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On the parallel Correlation of Electrostatic Fluctuations in the Edge Plasma of W7-AS and JET

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1 The role of parallel dynamics and of parallel correlation measurements

For turbulent fluctuations of plasma density and floating potential in the edge plasma of toroidal confinement devices, correlation lengths of few cm perpendicular to the magnetic field have been determined, mostly using two- or multi-tip poloidal and radial Langmuir probe arrays in ion saturation current (I_{sat}) or floating potential (Φ_{fl}) mode, but also by correlation reflectometry, lithium beam emission spectroscopy and H_α/D_α light observation. In contrast, parallel to the magnetic field, high correlation of up to 90 % has been observed for Langmuir probes positioned on the same magnetic field line at up to 10 m separation, both in I_{sat} and in Φ_{fl} mode. No time delay within 1 μs prescision could be detected along the magnetic field in these cases.

To illustrate the kind of information we want to gain from parallel correlation measurements, let us consider two pictures of the fluctuations:

Firstly, in a linear picture, we imagine a three-dimensionally localised perturbation of plasma quantities. This will propagate, with characteristic velocities, in the directions perpendicular and parallel to the magnetic field. If such “fluctuation events” occur distributed at random in space and time and are observed by two probe tips 1 and 2 on the same magnetic field line, some events will be seen first on probe tip 1 and later on probe tip 2, some will be observed simultaneously on both probe tips, and for some the order of observation will be reversed. Although the maximum in the cross correlation function between the signals from the two probe tips may be at 0 time delay, it will be reduced and broadened when compared to the maxima of the autocorrelation functions. The broadening corresponds to the difference in arrival times at the two probes between different fluctuation events. If, on the other hand, the events propagate in some preferred direction and at some preferred velocity along the magnetic field, the maximum of the cross correlation function would be shifted away from time delay 0.

In our second picture, we consider that an unperturbed plasma never exists, and the nonlinear dynamics of turbulence underlying the observed fluctuations may well favour perturbations already in phase along the magnetic field (these would be a type of flute modes). However, the fluctuation amplitude might vary along the magnetic field. Then the cross correlation maximum between two probe tips on the same magnetic field line is at 0 time delay and not broadened with respect to the autocorrelation functions, but it may be reduced due to the variation in amplitudes.

The results of parallel correlation measurements may therefore help to decide whether a two-dimensional model of the fluctuations in the plasma edge (probably including the effects of field lines intersecting the target plates) is sufficient, or if a simulation of the three-dimensional dynamics is required.

Furthermore, information on the parallel correlation of the fluctuations helps to decide whether a localised Langmuir probe measurement of the radial particle and energy flux due to correlated density/temperature and radial E×B velocity fluctuations can be extrapolated to the whole flux surface and thus compared with global confinement times [1].

2 Results from various toroidal confinement devices

As mentioned above, high correlation (80–90 %) for both I_{sat} as well as Φ_{fl} fluctuations was found in the edge and SOL plasmas of several tokamaks and stellarators for connection lengths up to 10 m along the magnetic field (for a list of references, see, e. g., [2]). The measurements typically are performed by leaving one probe tip fixed and varying the radial position r_p of the second probe tip and the safety factor q (or rotational transform ι) of the magnetic field (the latter corresponding to a poloidal variation of the probe position) in a two-dimensional scan. The scan in q is crucial to find the maximum correlation since, due to the finite poloidal correlation length of the fluctuations, some amount of correlation is even found if both probe tips are on neighbouring field lines. For the (r_p, q) combination with maximum correlation between the two probe tips, the time delay τ of the maximum is determined. Whether this maximum correlation is indeed achieved with both probe tips on the same magnetic field line, or rather at a finite, though small, parallel wavenumber $k_\parallel$ of the perturbation, can only be determined by a code following the magnetic field line from one probe tip to the poloidal plane of the second. The precision of this calculation is usually limited by the precision to which coil and plasma currents can be measured.

As the propagation velocity of perturbations parallel to the magnetic field is expected to be very large (Alfvén velocity), high parallel connection lengths must be used to decide on the sort of questions raised in section 1. Indeed, when correlation measurements with a connection length of 32 m between the two probe tips were done on W7-AS, a reduction of the correlation to 40 % was observed [3], in contrast to the case of connection lengths < 10 m. As this measurement had to be done on a field line inside the last closed magnetic surface (LCMS) passing from the torus outboard side via the inboard side (i. e., predominantly good magnetic curvature) back to the outboard side, it was not clear whether the reduction in the parallel correlation was due to the long connection length itself, due to the passage of the good curvature region, or was probably specific for a measurement in the confinement region for large connection lengths.

3 Experimental set-up on JET

The size of the world's largest tokamak makes it possible to achieve parallel connection lengths of 20–40 m over sections of purely favourable or unfavourable magnetic curvature in the SOL. Langmuir probes for fluctuation measurements are available fixed on the vertical target plates of the Mark II Gas Box divertor and in a reciprocating system on top of the machine. Between this system and probes on the outer/inner vertical target plates one can achieve connection lengths of 22–26/40–42 m for slightly different values of the safety factor q and located purely in the region of unfavourable/predominantly located in the region of favourable magnetic curvature. In addition, again for slightly different q value, one obtains connections between probes on the outer and inner target plates over 62–68 m along the magnetic field.

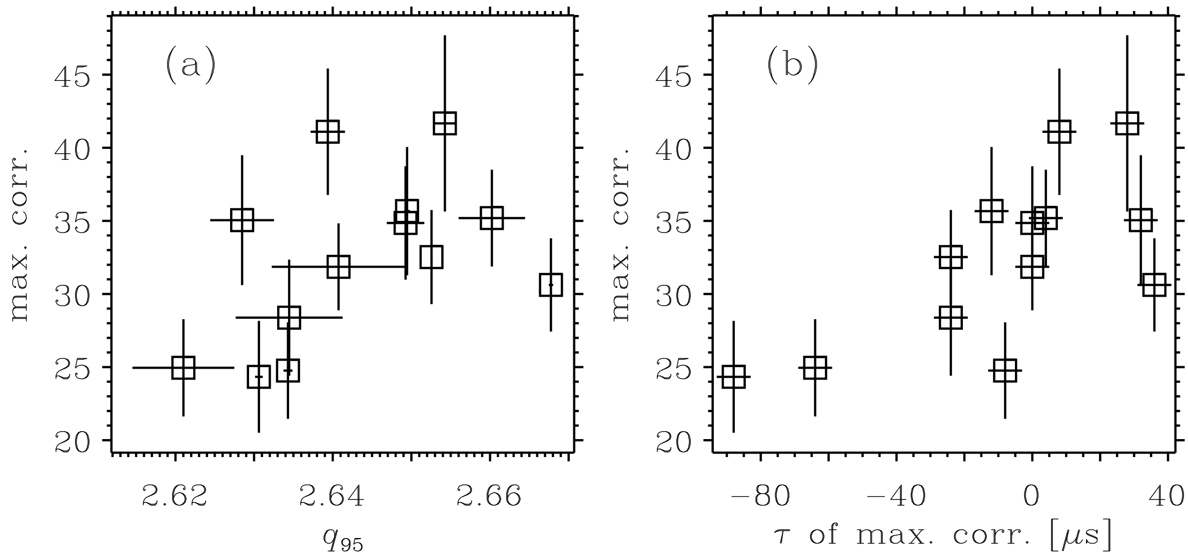
For technical reasons, all parallel correlation measurements on JET were done for I_{sat} fluctuations. Discharge conditions were $I_p \approx 2.4\,\mathrm{MA}$, $B_t \approx 2.0\,\mathrm{T}$ (with slight variations to obtain the required q scan), $\bar{n}_e \approx 1.7 \cdot 10^{19}\,\mathrm{m}^{-3}$, no additional heating.

As no large poloidal multi-tip array of Langmuir probes was available on JET and since a variation in q of 0.01 corresponds to a 1 cm poloidal shift at the position of the reciprocating probe system of a magnetic field line starting at an outer target plate probe, 1 cm being the typical poloidal correlation length of the JET SOL fluctuations, the task of finding parallel correlations was rather demanding.

4 Experimental results on JET

For correlations between the reciprocating probe and the outboard target plates we obtained a maximum of 42 % at $q_{95} \approx 2.65$ for a connection length of 22.6 m. The maximum correlation as a function of q is shown in fig. (a). In fig. (b) the time delay of the signal at the divertor probe with respect to the signal on top of the machine for maximum correlation is shown. Since the fluctuations propagate poloidally, such a time delay naturally occurs if q is varied. In contrast to the result on W7-AS, here the maximum correlation is found at a time delay of $\sim 20\,\mu$s.

So far, no dedicated scans of the q value have been made to find the maximum correlation between the reciprocating probe and the *inboard* target plate probe or between outer and inner target plate probes. According to the field line calculations, incidentally, the optimum q values for these connections are very close to the one required for the connection between reciprocating and outer target plate probe. Indeed, for $q_{95} \approx 2.53$ and a connection length of 65.8 m, a correlation of 37 % has been found between probes on the outer and inner target plates. Surprisingly, triple the connection length than between top and outer target plate probes and the passage along the region of favourable magnetic curvature seems not to further reduce the correlation significantly.



(a) Maximum correlation values found between a probe tip on top of JET and another tip on the outer vertical divertor target plate during radial reciprocations of the first probe for different values of q. (b) Time shifts of the correlation maxima. The maximum correlation is obtained at a time shift of $\sim 20\,\mu s$.

5 Conclusions

For the first time in a large tokamak, correlation measurements of I_{sat} fluctuations parallel to the magnetic field have been carried through on JET. The results show that parallel correlations in the SOL can be found for connection lengths of more than 60 m, however at a reduced level of 30–40 %. This level does not further reduce when the connection length is increased from 20 m to 60 m, suggesting the existence of a fluctuation component with large parallel correlation length in excess of 60 m rather than a steady decorrelation of all fluctuation components along the magnetic field. For the q value of maximum correlation, a time delay of $\sim 20\,\mu$s was found for the outer divertor probe signals with respect to the signals from the top of the machine.

The time delay and the reduced correlation indicate that a 2D modeling of the SOL turbulence is not appropriate for connection lengths beyond ~ 10 m. A comparison of the fluctuation behaviour with the predicitions of 3D turbulence codes for edge plasma parameters is planned in the near future.

In addition, the comparison of parallel correlation measurements for a variation of discharge conditions would be helpful for the understanding of the dominant effects in the parallel dynamics of fluctuations.

[1] M. Endler, submitted to Plasma Phys. Contr. Fusion (1999).

[2] M. Endler, J. Nucl. Mater. **258-263** (1999) 84.

[3] J. Bleuel et al., 24th EPS vol. 21A, part IV (1997) 1613.