Polarization Detection Dependence of Nonspecular Trail Geometry
Jonathan Yee and Sigrid Close
Space Environment and Satellite Systems, Aeronautics and Astronautics, Stanford University

Abstract
The nonspecular trail was detected in both LC and RC, as shown to the right as functions of time and altitude color coded for SNR. As mentioned, the curious RC return from a transmitted RC wave can be seen between 91 and 91.5 seconds in the right figure. In order to examine the detection dependence on geometry, the AZ and EL angles were used to calculate detected trail positions as a function of time. Since the magnetic field will influence the trail's diffusion, the coordinate frame and positions were rotated such that the axes were parallel and perpendicular to the magnetic field. An ellipse was then found that encompassed all the return points at each half integer altitude with the major axis parallel to the magnetic field and the minor axis perpendicular to the magnetic field. The ellipse radius in each direction should demonstrate any elongation in geometry with time.

Comparison
High Power, Large Aperture (HPLA) Radars have been used to characterize the plasmas formed as meteoroids ablate in Earth's atmosphere. These plasmas are referred to as heads, which are the plasmas surrounding the meteoroids, and trails, which are plasmas behind the meteoroids. A particular subset of trails is nonspecular trails, which are thought to be the reflection from field aligned irregularities (FAIs) when the radar beam is quasi-perpendicular to the magnetic field. For the first time, an analysis of the polarization, Left Circular (LC) and Right Circular (RC), dependence of detected nonspecular trail geometry is presented here from ALTAIR. We explored possibilities for the unexpected detections in RC, in addition to LC, and found that the RC returns are due to multiple scatters from denser regions of plasma before the plasma diffuses outwards into a LC return only "line-like" geometry.

Background
As meteoroids enter Earth's atmosphere, they begin to heat up and ablate particles which subsequently collide with neutral air molecules and form columns of partially ionized plasma called meteor trails in their wake. Nonspecular meteor trails, a specific subset, can be detected by HPLA radars by pointing the radar beam quasi-perpendicular to the magnetic field. These reflections are thought to be from FAIs that form in a three step process. First, an electric field develops within the initial plasma trail. Instabilities then develop at the edges of the trail that grow until the onset of turbulence within the trail, which then leads to the FAIs and radar detection. 1 Diffusion coefficients of these types of trails detected at ALTAIR resulted in lower magnitudes than predicted values for specular trails. 2, 3 However, these measured diffusion rates did show an enhanced diffusion in the perpendicular to the magnetic field direction which coincides with simulation predictions. 4 In examining this data set, differences in LC and RC detections appeared. It was postulated that these differences could be due to 1) changing plasma shape from a long thin wire, which would return equal parts LC and RC, to a spherical shape, which would only return LC, or 2) multiple scatters from initial denser region, LC and RC return, that diffuse with time to a more "line-like" LC only return. 5 The objective of this study was to determine which of these two possibilities explain the unexpected RC signal by utilizing detected positions and examining the changing geometric shape of the plasma.

ALTAIR Data
ALTAIR is a 46 meter diameter high-power, dual frequency radar operating at 422 MHz (UHF) and 160 MHz (VHF), located in the Kwajalein Atoll in the Pacific Ocean. ALTAIR transmits a RC signal at a peak power of 6 MW in a half-power beam width of 1.1° (UHF) and 2.8° (VHF). The data collected included dual frequency, dual polarized, and high range resolution in-phase and quadrature returns with additional azimuth (AZ) and elevation (EL) data derived from a combination of four additional receiving horns, which provide the 3-D position, velocity, and deceleration of an object. The trail presented here represents a selection of a single nonspecular plasma trail detected by ALTAIR at 6 AM local time on January 2, 2008.

Results
The results of the described analysis, color coded for radius magnitude, are presented above for LC return in the top two figures and RC return in the bottom two figures. Notice that the magnitudes are larger in the portion where there is only LC return than in the portion detected in both RC and LC. To aid in understanding how the geometry is changing, the running average major and minor radius were plotted for 94.5 km altitude as an example on the right. There is some difference between the minor and major radius, but only on the order of a hundred meters which is still within the measurement error.

Discussion
Based on the RC returns at the beginning of detection and none at later times, seen above, the plasma shape would have to diffuse from a long thin wire at the beginning of its formation to a spherical shape as it develops according to the first possible theory. However, based on our analysis of the ellipse radii, it can be seen that the shape is much closer to a circle at the time of the RC detection since the major and minor radii are equivalent. Therefore, it cannot be that the RC return is due to an elongated shape diffusing to a spherical shape. Rather, the results demonstrate that the plasma starts as a smaller denser region, smaller radii with strong returns at earlier times, while the possibility of multiple scatterings is likely. This is then followed by the plasma diffusing outward, increasing radii with time in figure below, aligning along the magnetic fields, and returning only LC signal at later times.

Conclusion
The results of our analysis of this nonspecular trail have shown that the unexpected RC return is due to multiple scatters from the initial denser region of plasma, and not from a thin elongated plasma, thereby confirming what was suggested by Close. 6 This result, examined for the first time for nonspecular trails, provides an understanding of the change in meteor trail geometry as it diffuses in the ionosphere. In addition, it provides a starting point to understanding how radars scatter from meteor trail detections.

Future Work
While these results suggest that multiple scatters are the reason for RC return, it is only for one nonspecular trail. This analysis must be completed on more trails in order to validate the findings. Additionally, running simulations of diffusing plasma trails can help to further confirm these results.

Acknowledgments
The authors would like to thank the people at ALTAIR and Bill Cooke at Marshall Space Flight Center for providing the terabytes of meteoroid trail data.

References
2. Yee, J., et. al., AIAA Atmospheric Space Environments Conference, 2011

Technical Questions
Email: jcyee@stanford.edu
Site: siss.stanford.edu
Location: SESS Lab, Durand 032B, Stanford, CA