

## **The degradation of impurity confinement during ECRH and radial correlation measurements of small-scale density fluctuations in T-10.**

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### **Introduction.**

The work continues the investigations of small-scale turbulence properties and anomalous plasma transport associated with it. The degradation of confinement in “L” mode discharge under ECR heating was investigated by means of diffusion of injected potassium and argon impurities. The radial correlation properties of density fluctuations were obtained with the heterodyne reflectometry.

### **The degradation of impurities confinement in “L” mode discharge under ECR heating.**

The investigation of multicharged impurities diffusion was carried out by means of observation of spatial and time evolution of He-like lines intensities of injected potassium and argon with soft X-ray monochromator RM-2<sup>1</sup>. Two different experiments were performed.

In the first case the behavior of non-recycling impurity was investigated. The pellet of KCl was injected in discharge in Improved Ohmic Confinement (IOC) mode. After the impurity accumulation in the center of the plasma column,  $K^{+17}$  concentration begins slowly to decay. At that stage the central ECRH was switched on. The time dependencies of concentration of He-like  $K^{+17}$  ion at different radii shown in Fig.1. One can see that the increase of the decay under ECRH occurs in two phases. The first one begins immediately after the ECRH start with the characteristic decay time of 25 ms. The corresponding decay time in IOC mode is about 60 ms. This phase may correspond to the decreasing of the pinch velocity due to the lowering of the longitudinal electric field with the increase of electron temperature. The second phase begins at 17 ms of ECRH. The characteristic decay time during this phase is about 6 ms. This fast phase of decay associates with increased diffusion coefficients and it coincides with the increase of the recycling at the limiter. The experiment clearly shows that the degradation of impurity confinement occurs with definite time delay after ECRH start and may coincide with the increase of the particles fluxes at the periphery. Similar result was observed as “delayed confinement degradation” in ASDEX and in T-10<sup>2, 3</sup>.

The another experiment uses an Ar as a 100%-recycling impurity. The experiments include the injection of Ar in discharge during the stationary stage of central ECR heating. The time oscillograms of some plasma parameters in this discharge are shown in Fig.2. Argon concentration in the center reaches the stationary level after injection. As the ECRH switched off, despite of electron temperature decrease (fig. 2b), the intensity of  $Ar^{+16}$  line reaches the same value as during ECRH (fig 2c). The average electron density also slightly increase after ECRH (fig. 2a), but not sufficient to provide such light intensity rise. So the only mechanism to explain this behavior of Ar is the impurity accumulation in IOC mode, which induced by decreasing of periphery fluxes after the ECRH switches off.

The time dependencies of  $Ar^{+16}$  concentrations at different radii are shown in Fig.3. After the injection the concentration of Ar in center of plasma column rapidly reaches stationary value. The estimated diffusion coefficient of Ar for this phase of discharge is about

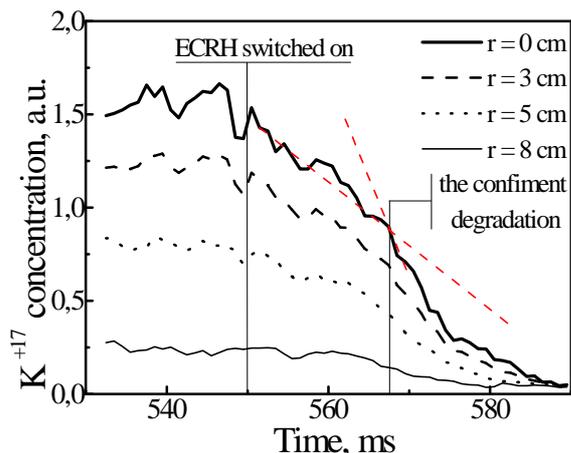


Figure 1. Time evolution of  $K^{+17}$  ion concentration at different radii.

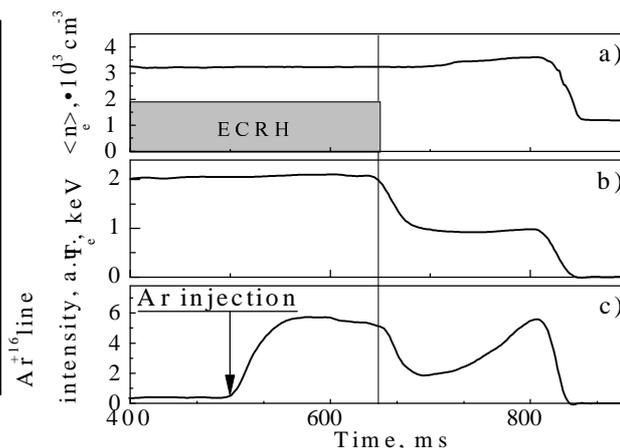


Figure 2. Time traces of average electron density (a), central electron temperature (b) and central  $Ar^{+16}$  line intensity (c) in pulse # 61750.

5500  $\text{cm}^2/\text{s}$ . From Fig.3 one can also see that the concentrations of Ar in the center of plasma column is flat.

After ECRH switches off Ar accumulates and its concentration in the center increases more than in 10 time in correspondence with ECRH phase of discharge. Unfortunately the argon concentration at plasma periphery is not measured, which makes difficult to reconstruct the whole radial profile of argon. The estimation of such profile was done taking into account the facts that as Ar is 100%-recycling impurity, the total number of Ar particle remains the same during all discharge and in IOC mode the main part of argon inventory is accumulated in the plasma center. The reconstructed under this assumption Ar profile during ECRH is shown in Fig.4. The points show the experimental values and the lines – approximation. As one can see, the stationary Ar profile during ECRH is hollow. So it is possible to conclude that “L” mode with ECRH causes not only the degradation of impurity confinement but leads even to the preferential impurity expulsion from the center.

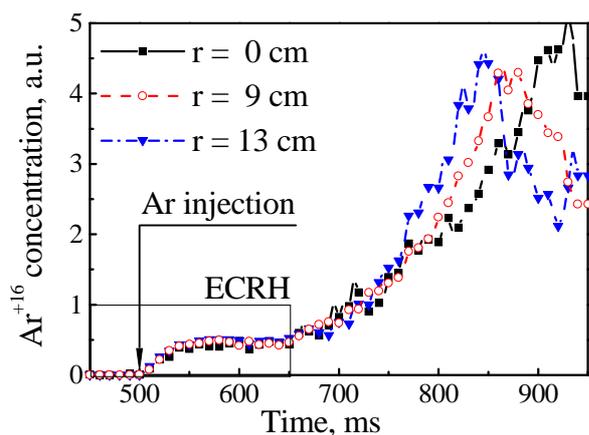


Figure 3. The time evolution of  $Ar^{+16}$  concentration at different radii in pulse # 61750.

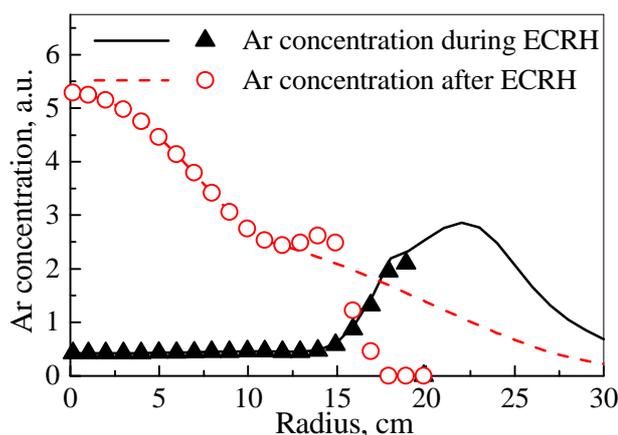


Figure 4. The Ar radial profile during ECRH and in IOC mode. Points – experimental values, lines – reconstruction

## The radial correlation's measurements.

The main goal of the turbulence investigations in T-10 tokamak was to establish the relationship between energy and particle transport and small-scale fluctuation properties<sup>4</sup>. A number of theoretical works, devoted to particle transport, predict the presence of long-scale radial correlations<sup>5, 6</sup>. New experiments were carried out to observe the radial correlation lengths.

Two independent O-mode heterodyne reflectometer systems were used. One of them operates at a fixed frequency (FF) 54.9 GHz which correspond to reflection radius 13 cm. The second reflectometer with varied frequency (VF) from 39.4 to 54,9 GHz (from 13 to 20 cm). It gives the possibility to observe density fluctuations at two radial positions simultaneously in one shot. The amplitude and phase fluctuations of the reflected signals of both reflectometers were recorded. The frequency of second reflectometer changed from shot to shot in a series of reproducible discharges. Thus the radial dependencies of coherence and cross-phase between two signals from different reflecting radii were obtained.

Fig. 5 demonstrates the amplitude, cross-phase and coherency spectra at two different radii. The Fig. 5a) presents the Fourier spectra of VF system signals at radial position 13 cm (dashed line) and 17.7 cm (solid line). The quasi-coherent fluctuations exist at both radii as a peaks in Fourier spectra in the frequency range  $100 \pm 200$  kHz<sup>7, 8</sup>. Fig. 5b) shows the comparison of the cross-phase between signal of VF and FF system at zero separation (dashed line) and at 4.7 cm (solid line). The uniform slope at all frequencies is clearly seen for the case of zero separation. (The slight slope of the cross-phase may be explained by the systematic time delay in waveguides and cables.) In difference the appearance of the negative slope is observed for the case of 4.7 cm separation of reflection layers. The slope occurs only in the frequency range of the quasi-coherent fluctuations and corresponds to time delay  $1.6 \mu\text{s}$ . Coherency spectra for these two cases plotted on Fig. 5c). Owing to the final radial correlation length, quasi-coherent fluctuations coherency decrease in  $\sim 10$  times at the  $\Delta r = 4.7$  cm with respect to  $\Delta r = 0$  cm.

The dependence of time delay from radial separation of reflection layers shown in Fig. 6. The open circles correspond to phase fluctuation and the solid triangular – to amplitude fluctuation of reflected signals. This delay can be associated with real delay of fluctuations

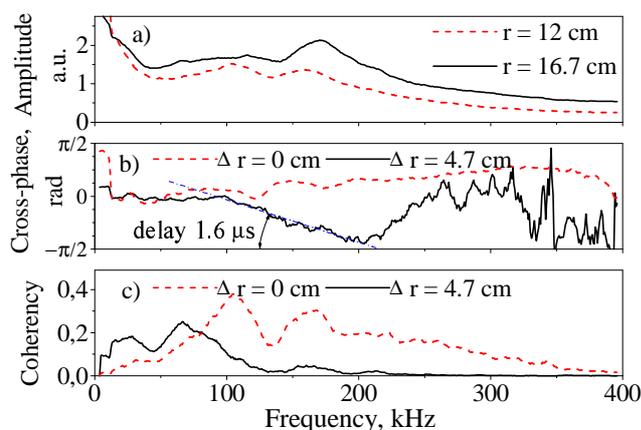


Figure 5. Amplitude, cross-phase and coherency spectra of the fluctuations of reflected signal amplitude.

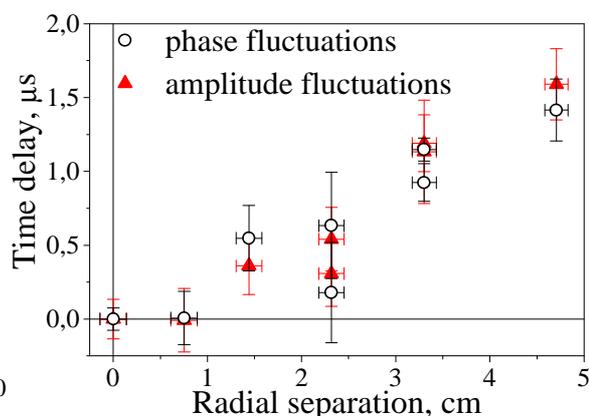


Figure 6. The dependence of time delay from the radial separation between reflection layers.

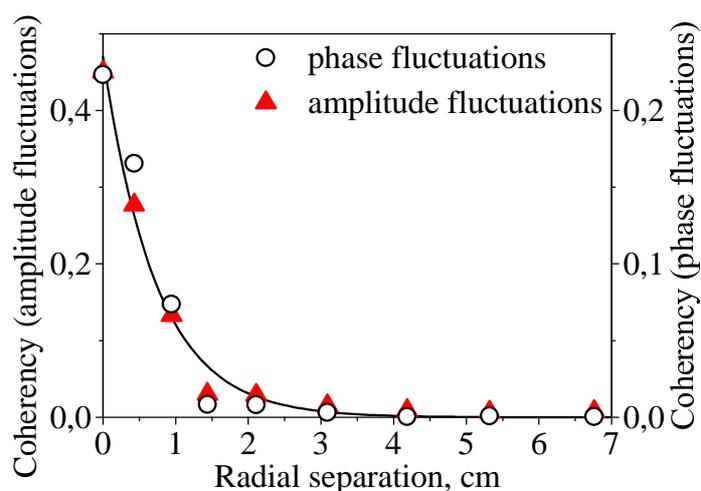


Figure 7. The dependence of coherency from the radial separation between reflection layers for quasi-coherent fluctuations.

fluctuations has a longer correlations length, that the quasi-coherent ones. This fact may take place due to different turbulence mechanism or non-locality of reflectometer measurements and needed additional investigations. Fortunately for the quasi-coherent fluctuations the locality of reflectometry is not so crucial because their frequencies and amplitudes are strongly depend on radius. Thus it was possible to eliminate the non-local properties of reflectometry by means of proper choosing the frequency range for taking the coherency data. Moreover it was possible to estimate that the non-local effect is small for the case of quasi-coherent fluctuations.

### Acknowledgements.

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due to their propagation as it was suggested in experiments with EC correlation measurements in W7-AS<sup>9</sup>. The delay also may be considered as an effect of rotation of helical “finger” structure of perturbations, obtained in 3D gyrokinetic simulations<sup>10</sup>.

The Fig. 7 represents the dependence of coherency of phase (open circles) and amplitude (solid triangular) of quasi-coherent fluctuations from the distance between the reflection layers. The obtained radial correlation length  $\lambda = 0.7$  cm. The interesting fact is that the amplitude of low frequency (20÷80 GHz)