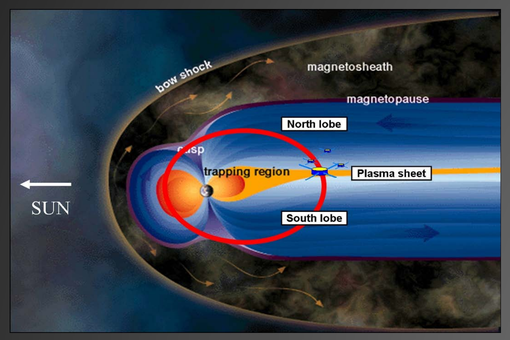
Satellite Observations of Band-Limited Pc1 Waves Associated with Streaming H^+ and O^+ Ions in Earth's High-Latitude Magnetosphere

Student: **C.R.G. Kahlstorf** ***Faculty Advisors:*** **M. J. Engebretson, D.L. Murr, and J.L. Posch, Dept. of Physics, Augsburg College, Minneapolis, MN 55454 USA**

A. Keiling, Space Sciences Laboratory, University of California – Berkeley, Berkeley, CA 94720 USA

H. Rème, CESR/CNES, Toulouse, CEDEX 4, France

K.-H. Glassmeier, Institut Für Geophysik und extraterrestrische Physik, Technishe Universität Braunschweig, Braunschweig, D-38106, Germany



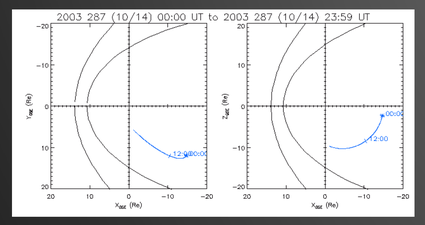
Introduction

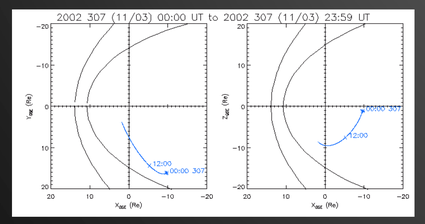
Earth is protected from much of the Sun's harmful radiation by the *Magnetosphere*. This protective shell is elongated on Earth's night side in the same way a comet's visible tail is elongated, each by the solar wind – this elongated region is known as the *Magnetotail*. The Cluster Satellite mission, a joint effort between the *European Space Agency* (ESA) and the *National Aeronautics and Space Administration* (NASA), is comprised of 4 satellites orbiting in formation with an orbital apogee of 18.7 R_E (Earth Radii) – that's about 1/3 the distance to the moon.

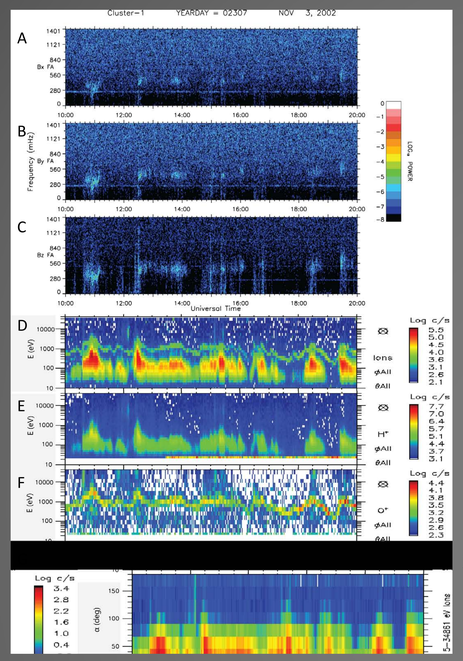
Procedure

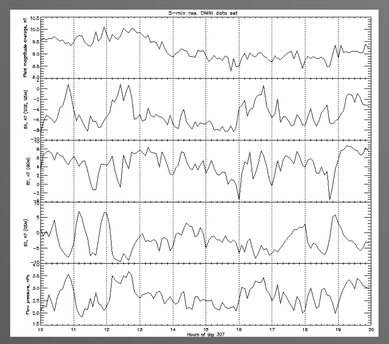
The wave events observed in this study were originally encountered while searching a Cluster data set for a previous study of waves with frequencies between 0.2 and 5 Hz, known as Pc1-2 waves. The method used to find the waves was visually searching Fast Fourier Transform (FFT) spectrograms for waves in magnetic field data, recorded at 22.6 vector samples per second.

As far as we know, waves of the type reported here, and in association with ions "streaming" in one direction along the locally observed magnetic field, have not been reported previously. Upon discovery of the waves shown herein, we began to investigate the characteristics of the waves and particles, and to determine the conditions under which these events occurred.





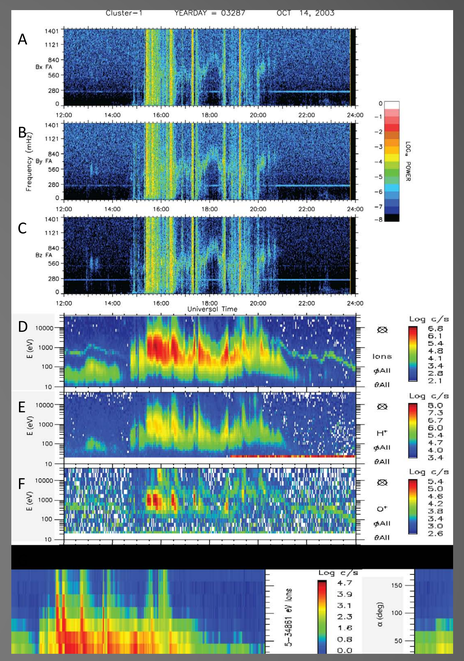


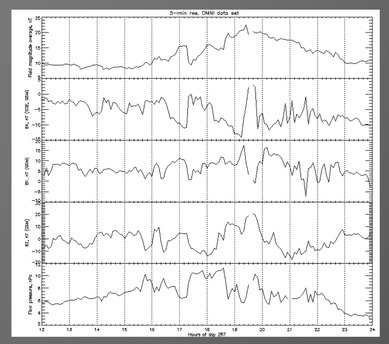


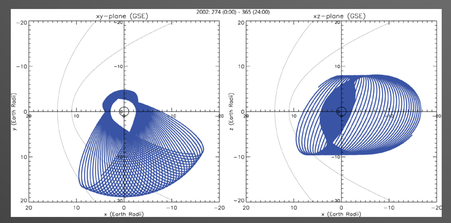
1. (LEFT) The wave event of November 3, 2002: Wave power is shown in panels A-C. Color-coded wave intensity is shown as a function of frequency (0 – 1.4 Hz) and Universal Time (10 – 20 hours) on this day. Increases in wave power are evident at approximately 400-500 milliHertz in all 3 vector components.

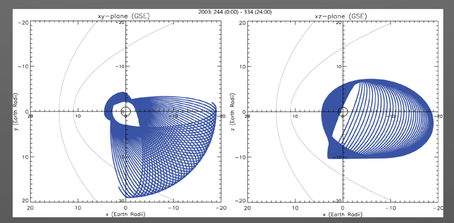
   These waves, which are not monochromatic but are limited in frequency spread ("band-limited"), are associated with bursts of protons (H^+) amidst a sustained population of Oxygen ions (O^+). From the lower 4 panels (D-G), it is apparent that the magnetic disturbances have some correlation to the increased population of protons. Additionally, waves occurred only when H^+ fluxes increased by factors of 10-1000 and energies of both ion species increased by factors of up to 10 (D-F). Also note, the band of O^+ is quite obvious in the panel of all ion populations (D), with the O^+ having approximately 16 times greater energy. The final panel (G) shows the pitch angles of the population of ions to be mostly aligned with the magnetic field. The spacecraft is near the southern polar cap on the dusk side during the event, so this means the population is advancing tailward, away from Earth. Comparison of the mass ratio of H+ to O+ (1:16) with the energy ratio (1:16) indicates that these ions move with the same velocity, ~140 km/s.
2. (RIGHT) The wave event of October 14, 2003: The magnetic disturbances at ~13:00- 13:30 UT and near 20:00- 21:00 UT have similar characteristics to those of the previous event. Band-limited waves near 13:00 UT had a slightly higher but variable center frequency of ~550 milliHertz (panels A-C). Later waves included a sequence of broadband and band-limited forms. Again, waves occurred only with increased H^+ fluxes and increased ion energies (D-F). Finally, the path of the ion populations is once again aligned with the magnetic field. In this case too the spacecraft is at high southern latitudes, and the ions are streaming away from Earth.

   The figures to the right and left show the magnitude and three vector components of the interplanetary magnetic field (IMF) and the flow pressure of the solar wind as it impacts Earth's magnetosphere. These figures show that the waves were generally associated with intervals of southward IMF (Bz < 0), but had no dependence on solar wind pressure. The waves were also associated with disturbed geomagnetic conditions associated with strong auroras (not shown).

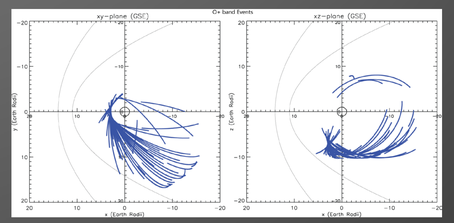




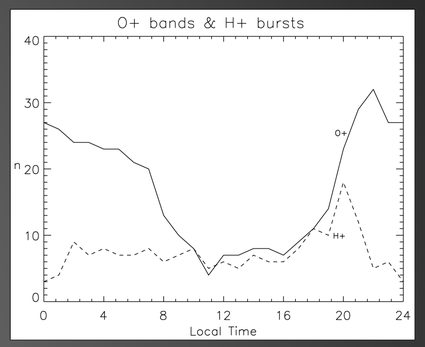




In an attempt to discover more O^+ band events, the entirety of the months before, during, and after the observed events (waves associated with the O^+ band and H^+ bursts) on Nov. 3, 2002 and Oct. 14, 2003 was surveyed, a total of 92 days of 2002 and 91 days of 2003. The apogee of the spacecraft during both data sets (2002 & 2003) was near midnight at the beginning of the set, and near dusk at the end of the set.



Of the 183 days surveyed, O^+ bands were observed during 55 days with a total of 52 separate events. Each O^+ band was accompanied by as few as 1 H^+ burst up to as many as 14 bursts. Nearly 89 per cent of the events were observed in the southern hemisphere



The plot above shows the distribution of the O^+ bands and the H^+ bursts against local time (LT), where *n* is the number of occurrences at the given time.

The H^+ bursts occurred with a rather even distribution, peaking near 20:00 LT. The O^+ bands exhibited a lull in activity during midday, though the overall activity level is much higher than the H^+ bursts, suggesting that it is quite common for there to be relatively large periods of time with no bursts of protons. This is confirmed visually by the energy spectrograms of the observed events.

It is actually rather frequent for streaming O^+ ions to occur without significant fluxes of protons. Furthermore, the mean average length of the O^+ band is nearly 10.4 hrs with a median of 8 hrs and mode of 3.5 hrs, while the mean average length of the proton bursts within the O^+ band times is approximately 1.7 hrs with a median of 1.25 hrs and a mode of 45 minutes. ~75.5 percent of all the observed bursts within the O^+ band times were at an energy less than the oxygen energy, (i.e. energy of $O^+ > H^+$), similar to the wave events.

Discussion

These observations raise two major questions. First, what is the detailed mechanism by which these streaming ions generate the observed waves? More puzzling, perhaps, is why two ion species, with the same charge but different masses, should flow along magnetic field lines at the same velocity. Acceleration by an electric field would produce a mass-dependent acceleration, for example. The well-known **v** =**E** x **B** drift velocity does in fact produce mass-independent drift, but in a direction perpendicular to **B**. Theoretical work is needed to determine whether field line curvature can convert such a drift velocity into motion parallel to the field.

Future Work

Though to date we only have discovered two such magnetic wave events associated with bursts of protons amidst a sustained O^+ band, it would appear that the particle configuration is not uncommon. We plan to survey the supplementary months of 2002 and 2003 ion spectrometer data to observe the events throughout an entire precessional period. We will also compare the observed O^+ band times with magnetometer data to assess whether there are any other events (other than the 2 displayed here) that exhibit a magnetic disturbance.