GAM observation in the TUMAN-3M tokamak using Doppler reflectometry

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Introduction

Geodesic Acoustic Modes (GAMs) as a class of high-frequency Zonal flows are manifested as the oscillating ExB velocity and, as such, can be detected using Doppler reflectometry (DR) technique [1]. In the present report the results of GAM-like oscillations study in the TUMAN-3M tokamak are presented and discussed. The experiment was performed using Doppler reflectometry in limiter tokamak configuration with ohmic H-mode transition. Langmuir probes were used to cross-check some DR results.

GAM detection by Doppler reflectometry in the TUMAN-3M tokamak

The two-frequency reflectometer was used to reveal the GAM in the TUMAN-3M tokamak. This made it possible to derive simultaneously the rotational velocity oscillations for two different radial positions. The reflectometer microwave scheme has been described elsewhere [2]. The GAMs are revealed as harmonic oscillations of the rotational velocity derived from the Doppler frequency shift. This frequency shift was estimated using two independent techniques. The first is to apply a sliding Fourier transform to the complex IQ signal and to estimate the Doppler shift as a simple weighted spectral mean, or a "center of gravity" of spectrum. The second technique is to estimate the instantaneous Doppler shift as a phase derivative of the complex signal. The GAM was observed as

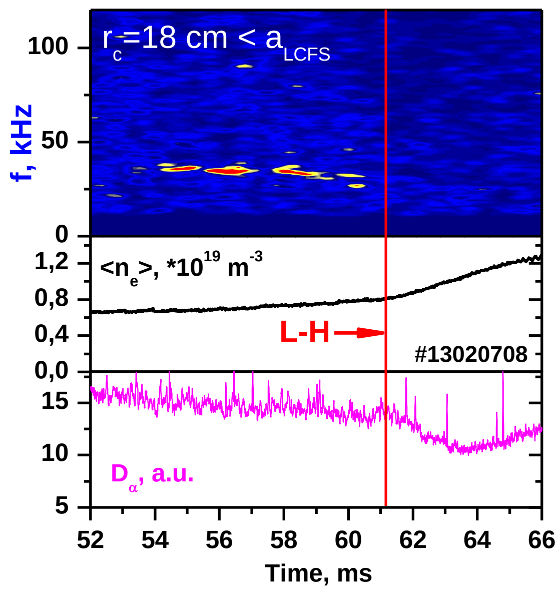

Fig.1. Spectrogram of Doppler frequency shift fluctuations and time evolution of averaged plasma density and D_α emission intensity

coherent oscillations of rotational velocity in 27-35 kHz frequency range, provided the backscatted region was located inside last closed flux surface (LCFS). This frequency range was in line with theoretical estimations performed for the conditions of the TUMAN-3M periphery [3]. The amplitude of GAM-caused velocity oscillation was found to be quite large, and occasionally exceeded the mean value of perpendicular velocity. The relevant amplitude of the radial electric field oscillations was found to be up to 5 kV/m. The strong GAM frequency peak in the Doppler shift spectrum was half an order of magnitude above the spectral background level.

Conditions for GAM existence

The typical limiter discharges with the ohmic H-mode transition has been studied in the TUMAN-3M tokamak. The main plasma parameters were as follows: R = 53 cm, $a_{limiter}$ = 25 cm, a_{LCFS} = 22 cm, I_p = 130 – 140 kA, <n> = (0.7-1.8)·10^{19} m^{-3}, B_T = 0.7 - 1 T, q_{cyl} = 2.6 – 3.6. The characteristic feature of the L-H transition is plasma density increase accompanied by D_α emission intensity drop. The transition is clearly seen at 61 ms in Fig. 1. The GAMs are manifested in the velocity spectrogram as a chain of colored spots, close to the expected GAM frequency (see Fig.1). The same frequency was observed in floating potential oscillations measured by Langmuire probe, provided the probe was situated ~1cm inside the LCFS. Electron temperature measurements were not available in this experiment. The electron temperature recalculated from the GAM frequency using the well-known theoretical formula was found to be in the range 50 to 100 eV; this is consistent with the typical range of edge electron temperature in the TUMAN-3M tokamak measured in previous experiments.

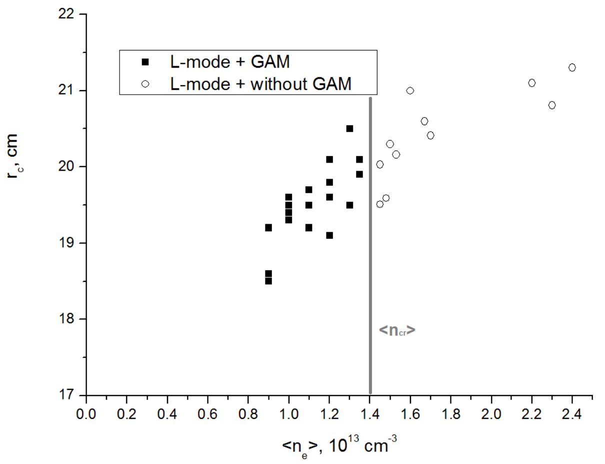

Fig. 2 Diagram of GAM existence in terms of cut off radius versus central line averaged plasma density

The GAM manifestations were observed only when the back scattering region was inside the LCFS. Moreover, no GAM-like oscillations were observed in the signals of the reflectometer at zero tilt of the antenna when the reflectometer detected plasma density fluctuations in the equatorial plane of the tokamak. In addition, there were no GAM oscillations detected in ion saturation current of the Langmuir probe situated on the mid-

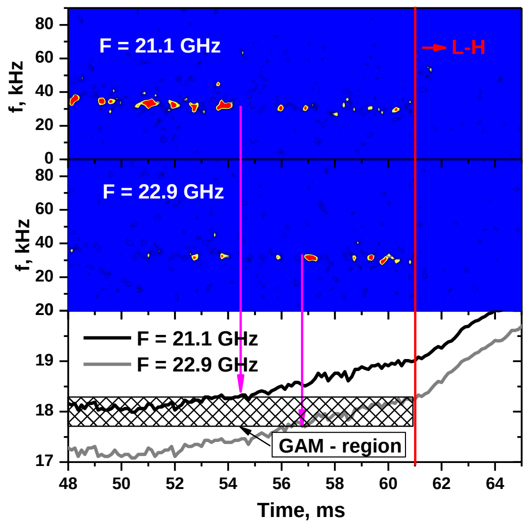

Fig. 3 Doppler frequency shift spectrograms for two probing frequencies and relavant time evolutions of cut off radius.

plane. All these observations are in line with theoretical predictions of the GAM plasma density structure in the mid-plane of a tokamak.

The GAMs were observed only before the L-H transition in the TUMAN-3M (see Fig.1). The GAM disappearance after the L-H transition correlates with the observed decrease of RMS value of the Doppler shift fluctuations. The Doppler frequency shift fluctuations are, at least partly, caused by perpendicular velocity fluctuations. These higher frequency fluctuations are thought to be a driving mechanism of GAM.

A critical value of the line averaged density ($\langle n_c \rangle = 1.4 \cdot 10^{19}$ m^{-3}) was observed, above which GAM did not develop. All black points in Figure 2 correspond to the GAM existence, and the open circles mark respectively the GAM absence in the diagram in terms of cutoff radius versus central line averaged plasma density. The GAMs are expected to be suppressed due to parallel viscosity increase with plasma density. Another damping mechanism has been studied in discharges with various q-values. The GAMs were found to disappear at $q < 2.6$. It is in a qualitative agreement with theoretically prediction of the GAM Landau damping.

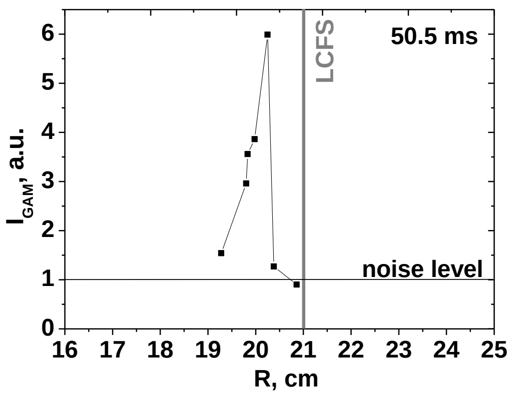

Fig. 4 Radial dependency of GAM intensity

GAM localization

The two spectrograms of Doppler shift were simultaneously obtained using two probing frequencies are shown in Fig. 3 GAMs were seen mainly in the low probing frequency channel until 54 ms. Then GAMs were detected at the high frequency channel. The relevant cut-off layer positions are shown in the Fig. 3. One can speculate that this spectrogram evolution is due to the radial localization of GAM developed near 18 cm. The expected GAM radial location is illustrated as a dashed band. The radial structure of GAMs was also studied by a variation of the probing frequencies from shot to shot. A series of reproducible tokamak discharges were selected for the radial profile reconstruction. The Fig. 4 reveals the narrow radial structure of the GAM of about 1 cm. It is close to radial characteristic length of geodesic acoustic eigenmode estimated as the Airy scale $\lambda = \rho_i^{2/3} L_T^{1/3} \approx 0.5 \div 1\,\mathrm{cm}$ [3, 4]. (ρ_i: ion gyroradius, L_T: electron temperature gradient scale length).

Correlation between GAM existence and turbulence level

The GAMs are always manifested in the TUMAN-3M as a series of burst reminding of the intermittency pattern predicted by the predator-prey model [3]. Typical duration of a single GAM burst is about 200 μs; that corresponds to 5–7 periods of oscillations. The relation between the GAM intensity (white curve in Fig. 5) and the background turbulence level (red curve $A^2(t)$) was studied. It is seen that the turbulence is suppressed during the GAM bursts and rises between the bursts. The relevant 2D plot of the cross-correlation function between these values is shown in the Fig.5. Similar time evolution of the GAM intensity and plasma turbulence level has been previously observed in the ASDEX-Upgrade tokamak during so-called I-phase [5].

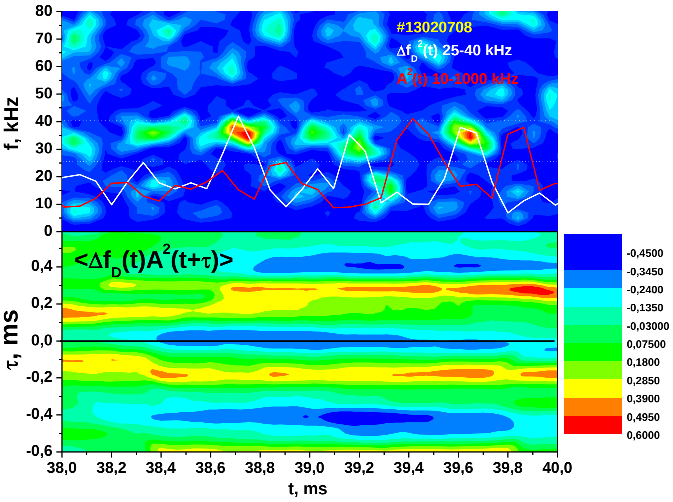

Fig. 5 Doppler frequency shift spectrogram and time evolutions of GAM intencity and backscattered signal power(in the figure above). 2D plot of the cross-correlation function

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