Dependence of the amplitude of GAM-induced core potential oscillations on density in the T-10 tokamak

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The Geodesic Acoustic Modes (GAMs) are intensively studied experimentally more than decade, because theories considered them as a possible mechanism of the plasma turbulence suppression [1]. In the T-10 tokamak GAMs have been studied by the heavy ion beam probing (HIBP) [2]. HIBP measures the absolute potential, the relative density and their fluctuations in the upper outer quadrant of plasma cross section at radii $0.3 < r/a < 1$. Presently the ohmic regimes were studied ($B = 1.5 – 2.4$ T, $I_p = 140 – 300$ kA, $T_e(0) \sim 1$ keV). Control of gas puffing allows us to vary the line-average density, obtaining its plateau in the range of $\bar{n}_e = (1.6–3.5)\times 10^{19}$ m^{-3}, or ramp-up/-down density and current during the discharge. Previous experiments have shown that at the plasma edge, $r/a \sim 0.8$, the mean value of potential was $V \sim$ -0.2 -0.3 kV depending on the density.

The power spectrum of potential oscillations consists of the narrow GAM peak with the frequency $f_{GAM} \sim 14 – 24$ kHz and the wide peak of quasicoherent oscillations with $f \sim 70\pm 30$ kHz. GAM often has high-frequency satellite. Both GAM and satellite are intermittent and looks like the stochastic sequence of flashes with typical pace of several ms and amplitude $\Delta\Phi$ from 20 to 70 V. (Fig. 1). Distribution of "instant" (averaged by 0.2 ms) amplitudes of GAM and its satellite was analysed, and the "mean" amplitude (averaged by 1–16 ms) was estimated. The effective amplitude of GAM can be calculated from the PSD spectrogram as

$$\Delta\Phi(t) = \sqrt{2\int_{f_{\min}(t)}^{f_{\max}(t)} S_{\varphi}(f,t)df}$$

where $S_{\varphi}(f, t)$ is power spectral density (PSD) of potential.

The error bars of the amplitude depend on PSD parameters, number of points for fast Fourier transformation N_{FFT} and window length. Figures 2 and 3 shows the spectrograms of the potential and time evolutions of the GAM amplitude with two different intervals of average $N_{FFT} = 256$ (a) and 2048 (b). In the first case (a) the strong scattering and intermittent events with characteristic time ~ 1 ms can be seen. As the compromise between temporal resolution and accuracy of amplitude N_{FFT}=2048 was chosen.

For the series of discharges with various steady-state densities we find the dependence of mean GAM amplitude on $\bar{n}_e$. It is fitted by function $\Delta\Phi \sim 1/\bar{n}^{\alpha}$, where α=1.1±0.03 (Fig. 4). In discharges with transient density we observe the similar dependence. If we increase the current I_p, this dependence is shifted to higher amplitudes (Fig. 5).

The interaction of the small-scale dissipative trapped electron mode driven turbulence with GAMs was analyzed with simplified two-fluid MHD model including the collisional damping of GAMs and Reynolds stress exciting GAMs [3]. The model reproduces the predator-prey behavior of GAMs and gives following dependence on density:

$$\Delta\Phi_{GAM} \propto \frac{1}{n}\left(1-\frac{n}{n_{cr}}\right)^{1/2}.$$

When the density is less than some critical value n_{cr} (that fits the present experiment), $A \sim 1/n$. So, suggested model shows reasonable consistency with experimental observations.

Conclusions

The GAM amplitude dependency on electron density has been studied in steady-state and transient discharges with wide range of plasma parameters (B = 1.5–2.4 T, I_{pl} = 145–300 kA, $\bar{n}_e = 0.6 - 4.5\times10^{19}$ m^{-3}, $q_{lim} = 2.4 - 4.8$) in the T-10 tokamak.

Experimentally observed dependency $\Delta\Phi_{GAM}(\bar{n}_e)$ agrees with $1/\bar{n}_e$ scaling predicted by the model of collisional damping of the GAM.

GAM amplitude increases with growth of plasma current and has a weak dependence on the toroidal magnetic field.

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References

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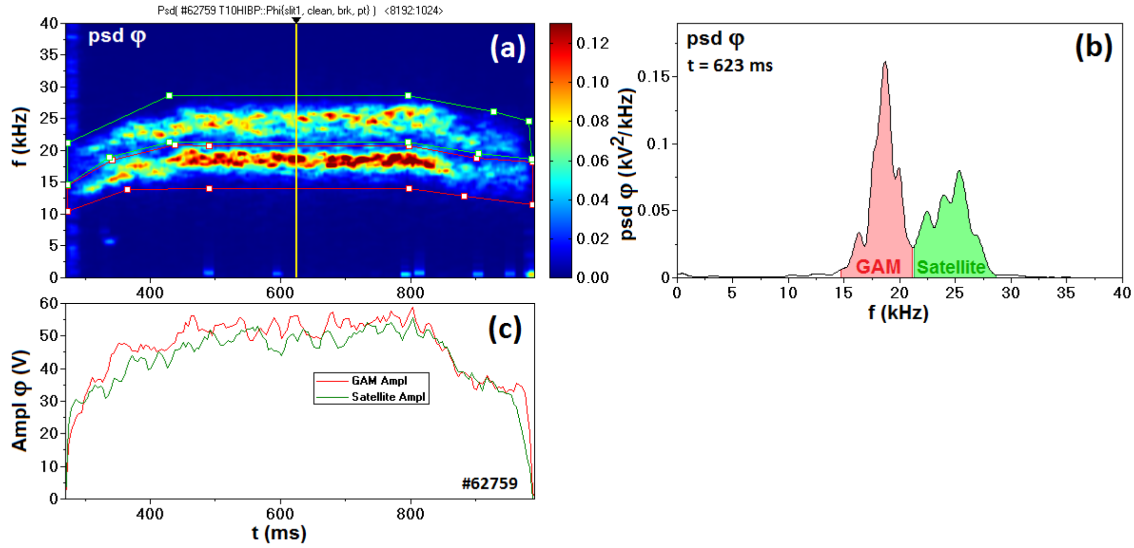

Fig. 1. (a) Time evolution of the power spectral density (PSD) of potential φ. (b) Spectra of GAM and high-frequency satellite at t=623 ms marked by yellow line in (a). (c) Amplitudes of GAM (red line) and satellite (green line) calculated by integration over variable frequency ranges shown lines with markers in (a).

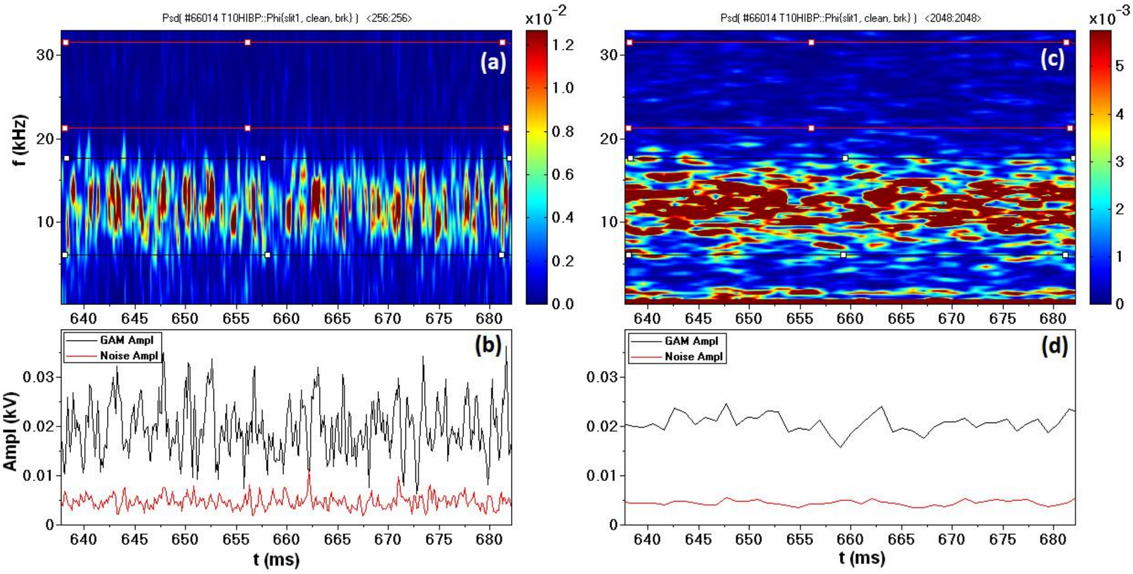

Fig. 2. Intermittent character of GAM and effect of the processing time interval on the scattering of GAM amplitude: (a) and (b) N_{FFT} = 256 points, (c) and (d) N_{FFT} = 2048 points.

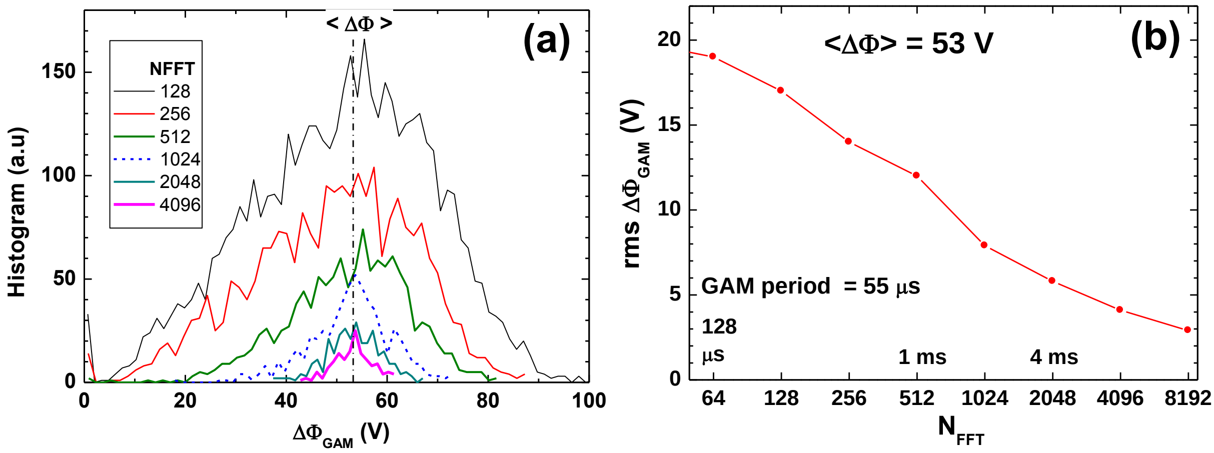

Fig. 3. Histogram of instant GAM amplitudes (a) and dispersion (b) for different intervals of average N_{FFT}.

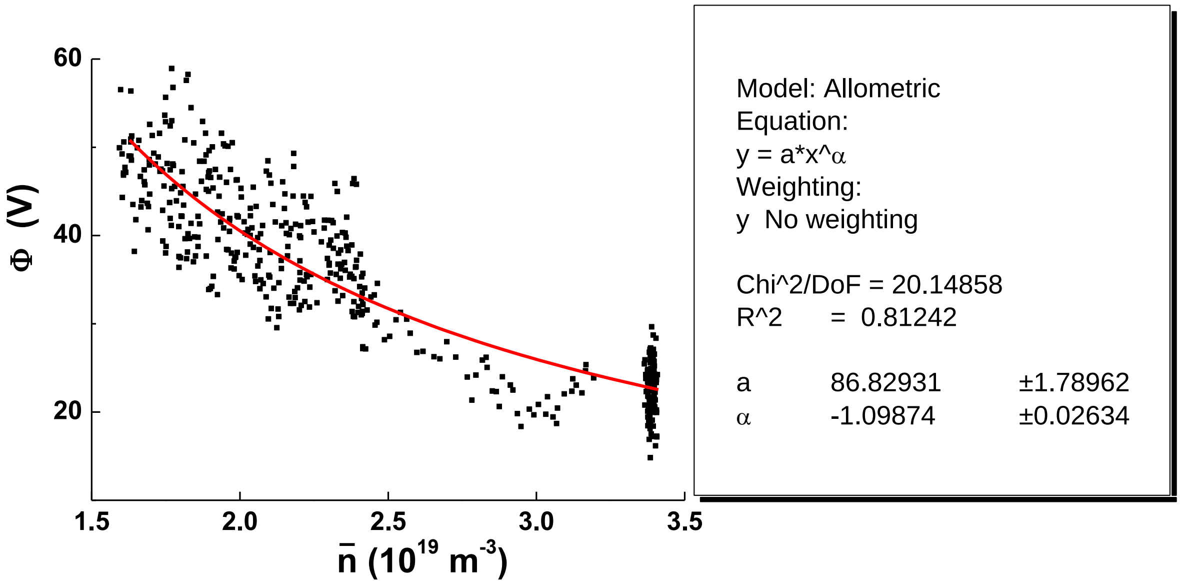

Fig. 4. Dependence of GAM amplitude on line-average density for discharges with B=2.4 T and I_{pl} = 220 kA. Approximation by function $y = ax^{\alpha}$ gives the exponent α = -1.1.

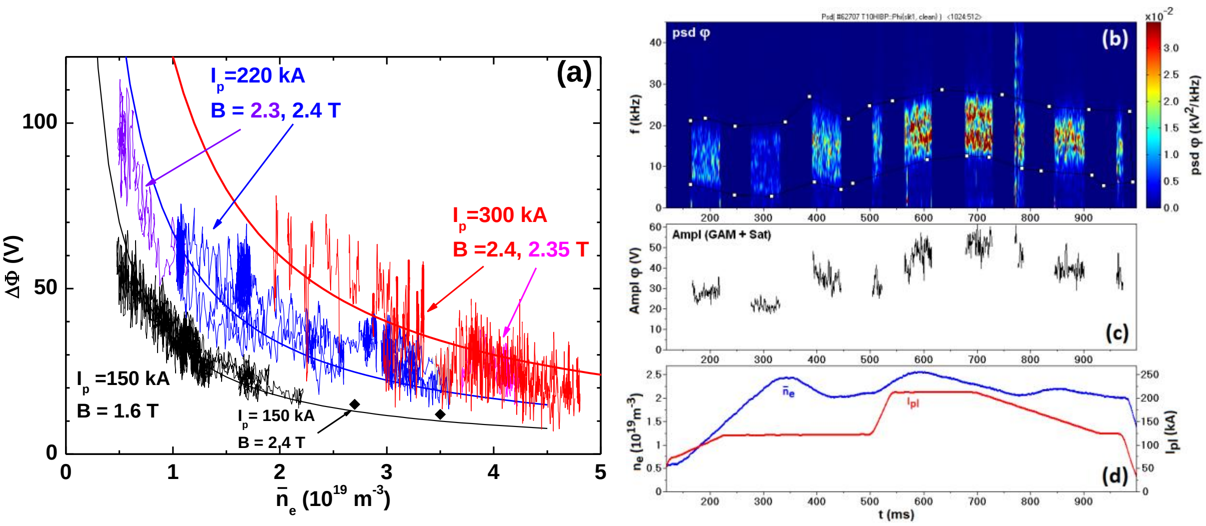

Fig. 5. (a) Generalized dependence of GAM amplitude $\Delta\Phi$ on the line-averaged density at different plasma currents, obtained in various regimes with wide variation of plasma current and density.

(b, c, d) Evolution of GAM + Satellite amplitude $\Delta\Phi$ in one shot with plasma current ramp-up.