Statement of the Problem and Scientific Significance of Proposed Research

We propose to study how the solar cycle affects ion cyclotron waves in the auroral acceleration region of the magnetosphere. During the Sun's eleven year cycle, the activity of the solar surface, and consequently the solar wind and X-rays emitted, varies dramatically. Since radiation from the Sun ionizes most of the plasma in the ionosphere, the state of the ionosphere is dependant on the solar cycle. Furthermore, due to the fact that the upwelling from the ionosphere is the source of heavy ions such as oxygen in the Earth's magnetosphere, the ion composition of the magnetosphere changes dramatically during the solar cycle, with the number densities of heavier ions being much higher during the periods of maximum solar activity [*Moore et al.*, 1999]. The presence of heavy ions alters the behavior of many types of waves throughout the magnetosphere, but in this proposal we will concentrate on ion cyclotron waves in the auroral acceleration region. Of the many types of waves present in the magnetosphere, ion cyclotron waves in the auroral acceleration region are of interest largely because of their ability to heat ions [*Cattell et al.*, 1991] and their tendency to exist at the same time as other interesting phenomena such as solitary waves [*Ergun et al.*, 1998]. Ion cyclotron waves also influence the motion of electrons [*McFadden et al.*, 1998] and have been suggested as a source of anomalous resistivity [*Hudson et al.*, 1978]. This question of how ion composition affects the ion cyclotron waves is important for several reasons, including understanding the basic plasma physics of how heavy ions change the ion cyclotron waves, and also how these changes in the ion cyclotron waves relate to space weather.

As a problem of plasma physics, the effects of heavy ion composition on ion cyclotron waves is interesting because of the complexity that it adds to the physical situation. Due to their masses, heavy ions enable the ion cyclotron waves to exist over a broader range of frequencies, which leads to the ion cyclotron waves interacting with more particles. While plasmas with significant heavy ion populations are sometimes studied in laboratory plasmas, laboratory plasmas seldom have the low number densities seen in the magnetosphere. So the magnetosphere is the most accessible place to study ion composition effects on ion cyclotron waves in this plasma regime, though the results should be applicable to the magnetospheres of other planets in the solar system, such as Jupiter. In fact, because of the heavy ions injected in Jupiter's magnetosphere by Io's volcanic activity [*Frank and Paterson*, 2001], heavy ions likely affect ion cyclotrons waves even more on Io. There are also probably astrophysical situations where ion cyclotron waves in plasmas with significant heavy ion composition play a role. So studying this problem as a pure plasma physics problem would also help to understand the physics in other areas.

While it is currently believed that the solar cycle dependence of heavy ion composition in the magnetosphere is due to increased ion outflow out of the ionosphere [*Elliott et al.*, 2001], ion cyclotron waves influence what happens to the heavy ions once they reach the magnetosphere. The ion cyclotron waves will affect both how the heavy ions influence the aurora, and how the heavy ions flow from the ionosphere to the radiation belts and ring current. Once in the ring current, the heavy ions have been shown to play an important role in altering the waves that are formed in that region, and consequently changes the expected lifetime of the enhanced ring current, which is an important factor in solar storms [*Thorne and Horne*, 1997]. So from the perspective of space weather, the problem of ion composition and ion cyclotron waves is an interesting problem.

Plan of Procedure

We propose to use spacecraft data to study the solar cycle dependant effects of ion composition on ion cyclotron waves. In particular, we will concentrate on Polar spacecraft data, though if time permits we would also like to examine Fast Auroral SnapshoT (FAST) spacecraft data [*Carlson et al.*, 1998] as well in order to probe the altitude dependence of these effects. these results will then be compared to analytical and computer simulation predictions of the effects of ion composition.

Polar Spacecraft Data

The analysis of Polar spacecraft data is central to this study of solar cycle dependant affects of ion composition on ion cyclotron waves. The Polar spacecraft was launched in 1996, and is still operational so that data is available for both the minimum and maximum of solar activity. At the beginning of this study, our analysis will concentrate on data from solar minimum and solar maximum, since the contrast is expected to be the largest for this data, but as the study progresses we plan to include data from the entire period of Polar's operation.

Polar has a polar orbit with a period of 18 hours, an inclination angle of 85 degrees, an apogee of 9 R_E, and a perigee of 1.8 R_E geocentric. (The FAST spacecraft's orbit, which we may use for altitude comparison, has an altitude range from 350 to 4200 km.) Due to the precession of its orbit, Polar has made observations in a wide variety of regions of the magnetosphere. For the purposes of this study, we will be concentrating on the data from the low altitude region of Polar's orbit where the orbit crosses the auroral acceleration region.

The focus of this study will be to analyze ion cyclotron waves using electric field data from Polar's Electric Field (EFI) [*Harvey et al.*, 1995]. Ion composition will be examined using Polar's Toroidal Imaging Mass-Angle Spectrograph (TIMAS) [*Shelley and et al.*, 1995] and magnetic field data from Polar's Magnetic Field Experiment (MFE) [*Russell*, 1995] will be used as well. Several characteristics of Polar's electric field data set make it suitable for this kind of study. One is that unlike the electric field data from most spacecraft, data from EFI is fully three dimensional. The ability to measure all three components of the electric field directly leads to a clearer understanding of any wave modes which might be present. The other important feature of EFI is its burst mode. Due to telemetry limitations, during most time periods electric field data is saved at a relatively modest rate. During periods of interest EFI saves data at a higher rate (typically 1.6 or 8 kHz) and the data is slowly sent back to Earth over the course of Polar's orbit. During most of Polar's orbits three bursts of data are taken, two at high altitudes, and one at a low altitude. The low altitude burst electric field data will be the focus of our study.

Data Analysis

Some of the data to be analyzed is key parameter data which can be downloaded publicly from the web, while more detailed data, such as the Polar EFI data, will be obtained using other tools such as specialized software tool. Much of the framework for the statistical study of the burst data will be adapted from similar software that we have written for a statistical study of solitary waves (which is a continuation of the work done in *Dombeck et al.* [2001] and *Crumley et al.* [2001]) that we are working on. In fact, another possible area of consideration for this study of ion cyclotron waves would be to look at how their occurrence correlates with the occurrence of solitary waves.

Educational Components

This proposal would directly augment our educational mission in the physics department. The majors in our program are required to do senior theses. Students who chose to work on a thesis connected to this proposal would have an opportunity to start their research in the summer before their senior year. This would allow them to focus more intensely on their research, which would likely lead to more meaningful results for their research, as well as leaving them with a deeper experience of how research is completed. The elective courses that we have been able to offer this year leave our students especially well-prepared to take advantage of the opportunity of working on this study. In the Fall of 2003, I have taught two credit courses in Space Physics and in Scientific Computer Programming that many of our majors have taken. The background that these courses give the students will help them get up to speed quickly and be able to make contributions to the software that will be used to analyze the spacecraft data, as well as to understand the physics behind the problem that we would be studying.

This proposal also would be an opportunity to bring some space physics into our laboratory sequence. I plan to develop a junior-level lab that gives students a chance to apply what they are learning in their Electromagnetism course to the case of magnetospheric plasmas. The lab would consist of comparing some spacecraft data of plasma waves to analytical predictions and results from a simple simulation.

Research Facilities

In our physics department we have good computer resources including our lab SGI workstations, in addition to campus wide resources. We plan to use these machines for the analysis of satellite data. In addition, the computer science department has a Beowulf-class computer cluster which can be used for computer simulations. In addition, we have access to supercomputer time through the University of Minnesota Supercomputing Institute, which also will be used for simulation work.

[*Cattell et al.*, 1993] [*Cattell et al.*, 1981] [*Bergmann et al.*, 1998] [*Chaston et al.*, 2002] [*Kintner et al.*, 1979] [*Lysak et al.*, 1980]

Bibliography

Bergmann, R., J. P. Crumley, C. A. Cattell, R. L. Lysak, and C. Chaston, Electromagnetic generalization of EIC waves, *Trans. Am. Geophys. Union (EOS), 79 (45), Fall Meet. Suppl.*, SM71A–12, 1998.

Carlson, C. W., R. F. Pfaff, and J. G. Watzin, The fast auroral snapshot (FAST) mission, *Geophys. Res. Lett.*, *25*, 2013 – 2016, 1998.

Cattell, C. A., M. K. Hudson, R. L. Lysak, D. W. Potter, M. Temerin, R. B. Torbert, and F. S. Mozer, Observations of electrostatic shocks and associated plasma instabilities by the s3-3 satellite, in *Relation Between Laboratory and Space Plasmas*, edited by H. Kikuchi, pp. 115–126, Reidel, 1981.

Cattell, C. A., F. S. Mozer, I. Roth, R. R. Anderson, R. C. Elphic, W. Lennartsson, and E. Ungstrup, ISEE 1 observations of electrostatic ion cyclotron waves in association with ion beams on auroral field lines from approximately 2.5 to 4.5 R_e, *J. Geophys. Res.*, *96*, 11,421–11,439, 1991.

Cattell, C. A., T. Nguyen, M. Temerin, W. Lennartsson, and W. Peterson, Effects of solar cycle on auroral particle acceleration, in *Auroral Plasma Dynamics, Geophysical Monograph Series*, edited by R. L. Lysak, p. 219, AGU, 1993.

Chaston, C. C., J. W. Bonnell, J. P. McFadden, R. E. Ergun, and C. W. Carlson, Electromagnetic ion cyclotron waves at proton cyclotron harmonics, *J. Geophys. Res.*, 2002.

Crumley, J. P., C. A. Cattell, R. L. Lysak, and J. P. Dombeck, Studies of ion solitary waves using simulations including hydrogen and oxygen beams, *J. Geophys. Res.*, *106*, 6007–6015, 2001.

Dombeck, J. P., C. A. Cattell, J. P. Crumley, W. K. Peterson, H. L. Collin, and C. A. Kletzing, Observed trends in auroral zone ion-mode solitary wave structure characteristics using data from Polar, *J. Geophys. Res.*, *106*, 19,013–19,021, 2001.

Elliott, H., R. Comfort, P. D. Craven, M. Chandler, and T. E. Moore, Solar wind influence on the oxygen content of ion outflow in the high-altitude polar cap during solar minimum conditions, *J. Geophys. Res.*, *106*, 6067 – 6084, 2001.

Ergun, R. E., et al., FAST satellite wave observations in the akr source region, *Geophys. Res. Lett.*, *25*, 2061–2064, 1998.

Frank, L., and W. Paterson, Survey of thermal ions in the Io plasma torus with the Galileo spacecraft, *J. Geophys. Res.*, *106*, 6131 – 6150, 2001,

Harvey, P., et al., The electric field instrument on the POLAR satellite, *Space Sci. Rev.*, *71*, 583–596, 1995.

Hudson, M. K., R. L. Lysak, and F. S. Mozer, Magnetic field-aligned potential drops due to electrostatic ion cyclotron turbulence, *Geophys. Res. Lett.*, *5*, 143–146, 1978.

Kintner, P. M., M. C. Kelley, R. D. Sharp, A. G. Ghielmetti, M. Temerin, C. Cattell, P. F. Mizera, and J. F. Fennell, Simultaneous observations of energetic (keV) upstreaming and electrostatic hydrogen cyclotron waves, *J. Geophys. Res.*, *84*, 7201–7212, 1979.

Lysak, R. L., M. K. Hudson, and M. Temerin, Ion heating by strong electrostatic ion cyclotron turbulence, *J. Geophys. Res.*, *85*, 678–686, 1980.

McFadden, J. P., et al., Electron modulation and ion cyclotron waves observed by FAST, *Geophys. Res. Lett.*, *25*, 2045–2048, 1998.

Moore, T. E., et al., Ionospheric mass ejection in response to a cme, *Geophys. Res. Lett.*, *26*, 2339 – 2342, 1999.

Russell, C. T. (Ed.), *The Global Geospace Mission*, Kluwer Academic Publishers, Dordrecht, Netherlands, 1995.

Shelley, J., and et al., The Toroidal Imaging Mass-Angle Spectrograph (TIMAS) for the Polar mission, in *The Global Geospace Mission*, edited by C. T. Russell, p. 397, Kluwer Academic Publishers, Dordrecht, Netherlands, 1995.

Thorne, R. M., and R. B. Horne, Modulation of electromagnetic ion cyclotron instability due to interaction with ring current o+ during magnetic storms, *J. Geophys. Res.*, *102*, 14,155–14,163, 1997.