§7. Strong Effects of Low Level Background Vorticity Distribution on the Formation of Ordered Arrays of Clump Vortices in Non-neutral Electron Plasma

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We experimentally examine the time evolution of vortex dynamics of strongly magnetized pure electron plasma in a two-dimensional plane transverse to a homogeneous external magnetic field. The guiding centers of confined electrons form an incompressible fluid with infinitely large Reynolds number, and the density of the electron plasma is proportional to the vorticity of the $E \times B$ flows so that the circulation corresponds to the total electric charge. The vorticity distribution is measured in terms of the luminosity distribution on a phosphor screen to which all the electrons are collected absolutely determining the total charge.

Thin-string distributions of electrons ($1/e$ diameter < 1mm and 230mm long) successively form highly ordered arrays in quasi-steady states while decreasing in number by intermittent mergers from the initial 19. In the merging process the electron strings are filamented to be partially rolled up by other strings, and the rest contributes to form a low-level rugged distribution in the background (BG). The generation of the BG vortex (BGV) distribution drastically alters the evolution of the distribution of remaining strings (clumps) from that in vacuum. Here we focus on evaluation of the role of BGV on the organization of ordered arrays of clumps (vortex crystals) in the simplest configuration.

We examine the dynamics of three clumps, which are the minimum to determine a unit cell in the 2D space, immersed in a continuous BGV distribution provided as the initial condition. Here we need not depend on self-generation of the BGV through filamentation and merging as occurring in the crystallization of many clumps. When the clumps with equal circulation are placed at the vertices of an equilateral triangle in vacuum, the three clumps keeps the same symmetric configuration for more than 10 turnover time. This observation confirms the classical problem of equilibrium distribution of vortex strings. However, in a longer time scale, the symmetry of the clumps' position degrades gradually until the unilateral triangle disappears, suggesting that the symmetric configuration in vacuum is not robust against perturbations to the dynamics of each clump.

By the addition of BGV, the three-clump system exhibits highly robust sustainment of the symmetric configuration. This supporting role of BGV is further appreciated when we observe that three clumps, placed at the vertices of a unilateral triangle but with different circulation, maintain the symmetric configuration for more than 100 turnover time in the presence of BGV. In the asymptotic state in quasi-equilibrium, as shown in Fig.1, a circular zone of depleted vorticity (vorticity hole) in BGV surrounds each clump. The size of the vorticity hole is larger for a clump with larger circulation.

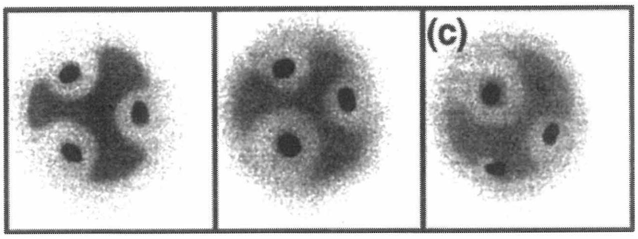

Fig. 1 Quasi-equilibrium distribution of vorticity.

It should also be noted, however, that the amount of the negative circulation of the hole is less than 20% of the clump's circulation so that the effective circulation of the dressed clumps are not in a mechanical balance. A natural conclusion is that the BGV with "infinite degree of freedom" takes part in the total dynamics apparently exhibiting a quasi-stationary state of symmetric configuration of the clumps.

Further role of the BGV to positively generate a symmetric structure is demonstrated by examining the time evolution of the clumps-BGV system, where the clumps are placed in a straight line in the initial BGV distribution. After a couple of turnover time when the clumps exhibit chaotic orbital motion, the clumps form a triangle that gradually evolves to the unilateral shape. The symmetry is quantified by a parameter S, the area of a triangle divided by the square of the peripheral chord length. With an appropriate coefficient, S is maximized at 1 when the triangle is unilateral. The time evolution of S is plotted in Fig.2 (b) for three identical clumps immersed in different BGV with initial profiles as plotted in Fig.2 (a) with common symbols. The observation indicates that S tends to settle down into the region close to 1 (say .> 0.9) for higher circulation of BG.

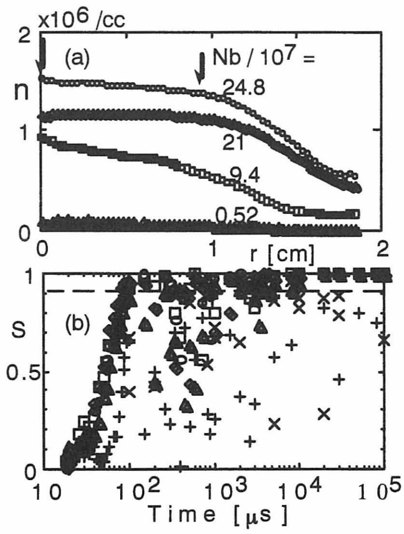

Fig. 2. BGV accelerates symmetric cell formation