# The experimental investigation on the role of $E \times B$ flow shear in tilting and breaking of turbulent eddies

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## Introduction

It is widely accepted that the stable shear flow can suppress turbulence and turbulent transport in plasmas by decorrelating turbulent eddies in the shear layer. When a turbulent eddy is placed in a flow whose speed varies transverse to the flow direction, the eddy is stretched and distorted as different fluid parcels in the eddy are advected (carried along) at different speeds. Also, it has long been believed that whether the structure is broken or not depends on the ratio of the flow shear rate $\omega_s$ to the natural decorrelation rate of the structure $\omega_D$ [1]. However, the direct evidence of the splitting of turbulence eddies by the flow shear has not been observed. In order to test this conception, some relevant work has been performed in TEXTOR. At TEXTOR a natural edge $E_r \times B$ flow shear layer exists in ohmic plasmas. In addition, an enhanced poloidal flow shear can also be externally produced by positively biasing an electrode inserted into the plasma edge. In this contribution, we report mainly the impact of the (i) natural flow shear and (ii) externally induced flow shear on stretching, and especially, splitting of turbulent structures as well as on other properties of turbulence in the plasma boundary.

## Experimental setup

The experiments were executed in ohmic deuterium discharges in the TEXTOR tokamak with the major radius $R$=175 cm and minor radius $a \approx$47.5 cm. Typical plasma current was $I_p$=300-350 kA, toroidal magnetic field $B_T$=1.6-2.6 T and the central line-averaged electron density $\bar{n}_e$=(1.5-3.5)$\times 10^{19}$ m$^{-3}$. In order to directly view the 2D (radial versus poloidal directions) edge turbulence structures, a GPI diagnostic has been recently developed at TEXTOR [2]. The in-vessel GPI setup is as follows: the neutral deuterium gas is puffed radially into the plasma edge via a gas inlet system installed on the liner ($\sim$ 8 cm outside the last closed flux surface (LCFS)); The gas-puff-induced emission is then viewed by an optical telescope mirror along the magnetic field line. Finally, the image of the gas cloud is transferred to a 64x64 pixel Princeton Scientific Instruments Inc. PSI-5 camera. Each image covers an area of 12$\times$12 cm$^2$ in the radial vs poloidal plane across the LCFS. The framing rate was varied from 2 to 6 $\mu$s frame$^{-1}$. The

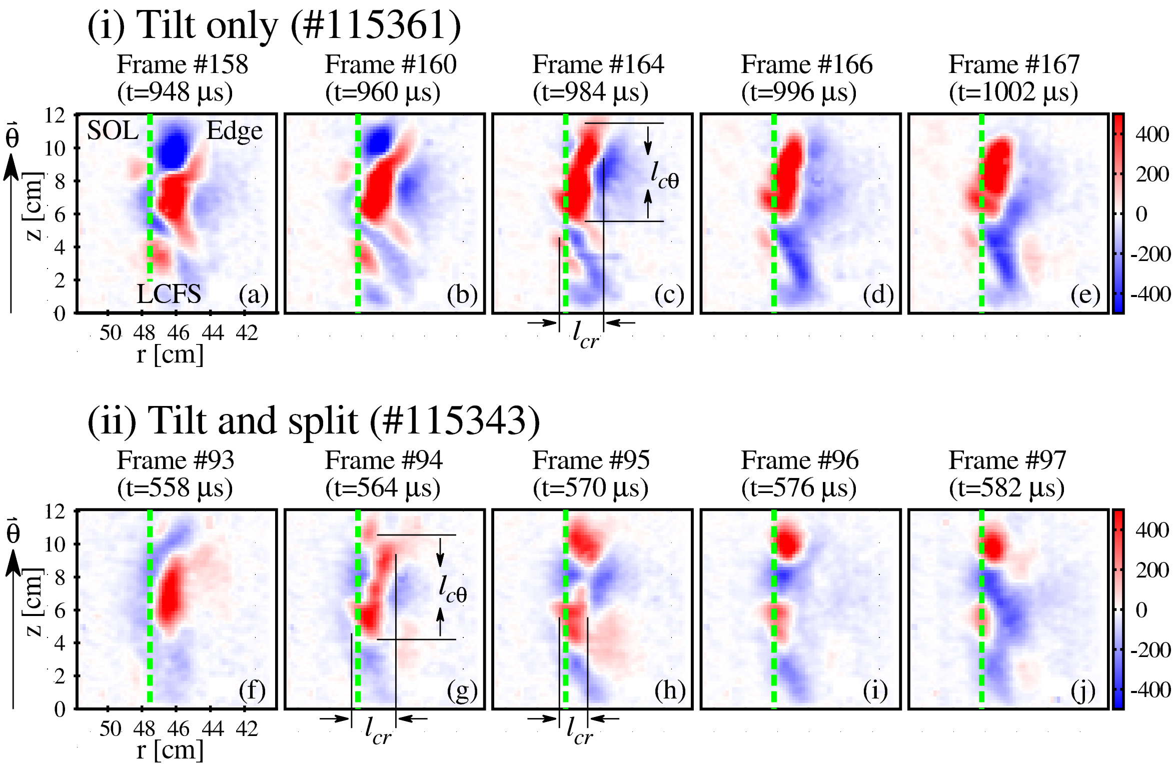


Figure 1: *Time sequences of images, showing the influence of $E_r \times B$ sheared flows on tilting and breaking the turbulence eddy at the edge of the TEXTOR tokamak for two different types: (i) The eddy structure is tilted only in the poloidal direction by a weak flow shearing; (ii) The eddy structure is tilted and broken by a strong flow shearing. The green dashed line denotes the LCFS location.*

camera took 260 image frames in each plasma discharge.

The external edge biasing was also performed using a biasing electrode inserted into the plasma edge at a radial position of 43 cm. The applied electrode voltage varies from 0 V to 300 V. In the stationary phase of the discharge, the electrode biasing lasts for 400 ms, during which the GPI exposes about 0.6 ms.

**Results and discussion**

Figure 1 displays two GPI images, showing two types of turbulent structures propagating through the scene: (i) “Tilt only” and (ii) “Tilt and split”. The images were measured with an exposure time of 6 $\mu s$. To show only the fluctuating part of the signal, we subtract the time-averaged mean values from the light intensity detected at each pixel for every image. The light intensity scale is shown on the right. The red color structures are identified as turbulence eddies. It can be seen that the structures move across the frame with the radial speed of $V_{rad} \approx 300\ m/s$. The poloidal and radial sizes of structures can be roughly considered as the poloidal and radial correlation lengths. Top panels show that the turbulent structure is tilted in the poloidal direction by weak shear flows naturally occuring in the plasma edge. In case of a strong flow shear, structure is tilted first and then even broken, i.e., from one structure into two pieces, as seen in the bottom panels of Fig. 1, thereby making the radial correlation length shorter. From the

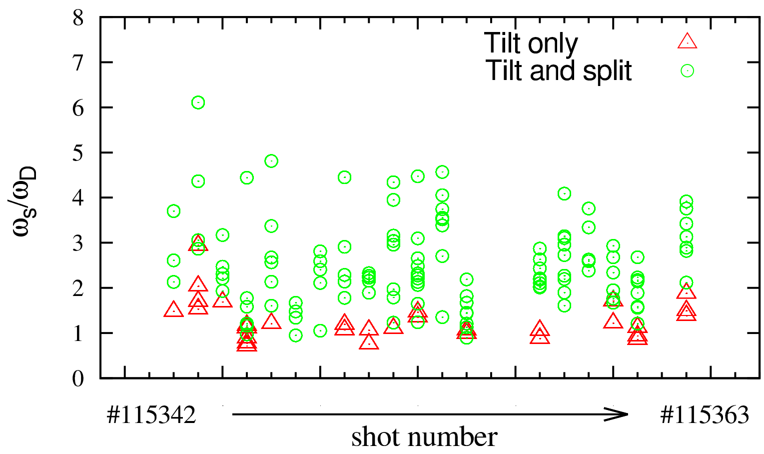


Figure 2: *The ratio of the $E_r \times B$ flow shear rate ($\omega_s$) to the natural diffusive scattering rate of ambient turbulence ($\omega_D$) in a number of discharges at TEXTOR for the eddy "tilt only" and "tilt and split" events. The x-axis corresponds to different shot numbers.*

Langmuir probe data, we get the natural (random without flow shear effects) turbulence decorrelation rate $\omega_D \approx 1 \times 10^5$ s$^{-1}$. With values of $E_r \times B$ flow shear ($dV_{E_r \times B}/dr$) and radial/poloidal correlation lengths, we obtain $\omega_s = \frac{dV_{E_r \times B}}{dr} \cdot l_{cr} l_{c\theta}^{-1} = \frac{dE_r}{Bdr} \cdot l_{cr} l_{c\theta}^{-1} = 1.2 \times 10^5$ s$^{-1}$ in type (i) and $\omega_s = 2.6 \times 10^5$ s$^{-1}$ in type (ii). Thus, the ratio of $\omega_s/\omega_D$ is 1.2 and 2.6 for the "tilt only" and "tilt and split", respectively. Obviously, the occurrence of the eddy breaking depends on the magnitude of the flow shearing rate.

To substantiate the relation between the $E_r \times B$ flow shear rate and the eddy breaking phenomena, we have estimated the ratio of $\omega_s/\omega_D$ in each type of the "tilt only" and "tilt and split" events collected from different discharges. Figure 2 shows the ratio $\frac{\omega_s}{\omega_D}$ for many different individual structures, represented by either circle ('only tilted') or triangle ('tilted and broken'), as a function of the shot number. All structures are arranged according to their shot numbers to avoid the overlap of different structures. As can be seen, the "Tilt and split" structures usually have the ration $\frac{\omega_s}{\omega_D}$ above 2, while the lower values mostly correspond to "Tilt only" structures.

In the biasing experiment, with gradual increase of the shear flow (achieved by increasing the electrode biasing voltage) the tilting of turbulent eddies is also enhanced. Figure 3 shows the contour plots of 2D ($k_r$ *vs* $k_\theta$) wavenumber spectra of GPI data measured at different biasing voltages (top panels) and the time trace of the GPI signal from one pixel at the radial position of 47 cm (bottom panels). Wavenumber spectra are obtained using the two-dimensional fast fourier transformation (2D FFT) and averaged over all images in one shot. The top pannels demonstrate the influence of the background shear flow on the shape of turbulent structures, while the bottom ones show corresponding fluctuation amplitudes. At zero biasing voltage (Fig. 3(a)), the ratio of $\frac{\omega_s}{\omega_D}$ approximately equal to 1.2 and the wavenumber spectrum is roughly symmetric. As the ratio of $\frac{\omega_s}{\omega_D}$ is enhanced from 1.8 to 2.5 (the corresponding biasing voltage 60 - 150 V), the shape of the spectrum becomes gradually elliptic, as seen in Figs. 3(b-d), with the orientation

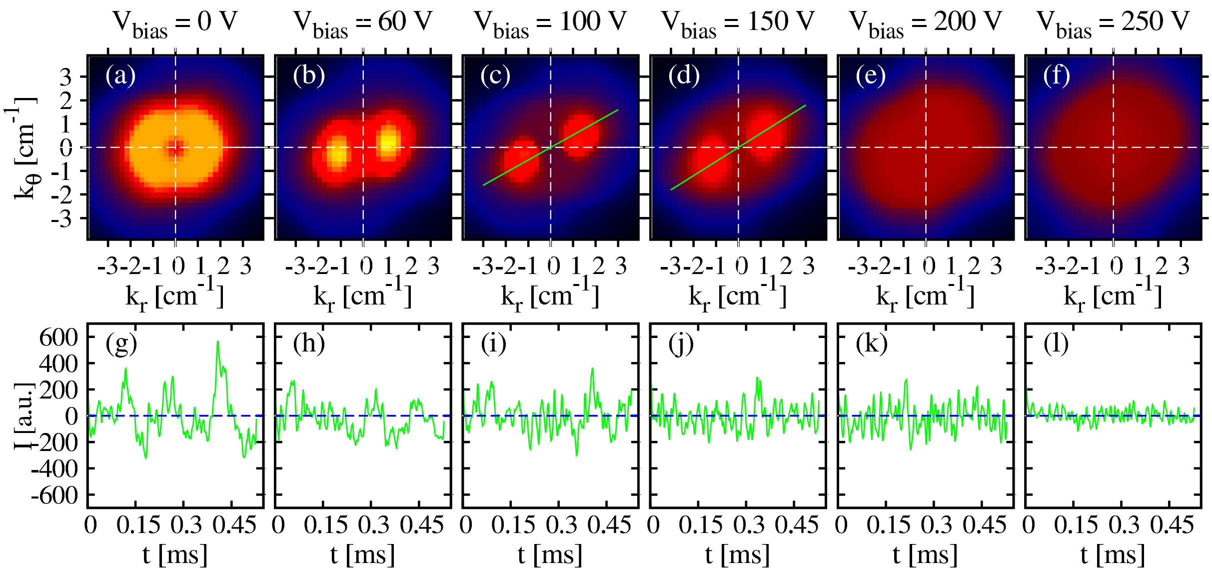


Figure 3: *Top panels: Contour plots of 2D ($k_r$ vs $k_\theta$) time-averaged wavenumber spectra of GPI data measured at different biasing voltages. Bottom panels: Time traces of the GPI signal from one pixel at the radial position of 47 cm.*

angle of $15^\circ - 30^\circ$ with respect to the $k_\theta$=0 axis. This modification is due to continuous tilting effects on an initially circular eddy structure. As the bias is further increased to a ratio $\frac{\omega_s}{\omega_D} \approx 3.1$ ($V_{bias} \geq 200\ V$), the shape of the spectrum comes back to the symmetric form. This result can be explained by the breakup of one eddy into two pieces with a consequent reduction in the radial and poloidal correlation lengths. Apart from this, the diminishing influence of the shear flow on turbulence is visible as well in the bottom panels of the figure. As the biasing flow is steadily increased, the turbulence fluctuation level is continuously reduced.

## Conclusion

In conclusion, we present direct evidence of eddy breaking and tilting events observed at the edge of the TEXTOR tokamak using a 2D GPI diagnostic. The magnitude of the flow shearing rate plays a key role for the eddy breaking and needs to be larger than some lower limit up to which only tilting of eddies is observed. The flow shear, externally produced by the biased electrode, also leads to similar changes in the shape of the turbulent structure. When the flow shear is increased from $\frac{\omega_s}{\omega_D}$=1.2 to $\frac{\omega_s}{\omega_D}$=2.5 the shape of the eddy structure changes from circular to oriented elliptic shape. As the shear rate is further increased to $\frac{\omega_s}{\omega_D}$=3.1, the eddies are broken up, resulting in the decrease of $l_{cr}$ and $l_{c\theta}$, and thus the recovery of the initially isotropic shape.

## References


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