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Quasi-periodic frequency sweeping in electron cyclotron emission of mirror-confined plasma sustained by high-power microwaves

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The complex dynamics have been observed in the spectra of the electron cyclotron emission of a nonequilibrium plasma created by powerful microwave radiation of gyrotron (37.5 GHz, 80 kW) under electron cyclotron resonance (ECR) conditions and confined in a tabletop mirror trap [M.E. Viktorov, et al. // EPL V.116, P.55001 (2016)]. The dynamic spectrum of the emission is a set of highly chirped radiation bursts with both increasing and decreasing frequencies which are repeated periodically. Such patterns are not described in the frame of a quasilinear approach which is standard for the description of a broadband plasma emission. On the other hand, the simultaneous observation of several chirping bursts in the same frequency range is typical for the formation of nonlinear phase-space structures in proximity of the wave-particle resonances of a kinetically unstable plasma, also known as the "holes and clumps"mechanism [H.L. Berk, et al. // Phys. Lett. A V.234, P.213 (1997)]. Our data provide the experimental evidence for the spontaneous formation of self-consistent structures in the new frequency domain (a few GHz) linked to the electron cyclotron frequency in a laboratory mirror-confined plasma.

Microwave emission is observed at a plasma decay stage with a delay of 0.1-1 ms after ECR heating switch-off. The microwave emission is observed only in a few frequency bands ($f = 1$–10 GHz) which are independent of the experimental conditions and the emission frequency is always less than electron cyclotron frequency in the trap center. We assume that the emission frequency is downshifted with respect to the electron cyclotron frequency due to the relativistic effects. The frequency shift corresponds to the energies of resonant electrons of up to 300 keV which is in a good agreement with experimental measurements of energy distribution function of electrons escaping the magnetic trap. Within every frequency band the emission spectrum is a set of fast narrowband chirping bursts ($df/dt \approx 30$ MHz/sec, $\Delta f/f \approx 10^{-3}$) with a duration up to $10\,\mu s$, while the duration of a burst series can be up to 1 ms. Frequency change $\delta f_{\mathrm{chirp}}$ in a chirp at a single mode is in the range 100-300 MHz which corresponds to the ratio $\delta f_{\mathrm{chirp}}/f = 0.05$–$0.1$. Following the model [H.L. Berk, et al. // Phys. Lett. A V.234, P.213 (1997)], the frequency drift within each wave packet is proportional to the instability growth rate and has a predetermined time dependence. Resulting from the analysis of the microwave emission spectrum, the value of the growth rate is consistent with previous studies of excitation of extraordinary waves at the stage of plasma decay, which confirms the applicability of the discussed model.

In the present work, we review the available experimental data and discuss applicability of the "holes and clumps"paradigm to our case. We show that separate nonlinear wave-particle resonances are indeed possible in the described experiment in spite of the huge variation of the magnetic field typical of a mirror magnetic trap [A.G. Shalashov, E.D. Gospodchikov, M.E. Viktorov // arXiv:1903.05218 (2019)].

Country or International Organization

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