NATURAL AND MAN-MADE WHISTLER-MODE WAVES IN THE IONOSPHERE AND MAGNETOSPHERE

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ABSTRACT

Whistler-mode waves are one of the most interesting plasma wave type which permeate the Earth's magnetosphere. These waves are inherently 'slow' (i.e., phase velocities much less than the speed of light in free space) and can thus resonantly interact with trapped radiation belt electrons having energies of a few keV to many MeV. An important consequence of such interactions is the coherent amplification and natural spontaneous generation of waves along closed field lines in the inner and outer radiation belts, and the pitch angle scattering of the energetic particles. The latter process is particularly important in current efforts aimed at quantification of the loss rates of energetic radiation belts electrons.

WHISTLER-MODE WAVES IN THE RADIATION BELTS

Near-earth space is populated by a wide variety of electromagnetic waves, ranging in frequency from fractions of a Hz to many tens of MHz. Of the many different types of waves, arguably the most interesting variety is the so-called whistler-mode waves, propagating in the frequency range between the electron and proton gyrofrequencies. Whistler-mode waves typically possess refractive indices of >20, and are thus slow waves, propagating at speeds 0.1 to 0.01 times the speed of light in free space. Because of this, these waves can effectively interact (in cyclotron or Landau resonance) with energetic electrons, leading to amplification (by as much as 30 dB) of the waves and pitch angle scattering of the electrons. At mid-latitudes inside the plasmasphere, the different type of whistler-mode waves include monochromatic signals from ground-based VLF transmitters, lightning-generated whistlers, triggered ELF/VLF emissions, and naturally generated plasmaspheric hiss. There is now ample evidence indicating that these whistler-mode waves determine the loss rates of radiation belt electrons, and that lightning-generated whistler waves may be particularly important in this connection. Immediately outside the plasmapause, the dominant whistler-mode wave is discrete ELF/VLF chorus, typically constituting the most intense electromagnetic signal in near-Earth space. Chorus emissions are known as the drivers of pulsating aurora, as well as the morningside diffuse aurorae. Outstanding new data on chorus emissions is now being acquired on the CLUSTER spacecraft, the orbit of which are well poised to probe the vicinity of the plasmapause, with wideband continuous waveform data being available from multiple spacecraft separated by distances of hundreds of kilometers. Although the mechanisms of natural generation of whistler-mode waves are believed to involve transverse cyclotron resonance with energetic (tens to hundreds of keV) electrons, the particular nature of the processes which lead to the observed highly coherent forms are not yet known. This lack of understanding is somewhat surprising, since whistler-mode waves may arguably be the most (longest) studied wave type in the Earth's magnetosphere. However, theoretical and computer simulation studies of whistler-mode waves are hampered by the highly coherent (few Hz bandwidth, thus requiring highly resolved features of the particular distribution function) nature and relatively wide (many kHz) overall bandwidth exhibited by the discrete waves. In this paper, we provide a review of our current understanding of the mechanisms of generation and amplification of whistler-mode waves, including ground- and satellite-based observations, and theoretical and computer simulation modeling efforts, as well their effects on the energetic electrons trapped in the radiation belts.