§8. Controlled Experiment on Transport and Structures in Plasmas Associated with Vortex Dynamics and Turbulence

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One of the critical issues for improved confinement of hot plasmas depends on deeper understanding of the transport mechanism in association with the dynamics of spatial structures that appear spontaneously as collective motion or vortices. The purpose of this research is to examine this aspect by using a strongly magnetized pure electron plasma that wears a significant property of conservation in total number of particles, energy and angular momentum. Within a desk-top size plasma the spatial structures are observable down to ~10μm, so that the transport processes can be traced over a wide range of length-scales under substantially reduced dissipation or unidentified transports that tend to complicate data analyses.

The achievements in 2007 are published in Refs,1 to 3. Ref.1 examine the free-decaying two-dimensional (2D) turbulence initiated by a linearly unstable density distribution in terms of the transport of energy and enstrophy in the wave-number space. The time-resolved spectra are synthesized with a weighting of duration of each time frame to artificially construct a spectrum in a stationary state that is to be sustained by the balance between input and drain. The discrepancy between the synthesized spectrum and theoretical model of 2D turbulence are attributed to long-lasting coherent vortices characterizing the origin of the time-dependent turbulence.

In ref.2, experimental examinations are carried out about the mode-identification and contribution of high-frequency (HF) oscillations to the 2D vortex dynamics or turbulence as observed accidentally to be generated in association with preparing unstable density distributions as the initial condition. The experimental control include feed-back suppression of HF oscillations as well as HF generation with stable initial distributions. The examination has led to the conclusion that the HF oscillations belong to the axi-symmetric Trivelpiece-Gould mode wave supported by the $m=0$ component of the separated patches of density distribution executing vortex motions and that the HF waves have not noticeable effects onto the low-frequency vortex dynamics.

The short-comings of Fourier analyses are supplemented in Ref.4 by the introduction of wavelet expansion of the observed data. The wavelets simultaneously allow structure analyses both in the physical space and wave-number space. The vortex dynamics in the physical space are related directly to the spectral dynamics in the wave-number space. The scale-dependent extraction of the coherent structures has led to the confirmation of the tentative conclusion in Ref.1 about the discrepancies in the energy spectra in the wave-number space.

Ref.3 has reported the contribution of turbulent structures in the background onto the formation and decay of ordered arrays (vortex crystals) of coherent vortices. A remarkable finding is that the number of the crystal components decreases logarithmically with a coefficient that depends on the density (vorticity) of the background components.

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2) Y. Kawai, Y. Kiwamoto, Y. Soga and J. Aoki, "Propagation of axisymmetric Trivelpiece-Gould mode along vortex columns generated by diocotron instability", Phys. Plasmas, Vol.14, No.10, pp.102106-1~5 (2007).

3) Y. Kiwamoto, N. Hashizume, Y. Soga, J. Aoki, and Y. Kawai, "Formation and Relaxation of Two-dimensional Vortex Crystals in a Magnetized Pure Electron Plasma ", Phys. Rev. Lett., Vol.99, No.11, pp.115002-1~4 (2007).

4) Y. Kawai, Y. Kiwamoto, "Wavelet analysis of turbulence structures in magnetized pure electron plasmas", submitted for publication in Phys. Rev. E (2008.4).