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The effects of thermal electrons on whistler-mode waves excited by anisotropic hot electrons: Linear theory and 2-D PIC simulations

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The wave normal angle of excited whistler waves was previously considered to be controlled by the parallel plasma beta ($\beta_{||h}$) of anisotropic hot electrons, while the effects of thermal electrons were usually neglected. By combining both the linear theoretical and 2-D PIC simulation models, we have investigated the effects of thermal electrons on the whistler anisotropy instability. In the high-beta ($\beta_{||h}\geq 0.25$) regime, the wave normal angle of the dominant whistler mode with the largest growth rate is always zero degree, which is not affected by thermal electrons. While, its wave frequency and linear growth rate decrease with the density and temperature of thermal electrons. These results are also confirmed by PIC simulations. In the low-beta ($\beta_{||h}\leq 0.25$) regime, with the increase of the density and temperature of thermal electrons, the wave normal angle of the dominant whistler mode turns to zero from a large value. This change could be due to the stronger damping caused by thermal electrons for oblique whistler mode, since oblique wave usually has a smaller cyclotron resonant velocity than parallel wave. PIC simulations also show a consistent result, but reproduce a broad magnetic spectrum, even in the case including sufficient thermal electrons. Furthermore, thermal electrons with large parallel velocities are resonantly accelerated in the perpendicular direction, while part of hot electrons are trapped and accelerated in the parallel direction. Our study suggests that the wave normal angle of whistler mode in the Earth's magnetosphere could be determined by both anisotropic and thermal electrons.

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