

Revealing of Geodesic Acoustic Mode Oscillations in TUMAN-3M Tokamak via Doppler Reflectometry

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Introduction

Turbulence-driven poloidal flows identified as Zonal flows are theoretically predicted to be responsible for plasma turbulence saturation. Zonal flows are extensively investigated since they act to moderate plasma turbulence and transport in tokamak and stellarator [1]. Geodesic acoustic modes (GAM) as a class of higher-frequency Zonal flows are the radial electric field structures localized in narrow radial zone with $m = 0$ and $n = 0$ in toroidal plasma. These oscillations are most accessible to experimental study. Doppler reflectometry has recently been employed to detect the GAM as oscillations of poloidal velocity in the ASDEX Upgrade tokamak [2]. The similar diagnostics has been used to reveal the GAM oscillations in the TUMAN-3M tokamak during the transition to ohmic H-mode [3].

Doppler reflectometry data processing

The Doppler reflectometry is based on deriving of the plasma rotation velocity V_{ϑ} from the Doppler frequency shift Δf_D of backscattered radiation expected under an oblique incidence of microwave beam onto cutoff surface (see, for example, [4]). The velocity V_{ϑ} in laboratory frame is $V_{\vartheta} = V_{E \times B} + V_f = (\lambda_i / 2) \Delta f_D / \sin \alpha$, where V_f is scattering fluctuation velocity, and λ_i is incident beam wave length and α is antenna tilt angle. For periphery region of a tokamak the $E_r \times B_t$ drift velocity dominates [4]. Therefore the GAM oscillations $E_r(t)$ can be directly evaluated from $\Delta f_D(t)$ provided the radial resolution of the method is satisfied. The Tuman-3M Doppler reflectometer is based on the single antenna setup described in detail elsewhere [4]. The reflectometer operated in the K-band (17-25 GHz for O-mode propagation) that the microwave cutoff was inside last closed flux surface (LCFS) in a vicinity of the H-mode transport barrier. The quadrature (IQ) detection in microwave region was employed to obtain the complex output signal ($I(t) = I_{\cos}(t) + iI_{\sin}(t)$) and the backscattering spectra $S(f)$ for the both upper and lower side frequency bands. The Doppler

frequency shift is determined as a “center of gravity” of the spectrum or/and a derivative of the complex signal phase.

$$\Delta f_D(t) = \frac{d}{dt} \{ \text{Phase}[I_{\cos}(t) + iI_{\sin}(t)] \}, \quad \Delta f_D(t) = \frac{\int_{-f_c}^{f_c} f |S(f)| df}{\int_{-f_c}^{f_c} |S(f)| df} \quad (1)$$

Here: f_c is the Nyquist frequency limited by sampling time $0.5 \mu\text{sec}$. These two approaches give approximately the same results. Contrary to the ASDEX Upgrade results the oscillations interpreted as the GAM in the TUMAN-3M experiment can not be evidently seen as a quasi-monochromatic fluctuation dominating above the background broad band $\Delta f_D(t)$ fluctuations. The following averaging procedure has to be used to reveal quasi-coherent oscillations of the poloidal velocity. The spectrum of the Doppler shift was computed with use of temporal windows of 128 or 64 μsec . The ultimate spectrum was obtained by averaging over 50 - 100 spectra calculated in sequential windows. To study an influence of the GAM oscillations on the level of plasma scattering fluctuations the cross-correlation spectral analysis has been employed. The corresponding spectral function of coherence $C_{A,\Delta}(f)$ is given by:

$$C_{A,\Delta}(f) = \frac{\langle FT(A^2(t)) \cdot FT^*(\Delta f_D(t)) \rangle}{\sqrt{\langle |FT(A^2(t))|^2 \rangle \langle |FT(\Delta f_D(t))|^2 \rangle}} \quad (2)$$

Here: $FT(A^2(t))$ is a spectrum of $A^2(t) = (I_{\cos}(t))^2 + (I_{\sin}(t))^2$. The averaging has been performed in line with the statistics described above.

Experimental results

The investigations have been carried out during typical TUMAN-3M transition to ohmic H-mode triggered by impulse gas puffing [2]. The main plasma parameters are: $a_1 = 0.25 \text{ m}$, $R_0 = 0.53 \text{ m}$, $B_{\text{tor}} = 0.76 \text{ T}$, $I_p = 128 \text{ kA}$. The transition is followed by an increasing of the averaged plasma density accompanied by D_α emission reduction, as indicated in Fig.1c. The evolution of the mean poloidal velocity is shown in Fig.2c and Fig.3c. Fig.2c and Fig.3c present the smoothed $A^2(t)$ magnitude indicating the evolution of the mean fluctuation level in total spectral range. The theoretically predicted [1] GAM frequency is determined for the TUMAN-3M condition by this formula:

$$f_{\text{GAM}} = 1/2\pi R_0 \sqrt{2T_e/m_i} = 3\sqrt{T_e(\text{eV})}, \quad \text{kHz} \quad (3)$$

There are no electron temperature measurements in a run of the Doppler reflectometry experiment. Therefore, to estimate the expected GAM frequency region the electron temperature was taken from the data obtained previously in the similar tokamak discharges

with use of Thomson scattering diagnostics. The estimated GAM frequency region occurred between 20 and 40 kHz for minor radius from 18 to 22 cm. These frequencies are higher than typical MHD frequencies (6-8 kHz) in the TUMAN-3M. Fig1a and Fig2b show spectrograms of the averaged spectra of the Doppler shift oscillations. The frequency of 8 kHz related to the MHD fluctuation is seen in Fig.2b for temporal interval from 6.5 to 10 ms. However, another spectral peak at 36 kHz occurred during the transition may be treated as

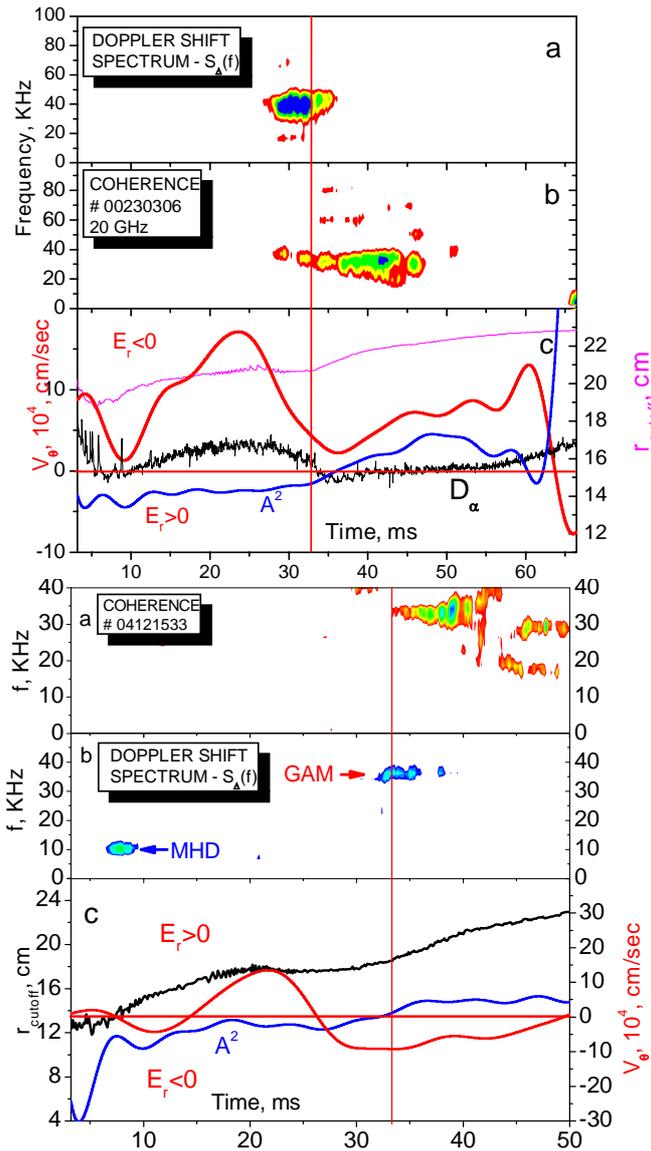


Fig.1 a, b - Spectrograms of Δf_D and coherent spectra during L-H transition marked by vertical line. c - Evolutions of cutoff radius, fluctuation level A^2 and mean poloidal velocity
 Fig.2 The same as in Fig.1. a - spectrogram of coherence, b - spectrogram of Δf_D .

the GAM oscillation. Similarly in Fig.1a the frequency maximum in the GAM region is evidently seen just before the transition in a discharge with another evolution of the mean poloidal velocity. There is no quasi-coherent oscillation of the poloidal velocity in the GAM frequency region in a condition of the cutoff location in SOL. The peak of Δf_D spectrum happens to be followed by spectral maximum of the coherence $C_{A, \Delta f}(f)$. The corresponding spectrograms of the coherence being above noise level are presented in Fig.1b and Fig.2a. The coherence is increased just after the spectral peak of the Doppler shift spectrum. The coherence peak frequency is somewhat below the GAM frequency. It should be noted that the GAM

oscillation accompanied by the coherence growing is detected only during the peripheral transport barrier formation

provided the cutoff is near the LCFS. Even so, the correlation between $\Delta f_D(t)$ and $A^2(t)$ oscillations is not always observed. This correlation in a time scale is illustrated in Fig.3.

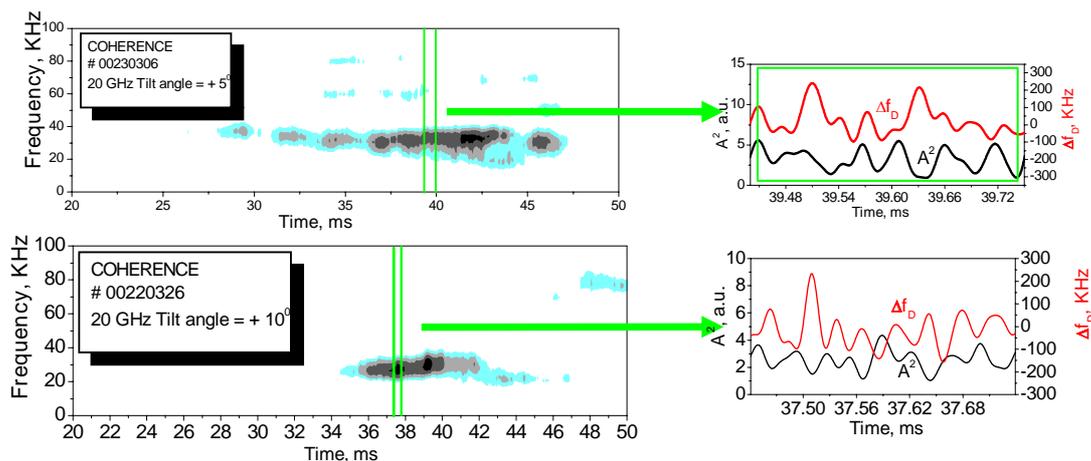


Fig.3 Spectrograms of coherence for two different discharges and comparison of $\Delta f_D(t)$ and $A^2(t)$ in time windows marked in left pictures

Figure 3 presents the both coherence spectrograms for two different discharges and waveforms of $\Delta f_D(t)$ and $A^2(t)$ in time frames related to the coherence maxima. The similarity of the signals is evidently visible. The phase difference between the oscillations is about π .

Conclusion

The GAM frequency poloidal velocity oscillations revealed with the Doppler reflectometry in the TUMAN-3M occurs provided the cutoff is in a vicinity of the peripheral transport barrier. The contrast of the GAM peak is not considerable. The low contrast could be explained by relatively low radial resolution of the method which is about 1 cm. So the relatively broad Zonal flow appeared in plasma periphery is only detectable with use of the Doppler reflectometry in the TUMAN-3M tokamak.

The discovered correlation between the plasma fluctuation level and the poloidal velocity oscillation indicates some mechanism of impact of the GAM oscillations on the plasma turbulence.

Acknowledgements

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Reference

- [1] – P.H. Diamond et. al. Plasma Phys. Control Fusion 47 (2005) R35
- [2] - G.D.Conway, et.al., 31st EPS Conf. on Plasma Phys. ECA Vol.28G, P-4.124 (2004)
- [3] - S V Lebedev et al., Plasma Phys. Control Fusion 36 (1994) B289-B299.
- [4] – V.V.Bulanin et.al. Plasma Physics Reports 26 (2000) 813–819