SPACE-TIME DYNAMICS OF LOW FREQUENCY PLASMA DENSITY FLUCTUATIONS IN URAGAN-3M TORSATRON

V.L. Berezhniy, A.I. Skibenko, O.S. Pavlichenko, E.D. Volkov, V.L. Ocheretenko, I.B. Pinos, S.A. Tsybenko

Institute of Plasma Physics of National Science Centre "Kharkov Institute of Physics and Technology", 61108 Kharkov, Ukraine

Experimentally investigated the space-time dynamics of low-frequency plasma density fluctuations for two regimes of discharges in torsatron U-3M and with laser-ablation-injection of carbon.

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Fluctuations of electron density, $\tilde{n}_e$, as well as fluctuations of other plasma parameters play an important role in the energy balance, particles and heat transport, and confinement of thermonuclear plasma. Fluctuations are result of excitation in plasma of different instabilities and under some conditions can lead to plasma turbulence. The discovery of regimes with improved plasma confinement in tokamaks and stellarators strongly stimulated investigations of plasma density fluctuations. In majority of experiments for this purpose the method of ultra-high frequency (UHF) reflectometry is used, and usually the level of fluctuations $\tilde{n}_e$ is found from measurement of phase of reflected UHF signal. The most optimal way to measure the phase is the usage of the heterodyne reflectometer and a phase detector. In experiments on U-3M, like much more frequently in many other experiments, a simpler scheme of homodyne reflectometer is used [1]. In this scheme there are some limitations on phase measurements [2-5]. One of such limitations is so called "phase runaway" [5], which manifests itself as increase or decrease of the phase in strongly turbulent regimes of discharges.

To exclude of this effect, sometimes the signal of reflectometer is filtrated at low frequencies (0÷10) kHz where the effect manifests itself more often than in other frequency ranges [6]. However, in many tokamaks [2] and stellarator-type devices [7,8] just this low-frequency (LF) interval is characterized by the maximal level of fluctuations which goes down with frequency increase. Similar rise of $\tilde{n}_e$ in the range (0÷10) kHz was also observed on U-3M in discharge with laser injection of carbon [9] and on the TJ-II stellarator when N_2 was puffed into plasma and also in the discharges with partial disruption [8]. From these two examples, LF fluctuations contribute significantly in the whole level of fluctuations, and this LF portion increases with inflow of impurities into the confined plasma. That is why on the U-3M device we made an attempt to evaluate the relative LF level of fluctuations $\tilde{n}_e$ by use of their amplitudes [2,10], which were found from power spectral density of reflectometer signal.

For investigation of plasma density fluctuations, $\tilde{n}_e$, the 4-channel reflectometer [9] was used. All antennas were disposed in the same poloidal plane (Fig. 3), and measurements were provided in two regimes: with average plasma density $\bar{n}_e = 1.3\cdot10^{13}$ cm^{-3} and $\bar{n}_e = 2\cdot10^{12}$ cm^{-3}. One frame antenna was used for RF production and heating of plasma in the frequency range $\omega = \omega_{ci}$ (P_{RF} = 200 kW, f = 8.8 MHz) with magnetic field strength B_0 = 0.7 T. For both regimes the decrease of $\tilde{n}_e$ was observed with increasing frequency of fluctuations in the range 0÷60 kHz as is shown in Fig. 1a and Fig. 6a. We suppose that the amplitudes of fluctuations is proportional to level $\tilde{n}_e$ [10] and besides, everywhere the level of fluctuations is normalized to its maximum value measured by the outer channel 3. By simultaneous probing at fixed frequency with all channels, the dynamics of $\tilde{n}_e$ in the course of discharge was obtained (Fig. 2, solid lines). The asymmetry of $\tilde{n}_e$ level was found out along the poloidal direction (Fig. 3, lower of two meanings in the legend): at the outer side it was ~ 2 times higher than inside, and at the upper half-plane it was ~ 50 % above the value measured in the lower half-plane. The $\tilde{n}_e$ level rises from plasma center to periphery in both regimes with $\bar{n}_e$= $1.3\cdot10^{13}$ cm^{-3} (Fig. 4, open points) and $\bar{n}_e$= $2\cdot10^{12}$ cm^{-3} (Fig. 8, open points).

When carbon impurity was injected into the plasma by laser ablation [9], the amplitude of lower frequency range fluctuations, f ≤ 20 kHz, raised, but at the same time the amplitude of higher frequency range fluctuations, f ≥ 20 kHz, dropped (Figs. 1b and 6b). Just in the time of carbon injection the $\tilde{n}_e$ level started to rise (Figs. 2 and 7). Especially significantly the $\tilde{n}_e$ level increased in the narrow range 7÷12 kHz but with that the fluctuations became weakly correlated in radial direction (γ<0.4), Fig. 5. The poloidal asymmetry of $\tilde{n}_e$ does not change the character found without carbon injection (Fig. 3, upper of two meanings in the legend), though the tendency observed for radial dependence was changed, i.e., $\tilde{n}_e$ started to decrease with minor radius (Figs. 4 and 8).

The low plasma density regime ($\bar{n}_e$= $2\cdot10^{12}$ cm^{-3}) is characterized by the fast drop of T_e just after finishing the RF power and by gradual, during ~ 1.5 ms, rise of n_e [9]. The reason for plasma density rise is ionization of gas (H_2) from the large vacuum vessel. The stage of n_e rise is followed by an exponential decay of the cold plasma density. If the number of injected carbon atoms is less than 10^{16}, the rise of n_e after switching off the RF generator is due to inflow of gas from the vacuum vessel. However, if the total number of injected carbon atoms exceeds ~$2\cdot10^{16}$, the n_e rises just after C injection but after termination of the RF power n_e almost does not increase.

After RF pulse termination, the level of $\tilde{n}_e$ was doubled from the level at the quasistationary stage of discharge, and was factor ~ 1.5 higher than under carbon injection in the range of frequency range 7÷12 kHz however the radial dependence of fluctuations stopped to be observed (Fig. 9). The level of $\tilde{n}_e$ in the range of 20÷60 kHz decreases similar to discharges with carbon injection.

The fluctuation amplitudes in the divertor plasma flow (as was measured by the UHF open resonator [11]) and everywhere in the periphery plasma with $n_e \approx 10^{11}$ cm^{-3} was found the same in the frequency range 10÷20 kHz. The coherence of fluctuations at these frequencies was in the range $0.47 \le \gamma \le 0.52$ (Fig. 10).

Summarizing, we found that:

1. The level of plasma density fluctuations, $\tilde{n}_e$, grows from the plasma center to plasma periphery. This is in agreement with results obtained earlier [12] for $\tilde{n}_e$ radial profile by measuring the change of phase of reflected reflectometer signals.
2. The amplitude of fluctuations decreases with increasing their frequency.
3. The asymmetry of $\tilde{n}_e$ in poloidal direction, relatively the central plane, and between outer and inner parts of plasma was observed.
4. The laser injection of carbon atoms did not cause a reduction of $\tilde{n}_e$ in the whole spectrum of fluctuations, in contrast to what observed in experiments on DIII-D when Ne was puffed [13]. In our experiments with C injection into plasma of U-3M torsatron, the level of $\tilde{n}_e$ decays faster with increasing frequency of fluctuations in comparison to the case without C injection. Just after injection of C atoms a noticeable growth of $\tilde{n}_e$ in the frequency range 7÷12 kHz was registered following by their radial decorrelation, ($\gamma < 0.4$ and the tendency appeared to changing the direction of $\tilde{n}_e$ level rise from plasma periphery to the center. The poloidal asymmetry of $\tilde{n}_e$ remained in discharges with carbon injection.

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ПРОСТРАНСТВЕННО-ВРЕМЕННАЯ ДИНАМИКА НИЗКО-ЧАСТОТНЫХ ФЛУКТУАЦИЙ ПЛОТНОСТИ ПЛАЗМЫ В ТОРСАТРОНЕ УРАГАН-3М

В.Л. Бережный, А.И. Скибенко, О.С. Павличенко, Е.Д. Волков, В.Л. Очеретенко, И.Б. Пинос, С.А. Цыбенко

Экспериментально исследована пространственно-временная динамика низко-частотных флуктуаций плотности электронов в двух режимах разрядов и с лазерной инжекцией примеси углерода в торсатроне У-3М.

ПРОСТОРОВО-ЧАСОВА ДИНАМІКА НИЗЬКО-ЧАСТОТНИХ ФЛЮКТУАЦІЙ ГУСТИНИ ПЛАЗМИ В ТОРСАТРОНІ УРАГАН-3М

В.Л. Бережний, А.І. Скибенко, О.С. Павличенко, Є.Д. Волков, В.Л. Очеретенко, І.Б. Пінос, С.А. Цибенко

Експериментально досліджена просторово-часова динаміка низько-частотних флуктуацій густини електронів у двох режимах розрядів та з лазерною інжекцією домішок вуглецю в торсатроні У-3М.

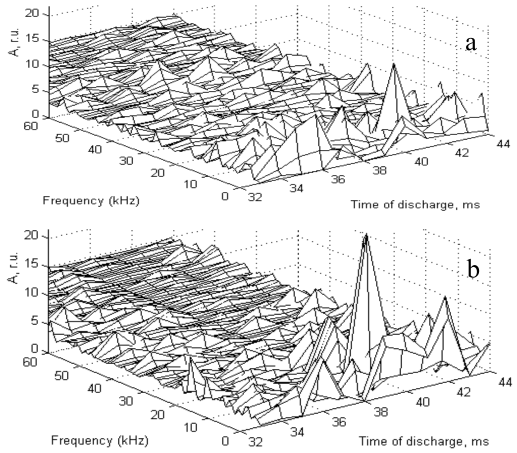

Fig.1. Density fluctuation spectra $\tilde{n}_e$:
a – without, b – with C injection; $\bar{n}_e = 1.3 \cdot 10^{13}$ cm^{-3}

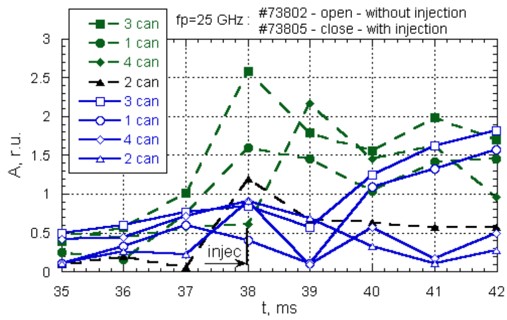

Fig.2. Time evolution of the $\tilde{n}_e$ level

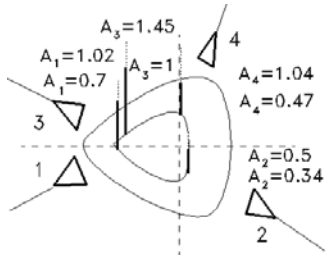

Fig.3. Poloidal structure of the $\tilde{n}_e$ level

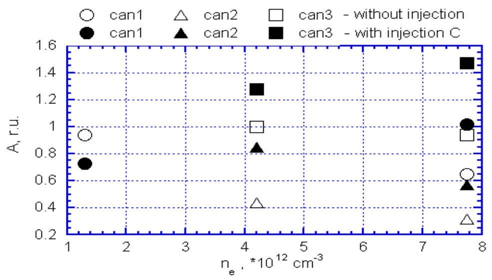

Fig.4. Amplitudes of $\tilde{n}_e$ for 3 radial cut-off layers

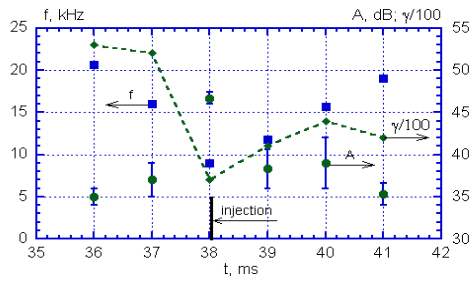

Fig.5. For discharges with C injection: frequency of fluctuations, $\tilde{n}_e$, with maximal amplitudes, their amplitude and coherency

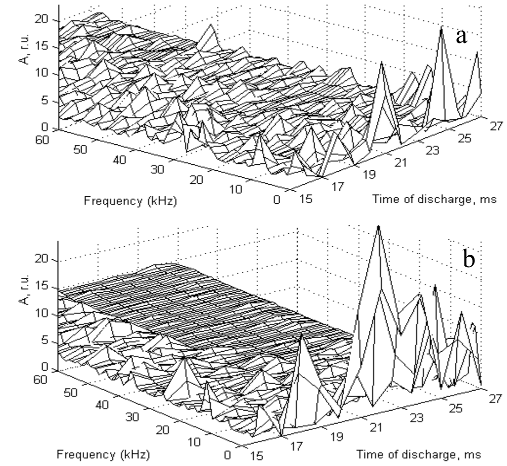

Fig.6. Density fluctuation spectra $\tilde{n}_e$:
a – without, b – with C injection; $\bar{n}_e = 2 \cdot 10^{12}$ cm^{-3}

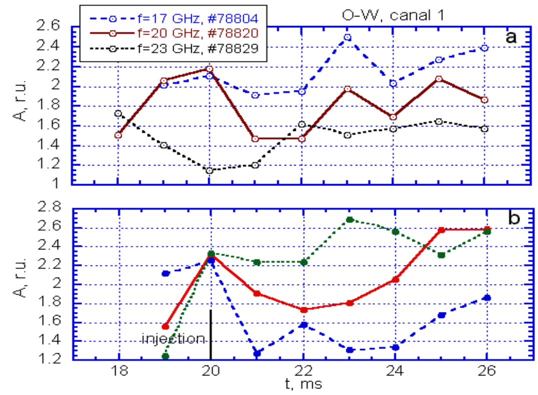

Fig.7. Time evolution of the $\tilde{n}_e$ level:
a – without, b – with injection of $2 \cdot 10^{16}$ C atoms

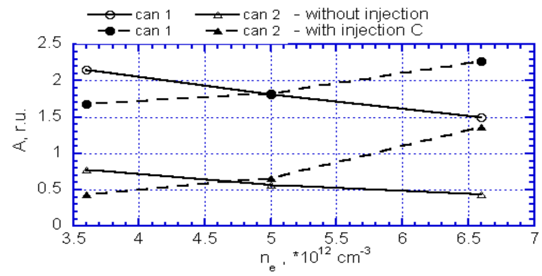

Fig.8. Amplitudes of $\tilde{n}_e$ for three radially separated cut-off layers

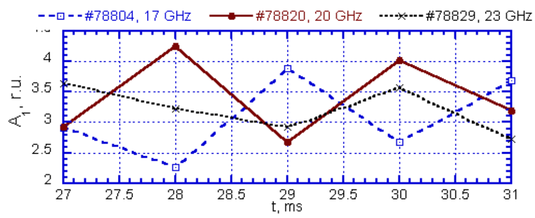

Fig.9. The $\tilde{n}_e$ level after switching off RF power

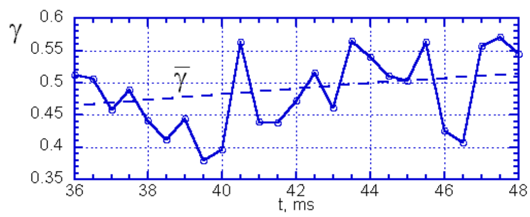

Fig.10. The coherency between fluctuations of the confined periphery and divertor plasmas