Simulating Radio Images of Lightning Events

Tornike Shubitidze,
Advisors: Dr. Ningyu Liu, Julia Tilles
Department of Physics, University of New Hampshire, Durham, NH 03824

Introduction

- Lighting is an electrostatic discharge that occurs within charged regions of a thundercloud. This discharge produces strong electromagnetic fields.
- These EM fields carry out information related to lightning initiation events such as narrow bipolar events (NBEs).
- By adapting radio astronomy imaging techniques, one can study extremely transient lightning-associated events. These events can be mapped onto 2-dimensions with sub-μs time resolution using interferometry[2].
- Using a three-antenna, 20-80 MHz radio interferometer, NBEs were shown to be composed of extended and/or multiple radio sources. These sources cannot be well-resolved by the interferometer.
- This poster presents the preliminary work of developing a forward model to simulate the images of two point source distributions/dynamics to compare with observational results

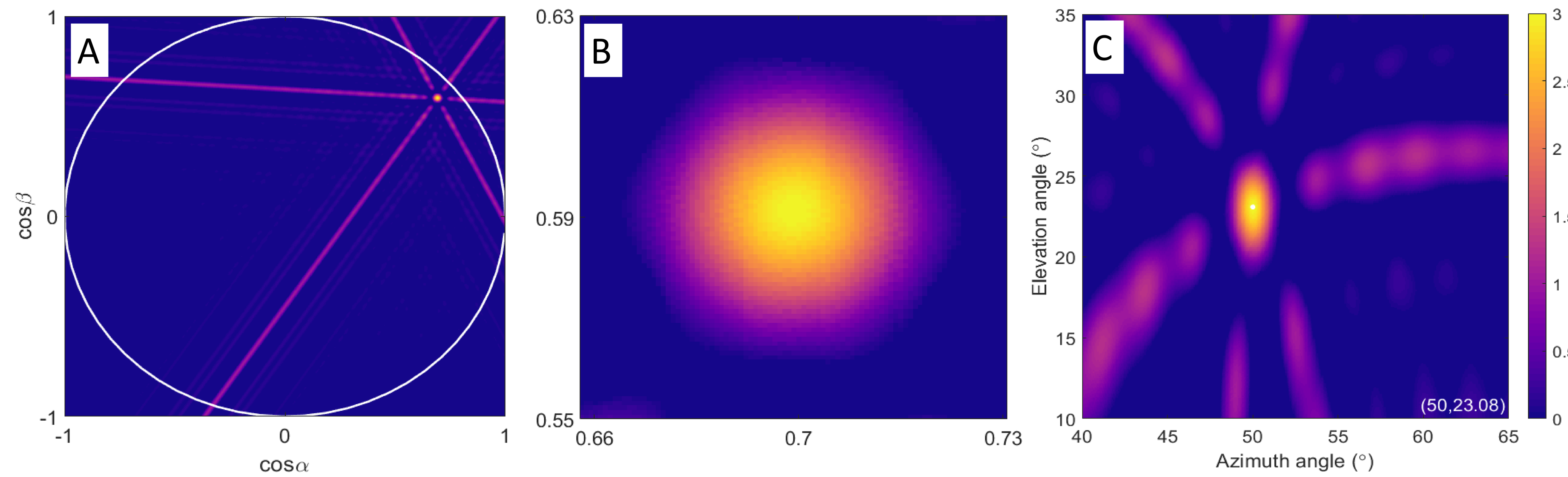
Interferometry

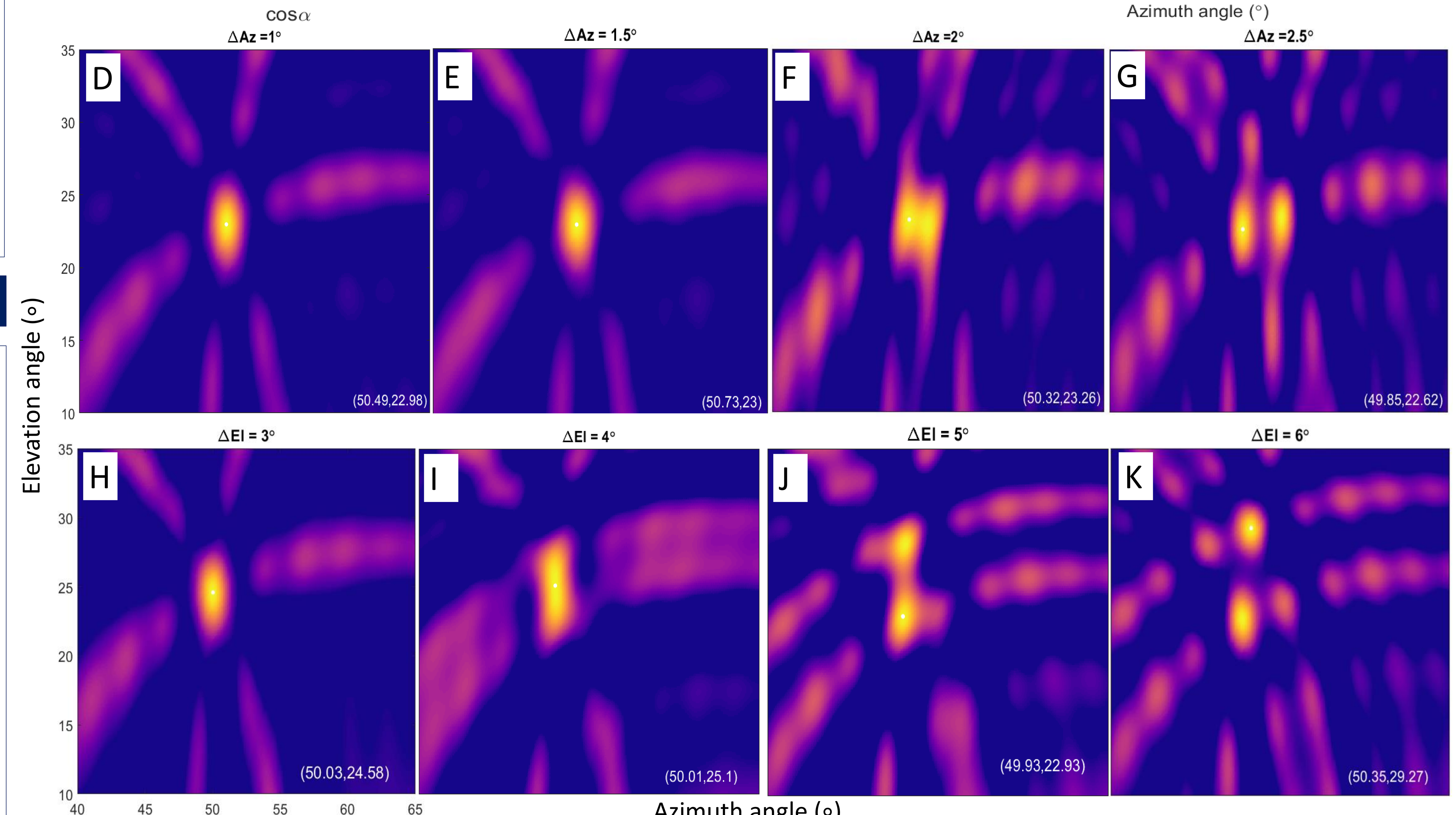
- With two antennae A and B, we approximate the incoming EM signal from lightning as a plane wave so the signal at each antennae are identical. However, one signal must travel exactly $c\tau_{AB}$ to reach B after reaching A, where τ_{AB} is the time delay between the signals received at A and B and c is the speed of light. The line connecting antennae A and B is called a baseline.
- By adding a third antennae, C, the total number of baselines becomes three. Each baseline has a unique orientation with respect to the cardinal directions. Given these three angles of orientation with respect to North, the direction to the source can be determined. The interferometer outputs angular directions α and β, that a source makes with respect to East and North directions respectively. These angular directions are the axes of the "cosine-plane" coordinate system.
- A source is first projected onto a unit hemisphere, representative of the entire sky, and then straight down onto the instrument plane. The resulting unit disk is called the cosine plane. This disk is very similar to a fish eye lens and a depiction of both the cosine plane and unit hemisphere are shown on Figure 1 [2].
- To determine the direction of an emitting source, one must determine the time delays τ_{AB}, τ_{AC}, τ_{BC} that such a source makes with respect to baselines AB, AC, and BC, respectively. The time delay that an emitting source makes with respect to baseline XY, with length d_{XY} and azimuthal orientation, Az_{XY}, can be related to the cosine plane coordinates, $(\cos(\alpha), \cos(\beta)) = (l, m)$, using the following relation[1].

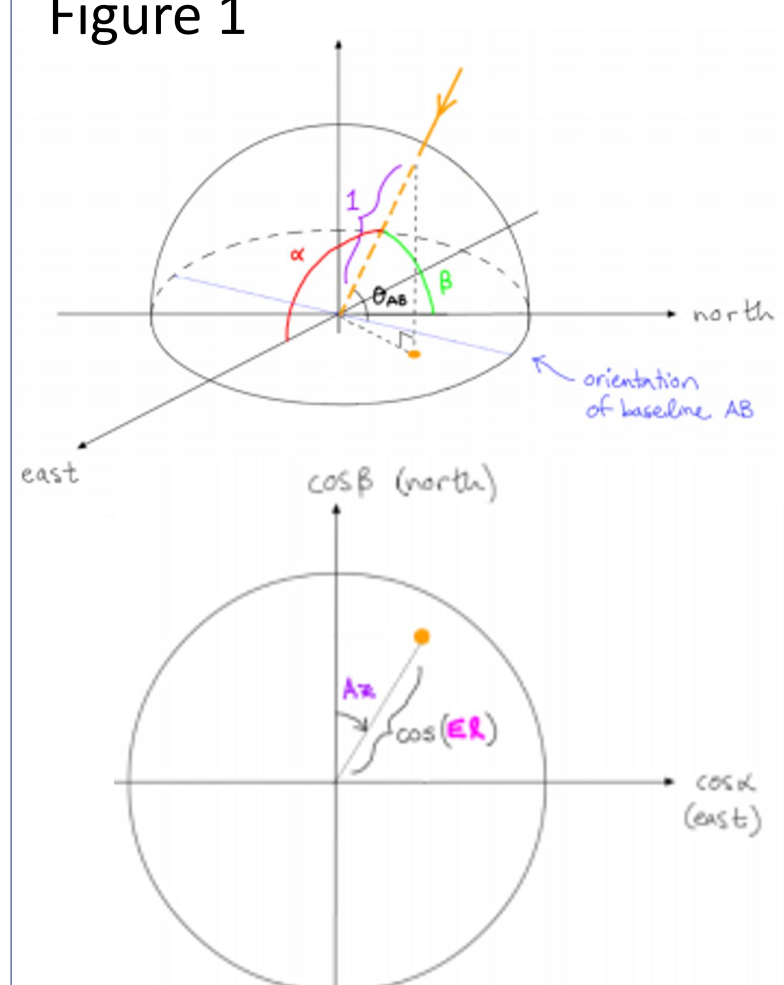
$$\tau_{XY} = \frac{d_{XY}}{c}(l * sinAz_{XY} + m * cosAz_{XY})$$

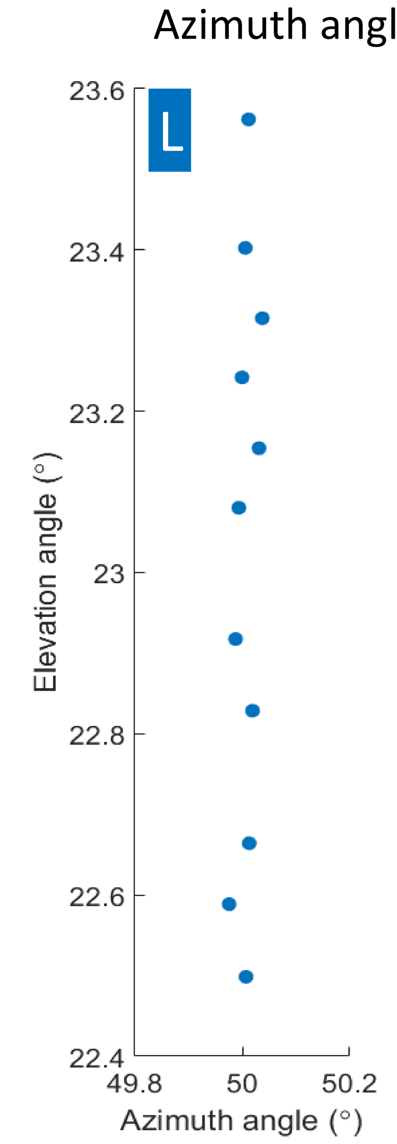
- Time delay, τ_{XY}, is determined by cross correlating the two signals, f_X and f_Y, with the relation $(f_X \star f_Y)(\tau) = \int f_X^*(t) f_Y(t+\tau)dt$
- The unit hemisphere can be viewed in an azimuth-elevation projection, where the azimuth angle (Az) is the angle made clockwise with respect to north and elevation angle (El) is the angle made from the source location to the origin. Azimuth angle and elevation angle are defined as $Az = \tan^{-1}(\frac{l}{m})$ and $El = cos^{-1}(\sqrt{l^2+m^2})$.

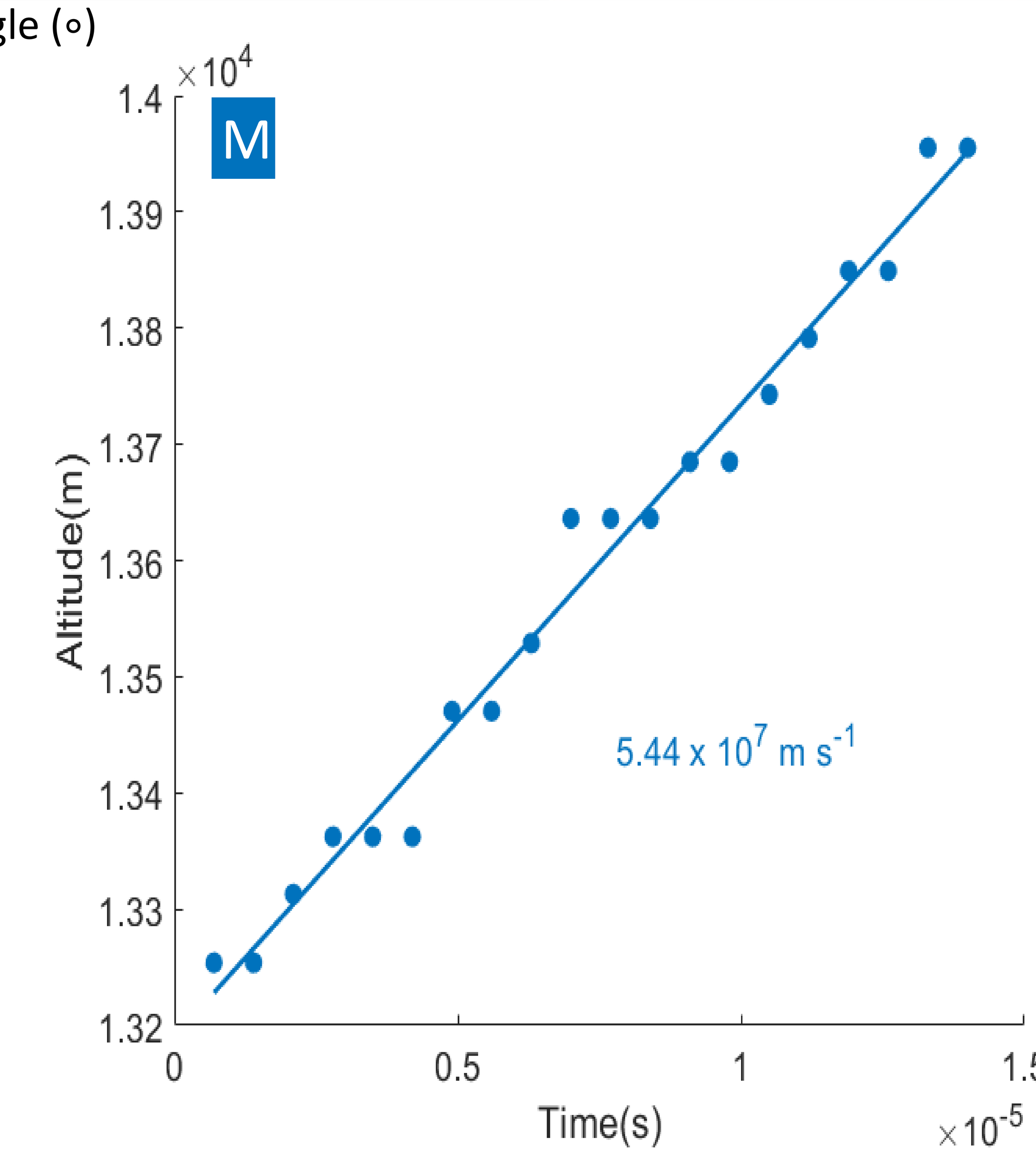
Radio Images of Simulated Sources











Results

- Images A-C show an ideal point source, constructed from a point source function of the antennae array. All concurrent images have a 0.7 μs exposure and the same color bar scale.
- Images D-G shows the effect of two point sources of equal power, separated angularly in azimuth. Two sources are distinguishable at two degrees of angular separation in azimuth
- Images H-K shows the effect of two point sources of equal power, separated angularly in elevation. Two sources are distinguishable at 5 degrees of angular separation in elevation
- While two sources with a separation of less than 4-5 degrees in elevation cannot be distinguished, the change in location of the single centroid can be tracked over time.
- Plots L and M shows the apparent centroid location of two sources, separated by 1 degree in elevation. The bottom most source begins with an intensity of 1 while the second source is turned off. Over a total time of 15 μs, the intensity of the two sources are gradually flipped and the centroid location is tracked.

Conclusion

- Forward model is developed and validated against results presented in Tilles et al. (2019).
- Results depicted on plots L and M confirm that two stationary sources of varying intensity can reproduce the observations in Tilles et al. (2019).
- In general, two point sources of various separations can produce centroid shifts that don't necessarily depict actual source propagation
- Next step in this research is to combine with an electrostatic discharge solver for further investigation of dynamic source distributions that agree with observations.

Acknowledgements

I'd like to thank my advisors, Dr. Ningyu Liu and Julia Tilles, for their invaluable help and guidance throughout this project

References

[1] Stock, M. (2014). Broadband interferometry of lightning. PhD dissertation, New Mexico Institute of Mining and Technology

[2] Tilles, J. N., Liu, N., Stanley, M. A., Krehbiel, P. R., Rison, W., Stock, M. G., ... Wilson, J. (2019). Fast negative breakdown in thunderstorms. *Nature Communications*, *10*(1).