Direction Finding of Simultaneous Cyclotron Harmonic Auroral Radio Emissions

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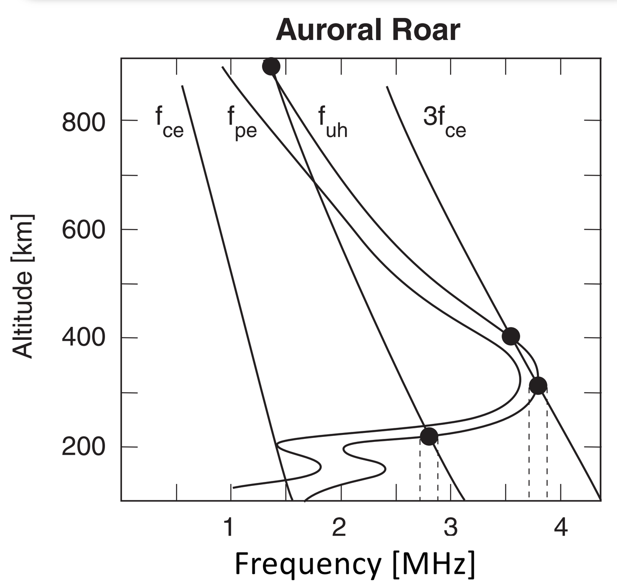
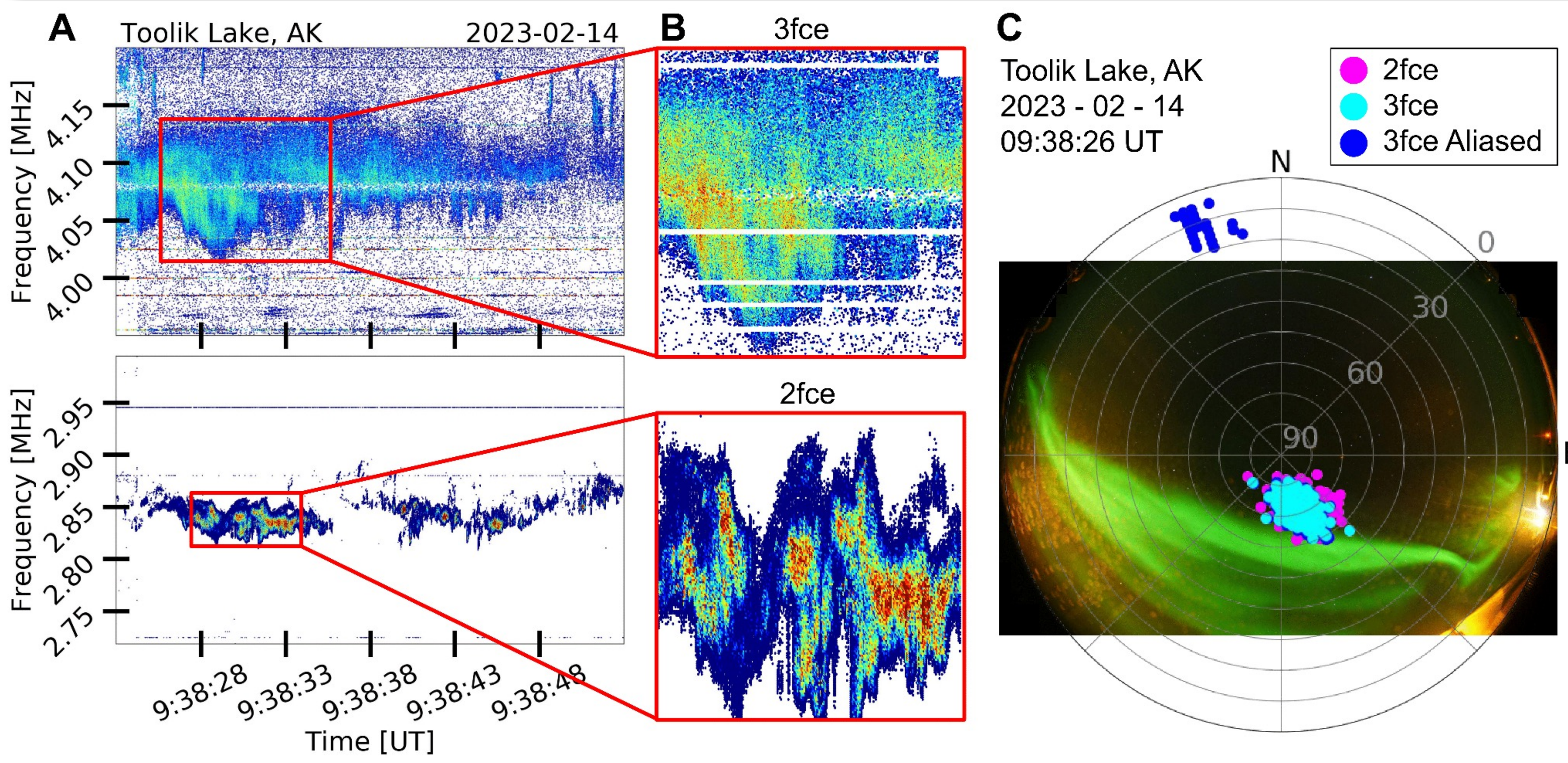
Intro



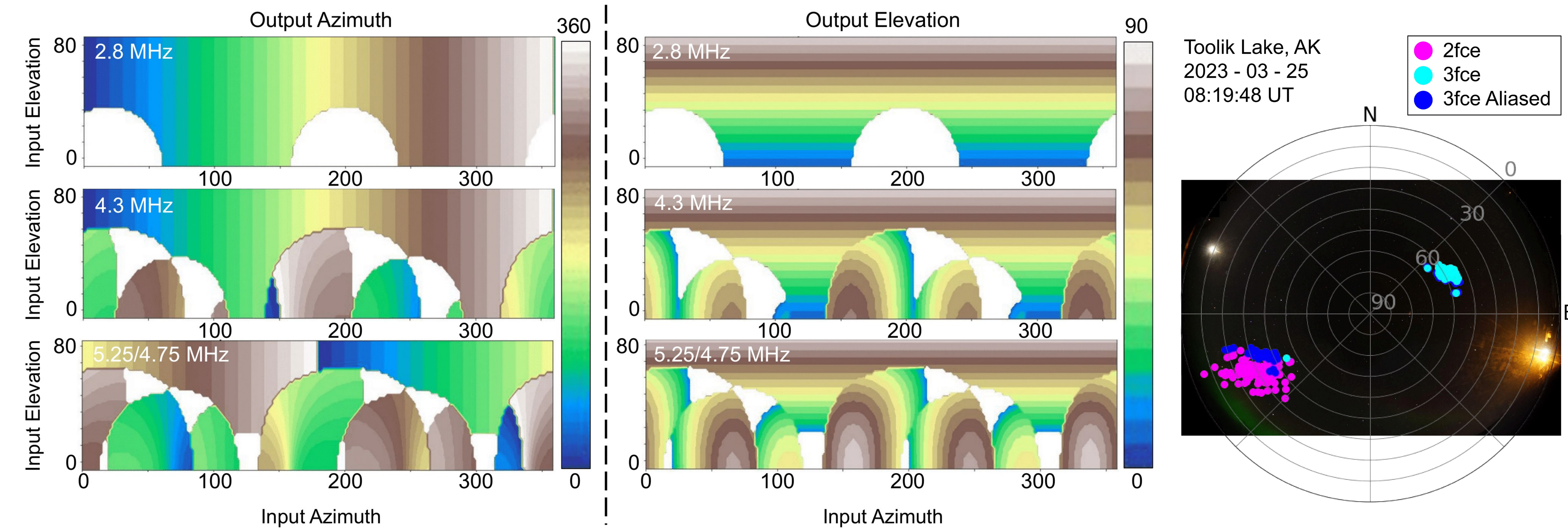
The dots indicate the source altitude of the $2f_{ce}$ and $3f_{ce}$ emissions, assuming they are generated when two and three times the cyclotron electron frequency (f_{ce}) match the upper hybrid frequency (f_{uh}). [LaBelle and Treumann, 2002] In contrast with previous studies that looked at the 2fce and 3fce separately, this study focuses on times when $2f_{ce}$ and $3f_{ce}$ occur simultaneously.

Methodology



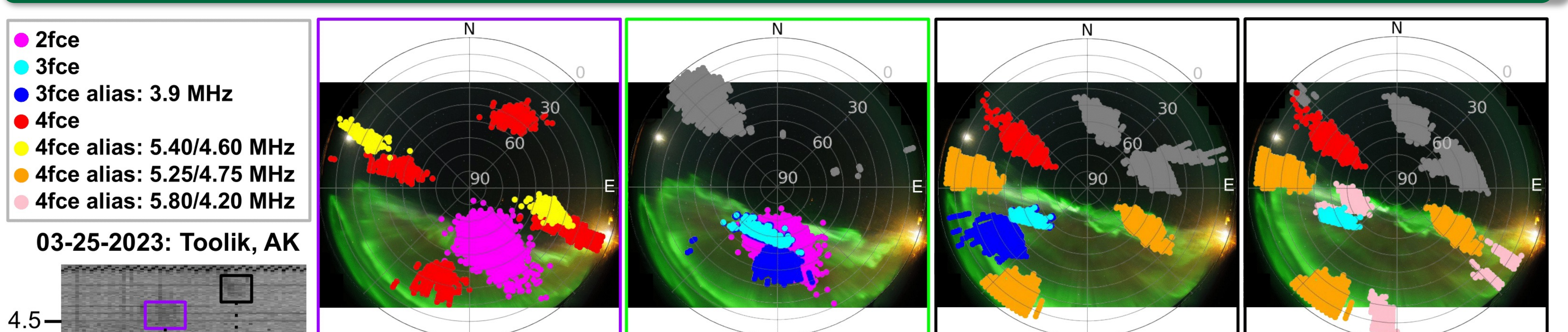
(A) Selection tool developed to analyze auroral events from spectrograms. (B) It also allows for the removal of interference lines and filtering by power and frequency. (C) The distribution of the DOA (direction of arrival) with all sky camera image superposed. The radial direction is elevation, and the angular direction is azimuth. This event is modelled using PHaRLAP in the last section. Those results confirm that these emissions come from the same bright auroral arc.

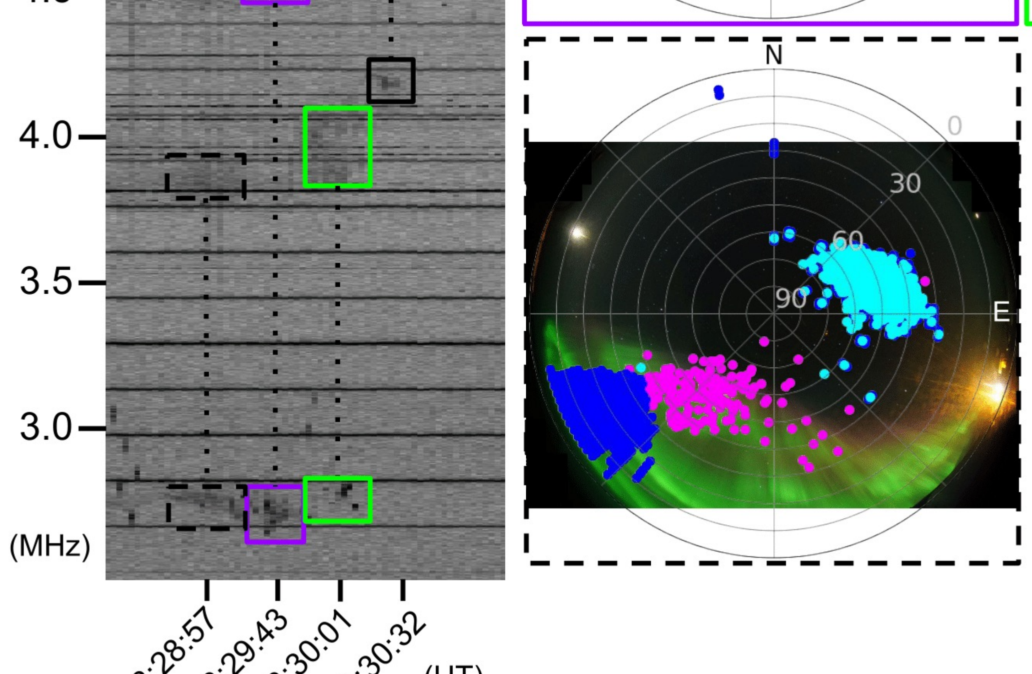
Signal Aliasing



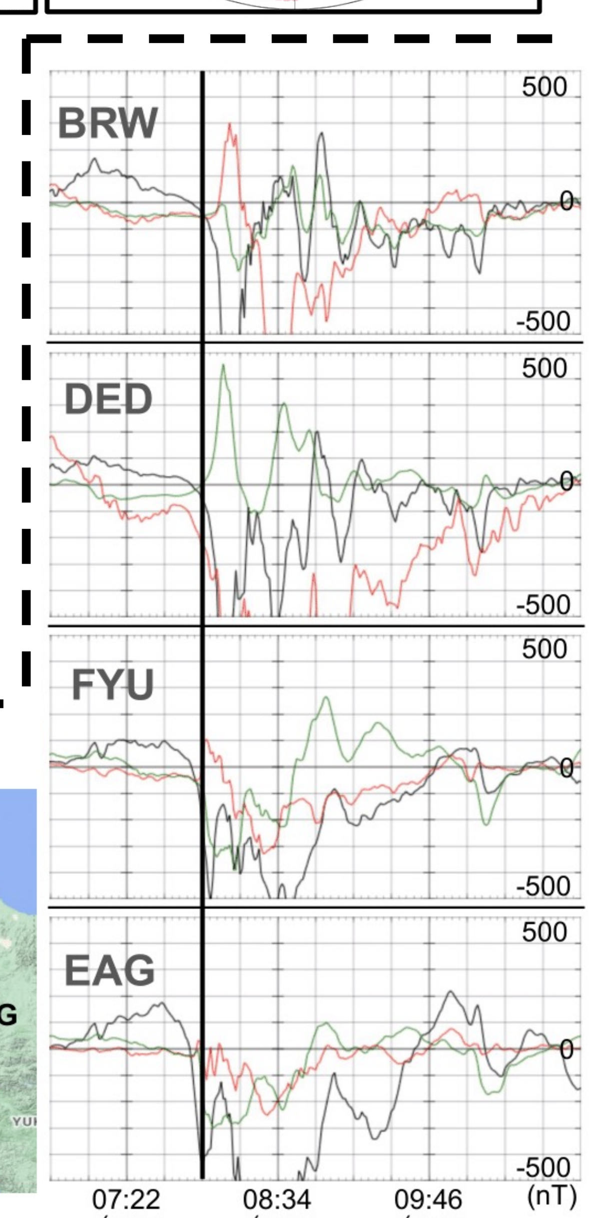
Spatial aliasing can occur in the DOA when the spacing between the antennas is too large compared to signal wavelength. For all possible input azimuth and elevation angles given in the color bar, the plots indicate the location(s) where the output angles can be mapped to. The left column shows output azimuths, and the right column shows output elevations. Each row shows a different frequency corresponding to 2-,3-, and 4 f_{ce} events. The left panel shows DOA calculations incorporating the aliasing. Without accounting for aliasing, the $3f_{ce}$ is coming from the wrong direction, but accounting for aliasing puts it in the same direction as the $2f_{ce}$ and the auroral arc.

Case Studies

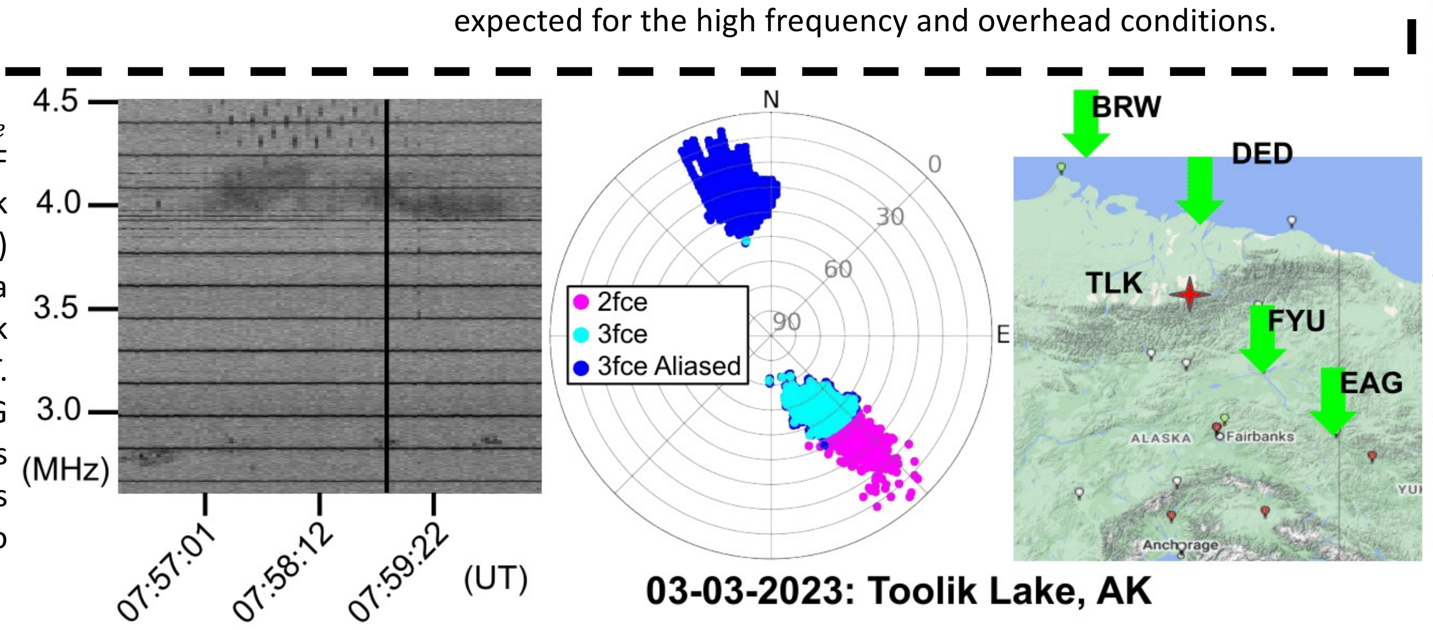




A 2-,3-,4- and potentially $5f_{ce}$ event divided temporally by the colored boxes. At the first-time interval (lower left), the aurora is to the SW and produces a 2-,3f_{ce}. It expands to the east over the next minute, and a 4fce occurs consistent with roughly the same direction (upper left). The $2f_{ce}$in the next interval is still south, but the $4f_{ce}$ disappears and a $3f_{ce}$ is seen again also from the south (green panel). In the fourth time interval (black outline), it is possible that $3f_{ce}$ emission occurs at 4.2 MHz and temporally aliased $4f_{ce}$ emission at 4.7 MHz (implying that the actual emission frequency is 5.2 MHz), or it may be that the 4.2 MHz is an aliased $5f_{ce}$ emission with actual frequency of 5.9 MHz. These two scenarios are shown in the two black outlined panels. The $5f_{ce}$ seems more likely, since the determined directions match exactly to the nearly overhead arc, and minimal refraction is expected for the high frequency and overhead conditions.

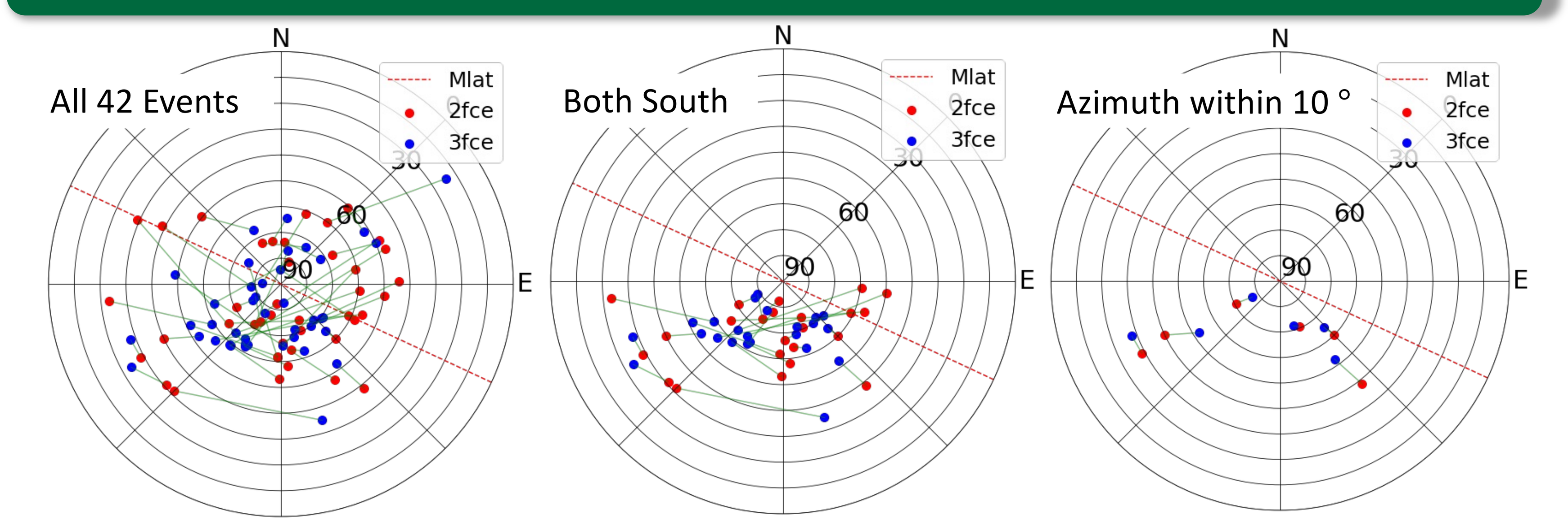


An example of simultaneous 2-, 3 f_{ce} harmonics is shown to the right, with DF data take at the time of the vertical black line (middle panel). Mag data (right panel) show a substorm onset marked by a prompt bay in the H-component (black trace) starting at approximately 07:58 UT. The magnetic field activity appears at EAG and FYU first, and after a few minutes delay it appears at DED and BRW. This indicates that the onset shifts from SE to NW, consistent with the DF result.

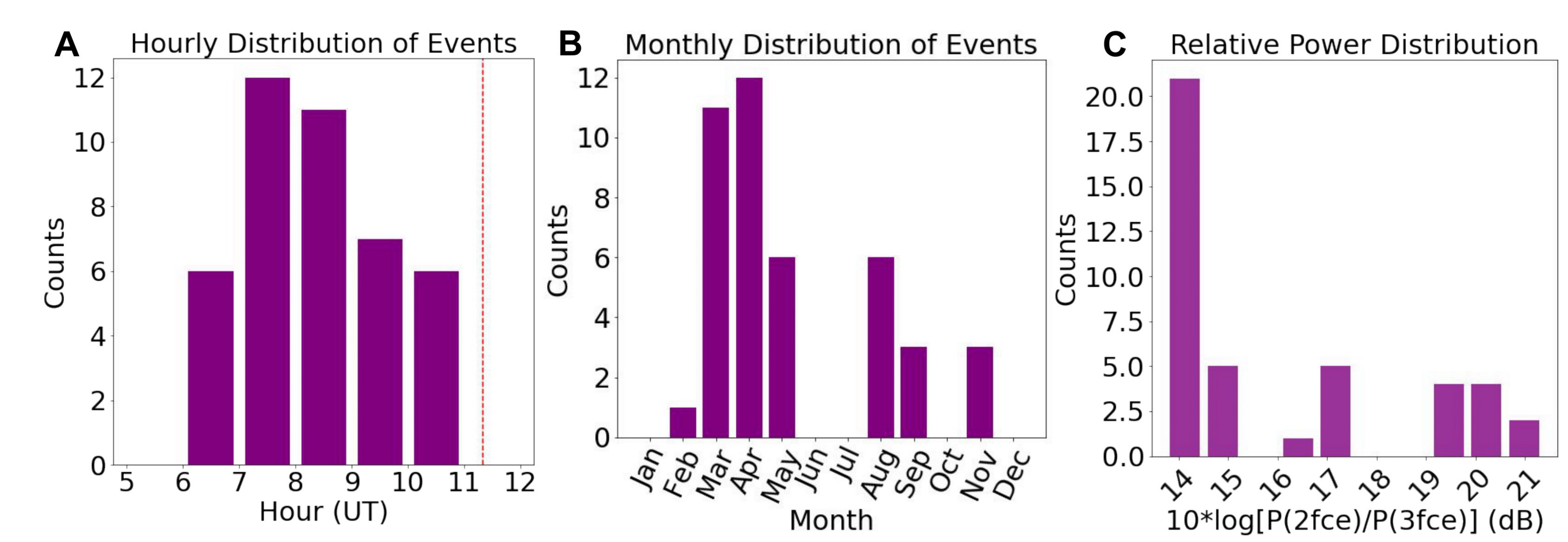


03-03-2023: Toolik Lake, AK

Statistical Results

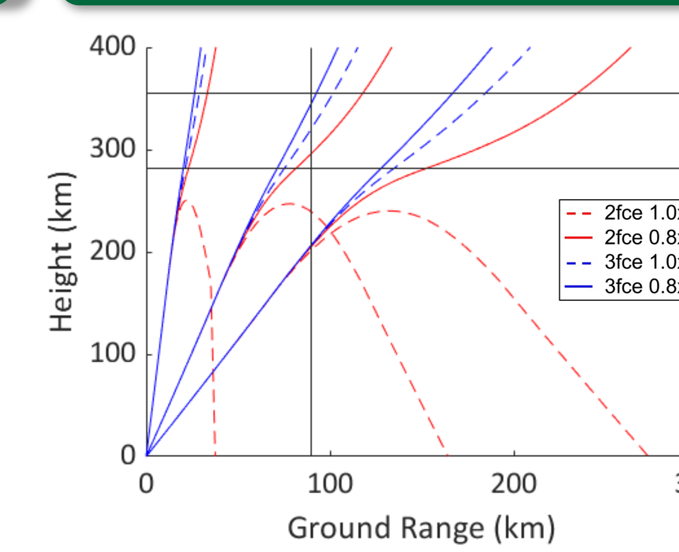


Lines connects the mean DOA of simultaneously occurring 2fce and 3fce events, which are symbolized by red and blue dots, respectively. The red line approximately the magnetic latitude of Toolik. 70% of the events had a higher $3f_{ce}$ elevation as expected for a bottomside source (left panel). Cases where both emissions came from the south (middle panel) have more reliable DOA measurements; 1/6 of these southerly events were widely separated in azimuth, and that represents a lower bound on fraction of emissions coming from different sources. 1/6 of the pairs had azimuth directions within 10° (right panel), and that represents a lower bound for events that could come from the same auroral arc. In 100% of the events the 3fce elevation is greater than or equal to the 2fce elevation to within uncertainty.



(A) Distributions of all events as a function of time of day, where the red dashed line indicates local magnetic midnight. (B) Month of year distribution for all events. The gap in June and July reflects that $2f_{ce}$ events occur during the winter months (Weatherwax+ 95). The $3f_{ce}$ events mostly occur in the summer months when there is more sunlight. Therefore, the occurrence of simultaneous events has peaks in spring and fall. (C) Relative power ratio of $2f_{ce}$ to $3f_{ce}$ events, showing that $2f_{ce}$ events in this sample are 14-20 dB; there is a possible systematic error of 6.5 dB due to the thresholding mentioned.

Ray Tracing



The PHaRLAP ray tracing toolbox was used to analyze sources of $2f_{ce}$ and $3f_{ce}$ events in an effort to model the event on feb14 shown in the methodology section. A range of elevation angles was modelled matching the observed ones at several elevation angles: 66°, 76°, and 86°. The dashed lines use the electron density profile generated directly by IRI for the given date and time. The solid lines use the same density profile multiplied by 0.8. The modified profiles allows both harmonics to to reach the theoretically expected source height based on the $f_{uh} = Nf_{ce}$ matching condition.

Conclusion

1. This comprises a test of the theory that the $3f_{ce}$ elevations are higher than the $2f_{ce}$ elevations.
2. Lower bound of 1/6 on clearly separated, and 1/6 on coming from the same arc (where the energy must be shared between both events).
3. Show a novel way of accounting for the spatial aliasing, which can be applied to other antenna systems.

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