Ion holes are solitary electrostatic structures/waves (ESWs) formed in a nonlinear stage of various ion-streaming instabilities. These structures have been previously observed in the auroral region and recently in the Earth's bow shock. However, all previous measurements are limited to single-spacecraft observations. In this study we present the first multi-satellite observations of ion holes aboard four Magnetospheric Multiscale spacecraft in the Earth's magnetotail. We perform multi-spacecraft interferometry to estimate ion hole velocities, spatial widths and amplitudes. Surprisingly, these ion holes are observed in a plasma with ions several times hotter than electrons, which contradicts simplified theories stating that ion holes can only exist in plasma with electrons a few times hotter than ions. The detailed analysis shows that the existence of the ion holes is due to specific kinetic features of the electron and ion velocity distribution functions not envisioned by the simplified models.

1. We examined the magnetic, parallel and perpendicular electric field of tens of ion holes and determined their distances from each other.
2. Initially we posed that the ion holes can exist in the earth’s magnetotail by determining the average velocity, electrostatic potential, and plotting the particle distribution functions. With the results from this analysis, we will be able to rule out certain types of instabilities as probable sources of ion holes and determine the instabilities that create them.
3. We performed interferometry analysis to determine the time delay between each spacecraft mission in the auroral region. The analysis of these structures from various missions initially conflicted. However, with the data from the Magnetospheric Multiscale Mission, we now have the opportunity to analyze these structures in greater detail via multi-satellite analysis.

The goal of our research is to determine how ion holes can exist in plasma with electrons a few times hotter than ions. The detailed analysis shows that the existence of ion holes is due to specific kinetic features of the electron and ion velocity distribution functions not envisioned by the simplified models.

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Open Questions

- What is the 3D shape of ion holes?
- What are the properties of ion holes in other regions?