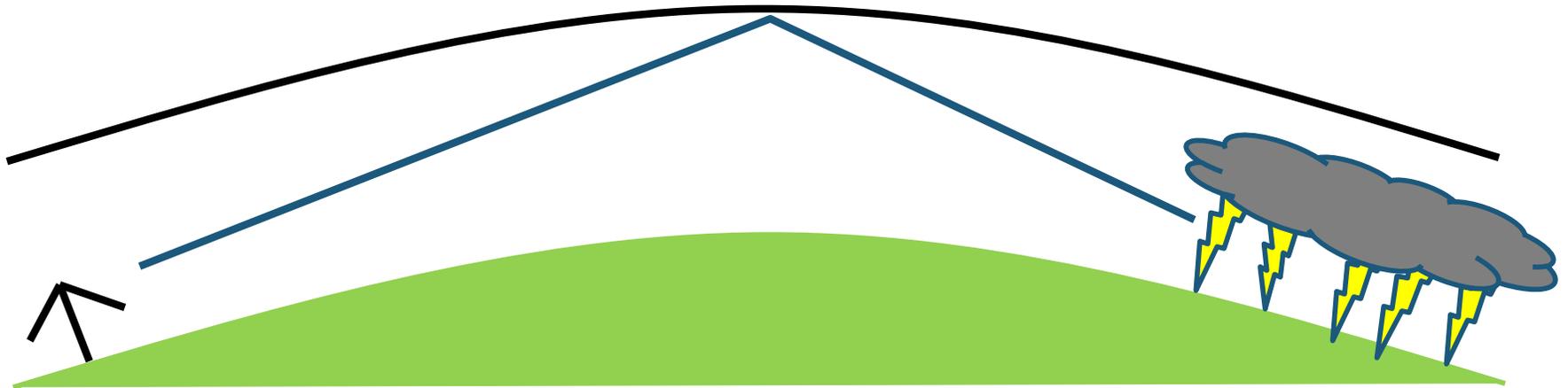




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Geometry of the Observations

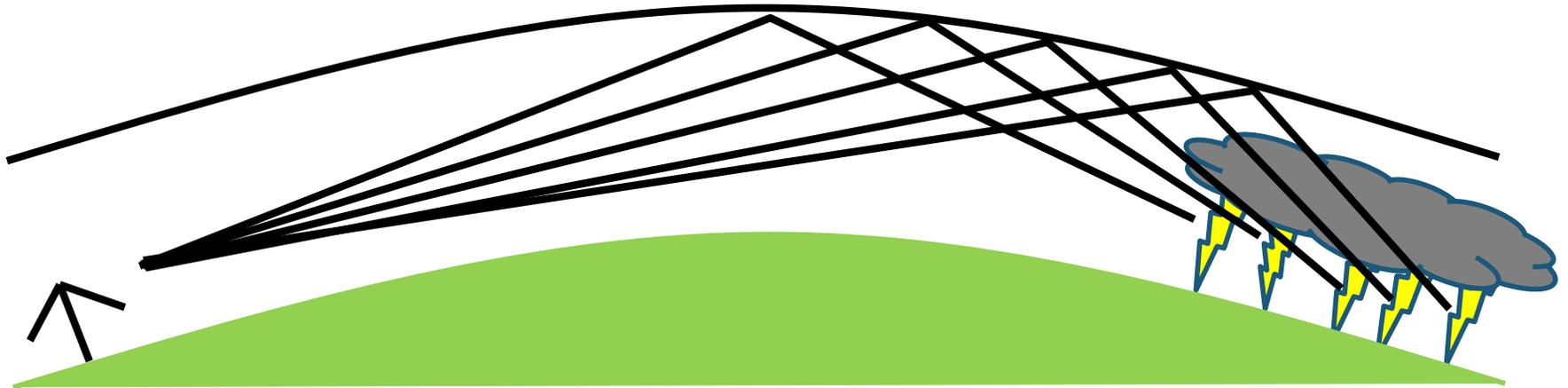




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Geometry of the Observations





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Geometry of the Observations

