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"Kinetic Alfvén Wave Electron Acceleration on Auroral Field Lines"

<u>Summary of Research</u>

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Major Results:

- S3-3 Langmuir sweep study published. Study showed statistics and average density and temperature variation on auroral field lines up to 8000 km altitude [*Kletzing et al.*, 1998].

- Alfvén wave paper published. Our model of Alfvén wave propagation on auroral field lines was successfully extended to handle varying density and magnetic field for the inertial mode. The study showed that Alfvén wave can create time-dispersed electron signatures [*Kletzing and Hu*, 2001].

- A study was undertaken to extend Langmuir sweep I-V curves to handle the case of an kappa electron distribution as well as Maxwellian. The manuscript is in preparation.

- Participated in International Space Science Institute study of Alfvénic structures which resulted in a group review paper [*Stasiewicz et al.*, 2000].

The proposed work was to develop to develop an extended model of Alfvén wave propagation along auroral field lines to study electron acceleration. As part of this work, a major task was to characterize density and temperature along auroral field lines by using spacecraft Langmuir sweep data. The work that was completed under this funding was successful at both tasks. Three papers have been published as part of this work and a fourth manuscript is in preparation.

Originally planned for three years, the work was significantly slowed by the move of the PI, Craig Kletzing, to the University of Iowa (UI). The time demands of a new position, setting up computers, and getting settled caused delays in our work. Once these distractions were taken care of, work began to proceed at about the expected pace. The first task that was undertaken was analysis of Langmuir sweep data to produce statistical forms for the electron density and temperature along auroral field lines. This task was largely successful and resulted in the publication of a paper in JGR in 1998. A copy is attached to this report. This also lead to an unanticipated avenue of research into Langmuir sweeps for kappa distributions of electrons. This work was reported at AGU and a manuscript is currently in preparation. We then turned to the simulation model to understand auroral electron acceleration by Alfvén waves. This task was very successful and has resulted in a publication of paper in GRL this past spring. A copy is attached to this report. It was found that inertial Alfvén waves traveling along a field line with density and magnetic field varying as they do in the auroral zone can accelerate electrons to a range of energies that leads to a time-of-flight dispersive effects at low altitude.

The work to characterize temperature and density on auroral field lines using the data set from S3-3 was completed and reported on at both AGU meetings and in a journal publication as noted above. The temperatures in the auroral ionosphere that are found are quite cold, mostly at 5 eV or less up to 7000-8000 km. At these altitudes the some evidence for increased plasma temperature are seen. The density profile is that expected for the auroral zone as reported by the UC Berkeley group and others. One result of interest is that the polar cap has a background density which is roughly twice that of the auroral zone. This suggests that auroral precipitation processes lead to significant erosion of the overall background density. The majority of this task was the analysis of data from the S3-3 spacecraft. We also proposed to analyze data from the Viking spacecraft. Initially we were quite hopeful that this data would yield good results as we discussed in our annual reports. However, after digging deeply into this data set, it was found that the data were not of sufficient quality to yield a consistent result. Reluctantly, we had to abandon this task.

An unanticipated outgrowth of this work on Langmuir probes was an extension of probe theory to handle the case of the kappa distribution function. This distribution has been used by several researchers to characterize plasma distributions with high energy tails. This work was motivated by the somewhat small number of Langmuir sweeps that could be fit with a Maxwellian distribution I-V curve. Further motivation came from research reports that have found that the plasma sheet (the source of auroral electrons) is best characterized by the kappa distribution. After completing the theoretical work, we returned to the S3-3 data set and found that the number of successful fits doubled when using the kappa distribution I-V curves. This work was reported at the Spring 2000 AGU meeting.

The primary goal of the funded work was to study Alfvén wave acceleration of auroral electrons. Our plan was to extend our model from constant density and magnetic field to one with realistically varying density and magnetic field. Because this is no longer analytically tractable with varying background quantities, we developed a simulation code to solve for the Alfvén fields. Initial development of the new simulation model was straightforward and proceeded quickly. However, getting the simulation fully debugged, stable, and verified took longer than expected. Initial runs were stable on short time scales, but as we turned to the problem that we actually wished to solve, in which a Alfvén wave propagates from more than 4 R_E away to the ionosphere, we found that the simulation was unstable because of widely varying background conditions. This was solved by greatly increasing grid resolution. This significantly slowed our run times, but produced accurate results when we checked against benchmarks. We also wished to be able to watch the wave reflect from the ionosphere and pass out through the upper simulation boundary as if the simulation were unbounded. Development of algorithms to properly handle these boundary conditions took additional time, but were, in the end, successful.

With the code successfully producing the wave fields, we proceeded to analysis of the effects on electron acceleration. A long standing problem in auroral physics is how to explain time-dispersed electron signatures seen at low altitude by rockets and satellites. We found that these signatures can be generated by Alfvén waves. The mechanism is fairly straightforward. At at any given altitude, the Alfvén wave parallel electric field can accelerate electrons to speeds of the order of twice the Alfvén velocity through a resonant acceleration process. Because the Alfvén speed increases as one moves towards the ionosphere, the velocities to which the electrons are accelerated also increase. Eventually the Alfvén speed becomes to large and the acceleration becomes ineffective. However, before this occurs a broad range of electron energies are generated. As the electrons move down the field line, the fast electrons overtake the slow ones producing the time-of-flight dispersion signature. We were able to show that not only could we produce the qualitatively correct picture, but that quantitatively we could very nicely match results from a rocket flight in Greenland in 1985. The details are in the attached GRL paper.

Two interesting side avenues of research also stemmed from this work. In June, 1997, the PI attended the Interrelationship between Plasma Experiments in Laboratory and Spaces (IPELS) conference. This meeting brings together laboratory and space plasma physicists to allow comparisons between results. Because of the difficulty of directly verifying parts of the theory of inertial shear Alfvén waves, we have had a strong interest in laboratory experiments which may be able to verify that the theoretical work is correct. Discussions at that meeting resulted in a successful proposal to NSF to do laboratory experiments in collaboration with laboratory plasma physics group at UCLA which runs the LArge Plasma Device to verify some of the results of our NASA funded work. The second offshoot was an invitation to be part of an ISSI study team on Alfvénic structures. This study team produced a review article for Space Science Reviews which includes our work.

In summary, this grant was extremely successful in accomplishing its major goals of understanding auroral electron acceleration by Alfvén waves. Three published papers, a four manuscript in preparation, and several talks have disseminated this work to the research community. We have proposed this year to continue this work and hope that we are successful.

References

Kletzing, C. A., and S. Hu, Alfvén wave generated electron time dispersion, *Geophys. Res. Lett*, *28*, 693, 2001.

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