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Tomographic observation of solitary wave deformation by nonlinear effects of background asymmetry

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It is important to understand the relation between turbulence and structure. A new problem, for example, arises as relation between turbulence field and "symmetry breaking" in structure. The problem requires not only local measurements but also measurements of the structure and fluctuations across the entire plasma cross section. This paper reports tomography measurement of the entire plasma cross section, which shows the solitary wave deformation due to background (or steady-state) structure asymmetry of the plasma in a linear device, name PANTA [1]. The observation suggests a new route to turbulence.

In PANTA plasma, solitary wave oscillations [2] are observed, and as shown in Fig. 1(a), tomography measurements revealed that the background structure is spatially asymmetric. By using the Fourier-Bessel Function (FBF), the background structure can be separated into symmetric and asymmetric components of 20%. In addition, a new conditional averaging method, CECAME [3], was proposed, which successfully separates the periodic deterministic trend and the turbulent probabilistic part. The deterministic trend should be rotationally symmetric under a symmetric background, but as shown in Fig. 1(b), the spatial structure shows symmetry breaking, confirming that the spatial pattern is deformed during one period (T~838μs).

To quantify the oscillation pattern, the moment vectors ($A_m(t)$, $B_m(t)$) were evaluated from the reconstructed 2D images $\tilde{\varepsilon}(r, \theta, t)$ using FBF. Here, the moment vector is defined as

$$A_m(t) = \frac{1}{\sqrt{\pi}} \int \tilde{\varepsilon}(r, \theta, t) \cos(m\theta)\, r dr d\theta,$$
$$B_m(t) = \frac{1}{\sqrt{\pi}} \int \tilde{\varepsilon}(r, \theta, t) \sin(m\theta)\, r dr d\theta, \quad (1)$$

where m is the azimuthal mode number. Changes of each vector can express the time evolution of the corresponding mode of oscillation pattern. Moreover, this time evolution can be frequency decomposed using Fourier transform, and the oscillation pattern intensity and its deformation degree can be quantitatively expressed on a plane of azimuthal mode number and frequency.

Considering an ideal solitary wave oscillation without deformation, it can be represented by a superposition of harmonic modes ($\omega_m = m\omega$) rotating in the same direction, electron diamagnetic direction in this case. Moment vector analysis suggests that the solitary waves deformation is related to the emergence of the following two types of modes: i) non-harmonic modes ($\omega_m \neq m\omega$), and ii) modes rotating in the ion diamagnetic direction (inverse rotation modes). Also, a simple algebraic model can explain the emergence modes described above: the nonlinear coupling of the background asymmetry $\bar{\varepsilon}_A \propto \cos(m\theta)$ and the ideal solitary wave oscillation composed harmonic modes $\tilde{\varepsilon}_h \propto \cos(m'\theta + m'\omega t)$ can emerge such non-harmonic modes,

$$\bar{\varepsilon}_A \cdot \tilde{\varepsilon}_h \propto \cos(m\theta)\cos(m'\theta + m'\omega t)$$
$$= \cos\big((m+m')\theta + m'\omega t\big) + \cos\big((m-m')\theta - m'\omega t\big).$$

Finally, the important effect of the asymmetry of background structure ($\omega \neq 0$) is revealed by tomography, which can measure the entire plasma cross-section, suggesting a new route to turbulence in the plasma [1].

References
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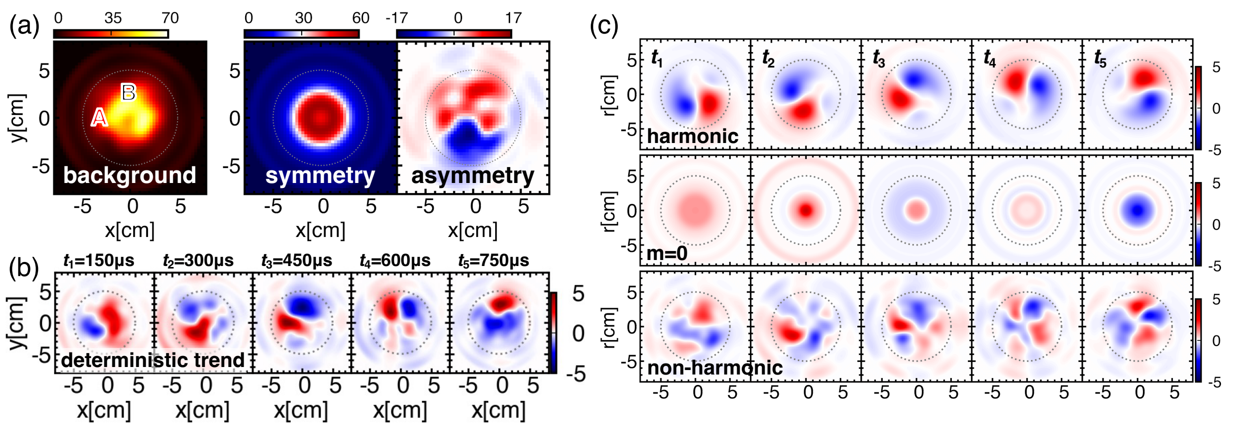

Figure 1: (a) Background structure and its symmetry and asymmetry component. (b) Temporal evolution of the 2D structure of deterministic trend of solitary wave oscillation. (c) Spatial structure of harmonic, symmetric (m=0), and non-harmonic modes decomposed from deterministic trend. The model also suggests that spatially symmetric modes also emerge, as shown in (c).