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Solar radio zebra emission as a probe for the plasma properties during the solar flares

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Radio zebras are detected in radio observations from Sun, Jupiter, and also from the Crab pulsar. They are Type IV radio fine structures and can diagnose the local density, magnetic field, and velocity distribution of the particles released into the magnetic loops during the solar flares. The double plasma resonance model of solar radio zebra assumes the dense and cold background isotropic plasma and rare hot component with a loss-cone type of distribution function for $\omega_{\rm pe} > \omega_{\rm ce}$. This constitution generates the upper-hybrid waves that transform into electromagnetic radiation and emit into a narrow cone towards the observer.

We used analytical theory and 3D electromagnetic relativistic Particle-in-Cell simulations for analyses of this instability. For DGH velocity distribution function of hot electrons, we found that increasing the temperature the growth-rate maxima shift to lower values of ratio $\omega_{\rm pe}/\omega_{\rm ce}$ and the maxima are not distinguishable for temperature $v_{\rm t} \geq 0.3\,c$. We estimated the brightness temperatures, physical size, the energy density in the double plasma resonance region, and the conversion rates to electromagnetic waves from zebra observations. We also calculated the growth rates for loss-cone power-law and loss-cone Kappa distribution functions and different loss-cone angles.

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