DIRECT MEASUREMENTS OF EXB FLOW AND ITS IMPACT ON EDGE TURBULENCE IN THE CASTOR TOKAMAK

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Experimental evidence of the correlation between edge sheared ExB flow and reduction of electrostatic turbulence has recently been found in the CASTOR tokamak (R=0.4 m, a=0.085 m, B_T=1T) in so called “separatrix biasing” regimes [1]. The biasing electrode is placed at the separatrix in a configuration, which has demonstrated strongly sheared electric fields and consequent improvement of the global particle confinement. A set of movable electrostatic probes (rake, Langmuir, Gundestrup) is used [2] to provide simultaneous measurements of poloidal and toroidal flows, electron temperature, density, and radial electric field at the same poloidal location and with high temporal resolution. Two series of biasing experiments have been performed with this extensive probe diagnostic set-up, also in discharges with Lower Hybrid (LH) wave injection.

Perpendicular Mach number versus the radial electric field

The first series of shots was devoted to the systematic investigation of the relation between the ExB and ion flow velocities in biased discharges. To that end, the “Ideal Gundestrup Probe” (IGP) was located at two distinct radial positions in front of and behind the biasing electrode, in the region of highest radial electric field (r=70 mm and r=85 mm), deduced from the radial profile of the floating potential measured by the means of the rake probe, see Fig. 1.

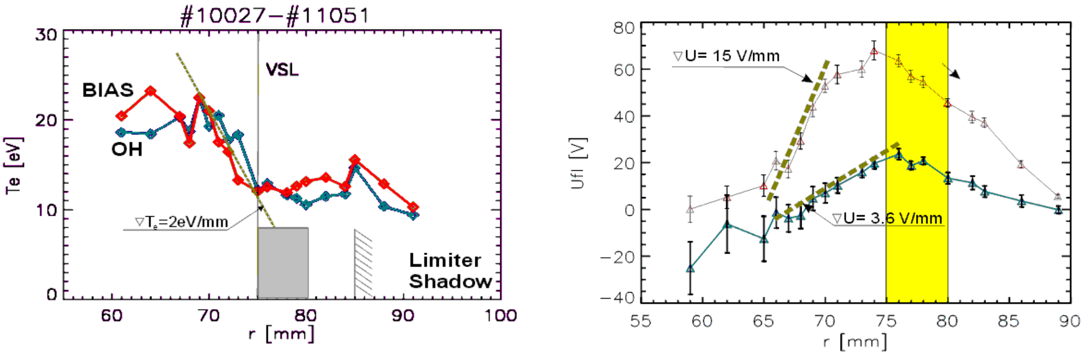

Fig 1: *Radial profile of electron temperature (left) and floating potential (right) in ohmic and biased phase of discharges measured by the single Langmuir probe located at the top of the IGP. Position of the separatrix is at r=75 mm, which corresponds to the location of the top of the biasing electrode. The radial extent of the biasing electrode is marked by the yellow box.*

It is seen from the figure, the gradient of the floating potential is enhanced with biasing (U_b= +100 V) at both sides of the electrode, i.e. in the SOL as well as inside the separatrix. The radial electric field is calculated following the expression

$$E_r = -(\nabla U_{fl} + \alpha \nabla T_e)$$

where the factor α is rather uncertain in magnetized plasmas [3] and ranging from 1.3 to 3. As seen from the left panel of Fig. 1, the actual radial profile of the electron temperature must be taken into account because of rather large local gradients of the electron temperature observed within the separatrix (∇T_e ~ -2 V/mm), but also in the SOL (-1V/mm). Note the similar shape of Te(r)-profiles in ohmic as well as at separatrix biasing regimes.

Series of discharges at different biasing voltage have been performed. The resulting dependency of the perpendicular Mach number on the radial electric field is shown in Fig.2.

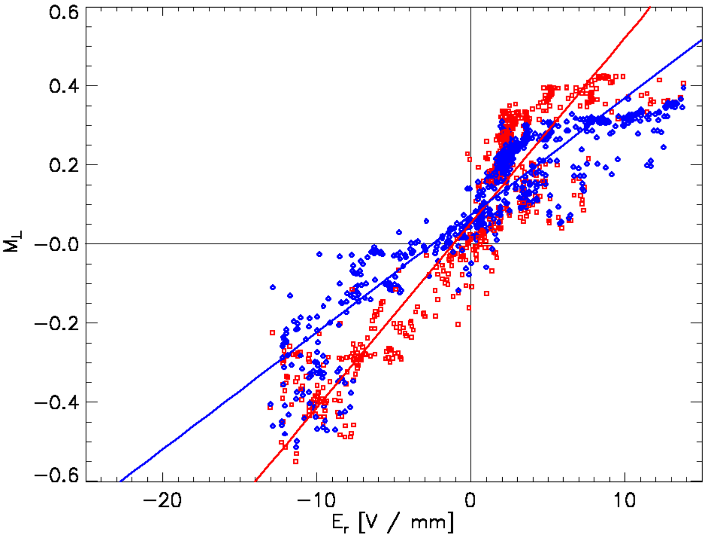

Fig. 2.
Perpendicular Mach number versus the radial electric field. The red points correspond to Mach numbers deduced from the KD model [4], while the blue marks are calculated using the VG model [5].
$E_r < 0$ - IGP is within sepratrix
$E_r > 0$ - IGP is in the SOL

It is evident from the figure that the perpendicular Mach number is proportional to the magnitude of the radial electric field. The slope of the curves is determined by the ion sound velocity, which is either $c_s = v_{ExB}/M_\perp$ ~ 21.5 km/s (KD-fit) or 32 km/s (VG-fit). It is interesting to compare this experimental value with the expression

$$c_s = \sqrt{\frac{k(ZT_e + \gamma T_i)}{m_i}} \cong 9.8.10^3\sqrt{ZT_e + \gamma T_i}\ ,$$

which gives for the experimentally measured electron temperature 16 eV a significantly higher value,~ 40 km/s, even in the case of $T_i=0$, $Z=1$. This may indicate that the actual value of the electron temperature is less than that measured from I-V characteristics of the single Langmuir probe. This may appear, for example, if the edge plasma is non-maxwellian, and contains a few percent of suprathermal electrons. It is clear that this observation needs further analysis.

Fluctuation and flow velocities

In the second experimental series, the measured ion mass flow is compared with the phase velocity of fluctuations moving poloidally across the Gundestrup collectors (see Fig. 3). The ion mass flow is measured by the standard arrangement of the Gundestrup probe, i.e. signals of all the segments are digitized at a standard sampling rate (1 μs/sample), then averaged over the time interval 0.5 ms. From these date, the perpendicular Mach number of the ion flow is derived. Simultaneously, the signals from the most upstream and downstream pairs of the segments, i.e. 2,3 and 6,7 are recorded faster, at a sampling rate of 5MS/s. Then, the cross-correlation function is calculated and the transit time of a poloidally localized structure across the corresponding segments is deduced from the shift of its maximum (see the right panel in Fig. 3). The phase velocity of fluctuations is calculated as the ratio of the distance between the adjacent segments (4.5 mm in our particular case) and the transit time. It has to be emphasized that time delays by one sample have been considered as statistically uncertain and consequently not taken into account in the calculation of fluctuation velocities. Thus, the maximum velocity, which can be determined in this way is of about 11 km/s.

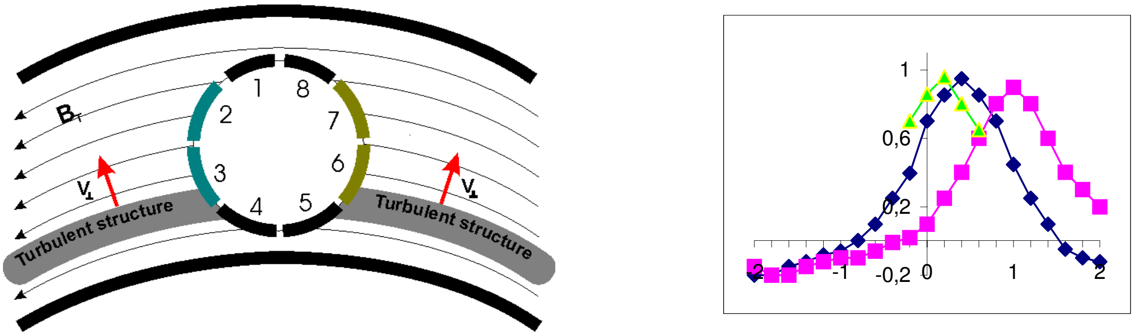

Fig.3: *Left: Principle of comparison of flow and fluctuation measurements. Right: Shape of the cross-correlation function of fluctuating signals of the segments nearly perpendicular to the magnetic field lines (schematically).*

Two examples of the evolution of the fluctuation velocities in the combined OH-Bias-BiasLH-LH-OH discharges is shown in Fig. 4. The biasing period is 4 ms (from t=8 to t=12 ms). The LH phase of the discharge is also 4 ms long, starting at t=10ms.

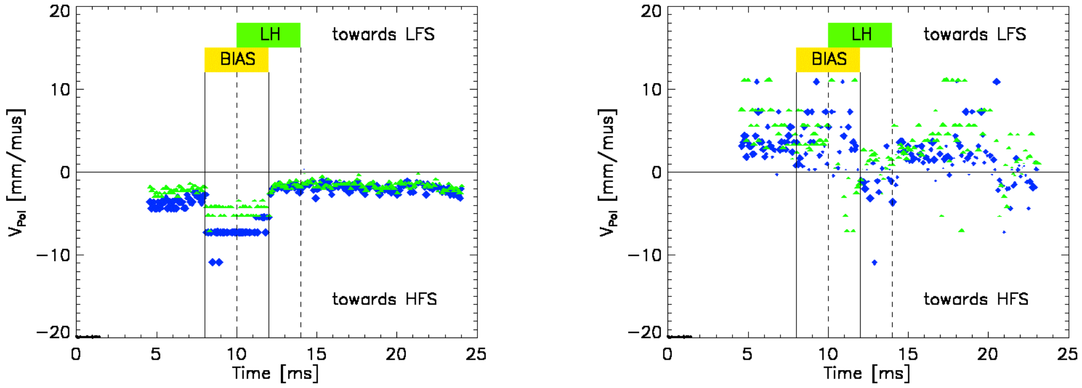

Fig: 4: *Evolution of the phase velocity of fluctuations as measured simultaneously by the pair of segment 2,3 (blue marks) and 6,7 (green marks). Left: IGP is positioned in the SOL, Right: IGP is inside the separatrix.*

The left panel shows the evolution in the SOL. It is seen that the upstream and downstream pairs yield roughly the same values of the fluctuation velocity, ~2 km/s. The velocity increases during the biasing phase, as expected, but a difference between pairs is already visible. Nevertheless, if the details are not taken into account, the physical picture agrees well with the generally accepted model of edge turbulence, in which the turbulent structures are "flutes", localized in the poloidal and radial direction and associated with a particular magnetic surface. The right panel shows the evolution inside the last closed flux surface. Here, the propagation is reversed, as expected. However, the data are much more scattered then in the previous case and the pairs of segments measure different values of the phase velocity. Sometimes, the upstream pair measure fluctuations propagation in the opposite direction then the downstream pair. This last mentioned effect is even more evident when the IGP is in the proximity of the separatrix. We conclude from these observations that the parallel wavenumber of the turbulent structures increases inside the separatrix. Possibly, the structures live their own life independently on the bulk plasma. Maybe some structures may leave the magnetic surface.

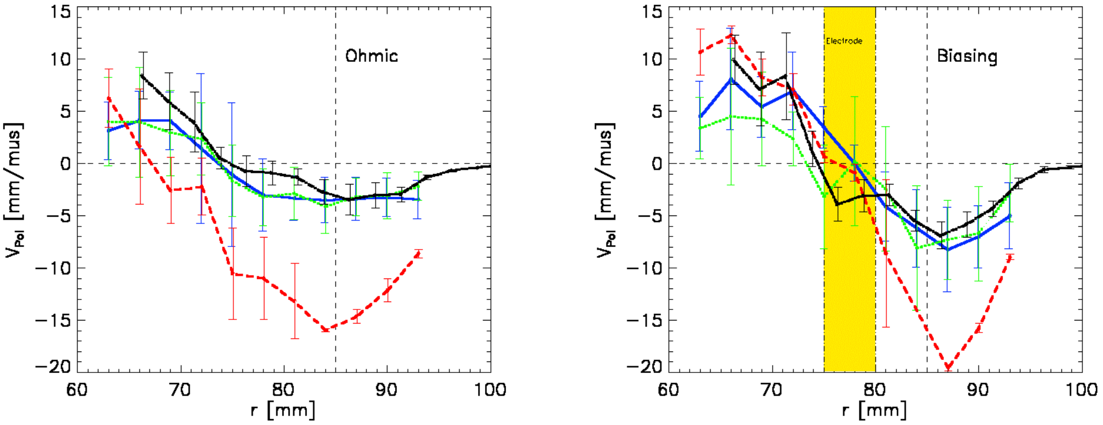

Fig.5: *Radial profile of fluctuation velocities (blue and green lines), and flow velocity (red line) measured by the IGP. The black line is the ExB velocity deduced from the rake probe data.* *__Left__: ohmic phase of the discharge.* *__Right__: Biased phase of the discharge.*

It is evident from the figure that the flow and fluctuation velocities are comparable within the separatrix (in paricular with biasing), while a large discrepancy in their magnitudes is measured in the SOL. A clear agreement of fluctuation and ExB velocities is observed.

The edge plasma can be also effectively modified by injection of Lower Hybrid Waves, as illustrated in Fig. 6 shows an example of such impact. The radial profile of the floating potential appears to be flat during the LH phase of the discharge. Consequently, the fluctuation and flow velocities are close to zero in a broad range of radii. However, the fluctuation and flow velocities differs significantly.

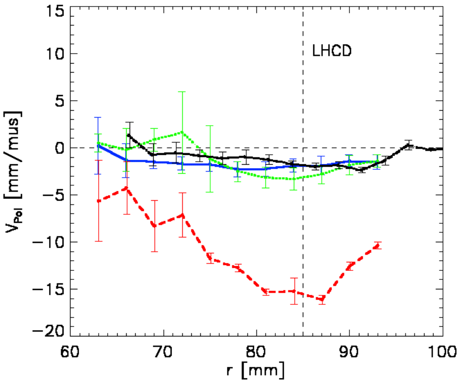

Fig. 6: *Radial profile of fluctuation and flow velocity measured by the IGP during the LH phase of the discharge.*

Conclusions

It is demonstrated that separatrix biasing and lower hybrid wave injection provide non-intrusive tools to modify flows and electric fields on closed magnetic flux surfaces. The plasma flows, especially the poloidal ExB drift velocity, are strongly modified in the sheared region, reaching Mach numbers as high as half the sound speed.

It is also shown that the Ideal Gundestrup Probe offers a unique possibility to study the link between the ion flows and poloidal propagation of turbulent structures simultaneously.

References:

[1] G. Van Oost et al, ITC-11, TOKI 2000, to be published in J. Plasma Fusion Res. Series
[2] J. Stöckel et al, this Conference, Poster No. P1.057
[3] R. Schrittwieser et al, this Conference, poster No. 1.106
[4] K. Dyabilin et al: In Proc. of 27th EPS Conf on Contr. Fusion and Plasma Physics, Budapest, 2000, p. 1653
[5] H. Van Goubergen et al, Plasma Phys. Contr. Fusion, 41, 1999, L17