Self-Consistent Model for Regions of Downward Auroral Current

Investigator: Jay R. Johnson, C. Z. Cheng

The primary focus of this proposal is to develop a model for understanding plasma and field properties in downward auroral current regions. In these regions, upgoing electron beams and heated ion populations are commonly observed. Observations of particle distributions in this region are also consistent with a downward pointing parallel electric field. The FAST satellite typically detects broadband electromagnetic wave activity near the ion cyclotron frequency over the range 4Hz-20kHz in downward current regions and there is evidence for wave energy absorption near the ion cyclotron frequency and its harmonics. It is of interest to understand the relationship between the particle populations and the concomitant waves.

Strong electron beams are one of many sources of free energy which can excite waves in the ion cyclotron frequency range. Those waves propagate into the ionosphere and where they dissipate and transfer wave energy to particle acceleration. Dissipation of wave energy leads to ion heating through collisions and/or ion cyclotron heating. As a result of the heating, ions flow out along field lines leading to modifications in the background plasma and electric field. These plasma changes feed back on the ion cyclotron instability and wave propagation. The goal of this work is to understand the long-time behavior of these regions considering the wave-particle feedback.

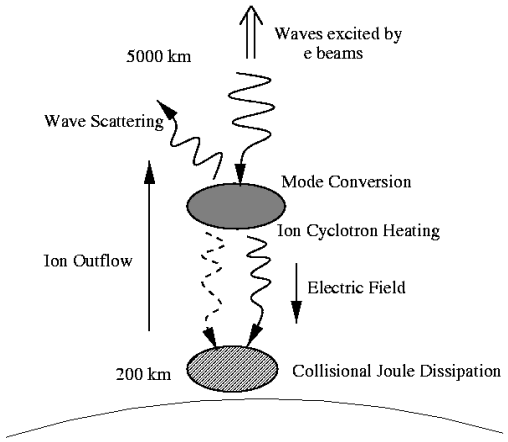

Figure 1. Electron beams accelerated by downward pointing electric field excite electromagnetic ion cyclotron waves. These waves are guided along field lines to a heavy ion resonance where wave energy scatters. Part of the wave energy is absorbed, but part is transmitted to the ionosphere where collisional heating of ions occurs. The dissipation leads to ion heating and ion outflows which modify the background plasma.

The first phase of this project is understand excitation and propagation and to identify how wave energy is transferred to ions in the ionosphere. Figure 1 illustrates the physical processes. Waves with frequency near the proton cyclotron frequency are excited in the auroral acceleration region (5000 km above the Earth's surface). The waves propagate

into the topside ionosphere (because they have field aligned group velocity) where they encounter heavy ion resonances (helium and oxygen) in the increased magnetic field. The waves scatter off the resonant layer, but some wave energy is absorbed and some wave energy is transmitted to the ionosphere. In the collisional ionosphere, the waves may also be absorbed by ions. The remaining wave power is reflected off the ionosphere and may be efficiently absorbed at the heavy ion resonance. Heating of ions leads to outflows and modification of the parallel electric field.

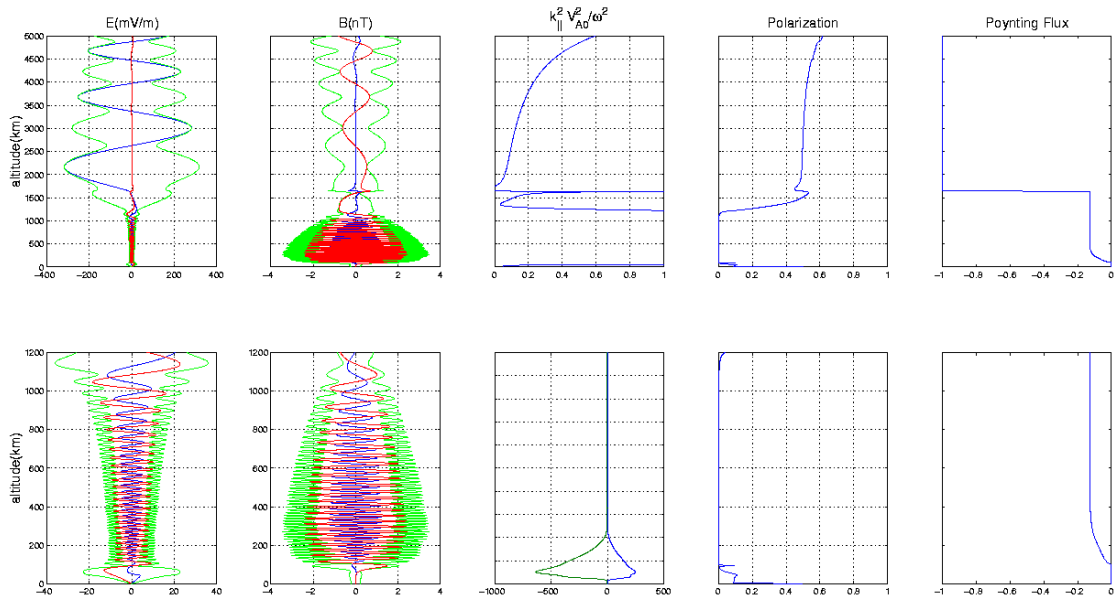

Fig 2 Solutions of the low frequency electromagnetic wave equations for waves excited in the auroral acceleration region. Plotted from left to right are: electric field, magnetic field, local wavevector, polarization, and Poynting flux as a function of altitude. The upper panels show the entire region from the auroral acceleration region to earth. The lower panel expands the solution in the ionosphere. Note especially that Poynting flux is lost near the He^+ resonance and in the ionosphere. For these solutions, the wave frequency is 128 Hz, oxygen and hydrogen each comprise 5% of the plasma concentration in the auroral acceleration region and the wave normal angle in the auroral acceleration region is 60°

In Figure 2 we show solutions of the electric fields as a function of altitude. In the electric field, it is easy to see that where the wave encounters the helium layer, there is an abrupt change in the character of the electric field which corresponds with helium heating. Lower in the ionosphere the ratio of E/B becomes larger due to changes in the Alfven velocity. The wave polarization chanes from mixed polarization to nearly right hand polarization indicating strong coupling between the compressional and transverse modes in the topside ionosphere.

Two particular scientific points of interest have developed from our research project. First, we have provided theoretical evidence that high-frequency ion cyclotron waves (which commonly are observed modulating the aurora) could be detected on the ground, as shown in Figure 3(b). This finding is suggestive that modulations of optical aurora and/or electromagnetic rocket observations could be correlated with high-frequency ground based magnetometer measurements.

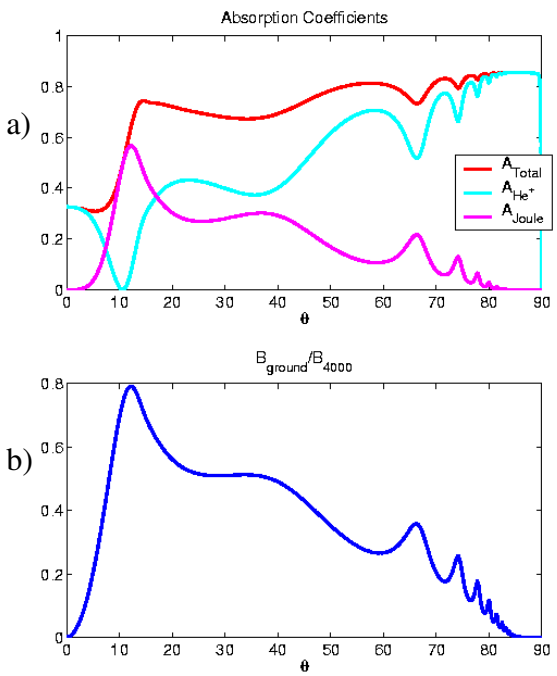

Figure 3. (a) Absorption coefficients as a function of angle between the wavevector and magnetic field direction in the auroral acceleration region. Note that Joule absorption and ion cyclotron resonant absorption both play an important role. Joule dissipation is large because the wave reaches the ionosphere as confirmed in panel (b). In panel (b) we compare the magnetic field wave amplitude at the ground with the amplitude in the source region. The results demonstrate that ion cyclotron waves with wave normal angle less than 85° can reach the ground with substantial amplitude. For both figures, the wave frequency is 128 Hz and the concentrations of oxygen and helium in the auroral acceleration region are 5%.

Such information would be useful for understanding wave propagation and absorption in the collisional ionosphere as well as heating of ionospheric ions through Joule dissipation.

Second, this work addresses one of the outstanding questions raised in the work of *Lund and LaBelle, [1997]*: "Can the beam-generated instabilities based on local plasma theory in the auroral acceleration region (5000 km) provide a source for ion cyclotron waves observed at rocket altitudes (400 km)?" To address this issue, we examined ion cyclotron wave propagation from the auroral acceleration region to the ionosphere using a realistic collisional model for the ionosphere. We found that ion cyclotron waves that are excited with wavenormal angle less than 85° may reach rocket altitudes (as shown in Figure 3). This result is in contrast to the ray-tracing result for wave propagation that predicted only parallel propagating waves could reach rocket altitude in contrast with the observations. The underlying physical reason that the oblique waves could reach ionospheric altitude is because of a mode conversion process which is beyond the scope of ray-tracing. Morover, the mode conversion process also causes the H^+ ion cyclotron waves to have more spatial spread than the O^+ ion cyclotron waves consistent with observation.

However, this result has also raised a number of additional scientific issues. While there are many mechanisms for ion cyclotron wave generation that would be able to generate more field aligned waves, electron beam generated instabilities often have growth rates that peak around 85°, which is around the limit of the transmission window. Therefore, it is possible that other instabiltity mechanisms related to background distribution could excite waves with less oblique wavevector.