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# Current filament structures in the edge region of the RFX-mod device

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Turbulence represents an outstanding critical issue in the physics of magnetically confined plasmas for thermonuclear fusion research. Indeed plasma turbulence has been recognized since the beginning as the cause of the so-called *anomalous* particle and energy transport [1]. In recent years it has been observed that, within incoherent fluctuations, coherent structures emerge similar to vortices observed in fluid turbulence. These structures have been detected in a variety of devices, ranging from tokamaks [2], through stellarators [3], up to reversed field pinches [5] and linear devices [6, 4], and represent a feature shared with astrophysical plasmas [7]. Turbulent structures, often referred to as *blobs*, are responsible for the high degree of intermittency generally observed.

*Blobs* arising in fusion-relevant plasmas have been extensively studied in the plane perpendicular to the main magnetic field [2], and only recently their 3D features have been experimentally addressed [8]. Present theories about blob formation and dynamics suggest an interchange-like origin, with effects induced by sheath boundary conditions of the material objects intersecting the magnetic flux surface. Plasma quasi-neutrality implies the condition $\nabla \cdot \mathbf{j} = 0$ on the total current $\mathbf{j}$: considering the non vanishing $\nabla_\perp$ components of the diamagnetic and polarization currents, a parallel current density perturbation $\tilde{j}_\parallel$ must arise [9]. Nevertheless, although interchange is believed to be responsible for blobs in the Scrape Off Layer plasmas, they do not represent the only possible mechanism for the generation of electromagnetic coherent structures. Drift wave instability, which is thought to dominate plasma turbulence in the edge region, is a non periodic motion involving disturbances on a background pressure gradient of a magnetized plasma and eddies of fluid-like motion in which the advecting velocity of all charged species is the $\mathbf{E} \times \mathbf{B}$ velocity [10]. In the limit of not so small $\beta$ ($\beta \gtrsim m_e/M_i$), condition often encountered in the edge of fusion relevant plasmas, the resulting turbulence and transport level will be determined by electromagnetic effects in the framework of drift-Alfvén dynamics, which represents the paradigm for the description of the coupling of drift-waves with Kinetic Alfvén waves (KAW) [10]. In this framework the parallel electron dynamics is actually modifed with respect to Boltzmann's relation, and the coupling between parallel drift wave electron currents and KAWs creates a non-adiabatic electron response by induction (this at intermediated $\beta$, $m_e/M_i \ll \beta \ll 1$). In the nonlinear regimes, drift-Alfvén turbulence may generate nonlinear structures in the form of electromagnetic vortices [11] called *Drift Kinetic Alfvén vortices* (DKA). These structures have been observed both in astrophysical plasmas [7] and in linear devices [6], and only recently in the edge region of in the RFX-mod reversed field pinch experiment [12]. The data presented hereafter have been obtained in the RFX-mod ($R/a = 2m/0.459m$ ), operating at relatively low plasma current ($I_p \leq 400$kA) and with average density normalized to the Greenwald density $n/n_g \approx 0.4 - 0.5$. The typical plasma parameters observed in the edge region for these type of discharges are density of the order of $1 - 2 \times 10^{19}$ m$^{-3}$, temperature in the range 20-40 eV and magnetic field $B_0$ around 0.15 T. The corresponding $\beta$ are in the range of 1-2 % thus ensuring the condition $\beta \gg m_e/M_i$ whereas the typical scale length $\rho_s = c_s/\Omega_i$ is equal to 3-4 mm. It is worth to remember that in the edge region of RFP plasmas the magnetic field is essentially poloidal, so that the perpendicular plane corresponds to the radial-toroidal plane.

A new insertable probe has been developed in order to study electromagnetic turbulence and is described elsewhere [8]. The probe allows the simultaneous measurements of plasma density, electron temperature, electron pressure, plasma potential and their radial profiles at the same toroidal location, as well as the radial and toroidal components of the $\mathbf{E} \times \mathbf{B}$ plasma velocity and of the the local fluctuation of vorticity $\omega = \nabla \times \mathbf{v}$, where $\mathbf{v}$ is the electric drift velocity, from the floating potential ones $V_f$, as $\omega_{\parallel} = \frac{1}{B} \nabla^2_{\perp} V_f$. Moreover at the same nominal position of vorticity measurements, the probe allows a measurements of the parallel current density, directly calculated from Ampere's law $j_{\parallel} \simeq j_{\theta} = \frac{1}{\mu_0}(\partial_{\phi} b_r - \partial_r b_{\phi})$. Data were digitally sampled at 5 MHz with a minimum bandwidth of 700 kHz. The data collected with the insertable probe have been completed with measurements obtained from a toroidal distributed array of magnetic pick-up coils located inside the vacuum vessel. Despite the peculiar magnetic topology, the edge region of RFP plasmas shares many features with other magnetic devices, among which the strong intermittent character of electrostatic fluctuations [5], and the highly sheared $\mathbf{E} \times \mathbf{B}$ flow detected at the edge [13]. The data analysis technique used to disentangle coherent structures from turbulent background is based on wavelet analysis and has been extensively described elsewhere [14]. It allows to locate within the signal the presence of structures at a given temporal scale. This method has been used together with the traditional conditional averaging technique to better extract the common features of the observed structures.

The main observations of this contribution are shown in figure 1. The figure shows the result of a conditional average applied to various plasma parameters performed using as a triggering event the presence of an intermittent structure on electron pressure at typical scale $\tau = 4\mu$s (frame (a)). The pressure perturbation is found to be due essentially to the density. frame (b)

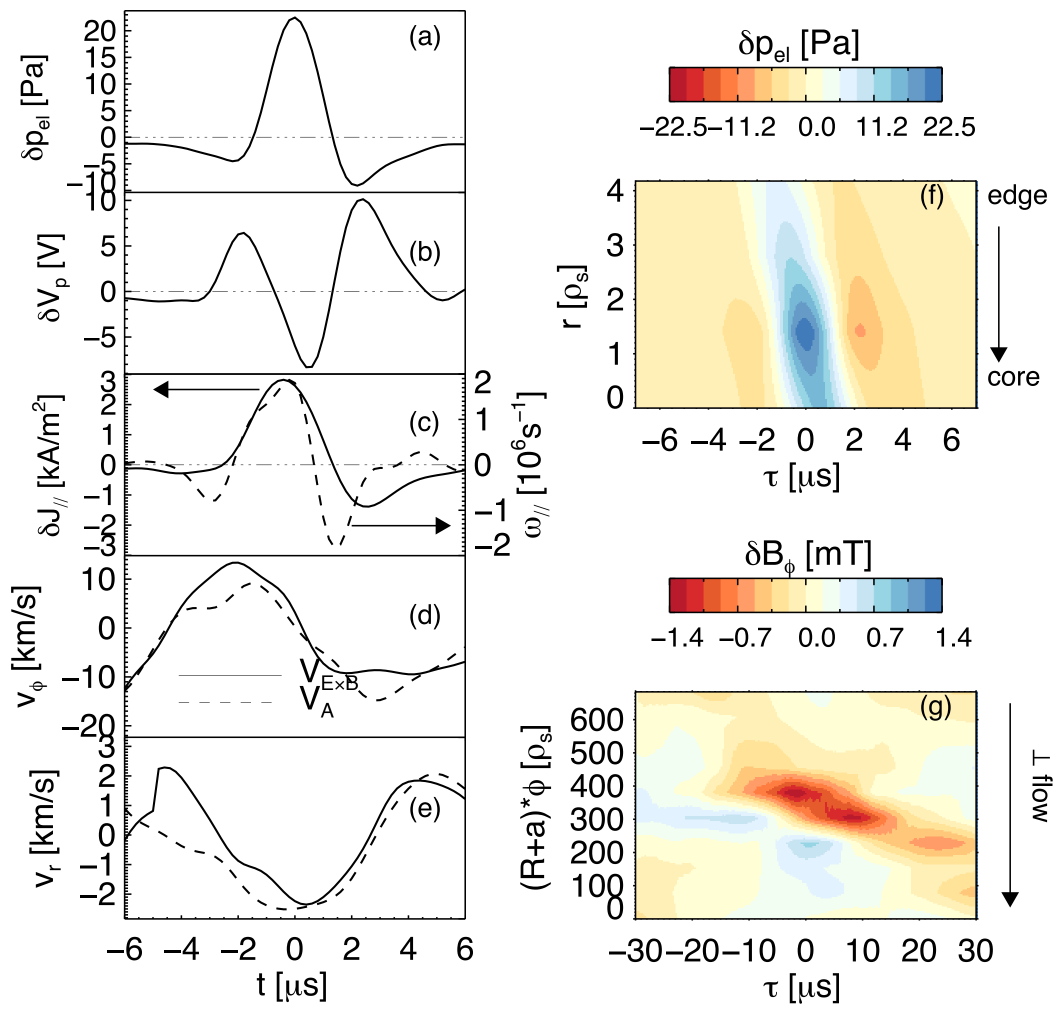


**Figure 1:** Average coherent structure detected at $\tau = 4\mu s$ using electron pressure as reference signal. (a) Electron pressure (b) plasma potential (c) parallel current density and parallel vorticity (d) (d) $\mathbf{E}\times\mathbf{B}$ toroidal velocity and alfvén velocity (solid and dashed lines respectively), (e) $\mathbf{E}\times\mathbf{B}$ radial velocity and alfvén velocity (solid and dashed lines respectively) (f) Electron pressure as a function of time and radial position normalized to ion sound gyroradius $\rho_s$ (g) Toroidal magnetic field as a function of time and toroidal coordinate normalized to $\rho_s$

shows the electrostatic potential perturbation, which displays a minimum slightly out of phase with respect to pressure one, underlying the drift-origin of the coherent structure. The electrostatic potential gives rise to an electric field in the perpendicular plane, responsible for the vortex-like fluid motion. frame (c) shows both the parallel current density and the parallel vorticity, both directly estimated from measurements without any frozen turbulence hypothesis and using direct spatio-temporal information. A clear parallel current perturbation is observed and this current perturbation is found in phase with the pressure peak and the measured vorticity: this observation is a clear mark of the nature of the structure observed, proving the proportionality existing between scalar and vector potential. The two last frames display the two components of the perpendicular $\mathbf{E}\times\mathbf{B}$ velocities (toroidal and radial), compared to the corresponding Alfvén velocity perturbation: this comparison is equivalent to the observation that $\frac{E_\perp}{B_\perp} = \frac{\overline{B}}{\sqrt{\rho\mu_0}} = \overline{V}_A$, confirming the alfvenic character of fluctuating velocities, and thus strongly supporting the interpretation as DKA of the observed vortex structure. The dimension of these structures may be estimated using the spatially resolved measurements. In frame (f) the average pressure perturbation as a function of minor radius and time is shown, where the conditional average procedure has been carried out using the same trigger on pressure. The radial dimension has been normalized to local ion sound gyroradius in order to show that the radial extent is a 2-3 $\rho_s$ as theoretically expected for the DKA vortices. On the other perpendicular direction the physical dimension may be inferred by following the magnetic footprint associated to a DKA vortex as detected from the toroidally distributed array of pick-up coils. The results of the conditional average is shown in frame (g). The structure is elongated in the toroidal direction, with typical size of 100 $\rho_s$ corresponding to approximately 30-40 cm. In summary we have shown that electromagnetic structures responsible for the high degree of intermittency observed at the edge of RFX-mod reversed field pinch experiment can be unequivocally classified as DKA vortices. Owing to the many analogies with tokamak and stellarator edge properties, these measurements suggest the necessity to complement the *blob* description with a complete electromagnetic characterization and support the theory of Drift-Alfven dynamics as a paradigm for the description of the edge region of thermonuclear plasmas.

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