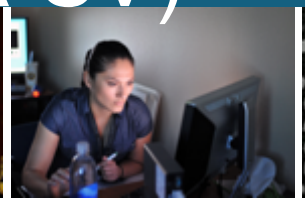
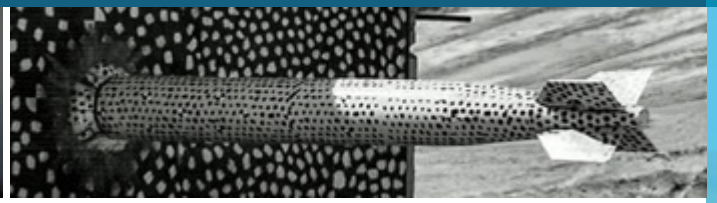
SAND2021-10996C

Sandia National Laboratories

High-speed, high-fidelity radio imaging of lightning using the Long Wavelength Array at Sevilleta, New Mexico (LWA-SV)





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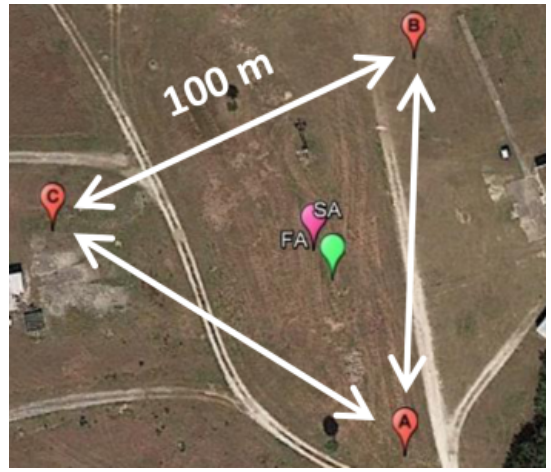
Background: lightning observed with high-speed optical video

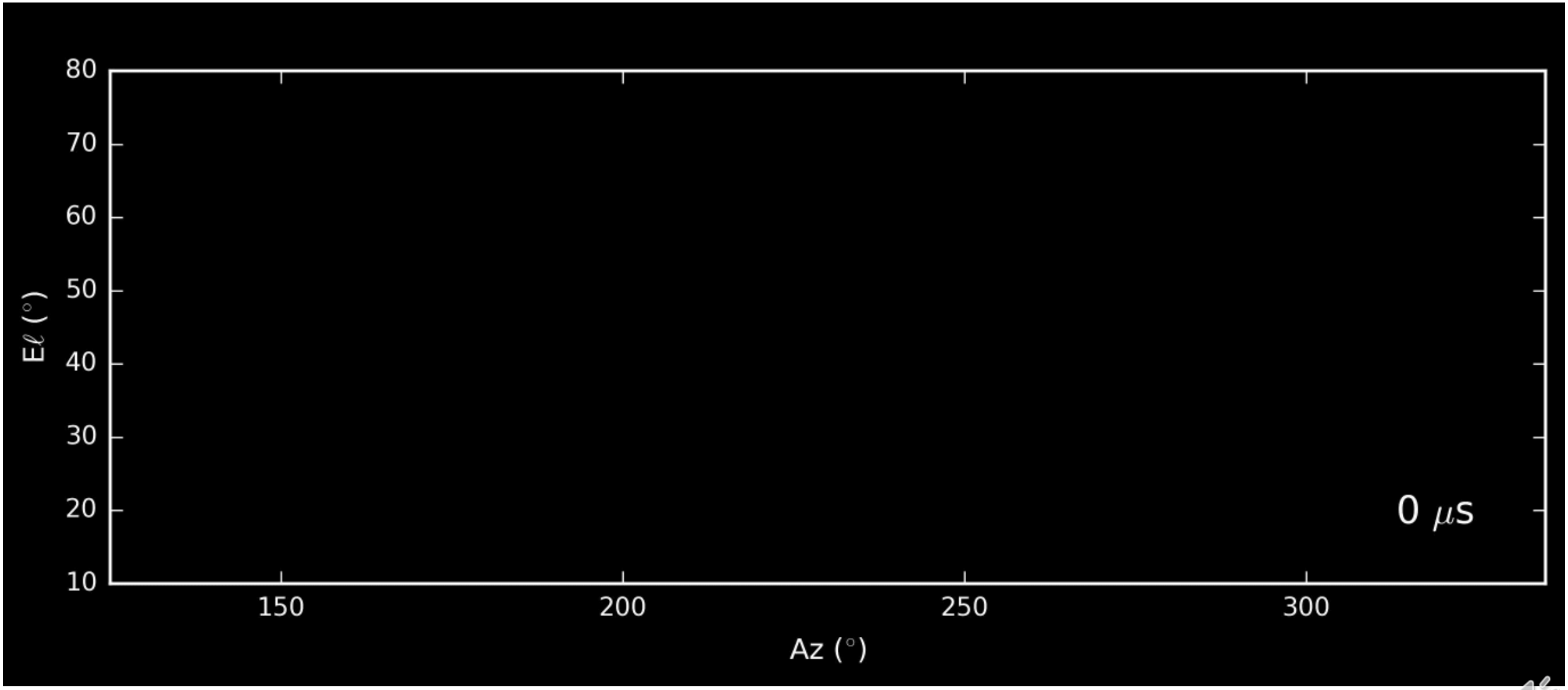
- Lightning is a large-scale natural atmospheric electric discharge.
- Optical light created by current flow (joule heating) in lightning leaders.
- Lightning leaders propagate at speeds of 10^5 to 10^6 m/s.
- Lightning initiates inside clouds.

Background: lightning interferometry with sparse arrays

- Sparse (3-antenna) array with 100-meter baselines.
- Broadband (~80 MHz), digitizing each time-domain signal at 180 MHz, 16 bits.
- Developed by New Mexico Tech.



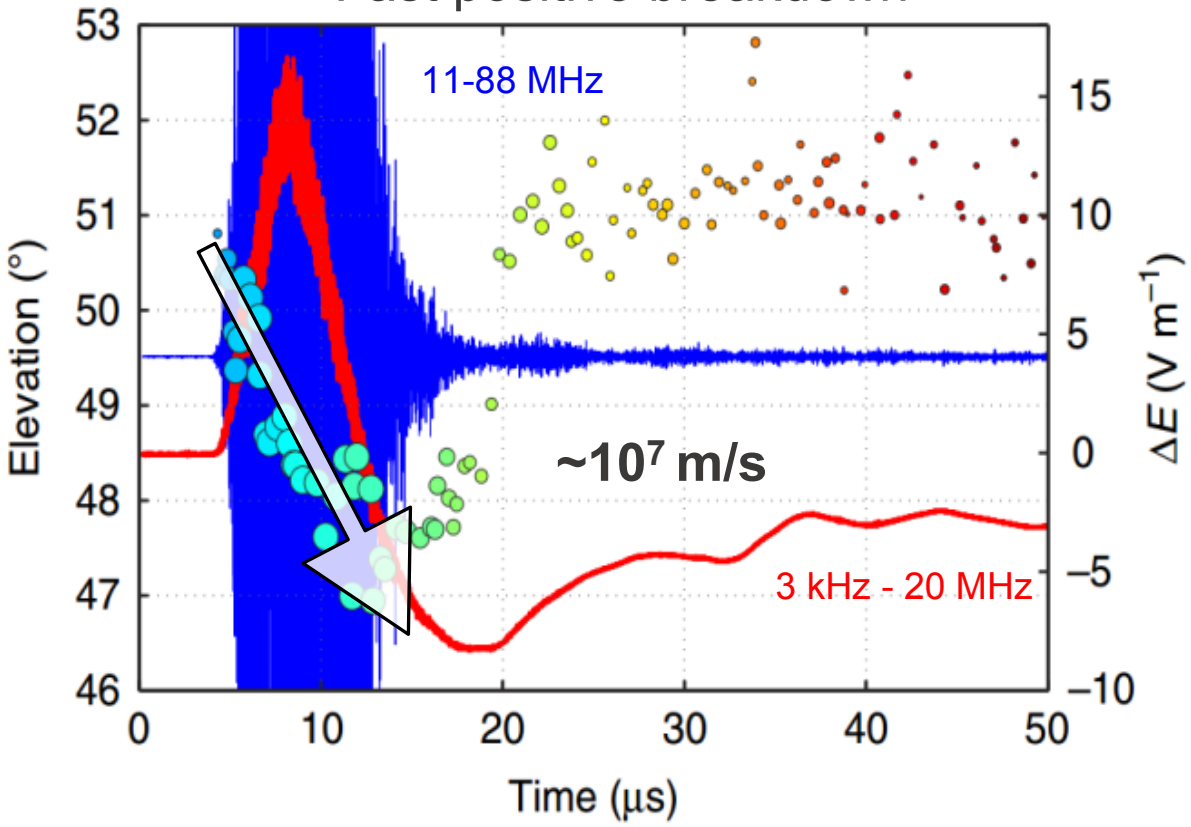
Background: lightning mapping with sparse arrays



Background: lightning initiation with sparse arrays

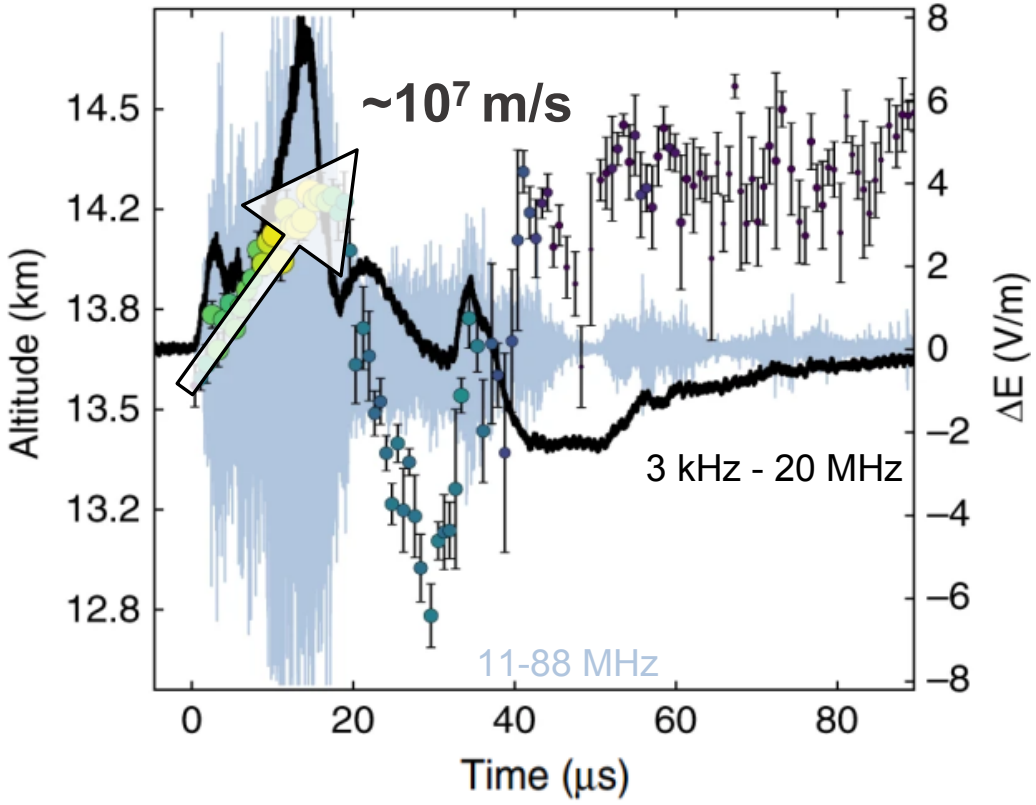
- Lightning initiated by fast (>10^7 m/s) electrical breakdown.

Fast positive breakdown



Rison et al., 2016, *Nature Communications*

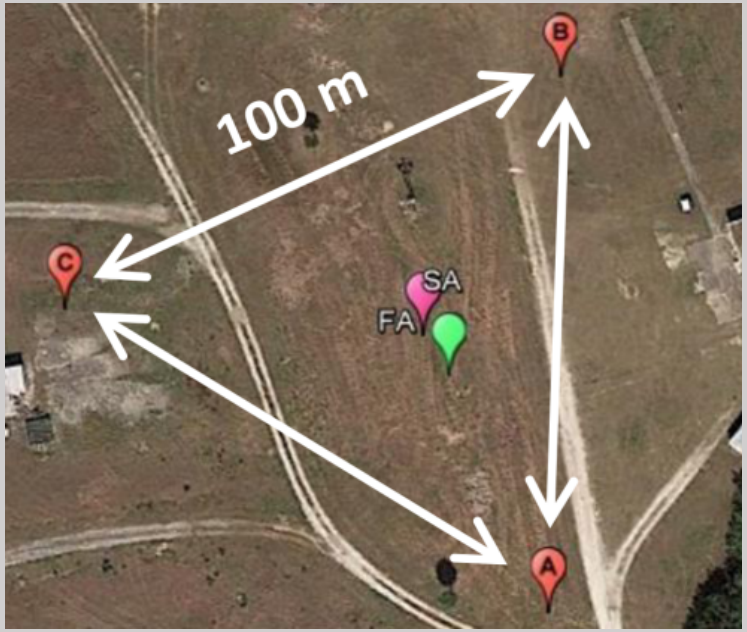
Fast negative breakdown



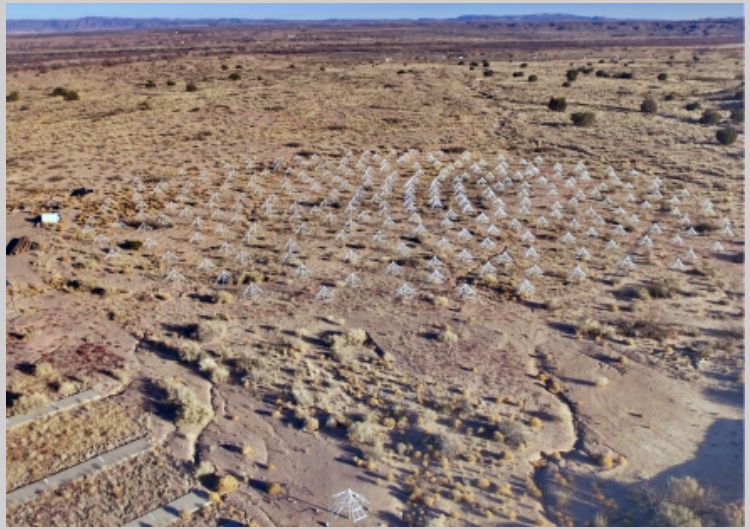
Tilles et al., 2019, *Nature Communications*

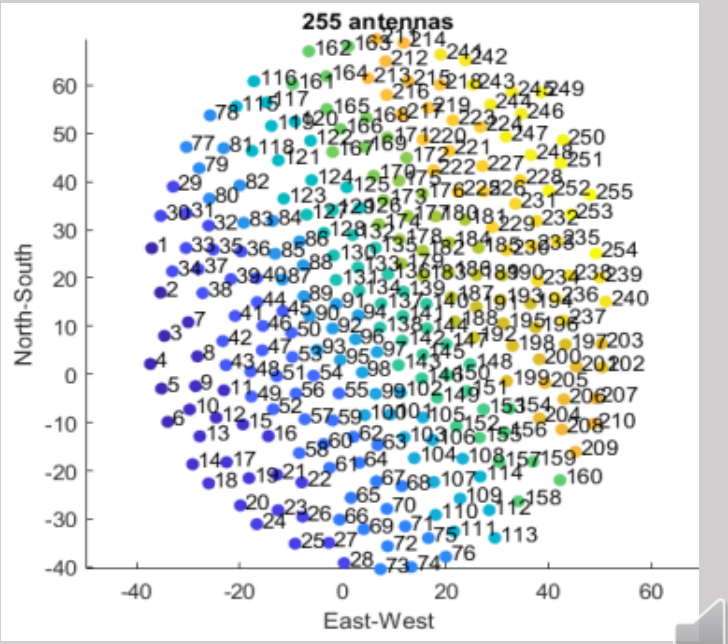
Comparing sparse (3-antenna) array with the LWA-SV

3 antenna array → 3 baselines



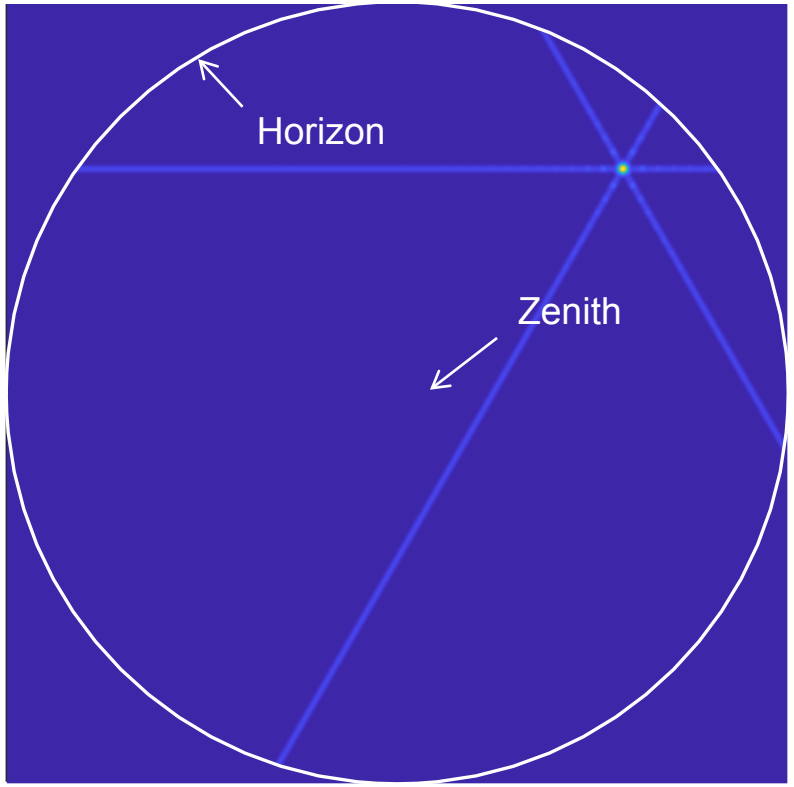
255 antenna array → 32,385 baselines



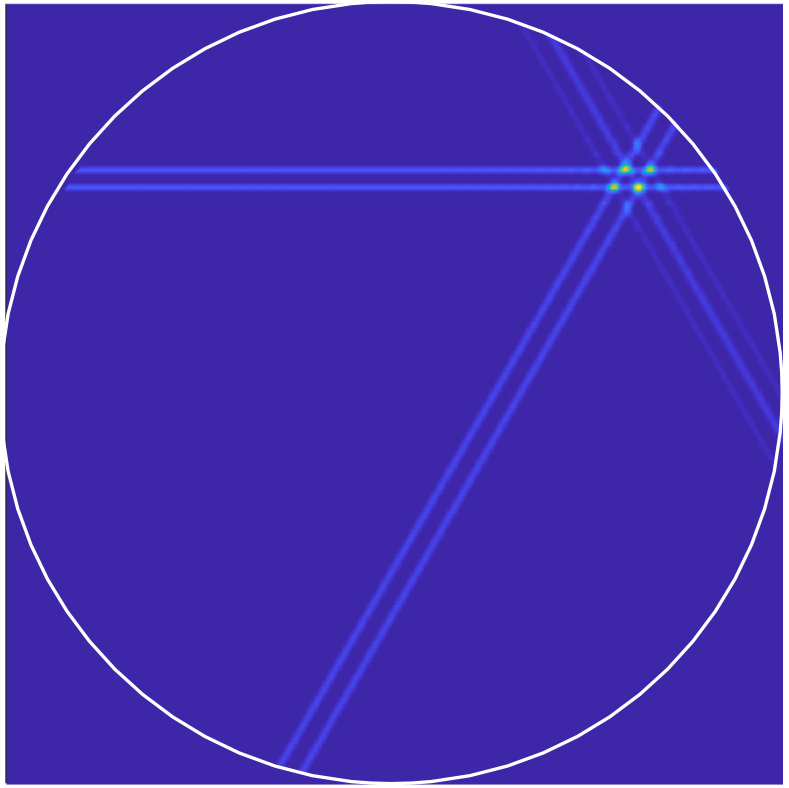


Comparing sparse (3-antenna) images with the LWA-SV

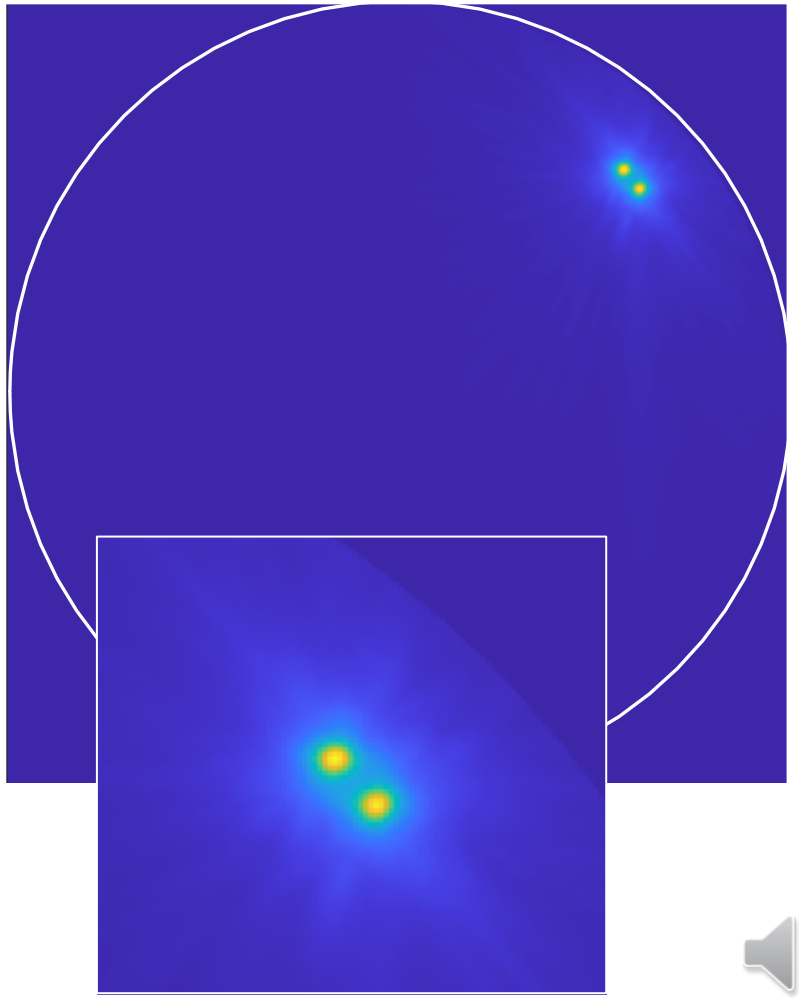
- 3 antennas, 80 MHz
- 1 point source



- 3 antennas, 80 MHz
- 2 point sources



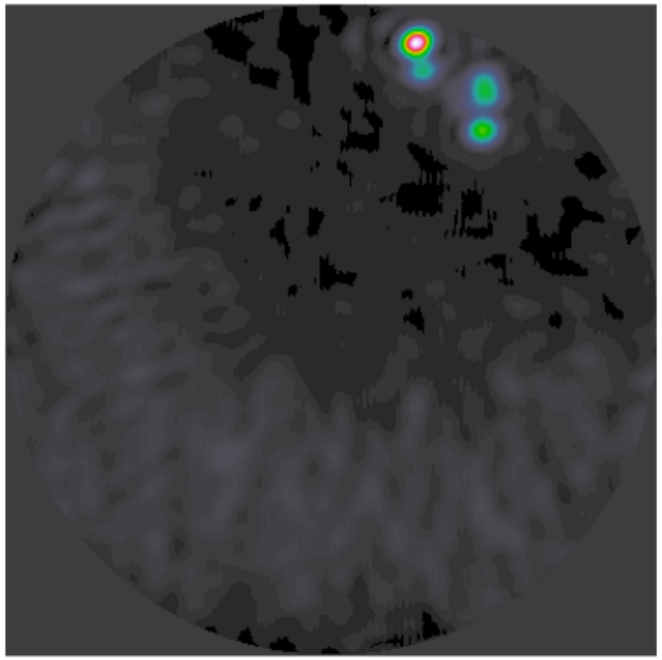
- 32 antennas, 80 MHz
- 2 point sources



Locating lightning centroids with the LWA-SV

- Can locate >1 centroid per “observation” (i.e., image)

1 ms exposure image



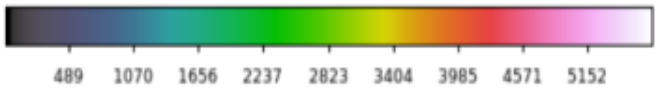
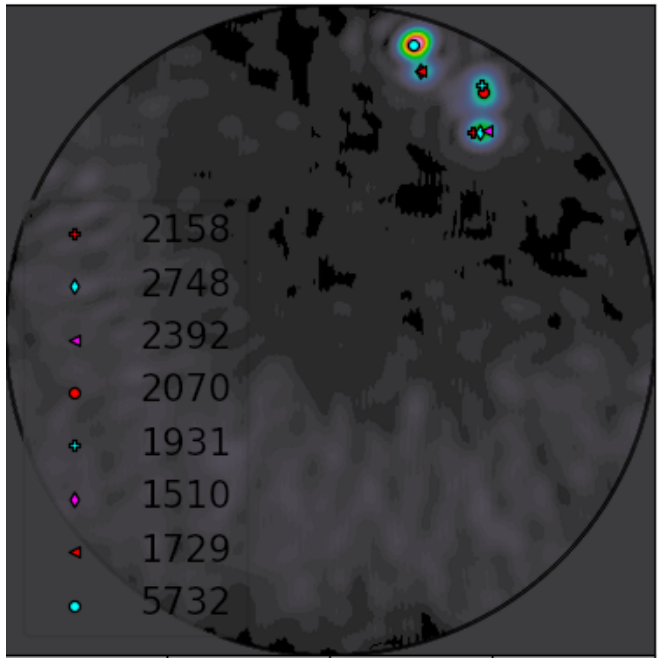
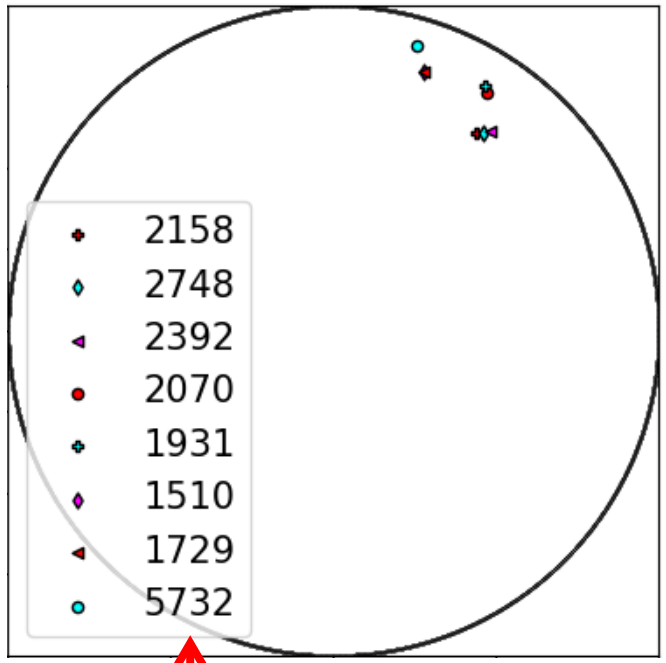


image amplitude

1 ms exposure image + centroids

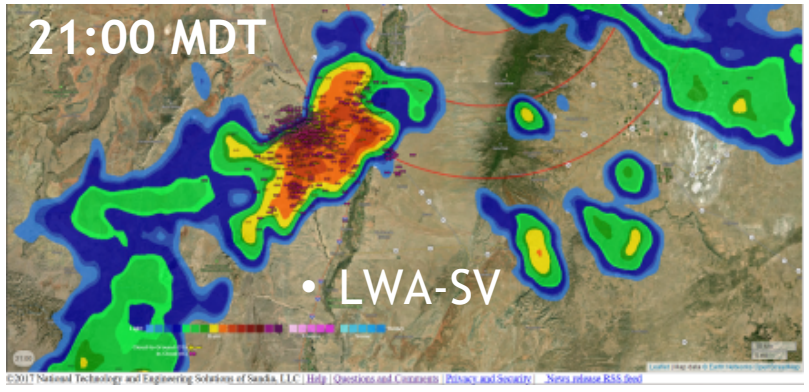


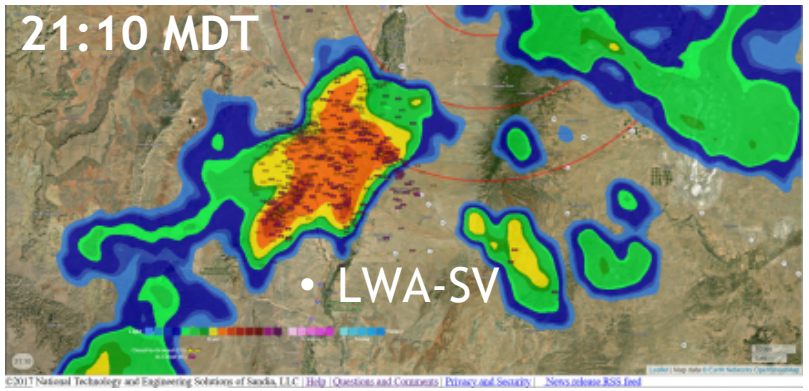
Centroids

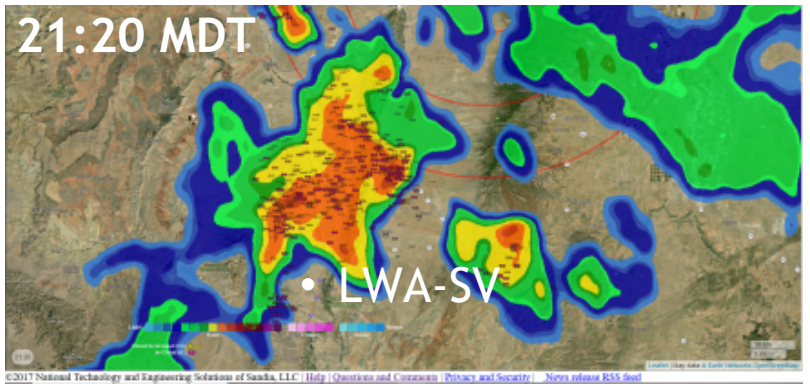


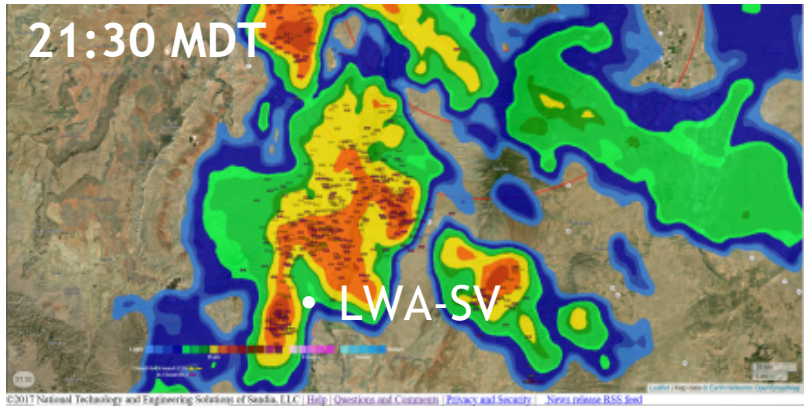
peak image amplitude per centroid

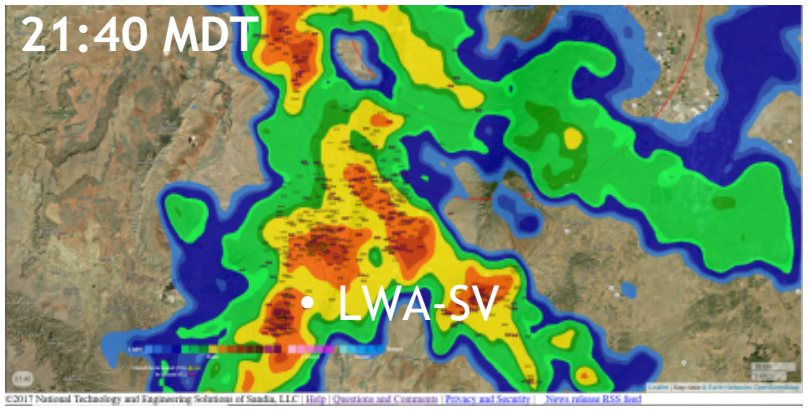
Example storm – July 6, 2021, 3:00-4:30 UTC (21:00-22:30 MDT)

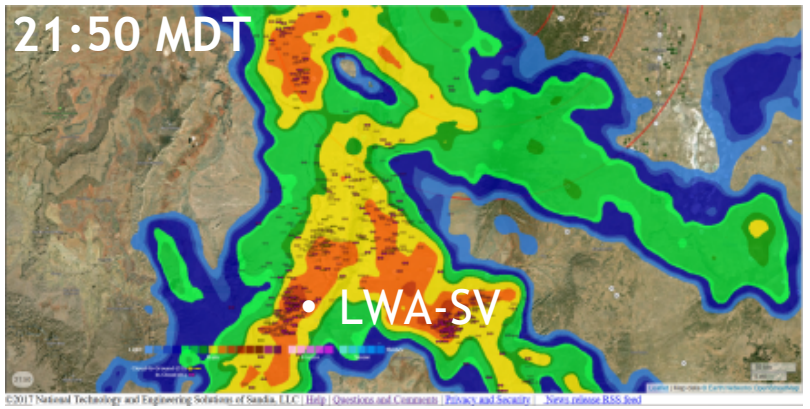


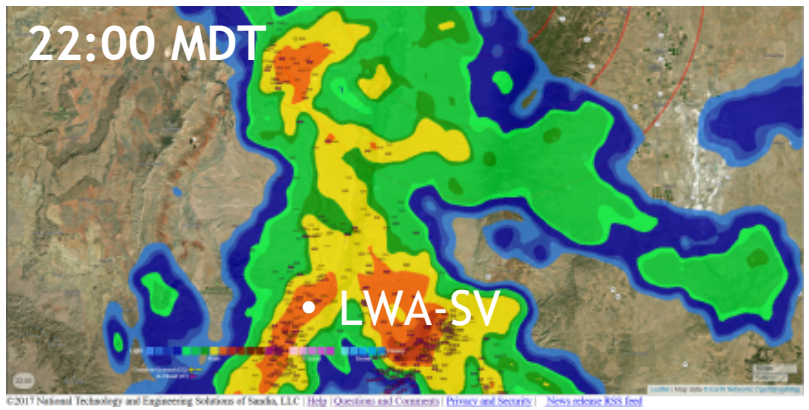


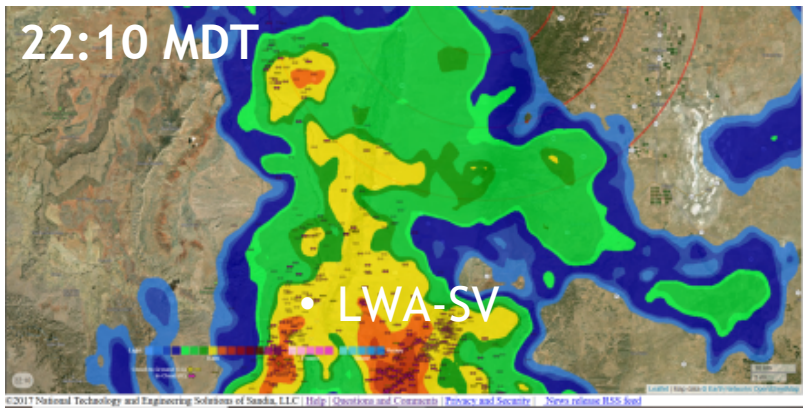


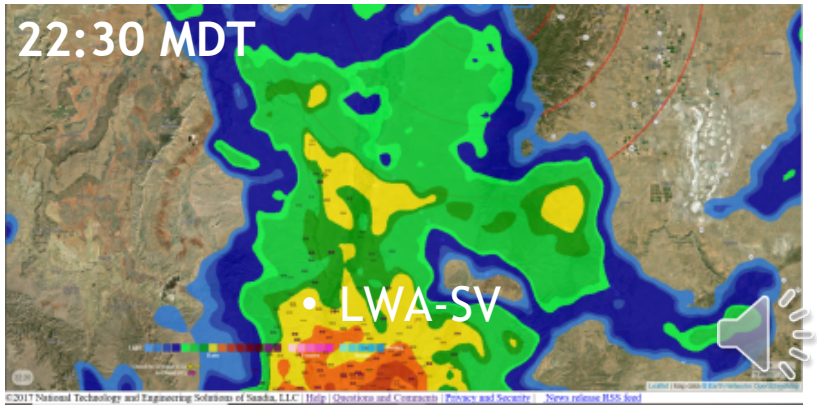




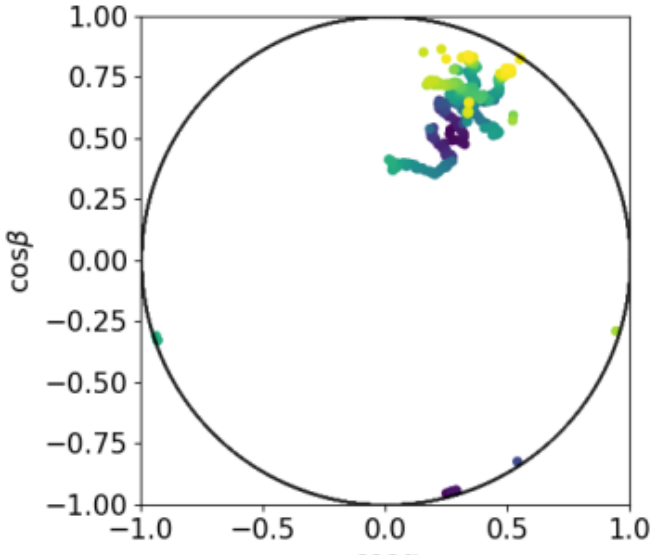


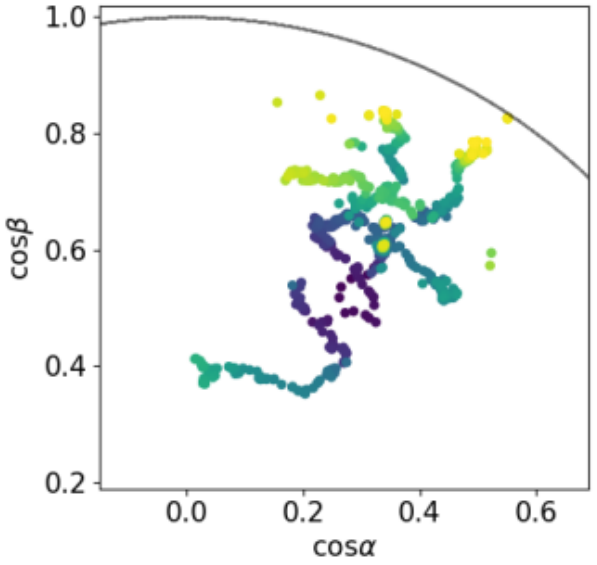


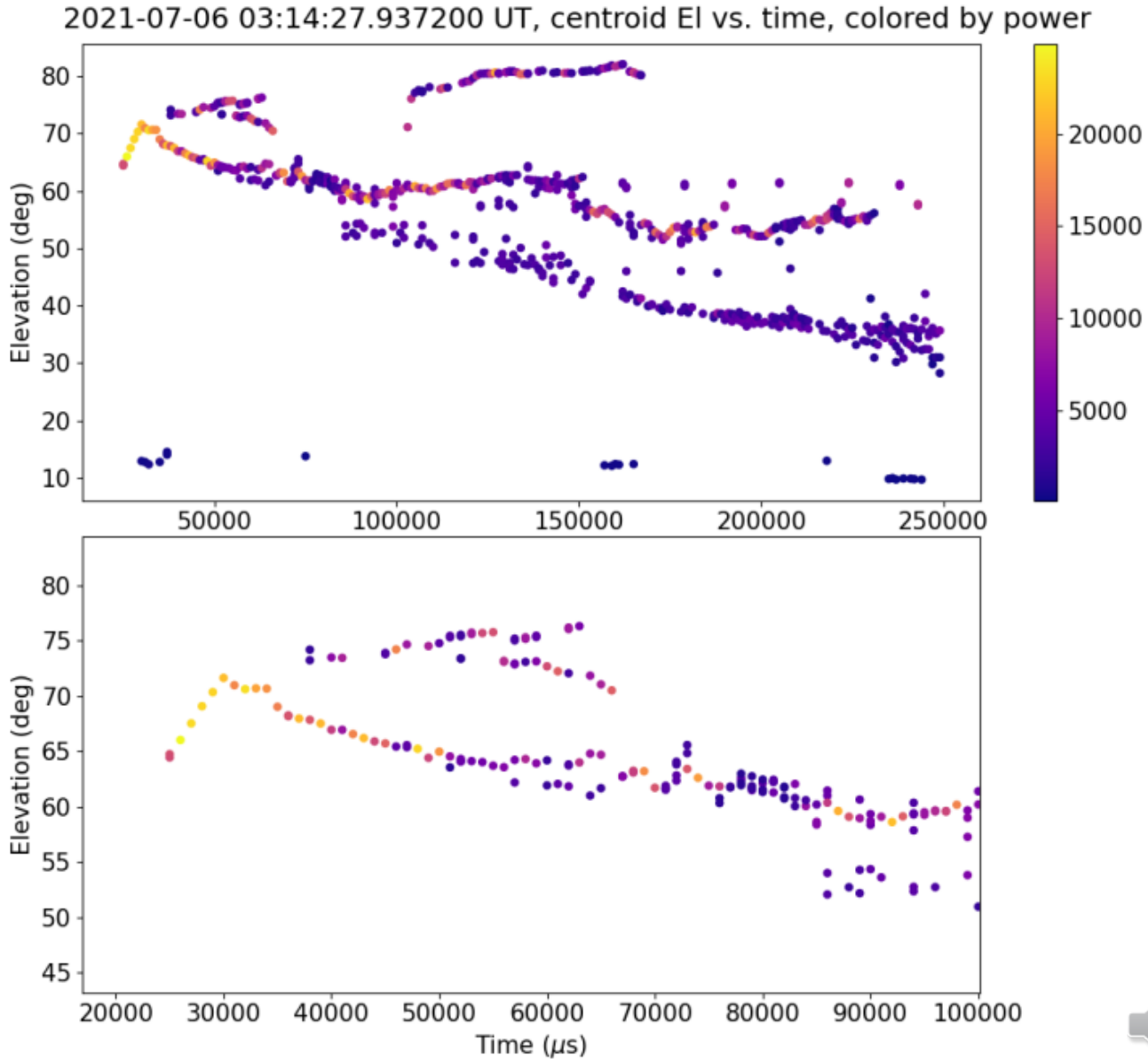




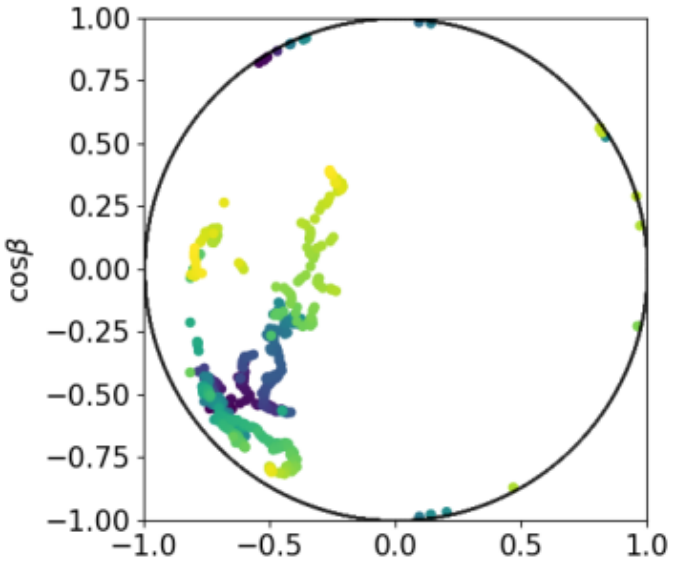
Example lightning flash A – July 6, 2021

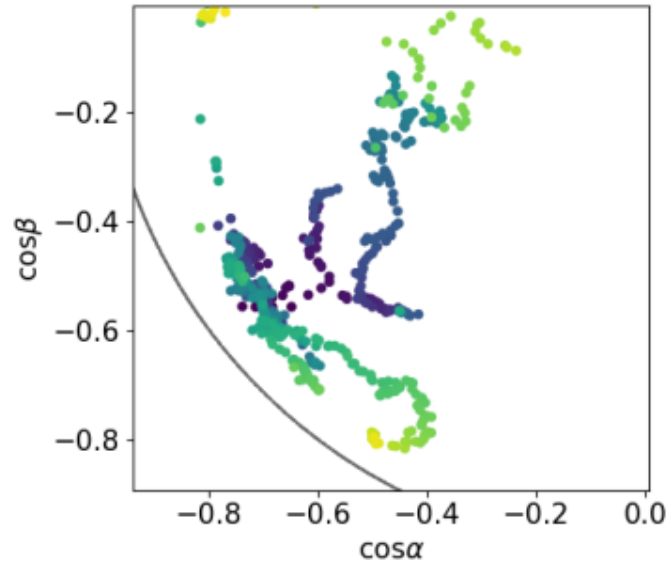


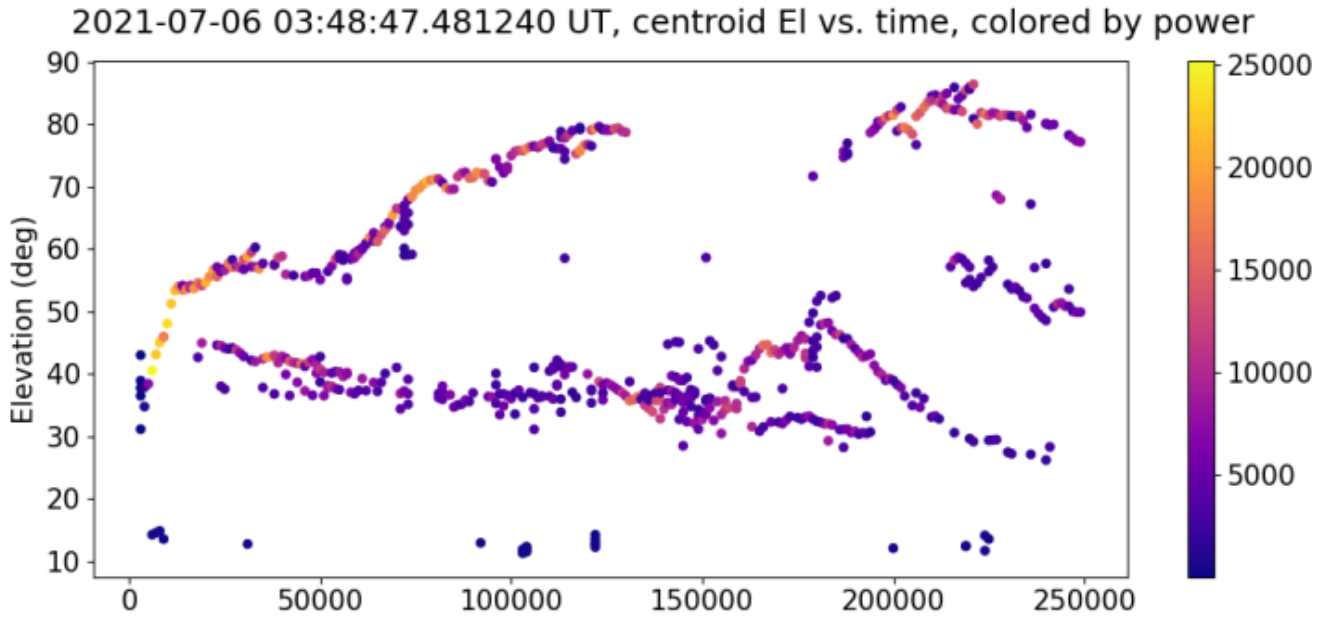


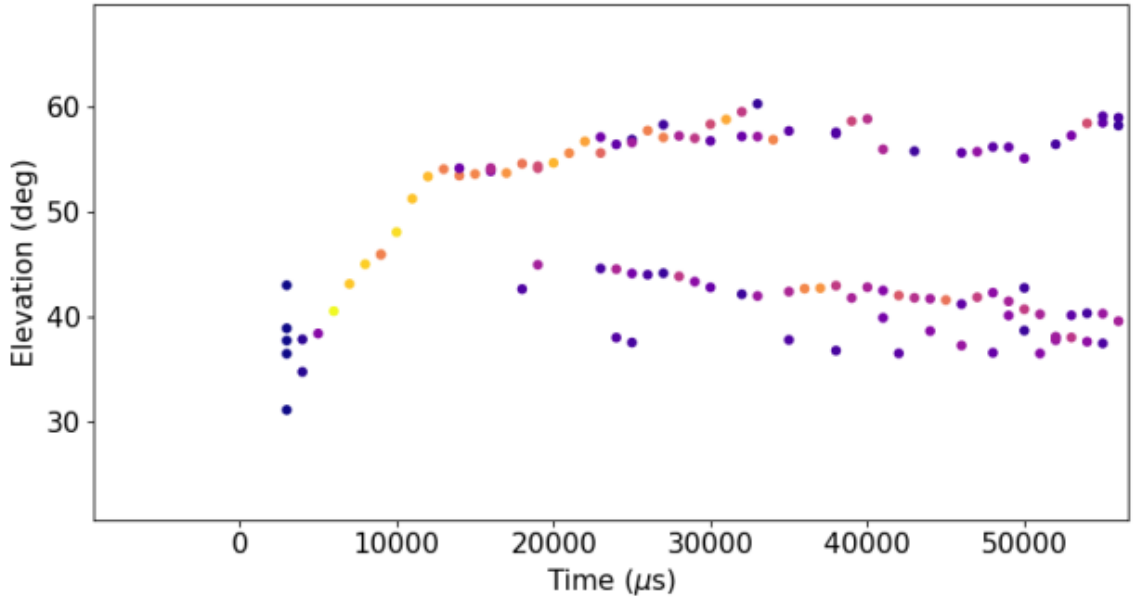


Example lightning flash B – July 6, 2021



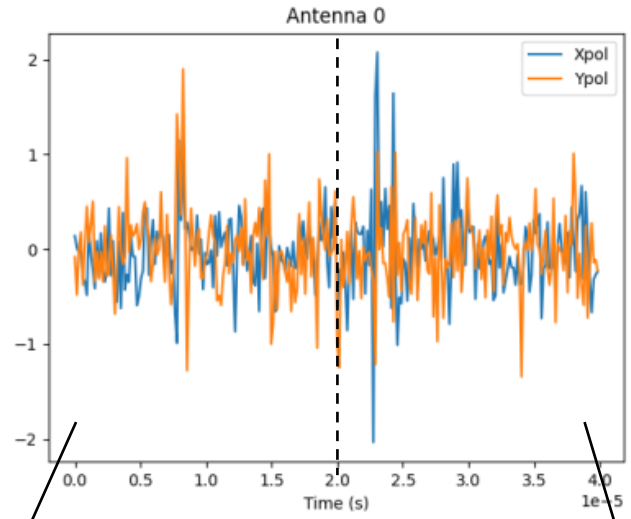






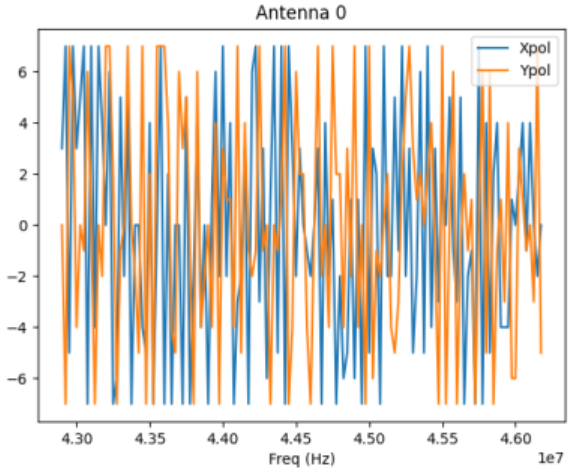
Time domain manipulations – waveforms

Time domain
(one 40 µs observation)

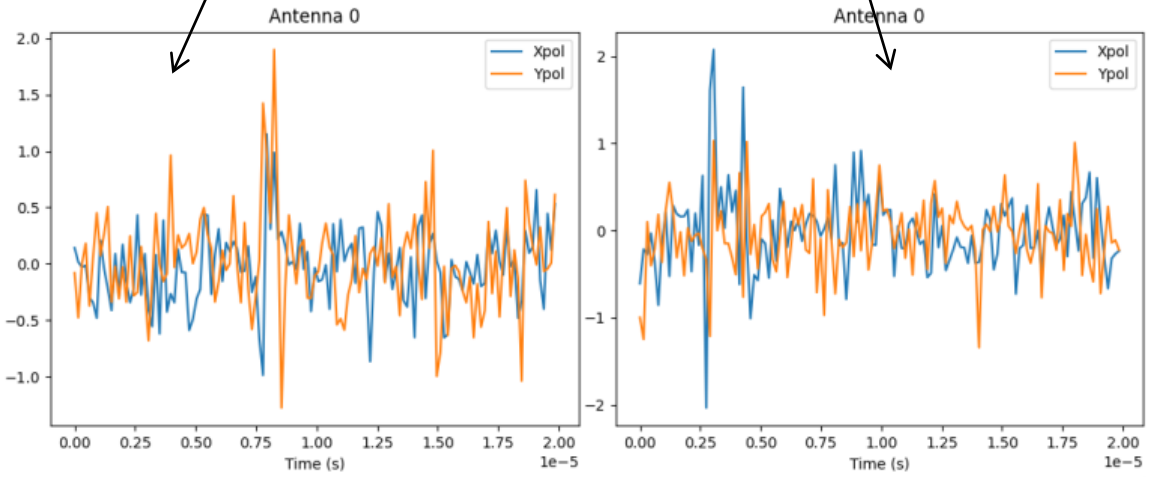


IFFT

Frequency domain
(one 40 µs observation)

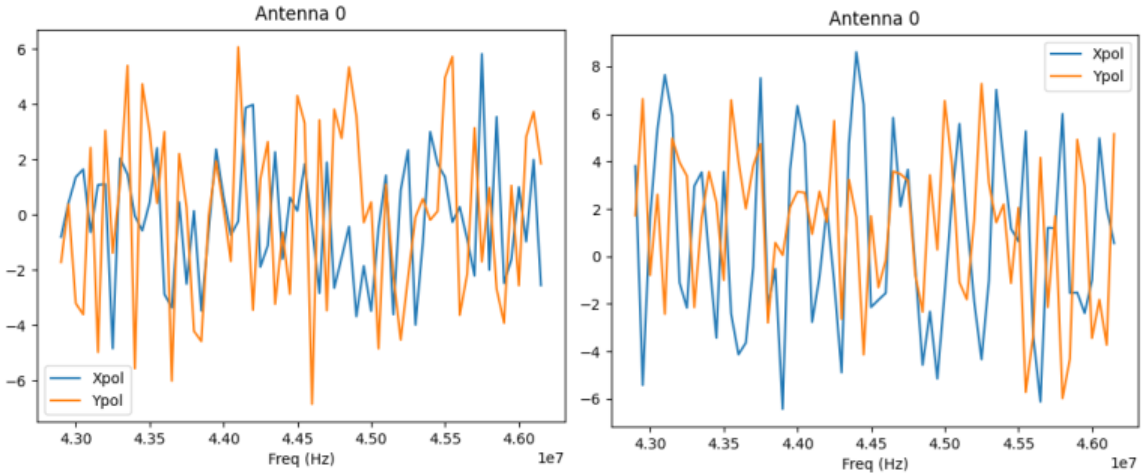


(two 20 µs observations)



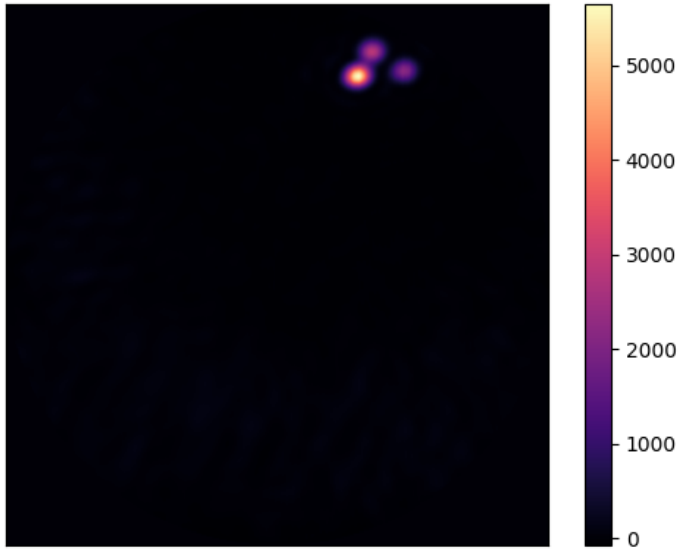
FFT

(two 20 µs observations)

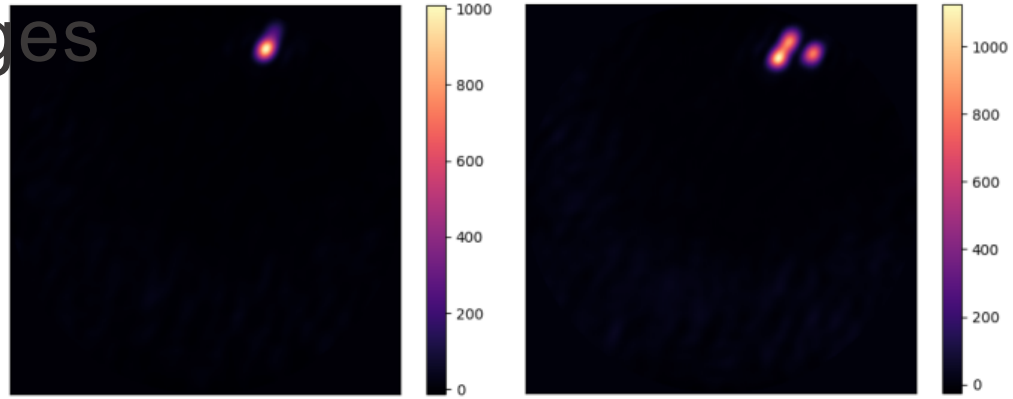


Time domain manipulations – images

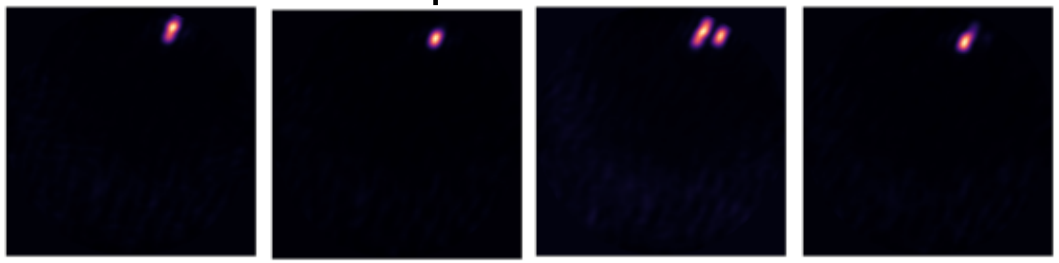
one 40 µs observation



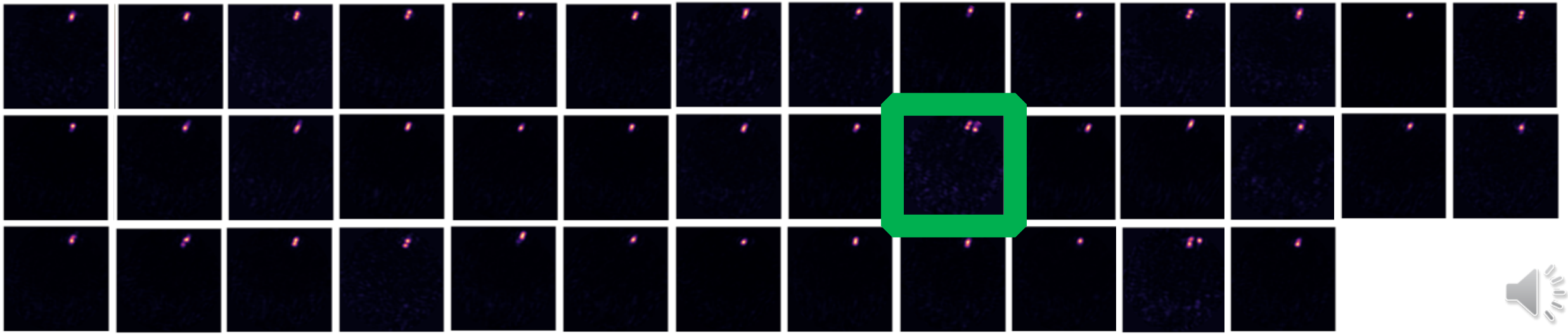
two 20 µs observations



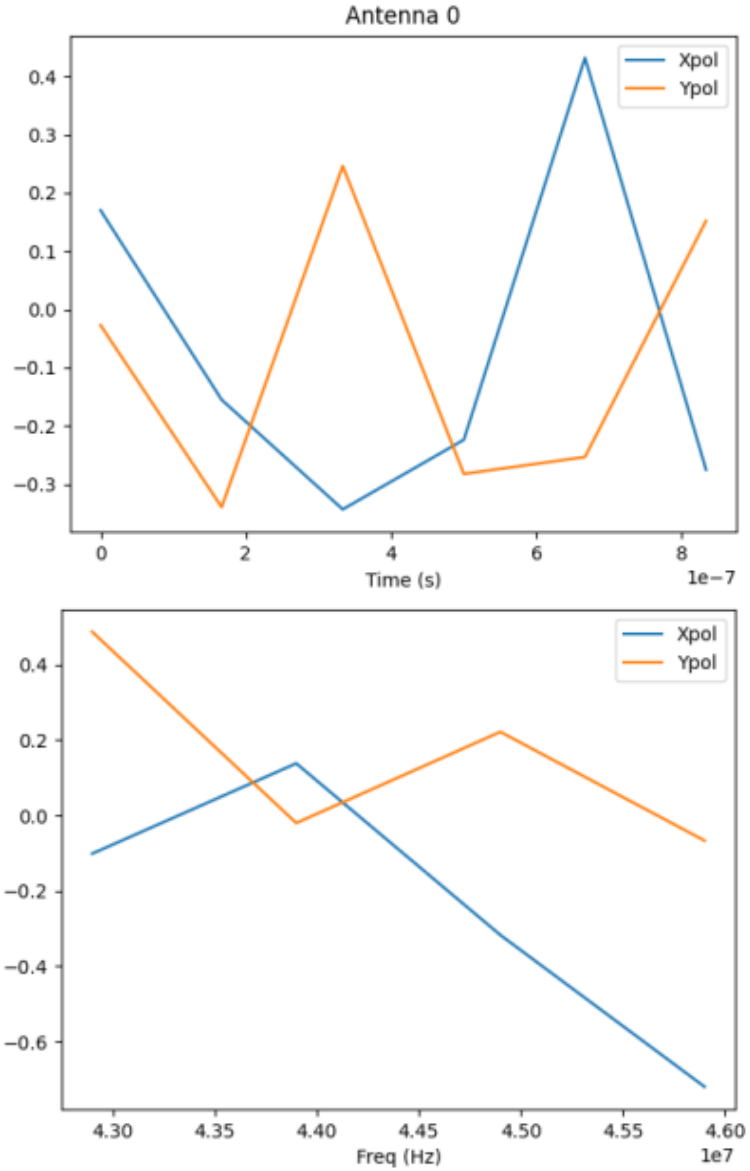
four 10 µs observations

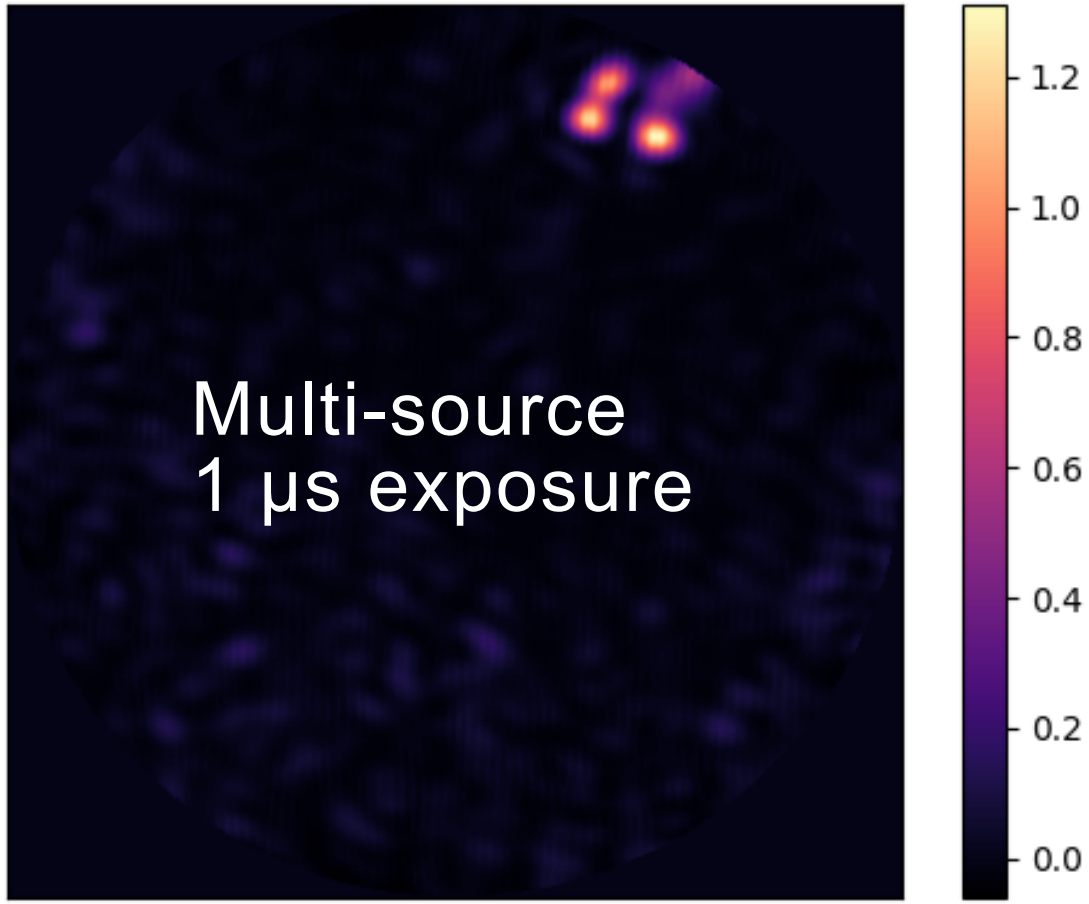


forty 1 µs observations

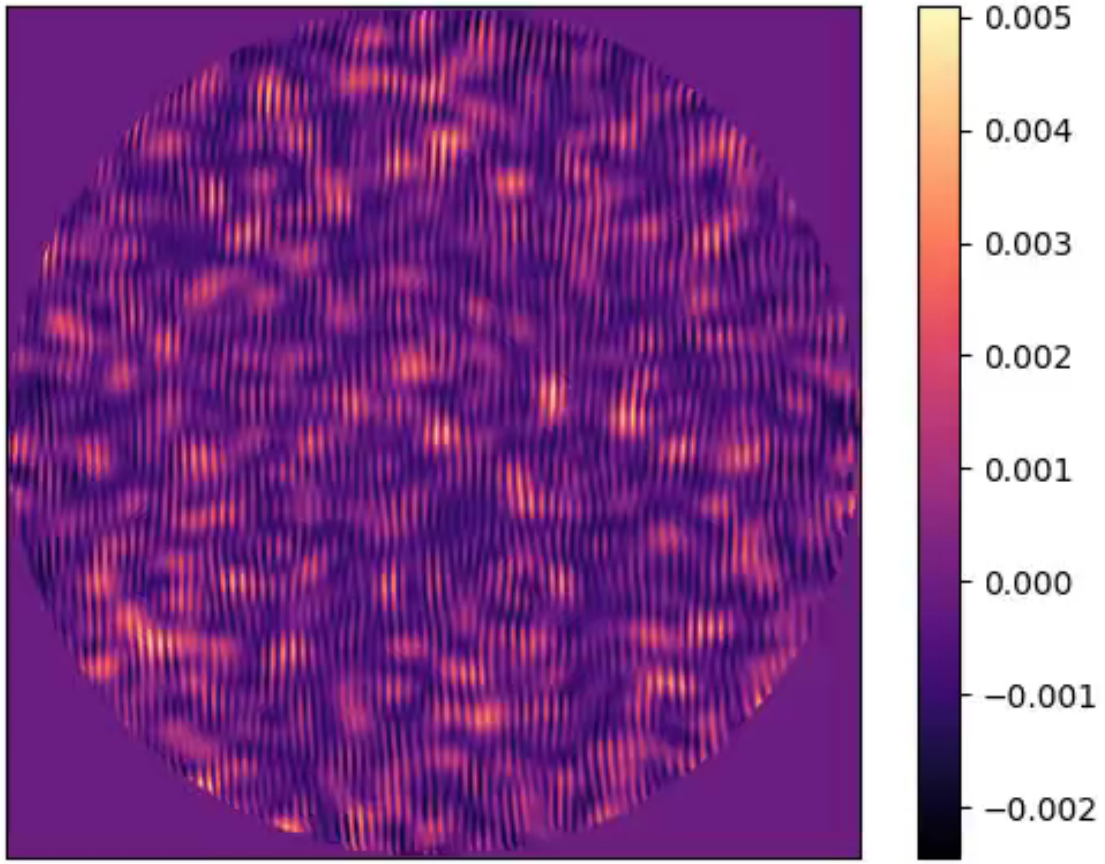


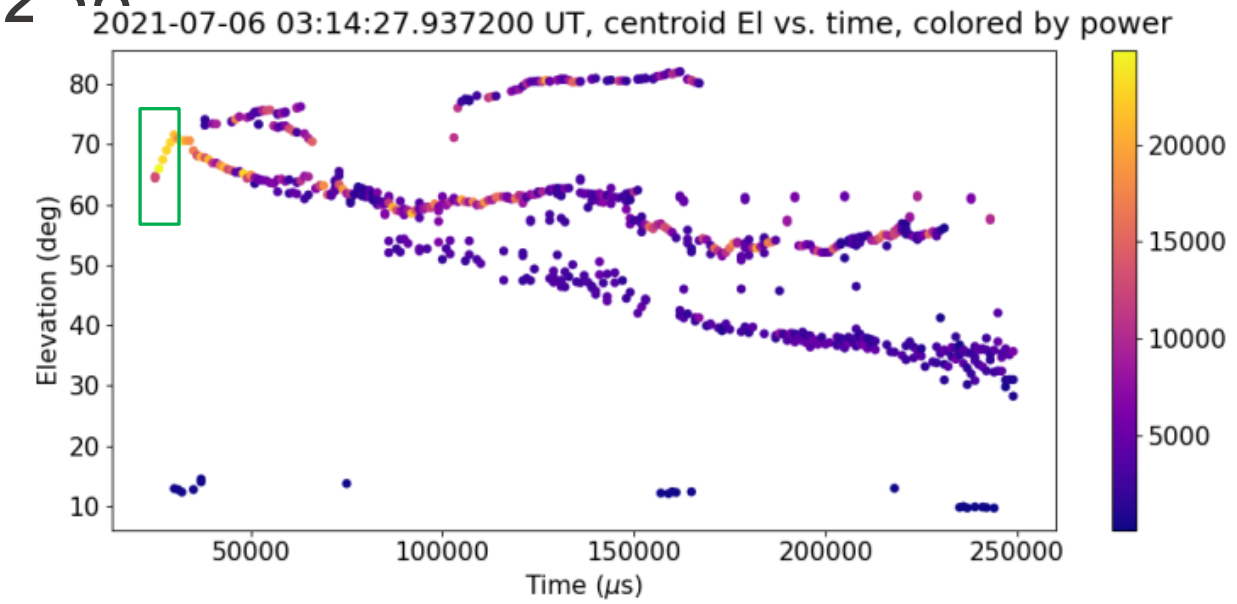
1μs imaging with 4 MHz bandwidth, 238 antennas (28,203 baselines)

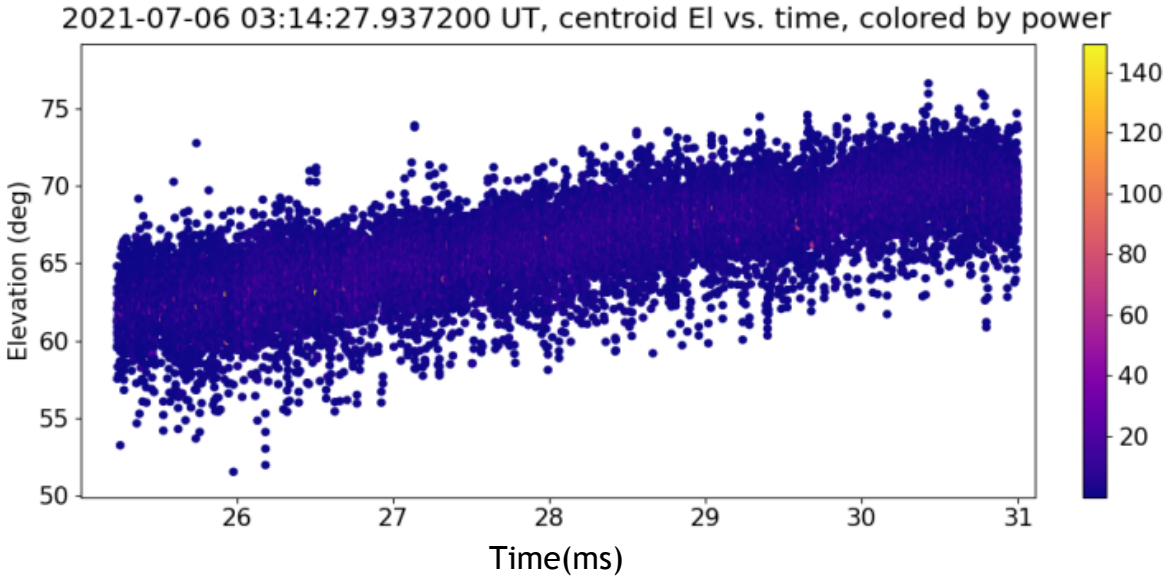




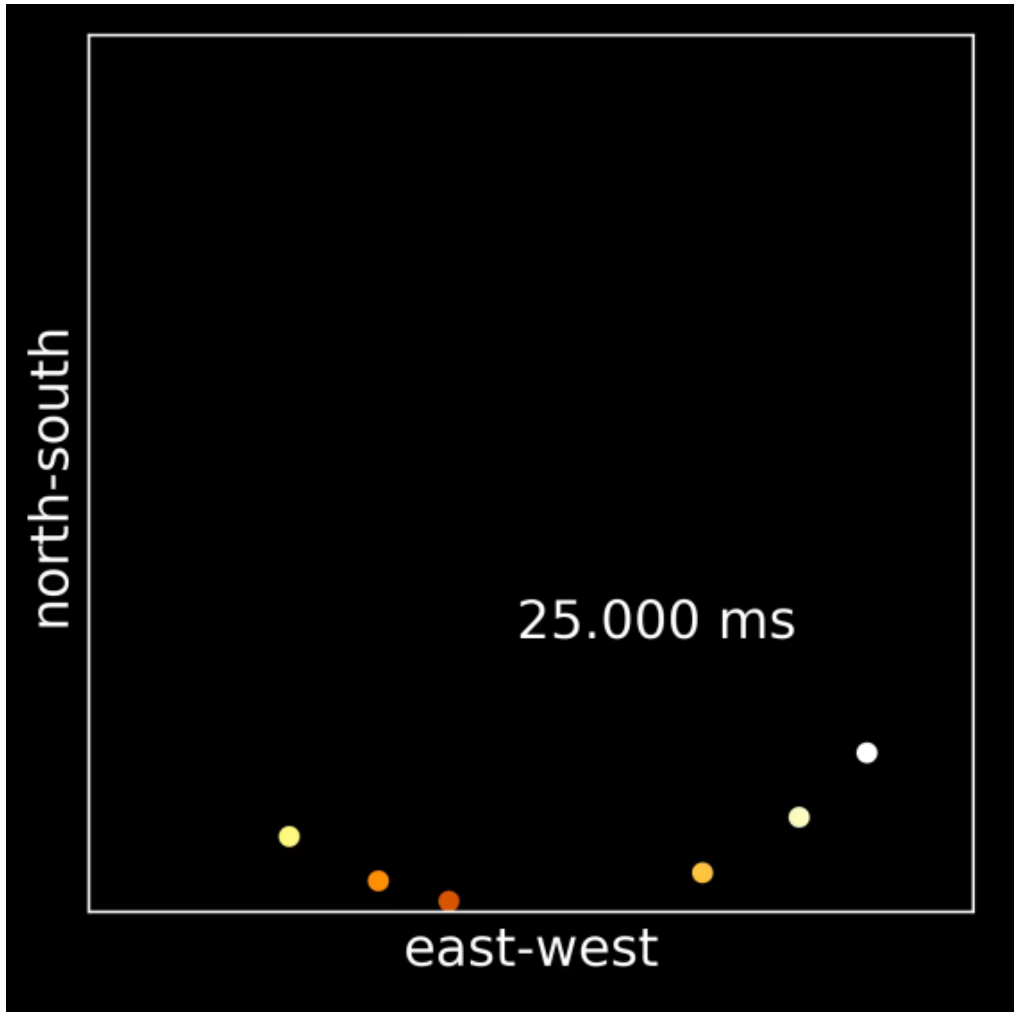
Lightning initiation at 1μs resolution, 4 MHz bandwidth, 2^38 antennas (28,203 baselines)

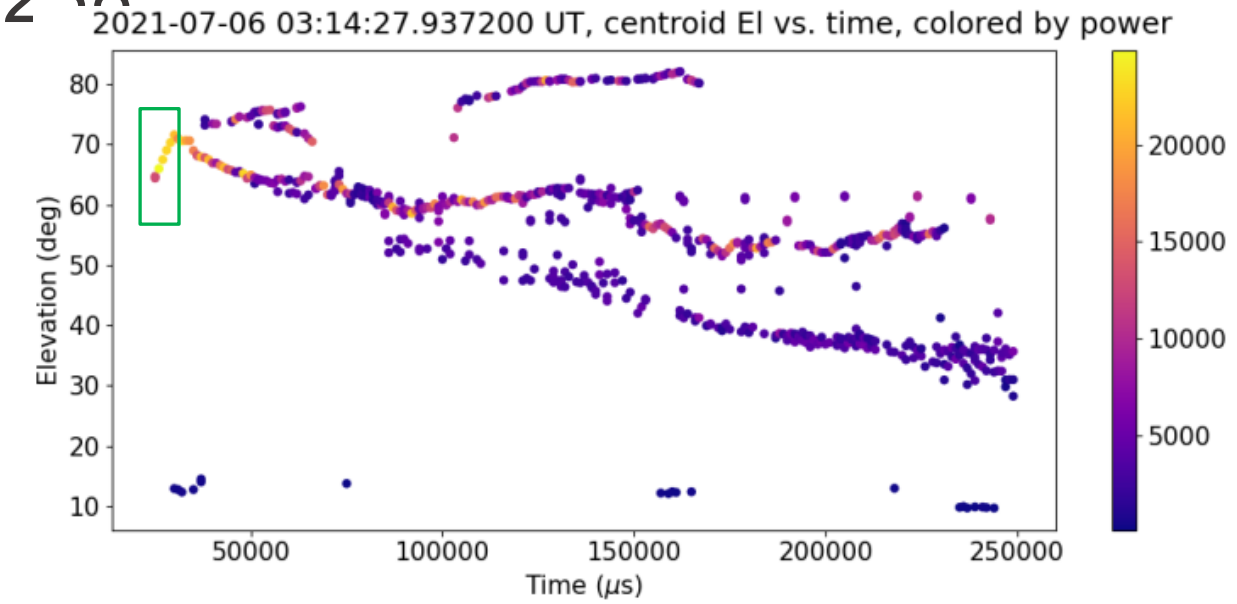


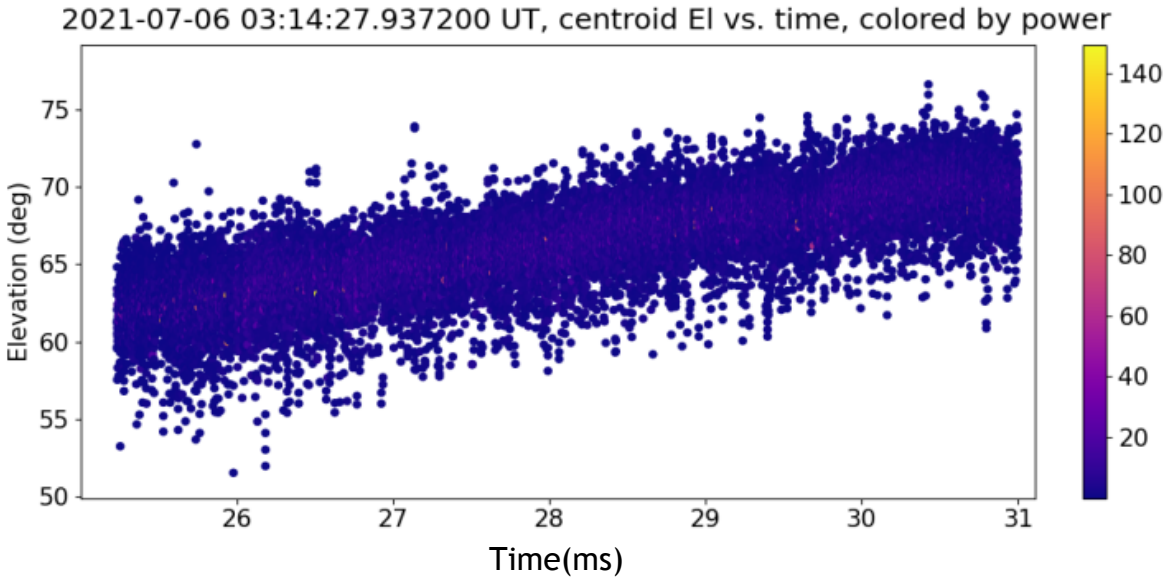




Lightning initiation at 1μs resolution, 4 MHz bandwidth, 238 antennas (28,203 baselines)

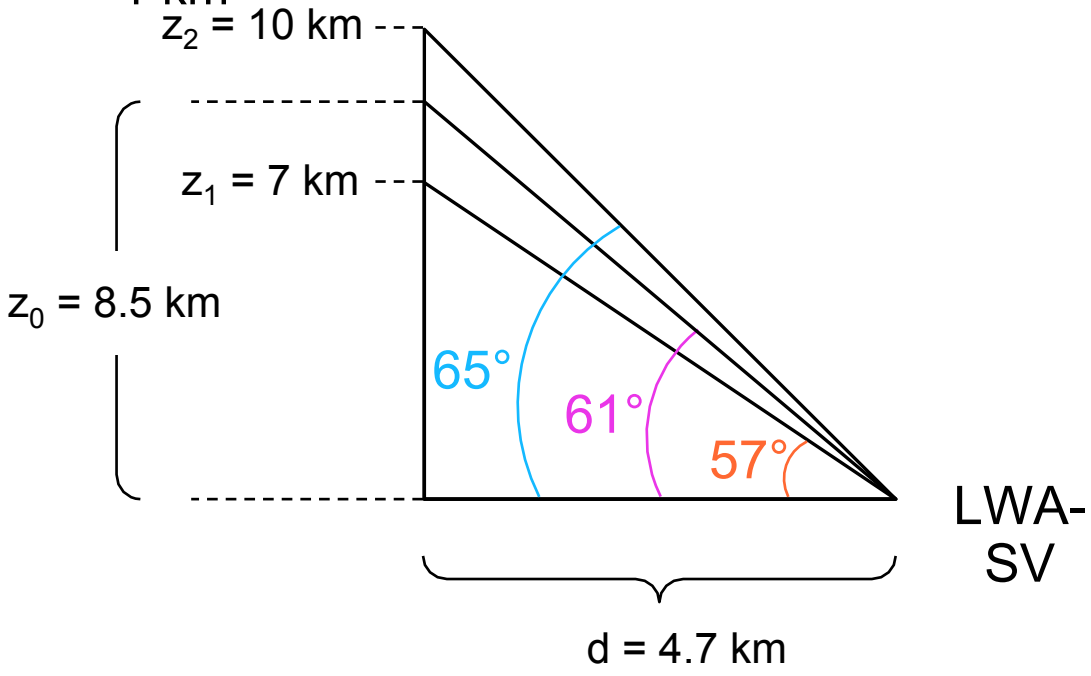


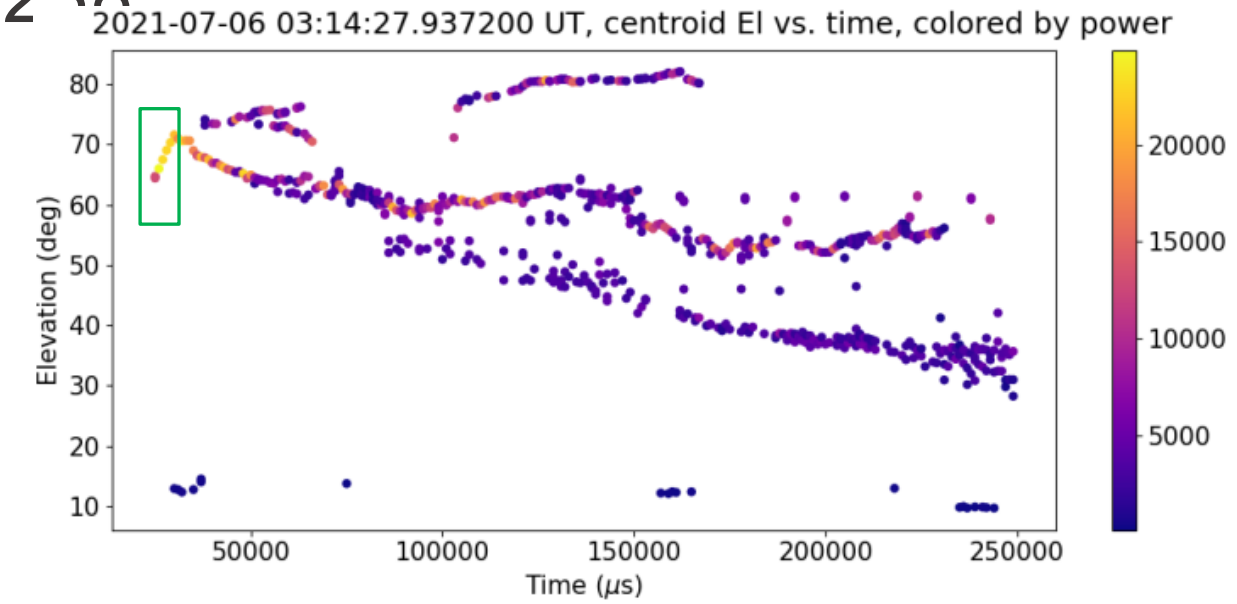


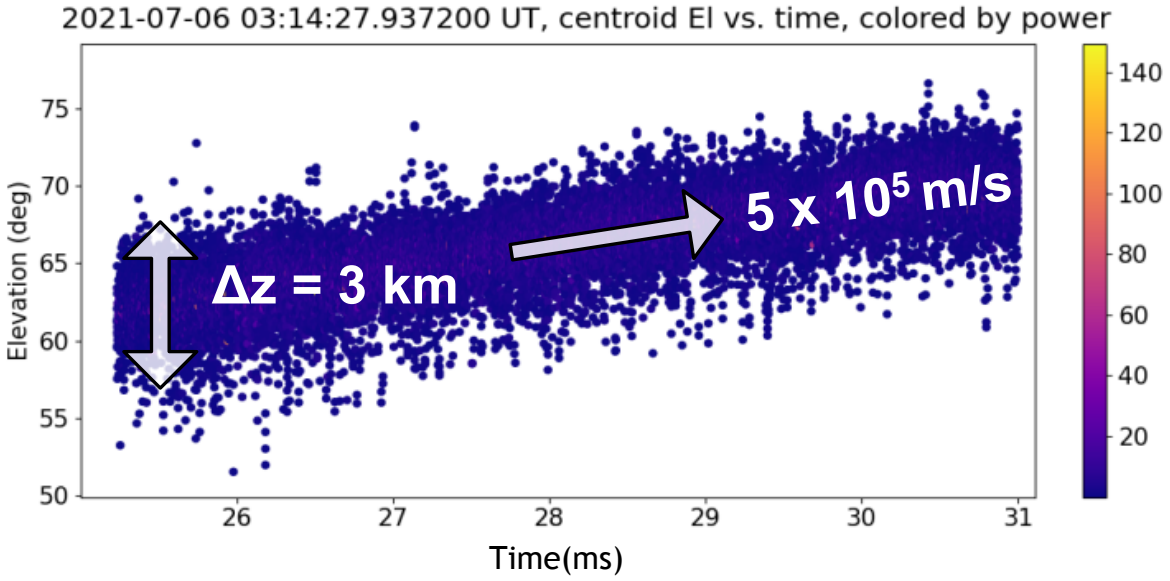


Lightning initiation at 1μs resolution, 4 MHz bandwidth, 238 antennas (28,203 baselines)

- Assuming initiation height of 10 km MSL (i.e., ~8.5 km above LWA-SV) → Δz = 3 km
- Assuming initiation height of 5 km MSL (i.e., ~3.5 km above LWA-SV) → Δz = 1 km







Conclusions

- LWA-SV lightning imaging demo at 1 μs resolution using <1/10th the available bandwidth.
- LWA-SV resolves extended-source lightning emissions not previously possible with sparse arrays.
- LWA-SV resolves tens of thousands of RF sources during ~5 ms during/after lightning initiation.
- LWA-SV observations suggests large (>1 km) lightning initiation region.

- High-fidelity images of lightning initiation to come…