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Chorus emissions as nonlinear coherent structures and their role in acceleration of radiation-belt electrons

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We present a nonlinear theory of generation of chorus emisions in the Earth's magnetosphere, based on the operation of the magnetospheric cyclotron maser in the regime of a backward wave oscillator (BWO).

The BWO regime develops as an absolute instability of a quasimonochromatic whistler wave in a narrow near-equatorial region of the magnetosphere. The instability occurs if a sufficiently sharp gradient exists on the electron distribution function in parallel velocities. Such step-like features are formed self-consistently at the initial stage of the cyclotron instability, in particular, due to the interaction of energetic electrons with noise-like emissions. The field-aligned size of the region where the BWO instability takes place and which serves as a source of chorus emissions is determined by the magnetic-field inhomogeneity and is estimated as $l \sim (\lambda R_0^2 L^2)^{1/3}$, where R_0 is the Earth radius and λ is the wavelength.

The nonlinear stage of the BWO regime is characterized by the amplitude modulation, resulting in the formation of quasi-periodic or stochastic sequence of bursts. The amplitude saturation is determined by the sideband instability of the generated waves, which also gives rise to the frequency drift in each burst. This allows one to estimate the characteristic amplitude and frequency drift of chorus elements. The amplitude and dynamical parameters of these coherent signals, following from theoretical consideration, are in good quantitative agreement with Cluster measurements of chorus emissions in the generation region.

We supplement the theoretical predictions by numerical simulations of the BWO equations. In the simulations, we take into account some additional factors such as fluctuations of the energetic-electron flux and variations of the ambient magnetic field. These factors can be of importance to explain specific observations related to the statistics of chorus elements and field-aligned motion of the chorus source region.

The important secondary phenomenon accompanying the chorus generation is direct acceleration of radiation-belt electrons by chorus signals near the generation region. We consider the acceleration in the regime of trapping of resonant electrons by the potential well of a chorus wave. For such a regime, the time-varying frequency of chorus elements is essential and can lead to much higher acceleration efficiency than in the conventional acceleration regime due to stochastic energy diffusion. We discuss the dependence of the acceleration rate on the parameters of plasma and accelerating waves. Estimates show that an increase in the energy of a resonant electron can reach several to tens of keV during a single interaction with a chorus signal.