3-dimensional investigations of quasi coherent structures

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Today's simulation of turbulence and its propagation in plasmas shows a complex 3-dimensional picture [1]. However, experimental evidence for turbulence is often observed by 1-dimensional diagnostics [2], only. Integration along lines of sight complicate the analysis further. In addition turbulence diagnostics have a limited sensitivity with respect to the wave number spectrum which allows to diagnose only a small window of the variety of micro structures in plasmas. Therefore a comparison of simulations and experiments is difficult. However, it is indispensable for simulations to have 3-dimensional information on turbulence and structures to compare with. The paper discusses the 3-dim analysis of quasi coherent modes visible on a major part of the plasma radius and especially on the $q = 1$ surface.

At TEXTOR a multi location reflectometry system [3] with good radial resolution was used to study short and long range correlations of density fluctuations in the range $k_\perp \leq 3\,\mathrm{cm}^{-1}$. The different locations of the antenna arrays yield information on the toroidal extent of structures in the plasma. Therefore the plasma conditions are chosen in such a manner that a field line connects both antennae arrays. In the case under investigation I_p is in counter clock wise direction and magnetic field in clock wise direction connecting the low field side (LFS) array with the top array. The toroidal separation is $\Delta\phi = 247.5^\circ$ and the poloidal separation $\Delta\theta$ is in the same range matching the $q = 1$ condition. To reach the $q = 1$ surface a low density high current ohmic plasma was used to extent the operation range of the reflectometer (26 GHz to 40 GHz) towards the plasma center. In all cases reported here, the reflectometer was operated in O-mode polarization to make sure that the reflection comes from the same iso density surface. With a second reflectometer the radial separation between top and LFS array as well as within the top array

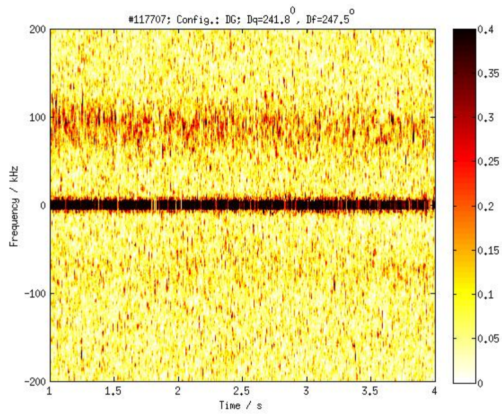

Figure 1: *Coherence for LRC during flat top conditions showing the enhanced coherence in the range* 80 kHz *to* 120 kHz

could be varied in addition. The multi antenna set up on the top and LFS allowed the measurement of short range correlation (SRC, $\Delta\phi = 0°$) and long range correlation (LRC, $\Delta\phi = 247.5°$) in the same discharge. It could be demonstrated by fig. 1 that the coherence (γ) for LRC along a magnetic field lines exceeds the background in a certain frequency range (50 kHz to 150 kHz), only. Low frequency turbulence or turbulence like structures are not correlated for a toroidal distance of more than 7.46 m. From this observation the existence of at least two different types of turbulence is confirmed. The disappearance of correlation for the negative frequency branch in fig. 1 suggests a fast toroidal rotation. Assuming an exponential decay a parallel correlation length at $1/e$ level of $L_{\|} \leq 3.5$ m is deduced.

The delay time (Δt) between an arbitrary antenna combination yields information on the propagation perpendicular to the magnetic field. In fig. 2 Δt is shown as function of $\Delta\theta$. The combinations from the SRC as well as the combinations from LRC are shown, the latter one after subtraction of the poloidal separation due to the $q = 1$ surface. Both data sets are partly overlapping. The slope of the SRC dataset yields a $\Omega_{\perp} = 11.5\,\mathrm{krad\,s^{-1}}$ and $\Omega_{\perp} = 12.4\,\mathrm{krad\,s^{-1}}$ for LRC, demonstrating that for the LRC combination $\Omega_{\perp}$ is measured, only.

To deduce a possible radial propagation of the structure radial correlations within the top array are calculated. Since a pure radial correlation is not possible a combination between radial and poloidal correlation is measured. The arrangement of the top array with respect to the plasma as well as the Shafranov shift results in a change of $\Delta\theta$ with Δr. In addition the correction for the pitch angle is taken into account. However, the measured Δt is not exceeding the expected value from a poloidal propagation and a radial propagation of the structure can be excluded. In fig. 2 those combinations with additional Δr (BC, DC and EC) are shown.

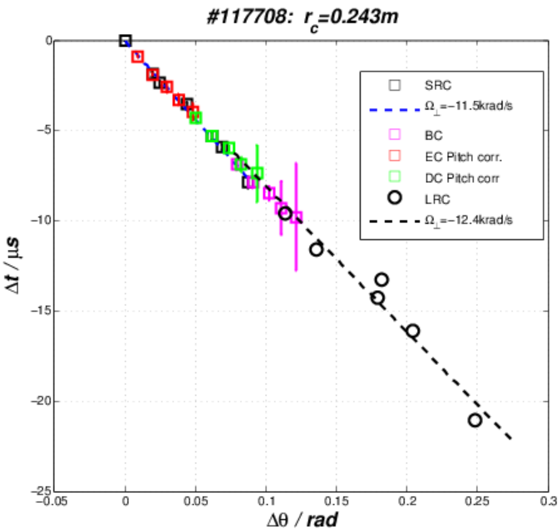

Figure 2: *Δt-values for SRC, LRC and radial correlations for different combinations of the top array, showing no radial propagation. Both SRC and LRC yield similar $\Omega_{\perp}$*

More information of the structure comes from the measurement of the cross correlation level as function of $\Delta\theta$. The full width at $1/e$-level yields the de-correlation time (τ_{dc}) which is measured to $\tau_{dc} = 17\,\mu$s. From the width of the auto correlation function (ACF) of a single antenna multiplied with $v_{\perp}$ the structure size can be calculated. The ACF filtered in the range 50 kHz to 150 kHz shows a stationary random process sitting on a Lorentzian background of broad band turbulence (see fig. 3). The envelope of the ACF is a decaying function which limits the number of oscillations of the ACF. The oscillation itself changes its period with increasing time from its origin. The whole process is similar to a damped oscillator, characterized by decay time and period of the oscillation. The oscillating part shows a coherent structure for 2 oscillations, wherefore this structure is called quasi coherent. It is difficult to calculate a perpendicular wavelength ($\lambda_\perp$). Per definition the ACF yields $\gamma > 0$ and therefore two successive peaks belong to a full oscillation of the quasi coherent mode. For the estimation of $\lambda_\perp$ only the odd maxima beginning with the central are used. Taking the full width at $1/e$ level as a measure, the structure size is calculated to $\lambda_\perp \approx 51\,\text{mm}$. This results in a mode number of $2\pi \cdot r_c/\lambda_\perp = 30$. The oscillations become visible in the Δt estimation in a way that above a certain poloidal separation two Δt-values show up in the cross correlation just one half period apart from each other.

Beside the SRC also the LRC are performed for different Δr. Using cross correlation the Δt values are calculated each milli second. Binning the measured Δt-values during the flat top in bins, each with a width of $1\,\mu\text{s}$, a probability distribution (PD) is obtained (see fig. 4), showing 4 different peaks, clearly. The time difference between the peaks corresponds to the oscillation frequency in the ACF. Approaching Δt for all combinations and same peak yields four straight lines where each slope is a measure of $\Omega_\perp$.

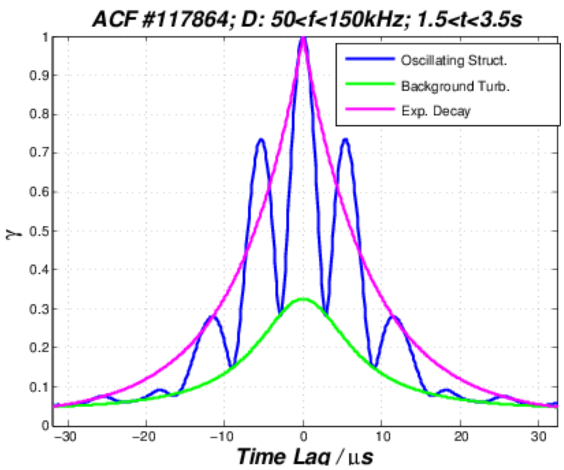

Figure 3: *ACF showing background turbulence and oscillating structure. The structure size is estimated from the exp. decay of the structure*

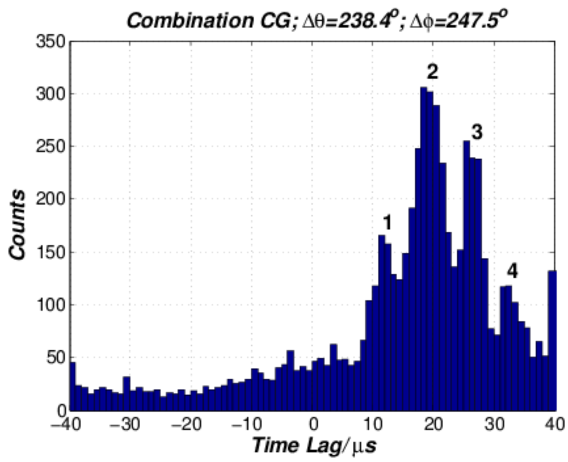

Figure 4: *PDF of Δt-values from #117870 for the combination with* $\Delta\theta = 238.4°, \Delta\phi = 247.5°$. *Radial separation of* $\Delta r = 15\,\text{mm}$

As known from SRC no radial propagation of the QC-modes is found. However, a radial inclination in toroidal direction cannot be excluded. The radial correlation length from SRC is quite small. In case of LRC a significant γ is found for a wide radial range (see fig. 5). For different

Δr, $\gamma(f)$ changes in amplitude and position of the maximum (f_c). With increasing Δr, f_c decreases at a rate of $\approx 1\,\mathrm{kHz\,mm^{-1}}$. As a consequence $k_\perp = 2\pi f_c / v_\perp$ decreases for structures with lower frequency (larger size) due to a larger inclination. The toroidal separation acts as a filter for the dominant frequency f_c. In addition the radial extension of the QC-mode increases. Even for $\Delta r = 36\,\mathrm{mm}$ a significant γ is observed. The maximum in γ is shifted 15 mm outward, which means that the quasi coherent mode propagates not on iso density surfaces. The envelope of all $\gamma(\Delta r)$ shown in fig. 5 fits also with the range of the QC-mode observed in the γ-spectra of different antenna combinations. Regarding the poloidal propagation, the inclination and helicity causes structures from $\Delta r \approx 40\,\mathrm{mm}$ to contribute to $\Omega_\perp$.

Concluding the observations, it has been demonstrated that the LRC along a magnetic field line can be accessed by correlation reflectometry. An upper estimate of the correlation length of $L_\| \leq 3.5\,\mathrm{m}$ has been calculated which is in the case of TEXTOR less than one toroidal turns at the $q = 1$ surface. The correlation is found only for structures 50 kHz to 150 kHz and demonstrates that other structures do not follow magnetic field lines or have shorter $L_\|$. The calculated $v_\perp$ for SRC and LRC conditions yield similar values which demonstrates the robustness of the method in case of given long living structures. The restriction on a certain frequency range implies that $v_\perp$ does not necessarily correspond to the bulk plasma. No hint for radial propagation is found when all geometrical corrections are applied. However, an inclination is observed. The toroidal separation acts as a filter for the mode frequency. High frequency structures are less inclined than those at low frequency.

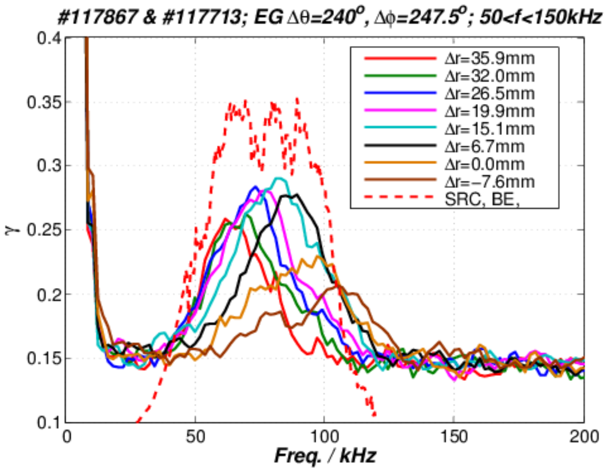

Figure 5: *γ-spectra for LRC ($\Delta\theta = 240.0°, \Delta\phi = 247.5°$) and different radial separation; γ_{max} is shifted outward by* $\approx 20\,\mathrm{mm}$

For the LRC along a field line the plasma current is essential. The fact that the LRC is not bounded to an iso density surface seems to support an outward directed inclination of the QC-modes. Due to the finite lifetime and in connection with the plasma current, one could think of short living current filaments. However, this hypothesis has to be proved in future experiments.

References

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