The Study of Correlation Properties of Geodesic Acoustic Modes in the T-10 Tokamak

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Abstract. Geodesic acoustic mode (GAM) of electrostatic and density fluctuations are simultaneously measured by Heavy Ion Beam Probe and Correlation Reflectometry. The local values of electric potential and density fluctuations demonstrate the significant coherency and constant phase shift at GAM frequency range. The existence of the long-distance (one quarter of the torus) correlations of electric potential and density for GAM implying that GAM is a global mode, was shown for the first time in tokamaks.

1. Introduction

It is believed the transport processes in the toroidal plasmas are dominated by the turbulence. The studies of the turbulent transport processes and the phenomena of the turbulence self-regulations like Zonal Flows (ZF) and Geodesic Acoustic Modes (GAMs) are of crucial importance to understand the physical picture of anomalous transport. It has been recently observed experimentally the correlation between GAM and high frequency turbulence, unless the level of the modulation was not found to be high [1-3]. The correlation properties of GAMs is an important issue in the transport and turbulence studies. The first characterization of the ZF in toroidal plasma was done with such approach and dual HIBP in CHS [4].

The paper is dedicated to the first result of the correlation measurements of the GAM oscillations made by different diagnostics. It reports the characterization of the GAMs on T-10, the correlation between the local values of potential and density, and the long-distance potential/density correlation.

2. Experimental set-up

Geodesic acoustic modes (GAM) were investigated in the T-10 tokamak using Heavy Ion Beam Probe (HIBP), Multipin Langmuir Probe (MLP) and Correlation Reflectometry (CR) diagnostics [5]. Regimes with Ohmic heating and with on- and off-axis ECR heating were studied (B = 2.2–2.5 T, I_p = 180-330 kA, n_e = 1.3 – 2.5 × 10^{19} m^{-3}). HIBP observed upper quadrant of the plasma column cross-section at the Low Field side. One CR antenna was located at the High Field Side of the same cross section as HIBP, another one has a toroidal shift of one quarter of the torus at the Low Field Side. Multipin movable and fixed limiter Langmuir probes were located at the CR diagnostic cross-section. This layout was oriented to the future study of the toroidal and poloidal mode structure of the GAM.

3.Experimental results

HIBP is a powerful diagnostics to study GAMs [4-6]. It is able to get simultaneously the oscillatory components for plasma electric potential and density by total secondary beam current, I_{tot}, if the beam attenuation does not affect the signal (path integral effect). This is the case of low density, which was studied here. It was shown the GAMs are more pronounced in the plasma potential rather than in density, fig. 1.

Figure 1(b) shows the potential and density power spectra, obtained by HIBP at the same time. It is clearly seen that GAM peak is dominant in the potential spectra while MHD m=2 peak dominates the density spectra. It was shown that GAM might have a complex structure, not similar to conventional periodical oscillations with a single frequency. GAM has an intermittent character presenting the stochastic sequence of the wave packages. For the observed T-10 conditions the “lifetime” of the package lies in a range of 0.5 -2 ms. So, the most direct tool to study the GAM properties looks to be the wavelet analysis, see Fig. 2(a).

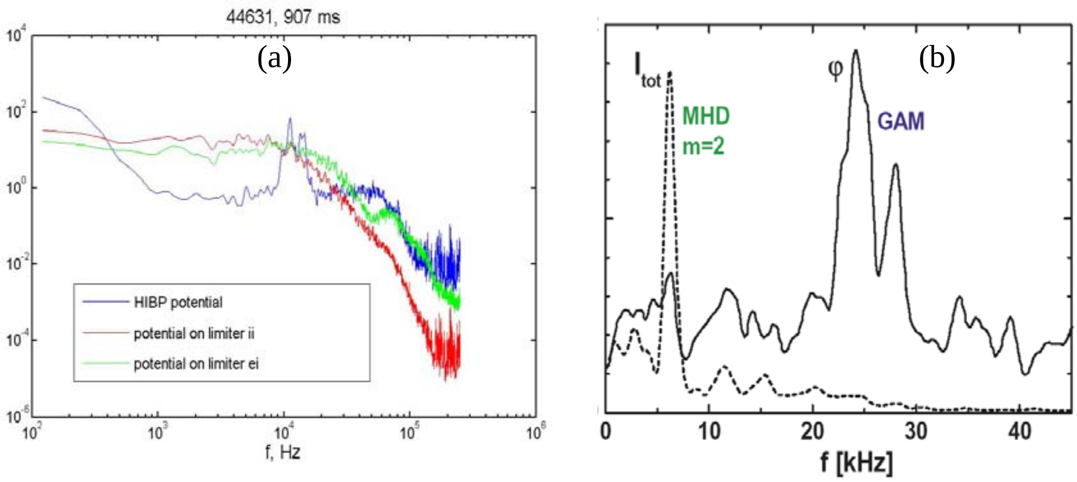

FIG. 1. (a) Potential power spectra in HIBP at ρ=0.8 (blue curve) and MLP at the limiter, at ρ=1 (red curve- ion side, blue curve- electron side). Clear double peak in blue curve at 20 kHz characterizes GAM, while no pronounced GAM peak in MPL spectra. (b) Potential and I_{tot} or n_e spectra by HIBP. GAM oscillations are more pronounced on the potential than on the density. In contrast, the amplitude of 7 kHz MHD m=2 oscillations is larger on the density and much smaller on the potential.

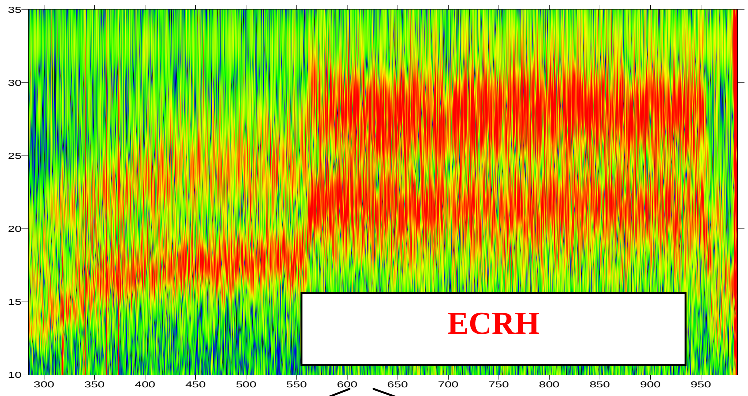

FIG. 2. (a) Wavelet spectrogram for HIBP potential.

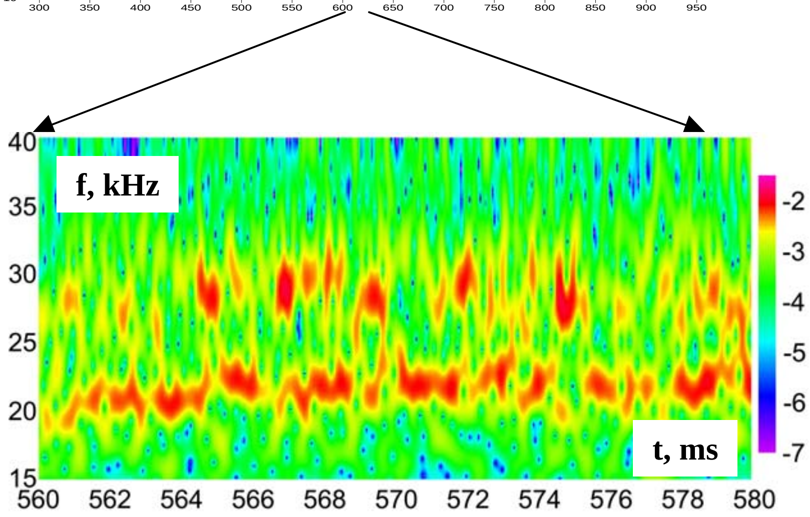

FIG.2(b) Example of the GAM intermittent behaviour for ECR heated plasma.

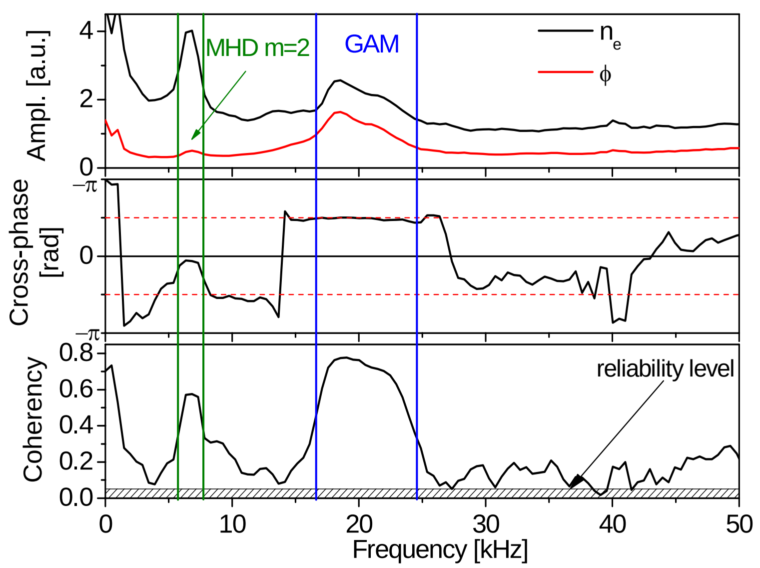

FIG.2(c) Local potential-density correlation. HIBP shows that high correlation at the GAM frequency interval and the permanent cross-phase. Note that for 7 kHz MHD m=2 oscillations the cross-phase differs from that of GAM.

Compare to OH, GAMs are more pronounced in ECRH plasmas, where the typical frequencies of the wave packages are observed in a narrow interval from 22-27 kHz at the outer one third of the plasma minor radius, Fig. 2,a,b.

Fourier correlation analysis with long time sampling (> 200 ms) shows clear correlation between local values of potential and density simultaneously measured by HIBP at the sample volume. The phase shift is found to be *π/2* for GAMs in the presented example. In contrast, for MHD *m*=2 peak, the phase shift is zero, Fig. 2(c).

Fourier correlation analysis with short time sampling (10 ms) shows the constant frequency and a bursty character of the correlation between HIBP potential and density at the GAM frequency, see Fig. 3.

The cross-phase between potential and density presents stochastic behaviour in general. But for quasicoherent modes like MHD m=2 and GAM cross-phase is more systematic, see Fig. 4. To make the figure more clear and free from stochastic component, the only phase with coherency exceeding some limit is presented with It's color. For the low coherency cross-phase was marked as zero (green color in the Fig. 4). To analyze the cross-phase for GAM, the histogram was made for the values, exceeding the threshold frequency. The result is shown in Fig 5. This method gives the same value as the long time sampling, compare to Fig. 2(b).

Fourier correlation analysis with long time sampling (>200 ms) reliably shows a clear correlation between HIBP potential and CR density at the GAM oscillations frequency, see Fig 6. The phase shift is a topic for further more accurate analysis. This observation suggests a global character of the GAMs.

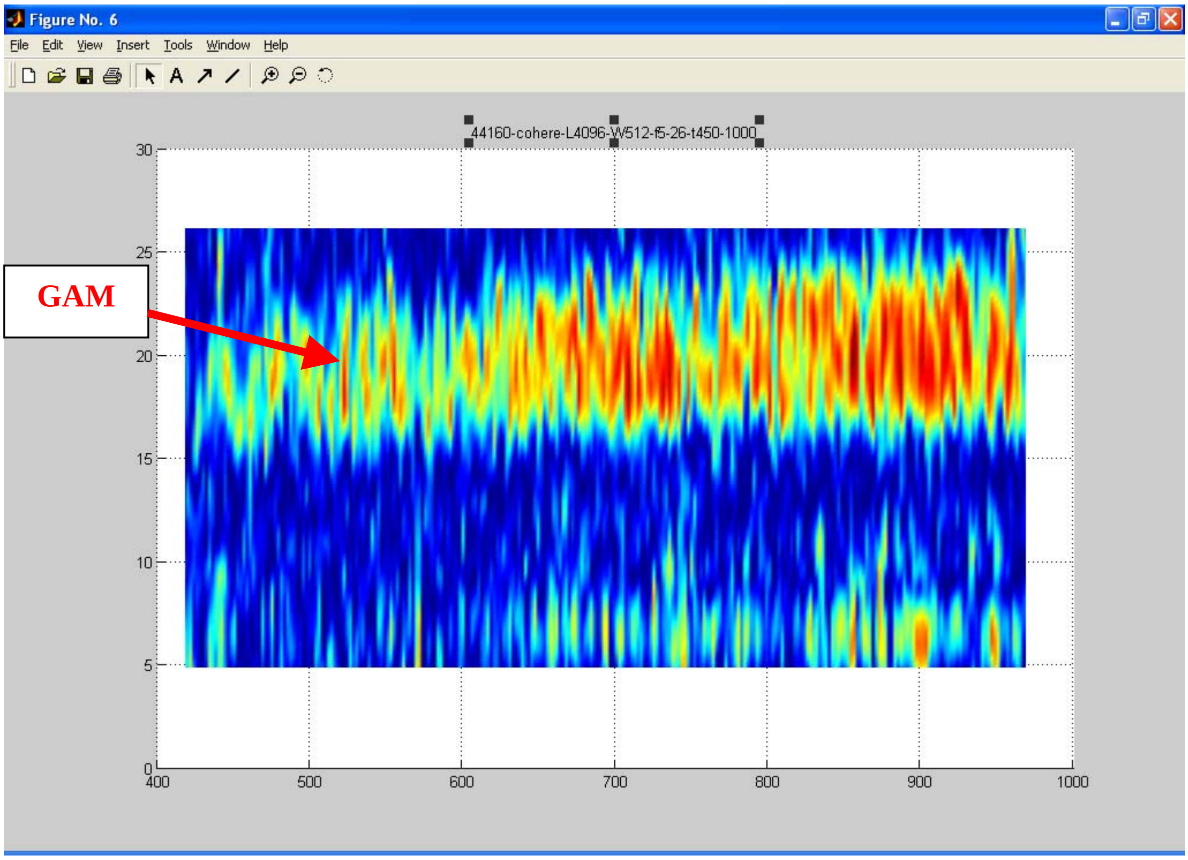

FIG. 3. Time evolution of Fourier periodogram for local potential-density correlation. Example of the GAM intermittent behaviour for Ohmic heated plasma. GAM frequency is around 20 kHz. MHD m=2 mode frequency is 7 kHz.

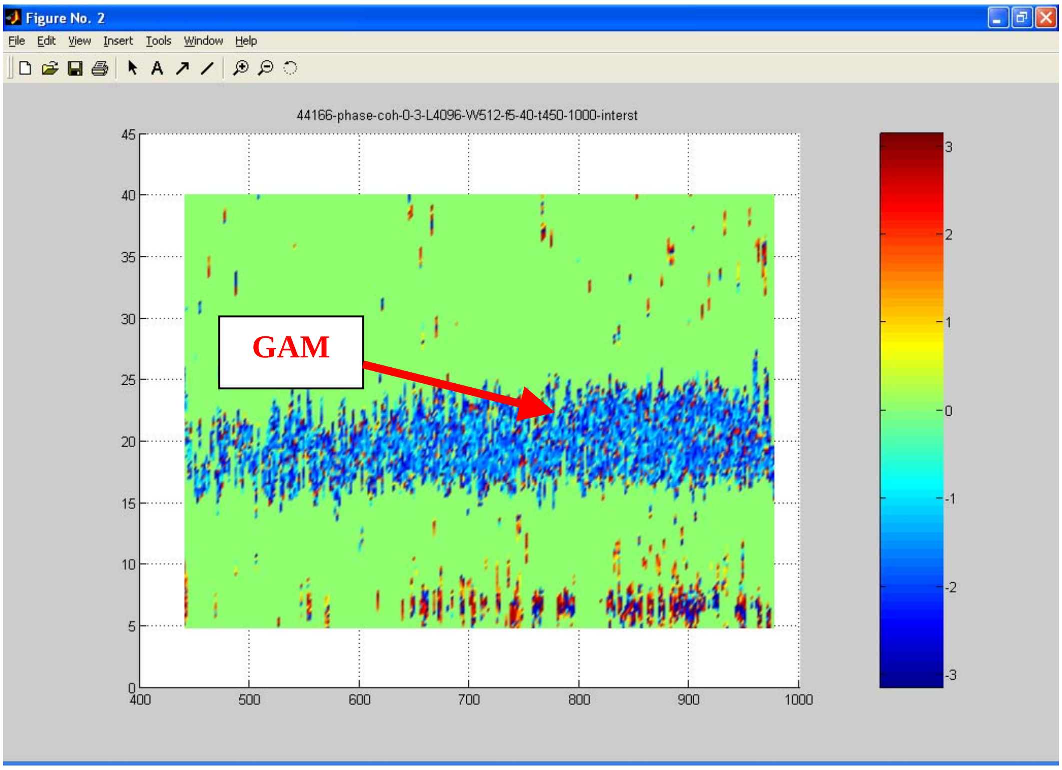

FIG. 4. Time evolution of the cross-phase for local potential-density correlation, shown in Fig 3. The limit value of the correlation is 0.3. If coherency > 0.3, cross-phase marked in color, if coherency <0.3 cross-phase marked in green (zero).

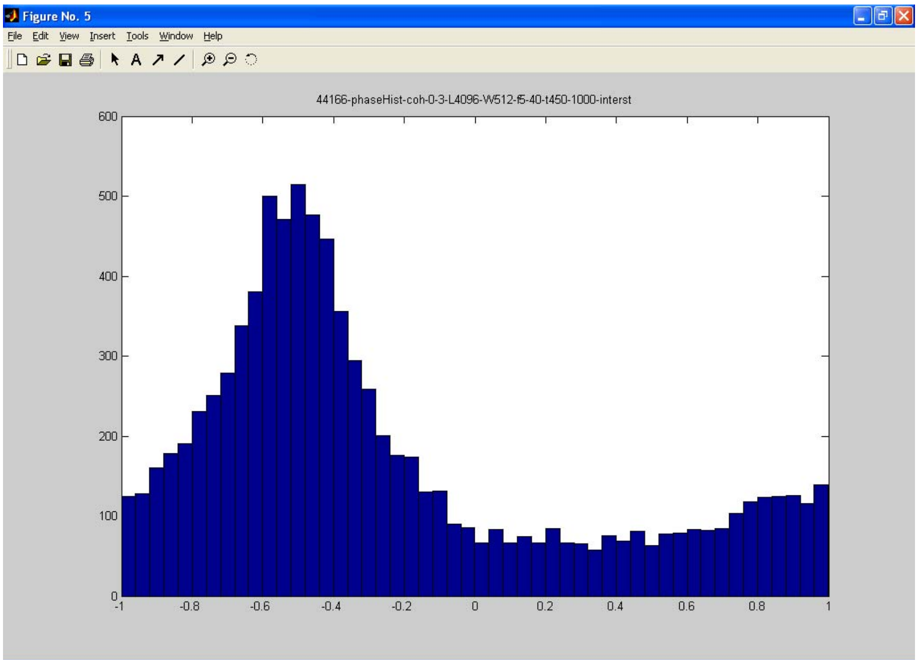

FIG. 5. An example of the cross phase histogram for data taken from Figs 3 and 4. The most frequent value is $\pi/2$ for GAMs.

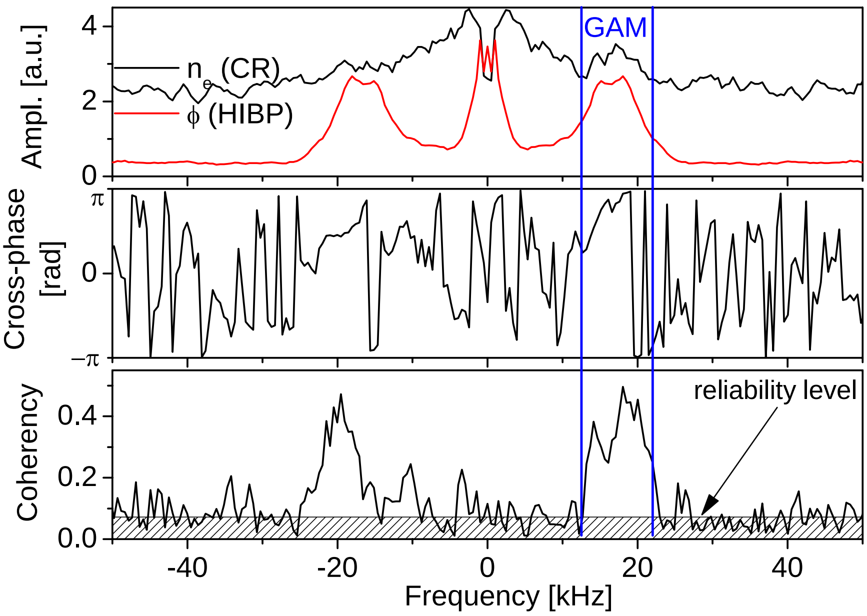

FIG. 6. Long-distance potential-density correlations. HIBP versus CR.

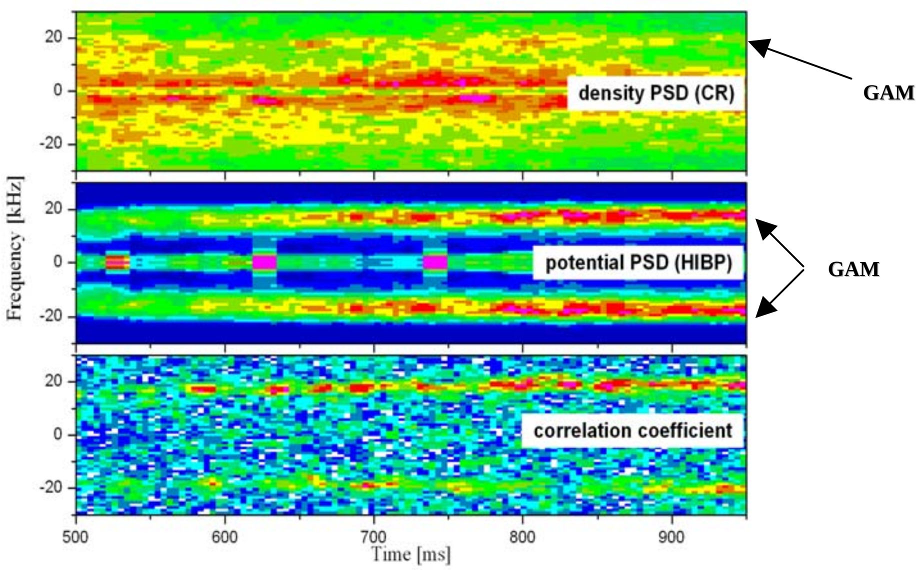

FIG. 7. Time evolution of long-distance potential-density correlations. HIBP versus CR.

Fourier correlation analysis with short time sampling (4 ms) shows the constant frequency and a bursty character of the correlation between HIBP potential and CR density at the GAM frequency, see Fig 7.

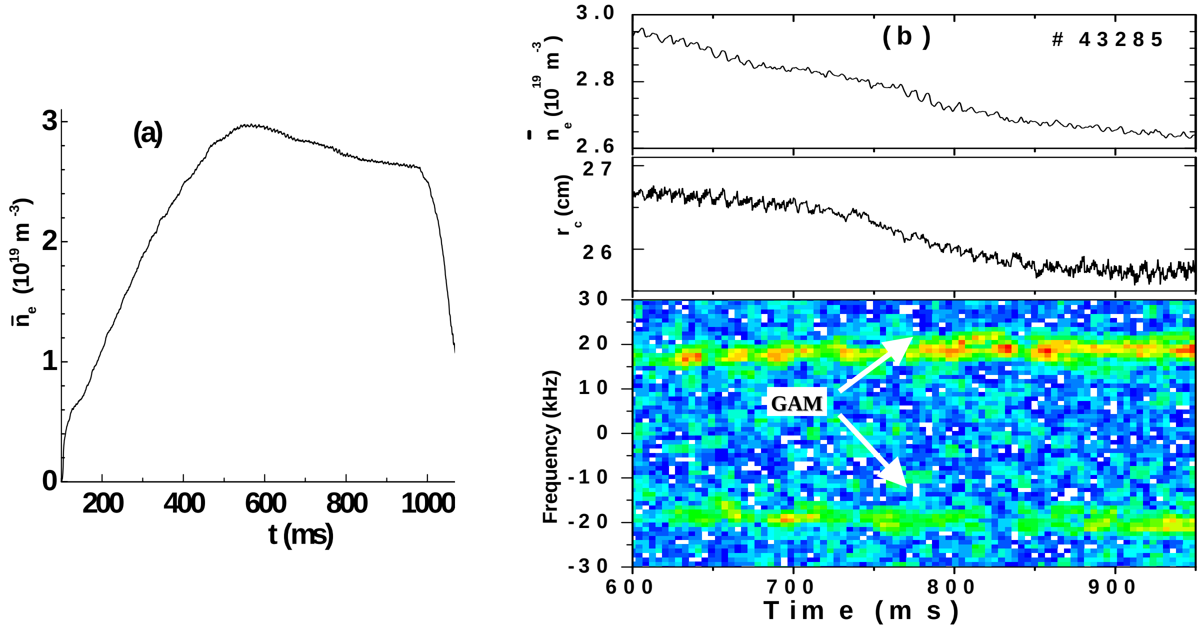

FIG. 8. Radial evolution of the long-distance potential-density correlations. (a) Time trace of the density evolution in the OH discharge. (b) Potential-density correlation for different radii for one shot, HIBP versus CR. Top box: evolution of line-averaged density. Middle: corresponding CR observation radius. Bottom box: potential-density correlation coefficient. HIBP radial position is r = 25±0.5 cm.

To study the radial range of the long-distance correlations the following experiment was performed: HIBP was located at the fixed position, while CR observation radius (reflection layer) varied during a shot with some decay of the local density. Fig. 8 shows the reliable existence of the correlation at the GAM frequency during all the shot. The correlation coefficient remains almost unchanged with around 1 cm radial variation of CR, while HIBP position was 1 cm shifted. This observation means the radial correlation length for GAM is higher 2 cm. This agrees with our earlier CR estimation of k_r = 3-5 cm [2].

Dependence of GAM amplitude on the density is shown in figs. 9 and 10. Figure 9 is obtained in a single shot with growing density, while fig. 10 is obtained from many Ohmic shots with various densities. In both cases we see that the GAM amplitude falls down with density.

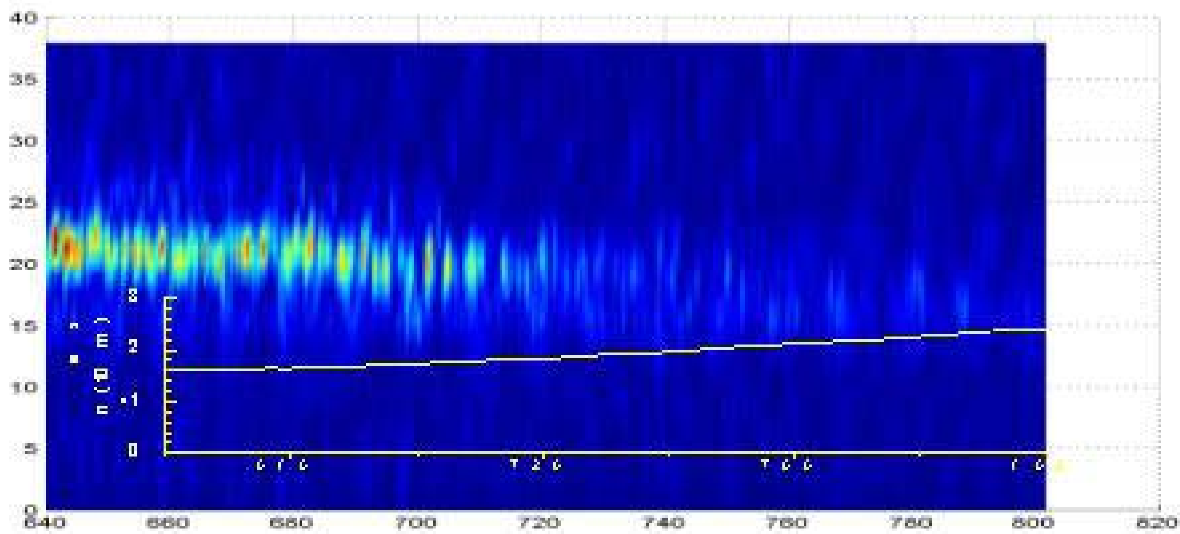

FIG. 9. Evolution of GAM spectrum in the shot with growing plasma density.

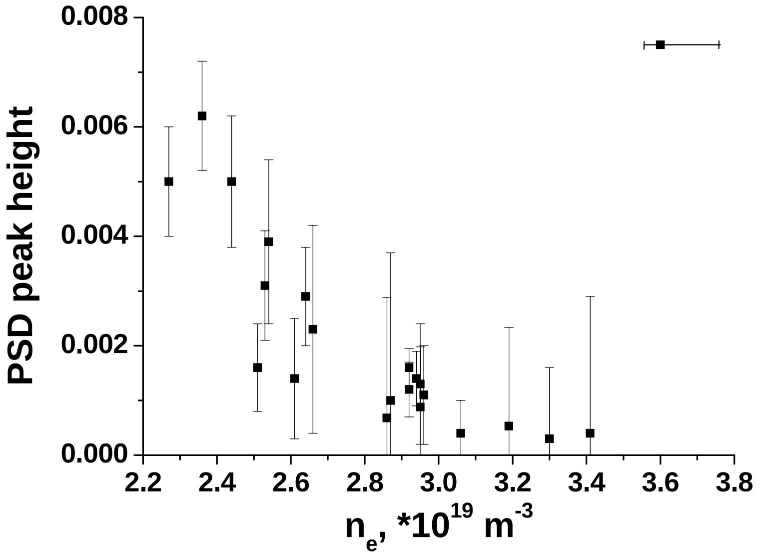

Fig. 10. Dependence of the GAM amplitude on the plasma density in Ohmic shots.

Summary

GAM correlation study was performed by HIBP and CR for the first time. It shows that GAM is mainly manifested in the plasma potential, it is not much pronounced on the plasma density fluctuations. GAM has an intermittent character in amplitude and frequency, potential and density presents high correlations with a constant phase shift for GAM frequency interval. The existence of the long-distance correlations for GAM was shown for the first time in tokamak. This suggests GAM is a global mode. Radial correlation length for GAM has a range of a few cm.

Acknowledgments

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