RAPID for Interferometry of Lightning

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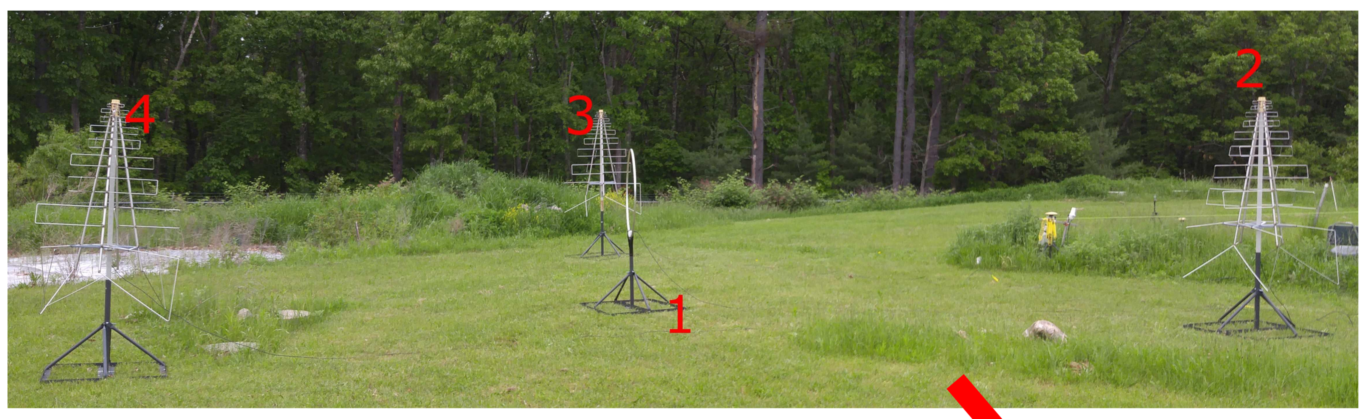
ABSTRACT: Lightning, with it's wide range of timescales (microseconds to seconds) and spatial scales (meters to tens of kilometers), has historically been difficult to study. Radio interferometry allows for unprecedented temporal and spatial resolution in the mapping of lightning, limited primarily by digitizer speed and number of antennas in the array. Here we demonstrate radio interferometry of lightning using a Radio Array of Portable Interferometric Detectors (RAPID) system, showing a couple examples of lightning events, and also discuss the spectrum of lightning in the range of 25 to 300 MHz.

In May and June 2017, a single RAPID system using an Ettus X300 radio (e-Series prototype) was deployed at Haystack Observatory in Westford, MA. This system had four analog inputs, three of which were connected to Square Kilometer Array Low Frequency Aperture antennas (SKALAs), each with a single linear polarization connected, and which can cover frequencies from 50 to 615 MHz. The fourth input was connected to a commercial active loop antenna from Wellbrook communications. The three SKALA antennas were used for interferometry, spaced approximately 10 meters apart in an equilateral triangle configuration, and operated in four different asynchronous modes, each with a different center frequency (70, 135, 300, and 420 MHz), 30 MHz bandwidth, and 16-bit resolution. The fourth loop antenna was placed in the center of the triangle, and had a center frequency of 25 MHz, with a 50 MHz bandwidth, and 16-bit resolution. Simultaneous measurements of the 25-, 70-, 135-, and 300-MHz channels were periodically collected using all four antennas (but not used for interferometry), providing spectral information on lightning events. The four signals were sampled at 200 MHz IQ with 14 bit resolution and digitally down-converted.

Setup

RAPID unit. SKALA antennas 2, 3, and 4 were used as an interferometer, with 10-meter baselines; antennas 1 (Wellbrook Communications), 2, 3, and 4 recorded signals from lightning concurrently at 25, 70, 135, and 300 MHz.



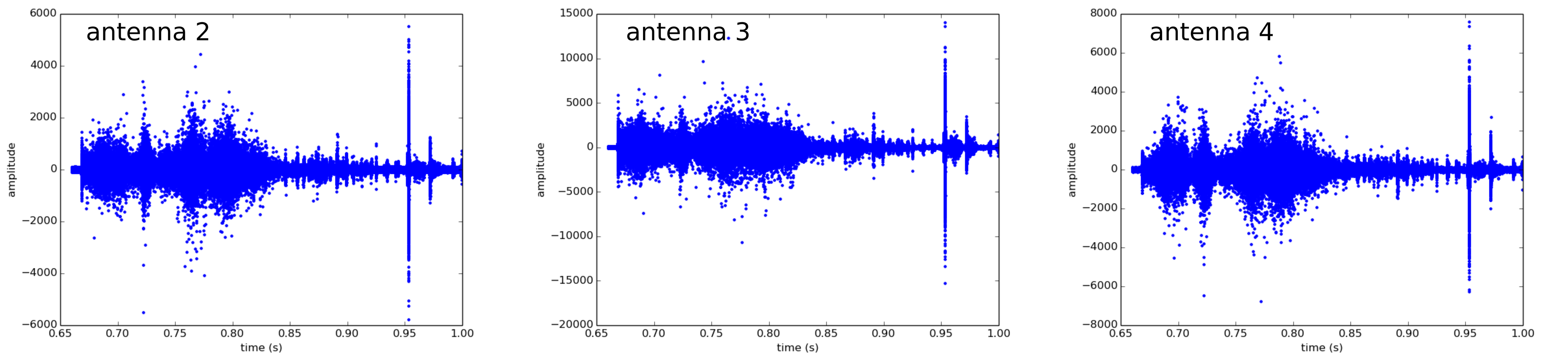
Fourier Synthesis Imaging/ Mapping (TDoA technique)

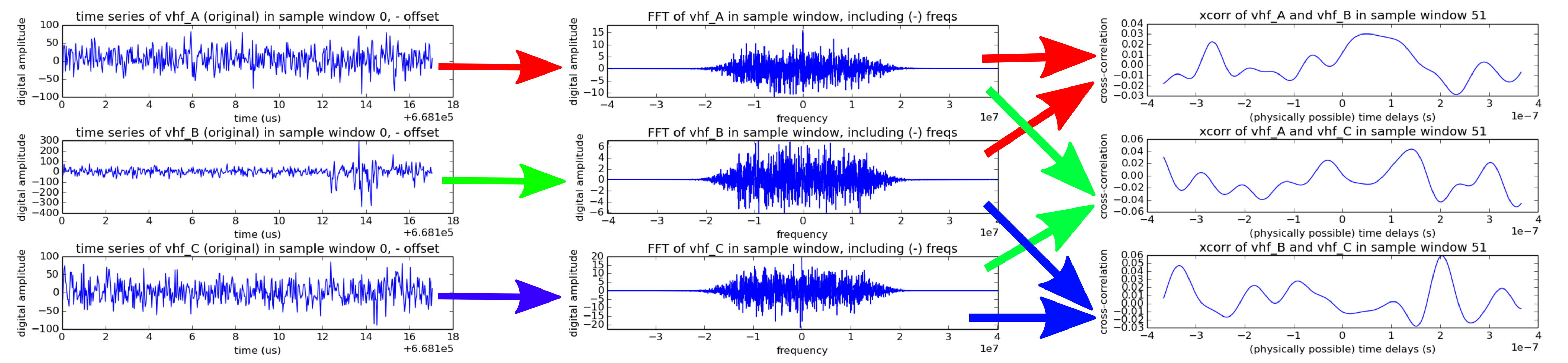
step 1: take three simultaneous measurements of lightning radiation (here with center frequency 70 MHz and 30 MHz bandwidth).

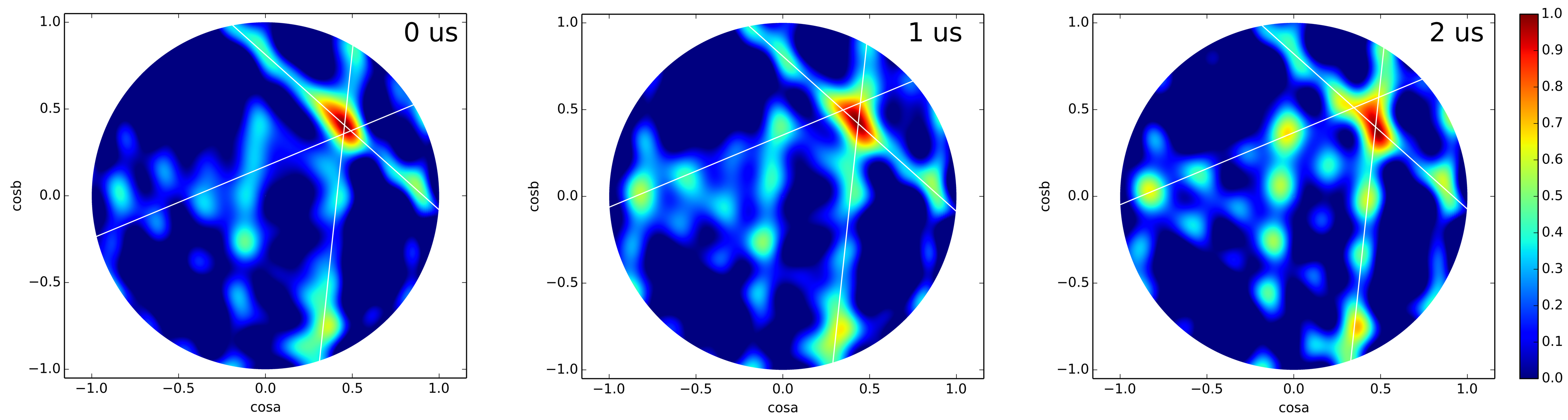
step 2: take smaller time series of each signal; gives "exposure time" per image (here with 17 microsecond exposure time).

step 3: perform cross correlation (XCORR) between every two signals (first take FFT of each signal, then multiply in frequency domain; transform back into time domain to complete XCORR). The maximum in XCORR corresponds to the TDoA of the signal arriving at two sensors.

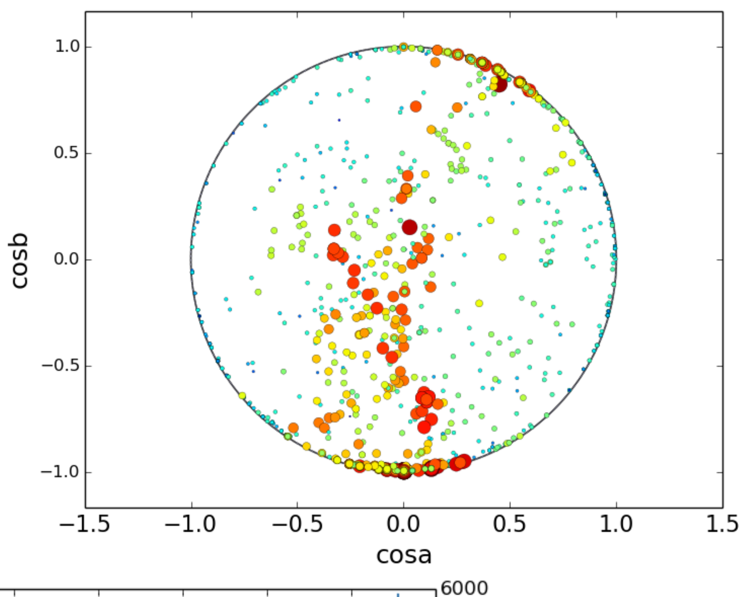
step 4: project each XCORR into the "cosine plane" or "sky"; can also transform into Azimuth and Elevation angle, which is similar to what is seen in an optical photograph. Below are three consecutive images, shifted 1 microsecond apart; white lines depict maximums in the XCORR for each baseline, and color indicates received signal power.

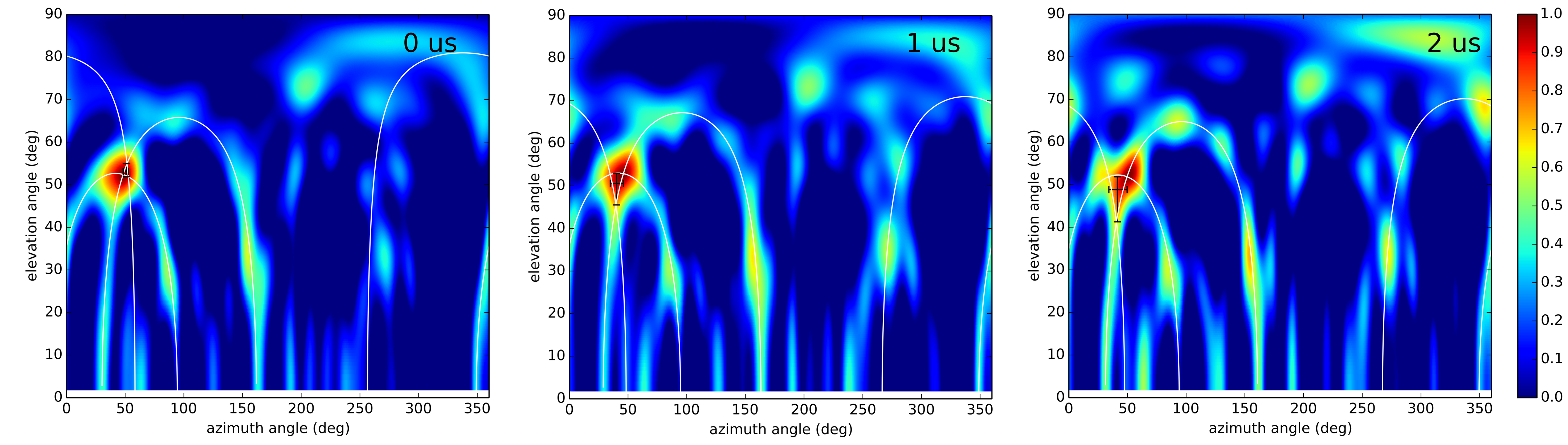


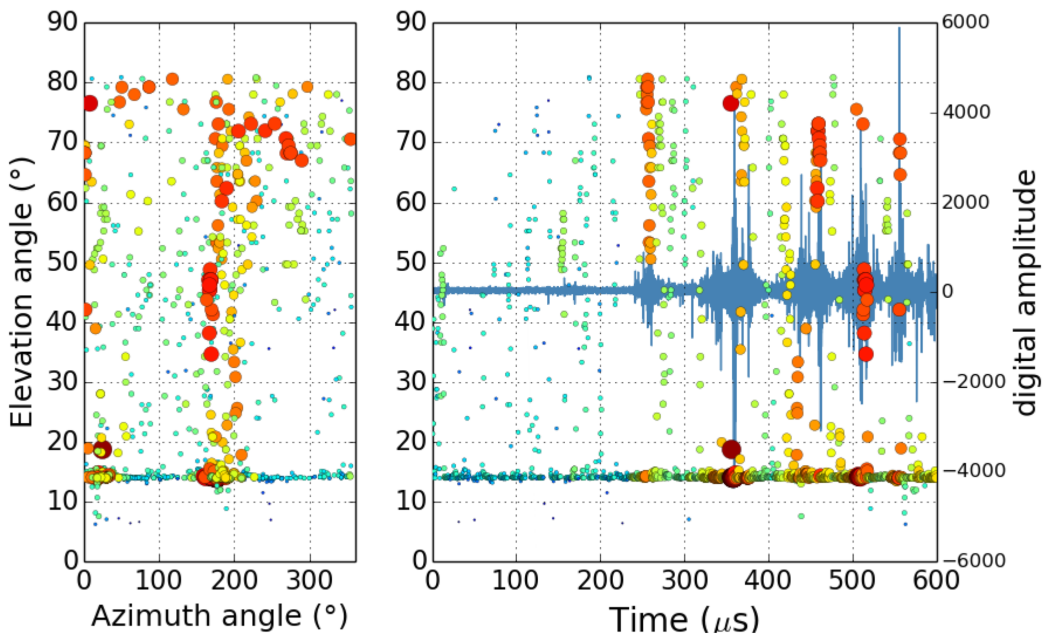




step 5: for each image, determine source ("centroid"), i.e. brightest point in sky. Can plot ("map") centroids as a function of time. To the right and below, each point represents the source in a 17-microsecond exposure image, but incremented by 1 us. Dot size and color depict received signal power.



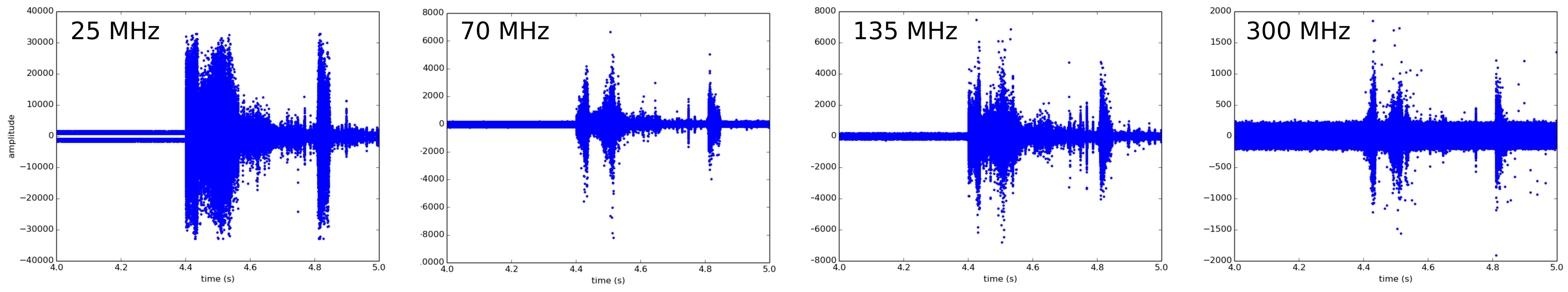




Lightning spectra

(a snapshot)

Signal received for a single lightning event at four different closely-spaced antennas with four different frequency centers. Amplitude becomes greatly attenuated from 25 to 300 MHz.



Conclusions

RAPID instruments can be used for lightning inferterferometry. We already have a substantial data set from two months of operation, with more than 20 lightning flashes with which we can do interferometry, and another 10 for which we can analyze the spectra from 25 to 300 MHz.

Next steps include improving the processing algorithm, comparing results with existing systems, and optimizing array configuration.