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Alfvén Waves and the Aurora (Hannes Alfvén Medal Lecture)

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The most compelling visual evidence of plasma processes in the magnetosphere of Earth as well as the other magnetized planets is the aurora. Over 40 years of research have indicated that the aurora is a consequence of the acceleration of charged particles toward the neutral atmosphere, where the excitation of neutral atoms and their subsequent relaxation to the ground state produces the auroral light. Much of this acceleration can be described by acceleration in a quasi-static electric field parallel to the geomagnetic field, producing nearly monoenergetic beams of electrons. While a variety of quasi-static models to describe such parallel electric fields have been developed, the dynamics of how these fields evolve is still an open question. Satellite measurements have indicated that a primary source of energy to support these fields is the Poynting flux associated with shear Alfvén waves propagating along auroral field lines. These Alfvén waves are generated in the magnetosphere and reflect from the ionosphere. On closed field lines, Alfvén waves bouncing between conjugate ionospheres produce field line resonances that have be observed both in space and by ground magnetometers.

However, some auroral emissions do not follow this scenario. In these cases, the accelerated electrons are observed to have a broad energy spectrum, rather than a monoenergetic peak. Such a spectrum is suggestive of a time-dependent acceleration process that operates on a time scale of a few seconds, comparable to the electron transit time across the acceleration region. While field line resonances have a time scale on the order of minutes, waves with periods of a few seconds can be produced by partial reflections in the Ionospheric Alfvén Resonator, a resonant cavity formed by the rapid decrease of the plasma density and increase of the Alfvén speed above the ionosphere. In order to develop a parallel electric field that can accelerate auroral particles, these Alfvén waves must develop small spatial scales, where MHD theory breaks down. In this regime, the waves are called kinetic Alfvén waves. These small scales can be produced most simply be phase mixing, although ionospheric feedback and nonlinear effects may also be important. Since kinetic Alfvén waves require perpendicular wavelengths the order of a few kilometers, this model also provides a natural explanation of the narrow scales of discrete auroral arcs. These interactions between magnetosphere and ionosphere and the development of parallel electric fields have been described by means of numerical simulations that serve to illustrate these complex processes.