Multi-satellite Analysis of Electrostatic Solitary Waves Using Magnetospheric Multiscale Mission

Laura Holley[1,2,3], Ivan Vasko[1], Forrest Mozer[1], Rachel Wang[1]

[1]Space Sciences Laboratory, UC Berkeley, [2]University of California, Davis, [3]Long Beach City College

Contact: lcholley@ucdavis.edu

Abstract

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.

Background

Ion holes have been previously observed by single spacecraft missions in the auroral region. The analysis of these structures from various missions initially conflicted.[1] 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 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 may them.

Methods

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 propagate exactly parallel to the magnetic field and projected the electric field onto **B**
3. We performed interferometry analysis to determine the time delay between each satellites' recognition of the ESW events via cross correlation. We were then able to compute the velocity of the ESW
4. We calculated the ESWs' true vector of propagation via the multi-spacecraft timings method [Tong et. al 2018]
5. We plotted the 1D ion velocity distribution functions [Figure 4], performed a change of basis to Vpar vs. Vperp, and plotted the 2D interpolated surface for visualization [Figure 5]
6. After averaging the results, we chose a representative event that is consistent with all the results from our observations

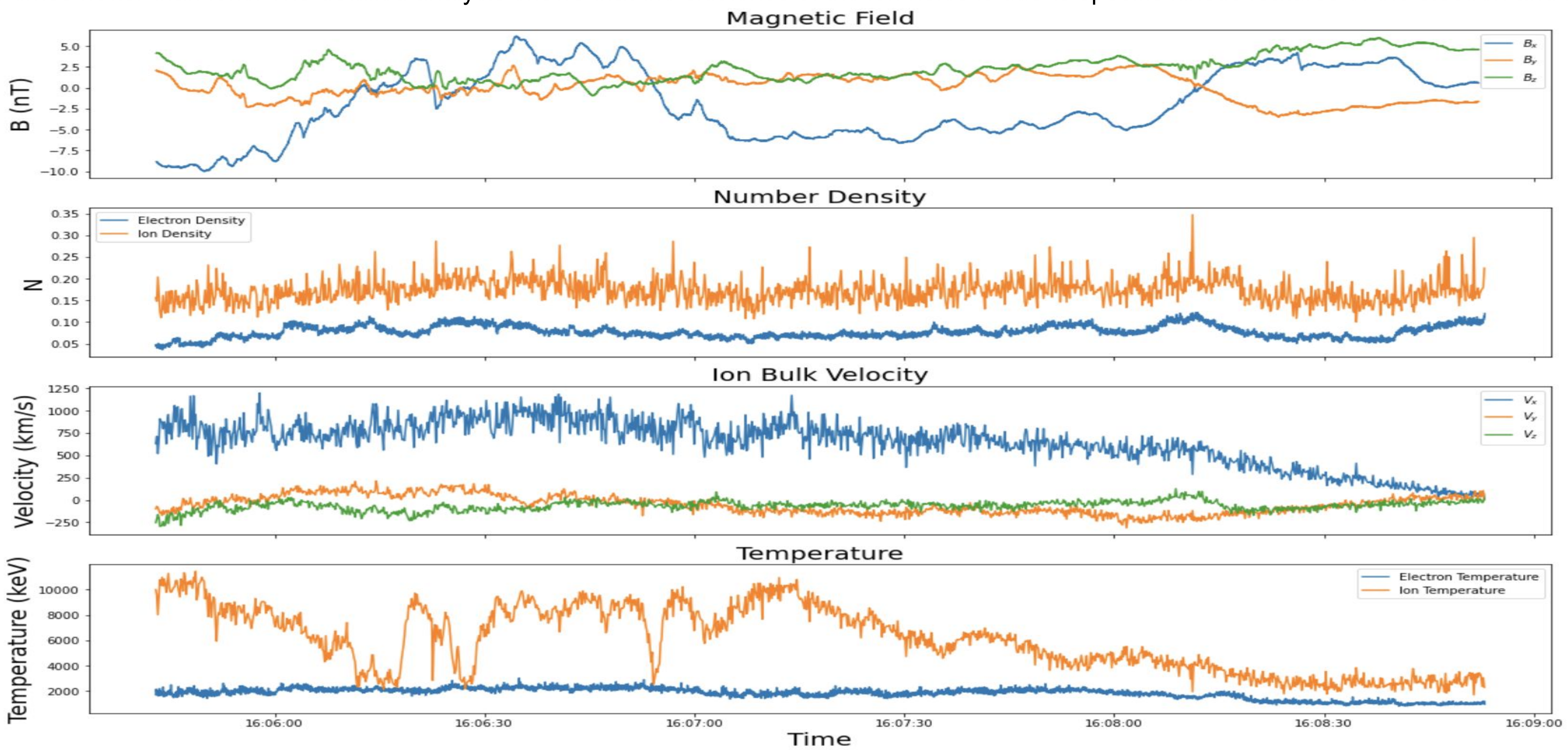


Figure 1: An overview plot on 2017-07-29 where the first panel is a plot of the magnetic field, the second panel is the number density of ions and electrons in the plasma, the third panel is ion bulk velocity , and the last panel is the ion and electron temperatures.

Figure 2: Parallel electric field of each MMS spacecraft. A distinct bipolar signature can be observed, which is consistent with ion holes. Time is measured in milliseconds from 16:08:04:702.

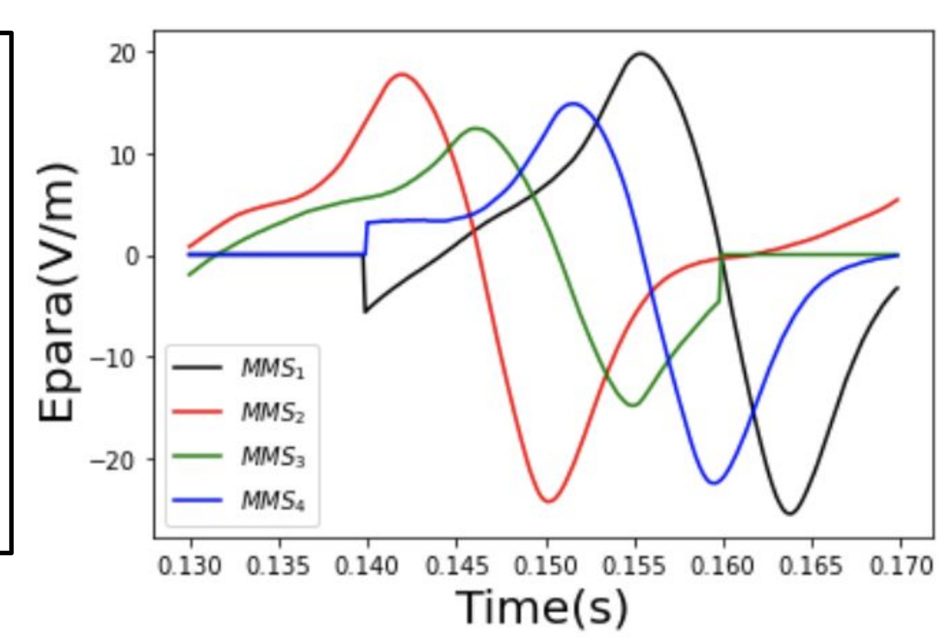


Figure 4: Ion velocity distribution function. The power law trend indicates the one count level of the instrument. Only signals above this floor are used in Figure 5 below.

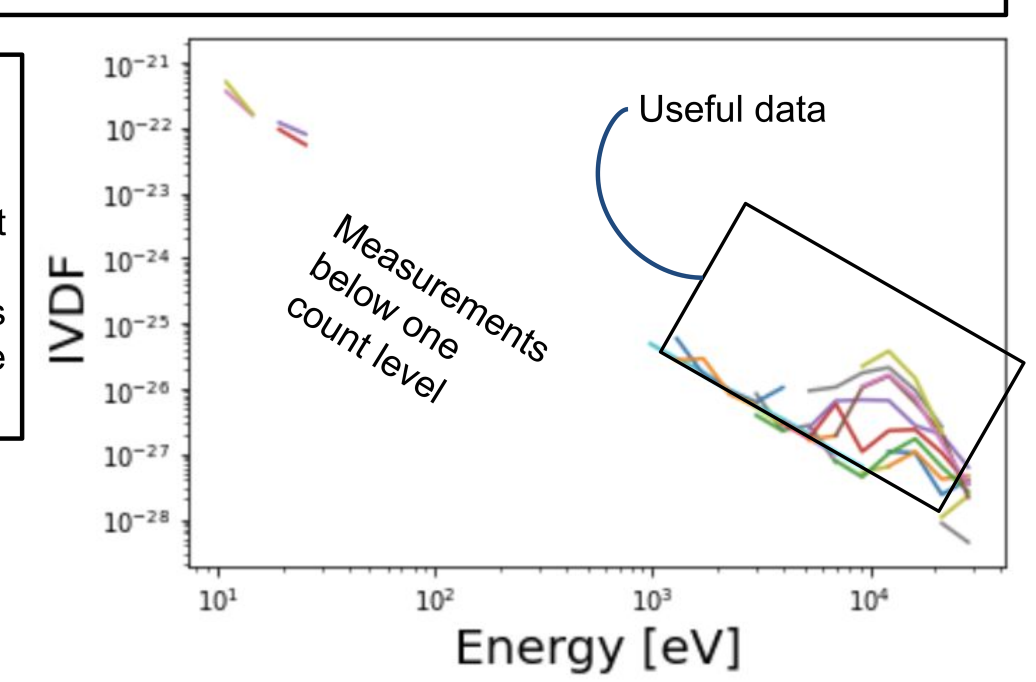


Figure 3: Electrostatic potential consistent with the ion holes in Figure 1. A negative potential can be observed, consistent with ion holes.

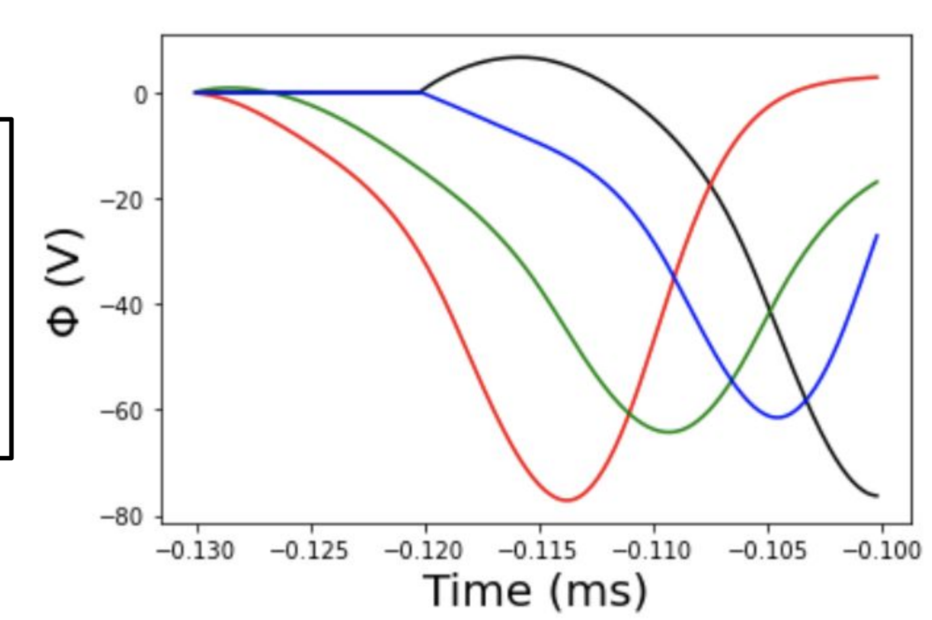
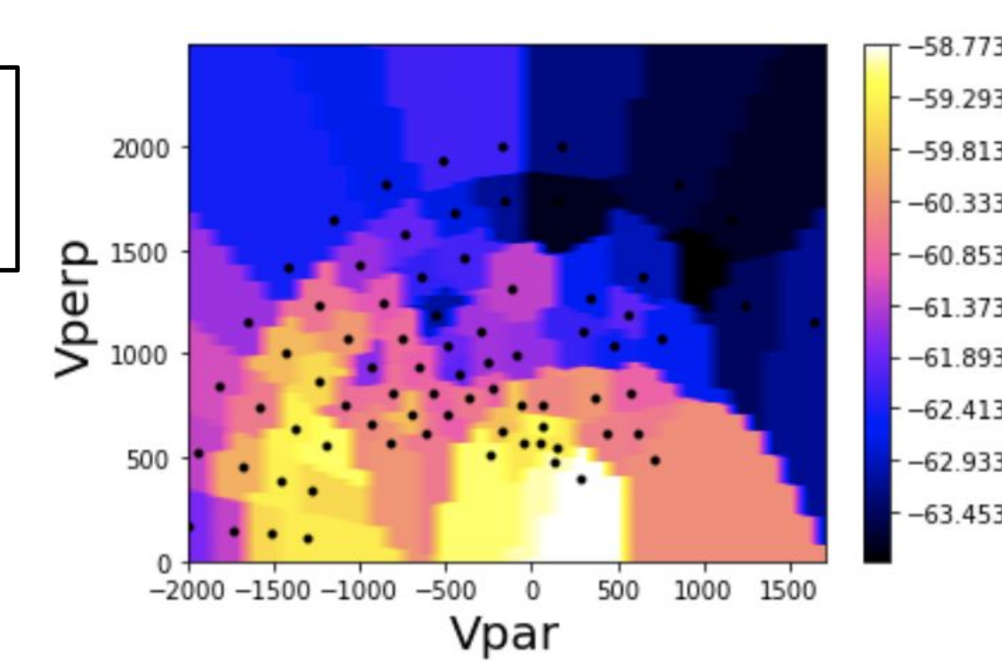


Figure 5: 2D surface plot of the ion velocity distribution for this event.



Results/Conclusions

- Average velocity of ion holes in this region: ~700 km/s
- Sign of electrostatic potential: negative, consistent with ion holes
- IVDFs not Maxwellian, this explains why ion holes exist in this region - (previous theories were developed for Maxwellian IVDFs)
- The velocities of ion holes are consistent with observations of ion beams (the velocities in between the beams) [Figure 5]
- Two-stream instability is a probable process of ion hole formation in the earth's magnetotail because the distribution function is non-Maxwellian.

Open Questions

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

References

[1] McFadden, J. P., C. W. Carlson, R. E. Ergun, F. S. Mozer, L. Muschietti, I. Roth, and E. Moebius, FAST observations of ion solitary waves, J. Geophys. Res., 108(A4), 8018, doi:10.1029/2002JA009485, 2003.

[2] Fuselier, S.A., Lewis, W.S., Schiff, C. *et al.* Magnetospheric Multiscale Science Mission Profile and Operations. *Space Sci Rev* 199, 77–103 (2016).

Acknowledgements

I would to thank the coordinators at SSL for their assistance. In addition, thank you to the professors at my previous school, LBCC, who encouraged me to apply to this program. ASSURE is an REU program funded by the National Science Foundation. Grant #: 2050736