Deformation of Weakly Unstable Density Distribution of Non-Neutral Plasma Stimulated by Resonant Clumps

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Accelerated deformations are observed in the density distribution of a pure electron plasma that is weakly diocotron-unstable when clumps are introduced along a circle where the rotation frequency advected by the target plasma is close to the phase-rotation frequency of an unstable wave with the mode number of \( \ell \). When the advection frequency is not close to the phase frequency, the clumps are modified in their orbit by the most unstable wave of the target plasma and bunched azimuthally into the distribution modulated by the wave.

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We report an experimental study of a weakly unstable system’s response to external perturbations imposed as an initial condition. The target system is the annular distribution of electrons which is susceptible to diocotron instability [1, 2]. A pure electron plasma with a typical density of \( n \sim 10^{12} \text{ m}^{-3} \), a total number of \( N \sim 1.6 \times 10^8 \), and a length of 220 mm is held in a Malmberg trap with various distribution shapes [3]. The growth rate of the diocotron mode is reduced by decreasing the degree of the distribution’s concave form [4]. The panels of Fig. 1 (a) show spontaneous deformation with the azimuthal mode of \( \ell = 2 \). The observed growth rate is evaluated as \( \gamma_{\text{obs}} = 2.2 \times 10^3 \text{ s}^{-1} \). This density distribution is taken as the target system in the following examination.

We introduce a set of string-shaped distributions of high-density electrons (clumps) as perturbations to the target system. Each clump is characterized by the peak density \( n_c \sim 3 \times 10^{13} \text{ m}^{-3} \) and the total number of electrons \( N_c \sim 1 \times 10^6 \). The first examination is focused on the response of the \( \ell = 2 \) unstable target to a two-clump perturbation. The experimental results are shown in Figs. 1 (b) and (c). The clumps are observed to accelerate the \( \ell = 2 \) deformation. The acceleration is greater when the clumps are placed outside the ring-shaped distribution (exterior clumps) than when the clumps exist inside it (interior clumps). The interior clumps are advected and bunched into a single blob indicating a relatively weak influence on the target.

These observations are summarized in Table 1 in terms of the growth rate as obtained by time-resolved mode analysis of the image data. The bottom row gives the predictions of the linear theory that are determined as the eigen values of the potential perturbation \( \delta \phi_{\ell}(r) \exp(i\ell \theta - i\omega_{\ell} t) \) which is required to satisfy the Poisson equation

\[
\frac{1}{r} \frac{\partial}{\partial r} \left( r \frac{\partial}{\partial r} \delta \phi_{\ell}(r) \right) - \frac{\ell^2}{r^2} \delta \phi_{\ell}(r) + \frac{\ell}{\omega_{\ell} n_0} \frac{\partial n_0}{\partial r} \omega_{\ell} \delta \phi_{\ell}(r) = 0,
\]

with a boundary condition of \( \delta \phi_{\ell}(r) = 0 \) both on the axis.

Fig. 1 Photographs showing the deformation of the hollow density distribution; (a) spontaneous deformation, (b, c, d, e) deformations stimulated by clumps.

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The density perturbation clumps are bunched into two blobs. Stage are quickly masked by the ever-growing factor of 7. In the case of three interior clumps, as shown in Fig. 1 (e), slight deformations observed in the early stage are quickly masked by the exterior clumps may be attributed to the observation of the radial matching. This should be appreciated by observing in Fig. 2(b) that $|\delta\phi_\ell(r)|$ is larger at the location of the interior clumps while a stronger contribution of the exterior clumps is apparent in Figs. 1 (b) and (d). The stronger influence of the exterior clumps may be attributed to the observation of Fig. 2(a) that the angular frequency $\omega_m(r)$ of the advection of the exterior clumps is closer to the rotation frequency $\omega_m/\ell$ of the mode $\ell$ wave than that of the interior clumps.

In summary we have observed the stimulated growth of weakly unstable modes of density perturbation resonantly triggered and enhanced by externally imposed azimuthal arrays of clumps.

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