The Role of Cold Plasma and its Composition on the Growth of EMIC Waves in the Inner Magnetosphere

Andrews University
J.N. Andrews Honors Program

Jesse M. Snelling[1], Jay R. Johnson[2], Eun-Hwa Kim[3], Mark Engebretson[4], Sheng Tian[5]

Office of Research & Creative Scholarship

[1]Department of Physics, Andrews University, [2]Department of Engineering and Computer Science, Andrews University, [3]Princeton Plasma Physics Laboratory, [4]Augsburg College, [5]School of Physics and Astronomy, University of Minnesota

jesses@andrews.edu

Abstract

While it is currently well accepted that the free energy for growth of electromagnetic ion cyclotron (EMIC) waves in Earth's magnetosphere comes from unstable configurations of hot anisotropic ions injected into the ring current, in some cases the measured anisotropy is not adequate to explain local instability. Additionally, the relative importance of the density and composition of a cold plasma population is uncertain. In this study, several intervals of observed EMIC wave activity are analyzed using WHAMP stability code with fitted plasma distributions to determine the role of a cold population in driving instability on each of the wave branches.

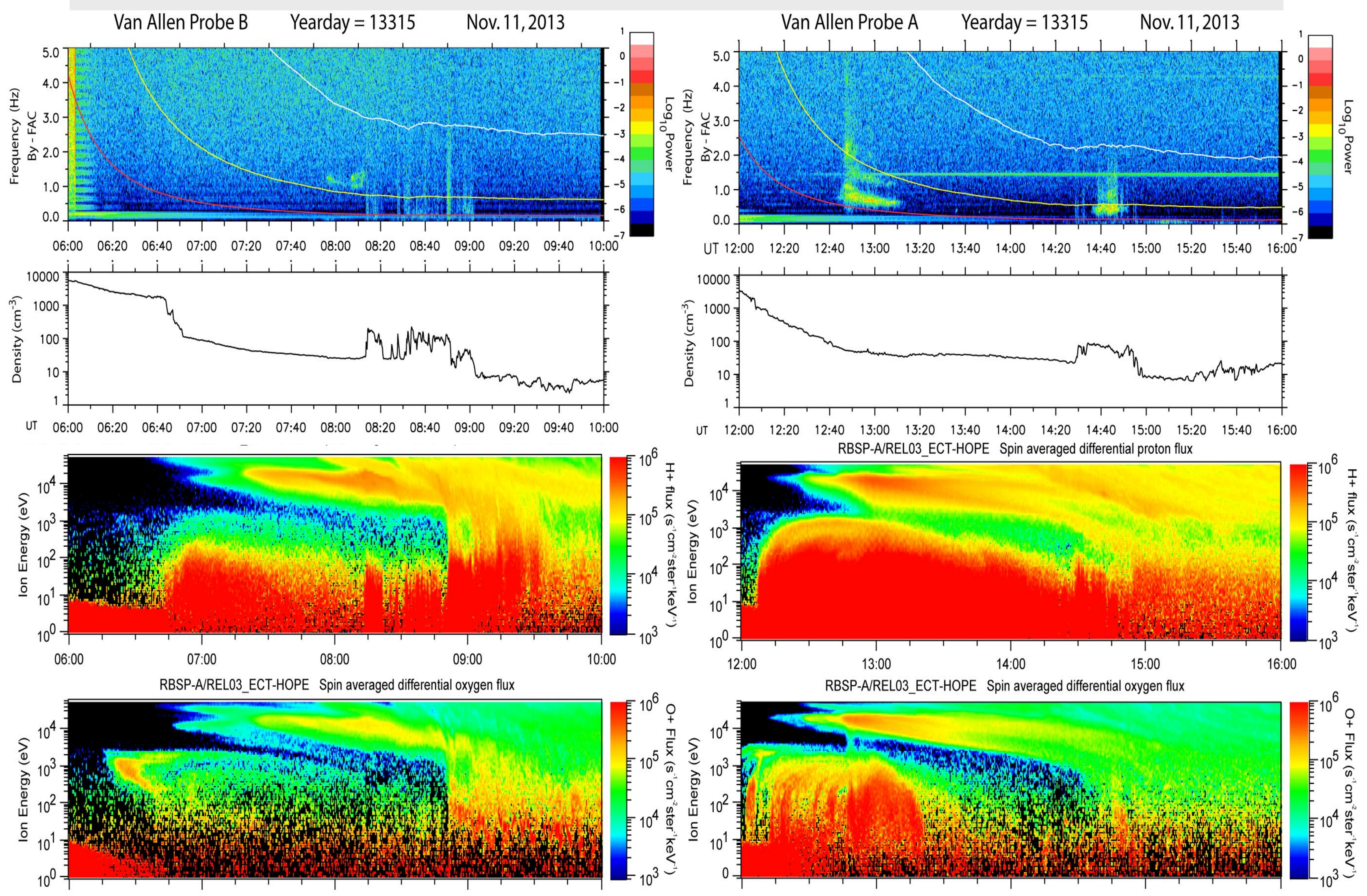

Figure 1. Events at 8:10, 12:50, and 14:45. **[1]** Note increased density when passing through plume structures. **[2]**

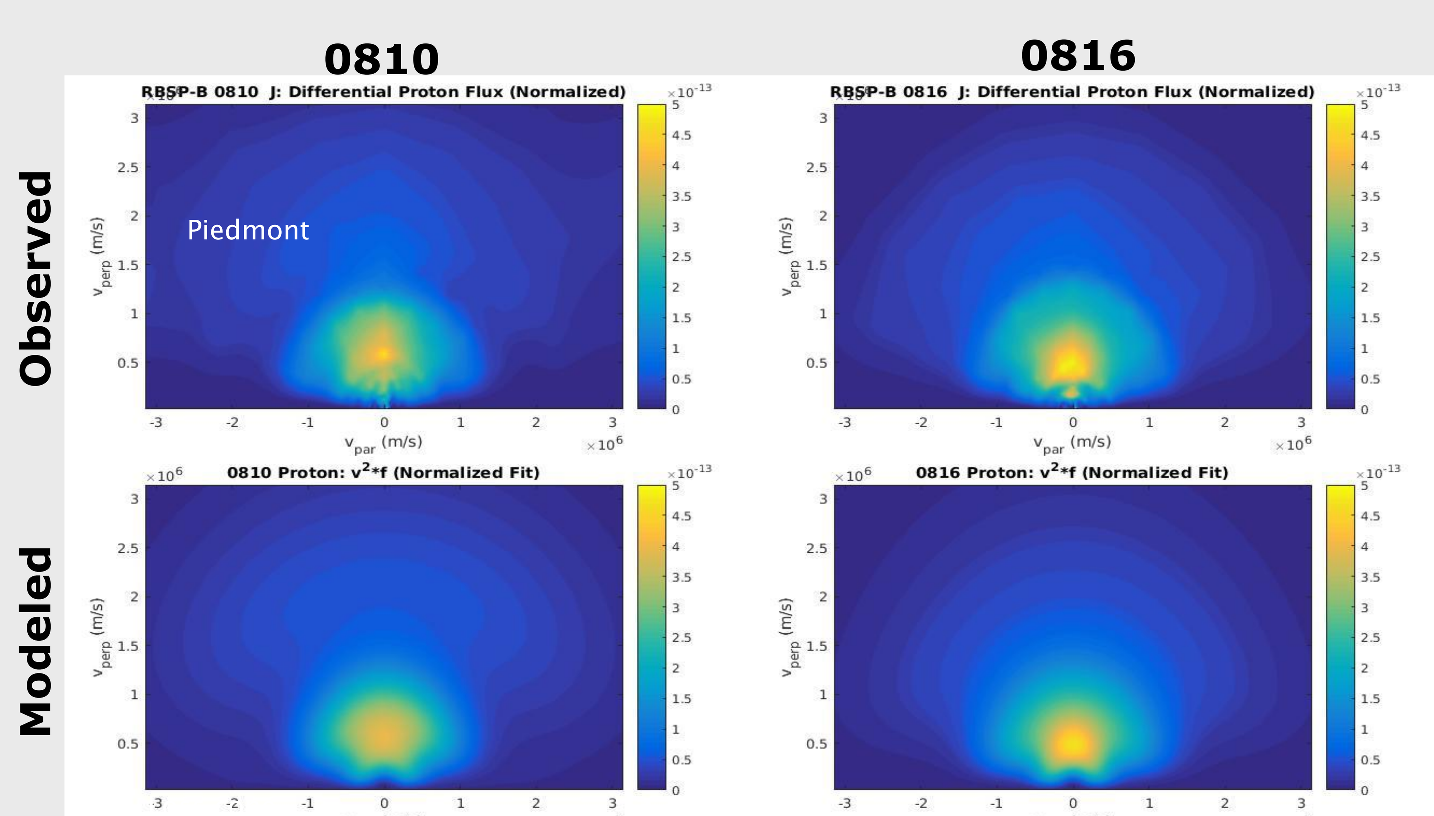

Figure 2. Observations and fit using parameters for WHAMP. Matlab's fminsearch with a cost function was used to minimize differences between surfaces.

Background

Energy can be transferred from particles to waves when the wave is travelling at the same speed as the particle. The wave speed is proportional to the Alvén velocity.

$$v_A = \frac{B}{\sqrt{\rho}} \qquad (1)$$

where v_A is the Alvén velocity and ρ is the total mass density of the plasma. The presence of a cold population, especially of heavier particles (helium and oxygen), increases ρ which results in a slower wave that will result in larger energy transfer. The anisotropy of the hot population is also a source of free energy. Spectrograms of the wave events obtained from NASA's Van Allen Probes (also known as Radiation Belt Storm Probes or RBSP) can be seen in *Figure 1.*

Methodology

Analysis

- WHAMP **[4]** was used to obtain dispersion relations for the events.
  - The total density of cold ions is known, but the ratios of cold H^+, He^+, and O^+ were not (likely due to spacecraft charging). Because of this, several plots were made for various compositions of cold plasma.
- Distribution functions based on RBSP data were sought to verify our assumption of bi-Maxwellian distribution necessary to use WHAMP. In some cases, they seemed to more accurately be described by a ring beam. Because of these irregularities, a fit of the distribution using WHAMP parameters was sought, specifically in the 8:10 event. See *Figure 2.*

Results

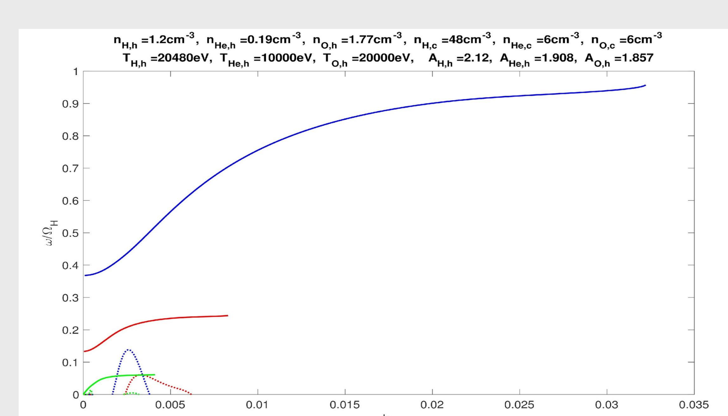

Figure 3. Dispersion relation for 12:50 at given values. Note the instability. This instability remained even when increasing the temperature of the hot ions significantly.

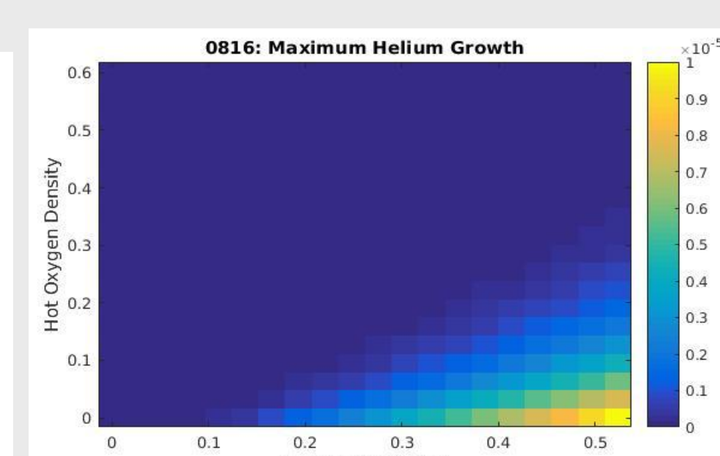

Figure 4. Above we see the helium branch growth dependence on Hot H+ and Hot O+. The Oxygen is greatly responsible for damping. A similar result was obtained for Hydrogen.

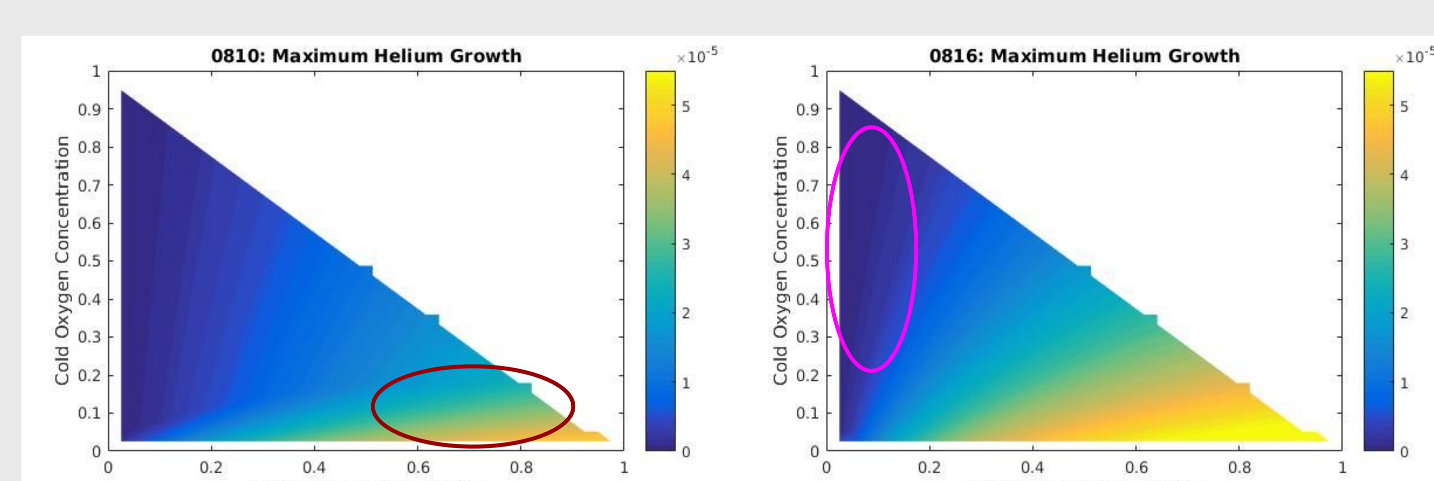

Figure 5. Analysis of 0810 event without hot oxygen present. We see that an influx of heavy ions at this time could account for damping.

Conclusions

12:50 Event

This event is confidently unstable at the given anisotropy and temperature of the hot population. Instability was retained even when varying the ratios of cold ions. Stability only occurs once the cold population density drops by nearly 90%.

14:45 Event

This event is stable if modeled by a bi-Maxwellian distribution. However, it could be unstable if the ring beam nature of the distribution is such to drive the *effective* anisotropy high enough. The distribution has not been fit as has been done for 0810, but this will be done to see if results are consistent. Growth rate behaviors have been observed to be consistent with expectations from *Equation (1).*

8:10 Event

This event was not unstable on initial analysis. An attempt was made to more accurately describe the distribution. This fit can be seen in *Figure 2.* Instability was highly responsive to changes in the shape of the distribution. Note that piedmont characteristic present at 0810 but not 0816. This highly anisotropic characteristic increases the free energy of ths system.

It was found that increasing total cold plasma density damped the hydrogen and helium branches while increasing instability of the oxygen branch.

As seen in *Figure 4*, it was found that for this event, the Hot O+ population was largely responsible for the damping of instability. This provides theoretical confirmation for some recent RBSP observations. **[6]**

Further Research

- Better approximate the ratios of cold plasma. With current instruments, actually measuring cold populations is extremely difficult.
- Analyze a much larger number of events.
- More accurately model tracing back to the equator for the 8:10 event to check if waves could have been generated from this location and traveled to the site they were observed.

Bibliography

[1] Engebretson, M. J., J. L. Posch, S. S. Tetrick, S. Tian, E.-H. Kim, J. R. Johnson, C. A. Kletzing, J. R. Wygant, G. D. Reeves, and J. F. Fennell, "Dual-Spacecraft studies of NASA/GSFC's Space Physics Data Facility's OMNIWeb, EMIC wave occurrence using the Van Allen Probes," ID#126714, presented at the Fall 2016 Meeting of the American Geophysical Union, San Francisco, CA, Dec. 12-16, 2016

[2] Moldwin, M.B., J. Howard, J Sanny, J. D. Bocchicchio, H.K. Rassoul, R. R. Anderson, "Plasmaspheric plumes: CRRES observation of enhanced density beyond the plasmapause," Journal of Geophysical Research, Vol. 109, A05202, May 2004

[3] cdaweb.sci.gsfc.nasa.gov

[4] Rönmark, K., "WHAMP- Waves in Homogenous, Anisotropic Multicomponent Plasmas," KGI Report 179, June 1982

[5] André, M. and T. Oscarsson, "Waves Below the Proton Gyrofrequency in a Multicomponent Plasma," KGI Report 189, February 1985

[6] Bhanu, R. "Statistical distribution of EMIC waves and dependence on geomagnetic activity: Van Allen Probe 2013-2015 observations," ID#SM51B-2424, presented at the Fall 2017 Meeting of the American Geophysical Union, New Orleans, LA, Dec. 15, 2017