Mode Conversion Radiation in the Terrestrial Ionosphere and Magnetosphere

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Abstract. A significant fraction of the radiation types observed in the Earth’s ionosphere and magnetosphere can be classified as mode-conversion radiation, in that they result from generation of electrostatic waves by unstable particle populations followed by conversion of some fraction of the wave energy to electromagnetic modes which then propagate relatively long distances. In particular, we address the complex frequency structure observed in terrestrial mode conversion radiation. Theory suggests that electrostatic eigenmodes trapped within source-region density structures, analogous to the quantum energy levels of hydrogen atom potential well, may account for the observed fine frequency structure. We review observational results, provide a synthesized, generalized version of the appropriate theory extending existing theoretical work, and assess the current state of comparison between the theoretical predictions and the observations. Understanding the mode-conversion radiation processes in near-Earth geospace may significantly enhance interpretations of observations of similar radiations from more remote space plasma environments such as distant magnetospheres, the solar atmosphere, and astrophysical plasmas.

Key words: Mode conversion radiation, Langmuir waves, wave trapping, non-thermal radiation generation, plasma radiation

8.1 Introduction

Wave phenomena in the Earth’s environment or in those of other planets are often characterized by discrete frequency structures. For example, recent satellite and rocket observations show that electric fields directly measured in the auroral ionosphere and magnetosphere are composed of coherent structures,
such as solitary waves, wave packets, or eigenmodes imposed by preexisting density structures. Satellite, rocket, and ground-based observations show that remotely-sensed electromagnetic (EM) radiations, such as Earth’s auroral kilometric radiation (AKR), auroral roar emissions from the ionosphere, or terrestrial continuum radiation are characterized by frequency fine structure.

Observations of EM radiation in high frequency wave modes can contribute much to understanding Earth’s environment, even though the energy density of this radiation is generally lower than that of the particles or lower-frequency and static electromagnetic fields. Through wave-particle interactions high frequency EM waves mediate the exchange of energy between larger energy reservoirs, such as different populations of particles. Radiation also provides a mechanism to transport energy over long distances and can play a cumulative role in energy balance in a system even if the instantaneous energy content in the waves is relatively small. Finally, and perhaps most significantly, EM radiation carries information about the plasma in its source region and the plasma through which it propagates, allowing for passive remote sensing of densities, temperatures, distribution functions, and irregularities, in some cases using inexpensive ground-based measurements. High frequency waves can be particularly effective for this purpose, because of their large information content. For example, early magnetospheric studies used ground-based measurements of whistler waves at 1–10 kHz to determine electron density in the outer magnetosphere. For a more recent example, Weatherwax et al. [62] explored the parameter space for excitation of auroral radio emissions at different electron cyclotron harmonics and described how coincident observations of these two types of emissions can provide a means of remote sensing the F-region electron density scale height.

Radiation mechanisms can be divided into two general types: direct and indirect. Direct emission occurs when the particle distribution function is unstable to electromagnetic wave modes, resulting in direct excitation of these wave modes. Examples in the Earth’s auroral ionosphere are Cherenkov amplification of whistler mode waves to generate auroral hiss and cyclotron maser emission excited by “horseshoe” electron distribution functions to generate intense X-mode AKR. These direct radiation mechanisms produce the most intense high frequency EM waves in the Earth’s environment.

In contrast, indirect emission occurs when the particle distribution function is unstable to electrostatic modes, which, after excitation to some level, convert to electromagnetic radiation via either linear or nonlinear mechanisms. Therefore these EM waves are often referred to as “mode conversion radiation.” Examples in the Earth’s environment are auroral roar emissions near electron cyclotron harmonics in the auroral ionosphere and the several types of terrestrial continuum radiation in the outer magnetosphere. These emissions tend to be weaker in intensity than the direct emissions, because of the extra step required in producing them from the unstable particle distribution function, and the resulting inefficiency.